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SC1: Time-scale calibration

Can we quantify chronostratigraphic uncertainty for timescale calibration?

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The calibration of the Geologic Time Scale (GTS) requires the integration of ordinated events in Earth history (chronostratigraphy) with the determination of numerical age dates from specific stratigraphic levels (geochronometry). The calibration of chronostratigraphy by geochronometry gives us the geochronology that is the GTS. Determination of the numerical precision of a radioisotopic date is straightforward enough. The combination of the analytical, decay constant, and tracer calibration uncertainties provides the numerical +/- associated with the determined age date (i.e., the precision). Determination of the precision of correlation of a given stratigraphic position within a single outcrop to the global chronostratigraphic chart is another matter entirely. How can we determine the uncertainty in chronostratigraphic correlation, can we quantify this uncertainty, and why does this matter to the GTS? The final calibration of the GTS requires some form of statistical treatment, typically though a variety of regression analysis. Past versions of the GTS have relied upon a range of options including cubic splines, LOWESS, LOESS, or the increasingly common Bayesian techniques. When completing these final analyses, the uncertainty windows through which the regressions should pass must include both the temporal uncertainties associated with the numerical +/- from each geochronometric age date, AS WELL AS the chronostratigraphic uncertainty associated with the correlation of the position of each age date in its local stratigraphy. The parameterization and quantification of this second set of uncertainties has yet to be addressed in sufficient detail and we need community discussion and engagement to help to move this process forward.

Keywords: Time Scale, Calibration, Uncertainty, Chronostratigraphy, Geochronology

*Speaker

Timing and pacing of the Hangenberg Crisis (Devonian-Carboniferous Boundary) in the Chanxhe sections, Belgium

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The Hangenberg Crisis, at the Devonian-Carboniferous Boundary, severely affected the marine realm. The crisis is characterised by several events associated with change in the sedimentation and biotic extinctions and turnovers. The Hangenberg Black Shale event that recorded the extinction peak in the pelagic realm corresponds to a widespread development of oceanic anoxia and/or dysoxia. The Hangenberg Sandstone event is associated with an extinction of neritic fauna in shallow-water settings, including the final demise of several classical Devonian faunas (stromatoporoids, quasiendothyrid foraminifers, placoderms, etc.). The succession of these events is nowadays explained by a combination of sea level fluctuations (third order transgressive sequence, out-of-sequence regression) and global climatic changes. Through the identification of Milankovitch cycles in the Chanxhe record, we aim at getting a better understanding of the timing and orbital forcing of the different events of the Hangenberg Crisis in shallow-water settings.
The sedimentary record of the interval of interest at Chanxhe is composed of 16 m of alternating decimetre-thick carbonate beds with shaly siltstones, which displays a clear cyclicity. The carbonate-siliciclastic alternations (_˜0.8 m) are bundled into larger cycles (_˜5 m) which are separated by intervals dominated by the shaly facies. This is followed by 11 m of carbonate dominated lithology with thin shale layers displaying a less clear cyclicity with _˜3 m thick cycles. Then the equivalent of the Hangenberg dark shales is recorded as two dark shaly intervals separated by a carbonate bed. After the Hangenberg dark shales, the section displays carbonates, with the Devonian Carboniferous boundary in massive carbonates 7 m above the top of the black shales.
Samples have been collected along the record every 10 cm which were measured by the portable X-Ray Fluorescence device (Tracer 5, Bruker), allowing to provide elemental data throughout the record. Spectral analysis is applied on Ca and Al, to identify the main cyclicity in the record. The 0.8 meter-thick limestone/shale alternations is clearly recorded in the Ca and Al records and are associated with precession cycles (18 kyr), while the 5 m-cycles are associated with short eccentricity (100 kyr). Prior to the Hangenberg anoxic events, the 100-kyr cycles became less clear and shorter (_˜ 3 m) which is interpreted as a long-term minimum eccentricity. During and after the Hangenberg, the cyclicity returns.. Severe anoxic events such as the Oceanic Anoxic Event II in the Cretaceous, as well as the upper Kellwasser Devonian anoxic event have been associated with long term eccentricity minima. It is essential to better understand the mechanism

*Speaker

behind the astronomical forcing and anoxia expansion, and the identification of the long-term minima through the geologic time scale is key to better understand the climate forcing.

Keywords: Milankovitch, time scale, Devonian, Carboniferous

Standard Auxiliary Boundary Stratotype (SABS) approved to support the Global boundary Stratotype Section and Point (GSSP)

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Auxiliary stratotypes have demonstrated value in extending the correlative potential of a Global boundary Stratotype Section and Point (GSSP) between continents, biogeographic provinces, climatic zones, depositional facies and preservational states, and numerous such stratotypes have been proposed over the past 30 years or more to support GSSPs (Head et al., 2022a). Until now the Auxiliary Stratotype Point has been the only such formally recognised means to support a GSSP. However, it relies on the incorrect assumption that a designated point in an auxiliary stratotype can precisely align with the supported GSSP, when in reality the GSSP represents a unique instant in geological time at a specific unique geographical locality. As a means to resolve this problem, the Standard Auxiliary Boundary Stratotype (SABS) was approved by the International Commission on Stratigraphy (ICS) on October 27, 2022 as a formal replacement for the Auxiliary Stratotype Point to support a GSSP. The SABS provides a detailed complementary expression of the boundary interval without designating a specific point. More than one SABS may support a single GSSP and each will be subordinate to the GSSP. SABSs extend the correlative potential of a GSSP between continents, biogeographic provinces, climatic zones, depositional facies and preservational states. Requirements for SABSs broadly follow ICS guidelines for GSSPs, and will require approval by their respective ICS subcommission. Following such approval, each SABS will be listed on the ICS website as well as that of the respective subcommission, and future SABSs will be accompanied by an announcement published in the International Union of Geological Sciences journal Episodes. Requirements for the designation and approval of a SABS are as follows:
1) The SABS serves as a formal replacement for the Auxiliary Stratotype Point, providing a detailed complementary expression of the boundary interval without designating a specific point. The boundary interval must be clearly indicated.

2) Requirements for SABSs broadly follow ICS guidelines for GSSPs but can be applied with greater flexibility.

3) More than one SABS may be designated to support a single GSSP, but restraint must be exercised, and each will always be subordinate to the GSSP itself.

*Speaker

4) Each future SABS must be approved by the voting membership of the respective ICS subcommission following statutory voting procedures. One or more SABSs may be proposed simultaneously with a GSSP proposal (with the GSSP and SABSs all voted upon separately) or SABSs may be proposed subsequently.

5) If a GSSP is retired, its supporting SABS(s) retire by default. Any such SABSs might later be reinstated if desired, following approval by the respective subcommission.

6) Any Auxiliary Stratotype Point or Auxiliary Stratotype Section already approved by its respective ICS subcommission to support a GSSP will be known as a SABS. If such an Auxiliary Stratotype Point or Auxiliary Stratotype Section had been approved only by a task (working) group of the respective ICS subcommission, that subcommission must endorse this approval for it to be recognised as a SABS. All other such proposed or suggested Auxiliary Stratotype Points or Auxiliary Stratotype Sections (table 3 in Head et al., 2022a) would need to meet the requirements for a new SABS.

7) Following approval by the respective ICS subcommission, each Standard Auxiliary Boundary Stratotype will be listed on the ICS web- site as well as that of the respective subcommission, and an announcement published in the International Union of Geological Sciences journal Episodes.

8) An informative monument or plaque will be erected at the stratotype if possible and desired.

References:

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Keywords: SABS, GSSP, timescale

SC2: The Anthropocene: stratigraphical concepts and evidence

Anthropogenic stratigraphic signals downstream of a metropolis: Extracting Vienna's impact from Danube river plain archives

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The Anthropocene describes a potential new chronostratigraphic unit of the Geological Time Scale and is defined by the intensified anthropogenic influence on the environment and geological processes, and its traces in geological archives. Even though this human impact can be seen on a global scale, regional studies characterizing the growth and extent of anthropogenic influence, are scarce, especially for urban or peri-urban environments.
In this project, we investigate the anthropogenic impact of the metropolis Vienna on its peri-urban environment and the proposed beginning of the Anthropocene epoch in the 1950s CE by applying sedimentological and geochemical methods. The human influence in urban sedimentary archives of Vienna has already been successfully detected in previous studies by Wagreich et al. (2022) using artificial isotopes and anthropogenic trace metals as Anthropocene stratigraphic markers on anthropogenic coarse sediments. We extend the study area from Vienna to the city of Hainburg to investigate Vienna's urban anthropogenic impact in both anthropogenic and natural sediments downstream of the Danube river. In this area, in the National Park Donau-Auen, direct human intervention into the archived sediments is nil, thus presenting an 'Urban Anthropocene Field Lab' to trace and quantify the anthropogenic stratigraphic fingerprint and to search for correlation to the proposed GSSP base of the Anthropocene.
Within flood plain sediments of the Danube, sedimentological, geochronological and chemostratigraphic markers are applied to characterize and date the anthropogenic strata in this area: The archive of fine-grained natural Danube deposits, i.e. erosional profiles and sediment cores, is analysed for trace metals, artificial radiogenic isotopes, and (micro-)plastics with the aim (i) to disentangle the anthropogenic fingerprint of Vienna from the sediment, (ii) to identify and evaluate the proposed Holocene-Anthropocene geological boundary around 1950 CE, and (iii) to evaluate a potential correlative stratigraphic reference section section/ point for the Anthropocene downstream of Vienna.

Keywords: chemostratigraphic markers, anthropogenic fallout, (micro)plastic, Holocene, Anthro-

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pocene, Vienna

Signature of the Great Acceleration in the varved succession at Crawford Lake, Milton, Ontario, Canada: implications for the Anthropocene as a series/ epoch

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Couplets of organic matter capped by calcite precipitated each summer in alkaline surface waters of Crawford Lake accumulate undisturbed below the chemocline of this 23-m-deep meromictic lake in Ontario, Canada. These varves record local impact from an Indigenous agricultural settlement over a 218-year interval around the middle of the last millennium and several hundred years later by colonial land clearing, logging and lumber milling followed by global impact coinciding with the initial major increase in Pu-239+240 (0.0007 ± 0.0002 Bq/g in varves spanning 1948–1951 to 0.0048 ± 0.0006 Bq/g in a sample spanning 1950–1953 CE). This records fallout from nuclear and thermonuclear testing, with strong activity during 1952–1953 CE and levelling associated with the fluctuations in yield, notably testing cessation between November 1958 and February 1961. High activity of Cs-137 also identifies the global peak in this radionuclide in 1963 CE followed by a rapid decline to Nuclear Age background radiation levels in the 1970s. Analysis of samples collected along varve boundaries in several freeze cores and in samples from gravity core CL-19 displays evidence of global atmospheric change (depleted values of δ15N) and rapidly increased industrial activity (sharply higher concentrations of spheroidal carbonaceous particles/ SCPs) during the Great Acceleration. The unusual hydrology of this meromictic lake, with its well-oxygenated but highly conductive and alkaline bottom waters, preserves the plutonium record, with Pu-239/240 ratios consistent with a global fallout, with exceptional fidelity. Values of F14C > 1 record artificially produced radiocarbon in most samples deposited since the mid-1950s, but the bomb pulse is not well represented in bulk sediment samples due to old carbon in this Silurian dolomitic limestone basin on the Niagara Escarpment. Lithologically, the SCP-rich sediments deposited in the 1950s through 1960s are dark, with very thin but annually resolvable calcite layers, punctuated by a distinct triplet of calcite laminae deposited during the summers of 1956, 1957 and 1958 CE. This is attributed to acidic precipitation

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resulting from rapid regional industrial expansion at a time of negligible controls on emissions, consistent with the elevated concentrations of heavy metals in these sediments. Reduced precipitation of calcite in the epilimnion of this well-buffered basin, and likely changes in dissolved organic carbon as indirect result of acidic deposition may explain the rapid expansion of the deep-dwelling colonial chrysophyte genus *Synura* at the expense of *Mallomonas* in response to increased depth of the photic zone during the warm summer months. Although changes in authigenic sedimentation and assemblages of siliceous and organic-walled plankton reflect limnologic changes in response to a variety of stressors, this small, isolated lake in rural Ontario has also recorded component signals of the Great Acceleration Event Array which documents a profound shift in the Earth System state during the mid-20th century. Therefore Crawford Lake, along with 11 other reference sections analysed under the aegis of the Anthropocene Working Group, contributes in detail to the stratigraphy of the Anthropocene on a global scale.

Keywords: varved sediments, meromictic lake, Earth Systems, Great Acceleration Event Array, bomb radionuclides, SCPs, siliceous microfossils

The Urban Anthropocene of Karlsplatz, Vienna (Austria), a reference section for the Anthropocene Series

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Anthropogenic strata form the layered urban archive in the underground of large cities. In a transdisciplinary project involving geosciences, isotope physics and urban archaeology, we looked for artificial isotopes and anthropogenic trace metals. The tested archaeological site Karlsplatz is situated in the City of Vienna in a park area. Archaeology and historical data set age constraints around 1922 (building of a sales hall), WW2 post-1945, and at 1959, with the opening of the Wien Museum. A layer on top of the WWII rubble that covers foundations of a 1922 building post-dates 1945, and pre-dates the levelling of the artificial park ground in front of the Wien Museum of 1959. The fine-grained sediment matrix of these layers is mixed with backfilled soil material. Samples were analysed for trace elements like lead, copper and zinc, and prepared for chemical separation of actinides analysed by Accelerator Mass Spectrometry (AMS). Several artificial radionuclides including the plutonium and uranium isotopes 239Pu, 240Pu and 236U were found in the post-1945 layer, and the 240Pu/239Pu isotope ratio clearly point to the presence of atmospheric atomic bomb fallout material of the 1950s. Thus, the bomb-spike can be identified and used as a primary stratigraphic marker even in coarse urban anthropogenic sediments exemplifying the correlation potential of these radionuclide markers and demarking a reference section for the base of the chronostratigraphic Anthropocene. These urban deposits, including rubble from World War II and anthropogenic soils as at Karlsplatz, show no continuous record as required for a GSSP. There are no annual layers in anthropogenic sediments since deposition rates are highly variable, and the layers get mixed and reworked during different construction and renovation phases. However, the Karlsplatz site may be used to define an auxiliary stratotype section and/or point of the Anthropocene, as the stratigraphic markers and technofossils in the urban rubble contain signals that have potential correlations with findings from other GSSP sites, namely the fallout radionuclides like plutonium, the trace metal concentrations, although strongly locally affected, and the technofossil record.

Keywords: Anthropocene, urban reference, Plutonium, technofossil

*Speaker

Understanding 'event stratigraphy' in the context of Anthropocene chronostratigraphic definition

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The Anthropocene Working Group of the Subcommission on Quaternary Stratigraphy is working towards formally defining an Anthropocene epoch/series, and its associated age/stage commencing in the mid-20th century. The proposal will recommend that the Anthropocene be constrained by a Global boundary Stratotype Section and Point (GSSP) in a sediment core and supported by several Standard Auxiliary Boundary Stratotypes (SABSs) that permit correlation of the base of the Anthropocene into many of the diverse depositional environments in which it is clearly recorded. Global correlation is achieved using the many geosignatures of the Great Acceleration Event Array (GAEA: Head et al., 2022a, 2022b; Waters et al., 2022). We evaluate recent proposals that the Anthropocene should be an informal 'event' characterised as an interdisciplinary, time-transgressive concept extending over tens of millennia and still ongoing, and not based exclusively on the stratigraphic record. We provide analysis of 'events' in geological history and scrutinize their definition.
We investigate how concepts of events and episodes should be more rigorously applied and how events can be used as suitable guides for chronostratigraphic boundaries, using analogous Quaternary and deeper-time examples. We recognise events as associated with rapid rates of process change over brief time intervals and distinguish between global phenomena that represent an Earth System state-shift, e.g. large bolide impacts or Snowball Earth terminations, and local to global phenomena that do not alter the functioning of the Earth System, e.g. tsunamis. Episodes, in the informal use of the term, are by contrast long-lived phenomena, markedly time-transgressive with slow rates of process change. These too can be differentiated between episodes that cause state-shifts (e.g. the effects of very large igneous provinces such as the Siberian Traps on climate, oceans and biota) and those that have more modest and reversible impacts (e.g. changes in orbital parameters amplified by other Earth effects that cause the glacial-interglacial oscillation). Time resolution interacts with perceived suddenness and consequently samples closely spaced in time may reveal events that are embedded within episodes.

In the context of human impacts on stratigraphical successions, we recognise an extensive time-transgressive 'episode' related to the global record of all geologically significant anthropogenic change, termed the Anthropogenic Modification Episode (AME). Nested within the AME are many brief and geologically correlatable events. The most notable is the GAEA, an array of global anthropogenic signals recorded in mid-20th century deposits, e.g.: onset of the radionuclide 'bomb-spike'; appearance of microplastics, novel organic chemicals and fly ash particles; marked changes in patterns of sedimentary deposition, and in heavy metal contents and carbon/nitrogen isotopic ratios; and biotic changes leaving a global fossil record. These events include short-duration signals that returned to pre-1950 levels within a few decades, as well as signals that will persist for millennia or will be permanent (e.g. significant reconfiguration of ecosystems including extinctions).

Given the intensity, magnitude, planetary significance and global isochroneity of the GAEA, it provides a suitable level for recognition of the base of the Anthropocene as a series/epoch (Waters et al., 2023). The chronostratigraphic Anthropocene, defined in strict accordance with ICS approved nomenclature and procedures, provides a clear and stable meaning to stratigraphic use of the term "Anthropocene".

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Keywords: Anthropocene, chronostratigraphy, event stratigraphy, episodes

Stratigraphic enrichment into the Anthropocene: a proliferation of proxies allowing ultra-high resolution of a transformed Earth System

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In the science of stratigraphy, correlation of strata and palaeoenvironmental interpretation is enabled by a large and growing number of proxy signals, some of which are now classical in nature, such as fossils, while others have been developed as a result of advances in analytical capabilities, such as chemical patterns including isotope ratios. Such proxy evidence provides the basis for the characterization and definition of chronostratigraphic units. The Quaternary, and in particular the Holocene, has seen impressive development of the variety and range of stratigraphic proxy signals. A key innovation was the use of (for stratigraphy) novel strata, of Greenland ice, for the Holocene GSSP, with 6 proxy signals detailed including some not previously used in timescale definition, such as deuterium excess, while 24 proxy signals were quoted in total, including for the five auxiliary stratotypes. In subdivision of the Holocene, the Northgrippian GSSP (also Greenland) used a comparable range of ice signals, though the Meghalayan GSSP, in a speleothem in India, is based upon oxygen isotope analyses calibrated by U-series dates.
In analysing 12 candidate sites and other reference sections for potential formalization of the Anthropocene (Waters et al., 2023), this innovation and diversification of stratigraphic proxies has continued, and markedly accelerated. In total, more than one hundred separate proxy signals were used to characterise the stratigraphy at decadal to annual, in some cases sub-annual, level. These include signals which are simply the result of ongoing technical development, and which are available to older (even if not always very much older) successions, such as eDNA. Many of the signals are novel, though, and reflect a proliferation of new forms of stratigraphic evidence associated with the Anthropocene. These include several artificial radionuclides, microplastics, industrial fly ash, various kinds of synthetic persistent organic compound and novel biostratigraphic signals, notably the rapid and near global spread of introduced species. Their rapid development and wide (commonly global) dissemination have allowed a step change in stratigraphic resolution that, uniquely integrated with detailed observational process records, allow analysis of an Earth System undergoing evolution in an unprecedented rate, scale and

*Speaker

manner.

Reference
Waters, C.N., Turner, S.D., Zalasiewicz, J. and Head, M.J. (2023). Candidate sites and other reference sections for the Global boundary Stratotype Section and Point of the Anthropocene series. The Anthropocene Review https://doi.org/10.1177/20530196221136422

Keywords: Anthropocene, chronostratigraphy, proxy signals, Quaternary

SC3: Developments in Quaternary chronostratigraphy

Stratigraphy and paleoceanography of the Sea of Japan during the Pliocene–Pleistocene transition: the dinoflagellate cyst record at IODP Site U1424

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The Pliocene–Pleistocene transition marks a significant intensification of Northern Hemisphere glaciation (iNHG) and the beginning of high-amplitude glacial–interglacial cyclicity that characterises the Quaternary. While many mechanisms have been proposed for this change in climate state, including the closure of the Isthmus of Panama and the onset of ocean stratification in the Pacific at _˜2.7 Ma, the role of the Pacific Ocean remains poorly understood.
The largely enclosed Sea of Japan has been a sensitive recorder of climate change since its formation, owing to its: shallow connections to the Pacific and adjacent basins that prevent bottom water exchange; reliance on the Tsushima Warm Current as its major source of nutrients, salt and heat; proximity to the Westerly Jet; and position relative to the East Asian Summer and Winter Monsoon systems. This makes it ideally suited for understanding the role and response of East Asia and the Pacific Ocean across this interval of crucial climatic change. Dinoflagellate cysts, acritarchs, and other palynomorphs are here used to elucidate hydrographic changes during the Pliocene–Pleistocene transition at Integrated Ocean Drilling Project (IODP) Site U1424, east-central Sea of Japan. The study covers 2.85 Ma to 2.41 Ma with an average sample spacing of _˜4 kyr, allowing paleoenvironmental reconstructions at suborbital resolution. This is the first high-resolution study using dinoflagellate cysts for the Sea of Japan.

A total of 125 samples were analysed, and results reveal more than 60 marine palynomorph taxa and moderate to excellent preservation. Detrended Correspondence Analysis (DCA) was conducted on the total marine palynomorph assemblage to ascertain the relationship between environmental changes and sample distribution. The results of DCA show that the distribution of samples is influenced by the age of the material. Prior to 2.650 Ma, there appears to be significantly less distinction between glacial and interglacial samples. It is hypothesized that effect of the onset of iNHG became most prevalent at this time. After 2.650 Ma, changes in assemblages correspond to shifts in marine isotope stages (MIS). In particular, strong responses coincide with glacial MIS 100 (2.52 Ma) and 102 (2.57 Ma), these being characterized by higher numbers of *Corrudinium harlandii*, *Habibacysta tectata*, *Spiniferites elongatus*, and cysts of *Protoceratium reticulatum.* Although initially rare, the first appearance of the thermophilic species *Tuber-*

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culodinium vancampoae at ~2.814 Ma suggests the influence warm-water inflow to the Sea of Japan, probably from the southern strait. Conversely, *Cymatiosphaera*? *invaginata* is abundant in some intervals, seemingly tied to specific glacial climate cycles. Although the paleoecology of this acritarch is not fully known, its prevalence elsewhere in the high- to mid-latitudes likely implies the flow of subarctic water masses into the Sea of Japan from its northern straits. Results of Canonical Correspondence Analysis (CCA) add support and show a strong relationship between the abundance of *C.*? *invaginata* and the distribution of samples representing glacial conditions. This acritarch has been found in other localities across the Pliocene–Pleistocene transition, including the North Atlantic and the Gulf of Alaska in similar high proportions. As such, it may usefully indicate the onset and prevalence of glacial conditions in higher northern latitudes. The position of the Pliocene–Pleistocene boundary at 2.580 Ma in the Sea of Japan is supported by that of the Gauss–Matuyama paleomagnetic reversal. Dinocyst assemblages close to the boundary are characterised by high abundances of *C. harlandii* and *Spiniferites* spp., and the presence of *Impagidinium* species (particularly *I. pallidum*), *Lingulodinium machaerophorum* and cysts of *P. reticulatum*, and low numbers of *C.*? *invaginata*. Being firmly within MIS 103, the assemblages reflect interglacial conditions.

Overall, the marine palynomorph assemblages record the fluctuating influence of these contrasting water masses during the iNHG. The shallow sills connecting the Sea of Japan to the North Pacific impose further controls on inflow during these times of strongly fluctuating global sea level.

Keywords: Pliocene, Pleistocene, Northern Hemisphere Glaciation, dinocysts, dinoflagellates, paleoceanography, paleoclimatology

Speleothem-based geochronological benchmarks over the past 60,000 years

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In the last two decades, significant advances in understanding the climatic controls on δ18O in precipitation and speleothems, together with continued developments in U-Th dating techniques, have propelled speleothems to the forefront of paleoclimatology, and provided a set of geochronological benchmarks for correlating and calibrating the past climate variability on various timescales. Up till now, a large array of records has revealed the hydroclimate variability worldwide around 4.2-3.9 ka BP. It appears that the so-called '4.2 ka event', as the GSSP between the mid- and late-Holocene, is not a synchronous event globally, and it is unclear either whether the events around 4.2-3.9 ka BP is a representative of one time-transgressive event in different geographical regions. Additionally, our new high-resolution and well-dated speleothem records from Mawmluh Cave in NE India do not appear to replicate the GSSP based on the speleothem KM-A record from the same cave. The new high-resolution and precisely dated speleothem records of the 8.2 ka event from Madagascar, Southern Indian Ocean and Beijing, China reinforce the double peak structure (at _˜8.25 and _˜8.11 ka BP), manifestinging an inter-hemispherically anti-phased relation. These new dates confirm the GAS between the early- and mid-Holocene based on the speleothem PAD07 record from Padre Cave, Brazil. A number of well-dated speleothem records pinpoint the timing of the Younger Dryas (YD) event worldwide. The YD abrupt termination process was dated from 11,700 ±40 to 11,610 ±40 yr BP, consistent to the GSSP of the Holocene onset established from Greenland ice core records, but more precise. I will also show a set of speleothem-based age benchmarks in the last glacial period, which allow us to correlate and calibrate the global millennial climate oscillations throughout the period.

Keywords: U Th dating, speleothems, benchmarks, timing, millennial events

*Speaker

The Middle Pleistocene Subseries: a potential second stage based on the Mid-Brunhes event

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The Global boundary Stratotype Section and Point (GSSP) at Chiba, Japan defines the base of the Middle Pleistocene Subseries and Chibanian Stage with an astronomical age of 774.1 ka. This boundary represents the approximate midpoint of the Early–Middle Pleistocene transition, a 1.4–0.4 ka interval marked by a progressive increase in the amplitude and asymmetry of climate oscillations and a shift towards quasi-100 ky periodicity. Both units currently extend upwards to the base of the Upper Pleistocene Subseries dated provisionally at ~129 ka. The Middle Pleistocene with a 645 kyr duration is the second longest subseries of the Quaternary. Introducing a second stage, beginning at the approximate mid-point of this subseries, would provide a useful division. The 'Mid-Brunhes Event' (MBE) more recently termed the 'mid-Brunhes Transition' is an abrupt step-change to increased amplitude of the quasi-100 kyr cycles and to warmer interglacials from MIS 11 onwards, as revealed by Antarctic ice core records, the LR04 benthic foraminiferal isotope stack, and a recent long alkenone paleotemperature record from the central Mediterranean Sea. Other long-term changes at this time include an abrupt weakening of the East Asian Summer Monsoon, suggesting an increase in average Northern Hemisphere ice volume. The base of this new stage would reasonably be placed at around the MIS 12–MIS 11 transition (Termination V, ~420 ka), an interval of rapid change clearly recognised in the marine record. This level appears to approximate the bases of the Holsteinian, Hoxnian, Likhvinian, and Zavadivian regional stages across northwestern and central Europe, the Russian Plain, and the Ukrainian Loess Plain; and can be traced across the Chinese Loess Plateau. Climatostratigraphic signals associated with Termination V (~420 ka) would serve as the primary guide to this proposed new stage for the Middle Pleistocene. The 'Bermuda' geomagnetic excursion occurring within a prominent relative paleointensity minimum at ~412 ka in MIS 11 offers additional stratigraphic characterization. Such a second stage would terminate the Chibanian, eliminating its redundancy as the sole stage of the Middle Pleistocene.

Keywords: Quaternary, Pleistocene, new stage, Mid, Brunhes event

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The Neogene–Quaternary boundary at the type locality of Monte San Nicola, near Gela, Sicily – a reinvestigation by the international program GELSTRAT

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The Global boundary Stratotype Section and Point (GSSP) at Monte San Nicola, near Gela, Sicily, Italy was proposed in 1996 to define the base of the Gelasian Stage, then the uppermost stage of the Pliocene Series, in recognition of the intensification of Northern Hemisphere glaciation. This GSSP acquired elevated significance upon its approval in 2009 to define also the base of the Quaternary System and redefine the base of the Pleistocene Series. It is placed at the base of the marly layer immediately overlying the prominent, laminated, reddish, sapropelic Nicola bed, and has an astronomically tuned age of 2.58 Ma. The Nicola bed is assigned to Mediterranean Precession-Related Cycle 250 and aligns with an obliquity maximum representing Marine Isotope Stage 103 which, together with the Gauss–Matuyama paleomagnetic reversal, facilitates global correlation. Fine details of the stratigraphy nonetheless remain uncertain, including the precise position of the Gauss–Matuyama relative to the GSSP. GELSTRAT was inaugurated in September 2021 during an INQUA-SQS International Field Workshop focused on the reinvestigation and reanalysis of the Gelasian GSSP using modern methods and a broad range of proxies. Sampling across the boundary interval at the type section in September 2021 was supplemented by further fieldwork in April–May 2022 and resulted in the collection of 404 samples across a _˜18 m stratigraphic interval spanning the GSSP and ranging from the top of bed A1 to _˜10 m above the top of the Nicola bed (A5). Samples were collected at _˜5 cm intervals. Pervasive fine-scale tectonic fracturing of the Monte San Nicola outcrop, coupled with the brittle nature of the dominant marl lithology, makes closer-interval sampling challenging although several narrow blocks of the finely laminated Nicola bed were collected for additional microstratigraphic analysis. GELSTRAT is an international collaborative program in which

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approaches planned or in progress include: calcareous nannofossils, foraminifers, pollen, dinoflagellate cysts, macrofossils, ichnofossils, foraminiferal stable isotopes, organic geochemistry, clay mineralogy, magnetostratigraphy, and 10Be analysis. The first high-resolution oxygen and carbon isotope record has been obtained in the Gelasian type section, together with detailed marine and terrestrial biotic climate signals across the boundary. The Nicola bed itself is undergoing analysis at ultrafine stratigraphic detail employing many of the above approaches but also microstratigraphy, X-ray tomography, micro-XRF elemental analysis (ITRAX), micro-RAMAN spectroscopy, Fourier transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). A refined characterization of the Gelasian GSSP will enhance its utility for the precise recognition of the base of the Quaternary on a global scale, and our integrated paleoclimate reconstructions will illuminate a crucial phase of Earth history.

Keywords: Quaternary, Pleistocene, Gelasian, GSSP, Monte San Nicola

The Meghalayan GSSP and the genesis of the '4.2 ka event': the long and short of it

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Perturbed climatic conditions around 4200 years ago have for long intrigued the minds of Quaternary geoscientists. Previously, this climatic event recorded more or less around the globe seems to have been thought of as originating from slow sub-Milankovitch components of the climate system. With these regards, such processes were expressed in terms of the millennial-scale variability in solar activity and North Atlantic deep-water formation, or in relation to the onset of Neoglaciation and discussed in the context of the smoothly decreasing trend in Northern Hemisphere summer insolation over the Holocene (among others). These findings came into a multi-disciplinary spotlight when the ancient Mesopotamian civilization was found to have been abruptly impacted by the changed climate at 2200 BC; moreover, the term '4.2 ka event' was coined first time in illustrating the climatic background to the cultural collapse. More recently, however, the picture has changed once again. Following the ratifications of the Quaternary System/Period and the Pleistocene Series/Epoch, and in particular that of the Holocene Series/Epoch, also the Holocene Series/Epoch has now been subdivided into the Greenlandian, Northgrippian and Meghalayan Stages/Ages, as formally ratified by the Executive Committee of the International Union of Geological Science in 2018. Ratification of these stratigraphic units on the geologic time scale locates the boundary between the Northgrippian and Meghalayan at 4.2 ka and places the Global Boundary Stratotype Section and Point (GSSP) in the Mawmluh Cave (India) speleothem KM-A, which shows a marked shift to less negative δ18O isotopic values around 4250 yr b2k, reflecting an abrupt reduction in monsoonal precipitation. This isotopic excursion represents the most notable feature of the KM-A speleothem and spans _˜415 years from 4303 ± 26 yr BP (onset) to 4071 ± 31 yr BP (intensification) and to 3888 ± 22 yr BP (termination). Thus, the δ18O excursion overlaps with the timing of the '4.2 ka event', which indeed had been previously ascribed to the weakening of the south Asian monsoon variability, similar to indications inferred from the KM-A speleothem. Since its ratification, the Meghalayan GSSP has received highlight but also criticism, including the questions of the representativeness of the '4.2 ka event' in the KM-A speleothem. Interestingly, it appears that the coverage the Meghalayan GSSP has generated has also changed the ways the researchers from various disciplines now regard the '4.2 ka event'. The interpretation of climatic conditions that may have been perturbed for a period longer than several centuries around 4200 years ago due to slow sub-Milankovitch scale forcing have given way to discussion of abrupt and short-term (_˜centennial) hydroclimatic/monsoonal anomalies inside the longer-term event, ignoring the potential time-transgressiveness of the climatic response to the potential millennial-scale forcing. Moreover, it appears as if the Mawmluh Cave KM-A speleothem would since the ratification be regarded as an (unofficial) stratotype for the '4.2 ka event'. Systematic renaming of the event and anomalies

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(not the GSSP) could possibly help disentangling the components behind the perturbed climate over an extended period. Unintentionally, the process may already be underway, with the use of coined terms such as "the 4.07 ka BP global climate anomaly", "4000 BP event" and "4.0 ka event" becoming cited in the literature. Finally, the results could be seen to detail the ways in which the ratification of the GSSP(s) may alter the ways we view the history of our planet. The findings of this study are supported by a literature review of more than 100 papers.

Keywords: Quaternary, Meghalayan, GSSP, 4.2 ka event, speleothem, dendrochronology

The current state of glacial stratigraphy from the Gelasian to Chibanian stages in the Midwest United States

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The repeated growth and decay of ice sheets in North American is the driving mechanism for sea-level change during the Quaternary. Problematically, most of the primary terrestrial records of glaciation in North America, i.e., old glacial diamictons, are eroded or covered by till deposited during the last or penultimate glacial episodes. However, one sector found in Nebraska, Kansas, Missouri, and Iowa was not glaciated during the last two stages, and the Quaternary package in this area can exceed 100 meters. Glacial diamictons in this region are difficult to distinguish in the field as the unweathered zones are generally gray, calcareous, and clay-rich. Though distinctions between tills made using normal or reversed magnatish and variation in the coarse clast fraction. Paleosols, weathering zones, or sand and gravel beds are commonly separate tills. Importantly, ash from the Yellowstone volcanic system can also be found between tills in certain locations. The tephras are from three separate events which occurred around 0.6 Ma, 1.3 Ma, and 2.1 Ma. Ages from cosmogenic-nuclide burial-dating on paleosols also indicate multiple distict advances; previous studies indicated at least six tills older than 0.2 Ma are present. New work analysing glacial signals left in the modern drainage network confirms that ice advanced into this area from the north via Minnesota rather than from the Great Lakes Region. Together, these terrestrial datasets and chronology represent critical parameters for models depicting previous iterations of North America glaciation - Ice lobes advanced past 40N over most of the Quaternary. Another implication is that Quaternary glaciation removed a significant volume of Phanerozoic strata from the North American Craton. Further work should be conducted to further constrain the timing of these ice advances and to potentially identify additional tills.

Keywords: Laurentide Ice Sheet, Glaciation, North America, Quaternary, Marine Isotope Stage, PreIllinoian

*Speaker

SC4: SNS Neogene stratigraphy and paleoceanography

The Neogene/Quaternary boundary at the Monte San Nicola Gela section and its global correlation

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The Gelasian Stage spans the interval from 2.58 and 1.80 Ma, and it represents the first stage of the Pleistocene Epoch and Quaternary Period. It was defined at Monte San Nicola section 6 km far from Gela town (South Sicily), just above the base of the sapropel A5 known as "Nicola Bed" (Rio et al. 1994, Lourens et al., 1996). The "Nicola Bed" corresponds to the MIS 103 and approximates the Gauss/Matuyama geomagnetic reversal. From a biostratigraphic point of view, the base of the Gelasian coincides with a sharp decrease of *Globigerinoides extremus*, a warm tropical species. Few meters above, a drastic reduction of Discoasterids have been described, with the extinction of *Discoaster pentaradiatus* at the MIS 100/99. Further, an increase of *Neogloboquadrina atlantica,* considered as polar species by Poore and Bergren (1975), occurs between MIS 100 and 96 (Lourens et al., 1996, Caruso, 2004; Becker et al., 2005; Capraro et al., 2022). *N. atlantica* well marks the interval between MIS 100 and 96 (2.52 and 2.4 Ma) and its increasing coincides with the stabilization of the Arctic ice sheet (Lisiecki and Raymo, 2005). The above mentioned calcareous planktonic species testify the drastic climate change occurred during the beginning of the Quaternary and have been astronomically calibrated in several successions from the Mediterranean area (Lourens et al., 1996, Caruso, 2004, Hilgen and Lourens, 2004, Capriaro et al., 2022). Initially, the Gelasian stage was proposed as the third stage of the Pliocene Epoch (Rio et al., 1994) and only later Gibbard and Head (2010) proposed it as the first stage of the Pleistocene, because this cooling is well recognizable in extra Mediterranean successions and occurs just above the Gauss/Matuyama geomagnetic reversal. This choice created considerable confusion in the Italian scientific community, since MIS 103 represents a warm climatic phase of the Earth' climate history which coincides with one of the strongest insolation peaks (MPCR 250; Hilgen, 1991). Most of Italian scientists were against this decision, because during the INQUA London congress (1948) was proposed the beginning of the Quaternary in coincidence of the first colonization in the Mediterranean area of molluscs considered as "northern guests" (i.e. *Arctica islandica, and Panopea norvegica* among all). However, their first real colonization is not easily recognizable as these molluscs live at bathymetries lower than 120 meters. On the basis of this considerations, Aguirre and Pasini (1985) proposed the Vrica section (Southern Italy) as GSSP for the base of the Pleistocene, introducing the term Calabrian (Gignoux, 1909) and, due to the absence of northern guests, proposed the base of Calabrian stage at the sapropel "e" coinciding with the increase of the polar species *Neogloboquadrina pachyderma* left coiling that falls at MIS 64 close to the Olduvai subchron. Although

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this latter bioevent has been astronomically calibrated at 1.805 Ma (Lourens et al. 1994, Caruso 2004, Hilgen and Lourens, 2004), the cooling trend is not so evident in the extra-Mediterranean successions and this has triggered a debate in the scientific community.

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Keywords: Gelasian GSSP, Monte San Nicola Gela, (Sicily), Calcareous Plankton biostratigraphy

Capturing Late Miocene ice volume variability from a global benthic foraminiferal oxygen isotope stack (8.0-4.0 Ma)

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Benthic foraminiferal stable isotope stratigraphies track changes in past deep-sea temperatures, global ice volume and the carbon cycle in response to astronomical forcing. Our understanding of Plio-Pleistocene climate has improved significantly through the study of global (LR04; Lisiecki & Raymo, 2005, Paleoceanography) and regional benthic foraminiferal δ18O and δ13C compilations (Ceara Rise; Wilkens et al., 2017, *Climate of the Past*). Here we present the first global Late Miocene benthic foraminiferal δ18O stack spanning 8.0-4.0 Ma. We use nine high-resolution, continuous benthic stable isotope stratigraphies to compile a "Base Stack", with data from the Atlantic (ODP Sites 982 (N), 926 (E) and 1264 (S)), Indian (IODP Site U1443) and Pacific Oceans (IODP Sites U1337, U1338 (E), (I)ODP Sites 1143, 1146, U1488 (W)). Where needed, we verified the stratigraphy and established independent astrochronologies to avoid miscorrelation of individual excursions. To complement the "Base Stack", we also compile a "Global Comprehensive Stack", which incorporates all available high-resolution single-hole benthic δ18O stratigraphies to optimise global coverage.

This new global Late Miocene benthic δ18O stack represents a reference section back to 8.0 Ma, which is tied to the Geomagnetic Polarity Time Scale from Chrons C2Arto C4n.2n using the Site U1337 magnetostratigraphy. We recognise new Marine Isotope Stages in the δ18O stack between 7.7 and 6.5 Ma. An exceptional global response, with 40-kyr cyclicity, is imprinted on all sites from 7.7-6.9 and 6.4-5.4 Ma. This response is dampened between 6.9-6.4 Ma, when sites display regional differences to astronomical forcing. The influence of deep-sea temperature and ice volume on benthic δ18O is explored at Site U1337 using Mg/Ca data combined with cycle shape analysis. The 40-kyr dominated δ18O cycles are asymmetric, suggesting dynamic ice volume control. The asymmetry is especially distinct from 7.7-6.9, prior to the late Miocene cooling and the growing influence of high-latitude processes.

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Keywords: Late Miocene, oxygen isotope stratigraphy, integrated astro, chemo, magnetostratigraphy, high latitude climate influence

Miocene sequence stratigraphy of the northeastern North Sea Basin: An eustatic fairytale interrupted by tectonism

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Here we present a detailed study of a mixed siliciclastic and bioclastic (diatomite) depositional system from the epicontinental North Sea Basin. The study area encompasses an almost complete Miocene succession and is thus excellent in order to understand the geological evolution during this Epoch.

The eastern North Sea Basin was during the warm and humid Miocene dominated by a fluvio-deltaic depositional setting. A constant and high supply of sediment from the Fennoscandian Shield resulted in a continuous stratigraphic record. Outcrop-samples, cores and cuttings samples from onshore and offshore wells have provided material for a robust biostratigraphic framework for the succession. Based on this framework, a sequence stratigraphic subdivision has been established and seven sequences have been defined. In general, the sequence development was strongly controlled by eustatic sea-level changes as indicated by the asymmetry of all sequences, i.e., thin transgressive systems tract and relative thick high- and lowstand systems tract. Three of the sequences also comprise falling stage systems tracts. However, two tectonic events strongly influenced the depositional history; 1) late Oligocene – early Miocene inversion tectonism resulted in shallower water in the Norwegian-Danish Basin and thus progradation of the fluvio-deltaic system south of the Fennoscandian Shield, 2) Increased subsidence of the entire basin during the late middle Miocene resulted in flooding of the delta systems despite a concurrent global sea-level fall associated with the Middle Miocene Climatic Transition (MMCT).

The detailed bio- and sequence stratigraphy and the high density and quality of data (outcrops, boreholes and seismic) allow a detailed reconstruction of the paleo-landscape and paleo-bathymetry during the early to middle Miocene. The eastern portion of the North Sea Basin was dominated by wave-dominated deltas. In the deeper parts of the basin, mud was transported westward by submarine currents and plastered along the slope. In the central parts of the basin, biogenic ooze (especially diatoms and sponge spicules) formed a significant part of the detrital sediment particles, especially during the Middle Miocene Climatic Optimum (MMCO).

The subsidence during the late middle Miocene resulted in a distinct change in deposition and formation/deposition of glaucony-rich clay basin wide. During the late Miocene resumed delta progradation from the Fennoscandian shield occurred. Associated with the Messinian sea-level fall, gravity flow deposits were laid down for the first time in the study area.

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Keywords: Miocene, sequence stratigraphy, paleogeography, North Sea

Late Burdigalian to Langhian (Early to Middle Miocene) planktonic foraminiferal high-resolution biostratigraphy from Walvis Ridge Site 1264 (south-eastern Atlantic Ocean).

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The late Burdigalian to Langhian interval represents a crucial period in Earth's climate evolution, being characterized by a global warming event (Miocene Climatic Optimum) from 17 to 14.7 Ma, followed by a gradual decline in temperature (Middle Miocene Climate Transition) which culminates in the marked Mi3b cooling event at 13.8 Ma. The ocean-climate system changed to a colder mode and progressed to modern conditions marked by strong meridional and vertical thermal gradients, increased zonality and dominance of high-latitude deep water sources. This climatic evolution favoured the contraction of tropical and subtropical bioprovinces to lower latitudes also affecting planktonic foraminiferal assemblages, which started to differentiate between low- and mid-latitude regions leading to the erection of different biozonal schemes. High-resolution quantitative biostratigraphic studies and a good age control (e.g., by the integration with magnetostratigraphy and/or cyclostratigraphy) are fundamental to enhance biostratigraphic resolution and the accuracy of bioevent age calibrations. All this improves the understanding of spatial and temporal distribution of biostratigraphic markers and the evaluation of synchronism/diachronism of biostratigraphic events at a global scale. As it concerns the late Burdigalian to Langhian interval, for instance, recent high resolution biostratigraphic studies from Mediterranean astronomically tuned deep marine successions highlighted discrepancies in age calibration of the main planktonic foraminiferal events with respect to the low latitudes. In particular, the evolutionary stages of the *Trilobatus-Praeorbulina-Orbulina* lineage resulted younger in the Mediterranean than at the low latitudes as reported in the literature.
Here, we present the results of high-resolution quantitative biostratigraphic analysis of the planktonic foraminiferal assemblages from the astronomically tuned Site 1264 (ODP Leg 208, south-eastern Atlantic Ocean, latitude ~28◦S). The investigated stratigraphic interval, spanning from ~ 17.5 to ~ 13.5 Ma, consists of foraminifer-bearing nannofossil oozes containing well preserved planktonic foraminiferal assemblages. The quantitative biostratigraphic analysis was performed with a time resolution of ~20 kyr, much higher compared to the previous studies, allowing us to obtain the quantitative distribution patterns of the marker species and to refine the stratigraphic position and the age calibration of the bioevents. Planktonic foraminiferal assemblages at Site 1264 are characterized by the presence of both taxa used as zonal markers

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in the (sub)tropical zonation (e.g., *Catapsydrax dissimilis*, the evolutionary stages of *Trilobatus-Praeorbulina-Orbulina* lineage) and taxa typical of temperate assemblages (e.g., *Globorotalia miozea* and *Globorotalia zealandica*), and by the absence of *Globigerinatella insueta* s.s. typical of the tropical assemblages. All these features indicate that planktonic foraminiferal assemblages at Site 1264 started to differentiate from those of the low-latitude regions since the late Burdigalian. Moreover, a comparison of the biostratigraphic record of Site 1264 with low-latitude distribution range of marker species and biochronology (literature data) highlighted: i) diachronism of some main events, such as the first occurrences of the evolutionary stages of *Trilobatus-Praeorbulina-Orbulina* lineage, *Globoratalia archeomenardii* and *G. praemenardii;* and ii) differences in the distribution patterns of marker species (e.g., *Paragloborotalia siakensis*).

Keywords: planktonic foraminifera, high resolution biostratigraphy, biochronology, Middle Miocene

Coiling directions in the mid Miocene paragloborotaliids (planktonic foraminifera): A correlation event for the base of the Langhian in the low latitudes

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The sequential addition of chambers during growth in trochospiral planktonic foraminifera means they will coil in either a sinistral (left-handed) or dextral (right-handed) direction. The ratio of sinistral to dextral forms may change during the stratigraphic range of a species leading to a dominance of coiling direction. This prevalence in coiling holds biostratigraphic value with a number of bioevents being recognised in Recent to late Miocene (_˜0-7 Ma) biochronology. However, no such events have been applied beyond this age despite a number of species being known to adopt preferential coiling. One such example is the genus *Paragloborotalia* which has been shown to undergo a change from random to sinistrally dominated coiling in the mid Miocene (_˜15 Ma) in the tropical-subtropical realm.

We investigated sites in the equatorial Pacific Ocean (IODP Sites U1337 and U1338, ODP Site 871), equatorial and mid latitude Atlantic Ocean (ODP Site 925 and JOIDES-3 respectively), the Caribbean (Trinidad, Jamaica and Barbados) and high latitude Southern Ocean (ODP Site 747) to assess the global the global synchronicity of the coiling change. Our high-resolution analysis of *Paragloborotalia siakensis* at Site U1337 shows a change from random to sinistral coiling at _˜15.37 Ma within planktonic foraminifera Zone M5. This shows excellent correlation with our lower resolution *P. siakensis* records from Site U1338, JOIDES-3 and Trinidad. The preference in sinistral coiling is maintained up until the extinction level of *P. siakensis* in the late Miocene (_˜10.50 Ma; Site 925, Jamaica). In the high latitudes (ODP Site 747) the absence of paragloborotaliids through a portion of the mid Miocene prevents accurate dating, although random coiling trends are found in the older paragloborotaliids (_˜17.3-19.8 Ma) compared to the sinistral dominance within the younger forms (_˜13.5-9.0 Ma). The analysis of *Globorotalia* at Site 747 show two changes in coiling direction namely random to sinistral at _˜15.14 Ma and sinistral to dextral at _˜10.02 Ma.

We propose the recognition of the coiling change in *Paragloborotalia siakensis* as a secondary bioevent in the mid Miocene at _˜15.37 Ma, and a useful biostratigraphic means of recognising the base of the Langhian in the tropical-subtropical realm. The bioevent will be of particular use in regions where the historic base Langhian planktonic foraminifera event, namely the *Praeorbulina-Orbulina* lineage, are rare or poorly represented.

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Keywords: Biochronology, coiling, Langhian, planktonic foraminifera

Integrated stratigraphy of Neogene diatom-rich sediments (Bahía Inglesa Formation) in northern-central Chile

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Reduced landward moisture transport due to cold upwelled surface waters of the Humboldt Current System (HCS) is one of the primary triggers of hyperarid conditions in the Atacama Desert. Marine sediments exposed along the coastline of northern Chile provide a unique archive of land-ocean coupling between coastal upwelling related to the HCS and paleoclimate in the Atacama Desert during the Neogene. Here we aim to establish a refined stratigraphic framework for the emplacement of diatom-rich deposits of the Bahía Inglesa Formation at Quebrada Tiburón (27$\circ$S).

The marine sediments exposed at Quebrada Tiburón lie transgressively above the pre- Cenozoic basement. Laminated diatomaceous muds is intercalated with sandy deposits. Benthic foraminiferal assemblages and test morphology reveal a shift from trochospiral and planospiral (predominantly epifaunal) to serial (infaunal) morphotypes between sands and diatomaceous muds, respectively. Together with plankton assemblages dominated by diatoms and *Globigerina bulloides*, the diatomaceous muds reflect a highly productive coastal upwelling regime and low oxic, eutrophic conditions at the seafloor. However, occasional layers of bioturbation within the diatomaceous succession also imply phases of relaxed upwelling conditions. The new stratigraphic framework will thus allow the assessment of Neogene up- welling behavior and variability off Chile on orbital time scales.

Preliminary results based on calcareous nannoplankton, diatoms and planktonic foraminifera indicate a stratigraphic range from the upper Miocene (Messinian) to the lower Pliocene for

the diatomaceous muds. Evidence from the δ18O of the benthic foraminifera *Uvigerina peregrina* further ties the upper part of the succession to an uppermost Zanclean age $<$ 3.9 Ma.

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In a next step, the stratigraphic framework will be further improved by new data from magnetostratigraphy, Sr isotopes, and tephrochronology.
This study contributes to CRC 1211 "Earth-Evolution at the dry limit", funded by the Deutsche Forschungsgemeinschaft (DFG).

Keywords: Neogene, biostratigraphy, chemostratigraphy, paleoceanography, eastern Pacific

SC5: Advances in Paleogene research

3D outcrop modelling as a tool for GSSP promotion and communication: A case study from Spain and Italy.

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A great effort has been made by the geoscience community (IUGS, ICS) in recent years to identify, enhance and give visibility to Geological Heritage Sites, the volume on "the First 100" Geological Heritage Sites being a good example. During the COVID-19 pandemic, *in situ* field activity was strongly affected, but this scenario greatly encouraged the development of 3D virtual field analogues. In order to adapt to these circumstances, the International Subcommission on Paleogene Stratigraphy (ISPS) adopted an innovative approach to make GSSPs and geoheritage sites available worldwide, using digital techniques such as photogrammetric surveys to construct 3D models.
Given the travelling restrictions at that time, we focused on two different areas in Spain (Zumaia and Gorrondatxe sections) and three areas in Italy (Massignano, Bottaccione and Monte Cagnero sections). These geosites are the most significant outcrops of the Paleogene GSSPs. To this end, we used the UAV-based photogrammetry technique for constructing 3D models. The work was done in several steps: collecting photos by Unmanned Aerial Vehicles (UAVs), photogrammetric processing, 3D modelling and uploading to the website using the Cesium 3D platform.

The 3D outcrops, together with a short video of the investigated area, are now available at the ISPS website (https://www.paleogene.org/) and are accessible for the scientific community and the general public. The models will be continuously updated with the incorporation of newly produced material and information. This new approach will contribute to the promotion and dissemination of geo-education.
Acknowledgements: Project "*Digitalization and online exploration of the Paleogene GSSP sections*" funded by ICS-IUGS.

Keywords: Geosites, GSSP, digitalization, online exploration, 3D models

*Speaker

Applying the Rules: A proposal to unify Cenozoic Chronostratigraphy and Geochronology

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Six internationally recognized chronostratigraphic ranks currently support narratives in Earth Sciences as illustrated by the International Chronostratigraphic Chart (ICC; Cohen et al., 2013). These are the eonothem/eon, erathem/era, system/period, series/epoch, and stage/age to which subseries/subepoch has recently been added. These ranks have been approved by the International Commission on Stratigraphy (ICS) and ratified by the Executive Committee of the International Union of Geological Sciences (EC-IUGS). The rank of subseries/subepoch was deemed necessary by many, not only within the ICS but also in the North American Commission on Stratigraphic Nomenclature which has incorporated it in its Code (Aubry et al., 2019). The inclusion of the rank of subseries/subepoch in the ICC reflects the essential role these units continue to hold in Cenozoic geohistory, stemming from their long use since the 1800s, their names indicating position, the subseries being convenient for stratigraphies difficult to narrow to stage rank, and the subepochs being of convenient durations for describing geological and evolutionary processes. Indeed, datasets compiled from Google scholar and Scopus show that some subseries are cited over 30 times more frequently than the corresponding or included stage (e.g., upper Eocene vs. Priabonian). We propose that all Cenozoic subseries should be included in the ICC.

The formalization of Cenozoic subseries and their official incorporation into the ICC have been hotly debated in recent years, with the three relevant ICS subcommissions expressing different views on the subject. The adoption of the Holocene subseries by the Subcommission on Quaternary Stratigraphy (SQS) led to their formalization and official incorporation in the ICC (ratification by the EC-IUGS, 14 June 2018; Walker et al., 2019), a move that effectively conferred formal and official rank to subseries and official representation in the ICC (ratification by the EC-IUGS, 1 May 2021; Aubry et al., 2021). This prompted the Subcommission on Neogene

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Stratigraphy (SNS) to also formalize its five Miocene and Pliocene subseries (ratification by the EC-IUGS, 13 October 2021; Aubry et al., 2022), while SQS proceeded with the formalization of subseries for the Pleistocene Series (ratification by the EC-IUGS, 17 January 2020 for the Middle Pleistocene and 30 January for the Lower and Upper Pleistocene; Head et al., 2021). The eleven subseries of the Neogene and Quaternary systems/periods thus officially belong to the international chronostratigraphic hierarchy and their boundaries are unambiguously tied to the GSSPs of their lowest component stages.

The Paleogene System/Period comprises eight informal but well established and broadly used subseries/subepochs. While the boundaries and content of these units must be defined and approved by the relevant subcommission, Finney and Bown (2017, p. 3) determined that "a mixed solution with formalized subseries/subepochs for one or two of the Cenozoic systems but not the others would be the worst possible outcome and difficult to defend. The ultimate decision should be for all or none". The main argument advanced by Pearson et al. (2017) against the formalization of subseries concerned their potential competition with stages, but this is no longer valid since the two ranks now belong to the same (formal) hierarchy. A greater concern for us is that the wide use to subseries by the broad Earth Science community is not served by clear definition, particularly within recent Geological Time scales (GTSs). Because they are excluded from the ICC, Paleogene subseries are excluded from the iconography of recent GTSs even though the associated texts include multiple references to subseries/subepochs by name, but without specifying their rank and without definition. The potential for destabilization of the Paleogene system is substantial and organizations and individual authors are treating them as if formal. Undefined in the ICC, the Paleogene subseries can be modified inconsistently to suit the needs of individual studies, hindering consistent implementation or communication of chronostratigraphic correlations. If the role of the ICS-IUGS is to effectively serve the needs of the scientific community in an evolving context, then Paleogene subseries/subepochs should be formalized and officially included in the ICC. Omitting them from the ICC is to ignore the needs of the broader scientific community (Aubry et al., in press).

Keywords: Subseries, Cenozoic, Paleogene, timescale, chronostratigraphy

New foraminiferal markers for the late Eocene (Sallow Benthic Zones 19–20) from the Helvetic Alps. Implications in biostratigraphical correlation and paleobiogeography

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We describe new foraminiferal taxa, which are new biostratigraphical markers for the late Eocene SBZ 19 and 20 (Priabonian). They include two new genera and new species and subspecies. They are useful biostratigraphical markers easy to identify in random sections and allow discriminating between SBZ 19 and 20.
The larger foraminifera were studied in three sections of the Priabonian Sanetsch Formation in the Helvetic Nappes of the Western Swiss Alps: The Sex Rouge (SE) and the Sanetsch Buvette (SA) sections in the Wildhorn Nappe Complex, and the Col des Essets (ETS) section in the more external Morcles Nappe. In the SE and SA sections, the Tsanfleuron Member and most of the Pierredar Limestone Member of the Sanetsch Formation are assigned to SBZ 19 (early Priabonian), while the uppermost part of the Pierredar Limestone Member is assigned to SBZ 20 (late Priabonian). In the external ETS section the entire Sanetsch Formation contains assemblages characteristic of SBZ 19, suggesting an earlier, middle-late Priabonian onset of the hemipelagic Stad Formation ("*Globigerina* Marls").

The three sections studied are characterized by different facies. *Nummulites-Asterigerina* facies dominate in ETS section, located in the NW, more continent-ward realm of the Morcles Nappe. Mixed orthophragminid/nummulitid facies dominate in the SE section, and orthophragminid facies in the SA section, both located in the realm of the more SE, internal Wildhorn Nappe Complex. These differences in facies, specifically the *Nummulites* facies derived from shallower depth, dominant in the ETS section are unlikely to have caused the absence characteristic taxa of SBZ 20 in the section. The lack of SBZ 20 is likely related to an earlier, middle-late Priabonian drowning in the NE, Morcles realm, contradicting general models (e.g., Menkveld-Gfeller, 2016) of successive drowning towards the NW.

The new taxa have been recognized in the literature from different Priabonian basins of the

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western Tethys, including southern Switzerland, northern Italy, the Ebro Basin and the Prebetic range in Spain, southern Greece, and the Thrace Basin in north-western Turkey. They are, thus, not endemic to the Alpine Helvetic realm, but have a wide geographic distribution in the western Tethys and will help to characterize the Shallow Benthic Zones 19-20 in this areas and to correlate the different basins.
The new genera provide further examples of polyphyletism and parallel evolution in foraminifera. On the one hand, a new species of the rotalid *Rotorbinella* illustrates the polyphyletic recurrent origin of a simple architectural test model (with the simplest canal system) through geological time within the same bioprovince. On the other hand, the evolution of the orthophragminid *Asterocyclina* in the Caribbean and western Tethys conspicuously illustrates the diachronic parallel evolution of the same qualitative characters in geographically separated populations. Parallel evolution also produces similar gradual changes of quantitative characters (size and configuration of the bilocular megalospheric embryo; nepionic reduction), which are used to define species or subspecies biometrically. In consequence, morphologically similar or identical species can independently and diachronically originate in distant bioprovinces. The use of the same specific name for morphologically and biometrically similar species from different bioprovinces, and especially their use for chronostratigraphic correlation should therefore be avoided or applied with extreme caution.

Keywords: Priabonian, Larger foraminifera, Biostratigraphy, Paleobiogeography, Helvetic Alps

Recognizing the Bartonian Stage in the Eastern Gulf Coastal Plain of the USA: The Little Stave Creek Section of Alabama

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Lutetian and Bartonian strata have long been recognized in the Gulf Coastal Plain. A recent proposal would place the Global Stratotype Section and Point (GSSP) for the Bartonian within the Bottaccione Gorge section near Gubbio, Italy. The primary guide event for correlation is the base of chronozone C18r. The proposal identified a secondary guide event, the lowest stratigraphic occurrence of the calcareous nannofossil *Dictyococcites bisectus*, to facilitate correlation. If accepted, the proposed GSSP may change long-held ideas about the Lutetian and Bartonian stages in the Gulf Coastal Plain. It is the purpose of this study to review the impact of the proposed Bartonian GSSP on the important Middle Eocene section at Little Stave Creek, Clarke County, Alabama.
Many of the important stratigraphic models for the eastern Gulf Coastal Plain incorporated the Little Stave Creek section as foundational data. The Little Stave Creek section is no longer available for direct study but geological data have been added to existing information on the section. Archival samples collected from carefully measured sections with identification of sequence boundaries, transgressive surfaces, and maximum flooding surfaces can allow paleontologists to overlay new data on existing stratigraphic models of the sedimentary sequences in the Little Stave Creek section.

Recognition of the Lutetian-Bartonian transition in the Gulf Coastal Plain is problematic. Traditionally, the base of the Bartonian has been associated with the upper Lisbon Formation at Little Stave Creek. This correlation was based primarily on macroinvertebrate and smaller benthic foraminifera correlation throughout the Gulf Coastal Plain. While both of these groups have well known zonations in the Gulf Coastal Plain, they have not been reliably calibrated to the global geologic time scale. The association of the larger foraminiferan *Lepidocyclina ariana* with the upper Lisbon Formation further supports the Bartonian age assignment of that unit.

Previous studies of calcareous nannofossils identified diverse floras in the Lisbon Formation of Little Stave Creek. The lower Lisbon Formation was correlated with biozone NP 15 while the remainder of the Lisbon was correlated with NP 16. The lowest occurrence of *Nummulites prestwichianus*, the traditional base of the Bartonian Stage in its type area of the Hampshire Basin of southern England, occurs within biozone NP16 (CNE 14) at the Alum Bay section on the Isle of Wight.

In this study, planktonic foraminifera from the Lisbon Formation were reexamined. Three

*Speaker

distinct assemblages were recognized: an assemblage associated with the lower Lisbon, an assemblage associated with the upper Lisbon, and an assemblage of wide-ranging species common to both the lower and upper Lisbon. The lower Lisbon assemblage contains *Turborotalia frontosa, Globoturborotalia ouachitaensis, Pseudohastergerina wilcoxensis, Jenkinsella triseriata,* and *Igorina broedermanni.* The upper Lisbon assemblage includes *Hantkenina liebusi* and *Dipsidrepella danvillensis.* Taxa common to both the lower and upper Lisbon include *Acarinina bullbrooki, Acarinina rohri, Acarinina topilensis, Morozovelloides crassatus, Subbotina eocaena,* and *Pseudohastergerina micra.* Of the thirteen taxa of planktonic foraminiferans found in the Lisbon Formation at Little Stave Creek, only *Pseudohastergerina wilcoxensis, Jenkinsella triseriata,* and *Igorina broedermanni* are restricted to the Lutetian.

Correlating the Little Stave Creek section to the proposed GSSP at Bottaccione Gorge is challenging. There are no reliable paleomagnetic records from the Little Stave Creek section making recognition of the primary guide event for the Bartonian (the base of magnetic chronozone C18r) impossible. The secondary guide event at Bottaccione is more promising. The lowest stratigraphic occurrence of the calcareous nannofossil *Dictyococcites bisectus* serves as the CNE 14/CNE 15 zonal boundary and occurs above the *Nummulites prestwichianus* bed at Alum Bay and is Bartonian in an historical sense. At Little Stave Creek, the lowest occurrence of *Dictyococcites bisectus* occurs just above the top of the lower Lisbon. This lowers the base of the Bartonian at Little Stave Creek to at least 35 m below the *Lepidocyclina ariana* horizon. While lowering the traditional base of the Bartonian at Little Stave Creek, the correlation is consistent with the planktonic foraminiferal results presented here.
Further work is needed to define correlations between the Lisbon Formation at Little Stave Creek and units such as the Cook Mountain Formation of Mississippi and Louisiana and the Wheelock and Yegua Formations of Texas. Such studies will facilitate the recognition of the Bartonian Stage in those regions.

Keywords: Bartonian, correlation, planktonic foraminifera, Gulf Coastal Plain, Little Stave Creek

Changes in benthic foraminiferal assemblages at the Eocene-Oligocene transition in the Transylvanian Basin (Romania)

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The Eocene-Oligocene boundary that marks a pivotal transition in the Cenozoic climate is intensively studied and best known at the global scale as a cooling event, coincident with the appearance of the first significant permanent ice sheet in Antarctica. This had a major impact on the global ocean and consequently on the marine biota, although its effects on regional palaeoceanography are not uniformly well understood and remained especially poorly constrained in the Transylvanian Basin (Romania). This study aims to identify the regional signals that may be related to a trend of global temperature drop and major palaeoceanographic changes linked to the development of polar ice sheets. We investigated a 35-meter-thick section of the Upper Eocene Brebi Formation from the Transylvanian Paleogene Basin to reconstruct the changes in shallow-marine palaeoenvironments across the Eocene-Oligocene transition. The proxies used are based on the fossil benthic foraminiferal assemblages, because the modern benthic foraminifera taxa are good indicators of various environmental parameters, e.g., temperature, pH, dissolved oxygen, and nutrients of the seawater. A total of 61 samples were collected and processed, and at least 300 benthic foraminifera specimens were picked from every sample. More than 60 species have been identified in the studied material. Diversity indices were calculated, and multivariate data analysis (principal component analysis and cluster analysis) was performed on the benthic foraminiferal dataset. In addition, a morphogroup approach and calculation of BFOI (Benthic Foraminiferal Oxygen Index) also yielded promising results. Our data show that the most common and most abundant benthic foraminifers in the samples belong to the orders *Rotaliida* and *Miliolida*. There are distinctive changes in species abundance distribution patterns along the section, indicating highly dynamic changes in the paleoenvironmental parameters. Our interpretations will highlight both the similarities to global trends and the regional differences inferred from the foraminiferal record in the Transylvanian Paleogene Basin.

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Keywords: palaeoclimate, palaeoenvironment, foraminifera, cooling event, Paleogene

Diachroneity in early Eocene planktic foraminiferal biohorizons

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The increasing planktic foraminiferal research on early Paleogene climate provides significant insights into past global warming, essential in the perspective of future climate changes. At the same time, the recent studies, as focused on paleoclimate, overlooked the requirement of reliable biostratigraphic schemes, in turn essential for reconstructions based on micropaleontological data. Here we highlight significant diachronism with respect to the current zonal scheme (Wade et al., 2011, ESR) for a number of Eocene planktic foraminiferal biohorizons. We realized temporal offsets in early Eocene planktic foraminiferal occurrences when detailed stratigraphy was available, such as through carbon isotopes records besides magnetostratigraphy, and adopting quantitative abundance of marker species at multiple locations. The datums are constrained by carbon isotopes as identifying Carbon Isotope Excursions (CIEs) related to early Eocene hyperthermals. The globally recognized CIEs offer indeed very useful constrains of the bioevents, as providing higher timing resolution than magnetostratigraphy but not yet adopted to characterize the biohorizons. We have conducted high resolution biostratigraphic analyses on lower Eocene sediments for the Pacific, Indian and Atlantic oceans together with the Tethyan Possagno section. Independent age control is provided by both magneto and carbon isotope stratigraphies. We find the *Morozovella aragonensis, Acarinina cuneicamerata* and *Guembelitrioides nuttalli* Bases and *Morozovella subbotinae* Top to be diachronous. The observed offsets clearly demonstrate the need of a revision of the Eocene planktic foraminiferal standard zonation. Quantitative knowledge of the species markers, a practice commonly adopted for calcareous nannofossil biostratigraphy, is critical to identify rare and common occurrences of species and can provide insight into their biogeography and ultimately into their biostratigraphic effectiveness.

Keywords: Early Eocene, planktic foraminifera, biostratigraphy, dischronism

*Speaker

The Late Lutetian Thermal Maximum in the Tasman Sea (IODP Site U1508, Southwest Pacific)

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The middle Eocene is marked by a gradual cooling trend punctuated by transient and geologically brief hyperthermals. These events are characterized by negative excursions in carbon and oxygen stable isotopes (measured in bulk sediment and benthic foraminifera), increased pCO2 levels and/or marine carbonate dissolution. The study of these perturbations of the global carbon cycle is essential to understand their consequences on Earth's climate and biota. Here we present a unique record of the Late Lutetian Thermal Maximum (LLTM), also called the "C19r event", in the Reinga Basin (Tasman Sea). This short-lived event (30 kyr of estimated duration from Atlantic Ocean records) is found to be difficult to identify in deep-sea sediments, and so far only three studies have described its paleoecological consequences in the deep sea in the Atlantic Ocean.

This study is the first record of deep-sea benthic foraminiferal response to the LLTM in the Southwest Pacific (International Ocean Discovery Program Site U1508). We refined the shipboard age model based on GPTS2012 using published magnetostratigraphy and improved biostratigraphic data, and assuming linear sedimentation rates between tie points. The study interval spans from the upper part of Chron C19r to the lower part of Chron C19n, and calcareous nannofossil zones CNE13 and CNE14. The LLTM event is located in the upper part of Chron C19r, at 41.38 Ma in the new age model.

Quantitative analyses of benthic foraminifera reveal a decrease in diversity of the assemblages and changes in the relative abundance of species during the LLTM. The CaCO3 % decreases from 80% to 68% across the LLTM, but calcareous taxa make up ≥85% of the assemblages and the foraminiferal tests do not present any evidence of carbonate dissolution. Decreased diversity of the assemblages points to environmental stress at the seafloor during the LLTM, possibly linked to oxygen deficiency as suggested by the dominance of dysoxic taxa and species of the Superfamily Buliminacea, which in the modern oceans tolerate low oxygen conditions and/or a

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high nutrient supply to the seafloor. A scenario characterized by oxygen deficiency associated with eutrophic conditions is supported by the decrease in the relative abundance of the oxic indicator Globocassidulina subglobosa, and the high relative abundance or infaunal, bi-triserial agglutinated forms.

Our preliminary results indicate enhanced export productivity in the Tasman Sea during the short-lived LLTM. These conclusions will contribute to better understand the relative role of changes in carbon flux vs. warming during rapid hyperthermal events, and to evaluate how global changes affect marine ecosystems.
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Keywords: Hyperthermal, Eocene, SW Pacific, Benthic foraminifera, Paleoecology, Paleoenvironment

Early Paleocene Os isotope stratigraphy within the Chicxulub impact basin

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The impact event at the Cretaceous-Paleogene (K-Pg) boundary, ˜66 million years ago, formed ˜200-km diameter Chicxulub impact structure on the Yucatán Peninsula of the Gulf of Mexico (1). The asteroid impact delivered osmium (Os) into the ocean, which records globally as a negative Os isotope (187Os/188Os) shift in the pelagic carbonate sequences for ˜200 thousand years (kyr) after the impact (2). This impact-induced changes in ocean chemistry provides a unique means of constraining the time scale of recovery after the environmental perturbation (3). However, this approach has been established with the data from only three pelagic sites among the many reported the K-Pg boundary sections. Here we report new record of 187Os/188Os ratios and concentrations of highly siderophile elements (HSEs: Os, Ir, Ru, Pt, Pd, Re) in the earliest to middle Paleocene limestone deposited on top of the Chicxulub impact structure recovered during the IODP-ICDP Expedition 364 (4).
The HSE concentrations throughout the earliest to middle Paleocene limestone show remarkably lower than those in the gray-green marlstone, which contains evidence for asteroid/chondritic material (5). The CI-chondrite normalized HSE patterns in the Paleocene limestone exhibit concentrations and signatures typical for the crustal materials, following a tilted pattern with low Os-Ir-Ru and higher Pt-Pd-Re concentrations.

Age-corrected 187Os/188Os ratios are low in the earliest Paleocene limestone (˜0.19) and then increase gradually. Subsequently, 187Os/188Os ratios recovered to steady state (˜0.45) around ˜2.5 million years (myr) after the impact. The 187Os/188Os ratios of the limestone within the Chicxulub impact basin are consistent with the values previously reported from the pelagic sites in that the ratios recover from low (˜0.17 to 0.2) to steady state (˜0.4) after the K-Pg impact (2). However, the recovery time for Os isotope ratios is quite different, 187Os/188Os profile recorded in the impact basin remain lower than the expected values compared to those of the pelagic sites for at least the first ˜1 myr of the Paleocene (2).

Our results suggest that the Paleocene limestone accumulated in the Chicxulub impact structure recorded continuous but unique temporal evolution of seawater Os isotopic composition after the K-Pg impact. A possible mechanism to achieve the delayed recovery of 187Os/188Os values

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within the impact basin demands (1) only small influx of radiogenic Os in global seawater, and (2) a large input of unradiogenic Os from impact ejecta deposited in the Gulf of Mexico and on Yucatán Peninsula, or (3) input from the impact melt sheet underneath the central basin via venting of hydrothermal fluids (6).

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Keywords: Osmium isotope, Cretaceous–Paleogene boundary, Bolide impact, Gulf of Mexico

The low-diversity benthic foraminiferal assemblage from Late Eocene deposits of Western Siberia

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The West Siberian Sea was among the largest shallow epicontinental basins and well connected to the Peri-Tethys through the Turgay Strait. The final stage of this marine connection and isolation of the Western Siberian Sea is marked by Upper Eocene sediments of the Tavda Formation. The gradual isolation of the basin affected the entire oceanographic environment of the Peri-Tethys, including water exchange and circulation, and shifted most basins of Eurasia to long-term suboxi and anoxic bottom-water environments, water column stratification, brackish or anomalohaline evaporitic conditions, or even endorheic lakes. The strangulation and subsequent disappearance of the epicontinental West Siberian Sea resulted in a complete paleogeographic and paleoclimatic reorganization of the region and coincides with the period when the continents initiated the upheaval to the present-day constellation. In contrast to the extensive studies on the geologic evolution of the Peri-Tethys Ocean and adjacent marine areas, the terminal phase of the marine sedimentation in the West Siberian Basin still has been little studied. We have analyzed the composition, structure, and diversity of benthic foraminiferal assemblages in core material from the southwestern part of Western Siberia to reconstruct the environmental and depositional settings during the terminal phase of marine sedimentation in the West Siberian Basin and to provide a better understanding of the stratigraphy (Upper Tavda Subformation).
The material includes a total of 65 borehole samples from the Kyshtyrla Quarry located on the southwestern periphery of Western Siberia. The study site is situated at the boundary between Western Siberia and the Turgay Strait and holds important clues to reconstruct the connection between the shallow epicontinental West Siberian Basin and the Peri-Tethys Ocean. Drilling was conducted down to a depth of 65 meters and core samples were taken every meter.

A low-diverse assemblage, comprising 8 species of benthic foraminifera, was identified from a total of 412 picked specimens. This includes 6 perforate-hyaline, 1 porcelaneous, and 1 agglutinated species. Analyses of the benthic foraminiferal faunas revealed various species of Cribroelphidium including C. parainvolutum, C. cf. parainvolutum, and C. sp., a few perforate-hyaline and porcelaneous foraminifera, and a single agglutinated taxon. The foraminiferal biotas strongly suggest that the core material studied corresponds to the Upper Tavda Subformation

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and is of Priabonian age.
The benthic foraminiferal biotas recovered are characterized by low species richness and diversity indices and are mainly composed of taxa that are indicative of shallow-water subtidal and, tidal conditions. However, from the bottom to the top of the core section, abundance, species richness, and diversity values markedly decrease, suggesting an increase in environmental stressors. The lowermost units comprise an amalgamation of moderately low diverse subtidal and intertidal taxa (Miliolinella, Cibicides, Cribroelphidium, Porosononion, Ammonia, Trochammina) with Fisher α values of up to 5.5. The upper core units are almost exclusively composed of monospecific, typical intertidal, and stress-tolerant species (e.g. Ammonia, Trochammina). The faunal changes recorded from the bottom to the top of the core are indicative for the transition from a shallow subtidal to a tidal-influenced habitat.

Keywords: biostratigraphy, paleoecology, sedimentation environments, shallow, water

A new biostratigraphic marker for the Latest Danian Event (Paleocene): The last consistent occurrence of *Praemurica* spp.

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During the Paleocene, about 60 million years ago, the earth's temperature was about 10∘C higher than today (Westerhold et al., 2020). Throughout several transient warming events as the Paleocene-Eocene Thermal Maximum (PETM, 56 Ma) and the Latest Danian Event (LDE, 62.1 Ma) temperatures rose even higher. These warming events, or hyperthermals, may have had various causes: 1. methane release by a change in ocean water circulation (Dinarès-Turell et al., 2012), 2. mantle plume volcanism of the North Atlantic Igneous Province emitting CO_2 (Pagani et al., 2006), and/or 3. a variation in the Milanković variables (eccentricity of earth's orbit, axial tilt and precession of the earth) changing the intensity and distribution of solar insolation (Bornemann et al., 2021).
Throughout the LDE, the deep ocean and surface waters warmed with respectively 1.6-2∘C and 2.8∘C (Jehle et al., 2019). Temperature reconstruction and the recognition of these climatic events can be conducted by carbon and oxygen isotope studies in foraminifera (unicellular organisms with a calcareous test). δ^{13}C and δ^{18}O negative excursions result from the input of light carbon (12C) in the ocean and the preference of foraminifera to take up less of the heavy oxygen ^{18}O isotope in their skeleton due to the higher water temperature.

Besides these geochemical indicators, biotic changes in the fossil record contribute to locate and date events in geological history. Planktic foraminifera are useful due to the fast evolution of distinctive species and widespread occurrence in marine sediments. The first and last occurrences of species can function as stratigraphic marker for an event, but are vulnerable to sporadic occurrences and reworking of material by other organisms (e.g., burrowing) may bring older fossils up and relocates the time marker. A more reliable marker can be provided by the use of first and last consistent occurrences rather than focus on the ultimate first or last species in the record.

The base of Paleocene planktic foraminiferal Subzone P3b, currently marked by the lowest occurrence (LO) of *Igorina albeari*, is set at 61.5 Ma in Geologic Time Scale 2020, which is 600 kyrs younger than the LDE (Speijer et al., 2020). However, the LO of this small but distinct biconvex and keeled planktic species correlates with the LDE in the former Tethys Ocean and lower latitudes. For the South Atlantic and Pacific Ocean the LO of *Igorina albeari* is 500 kyrs

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older than the LDE (Bornemann et al., 2021). The last consistent occurrence (LCO) of *Praemurica* spp., a planktic foraminifera genus, is a better stratigraphic marker on a global level based on our current study in the former Tethys Ocean, North Pacific Ocean, North and South Atlantic Ocean and Indian Ocean. Therefore, a revision of planktic foraminiferal Zone P3 is proposed, which consists of a lowered base of Subzone P3b to the onset of the LDE at 62.1 Ma marked by the LCO of *Praemurica* spp. instead of the LO of *Igorina albeari*.

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Keywords: Paleocene, Latest Danian Event, planktic foraminiferal Zone P3, *Praemurica* spp., *Igorina albeari*

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

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Planktonic foraminifera from the Rashrashiyah Formation of the Sirhan Basin in northern Saudi Arabia were examined for their biostratigraphy and stratigraphic ranges. Assemblages are well-preserved and diverse, with forty species and eleven genera. All samples are from the Priabonian *Globigerinatheka semiinvoluta* Highest Occurrence Zone (E14). The excellent preservation coupled with high diversity allows us to re-examine the stratigraphic ranges of many taxa. Our study reveals that several species of *Globoturborotalita* including *G. barbula, G. cancellata, G. gnaucki, G. paracancellata*, and *G. pseudopraebulloides* evolved earlier than previously proposed. Additionally, older stratigraphic occurrences are found for *Dentoglobigerina taci* and *Subbotina projecta*. Our revision to the stratigraphic ranges has implications for the phylogeny and indicates that the tropical/subtropical diversity of planktonic foraminifera in the late Eocene was higher than previous studies have documented.

Keywords: Biostratigraphy, Priabonian, planktonic foraminifera

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Deciphering the nature of subaerial/submarine Hg emissions associated with the North Atlantic Igneous Province during the Paleocene–Eocene Thermal Maximum

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The Paleocene–Eocene Thermal Maximum (PETM) was a period of extreme warmth (_˜56 million years ago) that lasted for _˜200,000 years and that had a profound influence on the global climate and ecosystems. The mean annual global temperature rose by 5–6 C over a few thousand years at the onset of the PETM, resulting from massive carbon release into the ocean and atmosphere. The emplacement of the North Atlantic Igneous Province (NAIP), both in the form of voluminous extrusive basaltic successions and magma intrusions into sedimentary basins, was most active around the Paleocene–Eocene transition, suggesting that volatile degassing from volcanic and thermogenic causes may have contributed to global warming.
A transect of five holes at IODP Sites U1567 and U1568 that sample the upper part of the Modgunn hydrothermal vent complex on the mid-Norwegian Margin were recently drilled during the International Ocean Discovery Program (IODP) Expedition 396. Stable carbon isotope stratigraphy and dinoflagellate cyst biostratigraphy confirm a PETM age for the vent infill. The aim of this study is to disentangle the relative contributions of subaerial and submarine emissions associated with basalt emplacement and sill intrusions into organic rich sediments during the PETM, which has implications on the causes of the carbon cycle perturbations over this hyperthermal event.
Variations in the concentration of Hg in organic carbon-rich sediments is widely used as a direct means of elucidating regional to global scale volcanic activity such as that associated with the NAIP, as well as earlier large igneous provinces. The PETM interval from the Modgunn site yields exceptionally abundant macrofossil wood (sub-centimetre to a few centimetres in diameter). The unconsolidated sediments allowed us to isolate fossil wood from more than

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100 samples over the PETM interval from three of the boreholes. This study will discuss new data on the variations of Hg concentrations in fossilized woody materials, as well as bulk Hg concentration normalised to TOC of the bulk sediments from the same stratigraphic levels. We use these paired data to disentangle the Hg input from global atmospheric Hg-loading (subaerial volcanic in origin) and local submarine vent sources (volcanic or metamorphic).

Keywords: Paleocene–Eocene Thermal Maximum, Mercury concentration, North Atlantic Igneous Province, Hydrothermal vent complex

SC6: Integrated stratigraphy and GSSPs of the Cretaceous System

Characterisation of the Coniacian-Santonian boundary at Olazagutia (GSSP, Spain) and Ten Mile Creek (USA): evidence of diachronism?

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The latest significant Cretaceous carbon cycle perturbation occurred during the Coniacian-Santonian interval. Even if the term of OAE3 (Oceanic Anoxic Event) is often used, this event is not a real global oceanic anoxic and not synchronous event, but reflects more a change in local conditions. The mechanisms and palaeoenvironmental conditions leading to and through this event are poorly known, more particularly the marine phosphorus cycle and changes therein, and the climate conditions. This study focuses on bulk rock and clay mineralogy, phosphorus and carbon isotope geochemistry, high-resolution biostratigraphy, to decipher changes in climate and primary productivity. Two sections from different palaeogeographic areas characterised by different paleodepths were studied. These investigated sections were proposed as candidates for the base Santonian global boundary stratotype section and point (GSSP): Olazagutia (NW Spain) and Ten Mile Creek-Arbor Park (Texas, USA). The first one was finally ratified in 2013, and the base of Santonian stage was defined by the first occurrence of the inoceramid *Cladoceramus undulatoplicatus*. However, in the Olazagutia section, a strong diachronism is observed between the inoceramid *C. undulatoplicatus* and the nannofossils *A. minimus*, *C. obscurus* and *L. cayeuxii*, suggesting that the occurrence of *C. undulatoplicatus* appears to occur significantly above the Coniacian-Santonian boundary, and its first occurrence appears to be environmentally controlled. Indeed, in both sections, the first occurrence of *C. undulatoplicatus* is coeval with phosphorus increase indicative of more mesotrophic conditions. But contrary to the Olazagutia section, the first occurrence of C. *undulatoplicatus* is synchronous with the first occurrence of *A. minimus* in the Ten Mile Creek section.
New data based on Sr isotopes performed of inoceramid shell from Olazagutia GSSP and the Ten Mile Creek sections, will be provided in order to confirm or not the diachronism of the first occurrence of *C. undulatoplicatus*.
Palaeoclimatic reconstruction shows that climate shifted from humid to relative drier conditions near the Coniacian-Santonian boundary, followed by a return to more humid conditions during the Santonian. Fluctuations in total phosphorus contents appear mainly to have been driven by

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changes in detrital input and consequently by the climate change observed in both Spain and Texas sections.

Keywords: Cretaceous, Coniacian, Santonian, GSSP, Inoceramid, Sr isotopes, Palaeoclimate

Pinocchiodinium erbae (Acritarch, marine phytoplankton) – stratigraphic distribution and constrains of the Barremian-Aptian transition

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The acritarch species *Pinocchiodinium erbae* Torricelli 2000 was originally described from the Lower Cretaceous section cored in the Cismon Valley (Southern Alps, Italy). Due to its peculiar and easily identifiable morphology and its common occurrence within the Selli level (OAE1a) documented in the Cismon section, it was proposed as a potential marker species for the Aptian sediments of the Tethys (e.g., Torricelli, 2001). The aim of this study is to update the stratigraphic distribution of *P. erbae* based on new evidences from other Tethyan localities and to characterize the Barremian–Aptian transition. The study of the Miravete section, cropping out in the Galve sub-basin (Eastern Spain), showed rich and diversified palynological assemblages. The interval sampled included the Artoles to the Forcall Formation (Barremian to lower Aptian). The age of the Forcall Formation (lower part) was formerly considered as Aptian, based on ammonite data (*Deshayesites oglanlensis* Zone, Moreno-Bedmar and Garcia, 2011). However, a recent re-examination of the ammonite material suggested an attribution to the uppermost Barremian (*Martelites sarasini* Zone, Frau *et al.*, 2020). The first occurrence (FO) of *P. erbae* was recorded within the lower part of the Forcall Formation, suggesting a late Barremian-early Aptian age for this event. This first result was challenged via a recent palynological investigation carried out in the Gorgo a Cerbara section (Northern Apennines, Central Italy) proposed as GSSP candidate for the base of the Aptian Stage (Erba, 1996; Unida and Patruno, 2015). The study focused on a 5.5 m thick interval spanning the Barremian-Aptian transition (from the uppermost Maiolica Formation to the lower part of Marne a Fucoidi Formation, including the Selli level). In this section, *P. erbae* was recorded a few centimeters below the base of CM0r. Its FO, within the Maiolica Formation (*Globigerinelloides aptiensis* Zone), is located 2.5 m below the proposed Barremian-Aptian boundary, as recently reviewed by Coccioni (2020). This is consistent with the ammonite data, assigning the upper part of CM0r in Gorgo

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a Cerbara to the uppermost Barremian (*M. sarasini* Zone, Frau *et al.*, 2018), and with the composition of the associated dinoflagellate cyst assemblages. These are characterized by common to abundant *Druggidium deflandrei* and *Pterodium* spp. and by other accessory species, showing a remarkable affinity with the palynological assemblages recorded within the Barremian historical stratotype in the Angles section (Southeast France; De Renéville and Raynaud, 1981). These results seem to point to an earlier appearance of *P. erbae*, likely dateable to the latest Barremian.

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Keywords: palynology, Cretaceous, Aptian, Barremian, acritarch, OAE1a, Italy, Spain, Tethys

Formal proposal for the Global Boundary Stratotype Section and Point (GSSP) of the Barremian Stage at Río Argos (Caravaca, SE Spain)

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After having been discussed and approved by the Barremian Working Group and the International Subcommission on Cretaceous stratigraphy, the Global Stratotype Section and Point (GSSP) formal proposal for the Barremian stage is now being discussed by the International Commission on Stratigraphy. The proposed candidate GSSP for the base of the Barremian Stage is defined at the base of bed 171 of the Río Argos section, near Caravaca (SE Spain) and correlated by the first appearance of the ammonite species *Taveraidiscus hugii*. This event falls within the NC5C calcareous nannofossil Subzone, the *Lilliputianella semielongata* planktonic foraminiferal Zone, and the *Dorothia ouachensis* benthic foraminiferal Zone. It roughly coincides with the beginning of a slightly negative trend interval in the δ13C curve. Indirect calibration to the magnetostratigraphic scale suggests that the boundary falls in the lowermost part of polarity chron M3r. According to the astrochronological analysis, a time interval of 0.74

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myr separates the start of the late Hauterivian Faraoni Episode from the base of the Barremian, which is dated at 125.77 Ma.

Keywords: Barremian GSSP, biostratigraphy, chemostratigraphy, magnetostratigraphy, sequence stratigraphy, cyclostratigraphy, astrochronology

The GSSP for the Campanian Stage - the path to selection and ratification

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In 2022, the GSSP for the Campanian Stage, taken at the base of magnetochron 33r in the Bottacione Gorge, Gubbio, Umbria, Italy, was ratified by the International Stratigraphy Commission. Additionally, auxiliary sections were selected in the UK, Poland, Austria, Mexico, and Kansas, USA. Together, these provide a framework permitting high-resolution correlation of the base of the Campanian Stage by the use of palaeomagnetics, carbon isotope stratigraphy and various biostratigraphical groups. The talk provides a historical background to the process of selection of the GSSP, problems encountered en route to submitting a proposal, the importance of auxiliary sections, eventual submission and ratification.

Keywords: GSSP Campanian ratification

*Speaker

Integrated stratigraphy of the Turonian Stage, northwestern Europe

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The Turonian chalk succession present in the Anglo-Paris Basin (France, UK) provides an expanded representation of the stage, albeit with significant condensation of the upper Turonian with the development of hardgrounds. The succession yields a high-resolution carbon isotope curve and detailed biostratigraphy based on ammonites, inoceramid bivalves, foraminiferans and microcrinoids. The integration of carbon isotope and biostratigraphical data provides a powerful correlation tool, which can be used on a global scale.

Keywords: Turonian correlation carbon isotopes

*Speaker

Sedimentary events at the Jurassic/Cretaceous boundary interval in the Slovenian Basin and Transdanubian Mts (Hungary): evidences from terrigenous input and trace metal enrichments

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The Jurassic/Cretaceous boundary interval (upper Tithonian – lower Berriasian) in the Transdanubian Mts (NW Hungary) was intensively studied throughout last decade (e.g. Fözy et al. 2022). The succession is typically developed in Ammonitico Rosso and Biancone facies, and is comprehensively dated using calpionellids, calcareous nannofossils, ammonites and magnetic stratigraphy (Szives & Fözy 2022; Lodowski et al. 2022). First-order sedimentary trends (terrigenous input, redox proxies) are characterized on the basis of elemental chemostratigraphy and carbon isotope stratigraphy (Grabowski et al. 2017; Lodowski et al. 2022).
The coeval succession in the Slovenian Basin is not as well investigated. The new results are presented from the Petrovo Brdo (PB) section, covering lower Tithonian to upper Berriasian (ca. 40 m). At 5 m of the section a sharp transition is observed between clay rich radiolarian cherts of Tolmin Fm. and calpionellid limestones of Biancone Limestone Fm. Calpionellid associations poorly preserved, therefore only rough biostratigraphic dating is possible. Crassicollaria Zone (upper Tithonian) was documented between 8 and 13 m of the section, while the beginning of the Calpionella alpina Subzone (present day J/K boundary) is situated at ca. 20 m. Transition between Tolmin and Maiolica Fm. falls in the UAZ 12 radiolarian Zone which is close to the lower/upper Tithonian boundary.

Despite only rough biostratigraphic dating and unsuccessfull magnetostratigraphic attempt in PB section, it turned out that the section might be quite precisely correlated with Hungarian sections (Lókút and Harskút) using magnetic susceptibility and elemental chemostratigraphy.

*Speaker

The terrigenous proxies in both areas reveal high values in the lower Tithonian, decreasing trend throughout the upper Tithonian – lower Berriasian and again rising values in the upper Berriasian. The trace metal (Ba, Cu, Pb, Zn) enrichments occur exactly opposite, with sharp increase and highest values in the upper Tithonian and lower Berriasian, and low values in the lower Tithonian and upper Berriasian.

The similarity of events indicates their large regional significance in the Western Tethys and potential for correlation of distant sections from different basins.

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Keywords: Jurassic, Cretaceous boundary, Slovenian Basin, Transdanubian Mts, chemostratigraphy

Calpionellid stratigraphy and microfacies in the Clue de Taulanne section (Vocontian Basin, SE France)

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The Clue de Taulanne section is located ca. 3.5 km to the NW from Castellane. The biostratigraphically studied part of the section included interval of ca. 100 m, of the early late Tithonian to earliest Valanginian age. Samples represent carbonate hemipelagic facies of a deep basinal slope with numerous resedimentation features (Beaudoin, 1977; Rameil, 2005). The section has been previously dated by Remane (1970) and Beaudoin (1977), using standart calpionellid zonation of A, B, C and D zones. Here we apply an updated calpionellid stratigraphy using a Reháková & Michalík (1997) Scheme developed in the Western Carpathians area.
Limestones are represented by bioclastic wackestone, in the upper part also mudstone. The most common bioclasts are calpionellids, calcareous dinocysts, ostracods, radiolarians, *Globochaete alpina* spores, fragments of echinoderms (in the Tithonian samples common *Saccocoma*). Aptychi and sections of ammonites are observed in part of the samples. Foraminifera are usually rare and represented mainly by calcareous benthic forms (spirillinids, nodosarids, lagenids), in some samples also agglutinated serial forms. A few specimens of planktic foraminifera were also found. Bioclasts typical of shallow zones are very rare (almost absent). Distinct admixture of silicilastic material was not observed. Bioturbations can be observed in many samples.

Originally siliceous bioclasts are calcified. Micritic matrix is often slightly recrystallized into fine microspar. Part of the Tithonian samples is more or less dolomitized.

Calpionellid zones and subzones were documented, from Chitinoidella boneti Subzone in the lower part of the upper Tithonian, through Tintinnopsella remanei Subzone and the upper part of the Crassicollaria Zone in the upper Tithonian, Calpionella alpina, Remaniella ferasini, C. elliptica subzones in the lower Berriasian, Calpionellopsis oblonga and Praecalpionellites murgeanui subzones in the upper Berriasian. The topmost 2.5 m belongs to the lower Valanginian Calpionellites darderi Subzone. Lack of Cps. simplex subzone might indicate erosion and stratigraphical gap in the lower part of the upper Berriasian.

*Speaker

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Keywords: Jurassic, Cretaceous boundary, calpionellids, Vocontian Basin, Berriasian

Carbon isotope stratigraphy: a key tool for the definition of Cretaceous GSSPs and their global correlation

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The global carbon cycle constitutes one of the most fundamental biogeochemical systems affecting all surface reservoirs on Earth, with complex interactions that modulate and drive climate change on both short and long timescales. Secular variation in stable carbon isotope ratios determined from fossil carbonate (δ13Ccarb) and organic matter (δ13Corg) provides evidence that the sizes of, and fluxes between, global carbon reservoirs have changed significantly throughout the geological record. A residence time of *c.* 100 kyr for carbon in the ocean – atmosphere system ensures that the rock record has the potential to capture a global high-resolution signal of palaeoenvironmental change affecting the carbon cycle. The geological history of carbon cycle perturbations is revealed in profiles of carbon isotope variation from individual stratigraphical sections, with episodes of major change evidenced by positive or negative carbon-isotope excursions or shifts in the direction or rate of isotopic change (Cramer and Jarvis, 2020). Coincident changes in multiple sections from different sedimentary basins enable the definition of carbon isotope events (CIEs) which, when calibrated using biostratigraphy, magnetostratigraphy and/or geochronology, provide a basis for correlation and dating. Carbon isotope stratigraphy (CIS) offers higher precision than possible using conventional biostratigraphy, potentially down to 10 kyr, and as a result it is being increasingly adopted for the refinement of Cretaceous stratigraphy and as one of the criteria for the definition of GSSPs (e.g., Walaszczyk et al., 2022). A unique feature of CIS is the ability to compare records derived from oxidised carbon (δ13Ccarb) and reduced carbon (δ13Corg, including individual organic compounds), with potential for the reconstruction of changes in atmospheric pCO2, and for correlation between marine and non-marine (terrestrial and lacustrine) environments.
The GSSP for the Campanian Stage was ratified in 2022 (Gale et al., 2023), completing the formalisation of GSSPs for all Upper Cretaceous stages. With the exception of the Santonian, all of the stage boundaries are associated with prominent CIEs that offer important tie points for global correlation. The case study of the Campanian (Jarvis et al., 2023) will be used to illustrate how CIS provides a key means for correlation between biotic provinces and enables the development of a robust holostratigraphy that can facilitate global correlation. By contrast, only 2 of 6 Lower Cretaceous stages have ratified GSSPs. The Lower Cretaceous is similarly characterised by a number of high-amplitude CIEs but the current reference curve (Cramer & Jarvis, 2020) is less well resolved, particularly in the Aptian and Albian, and major events do not necessarily coincide with traditional stage boundaries defined using biostratigraphy. The application of CIS to establishing an Aptian GSSP will be investigated to show how chemostratigraphy can provide criteria that enable a more robust correlation of key intervals of global palaeoenviron-

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mental change.

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Keywords: carbon isotope, chemostratigraphy, holostratigraphy, Cretaceous, GSSP, Campanian, Aptian

Synchrony of carbon cycle fluctuations, volcanism and orbital forcing during the Early Cretaceous

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Episodes of Environmental Change (EECs) were times of accelerated hydrological cycle that punctuated the Early Cretaceous. Uncertainties in the geologic time scales however preclude full understanding of the onset, unfolding, and termination of EECs. Here, we reanalyze the hemipelagic sedimentary series from France and Spain from the Valanginian to the Barremian to provide a comprehensive and accurate time scale of the Valanginian–Barremian interval based on the stable 405-kyr eccentricity cycle. According to our astrochonologic framework, the Weissert Event started 134.56 $\pm$ 0.19 Ma, in perfect synchronicity with the peak of volcanic activity of the Paraná-Etendeka Large Igneous Province. On average, EECs show a pacing of 2.40 Myr from the Valanginian to the Barremian, in phase with detrital supply and carbon isotope variations from marine carbonates. Long eccentricity cycles were hence key parameters in the regulation of climate and carbon cycles in the Early Cretaceous through changes in the detrital and nutrient supply, oceanic fertilization, organic carbon storage and global sea level. A long obliquity forcing, at 1.2 Myr, is also observed through the studied interval in both the detrital and carbon-isotope ratios series, allowing the identification of long isotopic stages in the Early Cretaceous. Our study highlights a positive correlation between continental runoff and sea-level change, suggesting that glacio-eustasy was the main driver of global-sea level fluctuations during the Early Cretaceous. We also demonstrate that the humid peak related to the Weissert Event is driven by the pacing of the long orbital cycles despite the emplacement of the Paraná-Etendeka province. Nevertheless, in comparison to other EECs of the Valanginian–Barremian, the Weissert Event appears as a singularly long event with stronger impact on climate and marine ecosystems compared to other EECs. We posit that this is a consequence of the concomitant effect of the emplacement of the

*Speaker

Paraná-Etendeka province and the long orbital cycles.

Keywords: Valanginian, Hauterivian, Barremian, orbital forcing, Paraná, Etendeka Large Igneous Province, Episodes of Environmental Changes

Jurassic–Cretaceous transition sequences in Japan and their contribution to defining the Jurassic–Cretaceous boundary

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The status of current knowledge including the lithology, stratigraphy, fossil contents and radiometric age data of Jurassic–Cretaceous (J–K) transition beds in Japan is reviewed. There are two types of sequences are recognized in the Japanese Islands: shallow marine-terrestrial sequences and pelagic sequences. The former includes the Torinosu Group and its equivalents in the Outer Zone of southwest Japan, the Tetori Group in the Inner Zone of southwest Japan, and the Somanakamura Group and its northern extension in northeast Japan. These strata were deposited in the eastern margin of the Asian Continent during the J–K transition time interval. The latter is typified by radiolarian-rich pelagic sequence embedded in accretionary complexes in the Southern Chichibu and Northern Shimanto belts of southwest Japan and the Tokoro and Sorachi–Yezo belts in Hokkaido.
The Torinosu Group and its equivalents are entirely marine origin and yield abundant molluscan fossils including bivalves and ammonoids of Tethyan affinity. Most ammonoid specimens from the group are indicative of Tithonian in age. The Somanakamura Group is characterized by an alternating occurrence of marine and non-marine succession. The J–K transition beds are correlated to a transitional part from non-marine to marine sequence. Marine beds yield abundant molluscan fossils including Berriasian ammonoids such as *Kilianella umazawensis*, *Dalmasiceras muneoi*, *Neocosmoceras*? *akiyamae* and others. These beds contain plant fossils and palynomorphs. The equivalent beds to the Somanakamura Group yield belemnite species belonging to the genus *Hibolithes* of Tethyan affinity. Both the Torinosu and Somanakamura groups contain radiolarian fossils of the *Pseudodictyomitra carpatica* Zone which encompasses the J–K boundary. Acidic tuff beds embedded in the terrigenous sequences have a high potential for U–Pb zircon radiometric dating.

The Tetori Group is characterized by an alternating occurrence of marine and non-marine sequences. The J–K transition sequence is correlated to a transitional part from non-marine to marine sequence. Marine beds contain abundant bivalves and yield Berriasian ammonoids such as *Neocosmoceras* sp. and others of Tethyan affinity. While they yield cylindroteuthidid belemnites such as *Cylindroteuthis* aff. *knoxvillensis* and *Arctoteuthis tehamaensis* of Boreal

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affinity. Thus Tetori Group can be correlated with the coeval sequences in northern California and Siberia based on the belemnite biostratigraphy.

Chert beds which represent the J–K transition are recorded on Ie Island, Okinawa, in the Southern Chichibu belt. Chert beds within mélange of the Shimanto belt in Shikoku and Kii Peninsula also include the J–K transition beds characterized by the radiolarian *Pseudodictyomitra carpatica* Zone. An accretionary complex composed mainly of basaltic rocks originated from seamounts in the Tokoro belt, east Hokkaido, contains radiolarian cherts with the J–K transition. Hemipelagic tuffaceous sequences of the Sorachi Group in central Hokkaido also include the J–K transition beds with a rich radiolarian fauna of the *Pseudodictyomitra carpatica* Zone. These pelagic and hemipelagic beds are barren of age-diagnostic megafossils such as ammonoids and belemnites. Co-occurrence of radiolarian fossils of superb preservation and calcareous nannofossils in a tuffaceous radiolarite sample (#181-R003) collected by the submergible "Shinkai 6500" from the outer slope in the Mariana Trench enables to correlate radiolarian zones directly to calcareous nannofossil zones.
The J–K transition beds in Japan represent a paleobiogeographic setting different from those in Europe which were accumulated in the western Tethys and Boreal provinces. A faunal comparison between Japan and Europe reveals similarities and differences which are related basically to paleobiogeographic settings. In addition, pelagic microbiotas including radiolarians and calcareous nannofossil in accretionary complexes and ocean bottom sediments in the northwestern Pacific enable to examine a trans-Pacific phenomenon which can be traceable in coeval sequences in the western part of South America as well. The J–K transition sequences in Japan can provide critical data in defining the J–K boundary, making a profound contribution to the selection of the Global Boundary Stratotype Section and Point.

Keywords: Jurassic, Cretaceous, ammonoid, belemnite, radiolaria, calcareous nannofossil, GSSP

Foraminifera and calcareous nannofossils integrated biostratigraphy at southern high latitudes: searching for precision in global correlations

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We established an integrated biostratigraphic framework of the upper Cenomanian to Santonian interval at southern high latitudes based on the stratigraphic distribution of planktonic and benthic foraminifera and of calcareous nannofossils. Data are collected from Integrated Ocean Discovery Program (IODP) Sites U1513 and U1516 drilled in the Mentelle Basin (eastern flank of the Naturaliste Plateau, Indian Ocean, SW Australia) during Expedition 369. These sites were located at a paleolatitude ranging from 57◦S to 62◦S during the Late Cretaceous.
The calcareous plankton assemblages across the Cenomanian-Turonian boundary interval are characterized by the absence of several taxa that are normally common at mid- to low latitudes, including most of the marker taxa used to constrain the boundary interval. However, among calcareous nannofossils *Helenea chiastia* and *Quadrum gartneri* are confirmed to be reliable bioevents to approximate the Cenomanian/Turonian boundary. Moreover, calcareous plankton bioevents, combined with the carbon isotopic data, are correlated with records at low latitudes in the Tethys and Western Interior Seaway. They provide a good chronostratigraphic and integrated stratigraphy framework that represents one of the best documented records across the Cenomanian-Turonian boundary interval for high latitudes of the Southern Hemisphere. Benthic foraminiferal markers occurring during the Cenomanian-Turonian transition in the southern high latitudes are predominantly gavelinellids associated with infaunal opportunist agglutinated and calcareous taxa, including *Gavelinella intermedia* and *Gavelinella vesca*, also documented from mid-Cretaceous Tethyan settings, and *Lingulogavelinella turonica* and *Scheibnerova protintidica*, principally known from the southern high latitude record.

The calcareous plankton assemblages from the lower Turonian to the Santonian interval reveal a Tethyan affinity for some of the assemblages, and confirms the applicability of the calcareous nannofossil CC zones of Perch-Nielsen (1985) and the reliability of the mid- to high latitude biozonation for planktonic foraminifera (Petrizzo et al., 2020). The Turonian/Coniacian boundary is inferred to fall within Zone CC13 and between the LO (last occurrence) of the planktonic foraminifera *Falsotruncana maslakovae* and the LO of the calcareous nannofossils *Micula staurophora* in agreement with mid- to low latitude records (NW Australia, Tanzania and Tethyan localities). The Coniacian/Santonian boundary lies within Zone CC16 and is placed at the LO

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of the planktonic foraminifera *Globotruncana linneiana,* in agreement with the definition of the Santonian Global Stratotype Sections and Points (GSSP).

The benthic foraminiferal assemblages show high similarities with the South American records, and only rara taxa, including *Gavelinella berthelini,* in the Turonian to lower Coniacian interval, and *Notoplanulina rakauroana*, in the lower Coniacian to upper Santonian interval, can be used for worldwide correlations. However, we record the FO of the agglutinated marker taxon *Bulbobaculites problematicus* in the lowermost Turonian used in the Tethyan zonation of Geroch and Nowak (1984).

In this study, the foraminifera and calcareous nannofossils bioevents observed in the Mentelle Basin are discussed and compared with the records reported from stratigraphic sections located at lower latitudes to verify the stratigraphic distribution of cosmopolitan taxa. Finally, we provide an integrated biostratigraphic scheme highlighting the synchronicity of marker species and their reliability for global correlations from low- to high southern latitudes.

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Keywords: Biostratigraphy, calcareous nannofossils, benthic and planktonic foraminifera, Late Cretaceous, Southern Hemisphere, Indian Ocean

Bio-sequence stratigraphy of Jurassic – Cretaceous transition in central Chile

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The Lo Valdés Formation is a marine unit assigned as a mixed carbonate-siliciclastic ramp of a back-arc basin context. This unit represents a transgressive system of the western margin of Gondwana during the upper Tithonian – upper Hauterivian (Salazar & Stinnesbeck 2015). This work integrates the sedimentary and tectonic dynamics with the bio-events marked during this time in central Chile.

The integration of microfacies and sequences stratigraphy with biostratigraphy and bioevents, shows that during the upper Tithonian was a relative increase in sea level, while in the Berriasian, a progressive deepening is suggested a middle ramp that extends to the end of the Berriasian. While, during the upper Tithonian to the upper Berriasian, fauna (ammonites and bivalves) similarity values increase gradually, showing coincidence with the gradual decline of the diversity and highest similarity values during the upper Tithonian, coincident with a high diversity; similarity declines during the lower Berriasian as most taxa (ammonites and bivalves) registered in the upper Tithonian are absent during the lower Berriasian (Salazar et al. 2020).

Then, at the base of the Valanginian, a shallowing would have been registered possibly as an internal ramp, characterized by the decrease of the pelagic material and an increase in the size of selection and rounding of the facies. Upsection, in the Hauterivian, the pelagic material increases progressively again, added also to the significant decrease in the content of bioclasts, representing a deepening and establishing an external ramp sub-environment, therefore an increase in the relative level of the sea to the upper Hauterivian.

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Keywords: Cretaceous, bioevents, stratigraphy, ammonites, bivalves

Palynological records from marine sections across the Jurassic-Cretaceous transition in the Netherlands

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The Jurassic-Cretaceous transition is notoriously difficult to characterize because of faunal endemism and hiatuses. The subsurface of the Netherlands is no exception to that rule, the Jurassic-Cretaceous transition took place during the final stages of the late Cimmerian rift and is generally characterized by non-marine facies and unconformities. Fortunately this is not the case for the Terschelling Basin and the northern part of the Dutch Central Graben. In these basins subsidence continued uninterruptedly, allowing marine sediments to accumulate during that time interval. These successions were penetrated by exploration wells, some of which were analyzed for palynology and organic carbon isotopes (δ13Corg). In the Terschelling Basin, published records1 describe cored intervals that yielded ammonites, dinoflagellate cysts and pollen and spores. Based on these finds, five ammonite zones (Primitivus to Kochi Zone) were assigned, to which the last or first occurrences of the dinoflagellate cysts can be calibrated. In the Dutch Central Graben, the depositional setting of the latest Jurassic to earliest Cretaceous interval is very dynamic, the sediments are coarse-grained and display intra-formational reworking. Despite the coarse-grained facies, both the *in situ* and reworked dinoflagellate cysts are surprisingly well preserved. The excellent preservation can be explained by assuming that the reworked specimens are derived from lithic clasts floating in the sandy matrix. Because of the excellent preservation, it is not easy to distinguish between reworked and in situ specimens but an attempt was made to look for marker taxa that would help to better constrain the latest Jurassic to earliest Cretaceous transition. Important marker taxa for that interval are, from young to old, *Rotosphaeropsis thula, Systematophora daveyi, Gochteodina virgula, Egmontodinium expiratum,* abundant *Cribroperidinium hanseni* (including very large specimens), *Dingodinium tuberosum*, *Perisseiasphaeridium insolitum*, *Egmontodinium polyplacophorum*, *Aldorfia* sp. A in Davey 1982, *Aldorfia spongiosa*, *Gochteodinia* cf. *mutabilis*, *Gochteodinia procera*, *Senoniasphaera jurassica*, *Glossodinium dimorphum* and *Muderongia* sp. A Davey 1979.
The depositional environment of these sediments varies considerably and is often restricted marine, which is reflected by high dominance/low diversity dinoflagellate cyst assemblages. Freshwater influence is indicated by the common occurrence of genera such as *Mendicodinium, Senoniasphaera* and *Muderongia.* Recurrent peak abundances of extremely large and thick-walled specimens of *Cribroperidinium hanseni* are undoubtably related to specific paleoenvironmental conditions, but a direct link between the two could not be established.

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Keywords: Jurassic, palynology, Cretaceous, the Netherlands, dinoflagellate cysts

Reassessment of the base of the Maastrichtian Stage at the GSSP locality Tercis-les-Bains (SW France)

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The ratified GSSP locality for the base of the Maastrichtian Stage is the abandoned quarry at Tercis-les-Bains in southwestern France. The boundary is defined by the arithmetic mean of 12 biostratigraphic criteria 90 cm beneath the first occurrence of the ammonite *Pachydiscus neubergicus* (Odin and Lamaurelle, 2001). The 12 biohorizons include ammonoids, dinoflagellate cysts, planktonic and benthic foraminifera, inoceramid bivalves, and calcareous nannofossils with some potential of global correlation. However, the GSSP decision earned some criticism over the years, mainly because of the diachroneity of *P. neubergicus*, the poor definition of first and last occurrences of planktonic foraminifera and calcareous nannofossils, and the lack of magnetostratigraphy due to a weak magnetic remanence (Gale et al., 2020). The main concern however is the missing definition of a primary marker for the base of the Maastrichtian Stage mandatory for a GSSP. Therefore, the International Subcommission on Cretaceous Stratigraphy assembled a new Maastrichtian Working Group that was appointed in October 2022.
Beside the abovementioned criticism, the Tercis section has clear advantages as GSSP locality. The succession is unusual extended and continuous across the boundary interval with a cyclic bedding of limestones, cherts and marls. Further, the carbon-isotope record of the section has a distinct variability permitting correlation with Boreal chalks, deep-water Tethyan succession at Gubbio (Italy) as well as open oceanic sites in the Atlantic and Pacific oceans (Voigt et al., 2012).

In early March 2023, some members of the Maastrichtian Working group revisited the GSSP section in Tercis to overcome the problems. Main aim is the definition of a primary marker for the base of the stage. Further, the sedimentary cyclicity of the succession will be studied to achieve an astrochronology for the boundary succession. This approach has the potential to develop an astronomically tuned timescale for the entire Maastrichtian Stage.

During the field campaign, the section was resampled to establish modern biozonations for calcareous nannofossils, planktonic and benthic foraminifera, inoceramids and palynomorphs. Quality assurance for the microfossil zonations will be achieved by duplicate assessment by specialists for nannofossils, planktonic and benthic foraminifera. Further, the succession was

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sampled in high resolution to resolve orbital cyclicity and to improve the resolution of carbon isotope stratigraphy. The common field work allows the establishment of a new stratigraphic framework on the same set of samples.

In addition to the work on the Tercis section, the working group plans to develop auxiliary boundary sections for correlation. Potential candidate sections in the Boreal Realm are the Vistula and Kronsmoor sections (Poland, Germany) with new stratigraphic data published over the last years (e.g., Plasota et al., 2015, Wilmsen et al., 2019). The Gubbio section in Italy is a good reference for the Tethys with a robust magnetic stratigraphy (Gardin et al., 2012), and the stratigraphic record of ODP Sites 1209 and 1210 (central Pacific Ocean) may allow for correlation of the boundary to the deep ocean.

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Keywords: Maastrichtian, GSSP, Tercis

The base of the Maastrichtian at the Oslen-Krivodol reference section, Bulgaria, based on nannofossils, inoceramids and strontium isotope stratigraphy

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The base of the Maastrichtian as defined by the GSSP at Tercis-de-Landes, France, is currently in investigation and testing by a newly installed Maastrichtian Working Group due to advancing stratigraphic methods since its ratification more than twenty years ago (Odin & Lamurelle, 2001). Although the Golden Spike point was set at a mean of marker bioevents, it was actually very near the guide event of the first occurrence of the ammonite *Pachydiscus neubergicus*, ca. 35 ka younger than the GSSP level. The main calcareous nannofossil marker is the last occurrence of *Uniplanarius trifidus* (*Quadrum trifidum* in Odin & Lamurelle, 2001), estimated at ca. 750 ka younger than the GSSP mean. Paleogeographically, Tercis was situated in the marginal realm of the Tethys-Atlantic transitional to the cooler temperate realm.
A largely similar paleogeographic situation at the northern Tethyan-European margin is provided by the Upper Cretaceous sedimentary successions cropping out in western part of Bulgaria in the area of the western Fore-Balkan Mountains. One of the most representative section comprising the Upper Campanian-Lower Maastrichtian interval is the Oslen-Krivodol section, situated in the western part of the so-called Central Balkan–Fore-Balkan (CBFB) Tectonic Zone, that forming the northern (marginal) segment of the Balkan Orogen in Bulgaria (Ivanov, 1998).

At the section of Oslen-Krivodol, a several meter thick succession of glauconitic limestones, clayey to nodular limestones and chalky sediments is exposed that includes inoceramids and belemnites. The lower part of the over 7 m thick Oslen-Krivodol succession is composed of green to greenish glauconitic limestones of the Darmantsi Formation (3.1m thick), overlying unconformably the Aptian sandstones of the Roman Formation. The succeeding Kunino Formation (over 4.5m) is represented by thin- to medium bedded limestones, clayey and nodular limestones. Belemnites rostra occur in the entire section, whereas inoceramid bivalves were collected only from two levels in upper part of the Kunino Formation. For a preliminary study, the sediments were tested for calcareous nannofossils using a simple suspension method, and belemnite rostra were used for strontium isotope stratigraphy. Although the sediments show minor thickness compared to other Campanian-Maastrichtian boundary interval (CMB) sites in more pelagic settings, a complete nannofossil zonal succession could be established, from the

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uppermost Campanian to the lowermost Maastrichtian. The following subzones could be distinguished: UC15cTP, UC15deTP, UC16aTP (uppermost Campanian of Thibault et al., 2016), and UC16bTP (basal Maastrichtian). The nannofossil bioevent for the base of the Maastrichtian, the LO of *U. trifidus*, is at 3.25m in the section. Strontium isotope stratigraphy indicates the CMB at a value of 0.707728 $\pm$0.000004, at 3.15m. Additional nannofossil bioevents in the CMB interval include the FO and LO (2.15m) of *Microrhabdulinus ambiguus* (curved spines) below those two levels, and the sudden decrease of warm-water nannofossil indicators like *Watznaueria* spp. (2.73m). Higher in the section (4.08m), *Arkhangelskiella maastrichtiensis* s.str. occurs, although smaller ($< 10\mu$m) morphotypes of this group exist already below that level.

Only two levels from the upper parts of the Kunino Formation have yielded abundant, but badly preserved (as internal moulds) inoceramid bivalves. The inoceramids are represented mainly by the representatives of genus *Cataceramus*, but *Endocostea* is also presented. The inoceramid assemblage is composed of the following species: *Endocostea typica* Whitfield, 1880; *Cataceramus pallisieri* (Douglas, 1942); *Cataceramus subcircularis* (Meek, 1876) and *Cataceramus barabini* (Morton, 1834). Based on the presence of *E. typica* we can indicate the eponymous inoceramid zone at the base of the Maastrichtian.

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Sofia University project SU 80-10-52

Keywords: Maastrichtian, Campanian, nannofossils, strontium isotopes, inoceramids

The Turonian-Coniacian boundary interval in the Gosau Group of Gams (Austria)

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The Gosau Group at Gams (Northern Calcareous Alps, Austria) provides evidence for continous upper Turonian to Coniacian marly deposits of the Grabenbach Formation and the presence of ammonites, inoceramids, foraminifera and nannofossils (Summesberger & Kennedy, 1996), including the type locality of the ammonite *Barroisiceras haberfellneri* (Hauer) at Radstatthöhe near Gams. A renewed field survey in the framework of a Bulgarian-Austrian WTZ project indicated several new biostratigraphic results, based on bivalves, dinoflagellates, and calcareous nannofossils along road cuts and artificial outcrops NE of Radstatthöhe.
The presence of *Barroisiceras haberfellneri* and the bivalve *Didymotis* attests for the interval of uppermost Turonian to lowermost Coniacian, where *Didymotis* events are known from several European sections. Small-sized representatives of the genus *Didymotis* were collected, which are preserved as internal moulds, only rarely with shell fragments attached. The specimens are almost equilateral, ornamented with relatively thick, widely spaced, rounded commarginal rugae. The radial ornamentation is visible in one specimen only. The sampled small-sized *Didymotis* with slender or no radial ornamentation are very similar to the *Didymotis* I morphotype considered to be part of the *Didymotis* I event in the upper Turonian *Mytiloides scupini* Zone at Salzgitter-Salder (GSSP for the base of the Coniacian, Walaszczyk et al., 2022). Based on this sparse *Didymotis* record we assume a late Turonian age (?Mytiloides scupini Zone) for the studied interval. Nannofossil data at Radstatthöhe report the presence of *Marthasterites furcatus* and *Lithastrinus septenarius*, indicating nannofossil standard zones CC13 and UC9 (upper Turonian-lower Coniacian). The absence of *Zeugrhabdotus biperforatus* may further indicate nannofossil subzone UC9a. One test sample from the Turonian-Coniacian boundary interval at Gams yielded a dinocyst association of moderate abundance and preservation. The association includes the following taxa: *Achomosphaera ramulifera, Canningia glomerata, Dinopterygium alatum, Isabelidinium cooksoniae, Kleithriashpaeridium readei, Raetiadinium truncigerum, Oligosphaeridium pulcherrimum, Spiniferites ramosus, Pterodinium cingulatum* and *Exochosphaeridium majus.* The concurrent presence of the dinocyst species *Raetiadinium truncigerum, Oligosphaeridium pulcherrimum* and *Canningia glomerata* marks an age not older than late Turonian for the sampled succession, compared to the data from the recently established Turonian/Coniacian GSSP boundary stratotype at Salzgitter-Salder, Germany.

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Keywords: Turonian, Coniacian, biostratigraphy

Towards an Aptian GSSP

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The base of the Aptian Stage is informally placed at the beginning of magnetic chron M0r. This definition is also used in the GTS2020 timescale. Recently, Frau et al. (2018) have revised ammonite stratigraphy at Gorgo a Cerbara, the site of the informal GSSP. They propose that ammonites found above the base of magnetochron M0r are of Barremian age (Martelites sarasini Zone). This revision of ammonite biostratigraphy provokes new discussions on the current informal base of the Aptian. If the revised ammonite-based chronostratigraphy is applied, the new base of the Aptian, as recorded at Gorgo a Cerbara, falls close to the base of the Oceanic Anoxic Event 1a. This corresponds to a rejuvenation of the Barremian/Aptian boundary of some 800 kyrs. The majority of the Aptian working group agrees to choose the base of Cisotopic anomaly marking the Oceanic Anoxic Event 1a as the event to define the base of the Aptian. A negative spike in the Corg- and Ccarb isotope record was first identified 25 years ago in a Tethyan pelagic limestone section (Cismon, N. Italy). Following the early studies numerous geochemical investigations demonstrated that the Aptian negative spike in the C-Isotope curve (up to several permil amplitude) is preserved in pelagic, hemipelagic, neritic and even continental Cretaceous environments. The C- isotope spike is intercalibrated with bio- and magneto-stratigraphy and provides an excellent and global marker for defining the base of the Aptian stage. Detailed high-resolution sections have been measured, for example, in pelagic sediments (Cismon), in intrashelf basin sediments (La Bedoule) or in outer shelf deposits (Cau) and also in DSDP/ODP/IODP sections. A GSSP based on geochemistry and possibly on data retrieved from core data will probably be proposed by the Aptian working group in the near future.

Keywords: Aptian, integrated stratigraphy, GSSP

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Towards an integrated biostratigraphy of the Albian of the Southern High Latitudes.

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We present an integrated micro- and nannofossil biostratigraphic evaluation of Albian strata documented at the Mentelle Basin (eastern flank of the Naturaliste Plateau, Indian Ocean, SW Australia) during Integrated Ocean Discovery Program (IODP) Expedition 369 (Sites U1513 and U1516, paleolatitude of between 57◦S to 62◦S during the mid-Cretaceous).
The Albian benthic foraminiferal record is characterized by deep-sea benthic taxa, dominated by cosmopolitan opportunist taxa, i.e., Gyroidinoides, Saracenaria/Lenticulina, Pleurostomella, Dentalina and agglutinated, monothalam forms like Glomospira and Ammodiscus. However, potential for possible correlations to lower- to mid-Cretaceous established calcareous markers can be considered. Besides opportunist taxa, the benthic foraminiferal assemblages documented at the Mentelle basin yield the contemporaneously globally documented Gavelinella intermedia, G. utaturensis, G. schloenbachi, as well as markers for the southern high latitudes documented in the Albian of South America, South Africa, and the Great Australian Basin, e.g., Lingulogavelinella albiana, Scutuloris sp. (Lambert and Scheibnerova, 1974; Scheibnerova, 1975, Lopes et al., 2017).

Upper Albian microfossil assemblages demonstrate the decreasing abundance of benthic foraminifera and the decline of calcareous-, and an increase in the relative abundance of agglutinated taxa illustrated particularly in the extraordinary increment in the percentage of Ammodiscus cretaceous, A. peruvianus, Glomospira charoides and Glomospira sp.

The planktonic foraminiferal assemblage is dominated by the small-sized Microhedbergella praeplanispira, followed by common biserial and planispiral taxa. The large-sized fractions contain Muricohedbergella simplex, Ticinella primula and Laeviella bentonensis allowing identification of the upper Albian, although no marker taxa have been observed hampering the application of the tropical-subtropical biozonation.

Calcareous nannofossils of the Naturaliste Plateau/Mentelle basin are characterized by relatively diverse but distinctly high-latitude assemblages providing biostratigraphic control for the non-barren intervals of the Albian record. Sequential first occurrences of Eiffellithus monechiae and Eiffellithus turriseiffelii indicate Upper Albian subzones CC8d and CC9a-b, respectively.

With the exception of shifts in the abundance of respective microfossil groups, preliminary abundance data, particularly of benthic foraminiferal assemblages, suggest, despite a depauper-

*Speaker

ate record in the upper Albian of the Austral Realm, considerable environmental stability. In bottom waters, no major benthic foraminiferal bioevents be identified.

Keywords: Foraminifera, nannofossils, cretaceous

SC7: Cretaceous palaeoceanography, palaeogeography, biota, climate change and critical events

Timing and Tempo of Deccan volcanism relative to the KPg extinction revealed by Mercury and Tellurium anomalies

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Mercury (Hg) and more recently tellurium (Te) are indicator of large-scale volcanism in marine sediments and provide new insights into relative timing between biological and environmental changes, mass extinctions and delayed recovery. Several studies evaluated the relationship between Hg anomalies in sediments and LIP activity across mass extinction horizons. The bulk (80%) of Deccan Trap eruptions occurred over a relatively short time interval in magnetic polarity C29r. U-Pb zircon geochronology reveals the onset of this main eruption phase 350 ky before the Cretaceous-Tertiary (KT) mass extinction. Maximum eruption rates occurred before and after the K-Pg extinction, with one such pulse initiating tens of thousands of years prior to both the bolide impact and extinction, suggesting a cause-and-effect relationship.We present a comprehensive high-resolution analysis of Deccan Traps Hg-Te loading, climate change and end-Cretaceous (KPB) mass extinction from a transect, which includes 30 sections deposited in both shallow and deep environments. In all sections, results show that Hg concentrations are more than 2 orders of magnitude greater during the last 100ky of the Maastrichtian up to the early Danian P1a zone (first 380 Ky of the Paleocene). Hg anomalies generally show no correlation with clay or total organic carbon contents, suggesting that the mercury enrichments resulted from higher input of atmospheric Hg species into the marine realm, rather than organic matter scavenging and/or increased run-off. Significant and coeval Hg enrichments are observed in multiples basins characterized by proximal and distal, as well as shallow and deep-water settings, supporting a direct direct fallout from volcanic aerosols. Hg isotope data from Bidart confirm a direct Hg fallout from volcanic aerosols. Te/Th ratios measured in the Goniuk (Turkey), Elles (Tunisia), Gubbio (Italy) Beida and Wadi Nukhul (Egypt) sections show the same trend as Hg/TOC and are consistent with a volcanic origin, albeit a minor extraterrestrial contribution of Hg to the boundary cannot be excluded. Te and Hg are however not correlated with iridium contents in the KPg interval and are consequently not related with impact and maximum eruption rates occurred before and after the K-Pg extinction, with one such pulse initiating tens of thousands of years prior to both the bolide impact and extinction. The most

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intense phase of Deccan volcanism (Wai Formations) began shortly before the K-Pg boundary, and was therefore not triggered by the Chicxulub impact.

Keywords: KPG mass extinction, Deccan Volcanism, Mercury, Tellurium

Astronomical calibration of the OAE1b from the Col de Pré Guittard section, (Aptian-Albian, Vocontian Basin, France)

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We propose to establish a new astronomical time scale for the Aptian-Albian transition from the Col de Pré Guittard section (GSSP Albian, Vocontian Basin, SE France) and investigate the correlation between the long Milankovitch cycles and the occurrence of four laminated black shales events: Jacob, Kilian, Paquier, and Leenhardt, collectively known as OAE 1b. The spectral analyses performed on magnetic susceptibility signals reveal the strong influence of precession, 100-kyr and 405-kyr eccentricity cycles. Using the number of 405-kyr eccentricity cycles, the duration of the interval containing the Jacob to Leenhardt levels is calculated at 4.03 million years (Myr), while the durations of the Jacob, Kilian, Paquier, and Leenhardt events are respectively calculated at 1.55 Myr, 1.62 Myr, and 0.93 Myr. The occurrence of these events is not directly related to the Milankovitch cycles, but they are recorded near the local maxima of the 405-kyr filter. Our findings demonstrate that the 405-kyr eccentricity has influenced the recurrence of anoxic levels in the Vocontian Basin, although other factors, such as the placement of traps or oceanic basalt plateaus, have also contributed to the development of larger-scale marine anoxia.

Keywords: Aptian – Albian, Cyclostratigraphy, Magnetic Susceptibility, OAE1b, Vocontian Basin

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Oceanic Anoxic Event 1b (Aptian – Albian transition): A protracted multi-phased event at the dawn of the middle Cretaceous warmth

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The Aptian-Albian transition encompasses the OAE 1b cluster event, an unusual Mesozoic OAE characterized by repeated carbon cycle perturbations and anoxic episodes, which extent (regional vs global) is currently not well-understood. The climax of OAE 1b is centered around the Kilian – Paquier interval, with this latter sub-event being the most geographically extended and pronounced stratigraphic interval. Nevertheless, numerous studies on OAE 1b have only focused on high-precision investigations of the Kilian and/or Paquier levels themselves, leaving vast uncertainties about the environmental changes and their drivers during the entire OAE 1b cluster. As such, it is unclear how the mechanisms leading to the formation of these sub-events differ from background environmental changes and if their occurrences are linked to unique or recurring perturbations. We have performed a high-resolution multi-proxy analysis of the Briers section, a well-exposed section in the Blue Marls Formation of the SE France Vocontian Basin, continuously covering the Kilian – Paquier interval. The Kilian and Paquier levels are characterized by higher total organic carbon (TOC) values and a substantial increase in the amount of marine organic matter compared to the background deposits, which are comprised of only continental organic matter. Hence, the transient increases in TOC values associated with the Kilian and Paquier levels are most likely the result of short-lived events of increased marine primary productivity and organic matter preservation. A high-resolution bulk carbonate and organic matter carbon isotope record shows that, apart from the Paquier level, all the fluctuations observed in the carbonate carbon isotope ratios are also mirrored in the organic matter record, although with higher amplitudes. This discrepancy in amplitude can be resolved by correcting the bulk organic matter carbon isotope record for fluctuations in the type of organic matter, demonstrating that both oceanic and atmospheric reservoirs were affected by similar carbon isotope fluctuations, which were hence of global extent. The abnormal bulk organic matter carbon isotope record of the Paquier level further confirms the large geographical expansion of unusual organic matter production and/or accumulation during this peculiar event. We suggest that Milankovitch-paced (long eccentricity) changes in monsoonal activity and their effect on the accumulation of organic matter in continental wetlands best explains the rhythmic change in the global carbon isotope record across the OAE 1b interval. Furthermore, thallium isotope analyses indicate that the Paquier level is the only OAE 1b sub-event that is associated with

*Speaker

global deoxygenation, whereas, in agreement with previously published study, mercury content indicate that only the Kilian sub-event is associated with global volcanism. High-resolution strontium isotope data reveal that gradually enhanced continental weathering occurred under a warmer climate following this volcanism. Global deoxygenation during the Paquier event occurred therefore only under the combined influences of a long-term increase in weathering rates in a warmer climate and short-term orbital modulation.

Keywords: Aptian, Albian, Anoxia, Tethys, OAE 1b

A CAUSAL LINK BETWEEN RE-ORGANIZATION OF OCEAN CIRCULATION PATTERNS DURING OCEANIC ANOXIC EVENT 2 AND EXTINCTION OF ROTALIPORIDS

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

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

This study documents quantitative changes in planktonic and benthic foraminifera from two European key-localities, Eastbourne (Anglo-Paris Basin, SE England) and Clot Chevalier (Vocontian Basin, SE France). Results are combined with published micropaleontological (planktonic and benthic foraminifera) and geochemical data (e.g., TEX, δ^1O, ϵNd) resulting in a highly-resolved reconstruction of biotic and oceanographic changes in sea-surface and at the water-sediment interface at upper bathyal depth within OAE 2. The data demonstrate syn-

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chronicity between sea-surface cooling (PCE), oxygenation of bottom waters (Benthonic Zone), changes in sea-surface and intermediate circulation patterns (ϵNd shifts) and extinction of rotaliporid planktonic foraminifera throughout the European epicontinental seas, Tethyan, Atlantic Ocean, and WIS. We suggest that the southward expansion of cool, relatively low saline and mesotrophic Boreal waters in the Northern Hemisphere during the PCE disrupted sea-surface thermal stratification at tropical latitudes and critically contracted the ecological niche occupied by rotaliporids playing a fundamental role in their extinction.

Keywords: Oceanic Anoxic Event 2, Plenus Cold Event, Benthonic Zone, foraminifera, rotaliporids, Eastbourne, Clot Chevalier

Size variation of the Aspidolithus/Broinsonia group during the Early Campanian (Loibichl section, Austrian Eastern Alps)

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The morphometric analysis of the *Broinsonia* or *Aspidolithus* group has been carried out under light microscope on 11 samples from the Lower Campanian (UC14a-UC14b) of the Loibichl section (Austrian Eastern Alps). For morphometric analysis, a total of 1021 specimens of the *Broinsonia* and *Aspidolithus* group were considered for the measurement of the maximum length of the coccolith (L), the b/a ratio (width of the outer rim/shield divided by the small diameter of the central area), and the number and arrangement of perforations in the central area using JMicroVision software. In addition, the CaCO3 content and stable isotope ratios of 13C and 18O were determined for stratigraphic and palaeoecological interpretations. This study aims to improve our understanding of taxonomic concepts of *Broinsonia* and *Aspidolithus* group and to see, if changes in morphometrics can be correlated with a different palaeoenvironmental conditions. Five morphotypes were distinguished: *B. enormis* subs. 1, *B. enormis* subs. 2, *A. parcus expansus*, *A. parcus parcus*, and *A. parcus constrictus*. Morphometric analysis has only allowed the distinction between small morphotypes (LB. enormis or "small" *A. parcus sensu* Gardin et al. (2021)) and "large" *A. parcus*/*B. parca* group (L$>$ 8 μm). Throughout the section, 3 of the evolutionary trends reported by Lauer (1975) can be observed at the study section: (1) slight overall increase in coccolith size; (2) reduction of the central area and (3) overall reduction in the number of perforations in the central area. Nevertheless, no significant trends are shown in the results that would allow a natural division from the "subspecies" of the *A. parcus* group. The multivariate method of R-mode cluster analysis using the Pearson Correlation Coefficient (PCC= 0.9006) shows two clusters. The first consists following parameters: L, the Nannoplankton Productivity Index (NPI), and the Productivity Index (PI), and the second consists of: the b/a ratio and Nannofossil Temperature Index (NTI), and the ratio of *Micula staurophora*/*Watznaueria barnesiae*. Comparisons with other sections and more detailed investigations in terms of global factors are necessary to confirm influence for size variation.

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Keywords: Calcareous nannofossils, Morphometry, Early Campanian

Planktic Foraminifera stratigraphy along the Oceanic Anoxic Event OAE2 of the Tunisian Southern Tethys

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The Bahloul Formation of northern Atlas Tunisia comprises deep water deposits rich in organic matter that span over the Cenomanian-Turonian boundary and Oceanic Anoxic Event 2. The black shale samples from a 38m thick section at Oued Kharoub section (36◦ 2' 21.01" N; 9◦ 32' 58.32" E) have been studied for their microfossil content, focusing on planktic foraminifera, in order to obtain a biostratigraphical zonation of the OAE-2 event at the Southern Tethyan margin. Characteristics of the assemblages were studied in detail, to gain insight into paleoenvironmental conditions and paleoecological dynamics. In addition, geochemical data (Total organic carbon) carbonate content and stable carbon isotope data, have been used to further enhance stratigraphic and paleoenvironmental understanding of the vertical stacking pattern of Oued Kharroub facies. Three planktic foraminifera biozones and several secondary associated bioevents could be identified. The base of the section represents the *Rotalipora cushmani* zone (*Dicarinella algeriana* subzone). The assemblages in this zone reflect relatively stable environmental conditions, with at least partly oxygenated bottom waters and abundant and diverse large keeled planktic foraminifera (*Rotalipora, Praeglobotruncana*). The LO of *R. cushmani*, along with the extinction of the genus *Rotalipora* is reported just below the first positive carbon isotope peak. It marks the beginning of the faunal turnover and the *W. archaeocretacea* zone, which spans over 20m in this section. With the extinction of *Rotalipora*, a crisis for keeled, deep dwelling foraminifera could be observed, that persists until the top of the section. One minor return of keeled taxa is reported in the middle of the *W. archaeocretacea* zone just above a silica-rich interval with an acme of radiolaria. Here, transitional forms between *H. praehelvetica* and *H. helvetica* occur, as well as large *Dicarinella*. This has been interpreted as a temporary upward movement of the oxygen minimum zone, which allowed larger keeled species to exist. A prominent development is the proliferation of *Heterohelix* (*Heterohelix* shift). Generally, the planktic foraminifera assemblages of the *W. archaeocretacea* zone in this section are clearly dominated by opportunists and surface dwellers. *Heterohelix*, *Whiteinella* and *Muricohedbergella* make out the vast majority of the PF assemblages. The FO of *H. helvetica* in this section coincides with a slight return of keeled genera (*Dicarinella*, *Marginotruncana*), the marker species however remains very rare. The paleoenvironmental situation during OAE-2 can be defined as highly stressed, with continuous oxygen deficient waters, which preclude the proliferation or even at times rare presence of larger complex morphotypes within the planktic foraminifera genera. The stable isotope excursion lasts from the LO of *R. cushmani* until slightly below the FO of *H.*

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helvetica. TOC values are elevated with a delay compared to the isotope excursion. They correlate with a general decrease of microfossils per gram sediment and a reduction in carbonate in the respective interval especially in the middle part of the *W. archaeocreatea* zone. Benthic foraminifera remain rare and low in diversity throughout the section, although small infaunal forms become more frequent in the upper part of the section (upper *W. archaeocretacea* zone and *H. helvetica* zone). The faunal assemblages remaining OAE-typical until the top of the section, where a *Guembelitria cenomana* acme and highest occurrence of *Heterohelix* occur, raise questions about the local environmental conditions after the OAE-2 and the stratigraphical position of the top of the investigated section interval.

Keywords: OAE2, Cenomanian, Turonian, planktic foraminifera, biostratigraphy, Tunisia

Disappearance of the Saccocoma-dominated microfacies: the cause and timing in light of the paleoenvironment evolution in the Transdanubian Range (Hungary)

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The disappearance of the *Saccocoma*-dominated microfacies (*Saccocoma* MF) is one of the most characteristic biotic events observed within the Jurassic/Cretaceous transition beds of the numerous successions of the Western Tethys. In the Transdanubian Range (Hungary), these planktonic crinoids start to vanish near the M19r/M20n magnetic chrons boundary (Lodowski *et al.* 2022); coeval event may be followed in the Velykyi Kamianets (Grabowski *et al.* 2019), as well as in other sections of the Pieniny Klippen Belt (Michalík *et al.* 2011). Even though - due to scarce microfacies reports - the exact age of this process cannot be precisely determined in case of the Southern Alps, according to Martire *et al.* (2006) the *Saccocoma*–rich facies also disappear within the upper Tithonian. Lodowski *et al.* (2022) considered that the process of *Saccocoma* MF demise started in between the NCE I and NCE II nannofossil calcification events (see Bornemann *et al.* 2003 and Casellato 2009). This coincidence suggests that the changes contributing to NCEs, such as climate, atmospheric pCO2, and Mg/Ca ratios may also have been important for saccocomids.
In this study, the process of the *Saccocoma* MF demise is compared to the record of paleoclimate, paleoredox and paleoproductivity changes across the Tithonian–Berriasian of the Transdanubian Range (Hungary). Paleoenvironmental framework was interpreted basing on geochemical data and statistical analyses of calcareous nannofossil communities; these account for a signal of climate aridization during the late Tithonian, as well as seafloor hypoxia combined with increased rates of nutrient burial during this time. Such conditions are interpreted here as driven by perturbations in combined system of atmospheric-to-marine circulation, when weakened monsoons resulted in less efficient Ekman transport, hence weaker monsoonal upwelling (De Wever *et al.* 2014). As a consequence, restricted mixing of the water column driven both the seafloor hypoxia and disruption in the "nutrient shuttle" mechanism. Importantly, the "fertility crisis" during the late Tithonian is clearly evidenced by nannofossil data: the NCE IIA event was documented as an evolution and explosion of *Nannoconus* sp., what also points to more oligotrophic (in relation to early Tithonian) surface waters. Consequently, the vanishing of *Saccocoma* is thought to result from insufficient – for these organism – amount of micronutrients in the upper ocean, which likely arose from climate-related oceanographic perturbations.

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Keywords: J/K transition, climate, redox, productivity, paleoecology, carbonates, western Tethys

Lithostratigraphy of the Jebel Boulahouajebs section (Lansarin Chain): proposal of a new formation for North Tunisia

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The Jebel Boulahouajeb section is located in northern Tunisia near Tebourba city, about 40 km west of Tunis. The studied section belongs to the Lansarine Chain, delimited by the vast plain of the Medjerda valley to the south and east, and by the plain of the Oued Ettine to the north and North–West. The Jebel Boulahouajeb section belongs the Tunisian trough ("sillon tunisien"), a strongly subsiding basin from the Jurassic to Cretaceous time in north-Eastern Tunisia. The Valanginian–Aptian succession of Jebel Oust, which is considred as a reference section of the Lower Cretaceous, which belong to M'Chergua Formation.
The Jebel Boulahouajeb's section corresponds to a deep marine palaeoenvironment characterized by pelagic-deep deposits. It present nearly 3000 meters of thickness. Dated in details for the first time as Early Cretaceous, on the basis of the ammonites and planktonic foraminifera (Melliti and al, 2019).

These sediments are characterised by shaly units with limestones and detirial sediments, which suggest that they were deposited in a variety of depositional environments, likely influenced by tectonic and climatic factors. Six lithostratigraphic units were recognised in Jebel Boulahouajeb, aged Barremian.

Lower Barremian strata at this site consist of 122 meters thickness (Unit Br1), constituted by massif limestone beds intercalated by green marls. In the uppermost part occur metric beige gray limestones benches straightened (5.8m) which make reliefs forming the ridge of Jebel Boulahouajeb.

The studied section shows the rapid North-Westward increase in thickness of the Upper Barremian marls, from less than several hundred metres to about 1780 meters, which represent 4 successives lithostratigraphic units (Br2-Br3-Br4 and Br5). The lower most upper Barremian succession, unit Br2 is interreptuted at the base by some sandstone beds. Laminated siltstone and mudstone, current-rippled cross-laminated very fine grained sandstone and wave-rippled cross-laminated fine-grained sandstone. The lithology of the Upper Barremian (unit Br6) 100 meters is characterized by several sequences of nodular marly limestones, metric beds of fossiliferous limestones and dark marls.

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The Tunisian Sillon subsided during the Early Cretaceous period. Since, it was affected by normal faults, along Lower Cretaceous sediments occured. This coincided with the Tethys transgressions, which remaind a major control on the sedimentation's increase of Jebel Boulahouajeb.
To sum up, the greatest accumulation of lower Cretaceous sediments recorded in the section studied, its continue marine sedimentation and the great richness in ammonites and foraminifera (Benthic and Planctonic): Not only The Jebel Boulahouajeb's section is proposed in this work as a new standad Lower Cretaceous section of the Northen Tunisia, but we present a new lithostratigraphic Formation: Boulahouajeb Formation.

Keywords: Keywords: Jebel Boulahouajeb, Early Cretaceous, New Lithostratigraphic formation, New Lower Cretaceous standard section, North Tunisia.

Paleoenvironmental reconstruction prior to and at the base of the Early Aptian Oceanic Anoxic Event in southern Tibet, eastern Tethys

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The Early Aptian Oceanic Anoxic Event (OAE 1a, _˜120 Ma) represents an episode of severe paleoenvironmental disturbance during the Cretaceous, marked with widespread deposition of organic-rich sediments. The OAE 1a has been extensively studied in the Pacific, Boreal and western and southern Tethyan regions. However, few investigations regarding the OAE 1a have been conducted in the eastern Tethys (especially in southern Tibet). Here, we present high-resolution geochemical and mineralogical data to reconstruct paleoenvironmental conditions of the OAE 1a in the Gucuo area of southern Tibet, eastern Tethys. Oxic-to-suboxic environments occurred prior to and at the base of OAE 1a. A redox shift from oxic to suboxic condition was recorded prior to OAE 1a, while the redox condition was changed from suboxic to oxic at the base of OAE 1a. A warm-humid climate prevailed prior to and at the base of OAE1a. This climate condition was a regional response to global warming during this interval. Freshwater-dominated salinity conditions prior to and at the base of OAE 1a suggested that massive freshwater was injected into the ocean due to a warm-humid climate occurred in this interval. High bioproductivity driven by global warming was responsible for organic matter accumulation in the Gucuo area prior to and at the onset of OAE1a. Massive freshwater injection and enhanced runoff under a warming climate promoted fluvial delivery of nutrients into the ocean, and thus flourished marine bioproductivity. A high surficial bioproductivity would generate massive organic matter, contributing to organic matter enrichment.

Keywords: Lower Aptian, Oceanic Anoxic Event, Global warming, Sedimentary environment, Organic matter accumulation

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Integrated stratigraphic revision of the Cretaceous Elbtal Group (Cenomanian–lower Turonian of Saxony, Germany)

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A completely new stratigraphic framework of the Cenomanian of Saxony (lower Elbtal Group) is presented herein, based on the detailed integrated investigation of 39 stratigraphic surface and subsurface sections that have been correlated in four cross-sections (Niebuhr & Wilmsen 2023). Until a few years ago, the onset of continental to deeper marine deposition in Saxony was largely assigned to the *naviculare* transgression of the early Late Cenomanian. However, Cretaceous deposition started in early Early Cenomanian times in both, the Saxonian (SCB) and Bohemian Cretaceous basins (BCB, cf. Uličný et al. 2009), indicated by contemporaneous non-marine (continental Niederschöna Formation / Peruc Member of the Peruc–Korycany Formation) and marine onlap (Oberhäslich Formation / Korycany Member of the Peruc–Korycany Formation). The Cenomanian transgressions proceeded in Saxony on a broad front from the north to south and, at first, followed the course of roughly south–north-discharging palaeovalleys of a fluvial drainage system dewatering the elevated Erzgebirge in the southwest. The observed facies pattern with the overall retrogradational stacking of depositional sequences can be explained by the pulsative 2nd-order sea-level rise of the Cenomanian age. Four complete Cenomanian depositional sequences and a fifth one, DS Ce-Tu 1, starting in the mid-Late Cenomanian and lasting into the Early Turonian, have been identified, bounded by conspicuous sedimentary unconformities. The basal unconformity of DS Ce-Tu 1, sequence boundary SB Ce 5, forms a conspicuous correlative surface across all investigated sections and was used as a datum line in the cross-sections. In total, six marine transgressions can be identified, related to the transgressive systems tracts (TST) of the depositional sequences DS Ce 1+2 and DS Ce 3 (early and late Early Cenomanian), DS Ce 4 (early Middle Cenomanian, *primus* Transgression), DS Ce 5 (early Late Cenomanian, *naviculare* Transgression) as well as late DS Ce-Tu 1 with its late Late Cenomanian *plenus* Transgression and its earliest Turonian maximum flooding interval (Lohmgrund Horizon). Each transgression overstepped the preceding one, thus continuously enlarging the depositional realm by means of non-marine and/or marine onlap. The early Middle Cenomanian *primus* Transgression reflects the most striking Cenomanian sea-level rise within the Saxonian Cretaceous Basin (genetic sequence CEN 3 in the Bohemian Cretaceous Basin, Uličný et al. 2009). Promontories, interfluves between palaeovalleys and large parts of the eastern Erzgebirge were flooded. The marine Oberhäslich Formation was accompanied by collateral fluvial / brackish deposits of the Niederschöna Formation during the early Early to early Late

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Cenomanian in DS Ce 1+2 to DS Ce 5, respectively. The marine transgressions reached the 40 km long Úštěk–Bad Schandau Sea Bight, the deepest of the north-sloping palaeovalleys, first and produced an up to 120-m-thick marine Cenomanium sedimentary record (Oberhäslich- and Pennrich formations), subdivided into five almost equally thick depositional sequences. The total thickness approximately corresponds to the accommodation space generated by the Cenomanian eustatic sea-level rise (70–100 m) and an overall low regional subsidence, resulting in an overall rather low sedimentation rate (ca. 20 m/myr). The thickness changes and facies patterns observed within the lower Elbtal Group are unrelated to tectonic processes and simply reflect the pre-transgression topography and sequence stratigraphic onlap patterns onto the eastern Erzgebirge in the southwest during Cenomanian (and Early Turonian) times.
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Keywords: : Lower Upper Cretaceous, stratigraphic revision, marine vs. continental lithofacies, sequence stratigraphy, correlation, onlap history

Paleoceanographic changes across the middle Cenomanian carbon-isotope excursion (MCE 1) from the UK chalk

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Planktonic foraminifera were studied across the Mid-Cenomanian Event 1 (MCE 1, identified by a positive carbon-isotope excursion) at Lydden Spout, near Folkestone (Kent, south-east England, UK), the reference section of the middle Cenomanian Event 1 (MCE 1) characterized by a prominent double-peak carbon-isotope excursion of 1‰ identified in different ocean basins and considered a global event. Biostratigraphic and quantitative analysis of planktonic foraminifera are correlated to the carbon cycle perturbation that identifies the MCE 1, to the positive oxygen-isotope shifts identified within the MCE 1, and to the occurrence of Boreal macrofossils (*Chlamys arlesiensis*, *Oxytoma seminudum*, and *Praectinocamax primus*).
Planktonic foraminifera show moderate preservation, are common throughout the section and comprise 40-50% of total foraminiferal abundance, although the population is mainly composed by small-sized specimens (< 250 micronm). Large-sized specimens become more common and show a continuous occurrence up-section after the termination of MCE 1. The stratigraphic interval studied is assigned to the *Thalmanninella greenhornensis* and *Rotalipora cushmani* Zones. Variations in abundance and species richness of the planktonic foraminifera are correlated with the inferred palaeoecological preferences of taxa and permit the identification of distinct palaeoenvironmental settings across the MCE 1.

The stratigraphic interval corresponding to the MCE 1 is characterized by the absence of single keeled oligotrophic rotaliporids, by the evolutionary appearance of double keeled meso-eutrophic dicarinellids, and by the appearance of *Muricohedbergella portsdownensis*, a species interpreted as a cold-water taxon that first appears at the same level of Boreal macrofossils, and a positive oxygen-isotope excursion of bulk carbonate within the lower part of MCE 1. These observations point to a palaeoceanographic scenario characterized by reduced stratification of surface waters and absence/disruption of the thermocline in a dominantly eutrophic regime during MCE 1.
Evidence provided by planktonic foraminifera, Boreal macrofossils and oxygen-isotope records documented for the late Cenomanian Plenus Cold Event (PCE) at Eastbourne (UK) reveal similarities that confirm the periodic inflow of cold Boreal seawater originating in the Norwegian Sea as previously postulated to explain the occurrence of Boreal fauna in the Anglo-Paris Basin. The southerly extension of this water mass may be related to the re-organization of circulation driven by the long eccentricity cycle.

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Keywords: Paleoceanography, middle Cenomanian event (MCE 1), planktonic foraminifera, Carbon and Oxygen stable isotopes

Microfossils response to the Cenomanian-Turonian Oceanic Anoxic Event 2 in the Southern Hemisphere

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The response of biota and the paleoceanographic conditions at high latitudes are investigated across the Cenomanian/Turonian boundary interval characterized by the Oceanic Anoxic Event 2 (OAE 2), an episode of major perturbations in the global carbon cycle. We present data from Integrated Ocean Discovery Program (IODP) Sites U1513 and U1516 drilled in the Mentelle Basin (Indian Ocean, offshore SW Australia, paleolatitude 59○-60○ S in the mid-Cretaceous). The correlation between the stable isotopic data and the integrated calcareous plankton biostratigraphy with the reference section at Eastbourne (UK) indicates that a complete record of OAE 2 was recovered at southern high latitudes. The distribution and variations in abundance of planktonic and benthic foraminifera, radiolaria, and calcipheres and their paleoecological preferences permit interpretation of the dynamics of the water mass stratification, and provide support for the paleobathymetric reconstruction of the two sites, with Site U1513 located northwest of the Mentelle Basin depocenter and at a deeper depth than Site U1516.

The lower OAE 2 interval is characterized by reduced water mass stratification with alternating episodes of enhanced surface water productivity and variations of the thickness of the mixed layer. Lithologies in the middle OAE 2 interval are almost entirely composed of radiolaria reflecting extremely high marine productivity and the low CaCO3 content is consistent with marked shoaling of the CCD which resulted from the emission of volcanogenic CO2 from the Kerguelen Plateau Large Igneous Province making waters more corrosive.

Conditions moderate after this extreme perturbation as reflected by the microfossil changes indicating a likely stable water column that was apparently more stable at Site U1513 than at Site U1516 where episodes of enhanced eutrophy continue into the lower Turonian. At both sites the termination of OAE 2 does not correspond to modifications in the microfossils assemblages; rather, they maintain the same features observed in the underlying interval.
Overall, this study provides a complete record of the paleoceanographic changes registered by

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the microfossil biota for understanding the causes and consequences of the paleoenvironmental perturbations associated to the OAE 2 at southern high latitudes.

Keywords: Cenomanian/Turonian boundary, Oceanic Anoxic Event 2 (OAE 2), calcareous nannofossils, planktonic and benthic foraminifera, radiolaria, paleoceanography, paleoecology, paleoclimatic changes

The Ocean Anoxic Event 2 (OAE2) in the Vigo Seamount (DSDP Leg 47B, Site 398D) offshore the NW Iberian Peninsula: a palynostratigraphical and geochemical approach

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The studied DSDP Site 398D (Leg 47B) is located in the southern part of the Vigo Seamount, about 150 km off the NW Iberian coast. Previous geochemical and biostratigraphical analysis suggests that an expression of the Ocean Anoxic Event 2 (OAE2) was likely to be present, corresponding to a short interval of dark organic-rich clays interbedded with red and grey claystone. This work details the palynostratigraphy and the carbon isotope record from the uppermost Albian to the lowermost Turonian of DSDP Site 398D, resulting in the relative dating of the deposits and the confirmation of the presence of the OAE2. A total of 45 samples were analyzed following standard palynological maceration protocols involving treatment with HCl and HF for removing carbonates and silicates, respectively. After the acid digestion, the samples were also analyzed by Isotopic Ratio Mass Spectrometry (IRMS) for the δ13C isotopic ratio of the organic matter. Four palynological assemblages were differentiated. The Assemblage A (cores 58-2, 82-84 cm to 57-5, 87-88 cm) is of a late Albian age according to the presence of *Quadricolpites* sp. and *Litosphaeridium siphoniphorum.* The Assemblage B (cores 57-5, 23-24 cm to 57-1, 113-115 cm) dates from the early Cenomanian according to the presence of *Wilsonisporites woodbridgei* and *Ovoidinium verrucosum.* The Assemblage C (cores 65-5, 54-55 cm to 65-4, 0-2 cm) has a middle Cenomanian age according to the presence of *Complexiopollis* sp., while Assemblage D (cores 56-3, 10-12cm to 56-2, 110-111 cm) has a late Cenomanian – early Turonian age according to the presence of *Atlantopollis heystii*, *A. reticulatus*, *Complexiopollis complicatus*, *C. vancampoae*, *C. praeatumescens*, and *Minorpollis* sp. Within the later assemblage, a sub-division was made at core 56-2, 127-128 cm, where the Cenomanian – Turonian boundary is located according to the presence of *Dichastopollenites dunveganensis, Tricolpites barrandei,* and *Trudopollis pertrudens.* The δ13C analysis indicates that the OAE2 is placed in the DSDP Site 398D between core 56-3, 12 cm, up to the abrupt contact with the Plantagenet Formation in 56-2, 19 cm. The anoxic event is expressed in 5-cm intervals with a low sedimentary rate (1 m/Ma), reaching a maximum of 23,95‰ of δ13C in the positive excursion and a Total Organic

*Speaker

Carbon (TOC) of 13%. During this event, a major microfloral change occurred (Assemblage D), indicated by a clear shift of dominance of angiosperm pollen, specifically the Normapolles group, and possible extinction of part of the marine palynomorphs (dinocysts).

Keywords: Palynostratigraphy, Cenomanian, Turonian, OAE 2, DSDP Site 398D, δ13C analysis

Assessing the biostratigraphic and palaeo(bio)geographic potential of Mesozoic Trigoniida (Bivalvia)

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The order Trigoniida is a major clade in the Bivalvia, dating back to the Silurian and surviving with a single relic genus, *Neotrigonia*, in Australian waters today. During the Mesozoic, Trigoniida were cosmopolitan, highly diversified and abundant, particularly in shallow marine environments. Out of 2250 marine nominal species-level taxa currently contained in our database, approximately 150 are Palaeozoic, 1850 are Mesozoic (Triassic: 400; Jurassic: 800; Cretaceous: 650) and only 30 are Cenozoic. Slightly more than 200 names are as yet unassigned, or are nomina nuda. We assess spatial and stratigraphic distributions of trigoniid families and superfamilies during the Mesozoic and identify patterns of evolution and expansion. At present, distribution is based on type localities only. However, given that the majority of species-level taxa occur at a single locality, or in a single country or region, we assume that global patterns are readily captured. Our data document the rapid expansion of Trigoniida in the Triassic and the turnover related to the Triassic-Jurassic extinction. Furthermore, increasing provincialism at family level during the Jurassic and Early Cretaceous, as well as the gradual demise of several clades during the Late Cretaceous are evident. We conclude that Mesozoic Trigoniida can be useful index fossils down to stage level, and their expansion dynamics map the availability and connectivity of siliciclastics-dominated shelf areas.

Keywords: Bivalvia, palaeogeography, Triassic, Jurassic, Triassic, biostratigraphy

*Speaker

Was the Brazilian Romualdo Formation (Aptian-lower Albian) ever marine? Integrated paleoecologic and isotopic data suggest otherwise

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The Romualdo Formation of the Araripe Basin represents one of the innermost records of the first stage of the post-Rift sequence of the opening of the Atlantic Ocean. Due to its fossil record comprising several well-preserved large vertebrate taxa, traditionally associated to marine environments, it is common to associate its deposition to shallow marine paleoenvironments. This interpretation is further supported by the presence of coquina levels, rich in bakevellid bivalves, echinoids, and nannofossils in the upper layers of this unit. However, several of the aforementioned groups present very little diversity compared to open sea environments, a feature that is even more evident when considering the Foraminifera, Decapoda, and, most of all, Ostracoda of the Romualdo formation, dominated only by the species *Harbinia micropapillosa*. The dominance of this taxon among ostracoda allowed for retrieving material sufficient for extensive C and O isotopic analyses to study what types of paleoenvironments were the most common in representative sections of the Romualdo Formation. In the present work, we evaluated populations from several outcrops, namely the Pedreira Vitória, Campo Belo, and Santo Antônio in the Pernambuco state, and the Sobradinho in the Ceará State. Eodiagenetic processes (dissolution/cementation) were effective in modifying isotopic signals only from specimens collected at the Pedreira Vitória and Campo Belo outcrops, which are, in terms of lithology, representative of more proximal, riverine to delta paleoenvironments. In the Santo Antonio and Sobradinho sections, the lithofacies are more lagoonal to transitional in character, diagenesis had little or no effect on fossil specimens recovered, and the isotopic signals recorded are closer to the expected during deposition. Additional specimens from the Sobradinho section display very light δ^{1}O values (between –11‰ and –17.5‰) that may be indicative of interaction with subsurface fluids after burial (as the presence of sulfur also suggests). When considering only samples with a weak diagenetic signal, present results are comparable with previous ones observed in other outcrops of Aptian-early Albian age, from the Araripe Basin. Proxies obtained in carbonates from

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the underlying Crato Formation also demonstrate variation in isotopic signatures expected for shallow paleoenvironments, such as coastal, playa and/or hypersaline lakes as well as sabkhas. Similar results are encountered in previous ostracods and benthic foraminifera analyses from the Cedro, Arrojado, and Canastra outcrops of the Romualdo Formation, to which transitional to restricted marine paleoenvironments were proposed. The paleoenvironmental interpretation of hypersaline lakes, however, is not consistent with the sedimentological or paleoecological record of the Romualdo Formation. In this unit, the extensive presence of levels rich in organic matter, interbedded with calcareous concretions and containing abundant and poorly diverse ostracod faunas, indicates brackish paleosalinity. Therefore, the hypothesis of a restricted lagoon system, with very marginal marine influence, makes a more plausible alternative, even for outcrops in the southeastern portion of the basin – the traditional pathway to seaway transition in previous paleoenvironmental models. In this newly envisioned scenario, the presence of the aforementioned macrofossils in the Romualdo Formation paleoenvironments would result not from its usage as an everyday ecological niche, but instead as an occasional breeding ground for these organisms, similar to the role played by mangrove forest ecosystems in present-day littoral and bay areas.

Keywords: Romualdo Lägerstatte, Brazilian pre, salt, brackish ostracoda, isotope geology, mangrove origins

Boreal-Tethyan calcareous nannofossil biostratigraphic correlation during the Cenomanian-Coniacian: New insights from Poigny core (Paris Basin) and Quero section (Belluno Basin)

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The Cenomanian-Coniacian was characterized by pervasive changes in the ocean/atmosphere system where perturbations linked to the carbon cycle are highlighted by stable isotopic data. These data indicate temperature changes during the late Cenomanian-Coniacian interval. Specifically, the Cenomanian was characterized by a long-term warming trend culminating in the Ocean Anoxic Event 2 occurred close to the Cenomanian/Turonian boundary. Conversely, the Turonian was punctuated by several cooling phases culminating with the "Late Turonian Cool Phase" and continuing in the Coniacian. These paleoclimatic changes induced paleoenvironmental stressors due to a combination of several interconnected factors (e.g., volcanic activity, changes about trophic conditions in the upper water column). Widespread modifications influenced the marine biota even leading to evolutionary turnover, especially recorded by primary producers such as the calcareous nannoplankton. If the biotic turnover is an essential tool for biostratigraphic purposes, a sound biostratigraphy is crucial for constraining climatic changes. Although calcareous nannofossils are a powerful biostratigraphic tool, some widely adopted Cretaceous calcareous nannofossil biohorizons seem to suffer from diachronism and taxonomic ambiguity (e.g., *Eiffellithus eximius*) that can blur their biochronological reproducibility during the Cenomanian/Coniacian interval. To shed light on calcareous nannofossil biostratigraphic discrepancies, we studied the upper Cenomanian/lower Coniacian assemblages from the Poigny core (Paris Basin) and Quero section (Belluno Basin, northeastern Italy) with the aim to decipher the calcareous nannofossil turnover during this interval. We integrated calcareous nannofossil data with those of planktic foraminifera and the stable isotopic values (Le Callonnec et al., 2021). Our data highlight the evolutionary trend of three *E. eximius* morphotypes that might have biostratigraphic utility. The first occurrence of these *E. eximius* morphotypes have been correlated with isotopic stratigraphy data in both sites. In fact, the isotope stratigraphy suggests that the first occurrence of *E. eximius* morphotype 2 and *E. eximius* s.s. are synchronous taking places in both sites around the Round Down and Hitch Wood Events, respectively. Instead, the first occurrence of *E. eximius* morphotype 1 seems to be diachronous between Poigny and Quero. In addition, we record variations in presence and abundance of many taxa between

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the two investigated sites (e.g., *Kamptnerius magnificus*, *Gartnerago* spp., *Eprolithus* spp.). We interpret these variations as probably due to different paleoenvironmental conditions of the diverse depositional setting such as temperature and trophic resources of the upper water column.

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Keywords: Upper Cretaceous, biostratigraphy, calcareous nannofossils, Poigny, Quero

Stratigraphic anatomy, facies patterns and palaeogeography of the Cenomanian transgression: new data from the Elbtal Group, Germany

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Until a few years ago, the view on the course of the Cenomanian transgression in Saxony (eastern Germany) was strongly biased by the perception that most of the marine flooding in the Saxonian Cretaceous Basin (SCB) was related to the *naviculare* Transgression of the early Late Cenomanian. However, a re-evaluation of the ammonite faunas from the alleged exclusively Upper Cenomanian Oberhäslich Formation shows that it also contains, in its lower part, several Middle Cenomanian taxa such as *Acanthoceras rhotomagense*, *Acanthoceras jukesbrownei*, early forms of *Calycoceras* (*Proeucalycoceras*) *picteti* and *Calycoceras* (*Newboldiceras*) *asiaticum asiaticum* (Wilmsen et al. 2022). Furthermore, an integrated stratigraphic reappraisal of the northwestern outcrop area of the Elbtal Group demonstrated that shallow-marine deposition of the Oberhäslich Formation even started in the Early Cenomanian and that, already by early Middle Cenomanian times, offshore marine deposits characterized this distal zone of the basin (Wilmsen et al. 2019). In addition, the stratigraphic superposition of the marine Middle Cenomanian sandstones onto fluvial deposits (Niederschöna Formation) of the Eastern Erzgebirge shows that the latter strata are evidently Early Cenomanian in age, supporting previously published palynological data that were not considered by subsequent authors.
Based on the integrated investigation of 39 Cenomanian sites at surface and subsurface, a completely revised stratigraphic framework and palaeogeographic reconstruction of the lower Elbtal Group are presented (Niebuhr & Wilmsen 2023). The new data show that Cretaceous sedimentation started already in the early Early Cenomanian, indicated by the contemporaneous onlap of non-marine (Niederschöna Formation) and marine strata (Oberhäslich Formation). The Cenomanian transgressions advanced from the north, at first following the course of roughly south–north-discharging palaeovalleys of a fluvial palaeodrainage system with an elevated principal source area in the southwest. Sequence stratigraphic analyses demonstrates the presence of four complete, unconformity-bounded Cenomanian depositional sequences (DS) and a fifth one, DS Ce-Tu 1, which started in the mid-Late Cenomanian and lasted into the Early Turonian. The depositional sequences comprise six major transgressive phases that overstepped each other and enlarged the depositional realm by means of non-marine and/or marine onlap: A, early Early Cenomanian (equivalent to the "*ultimus/Aucellina* Transgression"), DS Ce 1+2; B, late Early Cenomanian, DS Ce 3; C, early Middle Cenomanian (*primus* Transgression), DS Ce 4; D, early Late Cenomanian (*naviculare* Transgression), DS Ce 5; E, late Late Cenomanian (*plenus* Transgression), DS Ce-Tu 1; F, earliest Turonian (Lohmgrund Horizon), maximum flooding of

*Speaker

DS Ce-Tu 1 and climax of the 2nd-order transgressive Cenomanian hemicycle. The maximum observed thickness (100–120 m) is in the order of the accommodation generated during the entire 6-myr-long Cenomanian age by means of eustasy and regional subsidence, corresponding to a rather low mean sedimentation rate of 20 m/myr. Thus, the thickness changes observed within the lower Elbtal Group can quite simply be related to the pre-transgression topography and sequence stratigraphic onlap patterns onto the elevated palaeotopography in the southwest. The new stratigraphic and palaeogeographic framework of the lower Elbtal Group thus demonstrates that tectonic inversion in the SCB was essentially a post-Cenomanian process.

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Keywords: Lower Upper Cretaceous, integrated stratigraphy, facies development, palaeogeographic evolution

Stratigraphic Cycles in Cretaceous Turbidite Sand Sheets—-Implications for Progradation/Retrogradation Cycles

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Attempts have been made in the past to link stratigraphic cycles in turbidite sequences to progradation (i.e. thickening and coarsening upward) and retrogradation (thinning and fining upward). However, if the sedimentary system is laterally unconfined or shows much compensational stacking, the relationship between stratigraphic cycles and such vertical sequences may be more complex or stochastic. Meanwhile, progradation and retrogradation imply a basinward or landward shift in deposition respectively, but few 2D outcrop sections along depositional dip have been studied sufficiently to establish the longitudinal variations in stratigraphic cycles. In this study, two Cretaceous turbidite sand sheet systems, referred to as Pehoe Member B and Paine Member A (abbreviated here to Pehoe B and Paine A) are compared, to investigate the longitudinal stratigraphic variation and possible implications. With a logging scale of 1:10, statistical methods such as runs tests, moving average, and correspondence tests are used to detect stratigraphic cycles. Combined with facies and thickness analysis, Pehoe B and Paine A sand sheet systems are both interpreted to be laterally confined with dominantly vertical stacking overall. Along depositional dip, stratigraphic cycles of thickening and coarsening upward then thinning and fining upward, where present, are asymmetrical in proximal areas but appear to be more symmetrical in distal areas. The longitudinal variation of stratigraphic cycles is generally consistent with that of maximum thickness of amalgamated beds and total counts or counts/meter of all bypass features. Turbidite vertical sequences of both Pehoe B and Paine A reflect a general progradation then retrogradation process, with superimposed small scale fluctuations, which may infer allogenic variations in sediment supply (3rd to 4th order sequences).

Keywords: sand sheet systems, stratigraphic cycles, turbidite, progradation, retrogradation, Cretaceous

*Speaker

SC8: The Jurassic: events, correlation and timescale

A Southern Hemisphere Chronostratigraphic Framework for the Pliensbachian–Toarcian

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Lower Jurassic sedimentary successions from the Neuquén Basin, Argentina are unique in the abundance of radiometrically datable material (ash-beds) present, which can be tied to bio- and chemostratigraphic (carbon-isotope) zonations. Here, we present newly integrated carbon-isotope and Hg/TOC data from three localities in Argentina (Arroyo Lapa, Arroyo Serrucho/Las Overas and Chacay Melehue) to generate a biostratigraphically calibrated composite carbon-isotope curve and geochronological framework for the Pliensbachian–Toarcian transition in South America. Using a Bayesian framework we present an age-depth model for this composite record and estimate the age and duration of key intervals extending from the Latest Pliensbachian carbon-isotope excursion (CIE) through the Early Toarcian negative CIE associated with the Toarcian Oceanic Anoxic Event (T-OAE). This geochronological framework is subsequently combined with a statistical analysis of all available Karoo and Ferrar Large Igneous Province (LIP) radioisotopic ages to create a timeline of the key events in the Pliensbachian–Toarcian and their association with emplacement of intrusive and extrusive igneous rocks of the Karoo and Ferrar LIPs.

Keywords: Pliensbachian–Toarcian, Carbon Isotope Excursions, Early Jurassic, Large Igneous Province, Geochronology

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From the continent to the ocean: A basin-wide perspective on the Early Toarcian mass extinction

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The Central High Atlas Basin offers a rare opportunity to study the paleoenvironmental, sedimentological, and biological evolution associated with the Early Toarcian mass extinction on a basin-scale. Thanks to outstanding exposure quality and high accumulation rates, numerous detailed sections can be studied across this basin, which encompasses terrestrial, transitional, and open ocean paleo-domains. This unique setting allows us to study the interaction between climate change, siliciclastic sediment supply, sea-level fluctuations, and neritic carbonate production during an interval characterized by two major environmental perturbations; the Pliensbachian/Toarcian boundary event (Pl/To) and the Toarcian oceanic anoxic event (T-OAE). A major change in sediment supply coincides with the Pl/To event, characterized by a neritic carbonate factory collapse coeval to a considerable input of coarse siliciclastic materials accompanying a switch from dry to humid climatic conditions. This event also marks a major change in shallow-marine carbonate-producing ecosystem and one of the most dramatic coral extinction events of the Phanerozoic. The onset of the T-OAE is also characterized by a change in sediment supply and a carbonate factory collapse, but this later is short-lived as neritic carbonate production resumes already during the T-OAE. Moreover, differences in terms of sea-level fluctuations are observed between the two events; the Pl/To carbonate factory collapse is coeval with a 40 m sea-level fall while the T-OAE corresponds to an 50 m sea-level rise (minimum). One major overarching result from the Central High Atlas Basin is that chronostratigraphically complete sections are never encountered in this continental shelf setting due to the combination of highly fluctuating sea-level and sediment supply during the early Toarcian as a consequence of severe and repeated environmental/climatic perturbations. The most critical aspect is that hiatus surfaces are often cryptic (lacking clear physical evidence and/or of a duration lower than the highest possible biostratigraphic resolution) and can only be firmly recognized by the high-resolution sequence stratigraphic and chemostratigraphic framework developed here. This raises concerns about the completeness of numerous classical sections situated in similar continental shelf settings but which lack a robust basin-scale depositional architecture control.

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Keywords: Pliensbachian, Toarcian, T, OAE, Morocco, Carbonate factory demise, Coral reefs

Impacts of the Early Jurassic Toarcian Anoxic Event (T-OAE) on the Floras in Northern China

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The Early Jurassic Toarcian Anoxic Event (T-OAE) has been well-documented in the Tethys, Boreal, Panthalassa and the South Hemisphere. However, the impacts of this event to the terrestrial ecosystem has been poorly known. The North China Plate was uplifted in the Middle-Late Permian and it was dominated by typical land ecosystem through the whole Mesozoic. The terrestrial Jurassic strata are extremely developed and well exposed in this region. During the past two decades, the authors carried out a series of investigations on the Jurassic stratigraphy, palaeontology and palaeoenvironment of Northern China and have revealed that the T-OAE had markedly impacted on the terrestrial ecosystem in the region, and particularly the vegetation evolution.

1. Markedly decrease in specific diversity of the floras

The Lower Jurassic (Liassic) in Northern China is dominated by coal-bearing deposits, which is extremely rich in plant fossils. The Liassic floras were greatly abundant and highly diverse. They usually consisted of more than one hundred species, including mosses, lycopods, horsetails, ferns, ginkgoes, cycads, conifers and seed ferns. In contrast, the Toarcian floras greatly declined in diversity, which usually comprised less than two or three dozens of species, much lower than that of the Liassic floras. However, after the Toarcian event, the floras in Northern China recovered and reached their maximum abundance and diversity by the Bajocian age of the Middle Jurassic. They usually comprised more than 100 species and even 200 species.

2. Sharply increase of thermophilous or arid-tolerant (xerophilous) elements

The Liassic floras in Northern China were dominated by ferns and ginkgoes, with a fewer or even totally absence of thermophilous or arid-tolerant (xerophilous) taxa, usually less than two or three percentages of the total species of the floras. However, during the Toarcian, the floras in this region were characterized by much higher composition ratios of thermophilous or xerophilous elements, usually making up more than 10%, and even to 45% of the floras. These taxa include the tropical type ferns such as the Dipteridaceae, Marattiaceae, Matoniaceae; bennettitales in-

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cluding *Otozamites*, *Zamites*, *Zamiophyllum*, *Tyrmia*, *Ptilophyllum* and *Dictyozamites*; scale or awl-like leaf conifers as *Hirmeriella*, *Brachyphyllum* and *Pagiophyllum*, and gnetalean genera *Ephedrites* and *Cadmisega*, which were usually characterized by small leaves, thick cuticles and markedly sunk stomata. After the Toarcian crisis the thermophilous or xerophilous plant mostly disappeared from Northern China and the floras were again dominated by ferns and ginkgoes. The vegetation evolution in Northern China through the Early Jurassic was coursed by the ecosystem changings, particularly the climate, which were inked with the T-OAE in ocean.

Keywords: Toarcian of Early Jurassic, Oceanic Anoxic Event, Vegetation evolution, Impacts, Northern China

New Insights from the Prees-2 core into marine microfossil diversity following the end-Triassic mass-extinction

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The end-Triassic mass-extinction (ETME; 201 Ma) is commonly linked to the emplacement of the Central Atlantic Magmatic Province, triggering extreme environmental changes, and affecting both marine and terrestrial ecosystems. Marine phytoplankton groups were severely impacted by the ETME. Cyst-producing dinoflagellates and calcareous phytoplankton show high extinction rates. Instead, Early Jurassic epicontinental seas appear to have been populated by green algae (Prasinophycae) and enigmatic acritarchs, essentially holdovers from Paleozoic plankton communities. Here, we focus on the acritarch assemblages that become dominant during the Hettangian but have been largely ignored since the seminal work in the 1960s by David Wall. This research aims to understand how oscillations in acritarch, and dinoflagellate cyst diversity may reflect continued adverse conditions in the oceans following a major mass-extinction event. We use the recently drilled Prees-2 core, recovered in the UK's Cheshire Basin as part of the JET ICDP project. The samples were collected at one-meter intervals from the Redcar Mudstone Formation of the Lias Group. The unit consists of monotonous dark grey massive to faintly laminated mudstone and marl with sparse carbonate concretions. The dinocyst *Dapcodinium priscum* is the most abundant and prevalent marine micro-organism in the *tilmanni* chronozone, *i.e.*, the post extinction zone. However, in the ensuing *planorbis* Chronozone, associated with the "main negative excursion" in bulk organic carbon isotopes, *D. priscum* is replaced by *Beaumontella langii* together with a suite acritarch taxa from the Acantomorphitae subgroup. At the base of the middle Hettangian *liasicus* Chronozone dinocyst diversity further declines, and acritarchs from the Polygonomorphitae subgroup increase in abundance. Alternating cycles of dinocysts versus Polygonomorphitae acritarchs continue towards the top of the Hettangian. Future work, including inorganic geochemical analyses, will aid to understand how acritarchs took advantage of ecological opportunities to dominate the environment and fill the available econiches and how their diversification may have been a response to these geochemical changes. The observed polymorphism in acritarchs may be biologically and mechanistically related to the development of teratologies, linked to, for instance, metal poisoning.

Keywords: Hettangian, Acritarchs, Palynology, ETME

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Stratigraphy and microfacies of the Toarcian-Aalenian boundary from southern Germany

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The micropaleontological evolution from the Upper Toarcian (Early Jurassic) to the Lower Aalenian (Middle Jurassic) in the Swabian Jurassic basin in southwestern Germany remains largely unexplored. With the aim of evaluating the biostratigraphic significance of benthic foraminifera and ostracods, this work focuses on the quantitative analysis of microfaunistic changes during the Toarcian-Aalenian transition in a sediment core from the eastern Swabian Alb. In general, a decrease in the abundance of the microfauna can be observed with the onset of the Aalenian. The data also reveal a remarkable dominance of agglutinating benthic foraminifera species with the beginning of the Aalenian stage while calcareous species like the relatively abundant *Lenticulina sp.* almost completely disappear. Furthermore, ostracods shells present in the Toarcian assemblages are lacking in the Aalenian completely. The obtained data regarding the abundance and diversity indicate a significant change in the Aalenian paleoenvironment towards unfavorable conditions for calcareous microorganisms and allows a better understanding of the paleoecology within the Swabian basin.

Keywords: Microfacies, Toarcian, Aalenian, Germany

*Speaker

Integrated stratigraphy of the Bathonian-Callovian in Arabia and the first report on calcareous nannofossils and dinoflagellate cysts: Age constraints on the Tuwaiq sequence in the Riyadh area (Saudi Arabia)

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The Callovian Tuwaiq Mountain Formation (TMF) represents a large (> 1000 km) shallow marine, tropical mixed carbonate-siliciclastic platform system hosting the main source rock and reservoirs in Saudi Arabia. Petroleum exploration of this interval relies on a detailed sequence stratigraphic scheme that predicts the extent of the physical parameters of the target reservoirs. Several age dating issues hampered the improvement of the current sequence stratigraphic framework established by the BRGM since the 80s: (1) the position of the middle-upper Callovian MFS, (2) the position and duration of the middle-upper Bathonian / lower Callovian and the late Callovian / early Oxfordian hiatuses, (3) the age of the Wadi ad Dawasir delta in the South, (4) the spatial/temporal relationship of the siliciclastic influx of Wadi ad Dawasir delta with the carbonate units of the TMF. These issues will be addressed through an integrated stratigraphy approach (ammonites, calcareous nannofossil, dinoflagellate cysts, benthic/ planktonic foraminifera, carbon-isotope stratigraphy, cyclostratigraphy...) to refine the age uncertainties for the Late Dogger. We report the first record of Bathonian–Callovian calcareous nannofossils of a marine sedimentary sequence based on the identification of thirteen species to produce a synthetic stratigraphic chart. The nannofossils species richness is low in the lower part of the section and the record of *Carinolithus magharensis* (syn. *Hexalithus magharensis*) allows the approximation of the NJT11 Zone (early Bathonian) in the Riyadh limestone member. Calcareous mudstones/packstones of the transgressive Callovian reef sequences (Attash member) has higher species richness dominated by genera *Watznaueria.* The paucity of the

*Speaker

assemblages, the prevalence of coccospheres, and the relatively high organic contents in the Hiysan member are characteristics of a restricted interior basin that had little communication with the open ocean. This member is dominated by genera of *Cyclagelosphaera* and *Watznaueria.* The last occurrence of *Cyclagelosphaera wiedmannii* (NJT 12) and the first occurrence of *Stephanolithion bigotii subsp. Bigotii* (b*ase of NJ13)* provides detailed biostratigraphy for the TMF. The prominent abundance of *Zeugrhabdotus erectus* in the upper TMF record enhanced surface-water productivity which may have been one of the factors behind the formation of the Jurassic organic-rich deposits in Saudi Arabia.

Keywords: Dinoflagellate cyst, Calcareous Nannofossils, Bathonian, Callovian, Saudi Arabia, Cyclostratigraphy, Sequence stratigraphy

Astrochonology for the Early Jurassic – initial results from the JET Project

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Drilling for the Early Jurassic Earth System and Timescale ICDP project (JET) was undertaken between November 2020 and January 2021. The Prees-2 drill site is situated in a small-scale latest Triassic to Jurassic sag basin formed above a major Permian–Triassic half graben system in the Cheshire Basin, England, UK. The borehole was located to recover an expanded and complete succession from the mid Pliensbachian down to the Norian to complement legacy core from the Llanbedr (Mochras) Farm borehole drilled through 1967-69 on the edge of the Cardigan Bay Basin, N. Wales; the overall aim is to construct an astronomically calibrated integrated timescale for the Early Jurassic and to provide insights into the operation of the Early Jurassic Earth System. Downhole and core data from both boreholes are now compared with additional new high-resolution geochemical datasets from offset wells (Wilkesley, Burton Row) and from GSSP (East Quantoxhead, Robin Hood's Bay) and other outcrop sections to revise the estimated lengths of all the Early Jurassic stages.

Keywords: Jurassic, cyclostratigraphy, timescale, Lias

*Speaker

High-resolution 87Sr/86Sr record from the Csövár section (Hungary): Linking the volcanism of the Central Atlantic Magmatic Province and continental weathering at the Triassic-Jurassic boundary

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The Triassic-Jurassic Boundary (TJB, _˜201.3 Ma) marks a turning point in the evolution of life, as it is associated with one of the Big Five" mass extinction events in Earth history. The event has been tied to the volcanism of the Central Atlantic Magmatic Province (CAMP) as the primary cause of the extinction. Despite advances in our understanding of the effects of the CAMP's emplacement and associated environmental, biogeochemical and biotic perturbations, the intensity and timing of continental weathering in response to CAMP-driven elevated atmospheric CO2 levels remains unclear. Several previous studies have presented evidence of intensified chemical weathering around the TJB. However, the links between volcanic activity, carbon isotope excursions, and continental weathering have remained largely inferential and require further validation. Strontium isotope stratigraphy is a well-established and powerful tool for studying the stratigraphic record at the times of emplacement of large igneous provinces, as it provides insight into the timing and intensity of continental weathering, which in turn can help to elucidate the causes of the extinction event. Recent studies of Kovács et al. (2020) and Onoue et al. (2022) provide new 87Sr/86Sr data for the Late Triassic and the interval of the end-Triassic mass extinction event, indicating a rapid increase in continental weathering towards the boundary, after a decrease in the latest Triassic. These studies supplement the data obtained by Jones et al. (1994) and Korte et al. (2003) and used for the Rhaetian to Hettangian interval in the *Geologic Time Scale 2020* (McArthur et al. 2020). However, until now, there has not been any 87Sr/86Sr study that would cover the entire TJB interval from the late Rhaetian into the early Hettangian in a single section, thus avoiding inherent correlation uncertainties. Here, we present new high resolution 87Sr/86Sr data on bulk carbonates from the Csövár section in Hungary, which is an important continuous marine section spanning 3 million years. Seventy samples were measured, with an average 87Sr/86Sr value of 0,7077, ranging between 0,7076 and 0,7081. These results are in broad agreement with previously available data

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but their interpretation must await further screening for possible minor diagenetic overprint. An apparent Rhaetian shift towards less radiogenic values probably reflects the trends of global environmental and plate tectonic changes prior to CAMP. The impact of CAMP volcanism on seawater 87Sr/86Sr ratios is expected as a shift to higher values related to intensified continental weathering. However, the observed rise in the continental weathering flux is smaller than the increase estimated by studies of seawater Os isotope changes during the TJB (Cohen and Coe 2007), suggesting that hydrothermal forcing may have played a larger role than previously considered. Alternatively, the weathering of CAMP basalts, situated in the humid belt, may have counterbalanced the expected shift towards radiogenic Sr values, due to the weathering of isotopically more unradiogenic fresh flood basalts. Further studies of our new dataset will allow more precise reconstructions of paleoclimatic, paleoenvironmental, and paleoceanographic changes around the TJB. The evolution of seawater Sr isotopic composition during this event will also be compared with other intervals of LIP-related environmental and biotic crises.
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Keywords: Triassic Jurassic boundary, end Triassic mass extinction event, Strontium isotope stratigraphy, Sr isotopes, Rhaetian, Hettangian

Integrated stratigraphy in Solnhofen platy limestone: first results

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The Solnhofen platy limestone is famous for its excellently preserved fossils, including protobirds like *Archaeopteryx*. Research has focused on the study of the fossils, mostly the vertebrates, in the last 200 years. The Solnhofen platy limestone is accessible in more than 20 quarries of differing size in a region 100 x 200 km, and with section between 3 and 50 m thickness. It is generally accepted that the platy limestone had high sedimentation rates, although precise rates cannot be given. Stratigraphic analyses have been restricted to punctual studies with partly contradicting results. The ages of the different basins ("Wannen") are roughly constrained by ammonoids, but ammonoid zonation within a quarry is hardly possible because very few specimens have been collected stratified. First results on stable carbon isotope stratigraphy from the Blumenberg and the Ettling quarry are put into context with existing data and the Global Time Scale. Frist data on clay mineralogy from X-ray diffractometry data from Ettling are also presented. These results show that timing and sedimentation in the platy limestone is more complex than hitherto known, and that integrated stratigraphy is a promising tool for high-resolution correlation across the Kimmeridgian – Tithonian boundary in the Solnhofen Platy Limestone.

Keywords: Solnhofen platy limestone, stable carbon isotope curve, ammonoid biostratigraphy, Kimmeridgian, Tithonian, clay minerals

*Speaker

Mercury analyses of fossil plant substrates as indicators of Early Jurassic atmospheric Hg loading and LIP volcanism

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Past global environmental change events were commonly associated with Large Igneous Province (LIP) volcanism, however, the causal relationship between them has not been unambiguously accepted. In recent years, elevated levels of bulk sedimentary mercury concentrations across stratigraphic archives, have been commonly used as indicators of past large-scale volcanic activity, as volcanism is the largest source of natural Hg emission in the present-day environment. But this proxy is highly dependent on and impacted by variations in dominant lithology and/or depositional environment, and its usefulness is therefore debated. Furthermore, elevated Hg shuttling from terrestrial environments can obscure possible Hg loading into Earth's surficial environments.
Here, we present a new approach to reconstruct changes in past Hg-fluxes, more specifically past atmospheric Hg-concentrations, by analyzing Hg-levels in modern and fossil *Ginkgo* leaf tissue. The adoption of fossil leaf material as a past atmospheric mercury proxy is here tested as an independent approach to the validation of mercury as a proxy for past volcanism. Fossil leaves have been proven as a reliable indicator of paleo-pCO2. Importantly, leaves gain their Hg-concentration dominantly through direct atmospheric uptake.

We present new results on (i) the natural variability of Hg-concentration in Gingko leaves, and (ii) the possible impacts of changes in climatic conditions on leaf-Hg-concentrations utilizing leaves that were grown during controlled growth-chamber experiments (with variable atmospheric CO2 concentrations, humidity and atmospheric S concentrations). With this, a baseline for variability in leaf-Hg concentrations was established.
Subsequent analyses of the Hg-concentration in Early Jurassic fossil leaf-cuticle and wood fragments from two stratigraphic successions, spanning the Triassic–Jurassic transition at Astartekløft (Jameson Land, Greenland) and the Sinemurian–Toarcian interval in the Mochras core (Cardigan Bay Basin, UK), show 2–3 orders of magnitude variability in plant Hg-concentrations, significantly larger than natural plant or climatic Hg-variability observed in modern *Gingko* leaves. This suggests that plant tissue may be used to examine geochemical variations in past atmospheres, and thus tracing possible temporal occurrences of past volcanic events.

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Keywords: mercury (Hg), Ginkgo biloba, Large Igneous Province (LIP), direct atmospheric uptake

Magmatism and varying sequestration pathways control sedimentary Hg enrichment during the T-OAE (Réka Valley section, Mecsek, SW Hungary)

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The Phanerozoic is interspersed with major environmental change and mass extinction events, many of which have a temporal link to Large Igneous Province (LIP) volcanism. However, their causal relationship is not uniformly accepted, partly because of a scarcity of sections with direct evidence for both magmatism and biological/environmental change.
Elevated sedimentary mercury concentrations have, in recent years, been increasingly used as a proxy for LIP volcanism, because volcanism is the dominant natural source of mercury in the present-day Hg-cycle. Mercury is a volatile element, which is emitted in its elemental (Hg0) form into the atmosphere during an eruption and if it reaches the stratosphere, it can be globally distributed. Through wet and dry deposition, Hg can be deposited into both the terrestrial and marine sedimentary records. Within the sediment, Hg is commonly associated with organic matter, but elevated sedimentary mercury concentrations (up to ppm-levels) have also been detected in organic-lean (carbonate) sedimentary records, possibly linked to the occurrence of sulfide phases.

For this study, we analyzed a lower Toarcian record from Réka Valley (Mecsek, SW Hungary). The record represents an open marine/deep basin depositional environment, and consists of marl with sandstone intercalations, and black shales representing the Toarcian Oceanic Anoxic Event (T-OAE). New mercury data, spanning the Lower Toarcian (including the T-OAE) shows an increase in concentration parallel to the decrease in δ13Corg values (indicative of the T-OAE negative carbon isotope excursion), suggesting a temporal correlation between carbon cycle disturbance and Karoo-Ferrar LIP (KaFLIP) magmatism.
Furthermore, thermal-alteration experiments on the studied samples, combined with the integrated dataset of organic and inorganic geochemical proxy data for the same sample set allowed

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assessment of the affinity of sedimentary Hg with possible host-phases, to shed light on (changes in) the dominant Hg-sequestration pathways across this time-interval.

Keywords: mercury (Hg) sequestration, thermal stability, Toarcian Oceanic Anoxic Event (T, OAE), Large Igneous Province (LIP)

Astronomical calibration of the Early Jurassic Sinemurian Stage based on cyclostratigraphic studies of downhole logging data of the Prees-2 borehole (England; ICDP JET Project)

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In late 2020, an approximately 650 m long core was drilled at Prees in Shropshire, England, as part of the ICDP project JET (Integrated Understanding of the Early **J**urassic **E**arth System and **T**imescale). The main objective of this project is to obtain a complete and continuous sedimentary archive of the Early Jurassic. The Early Jurassic (_˜200-175 million years) was a period of extreme environmental changes, which will serve as an analogue for present and future environmental transitions. The project plans to provide a reference record for an integrated stratigraphy (bio-, cyclo-, chemo- and magnetostratigraphy) of this period. Analysis of geophysical borehole logs will allow the description of sedimentary cycles related to orbital parameters and paleoclimatic history if sedimentation environment and –rate permits. Here, downhole logging data from the Prees-2 borehole is used to construct an astronomical timescale for the Sinemurian stage, contributing to an integrated timescale for the Early Jurassic. Cyclostratigraphic methods including a statistical and visual approach lead to preliminary results of _˜6.5 ± 0.3 million years duration for the Sinemurian stage.

Keywords: Jurassic, timescale, Sinemurian, JET, cyclostratigraphy, downhole logging

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Enhanced hydrological cycling and continental weathering during the T-OAE archived in a lake system in the Sichuan Basin, China

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Studies on the perturbations of hydrological cycling and continental weathering under greenhouse climate conditions in the historical geological period are helpful to understand the current extreme climatic events. Previous studies on marine sequences have reported that there was an enhanced hydrological cycling and continental weathering during the T-OAE (_˜183 Ma; the Toarcian Oceanic Anoxic Event). Herein, we performed sedimentology and geochemistry researches on deep to semi-deep lacustrine deposits correspondding to the T-OAE interval (the Da'anzhai Member, Well LQ104X) in the Sichuan Basin. Results showed that the bioclastic limestone, discrete shell-bed and shell-laminar interbedded mudstones, and shell-lenticle and -aggregation mudstones represented shell-enriched tempestites. Sandstone and siltstone with normally and inverse-normally graded beddings represented hyperpycnites caused by floods. Sedimentological statistic results demonstrated that tempestities and hyperpycnites mainly occurred in the T-OAE interval suggesting enhanced hydrological cycling. Multiple weathering indices (CIA, PIA, CIW) showed that there was generally intensified continental weathering during the T-OAE interval. Comprehensive and detailed geochemical studies, such as K/Na, Na/Ti, and Rb/K ratios, showed that there was wetter climate and enhanced hydrological cycling but lower chemical weathering intensity in the upper part of T-OAE interval. The enhanced hydrological cycling elevated the rate of denudation of source rocks and transportation of weathered material, which shortened the time for chemical weathering in the source area. The correlation between continental weathering and the development of tempestites and hyperpycnites in the Da'anzhai Member in the Sichuan Basin with surface seawater temperature implied that the high temperature during the T-OAE interval enhanced hydrosphere cycling, increased the frequency of storms and floods, and intensified continental weathering.

Keywords: Toarcian, Jenkyns Event, Continental weathering, Hydrological cycling, Expanded lake, Sichuan basin.

*Speaker

Chemostratigraphy of the lower Toarcian Sachrang section (Eastern Alps) and paleoenvironmental changes associated with the Jenkyns Event

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The early Toarcian Jenkyns Event (_˜183 Ma) was a series of environmental changes including global warming, carbon cycle perturbations, and marine anoxia, which were associated with large volume greenhouse gas emissions during the main phase of activity of the Karro-Ferrar large igneous province. Although considerable evidence, such as the widespread deposition of black shales and various geochemical anomalies, supports the hypothesis of global expansion of oxygen-depleted marine environments during the early Toarcian, our knowledge of this event is overwhelmingly derived from very well-studied, albeit hydrographically restricted NW European epicontinental basins. Thus, additional data from localities that were in paleogeographic proximity to oceanic environments, where biasing effects may have been smaller, is highly desirable. Here, we present new geochemical (δ13Corg, δ13Ccarb, TOC, HI, Tmax, major elements, redox-sensitive trace elements) and biostratigraphic data (based on calcareous nannofossils and ammonites) from the Sachrang section (Eastern Alps). During the early Toarcian, the study section was deposited in a trench on the northwestern continental margin of the Neotethys Ocean, at a location proximal to the open ocean. The section exposes a _˜42-m-thick hemipelagic succession consisting of manganiferous shaly marls (lower _˜25 m) and black shales (upper _˜17 m) of the Sachrang Member of the Middle Allgäu Formation. Our biostratigraphic data confirm the presence of the lower Toarcian NJT5c, NJT6a and NJT6b nannoplankton zones, and ammonites document the Serpentinum Zone in the lower black shale. δ13Corg data exhibit low

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and fluctuating values ($\sim -31 \pm 0.5$‰), with a prominent negative carbon isotope excursion (CIE) that is the characteristic hallmark of the Jenkyns Event. Redox-sensitive trace element data suggest that dysoxic/suboxic conditions existed at the seafloor during deposition of the manganiferous marls, followed by a shift to euxinic conditions during deposition of the black shale. Declining concentrations in the upper part of the black shale, despite persistence of high TOC values, reflect drawdown of aqueous trace-metal reservoirs. Our findings contribute to an improved understanding of the nature and extent of oceanic oxygen depletion on continental margins during the Jenkyns Event.

Keywords: Toarcian, Jenkyns Event, anoxia

Base Oxfordian GSSP: the Subalpine Basin candidate sections (SE France)

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The Callovian/Oxfordian boundary has been studied across more than 60 outcrops in the Subalpine Basin (SE France) over the past few decades, producing remarkably consistent results. In conformity with recommendations for GSSP candidates, the most reliable of these sections appeared to be Thuoux and Savournon (Fortwengler et al., 1997; Fortwengler et al., 2012). More recently, integrated stratigraphic studies of the Thuoux and Saint-Pierre-d'Argençon sections have included biostratigraphy (ammonites, nannofossils and dinoflagellates), chemostratigraphy, physical stratigraphy, and cyclostratigraphy (Pellenard et al., 2014). Following these analyses, a new section, Lazer, was proposed as a very promising Callovian-Oxfordian GSSP candidate during a workshop organised in the Subalpine Basin by the French Jurassic group in 2013 (Pellenard, 2013). Lazer is located near Laragne-Montéglin, 15 km from Thuoux and 4 km from Savournon, a section previously proposed by the Oxfordian Working Group (Melendez et al., 2007). The Savournon section now appears less suitable for precise lithology and high-resolution stratigraphic studies. We therefore consider that Thuoux and Lazer are the best candidates for a GSSP section in the Subalpine Basin. These two sections have the highest sedimentation rate, with clear marker beds and the complete ammonite zonation recognised for Western European basins, based on Cardioceratidae, Oppeliidae, Aspidoceratidae, and Perisphinctidae. Such ammonite assemblages enable precise correlations between biogeographic provinces, in particular with the Boreal Domain, where Cardioceratidae are often dominant. In this contribution, we propose a synthesis of the stratigraphic data from the Subalpine Basin, focusing particularly on the geochemical signal (d13Ccarb, d13Corg, TOC, and d15N), and cyclostratigraphy based

*Speaker

on Magnetic Susceptibility (MS) and Gamma-Ray Spectrometry (GRS). Ammonite fauna more recently collected from Lazer confirm the precision of the biostratigraphic framework, marked by the disappearance of all Callovian genera and the abrupt appearance of *Brightia thuouxensis*, allowing the Callovian-Oxfordian boundary to be accurately identified between the *paucicostatum* and *thuouxensis* horizons, consistent with the biostratigraphy of the Thuoux, Savournon, and Saint-Pierre d'Argençon sections. Nannofossils and dinoflagellates also show great consistency in all sections, further justifying the biostratigraphic framework now established in the Subalpine Basin. The Thuoux section is the main focus, with Lazer as an auxiliary section, and these two sections are confidently proposed as firm candidates for the base Oxfordian GSSP.

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Keywords: Oxfordian GSSP, Subalpine basin, ammonite, dinoflagellate, nannofossil, cyclostratigraphy, chemostratigraphy

Prolonged local carbon sequestration contributed to global carbon cycle recovery following the Toarcian Oceanic Anoxic Event

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The Toarcian Oceanic Anoxic Event (T-OAE, Early Jurassic, ∼183 Ma) was marked by one of the largest carbon-cycle perturbations of the Mesozoic Era, thought to have been linked to carbon degassing associated with Karoo and Ferrar large igneous province (LIP) volcanism. The T-OAE is characterized by an up to ∼7‰ negative carbon-isotope excursion (CIE) in marine and terrestrial organic matter and calcite, superimposed on a longer-lasting positive CIE spanning the entire Lower Toarcian. Climatic disturbance at this time led to the geographically widespread development of marine (and lacustrine) dys- and anoxia and euxinia, and an associated increase in global average organic-carbon burial rates. Consequently, marginal marine basins in both hemispheres (as well as major lacustrine basins) commonly show significant sedimentary total organic carbon (TOC) enrichments over the interval of the T-OAE negative CIE. However, some marine basins experienced sustained organic-carbon sequestration, well past the main phase of the T-OAE. Here, we present new high-resolution stratigraphic and XRF-scanning data from cores spanning the Posidonienschiefer (Posidonia Shale) in the Lower Saxony Basin (NW Germany). Astrochronological analyses of the data show that carbon sequestration in this basin persisted for > 2 million years. Utilizing obtained carbon-burial fluxes and carbon-cycle mass balance calculations we show that prolonged local (basin-wide) carbon burial was instrumental for the rapid removal of significant amounts of carbon from the global ocean–atmosphere system, thus significantly speeding up Toarcian carbon-cycle (and climatic) recovery.

Keywords: Toarcian oceanic anoxic event, astrochronology, Posidonia Shale, Lower Saxony Basin

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Terrestrial Triassic-Jurassic boundary and end-Triassic mass extinction of the Junggar Basin, NW China

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In the southern margin of the Junggar Bain, NW China, there exists a continuous and completely exposed terrestrial Upper Triassic - Lower Jurassic succession in the Haojiagou Section, in which the terrestrial Triassic - Jurassic boundary (TJB) and the end-Triassic mass extinction event (ETE) are clearly recorded. The TJB is placed just above the coexistence bed of the last occurrence (LO) of the sporomorph of *Lunatisporites rhaeticus* and the first occurrence (FO) of the palynomorph of *Retitriletes austroclavatidites* and *Callialasporites dampieriandantent*. It is a little above the FO of *Cerebropollenites thiergartii*, of which the FO is a little below the marine TJB of Austria and England. Furthermore, the coexistence bed above is near the FO of the macro-plant fossil *Todites princeps* and *Clathropteris elegans*. The TJB of the Junggar Basin is, therefore, possibly a link for studying the correlation of the TJB between the Southern- and Northern Hemisphere, and even the correlation of the TJB between the non-marine and marine. According to the FO and LO of fossils in the Haojiagou section, the worst ETE happened by the end-Rhaetian, but it started since late Rahatian. The recognition of the lake-ice-rafted debris from the Late Triassic and early Jurassic deposits, implies that the sudden drop in the temperature or the "volcanic winter" in the Rhaetian is the critical factor causing the ETE in the Junggar Basin.

Keywords: Terrestrial Triassic, Jurassic boundary, end, Triassic mass extinction, Junggar Basin

*Speaker

The fossil insect assemblage of Alderton Hill, Gloucestershire, UK and its link to the Toarcian Oceanic Anoxic Event

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Strata in Western Europe representing the Toarcian Oceanic Anoxic Event (T-OAE, ~183 Ma ago) contains several horizons with abundant fossilised insect, suggesting that it is highly likely that the severe climatic change at this time led to high insect mortality. It is now well established that the T-OAE was a time of environmental change, driven by changes in the carbon cycle, and that it led to increased global palaeotemperatures, enhanced global chemical weathering rates, widespread marine anoxia, eustatic sea-level rise, a crisis in marine taxa and increased atmospheric CO2 levels. More recently it has been noted that on land, global warming, wildfires and acid rain associated with the T-OAE resulted in a decrease in diversity and richness of land plant assemblages, which then had significant effects on the rest of the trophic web including extinction of all basal sauropodomorph dinosaurs. However, the influence of the event on insects has not previously been investigated in detail.
There are seven primary locations in western Europe that have yielded fossil insects from the T-OAE, including two in the UK. We present the first comprehensive taxonomic and taphonomic review and analysis of one of these locations: Alderton Hill, Gloucestershire (UK). All insect material was collected in the mid-19th century from a single layer of early diagenetic calcareous nodules within the Whitby Mudstone Formation and is now held with six museum and institutional collections.

Through the examination of 366 known individuals, we have established that there is a diverse palaeoentomofauna assemblage of 13 insect orders, 28 families, 30 genera and 24 species. This diversity is comparable with the ordinal diversity of present-day insect assemblages from equivalent latitudes (30◦– 40◦N), indicating that the entomofauna of Alderton Hill provides a representative reflection of the insect community during the Toarcian and can therefore be used to draw conclusions about the assemblage. Hemiptera (true bugs), Coleoptera (beetles) and Orthoptera (dragonflies) are the most common orders, constituting ~ 55% of the total assemblage. Coleoptera and Hemiptera also dominate insect assemblages at similar palaeolatitudes

*Speaker

today. Hemiptera is the most taxonomically diverse order in the Alderton Hill insect assemblage, supporting the interpretation that they are likely to have diversified in response to the warm, humid conditions of the T-OAE. In particular, the family Progonocimicidae (Hemiptera: Coleorrhyncha) identified within the insect assemblage is characteristic of much warmer and humid conditions and would have most likely inhabited drought-resistant flora including conifers, which were dominant during the T-OAE. Preservation of highly sclerotised taxa including Coleoptera most likely reflects that their exoskeleton was favourable under the environmental fluctuations, but preservation may have been enhanced by a taphonomic bias towards more robust elements. Highly disarticulated compression fossils dominate the assemblage, $\sim$ 68% of which are isolated wings or wing fragments. In comparison, the coeval insect assemblage from the only other major UK site at Strawberry Bank (Ilminster, Somerset) is less diverse, generally less well-preserved and taphonomically biased towards Coleoptera.
Our results indicate that the Alderton Hill insect assemblage is the most well-preserved and representative record of insect diversity ever reported from Toarcian strata in the UK. Furthermore, the results of this comprehensive analysis of the Alderton Hill insect assemblage now allows for an in-depth comparison with the rich entomofaunas of Germany and Luxembourg, in order to assess the diversity and distribution of insect taxa during the T-OAE.

Keywords: Alderton Hill, Gloucestershire, Lower Jurassic, Toarcian, Insects

Sedimentology and sequence stratigraphy of the lower Aalenian Opalinuston Formation from southern Germany

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Aalenian sedimentary deposits in southern Germany have accumulated in a shallow-marine, epicontinental shelf environment. These accumulations are dominated by thick claystones and argillaceous siltstones, with increasing percentages of sandstones towards the top. Aalenian sediments are likely to represent a relatively complete stratigraphic record, however, the sedimentary evolution and paleoclimatic significance of these typically poorly exposed deposits remain largely unexplored. Here we present a suite of high-resolution x-ray fluorescence (XRF) core scanning data from southern Germany to identify Transgressive-Regressive cycles during the Aalenian stage. Results are based on three scientific drill cores of 200 – 250 m length that have been analyzed with an Avaatech XRF Core Scanner at a 10 mm sampling interval (10 keV, 500 μA). Resulting trends in elemental Si/Al ratios, which are indicative for subtle grain-size variations, combined with sedimentological observations on ichnofacies and bedform development were used to reconstruct shoreline trajectories and establish a sequence stratigraphic framework for the thick and largely homogenous lower Aalenian Opalinuston Formation.

Keywords: lower Aalenian, Opalinuston, Germany

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Discovery of Purbeckian-type ostracod fauna and charophyte flora across the Jurassic–Cretaceous boundary in the Middle Atlas of Morocco (NW Africa): Biostratigraphic and biogeographic implications

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Micropalaeontological investigations of the red beds called "Aït Bazza Formation", from the Marmoucha syncline in the eastern part of the folded Middle Atlas of Morocco, yielded a particular Purbeckian-type ostracod fauna and charophyte flora of high biostratigraphic and biogeographic interest.
The charophyte assemblage, precisely recognized at the upper part of the studied series, is mainly dominated by the clavatoracean species *Globator maillardii praecursor*, *Globator maillardii maillardii*, *Globator maillardii protoincrassatus*, *Dictyoclavator fieri*, *Nodosoclavator bradleyi*, *Clavator reidii pseudoglobatoroides*, and *Clavator grovesii grovesii*, associated with the porocharacean species *Porochara kimmeridgensis*, and *Feistiella bijuescensis*, as well as the characean species *Mesochara harrisii*. This assemblage facilitates reliable correlation with the latest Tithonian–early middle Berriasian European charophyte Globator maillardii maillardii biozone of Riveline et al. (1996). This chronostratigraphic constraint perfectly coincides with the data provided by the associated nonmarine ostracod assemblage, consisting of the species *Fabanella boloniensis*, *Limnocythere* sp., *Timiriasevia punctata*, *Mantelliana purbeckensis*, *Scapriculocypris trapezoides*, *Theriosynoecum forbesi*, *Alicenula leguminella*, *Damonella ellipsoida*, *Cypridea dunkeri dunkeri*, *Cypridea tumescens praecursor*, *Cypridea coelnothi*, *Cypridea* aff. *delicatula*, and *Cypridea tuberculata longtonensis*, characterizing the lower part of the Theriosynocum forbesi Zone, and the Cypridea dunkeri and Cypridea granulosa subzones of Horne (1995).
From the biogeographical point of view, these are the richest and most diverse Purbeckian-type ostracod and charophyte assemblages reported for first time from Gondwana, precisely at the Moroccan margin of the southwestern Tethys. This particular non-marine fossiliferous hotspot from Gondwana shows strong affinities to coeval faunas and floras previously described from Laurasia, precisely from the northern (France, Spain, Switzerland and Germany) and western (Romania) margins of the Tethys. Consequently, our discovery gives further solid argument

*Speaker

confirming an intensive biological exchange between southern and northern Tethyan margins across the Jurassic–Cretaceous boundary.

Keywords: Jurassic–Cretaceous boundary, Purbeck, charophytes, ostracods, biostratigraphy, biogeography, Middle Moroccan Atlas, North Africa, Gondwana

Splicing the Hettangian record using legacy core: the Wilkesley and Prees 2C cores in the Cheshire Basin (NW England)

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Following the upheavals of the latest Triassic, the Hettangian interval saw large-scale readjustment of faunal assemblages and geochemical cycles. Associated with the gradual break-up of Pangea, marine sedimentation was established in numerous basins in a nascent Laurasian epicontinental seaway where many of the key sections and drill sites yielding strata that recorded this critical interval of Earth history are situated. Even though these sections and drill cores have allowed us to establish detailed biostratigraphic schemes and to assess Earth system evolution, key questions about the duration of the Hettangian and integrated stratigraphy remain open.

While reducing the challenges of weathering, accessibility and completeness that outcrop sections are often fraught with, core records are by necessity limited to a small cross section and biostratigraphic constraints from macrofauna are therefore usually much looser than in surface exposures. To address this issue for the newly drilled Prees 2C core that yielded a virtually complete sequence of upper Triassic (Norian?-Rhaetian) to Pliensbachian strata from the Cheshire Basin, NW England, the archived remains of the Wilkesley core were utilised. Wilkesley was drilled as an exploration core, about 10 km NE of the Prees site in 1959-60, with a much larger diameter than Prees 2C, and the Jurassic part was entirely broken up for biostratigraphy, providing a wealth of stratigraphically significant specimens.

Registered core specimens of Wilkesley, which were retained in intervals of 30 cm, were used to generate chemostratigraphic records of organic carbon isotope ratios, carbonate and TOC content, and element geochemistry (Rb/Zr ratios) to supplement the rich ammonite record for this core. These datasets were used to correlate to equivalent records from Prees 2C, allowing combination of the ammonite evidence for an improved biozonation of Prees 2C.

Correlations between the two cores could be achieved with high fidelity throughout the entire Hettangian record, indicating lateral continuity of major rock properties over 10 km. These correlations indicate that sedimentation at Prees 2C, located closer to the depocenter of the basin, was on average 14 % higher than at Wilkesley. Correlations drawn on the basis of chemostratigraphic markers also always agree with biostratigraphic constraints, allowing reduction of the

*Speaker

overall biostratigraphic uncertainty for Prees. These additional constraints will be instrumental in ongoing study of the Prees 2C core to assess the duration of the Hettangian and its biozones, and hence Earth System behaviour in the Early Jurassic.

Keywords: Jurassic, correlation, chemostratigraphy

Geochemistry and preservation of fossils in the Prees 2C core (Hettangian-Pliensbachian)

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Marine macrofossils – at least for Paleozoic and Mesozoic time – are amongst the most sought-after carriers of palaeoenvironmental information, because they are often large enough to preserve primary geochemical signatures, at least in parts of their thick shells. Furthermore, as a consequence of decade-long dedicated research, their biomineralisation and the structural and geochemical trajectories of diagenesis are well understood.

The Prees 2C core, drilled in 2020 in the Cheshire Basin (NW England) yielded about 560 m of fossiliferous Early Jurassic strata of Hettangian to early Pliensbachian age. Besides forming the basis of a detailed ammonite biozonation, macrofossils are also subject to geochemical assessment. Several hundred specimens, primarily belemnites, bivalves, and brachiopods were taken from the working half of Prees 2C and shell material extracted for geochemical analysis. In addition to this, detailed petrographic observations of bulk rock using scanning electron microscopy gave further insights into shell preservation and secondary mineralisation.

Aragonite – at least in some instances – is still preserved in Prees 2C, which is evidenced by iridescent ammonite shell, but also partially very high Sr/Ca ratios coupled with very low Mg/Ca ratios in originally aragonitic molluscs. Macroscopic assessment suggests good preservation of shell textures in many cases. Large, thick-shelled bivalves are the easiest target for geochemical assessment for most of the Hettangian to middle Sinemurian interval and show element/Ca ratios comparable to those in other UK basins. Belemnites are locally abundant from the middle Sinemurian upwards and show typical enrichment of Sr and Mg over bivalves. Limited brachiopod finds fit into this pattern via intermediate Mg/Ca and Sr/Ca ratios falling between bivalves and belemnites. Mn and Fe contents are mostly low, supporting the good geochemical preservation of the macrofossil material.

SEM observations have added considerably to this macroscopic assessment as they revealed partially pervasive replacement of carbonate with euhedral albite, amongst other – more common – diagenetic features such as infills with carbonate cement, pyrite framboids and occasional sphalerite.

Keywords: Jurassic, macrofossils, diagenesis, geochemistry

*Speaker

Integrated stratigraphy of the Hettangian-Sinemurian (Lower Jurassic) in the Tata Geological Garden (Transdanubian Range, Hungary)

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The Kálvária-domb (Calvary Hill) at Tata is arguably the most important Mesozoic locality in the Transdanubian Range in Hungary. During a long history of research, most studies have been focused primarily on litho- and biostratigraphy of this site, with an aim of reconstructing the sedimentary basin evolution in a western Neotethyan paleogeographic context. Thick Upper Triassic shallow marine carbonate platform deposits (Dachstein Limestone Formation) are overlain by the Lower Jurassic, increasingly open marine and pelagic *ammonitico rosso*-type Pisznice Limestone Formation above a hiatal surface that corresponds to the Triassic-Jurassic boundary (TJB). However, previous biostratigraphic results have been inconclusive about the extent of the TJB gap and the age of the onset and cessation of deposition of the Pisznice Fm. Here we present new results of stable isotope chemostratigraphy and cyclostratigraphy, develop an age model, and establish correlation to constrain the Early Jurassic evolution of the disintegrating former Dachstein platform and its successor carbonate ramp and pelagic basin.

Previously published ammonite biostratigraphy established a Hettangian-Sinemurian age of the Pisznice Formation, although the presence of Middle Hettangian and Upper Sinemurian remained questionable. Besides, a largely untapped resource of published high-resolution (5 cm spacing) microfauna and microfacies data from thin sections are available and used here. In addition, we generated carbon and oxygen stable isotope data from the topmost Dachstein Fm. and the entire Pisznice Fm., and elemental composition data from the Pisznice Fm. (excluding its lowermost part) using a hand-held XRF instrument. These datasets have been used for chemo- and cyclostratigraphy to improve age constraints and correlation.

The TJB gap explains the lack of a negative carbon isotope anomaly observed in numerous other sections worldwide. The demise of the Dachstein platform system was likely related to the end-Triassic extinction that resulted in the collapse of reef ecosystem around the platform. The top of the Dachstein Fm. is best interpreted as a submarine erosion surface. The duration of the hiatus is not likely to exceed a few hundreds of thousands of years, if our new astrochronology,

*Speaker

biostratigraphic constraints on the Hettangian-Sinemurian boundary, and the best current estimates for the length of the Hettangian are considered. Orbitally controlled cyclicity is present throughout the Pisznice Fm. and is recorded in the fluctuating ratio of various carbonate components, changing elemental abundances, and stable carbon and oxygen isotopic ratios. Our astrochronology suggests that the lower part of the succession was deposited in ~1.8 Myr. This result is consistent with previous biostratigraphic results that assigned this member to the Hettangian and the stage duration estimates in the calibrated time scale. However, upsection where stylolitic surfaces occur, the astrochronologic duration of ~2.5–2.6 Myr contradicts the duration of ~4 Myr expected from calibrated biostratigraphy of the Sinemurian. Interestingly, the apparent discrepancy of the missing ~35% of biostratigraphically predicted time duration is comparable with the sedimentological considerations that suggest that up to 35–40% of the upper part of the section may have been dissolved along the stylolitic surfaces. Utilization of microfacies and geochemical data as well as the results of phase and coherence analyses can also contribute to a paleoenvironmental and depositional model that is based on detrital and biogenic elemental proxies and microfossil components. These investigations can validate, complete, and extend the prior results and provide new means of stratigraphic correlation of the Tata section with different other sections in Europe and beyond.

Keywords: Triassic/Jurassic boundary, integrated stratigraphy, astrochronology

Orbitally forced cyclic sedimentation in a lacustrine to paralic coal-bearing succession in Southwest Hungary during the Late Triassic–Early Jurassic

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The uppermost Rhaetian to Lower Sinemurian Mecsek Coal Formation was deposited in a half-graben with lacustrine to paralic environments. It contains economically important coal measures and was intensively explored and mined in the 20th century in Hungary. However, our understanding of the formation is still incomplete. Owing to the scarcity of age-diagnostic fossils and the effect of subsequent Alpine deformation, the exact time span of the formation is not well constrained and the depositional environment in wich the coal was deposited is also a matter of debate.
Although the presence of sedimentary cycles was already documented during the early phase of industrial exploration, no detailed cyclostratigraphic study has been carried out previously, mainly due to the prevailing assumption that these cycles are of autocyclic rather than allocyclic origin.

We conducted a cyclostratigraphic and astrochronologic analysis to help establish an age model for the Mecsek Coal Formation and to gain more information about its depositional environment. After the closure of the former mines, we used archive borehole data of the K-134, K-163 and K-176 cores that were drilled near the mining town of Komló. For the time series analysis, we first built a lithological index dataset from careful reinterpretation of the original lithological logs. Due to the faulting related to the Alpine deformation and intrusion of basaltic sills we were only able to analyse selected relatively short, undisturbed parts of the succession but after the removal of the basaltic sills (up to 1.9 m in individual thickness) we were able to construct three composite segments and a shorter stand-alone segment with only cm-scale faults. The three composites represent 175.9, 132.8 and 77.7 m thick segments (of which the first two are overlapping), whereas the shorter section represents 44.8 m of the entire _˜350 m thickness of the succession.

We detected the long and short eccentricity cycles as well as four cycles linked with obliquity and two precession cycles. Apparently sub-Milankovitch cycles are also present in the succession. The average sedimentation rate was 7.5–9 cm/kyr and it remained relatively stable throughout the studied sections. Remarkably, after the change to entirely paralic depositional environment, the signal of obliquity and precession cycles strengthened.

*Speaker

The 77.7 m thick composite represents the Triassic part of the formation, contains the base of the formation and a previously identified spore peak, but does not extend up to the Triassic-Jurassic boundary (TJB). Considering the time-gap between the spore peak and the TJB, the Rhaetian part of the Mecsek Coal Formation represents $\sim$460–490 kyr. The two longer composites are probably entirely Sinemurian in age, representing $\sim$2.2 Myr, whereas the shorter section is likely Hettangian in age and represents $\sim$545 kyr.
Our cyclostratigraphic analysis suggests that deposition of the thickest coal seams was orbitally controlled and corresponds to the absolute minima of seasonality, whereas the absolute maxima of seasonality resulted in the deposition of coarse-grained sandstone beds. However, this relationship is not consistently clear as it is affected by sedimentary noise and overprint by autocyclic processes. Nevertheless, allocyclicity and orbital signals can be unambiguously detected in the Mecsek Coal Formation despite the presence of faults and basaltic sills. This study also provides an example for possible uses of old, archive borehole data in modern research.

Keywords: Triassic/Jurassic boundary, astrochronology, cyclostratigraphy

The Kimmeridgian-Tithonian boundary in the Boulonnais, with emphasis on paleoclimate and stable isotope correlations

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The coast near Boulogne-sur-Mer offers excellent exposures of a nearly complete Upper Jurassic succession of sandstone units alternating with mudstone units. One of these units is the 25m thick, mudstone-dominated Argiles de Châtillon Formation (ACF) that straddles the Kimmeridgian-Tithonian boundary. These shallow-marine deposits represent a proximal lateral equivalent of the more distal marine Kimmeridge Clay Formation. The ACF is composed of two subunits that each contain an organic-rich interval (ORI). The two conspicuous ORI's have been linked to either periods of high sea level or greenhouse warming. The ACF was sampled for palynological and stable isotope analyses (δ13Corg) in order to provide age constraints and a better understanding of the climatic and environmental mechanisms that governed the organic matter accumulations. The carbon isotope records were used to correlate the ACF from the widely-spaced Boulonnais sections with the Kimmeridge Clay Formation from southern England and show that the upper part of the ACF in the most complete Cran aux Oeufs section correlates to the upper part of the *Autissiodorensis* ammonite Zone (*Irius* Subzone) and to the *Elegans* ammonite Zone. The correlation contradicts published biostratigraphic accounts on the ACF that suggest that the *Irius* Subzone is absent in the Boulonnais region. The palynological results enable a twofold subdivision of the ACF: the lower half displaying cooler and more humid climatic conditions and the upper half displaying warmer and more arid conditions. The climate change appears to mark the Kimmeridgian–Tithonian boundary. The palynological results show that the lower ORI was deposited under suboxic to anoxic stratified conditions. For the upper ORI, there are no indications of stratified conditions. Within this thicker ORI, cyclic variations are observed in the δ13Corg trends, the total organic carbon and in the distribution of amorphous organic matter. These cycles line up with humid-arid cycles which are derived from the palynological analyses and are likely alternating on a ˜100 kyr eccentricity timescale. Under the most humid phases of these overall arid climate conditions, sulfurization of carbohydrates was the dominant control on organic matter preservation. The onset of this climate-controlled process that drives organic matter enrichment in the Tithonian can be recognized on a basin-wide scale.

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Keywords: Kimmeridgian, Tithonian, Boulonnais, palynology, stable isotopes

SC9: Triassic Integrated Stratigraphy, GSSPs, and Extreme Climatic, Environmental and Biotic Events

Integrated stratigraphy of Carnian deposits in the Dinaric Alps, Glamoc (SW Bosnia-Hercegovina)

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From the Late Triassic time interval, particularly the Carnian has attracted ample attention as it represents a period of major innovations in the marine terrestrial ecosystems such as the dawn of marine nannoplankton and crinoids and the dawn of dinosaurs and "modern conifers". Most of the Carnian successions in the Tethys realm, however, are characterized by marked changes in the lithofacies from early Carnian limestone dominated sequences to a siliciclastic and shale dominated interval earlier described as the Reingraben event, and back to carbonate systems in the late Carnian. Because of these marked changes continuous palynological records covering the entire or most of the Julian and Tuvalian substages are still lacking. Here we present the first results of a new detailed palynological study of an almost complete Carnian succession in the Dinaric Alps near Glamoc, SW Bosnia Hercegovina, which covers most of the Julian and the entire Tuvalian. The palynostratigraphic assemblage zones are calibrated with marine biochronology based on ammonoids and conodonts and correlated with a bulk Corg-isotope curve.
Significant changes occur in the terrestrial palynomorph assemblages through the studied section. The terrestrial palynomorph assemblages are mainly dominated by pollen of the *Circumpollis* group (*Praecirculina, Partitisporites, Duplicisporites, Camerosporites*, as well as *Granuloperculatipollenites* and *Classopollis* in the highest part of the section), vesicate pollen (*Enzonalasporites*, *Vallasporites*) and bisaccate pollen (*Ovalipollis*, *Samaropollenites*, *Cedripites*, *Infernopollenites*, *Triadispora*, *Voltziaceaesporites*, *Brachysaccus*, *Lueckisporites*, *Taeniaesporites*) in particular in the lower part of the section. Spores occur in low numbers (5-10%) mainly in the lower part of the section.

The following 3 major pollen assemblage zones can be distinguished and summarized as follows:

Enzonalasporites – Partitisporites assemblage zone (Julian part of section): This assemblage is characterized by the high abundances of the vesicate pollen *Enzonalasporites vigens* and several members of the *Partitisporites – Praecirculina* group (*Partitisporites novimundanus*, *Praecirculina* granifer, etc). These prominent pollen elements are accompanied by a diverse group of bisaccate pollen such as *Ovalipollis* spp., *Samaropollenites speciosus*, *Cedripites microreticula-*

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tus, *Infernopollenites* spp., *Triadispora* spp., *Voltziaceaesporites*, *Brachysaccus*, *Lueckisporites singhii*, *Taeniaesporites* and others. Most of these bisaccate pollen types, except *Ovalipollis* spp., have their highest occurrence at or near the top of this assemblage zone.

Camerosporites - *Vallasporites* – *Aulisporites* assemblage zone (Tuvalian I and II): This assemblage is rather monotonous and dominated by *Camerosporites secatus* (up to 60%) accompanied by *Vallasporites* and *Aulisporites*.

Granuloperculatipollenites – *Classopollis* assemblage zone (Tuvalian III): This assemblage is characterized by a decrease in the abundance *Camerosporites secatus* and the first occurrence / significant increase of *Granuloperculatipollenites* and *Classopollis meyeriana* (together up to 80%).

Keywords: Integrated stratigraphy, palynology, ammonoids, conodonts, Carnian

The Late Ladinian to Early Carnian Daonella and Halobia from Spiti (Tethys Himalaya, northern India) and their bearing for the calibration of the Carnian GSSP

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The GSSP of the Carnian stage and of the Upper Triassic series, established in 2008 at Prati di Stuores (Dolomites, Italy), was defined on an ammonoid event, the FAD of *Daxatina canadensis*. The Prati di Stuores succession yields ammonoids and shows a primary magnetization, but it is poor in conodonts, especially in its lower part, and it lacks of pelagic bivalves of the genera *Daonella* and *Halobia*. These two genera are worldwide distributed and they have been used for long range correlations of Middle to Late Triassic marine facies since the 19th century.

The sedimentary succession of Spiti (Tethys Himalaya), consisting of Kaga and Chomule formations, is very rich in *Daonella* and *Halobia*, and for this reason it was taken into account by the Ladinian/Carnian boundary Working Group as potential candidate for the GSSP. Lack of primary magnetization and low potential for chemostratigraphy prevented from the final selection by the WG, but the abundance of *Daonella* and *Halobia* still makes this succession one of the best in the world.
Here we present the study of a large collection of bivalves that was preliminarly investigated in the early 2000s. Several hundreds of specimens from five sections have been studied. Five species of *Daonella* (*D. pichleri*, *D. bulogensis*, *D. tyrolensis*, *D. lommeli* and *D.* n. sp.) and two of *Halobia* (*H. fascigera* and *H. zitteli*) have been recognized. Ammonoids and conodonts from the same sections provide the chronostratigraphic calibration of the bivalves species. *Daonella* is documented from the Meginae to the Canadensis zones (Upper Ladinian to lowermost Carnian), while the FO of *Halobia* is recorded between the upper portion of Canadensis/lower portion of Aon zones, in the Lower Carnian. Evolutionary trends and correlations with tethyan successions are discussed.

Keywords: Ladinian, Carnian, chronostratigraphy, bivalves, ammonoids, conodonts

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NEW RADIOISOTOPIC DATES REVEAL A MIDDLE TRIASSIC AGE FOR LACUSTRINE SUCCESSIONS IN SW GONDWANA

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Fluvio-lacustrine basins in western Argentina potentially preserve some of the most complete non-marine Triassic successions in Gondwana, with abundant datable horizons and diverse fossil assemblages. The Triassic Peñasco Group of the Santa Clara subbasin in the Cuyana Basin of central-west Argentina is one such example, however, it has long lacked an accurate chronostratigraphic framework making correlations and constraints on the tempo of recorded events challenging. The upper section of the Group comprises a fluvio-deltaic-lacustrine succession of the Santa Clara Abajo and overlying Santa Clara Arriba formations. The paleolake has been interpreted as a stratified-balanced-fill lake basin with different hydrological stages of opening and closing through time based on carbon and oxygen stable isotope geochemistry. Previous palynostratigraphic analysis had inferred a Late Triassic (Carnian-early Norian) age for the Santa Clara Arriba Formation. For both units, however, new U-Pb CA-TIMS zircon ages from tuffs suggest an earlier depositional age (ca. 244 Ma for the base of Santa Clara Abajo Formation, and ca. 243 Ma for the upper Santa Clara Arriba Formation) and constrain the deposition to less than _˜2 my if maximum uncertainties are considered. These radioisotopic ages indicate the Santa Clara subbasin is one of the few localities globally preserving non-marine Anisian deposits with a precise chronostratigraphic framework. Moreover, our results illustrate the potential for constraining the relationship between Triassic Gondwanan palynomorph assemblages, paleogeography, and explain the spatiotemporal effects of biogeography on palynostratigraphy.

Keywords: Anisian, chronostratigraphy, correlations, palynostratigraphy

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An updated of conodonts biostratigraphy at the Wantou section (South China) - A potential candidate of GSSP for base of Anisian

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The boundary and Global Stratotype Section and Point (GSSP) for the base of the Anisian stage(Middle Triassic), have been proposed to be defined at the Wantou section within Nanpanjiang Basin (Guangxi Zhuang Autonomous Region, South China). Multidisciplinary researches on the Wantou section have provided a considerable amount multi-proxies of biostratigraphy, magnetostratigraphy, and chemostratigraphy constrained the Olenekian-Anisian Stage boundary in the section. The site of the Wantou section is permanently protected from major changes, but not limited to scientific research, by the Leye-Fengshan UNESCO Global Geopark. High-resolution conodont samplings and investigations have recovered thousands of conodont specimens, especially rich in Olenekian-Anisian boundary (OAB) strata at the Wantou section. The main marker event proposed to define the OAB is the First Appearance Datum (FAD) of the conodont *Chiosella timorensis s.s.* at the level of Bed 15e (9.16 m), which in the Wantou section is associated to other events, useful proxies for the identification of the base of the Anisan: 1) the peak of the carbon isotope positive excursion; 2) base of brief normal polarity prior to the normal polarity dominated interval.
Despite this, there is not yet a globally accepted conodont index for the base of the Anisian. The first appearance datum of *Chiosella timorensis* (Norgmi, 1968) has long been considered the potential index for the OAB. However, this specie has been obtained along with the traditionally late Spathian ammonoids of the *Haugi* zone (Goudemand et al., 2012), which generated doubts about its suitability. Subsequently, a number of possible alternative conodont indexes for the base of Anisian have been proposed, including *Gladignathodus tethydis*, *Magnigondolella alexanderi*, *Neogondoella curva*, etc.. However, the global synchronous feature, taxonomy, and relationship of these possible earliest Anisian conodonts remain understudied.
In this work, we discuss the *Chiosella timorensis* taxonomy and evaluate the global synchronously of the possible conodont base Anisian indexes, via the geomagnetic polarity magnetozones, and of δ13Ccarb excursions correlation, between the Western Tethys nominated Desli Caira, and Kçira-A section, and Eastern Tethys candidate Wantou, Guandao, and Youping sections. It suggested the FO of *Gl. tethysdis* situated below the MT1n (Middle Triassic first normal mag-

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netozone, designation followed Hounslow and Muttoni, 2010) or within the MT3n; the FO *Ch.timorensis s.l* situated below the MT1n or above the MT1n. The *Ng. curva*, occurs slightly above the *Ch. timorensis* in both sections, but the FO of *Ng. curva* situate below the MT3n or near the base of MT3n. On the controversy, the Ch. timorensis senso stricto keeps situating in the MT1-2 magnetozone among the sections, which indicates the FO of the *Ch. timorensis senso stricto* has advanced on the global synchronous correlation compared to other proposed alternative index species for the OAB. As we have stated previously, a multi-proxy approach to identify the OAB, will yield a more accurate and reliable cross-region correlation and lead to the recognition of the primary index with a global synchronous feature.

Keywords: Chiosella timorensis, Conodont, Olenekian, Anisian Boundary, geomagnetic polarity, magnetozone

Strontium and oxygen isotopic evidence for global cooling during the final assembly of the supercontinent Pangea

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The Norian stage (Late Triassic) has long been regarded as an interval of stable climates, but this substantial period (> 20 Myr) has received little study. Here oxygen and strontium isotopes have been measured on conodont apatite from the open-marine shelf succession at the Xiquelin Section (Baoshan terrane, Yunnan Province, China). The δ18Oapatite values translate into low to middle latitude sea surface temperature of 22 to 35○C and indicate cooling from the *Mockina bidentata* to *Parvigondolella andrusovi* conodont Zone during the Sevatian Substage. This temperature change in the eastern Tethys is also seen in the western Tethys, and the west Pangean margin, suggesting that the W3 warming (from Trotter et al. 2015) and post-W3 cooling during the middle-late Norian was a global event. Estimated sea surface temperature (SST) peak at 35○C at the base of the *M. bidentata* Zone and show a rapid ˜12○C cooling to 22○C during the *M. bidentata* Zone, associated with a decrease in 87Sr/86Sr. This is followed by a brief temperature and 87Sr/86Sr rebound, and then a second pulse of gradual cooling from 29○C to ˜25○C, associated with another decrease of 87Sr/86Sr values from the uppermost *M. bidentata* to the *P. andrusovi* Zone. The SST and 87Sr/86Sr records we present here indicate that post-W3 cooling coincided with an enhanced non-radiogenic strontium input that may have resulted from weathering of mafic and ultramafic rocks obducted during the closure of the Paleo-Tethys Ocean.

Keywords: Norian, Oxygen isotopes, Strontium isotopes, Conodont, Climate cooling, Paleo, Tethys

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Major biotic evolutionary tempos constraining Triassic stratigraphical subdivisions

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Stratigraphical subdivision was originally defined based on fossil assemblages. For an instance, John Phillips (1800–1874) formally defined the three great eras, Paleozoic ("ancient life"), Mesozoic ("middle life") and Cenozoic ("recent life"), based on their contrasting fossil assemblages, each apparently separated by an extinction event. More accurate stratigraphical definition and correlation are now possible using a wide variety of biozones of various fossil groups. Major evolutionary tempos of various fossil groups are outstanding within the Triassic, which are subdivided into the three series/epochs that contain seven stages/ages. We compiled the dataset of all marine fossil records from the Triassic strata, and recognized the originating, passer-by and extinct components from each stage. The analytical results show that the number of originating taxa and origination rate appear a rapid peak in Anisian and a moderately climbing slope in Carnian, with a relatively high extinction rates in their preceding stages, implying two new biotic evolutionary tracks in these two stages. However, the Carnian Pluvial Event (CPE) was associated with a biotic extinction in mid-Carnian (across the Julian-Tuvalian substage boundary). This means that the present Carnian dataset comprises the pre-CPE and post-CPE fossil records. When the Carnian is subdivided into the pre-CPE (Julian) and post-CPE (Tuvalian), then the Julian saw a much higher extinction rate and the Tuvalian witnessed the higher origination rate. The second evolutionary episode of the Triassic biota therefore started in Tuvalian, which is followed by a plateau in both origination rate and the number of originating taxa in the rest of Late Triassic. Accordingly, the Triassic biotas exhibit three evolutionary episodes, which are calibrated to the Induan-Olenekian, Anisian-Julian, and Tuvalian-Rhaetian intervals, suggesting three epochs/series. Here, we suggest that both the Julian and Tuvalian substages can be upgraded to the stage status and that the Triassic can be subdivided into three series, with the Olenekian-Anisian and Julian-Tuvalian boundaries representing the Lower-Middle and Middle-Upper Triassic. Furthermore, given the Late Triassic Epoch is too long (233.6-201.4 Ma), the Lacian, Alaunian, and Sevatian substages of the Norian Stage can be upgraded to the stage level, and the Upper Triassic Series may be further subdivided into two series and the series boundary is selected when the Late Triassic biotic evolution traits are studied in future.

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Keywords: Triassic, Series boundary, Carnian Pluvial Event, biotic evolution

Calcareous nannofossil biozonations for the Rhaetian (Upper Triassic)

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The calcareous nannoplankton first occurred during the Upper Triassic (Norian) and seems to spread from the Western Neo-Tethys toward the other oceans. This project focuses on the early evolution of calcareous nannoplankton during the Rhaetian from sediments located in the Neo-Tethys Ocean (Western and Southern) as well as the Palaeo-Tethys Ocean. To tackle the problem of diagenesis and poor preservation often impacting the Upper Triassic sediments, different methodologies were applied according to the lithology. Both soft and hard calcareous lithologies were analyzed using a scanning electron microscope (SEM), while for the soft lithologies, the standard smear slides were observed under a light microscope (LM).
Those combined analysed allow the identification of a new nannolith species, *Eoconusphaera hallstattensis* and confirmation of the disregarded subspecies Prinsiosphaera triassica crenulata. E. hallstattensis presents a short range of occurrence during the early Rhaetian from *Paracochloceras suessi* to *Vandaites stuerzenbaumi* zones. The succeeding taxa, *E. zlambachensis* first occurs during the *V. stuerzenbaumi* Zone but dominates the assemblage until the end-Triassic. *P. triassica crenulata* was for a long time interpreted as a diagenetic alteration of *P. t. triassica,* however, our observation of its characteristic parallel-oriented calcite lamellae both under SEM and LM reconsidered this misinterpretation. This last species, also present a relatively short range of occurrence from the top of *V. stuerzenbaumi,* when *E. hallstattensis* last occurs, until the end-Triassic.
In the Western Tethys sections, the range of occurrence of those three species is well known and represents good biostratigraphic markers for the Rhaetian with the distinction of three biozones: *E. hallstattensis* Zone, *E. hallstattensis – E. zlambachensis* Zone and *E. zlambachensis – P. t. crenulata* Zone. The Eoconusphaeraceae species are abundant and observed in the different oceans of the Rhaetian. This new biozonation has proven to be useful as it allowed us to date as well sediments of the Palaeo-Tethys in Romania.

Keywords: Biozone, nannolith, Neo, Tethys, Palaeo, Tethys, Eoconusphaera spp., Prinsiosphaera triassica

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New insights into the timing and causes of the end-Triassic extinction in Southern Tethyan carbonate platforms

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The end-Triassic Extinction (ETE) is one of the "big five" of the Phanerozoic and severely affected shallow-water benthic calcifiers of carbonate platforms, including scleractinian corals, megalodontid bivalves, involutinid foraminifers and dasycladalean algae. This biotic crisis has been linked with volcanism of the Central Atlantic Magmatic Province (CAMP) that injected massive amounts of CO in the ocean-atmosphere system causing perturbations of the global carbon cycle, climate change, ocean acidification and anoxia. However, the timing and causes of extinctions of carbonate platform assemblages are poorly constrained owing to an incomplete stratigraphic record in the classical sections of the Northern Calcareous Alps (NCA, Austria), Transdanubian Range (Hungary) and Lombardy Basin (Italy), where the extinction level of Rhaetian taxa coincides with a facies change, evidence for subaerial exposure, sea-level drop and/or drowning.

In this study, we present new integrated biostratigraphic and inorganic carbon isotope (δ^{13}Ccarb) records of three Southern Tethyan carbonate platform sections that show continuous carbonate productivity and no evidence for a stratigraphic gap at the extinction level of Rhaetian assemblages: Mt. Messapion (Pelagonian Domain, Greece), Valle Agricola (Southern Apennines, Campania, Italy), and Mt. Sparagio (Panormide Platform, Sicily, Italy). In these sections, as observed in the composite section of the Ghalilah Fm. (United Arab Emirates: Al-Suwaidi et al., 2016; Hönig et al., 2017; Ge et al., 2018), the extinction of Rhaetian assemblages is consistently documented within the upper part of a positive δ^{13}Ccarb excursion and appears to be diachronous compared to the classical sections of the NCA, Transdanubian Range and Lombardy Basin, where extinctions are associated with a major short-lived negative shift in the organic carbon (δ^{13}Corg) record known as Initial Carbon Isotope Excursion (Initial CIE) and traditionally regarded as the onset of the end-Triassic biotic crisis.

To reconstruct the timing of the ETE in resilient Southern Tethyan carbonate platforms, we combined the δ^{13}Corg and the δ^{13}Ccarb records of biostratigraphically well-constrained sections of the NCA and Transdanubian Range, we identified four stratigraphic intervals characterized by a different (decreasing/increasing) δ^{13}Ccarb trend and we anchored each interval to ammonite stratigraphy. The obtained bio- and chemostratigraphic framework is reproducible throughout

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the Tethyan domain and proto-North Atlantic and appears very promising for global correlations. In addition, our study suggests that, in the absence of the primary marker (i.e., the lowest occurrence of the ammonite *Psiloceras spelae tirolicum*), the position of the Triassic/Jurassic boundary can be reliably approximated using the δ^{13}Ccarb profile also in carbonate platform sections.

The resulting stratigraphic correlation between Southern Tethyan carbonate platforms and the reference sections of the NCA, Transdanubian Range and Lombardy Basin suggests that Rhaetian assemblages survived the Initial CIE in Southern Tethys, an observation that excludes the regressive phase at the top of the ammonite *Choristoceras marshi* Zone and the perturbation of the carbon cycle recorded by the Initial CIE as possible killing mechanisms at a global scale. In addition, this study suggests that the Rhaetian carbonate platform assemblages became extinct about 200 kys later in Southern Tethys, very close to the Triassic/Jurassic boundary, an interval characterized by global warming, ocean acidification and eutrophication triggered by increased continental runoff.

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Keywords: end Triassic extinction, Tethyan carbonate platforms, benthic foraminifers, global warming, ocean acidification, integrated bio and carbon isotope stratigraphy

Late Triassic conodonts from New York Canyon, Nevada, and their relevance to the position of the Norian-Rhaetian Boundary

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Sections of the Gabbs Formation exposed in the vicinity of New York Canyon, Nevada, have long been recognized as important sites for Late Triassic and Early Jurassic stratigraphy, with the section at Muller Canyon previously being proposed as the stratotype section for the base of the Hettangian. The Norian-Rhaetian parts of these sections continue to be important for the ongoing work of defining this boundary. The two candidate sections for the base of the Rhaetian are at Pignola Abriola in Italy and Steinbergkogel in Austria; both sections utilize the first occurrence of the conodont species *Misikella posthernsteini* as a proxy for the boundary, although there is disagreement between the sections as to when this species first appears. Although not a candidate section, data from New York Canyon will help to determine the most suitable position for the Norian-Rhaetian Boundary (NRB), especially in Panthalassa.

Previous reports of conodonts from a composite New York Canyon section recognized a relatively depauperate fauna consisting primarily of *Mockina englandi, Mo. bidentata* and morphotypes of *Mo. mosheri* in the Nun Mine Member, succeeded by isolated occurrences of *Zieglericonus rhaeticum* and *Mi. posthernsteini* in the Mount Hyatt and Muller Canyon members. On the basis of the conodont biostratigraphy developed in the Tethys region, the NRB in New York Canyon would be placed at the first occurrence of *Mi. posthernsteini.* However, this species was recovered well above the first occurrences of Rhaetian ammonoids (*Paracochloceras amoenum*, near the base of the Nun Mine Member) and together with radiolarians of the tozeri zone, commonly thought to be high within the Rhaetian of North America. Its occurrence is also above excursions in Sr- and C-isotopes recorded in the section, both of which may indicate correlation with co-eval excursions in Tethys at the NRB. Therefore, some authors place the NRB much lower in North America, coinciding with the first occurrence of the radiolarian *P. moniliformis* and the conodont *Mo. mosheri* morphotype C.

To help reconcile the biochronological and geochemical data from the New York Canyon area, new conodont samples have been collected from throughout the Nun Mine and Mt Hyatt members at the New York Canyon Road and Luning Draw sections. These collections include examples of *Mo. englandi, Mo. bidentata,* and *Mo. mosheri* morphotypes B and C, all previously reported from New York Canyon, although this is the first record of *Mo. mosheri* morphotype C from the Nun Mine Member. There are also examples of *Parvigondolella* spp. B and C from

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much lower in the Nun Mine Member than previously reported. Finally, there are examples of *Pa. andrusovi*, which has not previously been recorded from North America, and specimens of *Mo. bidentata* with only one denticle, perhaps transitional to *Parvigondolella*. Overall, this fauna records a progression from the *Mo. bidentata* Zone to the *Mo. mosheri* Zone of North America, equivalent to the *Mo. bidentata* and *Pa. andrusovi* zones of Tethys and indicative of a Sevatian fauna. This would be consistent with a higher placement of the NRB at New York Canyon; however, if the NRB is to be recognized at the first occurrence of *Mo. mosheri* morphotype C, then the boundary must be lower than previously thought, within the Nun Mine Member.

Keywords: Conodont, Norian, Rhaetian, New York Canyon, Panthalassa

New conodont data from the Olenekian-Anisian Boundary interval at the GSSP Candidate Section at Deşli Caira, Romania

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The Olenekian-Anisian Boundary (OAB) interval is an important time in Earth history, reflecting the last phase of marine ecosystem recovery in the aftermath of the end-Permian mass extinction. Despite this, the Global Stratotype Section and Point (GSSP) for the base of the Anisian remains undefined. The first appearance of the conodont *Chiosella timorensis* has been proposed as a potential index for the boundary; however, the discovery of this conodont with ammonoids traditionally considered to be Spathian has generated doubts about its suitability as a proxy. At the GSSP candidate section at Deşli Caira, Romania, the OAB has previously been drawn at the base of bed GR7, which contained the first occurrence of *Ch. timorensis*; however, additional collecting has shown that Spathian ammonoids persist higher in the section, and recent studies have instead placed the OAB at the base of bed 822A, approximately 3 m above the previous placement. The conodont faunas from this higher interval are less well studied than those from the lower level, and furthermore the beds in this part of the section have now been subdivided in more detail than they were previously, with bed 822 alone now being split into 5 sub-beds. Existing conodont faunas are only recorded as coming from bed 822, and so their position relative to the new subdivision is not certain. In order to improve the precision of conodont correlation around the higher position for the OAB, ten new samples were collected from bed 821 to bed 824. In addition to characterizing the fauna throughout the OAB interval, these new collections also enable the evolution of late Spathian and early Anisian conodont species to be understood in more detail, including temporal variations in the relative proportion of *Ch. timorensis* s.l. vs. s.s., and morphological variations in *Gladigondolella tethydis.*

Keywords: Conodont, Olenekian, Anisian, Romania, GSSP

*Speaker

The multielement apparatus of the conodont genus Gladigondolella in the Anisian

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The conodont genus *Gladigondolella* (Spathian to Carnian) is an important component of the Middle Triassic conodont fauna, and the species *Gladigondolella tethydis* has previously been suggested as an auxiliary proxy for recognising the Olenekian-Anisian Boundary. However, the composition of the multielement apparatus of this genus remains uncertain, and it has been variously reconstructed by different researchers. In an effort to ascertain which elements belong to the *Gladigondolella* apparatus, multivariate statistical analysis of elements previously ascribed to the apparatus by other authors has been undertaken. Utilizing new material from the Anisian of Romania, China, Oman, and Turkey, together with published occurrences from more than a dozen other locations, Bray-Curtis and Jaccard indices both demonstrate that *Cratognathodus* elements occur as frequently with other elements belonging to the *Gladigondolella* apparatus as those elements do with each other. This lends support to the hypothesis previously advanced by some authors that *Cratognathodus* elements also belong to the *Gladigondolella* apparatus and the genus name *Cratognathodus* should be restricted to the form species only. In the present reconstruction, the multielement apparatus in the Anisian has 8 different element types, including multiple P2 elements: *Cratognathodus* sp. (P2a) and *Ozarkodina saginata* (P2b); this likely represents dimorphism, such as that observed in some Paleozoic conodont genera. The recognition that *Cratognathodus* belongs to the same genus as *Gladigondolella* has significance for conodont biostratigraphy in the Anisian, and implications for the recognition of the Olenekian-Anisian Boundary.

Keywords: Gladigondolella, Cratognathodus, multielement, Anisian, Bray, Curtis index, Jaccard index

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The stability and collapse of marine ecosystems during the Permian-Triassic mass extinction

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The history of Earth's biodiversity is punctuated episodically by mass extinctions. These are characterized by major declines of taxon richness, but the accompanying ecological collapse has rarely been evaluated quantitatively. The Permian–Triassic mass extinction (PTME; ˜252 million years ago), as the greatest known extinction, permanently altered marine ecosystems and paved the way for the transition from Paleozoic to Mesozoic evolutionary faunas. Thus the PTME offers a window into the relationship between taxon richness and ecological dynamics of ecosystems during a severe extinction. However, the accompanying ecological collapse throuogh the PTME has not been evaluated in detail. Here, using food-web models and a marine paleocommunities dataset spanning the PTME, we show that after the first extinction phase, community stability decreased only slightly despite the loss of more than half of taxonomic diversity, while community stability significantly decreased in the second phase. Thus, taxonomic and ecological changes were unequivocally decoupled, with species richness declining severely ˜61 kyr earlier than the collapse of marine ecosystem stability, implying that in major catastrophes a biodiversity crash may be the harbinger of a more devastating ecosystem collapse.

Keywords: Resilience, food web, guild structure, cascading extinction on graphs, modelling, biodiversity, tipping point, environmental perturbation, end, Permian, South China

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Embracing Uncertainty: Integrating Geochronologic Data to Model Accurate Age Constraints for Triassic Earth-Life Events

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Many subdivisions of the Triassic timescale and constituent key global events (e.g., extinctions, sudden climate change, perturbations in global biogeochemical cycles) remain poorly constrained by precise and accurate geochronologic dates. This has made it difficult to correlate key stratigraphic archives from different regions, and limited the ability to pinpoint the temporal relations of these global events to their hypothesized causes. During the past 20 years, an increasing volume of radioisotopic, magnetostratigraphic, and cyclostratigraphic data from Triassic sedimentary sequences have been made available, but it is not always clear how they should be best compared and integrated, given that they are based on different isotopic systems, analytical approaches, and standard materials, even though considerable progress has been made regarding their intercalibration. Using recent geochronologic data from Triassic non-marine sediments in North and South America, we present an ad hoc method to extract intercomparable and accurate radioisotopic ages from different geochronometers and techniques (i.e., 40Ar/39Ar, ID-TIMS U-Pb, and micro-beam U-Pb). We then integrate these and other data (e.g., magnetostratigraphic constraints) in Bayesian age-stratigraphic models that calibrate key Triassic paleoenvironmental and paleontologic records. Finally, we show how the inferred ages and uncertainties from these models can be used to identify discrepancies in stratigraphic correlation, and test hypotheses regarding biotic change (putative effects of hypervelocity impact), macroevolutionary patterns (e.g., origin of dinosaurs), and sudden climate change (e.g., Carnian Pluvial Episode). These approaches allow for more accurate age estimates, albeit with lower precision, by acknowledging realistic geologic and analytical uncertainty, ultimately leading to more robust hypothesis testing in deep time.

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Keywords: Geochronology, Zircon, SIMS, LA, ICPMS, CA, TIMS

New conodont faunas and two proposed conodont evolutionary lineages improve the accuracy of global correlation to Induan-Olenekian Boundary (Lower Triassic)

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A precise global timescale for the Lower Triassic series is essential to understand the sequence of events following the end-Permian mass extinction crisis. A crucial step toward providing the necessary high-resolution chronostratigraphic framework for this interval will be the final resolution of a long-disputed Global Stratotype Section and Point (GSSP) for the base-Olenekian. Lower Triassic conodont biostratigraphy has been studied around the world in the past decades and significant recent progress on the recognition of evolutionary lineages is leading to a refined definition. The worldwide distribution of *Novispathodus waageni* sensu lato has been proposed as the marker for the IOB, and another species *Eurygnathodus costatus* represents a significant auxiliary marker. In this study, we report two conodont lineages based on new collections from South China with comparisons to other regions where only one or the other lineage is present. The south China sections yield abundant conodonts throughout the Lower Triassic and the Chaohu section is a well-studied GSSP candidate section for the Induan-Olenekian boundary; it exhibits continuous sedimentation in which transitional morphotypes are recognized. One evolutionary lineage starts with a segminate ancestor and ends with an unornamented platform, and includes *Sweetospathodus kummeli* → *Eurygnathodus costatus* → *Eurygnathodus* sp. D → *Eurygnathodus hamadai.* The second lineage is *Neospathodus dieneri* Morphotype 3→*Nv. waageni eowaageni* Morphotype A→*Nv. waageni waageni.* The integration of both lineages provides the basis for global correlation and eliminates the possibility that the first occurrence of species in one lineage or the other is simply a migration event. In addition, two new conodont species *Neospathodus yangtzeensis* and *Novispathodus shani* were recognized from South China (Jianshi; Chaohu, and Zuodeng) and Oman. We propose to establish the *Ns. yangtzeensis* Zone and/or *Nv. shani* Zone (or a corresponding *Ns. yangtzeensis*-*Nv. shani* Assemble Zone) in those regions since their wide paleogeographic distribution in Paleotethys and Panthalassic

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oceans. Which can significantly improve the accuracy of stratigraphic division and correlation of the Smithian and also play a role in restricting the IOB interval by their approximate early-middle Smithian interval age diagnostic occurrences.

Keywords: Early Triassic, conodont evolutionary lineage, GSSP, Induan, Olenekian Boundary, South China

Multiple organic carbon isotope reversals across the Middle Permian and Upper Triassic of eastern Tasmania: clues to Carbon Cycle Perturbations and Paleoclimate Reconstruction Near the South Pole

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During the mid-Permian de-glaciation phase, Tasmania was located in a high-latitude Southern Hemisphere setting, wedged between Antarctica and Australia. Significant global carbon cycle disturbances associated with major environmental changes resulting in extinctions occurred globally. Here we present new high-resolution pXRF, organic carbon isotopes, and sedimentological data from Bicheno 5 core, located in Eastern Tasmania. The record here represents ~300 meters of Middle Permian and early Upper Triassic sediments, with a significant unconformity in the Upper Permian associated with eustatic sea-level fall as an effect of regional uplift in eastern Australia. Three major carbon isotope excursion (CIE) intervals characterized by negative shifts of up to 6‰ were recognized; the Middle Permian, Upper Triassic Carnian, and Norian. The low-resolution palynological analysis shows well-preserved pollen and spore assemblages in the younger part of the core dominated by *Alisporites* spp. and *Aratrisporites* spp. We combine the new carbon isotope and palynological data with the eastern Australian Late Triassic spore-pollen biozones (*A.parvispinosus*, *C.rotundus, and P.crenulatus* Zone) and precise U-Pb dating. These CIEs can further be correlated with global δ13CTOC records from the paleo-Pacific Ocean (Panthalassa), Southwest England, and South China. Sedimentological data coupled with the pXRF data shows the relationship between the major carbon cycle perturbation and the environmental response to these events in the Antarctic region.

Keywords: C cycle pertubration, paleoclimate reconstruction, tasmania, middle permian, carnian pluvial event, middle norian event

*Speaker

Age determination of the "Black Zhifang Formation" (Triassic) in sourthern Ordos, North China through palynological biostratigraphy

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The terrestrial Triassic strata, extremely developed in the Ordos Basin of North China, are important in oil and gas exploration. The Lower Triassic, divided into the Liujiagou Formation and Heshanggou Formation, is dominated by red sandstones and mudstones, which were formed in arid climates, the upper Middle Triassic to the Upper Triassic Yanchang Group chiefly comprise of gray-black shales interbedded with sandstones and mudstones formed under warm and humid conditions, are the major hydrocarbon source rocks of the Triassic system of the Ordos Basin. While, the Zhifang Formation, between the red beds and the black shales, is mainly composed of purplish red and grayish green sandstones and shales. Recently, a set of thousand meters thick gray sandstones interbedded with dark mudstones occurred at the Jinghe River Section in Chunhua county, southern Ordos Basin, have been assigned to the Zhifang Formation. It is called as the "Black Zhifang Formation" due to lack of purplish red beds and different from the normal Zhifang Formation. And accordingly, this "Black Zhifang Formation" is considered as a newly found hydrocarbon source rock bed underlain the major source rock bed of the Yanchang Group in the Ordos Basin.
Sporopollen analysis of the " Black Zhifang Formation" along the Jinghe River section, shows that the contents of spores in this formation are lower than that of pollen grains, and the occurrence frequency of the *Punctatisporites*, which is an important element in the Middle Triassic palynological assemblage (Zhifang Formation) is rather low, accounting for only 1% - 2%; while the late Triassic genera and species are common , such as *Limaturasporites*, *Asseretospora*, *Osmundacites*, *Aratrisporites*, *Chordasporites*, etc., *Leiotrilletes* and *Calamospora*. So, the palynological assemblage from the "Black Zhifang Formation" is not consistent with that of the normal Zhifang Formation in other sections of the Ordos Basin, but, it is closer to the palynological assemblage of the Yanchang Group. In addition, *Danaeopsis fecunda*, a species usually occurred in the Late Triassic Yanchang Flora, is also found in these beds. Therefore, the so called "Black Zhifang Formation" at the Jinghe River section is likely to belong to the Yanchang Group, and should be the Late Triassic in age .

Consquently, this "Black Zhifang Formation" should actually belong to the Yanchang Group, and therefore, there would be no more hydrocarbon source rock than that in the Yanchang Group. So, correct stratigraphic division, dating and correlation have important impacts on the

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oil and gas exploration.
The important oil shale bed of member 7 of theYanchang Formation=Chang 7was formed during the Ladinian of Middle Triassic, indicating a big environmental-climate change event, in the Ordos Basin of North China. This event is coeval with the main tectonic activity of the Qinling Orogenic and the large unconformity between the Middle Triassic and Upper Triassic in the Sichuan Basin of South China. It implys a major geological event in the Ladinian age of East Tethys, which caused the above tectonic orogenic movement and major changes in the environment.

Keywords: Palynological BiostratigraphyYanchang GroupLadinianthe Ordos Basin

Linkage between Carnian Pluvial Episode and Wrangellia-Sambosan LIP

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The Carnian Pluvial Episode (CPE) was a global environmental change and biotic crisis that occurred during the Carnian in the Late Triassic. The climate during the CPE was characterized by a short-lived period of extreme precipitation, and major extinctions of marine taxa occurred in the Carnian. The CPE is thought to have been caused by a large igneous province (LIP) magmatism, which resulted in the eruption of the Wrangellia flood basalts (FB) in northwestern Canada. In addition to the Wrangellia FB, Carnian oceanic basalts of an intraplate origin, including oceanic seamounts and plateaus, have been recognized in the Jurassic accretionary complex of the Sambosan Belt, Japan. These Carnian basalts originated in an open-ocean realm of the Panthalassa Ocean on the Izanagi Plate and were accreted along the East Asian subduction zone during the Late Jurassic. The contemporaneous emplacement of oceanic and flood basalts in the Sambosan and Wrangellia may suggest a single LIP origin for these basalts. Here, we present new geochemical (major and trace elements) and Sr isotopic data to constrain the origin of the basaltic rocks of the Sambosan Belt.
Whole-rock geochemical analyses of the Sambosan basalts indicate that these basalts are classified as alkaline basalts with high Na2O concentrations. Discrimination diagrams based on least mobile elements suggest that the Sambosan basalts are analogues of the with-in plate basalts (WPB). In the Nb/Yb-TiO2/Yb diagram, these basalts are mainly lie within an OPB array with high TiO2/Yb and Nb/Yb ratios, which may indicate that these basalts are derived from a LIP magmatism. Based on the REE composition, the Sambosan basalts are classified into a light rare earth element (LREE)-enriched group (Type1; (La/Sm)n=2.1-3.3) and a relatively LREE-depleted group (Type2; (La/Sm)n=0.7-1.3). The (La/Sm)n–(Gd/Yb)n data of the Type2 basalts were formed by up to 5 % melting of garnet lherzolite with a primitive mantle composition, whereas the data for the Type1 basalts are plotted along the melting curve of garnet and these degrees of partial melting were 1%-5%, similar to that of typical ocean island basalts.

The Sr and Nd isotopic compositions of the Sambosan basalts indicate that they were formed from a depleted mantle source with no contribution from delaminated lower continental crustal material or recycling of subducted continentally derived sediments. In the 206Pb/204Pb-207Pb/204Pb diagram, most of the Sambosan basalts and the Wrangellia FB lie above the NHRL (North Hemisphere Reference Line). In addition, portions of these basalts have Pb isotopic compositions plotting on or near the 4.43 Ga geochron (age-corrected to 230 Ma) with depleted Nd isotopes and TiO2 concentrations, which are consistent with the composition of an early depleted, non-chondritic reservoir. High 206Pb/204Pbt and 207Pb/204Pbt ratios with

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the occurrence of xenocrysts trapped by recycled mantle components of the Sambosan basalts could indicate the involvement of the recycled oceanic crust (like HIMU origin).
The similarity of the isotopic compositions of the Sambosan basalts and the Wrangellia FB suggests that these basalts were derived from a single LIP magmatism associated with a mantle plume source in a mid-oceanic setting of the Panthalassa Ocean in the Carnian. In addition to the Sambosan basalts, Carnian oceanic basalts of intraplate origin, including oceanic seamounts and plateaus, have been recognized in the Jurassic accretionary complexes of the Taukha Belt in Far East Russia. The lithologies, accretion ages, and faunal similarities between the Sambosan and Taukha belts clearly indicate the extent of the East Asian Jurassic subduction zone for ca. 3000 km. The geochemical characteristics of most of the Sambosan and Taukha basalts are consistent with emplacement from a plume-related mantle source in a mid-oceanic location, and the timing of basaltic volcanism in the Sambosan and Taukha belts is constrained to Ladinian? to upper Carnian. The contemporaneous emplacement of oceanic and flood basalts in the Sambosan Belt, the Taukha Belt, and Wrangellia suggests the existence of a Carnian Large Igneous Province (LIP) in the Panthalassa Ocean, which we tentatively term the Wrangellia-Sambosan LIP.

Keywords: Triassic, Carnian Pluvial Episode, Wrangellia, Sambosan, LIP, basalt, geochemistry

Middle and Upper Triassic radiolarian biostratigraphy in the Western Neotethys: problems and possibilities

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Middle and Upper Triassic radiolarian biochronologic scales in the Western Neotethys (Mediterranean) are based chiefly on Kozur and Moster (1994), Kozur et al. (1996), and Kozur (2003) however, these biozonations are of limited use for the newly discovered radiolaria localities. The first main reason for this issue may be that this zonation is based on radiolarian material from a total of 6 sections from Hungarian, Italian and Austrian localities, but only two of these sites (the Felsöörs section from Hungary and the San Ulderico section from Northern Italy) contain ammonites or conodonts remains that are suitable for biostratigraphic correlation. On the other hand, these rich radiolarian materials were extracted from isolated samples and although they are taxonomically one of the most unique radiolarian faunas from this period, due to the lack of independent fossil age data from the sampling sites, it is relatively difficult to integrate into comprehensive biostratigraphic studies. A particular interest in these zonations is that they offer a very precise correlation with the ammonite and conodont zonations (Kozur 2003), despite the fact that these localities do not contain these fossils or only in a very limited number of cases. The definition of this radiolarian biozonation (Kozur and Mostler, 1994 etc.) needs to be revised, although the classification is more or less valid, the definition of species used for biozones is rather outdated. We propose herein to set up a new zonation based on the Unitary Associaton zonation (UAz) of radiolarian communities. The Uaz was introduced by Guex (1977 1987, 1991) and Guex et al. (2016) and this method was applied to correlate Upper Jurassic and Lower Cretaceous sections of the western Neotethys for the first time, but today a detailed UA biozonation is available for Middle Jurassic to Lower Cretaceous for the Tethyan Realm (summarized in Baumgartner et al. 1995). The UA method is based on graph theory and is designed for the construction of concurrent–range zones (Guex 1977). The UA Method accommodates best the discontinuous stratigraphic record of radiolarians, i.e. the highly diachronous FADs and LADs of individual taxa in different sections, resulting from the discontinuous nature of facies favouring optimal radiolarian preservation (Goričan et al. 2018). The new UA zonation has been constructed consisting of approximately 450 species ("*Radiolaria*" sp. were generally excluded) from 492 horizons of 60 localities from the Western Neotethys. Radiolarian Zonation consisting of 17 Unitary Associations from the Late Illyrian (*Paraceratites trinodosus* Ammonite Zone – *Camunum* Ammonite Subzone) to Upper Sevatian (*Sagenites quinquepunctatus* Ammonite Zone).

*Speaker

Keywords: UA zonation, radiolaria, Triassic, biochronology, Neotethys

Characteristics of reproduction and newborns of Keichousaurus hui. (Reptilia Sauropterygia) from Xingyi Fauna(Ladinian,Middle Triassic),Guizhou Province

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The morphology and reproduction of Mesozoic Marine reptiles is still controversial and attract the attention all over the world. Because of its small size and special preserved method, Keichousaurus hui, which lived 230 million years ago, provides a large number of samples for our study. Keichousaurus hui is yielded from the Xingyi fauna in Zhuganpo member of the Falang Formation of the Latin Period of the Middle Triassic in South China, living near shore. The body length of the Keichousaurus hui is about 5_˜50 cm, the head is triangular, the snout is short pointed, and three groups of holes could be seen from the front, namely the nostril, the eye hole and the superior temporal hole. Keichousaurus hui owns typical ribs with a thick head and a pointed tail almost as long as the backbone, so it is classified as Pachycodonidae. The living environment of Keichousaurus hui belonged to the bay environment surrounded by islands on three sides. In this period, the bay had weak hydrodynamic force, shallow water, sufficient light, normal salinity and abundant organic matter, which was very suitable for the survival of marine reptiles. With the mid-to-late Latin transgression events, the original environment was destroyed, and the rising sea level flooded the basin environment and connected the vast ocean, and the original shallow sea biota went extinct. The Falang Formation is mainly composed of laminaceous limestone and dark medium and thin laminaceous argillaceous limestone, which indicates that the environment was of low energy anoxia in the period, and the anoxia in the platform basin caused the rapid death of Marine organisms living in the basin.
A large number of Keichousaurus hui fossils provide more information of the morphological characteristics and reproductive methods. The sex difference of Keichousaurus hui can refer to the sex difference of Pachypleurosaurus, mainly showing the difference in the humerus. The rationality of this method can be further confirmed by pregnant specimens of Keichousaurus hui. The researchers found dozens of female Keichousaurus hui during pregnancy and childrearing period, described and measured the morphology of embryos and newborn individuals of Keichousaurus hui. It was found that the fetus of Keichousaurus hui appeared from the maternal birth canal with the head first, and had the characteristics of multiple viviparous birth. The female Keichousaurus hui that produced the most fetuses could conceive up to 11 each time.Two different forms of birth of female Keichousaurus hui have been found, which are presumed to be

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related to the environment. This study provides more information for the reproductive mode and delivery state of Marine reptiles and reconstructing the growth of ancient reptiles.

Keywords: Keichousaurus hui, newborns, Middle Triassic, reproductive mode, Xingyi Fauna

Drastic changes in weathering processes around the Norian-Rhaetian Boundary

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The Late Triassic time interval witnessed several important biological turnovers, extinctions and onset of new life forms. Among these events, the extinction around the Norian-Rhaetian Boundary (NRB) was of major importance and has been largely overlooked until now. The nektonic marine fauna has been the most affected, but in the same time some sensitive organisms such as scleractinian corals or the newly appeared coccolithophorids were preserved. To better constrain the tectonic, climatic and oceanographic framework during this time of changes, we collected new δ13Ccarb, 87Sr/86Sr and δ44/40Ca dataset across the late Norian - Hettangian interval, established from carbonate successions in Austria, Turkey and United Arab Emirates. A characteristic change in the 87Sr/86Sr record is a sharp trend towards unradiogenic values, which started in the latest Norian (middle-upper *M. hernsteini* - *E. bidentata* Zone) and continued across the lower Rhaetian (*E. bidentata* - *M. posthernsteini* Zone). This strong decline in 87Sr/86Sr ratios associated with the first appearance of *Misikella posthernsteini* could be used as a proxy for the definition of the NRB. The δ44/40Ca shows as well a marked decrease at this level. The strong correlation between the strontium and calcium isotopic systems indicates that they are coupled through the same driving process. The δ13Ccarb is in contrary quite stable around this interval, at odd with several negative peaks in δ13Corg reported in the literature. The δ44/40Ca measurements helped to exclude the hypothesis that the early Rhaetian decrease in 87Sr/86Sr would have been driven by volcanism, elevated hydrothermal circulation or enhanced silicate weathering. Indeed, the two first of these processes seems to have a negligible effect on Ca-isotopes, while the third one would result in a radiogenic 87Sr/86Sr trend, the opposite of the observed pattern. Instead, a large increase in chemical weathering of carbonates and evaporites as consequences of a major sea-level fall at the NRB is proposed. This new hypothesis could as well explain the stability of the carbon cycle during this interval as recorded in the δ13Ccarb, and the variability of the δ13Corg more prone to terrestrial influences.

Keywords: Norian, Rhaetian, strontium, calcium, carbon isotope, weathering

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Middle Triassic radiolarian biostratigraphy and chemostratigraphy in the bedded chert sequence from the Jurassic accretionary complex of Japan.

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The Triassic climate is generally considered a period of arid or semi-arid conditions, and there are two humid climate events in the late Anisian (Pelsonian) and late Ladinian (Longobardian) of the Middle Triassic. Although the causes of these humid climate events are uncertain, these events are likely to have led to the diversification of major pelagic groups (e.g., radiolarians and conodonts) during the Middle Triassic. To investigate the response of radiolarians to the Middle Triassic humid climate events, we examined radiolarian biostratigraphy and obtained geochemical profiles from a Middle Triassic bedded chert sequence (Section O) in the Inuyama area, central Japan. Section O consists mainly of rhythmic brick-red bedded cherts with a thickness of 21 m that accumulated in a pelagic, open ocean setting within a low-latitude zone of the Panthalassa Ocean. A total of 65 chert samples were collected from Section O for biostratigraphic study. Our radiolarian biostratigraphy shows that the six Sugiyama's radiolarian subzones were recognized in the study section: the TR 2C (Triassocampe deweveri) to TR 5A (Capnuchosphaera) zones, which can be compared to the late Anisian to early Carnian. Based on our radiolarian biostratigraphic data, the radiolarian faunal change from Fassanian (early Ladinian) to Longobardian (late Ladinian) taxa occurred across the thick siliceous claystone bed (4 cm thick) in Section O at 10.5 m above the section base. A geochemical analysis indicates that no significant marine redox changes were observed in the study section. In contrast, changes in biogenic apatite productivity that originated from marine vertebrates (e.g., conodonts and fish) increased across the Fassanian/Longobardian boundary. Furthermore, the continental weathering proxies such as CIA (Chemical Index of Alteration) and the WIP (Weathering Index of Parker) suggest that chemical weathering of hinterland rocks intensified in the Longobardian. Our results suggest that the humid events in the Logobardian may have triggered an increase in pelagic vertebrate productivity and the radiolarian faunal turnover in the pelagic realm of the Panthalassa Ocean.

Keywords: Triassic, Radiolaria, Ladinian: Anisian, Biostratigraphy, Chemostratigraphy

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The first definitely record of Dicroidium Gothan (seed fern) in China

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Dicroidium is a widely distributed seed ferns in the Triassic floras of Gondwana, exhibiting considerable variation in leaf morphology with forked rachises being a key characteristic (Anderson and Anderson, 2003). *Dicroidium* was considered as a Gondwana plant distributed in the Triassic until Abu Hamad et al. (2008) found some specimens from the late Permian sediments of the Jordan, which is located in the northern edge of the Gondwana (Blomenkemper et al., 2022). However, this genus has never been unequivocal recorded in the Laurasia. Recently, a new species of this genus, *Dicroidium sinensis* Sun et Deng sp. nov., described from the Middle Triassic Tongchuan Formation in the Ordos Basin of Northwestern China based on macromorphology and cuticular structures. This is the first definite record of *Dicroidium* in China, indicating that this genus is not only unique to Gondwana.

Our specimens exhibit large fronds, a robust primary axis, and a dichotomously furcated rachis, as well as an amphistomatic cuticle, absent papilla, haplocheilic stomata, and polar subsidiary cells. We assigned these specimens to *Dicroidium* based on the simple dichotomous bifurcation of the rachis, a key diagnostic feature for the genus (Anderson et al., 2019), and micromorphological similarities to other *Dicroidium* species (Bomfleur and Kerp, 2010). Our specimens differ considerably from all the known Gondwana species in leaf morphology and microstructures of cuticles, and therefore, a new species, *Dicroidium sinensis* Sun et Deng sp. nov. is proposed.

Up to now, as the oldest unequivocal representatives of *Dicroidium* appeared in the Late Permian of Dead Sea region-Jordan, the genus seems to have originated in the palaeotropics and later migrated southward and northward. During the Olenekian age of Early Triassic, it was distributed in the Southern Hemisphere such as Australia, South Africa and Antarctica. During the Middle Triassic, the genus occurred in both the Gondwana and Laurasia. After then, during the Late Triassic, *Dicroidium* was suggested only in the Gondwana, and it was the dominant genus of the Gondwana floras. Recent reports of some *Dicroidium* from the Lower Jurassic of the Antarctica indicates that it survived the end-Triassic mass-extinction event (Rees and Cleal, 2004; Bomfleur et al. 2018). As no any fossil remains have been found from the Middle Jurassic and younger sediments so far, this genus might disappear in the Early Jurassic (Bomfleur et al. 2018). How did a genus flourishing in the Triassic Gondwana floras appear in the Laurasia? We suppose that Pangea was present from Permian to Triassic, making it possible for the South *Dicroidium* to migrate the Laurasia. The genus *Dicroidium* thrived in warm and humid

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environments, and the climate of the Ordos Basin in the Middle Triassic was warm and humid, providing suitable conditions for Dicroidium to grow. Some circular to slightly elliptical galls found in the leaf of *Dicroidium sinensis* proved the interaction between plants and insects.

Keywords: Middle, Late Triassi, Seed fern, Dicroidium, Cuticular analysis, Insect galls, North China

Biostratigraphic revision of extinction patterns of radiolarians and conodonts across the Triassic-Jurassic boundary in the pelagic Panthalassa

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The latest Triassic (_˜201 Mya) is characterized by the end-Triassic mass extinction (ETE), which is one of the big five extinction events of the Phanerozoic. The ETE was closely linked to major perturbations of the global carbon cycle and the emplacement of the Central Atlantic Magmatic Province (CAMP). The release of volcanic and contact metamorphic carbon and sulfur gases from the CAMP is commonly invoked as the trigger for the climatic changes during the latest Rhaetian leading to the ETE. Although significant extinction events of major marine groups (e.g. ammonoids and bivalves) during the ETE interval have been reported, only a limited number of studies have reported on integrated biostratigraphic research of radiolarians and conodonts in the Panthalassa Ocean. Here, we present a high-resolution radiolarian-conodont stratigraphic distribution of an upper Norian to lower Hettangian bedded chert succession, including the Triassic-Jurassic boundary (TJB) interval in the Katsuyama-B section, Inuyama area, Mino Belt, central Japan. The bedded chert of this section was accumulated in a pelagic deep-sea environment in a low to middle latitudinal zone of the Panthalassa Ocean.The Katsuyama-B section is approximately 12.6 m thick, and consists mainly of the red and purple bedded cherts. The purple bedded chert interval (ca. 1.8 m) is intercalated in the upper part of the studied section. The biostratigraphic analysis confirmed that the radiolarian species in this section range from the TR8B (*Praemesosaturnalis pseudokahleri*) zone to the JR0B (*Bipedis horiae*) zone established by Sugiyama (1997). We also recognized three conodont zones proposed by Rigo et al. (2018) in the studied section: the upper Norian *Misikella hernsteini* zone, the lower Rhaetian *Misikella posthernsteini* zone, and the upper Rhaetian *Misikella ultima* zone. Our biostratigraphic studies revealed that some Rhaetian radiolarian and conodont faunas co-occurred with the Hettangian radiolarian fauna in the earliest Jurassic. Furthermore, our biostratigraphic analysis documented an unusually abundant occurrence of a previously unidentified *Mesosaturnalis* species across the TJB in the studied section, in a ca. 0.6 m thick stratigraphic interval. This finding suggests that this *Mesosaturnalis* species, which is highly abundant in a short interval across the Triassic–Jurassic boundary, is likely to be an excellent indicator for the TJB. Since no study of this radiolarian species has been published from the former TJB interval (e.g. Katsuyama and Kurusu sections) in Japan, the stratigraphic interval across the TJB of these sections are probably lacking.

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Keywords: Triassic, Jurassic boundary, radiolarian, conodont, extinction, Panthalassa

SC10: Correlation of glacial events and extinctions: the Permian and beyond

Recognizing the termination of the Late Paleozoic Ice Age Early Permian phase

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The Permian Time Scale is nearly finished with only the base-Kungurian GSSP remaining to be decided. The base-Sakmarian and base-Artinskian GSSPs have been recently ratified at points that differ somewhat from previous traditional levels, making this a good time to review how these boundaries affect correlation of Late Paleozoic Ice Age (LPIA) phases. Interpolation of radio-isotopic ages place the base-Permian (base-Asselian Stage) at 298.9 Ma, the base-Sakmarian at 293.5 Ma, the base-Artinskian at 290.1 Ma (or 290.5 Ma by different interpolation) and base-Kungurian at ~283 Ma. These boundaries approximate maximum flooding intervals as is generally the case when boundaries are defined by conodonts. Many workers have correlated a Carboniferous-Permian interval of widespread ice-sheets as Kasimovian to mid-Sakmarian age. However, a mid-Sakmarian age for the termination of widespread ice-sheets would now correlate with the base of the Sakmarian in the newly ratified time scale. Published radio-isotopic ages from the Parana Basin of southern Brazil suggest a terminal late Carboniferous (300-299 Ma) deglaciation. In addition, a major transgression near the base of the Copacabana Formation at Cochabamba, Bolivia dates to about 299-298 Ma. Deposits and published ages from the Kalahari and Karoo basins of Namibia and South Africa also correlate with this event, but two younger deglaciation events at ~295 Ma (mid-late Asselian) and at 282 Ma (early Kungurian) also occur. All of these dates fit within a framework of transgressive-regressive sequences (T-R), transgressive systems tracts (TST), astronomically tuned cyclothems and conodont biostratigraphy established from the Robledo Mountains of southern New Mexico to the high Canadian Arctic on Ellesmere Island, where the Kasimovian to Asselian interval is characterized by numerous 405 Kyr cyclothems that provide a distinct banded pattern in outcrop within our study region. This pattern is interrupted by major flooding events of longer duration 3rd order T-R sequences. We have demonstrated that cyclothems from approximately Kasimovian to mid-Asselian exhibit facies relationships that point to sea-level fluctuations on the order of 100 metres, but late Asselian cyclothems are associated with sea-level fluctuations of only ~30-40 metres. The difference is interpreted to reflect the potential ice-volume. A 3rd order T-R sequence boundary that is astronomically tuned to 294.9 Ma separates these units at Carlin Canyon Nevada and the Canadian Arctic. The maximum flooding surface (MFS) of the overlying T-R sequence correlates with the base-Sakmarian stage at 293.5 Ma. This MFS is probably the most significant flooding event during the Early Permian and in many sections the overlying progradational platform is mid-Artinskian. In more proximal sections a significant MFS separates Sakmarian and Artinskian carbonate platformal successions. The late Asselian

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TST with smaller amplitude cyclothems and base-Sakmarian MFS represent the primary far-field signature to recognize the termination of widespread ice sheets and must be associated with major pCO2 rise and global warming. This interval can also be recognized by major changes in conodont faunas. Although the warm-water taxon *Sweetognathus* first evolved earlier in the Asselian, it underwent a major species diversification near the base-Sakmarian in association with the extinction of the genus *Streptognathodus.* Species of *Streptognathodus* distinguish many biozones from the Kasimovian to Asselian, but it is ecologically replaced by *Sweetognathus* in Sakmarian and younger Permian; this provides an additional key signature to correlate the termination timing of major cyclothems associated with the main phase of the LPIA. Until recently, cyclothems in Kansas USA were correlated to be as young as early Artinskian, but the co-occurrence of abundant *Streptognathodus* and an older *Sweetognathus* homeomorph species indicate a late Asselian age. Following this event, the ice-volume in the Karoo and in Australia must have been insufficient to affect far-field facies distribution to clearly allow recognition of high-frequency cyclothems. However, the base-Kungurian boundary may be associated with the last deglacial transgression at 282 Ma.

Keywords: Early Permian, LPIA timing, Streptognathodus extinction, Sweetognathus, cyclothems

Upper Paleozoic stratigraphic framework of the Baoshan-Shan Block straddling China and Myanmar and its structural indications

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The Baoshan block in western Yunnan, China is a continental block with rather well-developed Cambrian to Triassic sedimentary records. The block thins northwards, and extends southwestwards into the Shan State of Myanmar. It constitutes a portion of a greater block that Jin (1994) named the Baoshan-Shan block. The latter is separated from the Tengchong block and the Tenasserim unit to the west by the Nujiang and Shan Boundary faults, and from the Changning-Menglian Belt and the Inthanon zone to the east by the Lancangjiang, Kejie, Nandinghe and Mae Yuam faults. Its east boundary in eastern Myanmar is tentatively considered to be the line connecting the Nandinghe fault (China) and Mae Yuam fault (Thailand), due to deficiency of reliable data. ("Shan block" is used for convenience in the following to describe the Burmese portion of the Baoshan-Shan block).
Mid-Carboniferous (or Namurian) uplift widely occurred in east Gondwana, as well as its northern marginal region, where the Baoshan-Shan block was located. This event shaped the relief of the Baoshan-Shan block and interrupted the sedimentation on it. Late Carboniferous sediments are hardly seen on the block. Lower Permian siliciclastic rocks (120-150 m) with glacio-marine sediments were deposited on tilted Lower Carboniferous limestones in the northern Baoshan block and on Devonian siliciclastic rocks in the southern Baoshan block. The southwestern Baoshan block through to the Shan block stayed emerged. Deposition of limestones started around the Sakmarian/Artinskian boundary in the northern and southern Baoshan block. But it was soon disrupted by the eruption of the Woniusi Basalts, which filled up the basin on the Baoshan block, with a thickness of ca. 700 m in the northern part and about 500 m in the southern part. The southwestern part and Shan block stayed as highland and was not reached by the basalts. This eruption resulted in a rather flat surface on the Baoshan block.

Coastal clastic sediments of about Roadian age, mainly red beds, formed on a weathered surface of the Woniusi Basalts in the northern and southern Baoshan block, and on Middle Devonian limestones in the southwestern Baoshan block, but are barely reported in the Shan block. Carbonate deposition with a transgression in the early Wordian took place across the whole Baoshan-Shan block. Carbonate formations rest conformably on the Roadian clastic deposits on Baoshan block, but in the Shan block, they rest on (often Middle) Devonian limestones/clastics or older sediments. This episode of carbonate deposition prevailed through to at least the Middle Triassic in most parts of the Baoshan-Shan block, resulting in the formation of thick carbonate successions.

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In some areas close to the southwestern margin of the Shan Plateau, Lower Permian clastic sequences with glacio-marine deposits occur, which are overlain by limestones of the age of late Artinskian or Kungurian. Whether these successions belong to the Shan block or the Tennassery unit (also called the slate belt) remains a problem waiting for further examination. Nevertheless, the Shan block through to the southwestern Baoshan block apparently lacks Upper Devonian to Lower Permian deposits. On a whole, the hiatus closely related the mid-Carboniferous (Namurian) uplift in east Gondwana has an expanding extent from the northern Baoshan block southwards to the Shan block, namely, from Serpukhovian to early Asseilian in the northern Baoshan block, from Tournaisian to early Asseilian in the southern Baoshan block, from Frasnian to Kungurian in the southwestern Baoshan block, and from the Frasnian to Roadian in the Shan block.
Such an architecture of Upper Paleozoic stratigraphic records prompts in-depth investigations into its relations with the Late Paleozoic glaciation and the rifting process at the northern margin of Gondwana.

Keywords: Late Paleozoic, stratigraphy, Baoshan, Shan Block, Yunnan, Shan

Biostratigraphical data of continental basins of Southern Alps (North Italy) during the Kungurian (Cisuralian, Permian)

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The Permian of the Southern Alps is marked by two tectono-sedimentary cycles separated by a marked stratigraphic gap. The lower one is mainly characterised by pull-apart basins with a volcano-siliciclastic infill formed during the Cisuralian (Orobic Basin, Collio Basin and Athesian District). These basins yielded an abundant and diverse fossil content of possible biostratigraphic value from Kungurian nonmarine units, including: tetrapod footprints, fossil plants, fossil sporomorphs, freshwater bivalves and conchostracans. The availability of several radioisotopic dates on volcanic intervals at the base and/or top of the fossiliferous nonmarine units allows a nonpareil correlation to the Global Chronostratigraphic Chart. Tetrapod footprints are known from the Pizzo del Diavolo Formation (Orobic Basin), the Collio Formation and Dosso dei Galli Conglomerate (Collio Basin), the Monte Luco, Tregiovo and Guncina formations (Athesian District). The ichnoassociation is diverse and characterised by reptilian ichnogenera such as *Erpetopus*, *Hyloidichnus*, *Merifontichnus*, cf. *Pachypes* and *Varanopus*. Other ichnogenera are attributed either to reptiles or synapsids (*Dromopus* and *Tambachichnium*). Anamiote tracks include *Amphisauropus*, *Batrachichnus* and *Limnopus* and are generally rare. This ichnoassociation constitutes the local tetrapod footprint biozone called Collio Ichnofaunal Unit (IFU). More importantly, it is a reference for the definition of the *Erpetopus* footprint biochron.
Plant remains are known from the Pizzo del Diavolo Formation (Orobic Basin), the Collio Formation (Collio Basin), the Monte Luco, Tregiovo and Guncina formations (Athesian District). This palaeoflora, dominated by conifers and including also typical Lopingian taxa (*Dolomitia*, *Pseudovoltzia*, and *Ullmannia*), is in agreement with a semi-arid seasonal palaeoclimate and is similar to other upper Cisuralian euroamerican plant assemblages from Southern Europe, North Africa and Western USA.

Fossil sporomorphs are known from the Collio Formation (Collio Basin), the Tregiovo and Guncina formations (Athesian District). New specimens from the Guncina Formation have been

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processed, enlarging substantially the association. Microflora mainly consists of bisaccate taeniate pollen such as *Corisaccites alutas*, *Hamiapollenites tractiferinus*, *Protohaploxypinus* spp., *Striatopodocarpites* spp., *Taeniaesporites* sp. with non-taeniates such as *Alisporites* spp., *Gardenasporites heisseli*, *Pteruchipollenites indarraensis* and others. Monosaccate pollen grains were abundantly found as *Crustaesporites globosus*, *Florinites luberae*, *Plicatipollenites malabarensis,* as well as polyplicate pollen such as *Vittatina costabilis* and *V. vittifera.* This association shows close compositional similarities to upper Cisuralian palynofloras from Europe and Kungurian-lower Guadalupian associations from Northern Gondwana and Russia.

Bivalves are known from the Collio Formation (Collio Basin) and the Guncina Formation (Athesian District). The FAD of the genera *Palaeomutela* and *Redikorella* characterises these associations.

Conchostracans are known from the Collio Formation (Collio Basin) and the Tregiovo and Guncina formations (Athesian District) and include two new *Pseudoestheria* morphotypes of possible chronostratigraphic value.

Because of the abundance and diversity of the nonmarine fossil associations and the age constraints provided by radioisotopic dates, the Southern Alps nonmarine fossil association is more and more a reference for continental biostratigraphy and chronostratigraphy at a regional and global level in the Cisuralian. In particular, fossil footprints, plants, and sporomorph associations have the potential to constitute biozones and chronozones. Therefore further research on the biostratigraphy and chronostratigraphy of the Southern Alps is of the outmost importance in the frame of the global nonmarine-marine correlations.

Keywords: Biostratigraphy, Permian, nonmarine, fossil footprints, fossil plants, palynomorphs, invertebrates

Stratigraphic meaning of the tetrapod fauna and ichnofauna from the Lower Permian Bromacker locality (Germany)

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The Lower Permian Bromacker locality of central Germany (Tambach Formation) yielded one of the most abundant and diverse skeletal and footprint associations of this time interval. Tetrapod footprints, known since the 19th century, include long and exceptionally-preserved trackways as convex hyporelief on the bottom of sandstone beds. The ichnoassociation includes the anamniote ichnogenera *Ichniotherium* and *Amphisauropus*, the synapsid ichnogenus *Dimetropus*, the reptile ichnogenera *Notalacerta* and *Varanopus*, and the synapsid or reptile ichnogenus *Tambachichnium.* New research highlights the additional occurrences of the anamniote ichnogenera *Batrachichnus* and *Limnopus* and the synapsid or reptile ichnogenus *Dromopus.* This is an ichnoassociation typical of the Kasimovian-early Artinskian *Dromopus* footprint biochron. Tetrapod skeletons, known since the end of the 70, include a diverse association with several well-preserved, articulated and nearly complete skeletons. The anamniotes include the diadectids *Diadectes* and *Orobates*, the seymouriamorph *Seymouria*, the trematopids *Rotaryus* and *Tambachia* and the amphibamid *Georgenthalia.* The synapsids include the sphenacodont *Dimetrodon* and the caseid *Martensius.* The reptiles include the captorhinormorph *Thuringothyris* and the bolosaurid *Eudibamus.* The varanopids include *Tambacarnifex.* The nearby locality of Tambach-Dietharz, belonging to the same formation, yielded the ostodolepid recumbirostran *Tambaroter.* This is a typical association of the Seymouran Land Vertebrate Faunachron (LVF), based on the associations of the upper Archer City ('Nocona') and Petrolia formations of Texas. The lower part of the Petrolia Formation is laterally equivalent to the Elm Creek Limestone, dated with Wolfcampian conodonts as either middle Sakmarian or early Artinskian. Therefore, the combined tetrapod associations and ichnoassociations from the Tambach Formation suggest a Sakmarian to early Artinskian age for this unit.
This is also consistent with the insect association of the Tambach Formation, which includes the *Moravamylacris kukalovae* Assemblage Zone (late Sakmarian-Artinskian). The conchostracan association is generally assigned to the Wilhelmsthal Assemblage Zone, but some forms are similar to the underlying Oberhof Assemblage Zone. Waiting for a revision, a general Early Permian age can be hypothesised from conchostracan data. Radiometric dating on the Rotterode Formation, directly underlying the Tambach Formation, indicate a late Asselian age (295.8±0.4 Ma). So, the Sakmarian-early Artinskian age inferred from tetrapod faunas and ichnofaunas is consistent with invertebrate biostratigraphy and radioisotopic ages. The age of the Tambach Formation is thus relatively well constrained, and this is of the outmost importance for a correct

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evaluation of some key events in the tetrapod evolution registered in this unit.

Keywords: Permian, nonmarine, tetrapods, footprints, Tambach Formation

Time indications in the Permian Rotliegend of Central Europe and the ‘Pangaea Gap’

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Dates for the correlation and calibration of the Rotliegend Group of Germany are integrated and presented in a new way (Menning et al. 2022). The Rotliegend of Central Europe begins in the Late Carboniferous Gzhelian Stage and ends in the Late Permian Wuchiapingian Stage. In Germany it is classified lithostratigraphically as a Group. The overlaying Zechstein Group starts with the Kupferschiefer (Copper Shale) and its equivalents which can be correlated from Ireland to Belarus and from the North Sea to the Upper Rhine Valley. Its Re-Os age is 257.3 $\pm$ 1.1 Ma.
The youngest marine horizon below the Rotliegend is the Aegir Horizon (Westphalian C, Bolsovian). According to Ar-Ar data (Lippolt et al. 1984, Fortschr. Geol. Rheinl. Westf.) its age is $\approx$ 311 Ma. Between the Aegir Horizon and the Kupferschiefer ($\approx$ 311 Ma to $\approx$ 257.3 Ma = $\approx$ 54 Ma) there are only a few, thin and local marine layers in the latest Rotliegend of the Central European Basin (Southern Permian Basin). During the Phanerozoic in Central Europe there is no other time span as long as $\approx$ 50 Ma almost with no marine layer (Stratigraphic Table of Germany 2016).

The best time indications for the Rotliegend are found in the well-known areas of the Saar-Nahe Basin (SNB), Thüringer Wald Basin (TWB) and Central European Basin (CEB): Most dates fall in a short time interval within the earliest Rotliegend. Biostratigraphic indications are often documented only in a single area, either in the SNB or in the TWB. Central European key fossils were not found in the Carboniferous-Permian boundary key succession of the Southern Ural area except for the plant *Autunia conferta*, which appears to be isochronous in the SNB, the TWB and the Southern Ural area as indicated by radio-isotopic ages (U-Pb CA-ID-TIMS RIA, Lützner et al. 2021, Schriftenr. Dt. Ges. Geowiss., Voigt et al. 2022, Int. J. Earth Sci.).

The age of the global Carboniferous-Permian boundary has long been a matter of debate. The currently accepted age is 299 Ma, based on U-Pb CA-ID-TIMS RIA from the Southern Ural area (Ramezani et al. 2007, Earth Planet. Sci. Lett.). For Central Europe, the recently revised Rb-Sr age for the Donnersberg Formation of the SNB utilizing the revised 87Rb decay constant (Villa et al. 2016, Geochim. Cosmochim. Acta) corresponds well to the U-Pb age of 299 Ma (Menning et al. 2022). Our calculated mean age for the SHRIMP data of Breitkreuz & Kennedy (1999, Tectonophysics) is 298.6 $\pm$ 1.9 Ma which reduces the time span for the volcanic succession of the Altmark Subgroup from 302–290 Ma to $\approx$ 300.5–296.5 Ma.

In general, the Regional Stratigraphic Scale of Germany is calibrated using RIA and, in ad-

*Speaker

dition, in the earliest and latest Rotliegend using orbital-climatically controlled eccentricity cycles (≈ 100 ka, ≈ 400 ka). Another fundamental time marker for correlation and calibration is the Illawarra Reversal at ≈ 265 Ma.

For the first time, the Rotliegend of Germany is geochronologically subdivided into Early (≈ 300.5–295/293.5 Ma), Middle (≈ 295/293.5–266 Ma) and Late Rotliegend (≈ 266–257.5 Ma). The very long duration of the Middle Rotliegend includes numerous and also extremely long stratigraphic gaps, as caused by the amalgamation and the associated immense uplift of Pangaea in Central and Western Europe. A very large stratigraphic gap in the CEB of ≈ 15 Ma (≈ 281–266 Ma, here called the Pangaea Gap) is constrained by conchostracans, the Illawarra Reversal and highly different palaeomagnetic properties of the sediments below and above the gap.

In the SNB, the youngest RIA is 294.5 ± 2.2 Ma (Donnersberg Formation). From here on until ≈ 265 Ma (Illawarra Reversal), the numerical ages of all Rotliegend units and their connection with the Global Stratigraphic Scale are uncertain and therefore correlations between Central Europe and the global key section in the Southern Ural area, partly biostratigraphically via North America, vary greatly.

Menning, M., Glodny, J., Boy, J., Gast, R., Kowalczyk, G., Martens, T., Rößler, R., Schindler, T., Seckendorff, V. von & Voigt, S. (2022): The Rotliegend in the Stratigraphic Table of Germany 2016 (STG 2016). – Journal of Applied and Regional Geology, 173, 1: 3–139; Stuttgart.

Keywords: Geological time scale, Rotliegend, time indications, radio, isotopic data, Milankovitch cycles, palaeomagnetism, Pangaea Gap

Lopingian (Upper Permian) palynomorphs from the Cadeby Formation, Cadeby Quarry, Yorkshire, UK

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Seventeen samples from the Cadeby Formation (Lopingian, Permian, EZ1) of Cadeby Quarry near Doncaster, South Yorkshire, UK, yielded organic residues including phytoclasts, cuticle, unstructured tissue and generally well-preserved palynomorphs. The palynomorph assemblages are dominated by taeniate and non-taeniate bisaccate pollen including *Klausipollenites schaubergeri, Limitisporites rectus*, *Lueckisporites virkkiae* and *Taeniaesporites noviaulensis*. The assemblages are generally similar to those from the English Midlands described from Kimberley Railway Cutting and the Haughton Hall Borehole, Nottinghamshire and those from the Marl Slate Formation (lower EZ1) of the Durham Sub-basin at Claxheugh Rock and Crime Rigg Quarry and to the mid EZ1 of the Salterford Farm Borehole and Woolsthorpe Bridge Borehole. The excellent preservation of the assemblages allows the recognition that *Dicappipollenites* Tiwari & Vijaya 1995 is a junior synonym of *Lueckisporites* Potonié & Klaus emend. Clarke 1965. The presence of rare microphytoplankton and microforaminiferal test linings indicate a neashore marine environment. The clastic (and organic) content of the Cadeby Formation, part of a dominantly carbonate succession, may represent erosion and transport of material from the hinterland reflecting a wetter climatic period, though the alternation of clastic and carbonate sedimentation in the section at Cadeby suggests some wet/dry palaeoclimatic cyclicity.

Keywords: palynology Permian Zechstein Dicappipollenites Lueckisporites palaeoclimatic cyclicity

*Speaker

Testing the seasonal geochemical record of brachiopod shells: a case study from the Wuchiapingian of Iran

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The Lopingian is represented by several sedimentary successions across Iran, most of them bearing rich fossil faunas, particularly brachiopods. As the tectonic setting of the region is very complex, consisting of an amalgamation of microplates sandwitched between the Arabian and Eurasian plates, correlation between these sedimentary successions may be difficult. Brachiopods, however, have been proven useful for correlations at a regional scale (Viaretti et al., 2021), who, based on the Unitary Association method, correlated the Hambast Formation at the Abadeh section in Central Iran with the Julfa Formation at the Ali Bashi Mountains Main Valley section in Julfa, Transcaucasia (Ghaderi et al., 2014).
As brachiopods are considered one of the best tools to investigate past conditions (e.g. Garbelli et al., 2022), a geochemical analysis has been performed on the brachiopod shells from the Abadeh section, with the aim of selecting the best brachiopod bioarchive. Specimens belonging to taxa with a laminar secondary layer (such as species of *Spinomarginifera, Araxilevis, Leptodus*) and taxa with a fibrous secondary layer (such as species of *Araxathyris, Transcaucasathyris, Rectambitus*) were analysed by SEM and cathodoluminescence (CL) and their oxygen and carbon isotope composition was measured. After diagenetic screening, *Araxilevis intermedius* (Abich, 1878) was shown to be the most suitable for geochemical analyses, since all the specimens belonging to other taxa were altered and/or too small to sample the shell avoiding contamination. The δ18O measured on all the brachiopod specimens also confirmed *A. intermedius* as the most reliable bioarchive. Considering these results, *A. intermedius* specimens from corresponding stratigraphic layers at Julfa were then selected and analysed by SEM and CL. The specimens from Julfa showed a better preservation of the shell microstructure compared to those from Abadeh. Most of the selected specimens possess a tertiary layer, and, except for one slightly luminescent specimen, the shells are non-luminescent.

The occurrence of large, thick and well-preserved shells in the two sections, confirmed by screening tests and published data as reliable bioarchives, offers the possibility to investigate in detail the palaeoclimate and palaeoenvironments of these Neotethys settings at low latitudes. The selected shells were then sampled with a sclerochronological approach, similar to that described by Garbelli et al. (2022), in order to investigate the occurrence of a seasonal pattern of δ18O and δ13C in the Wuchiapingian, a time interval which seems to record some important changes

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and possibly a cooling before the end-Permian hothouse (e.g. Wang et al., 2020).

Garbelli C., Angiolini L., Posenato R., Harper E.M., Lamare M.D., Shi G.R. & Shen S.Z. (2022). Isotopic time-series (δ13C and δ18O) obtained from the columnar layer of Permian brachiopod shells are a reliable archive of seasonal variations. Palaeogeography, Palaeoclimatology, Palaeoecology, 607, 111264.

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Keywords: Wuchiapingian, brachiopods, seasonality, sclerochronology, stable isotopes

Palynostratigraphy of the Permian Wolfang Basin, Australia: Implications for timing and glaciation

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The Wolfang Basin in Queensland, Australia is a small rift-controlled half graben that hosts significant coal deposits adjacent to the Bowen Basin. The age of the basin has previously been assessed to be limited to the Cisuralian based on palynological data from the nearby Blair Athol Basin, which features a similar stratigraphy. Recent work in Australia calibrating the biostratigraphic scheme using absolute zircon ages allows for much more accurate age assessments using palynology. New palynological data from the four major coal seams of the Wolfang Basin (the Wolfang Main, Wolfang Upper, Prospect and Gowrie seams) suggest that the period of deposition spanned a number of biozones. The Wolfang Main and Wolfang Upper seams are assigned a Kungurian-Roadian age based on the presence of *Praecolpatites sinuosus* (APP3.2). Samples from the overlying Prospect Seam feature the first appearance of *Microbaculispora villosa*, the index taxon for the APP3.3 Zone, suggesting an upper Roadian age. The uppermost sample in the Gowrie Seam is assigned to the APP4.2 Zone based the first appearance of *Didecitriletes ericianus* and intermediate forms between *M. villosa* and *D. ericianus*. This indicates deposition occurred in the basin at least into the Wordian but potentially into the Capitanian. Rifting in the Denison Trough of the Bowen Basin is broadly limited to the Cisuralian and is followed by a period of passive thermal subsidence in the Guadalupian wherein little to no deposition occurred in the basin before the foreland basin phase initiates in the Lopingian. The Wolfang Basin stratigraphy spanning this period (Roadian-Capitanian) suggests that localized tectonic activity was still ongoing in the region. This also coincides with the P3 glaciation, the signal of which may be observed within the carbon isotope record of the Wolfang Basin, providing a unique record of this phenomena not previously recorded in Queensland.

Keywords: Permian, palynostratigraphy, Australia, glaciation, Wolfang Basin

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Evolution pattern and paleogeographic distribution of Lower Permian carbonate buildups: A case study in eastern Inner Mongolia, North China

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The Lower Permian carbonate buildups in eastern Inner Mongolia, North China comprise Asselian–Sakmarian phylloid algal-microbial reefs and skeletal-microbial mounds and Sakmarian–Kungurian skeletal mounds. The phylloid algal-microbial reefs were constructed by microbes and phylloid algae. Accumulated phylloid algae provided the attachment sites for microbial growth rather than building frameworks. By contrast, microbes made a primary contribution to the framework construction by encrusting the surfaces of phylloid algae and by infilling the inter-phylloid algal spaces. The skeletal-microbial mounds were formed by microbes and skeletal grains through repeating the following steps: 1) skeletal grains accumulated in situ, or after short-distance transportation; 2) microbes grew on the surfaces of skeletal grains and inter-grains spaces, eroding skeletal grains, inducing the nucleation of CaCO3 crystallites near the cell surface, and trapping and binding suspended lime mud from ambient water; 3) some positive topographies slightly higher than adjacent sediments were formed; 4) most microbes were preserved as peloids due to incompletely calcification. Compared with the skeletal-microbial mounds, microbes also played a significant role in constructing skeletal mounds, however most microbes decayed before being calcified or were completely occluded by micrite after calcification of sheaths, resulting in little microbial-associated sediments being preserved.
As mentioned above, carbonate buildups in the subtropical North China are characterized by microbial sediment with various proportions of skeletal grains, such as phylloid algae. They have similar reef-building organisms to the typical Tethyan buildups, but have a different construction model, which is related to seawater temperature resulting from paleolatitude and warm currents. As such, the subtropical North China buildups are considered as a sub-type of the tropical Tethyan buildups.

In the sense of the evolution pattern, Lower Permian carbonate buildups show three phases at the global scale. The first phase (Asselian-Sakmarian) is marked by carbonate buildups constructed by phylloid algae, *Palaeoaplysina*, *Shamovella*, sponges and bryozoans. The second one (Artinskian) is represented by the vanishing of phylloid algae and *Palaeoaplysina* from carbonate buildups, due to the paleoclimatic transition from an icehouse to a greenhouse. The third phase (Kungurian) is characterized by the drastic decline of carbonate buildups in the subtropical

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Pangean domain, but well development in North China and the tropical Tethyan domain.

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Keywords: Phylloid algal-microbial reefCarbonate moundConstruction modelPaleoclimatePaleo-latitude

Mid-oceanic sea-level drop at the two Permian extinctions: evidence from accreted paleo-atoll carbonate complexes

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Pre-Jurassic mid-oceanic sedimentary records were rarely preserved, as those had been mostly subducted/disappeared along convergent margins due to non-stoppable plate tectonics since the Archean. Almost nil, however, a few of them could survive in the form of exotic blocks within accretionary complexes, i.e., deep-sea chert and paleo-atoll carbonates. Mid-oceanic reefy carbonates from the top of ancient seamounts archive sensitive sea-level changes through time, according to their near sea-surface facies and total absence in tectonic disturbances at trench and/or mid-oceanic ridge. The Middle-Upper Permian and Triassic carbonates in SW Japan (Akasaka, Kamura and other sections) represent accreted fragments from ancient seamount-top reef complexes, in which drastic facies changes at two extinction-related horizons are preserved, i.e., the Guadalupian/Lopingian (Middle-Upper Permian) and Lopingian/Induan (Permian/Triassic) boundaries. Sharp lithofacies changes are eye-catching at the two horizons in multiple sections. At the G-L boundary, the uppermost Guadalupian organic-rich dark gray limestone of shallowing upward sequence is abruptly truncated with an unconformity by the overlying Lopingian light gray limestone. At the P-T boundary, Lopingian white dolomite is truncated with a hiatus by the black Induan organic-rich limestone. The sharpness in facies change and evident erosional features indicate that sharp sea-level drops occurred for both timings in mid-oceanic setting regardless of local tectonism. These apparent sea-level drops in atoll carbonates likely recorded the appearance of cool climate on a global scale, further suggesting a promising trigger for global environmental changes relevant to the major Permian extinctions of marine organisms.

Keywords: atoll carbonate, sea, level drop, extinction, Guadalupian, Lopingian, Triassic

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SC11: Stratigraphy of the Carboniferous world

Moving forward with the redefinition of the Devonian/Carboniferous Boundary

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The definition of the base of the Carboniferous has been back on the agendas of the Devonian and Carboniferous subcommissions for more than a decade. This became necessary after the discovery of the marker fossil for the base of the Carboniferous, the conodont *Siphonodella sulcata*, in the GSSP section at La Serre, southern France.
A joined SDS/ISCS Task group has been working on the redefinition of the base of the Carboniferous for more than ten years. Its overall aim is to regain stratigraphical stability in this critical interval of Earth history without fundamentally changing the position of the DCB in respect to previously used levels for the base of the Carboniferous.

The working group has been following the basic idea that a newly defined boundary level has to ensure the best possible correlation across facies realms and palaeocontinents, and that the recognition of the boundary should be the most user-friendly. In this respect, the new boundary should not depend on a single criterion, but be based on a suite of multiple criteria.

In this respect, the working group has been focussed on multi-disciplinary approaches, which combine palaeontological, sedimentological, geochemical and petrophysical methods and data, setting points in time during the latest Devonian and earliest Carboniferous.

This has resulted in a calendar, which precise a succession of widely recognizable points in time for the latest Famennian and earliest Carboniferous. Since this DCB calendar combines results from very different facies realms, it is self-understanding that a section comprising all listed points will not exist. However, the application of this calendar enables to place every section as precise as possible into the framework of the DCB. Additionally, it clearly helps to identify local or regional variations and discrepancies due to e.g. facies differences or faunal particularities, and hence to adapt the position of the boundary accordingly. Thus, even a delayed entry of a stratigraphic marker would have less influence on the boundary position and the global correlation. The work on the calendar also implies revisions on existing biostratigraphic zonal schemes.

The working group is currently working on a proposal for the criteria for the new DCB defintion. If everything falls in line, this proposal will be accepted by SCCS before STRATI 2023, and thus could be officially presented at Lille.

*Speaker

Keywords: DCB, global correlation, redefinition

Insect biostratigraphy of the Pennsylvanian Souss basin, Morocco: implications for late Carboniferous non-marine – marine correlation

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Situated in the South-western branch of the late Palaeozoic Euramerican orogenic belt of the Hercynides, the Late Pennsylvanian Souss Basin was considered to have been an evolutionary hotspot for diverse biota which appear later in the Euramerican province from Europe to North America (Hmich et al., 2003, 2005, 2006; Lagnaoui et al., 2018; Belahmira et al., 2019; Werneburg et al., 2019). The continental Pennsylvanian deposits of the Souss Basin in the western High Atlas Mountains occur as tectonically bounded remnants of a once much larger intramontaneous basin. The recent Souss Basin consists of the two tectonically separated sub-basins of Ida Ou Zal and Ida Ou Ziki. The Carboniferous sedimentary succession of the Souss Basin includes: basal conglomerates of the Ikhourba in the Ida Ou Zal, and the Tajgaline formations in the Ida Ou Ziki subbasin, which are overlain by more than 1200 m thick gray braidplain sediments of the El Menizla and the Oued Issene formations respectively (Saber et al., 2001, 2007). All processes of the geotectonic and sedimentary evolution along with relevant biotic events are preserved in the sedimentary fill of the basin.
In order to elucidate the mainly climatically driven evolution of the Late Pennsylvanian Souss biota as well as the reconstruction of their biogeography, a geochronological frame is absolutely crucial. In addition, an implementing of an accurate geological time of the fossil host strata will lead to a well-established biostratigraphic framework for the Late Pennsylvanian (Stephanian) locally, correlating a part of the deposits of the Souss Basin with the West-European Regional Scale (WERS), the North American Stages (NARS), and globally with the Standard Global Chronostratigraphic Scale (SGCS).

Moreover, the biostratigraphic schemes of the late Palaeozoic-early Mesozoic Moroccan basins, including the Souss Basin, have become in the last decades a focus of the Nonmarine-Marine Correlation Working Group of the Subcommissions on Carboniferous Stratigraphy, Permian Stratigraphy, and Triassic Stratigraphy (Schneider et al., 2020). State-of-the-art of steady increase in sampling and cm-scale resolution lithostratigraphic logging techniques were used to

*Speaker

establish a high-resolution biostratigraphic framework from key outcrops in several Moroccan basins.

Despite the lack of a high-resolution radioisotopic ages, as well as marine intercalations with index fossils such as conodonts from the late Pennsylvanian Souss Basin, other alternative methods have been used, e.g. the macro-plant biostratigraphy (e.g Broutin et al., 1989), the insect biostratigraphy based on morphophylogenetic spiloblattinid lineages (Hmich et al., 2005; Belahmira et al., 2014). Additionally, further fauna-based proxies might be successfully integrated into biostratigraphic dating for the Late Pennsylvanian of the Stephanian (Kasimovian) in the Souss Basin, such as branchiosaur-like temnospondyls (Discosauriscids) of the *Branchierpeton* lineage (Werneburg et al., 2019) and clam shrimps (conchostracans) (Scholze et al., 2015; Schneider et al., 2018; Schneider et al., 2022) which occur associated with fossil insects and plants.

Nevertheless, new improved entomological data from the Late Pennsylvanian to early Permian continental and mixed marine continental sections, which are widespread in the paleotropical belt, especially in North America, have contributed to a high temporal resolution biostratigraphy for the non-marine Early Pennsylvanian (middle Bashkirian) up into the early Permian (early Asselian) subdivisions of the European, North American, and North African basins, as well as to non-marine-marine cross correlations Schneider et al. (2022).

In summary, the age of the fossiliferous strata from Souss is older than what was previously assumed (Hmich et al., 2005; Belahmira et al., 2014). Accordingly, the inferred age of the Late Pennsylvanian Souss stratigraphic units is constrained to the early to latest Stephanian A of the WERS, middle to the latest Missourian of the NARS, which are tied to the Late Pennsylvanian middle to late Kasimovian stage of the marine SGCS.

Ongoing research in the Moroccan late Carboniferous to Triassic basins is focused on the improvement of global correlations for the understanding of global processes (e.g. Zouheir et al., 2022).

Keywords: Biostratigraphy, insects, Carboniferous, Souss Basin, Morocco

Milankovitch paced sedimentation on a tropical mixed siliciclastic-carbonate margin during the Mississippian: the Rush section, North County Dublin

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Numerous rock formations of Mississipian age span much of central Ireland. These rocks, including limestones, claystones, sandstones, conglomerates and volcanoclastics, originally accumulated at low latitudes on shelves and slopes rimming Laurussia. A spectacular 150-metre thick section of the Tournaisian Tober Colleen Formation outcrops along the coast at Rush, north of Dublin. Here, muddy limestone and calcareous claystone and sandstone beds represent deposition in an upper slope environment. Logging and spectral analysis of these beds shows inherent cycles of 2, 8 and 25 metres thickness. With age constraints, these cycles have durations of approximately 100, 400 and 1200 kyrs and thus reflect short eccentricity, long eccentricity and possibly modulation of obliquity. Detailed documentation of the Rush section should allow comparisons to contemporaneous sections elsewhere, especially Europe, as well as modern tropical mixed siliciclastic-carbonate margins, such as North Queensland.

Keywords: Ireland, continental margin, limestone, Tournaisian

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Micrite from the Late Carboniferous bioconstructions in southern Guizhou, South China: characterization, origin, and role

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The origin of micrite as a part of the "carbonate factory" is significant in revealing the formation of carbonate rock and the biocommunity in bioconstructions. Although micrite is common in bioconstructions, there is still controversy about the types and origin of micrite in reef facies. The study area around Houchang town (southern Guizhou, South China) was located at the margin of a carbonate platform in the Late Carboniferous, well-known for numerous and various bioconstructions including coral reef/biostrome, phylloid algal reef, microbial mound, and *Tubiphytes* reef, which provide ideal objects for studying the micrite in the reef facies. Based on the detailed observations of the field, polished slabs, and thin sections, four types of micrite related to biota can be identified according to the origin: micrite baffled by skeletal organisms (BM-1), micrite bound by binder guild (BM-2), micritization of bioclastic (BM-3), and the micrite formed by microbes (BM-4). Type BM-1 formed by baffled are observed around the skeletal organisms (corals and phylloid algae), which baffle the micro-sediments in the water flow. Type BM-2 commonly distribute around the binder represented by *Tubiphytes*, cyanobacteria, sessile foraminifers, and bryozoans. The binder together with micrite BM-2 could form clots including microspar and microbioclastics. Type BM-3 most occur in the bioclastic wackestone and results from the breakdown of previously micritized shells of benthic organisms. The micritization weakened the shells, promoting their breakdown and abrasion to form peloids composed of micrite. Type BM-4 is formed by microbial calcification as well as induction, manifested as micrite crust, irregular layers of encrusters, and microbial peloids. By analyzing the link among the depositional environment of bioconstructions, reef-building organisms, and micrite related to biota, suggests that sediment input, type of framework builder, and wave energy play a vital role in the origin of micrite in the reef facies. Type BM-1 in the skeletal reefs could provide shelter for benthic dwelling organisms, enhancing the biodiversity of reefs and the stability of the reef ecosystem. For non-skeletal reefs, the BM-2 can be the framework to support the formation of reefs like *Tubiphyes* reef. The microbial mounds in the study area mainly compose of BM-4 contributing to the framework. The development of several micrite types is facilitated by the diversity of reef-builder. Further, the micrite could contribute to the growth of reefs in the study area, reflecting the crucial effect of micrite on the formation of reefs in the eastern Paleotethys Ocean during the Late Carboniferous.

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Keywords: Key words: Late Carboniferous, Micrite, Bioconstruction, Eastern Paleotethys Ocean, South China

Progress on the global Moscovian and Kasimovian stage boundaries in China

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No index fossils are yet selected for defining the global Moscovian and Kasimovian stages. Conodonts are regarded as the most potential boundary marker for the two stages. Based on conodonts from South China sections, the lineage *Diplognathodus benderi–D. ellesmerensis* across the Bashkirian-Moscovian boundary was recognized. *Diplognathodus ellesmerensis* has been found worldwide and its first appearance datum (FAD) is close to the traditional Bashkirian-Moscovian boundary in the type area of the Moscovian Stage. Therefore, the evolutionary FAD of *D. ellesmerensis* within the lineage *D. benderi–D. ellesmerensis* is considered the best marker for the base of the global Moscovian Stage. As for the global Kasimovian Stage, conodonts *Swadelina subexcelsa*, *Idiognathodus sagittalis*, and *I. heckeli* are potential markers for its basal boundary. All these species plus *I. turbatus* were found in the Naqing and Shanglong sections, South China, as well as the *I. swadei*-*I. heckeli*-*I. turbatus* lineage has been recorded. Among these conodonts, *I. heckeli* has a wider geographical distribution, an unambiguous species concept, and an evolutionary lineage, and its FAD marks extinction and biodiversification events and is closer to the traditional boundary than that of *I. turbatus* and *I. sagittalis.* Thus, *I. heckeli* has the most potential for globally correlating the base of the Kasimovian Stage at present. However, the FAD of *I. heckeli* is one substage higher than the traditional Moscovian-Kasimovian boundary that can be recognized by the FAD of *S. subexcelsa.*

Keywords: Carboniferous, Moscovian, Kasimovian, Stage boundary, China

*Speaker

The macrofloral biostratigraphy of the Nord-Pas-de-Calais Coalfield, France

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The Nord-Pas-de-Calais Coalfield is formed by an almost continuous series of Namurian–Westphalian deposits, from which has been historically described an extremely diverse macroflora. Recent evidence has highlighted a clear palaeofloristic pattern for this coalfield that can be compared with evidence from other coeval Variscan environments. For instance, the Nord-Pas-de-Calais vegetation diversified earlier than those in the British coalfields, and declined later than in other basins such the case of Ruhr coal swamp. In this communication, we further study this macrofossil flora focusing on the biostratigraphical changes through a series of multivariate data analyses. Clustering and ordination signals allow major floral discontinuities to be identified, as well as the boundaries of the standard macrofloral biozones of the Nord-Pas-de-Calais coal swamp, notably of the *Pecopteris aspera* Zone (middle Bruille Fm.), *Calymmotheca hoeninghausii* Zone (upper Flines Fm.), *Lonchopteris rugosa* Zone (lowermost Anzin Fm.), *Neuropteris semireticulata* Subzone (middle Anzin Fm.), *Laveineopteris rarinervis* Subzone (lower Bruay Fm.) and *Linopteris obliqua* Zone (upper Bruay Fm.). This new temporal framework allows deeper comparisons with coeval vegetation, and provides new insights into the dynamics of these ecosystems across the Variscan foreland. Results further show how the vegetation of the Nord-Pas-de-Calais coal swamp proliferated considerably at the start of the Westphalian, and continued to diversify as marine influence finally withdrew by the Duckmantian–Bolsovian boundary. But most importantly, evidence suggest this latter change clearly represented a significant reconfiguration of the coal swamps i.e., it was not just a loss of species richness, but a major change in the taxonomic structure of the vegetation.

Keywords: Biostratigraphy, Namurian, palaeobotany, tropical wetlands, Variscan Euramerica, Westphalian

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Paleozoic sedimentary cycle and terranes in the northern Andes

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Early Paleozoic sedimentary rocks are present in the Llanos Basin and in the Magdalena Valley. The Late Paleozoic is distributed in the Llanos Basin, Eastern Cordillera, Magdalena Valley, and the eastern flank of the Central Cordillera. However, outcrops of Paleozoic sedimentary rocks have been limited to the western Andean region by the Otú-Pericos dextral fault system. This fault interchangeably cuts the Magdalena Valley and the Central Cordillera. Additionally, the western flank of the Central Cordillera is made up of an oceanic basement of Cretaceous age. It is usual to use the term "Central Cordillera" to refer to the geological history of this sector, artificially assuming geological uniformity throughout this orographic accident without considering the chronological and stratigraphic data.
The Otú-Pericos fault separates at least two sectors in the Central Cordillera with independent geological histories up to the Jurassic. The northern sector of the Cordillera Central is located in its greatest extension to the west of the Otú-Pericos Fault. This sector has been included in the Tahamí terrane or Cajamarca terrane. This terrane is dominated by metamorphic rocks with protoliths of Permian or Triassic age with a metamorphic phase of Jurassic age. On the contrary, the southern Cordillera Central is composed of a Precambrian basement (Grenville) like other sectors of the Magdalena Valley.

The Silurian sedimentary cycle is present in the Quetame, Santander and Mérida massifs (Venezuela). Brachiopod fossils found in the El Horno Formation (Venezuela) suggest a connection during the Ordovician with Mexican terranes. In the Quetame massif (Eastern Cordillera) Silurian sedimentary deposits are located on top of Ordovician metamorphic rocks of the Taconic or Famatinian Orogeny. The Devonian, which crops out in various locations in the Eastern Cordillera and Magdalena Valley, includes marine (Middle Devonian) and continental (red beds) deposits of Late Devonian age with fossils of North American affinity. Devonian age sedimentary rocks are reported on the eastern flank of the Central Cordillera (El Imán and Amoyá Formations). A hiatus exists between the Silurian roof spanning much of the Early Devonian.

The Carboniferous cycle is recognized in the Llanos basin, Eastern Cordillera and the Magdalena Valley with outcrops to the south of the Central Cordillera. No proven Mississippian deposits are recognized in the northern Andes. The Pennsylvanian is made up of cyclical alternation of marine (limestone) and continental (red beds) deposits caused by sea level changes

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of glacial origin. Sedimentary deposits of Permian age are limited to the north of the Eastern Cordillera, Serranías de Perijá and Mérida. There is a paraconformity that separates the Carboniferous from the Permian sequence in this sector. The cycle is characterized by platform limestone with some deltaic deposits with flora (*Delnortea*) similar to that of the Texas Permian. On the eastern margin of the Magdalena Valley, there are Permian to Triassic granite bodies associated with volcanic and sedimentary deposits that suggest that this sector was formed in the vicinity of a volcanic arc.
It is notable that the Jurassic metamorphic cycle recognized north of the Cordillera Central (Cajamarca or Tahami terranes) does not extend south of the Cordillera Central and the Magdalena Valley. This suggests that the Otú-Pericos fault system acted as a tectonic boundary between the Cajamarca terrane and the southern Central Cordillera and Magdalena Valley. Deformed rocks exposed to the south of the Cordillera Central have been assumed to be an extension of the Cajamarca (Tahami) Terrane, however, Cretaceous-age fossils collected from these rocks suggest that the Cajamarca terrane is actually an isolated block of para-autochthonous origin transported to its current position from the south.

Keywords: Colombia, Central Cordillera, Magdalena Valley, Cajamarca Terrane

Carboniferous (Dinantian) stratigraphy in 3 deep boreholes from the Dublin Basin, Ireland

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Abstract: In recent years, the Carboniferous rocks of Ireland have become the main target for deeper geothermal exploration (Pracht et al. 2021). This transition from shallow (< 100m) to deep (> 500m) drilling by the Geological Survey of Ireland provides an excellent opportunity to re- evaluate some of the established stratigraphy. The 'Grangegorman' borehole was drilled on the campus of Dublin City University near the centre of Dublin and the Dublin Basin. It penetrated 998m of lower Viséan basinal limestone and mudstone. Two deep boreholes were drilled on the northern shelf/basin margin in the townlands of 'Attymany' and 'Streamsford', southeast of the town of Athenry. Here c.200m to 476m of basinal limestone overlay 177m to c.700m ramp and shelf limestone in which they terminate.

The Dublin Basin s.l. as we see it today (**Figure 1**, the grey coloured areas)) consists of an assemblage of variously named basins, sub-basins and troughs separated by structural highs and platforms. They are the result of the break-up of the Tournaisian carbonate ramp (Strogen et. al. 1996).or obvious reasons, the shallow marine platforms have received most attention. The stratigraphy of the various basins itself has received little attention, and our understanding of basin geometry, subsidence rates and evolution is largely based on extensively studied research 'hotspots', such as Navan and Tynagh.

Keywords: Ireland, Carboniferous, Mississippian, Dinantian, Dublin Basin, stratigraphy, deep boreholes

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Progress on Chinese Mississippian foraminiferal zonations and correlations

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Foraminifera are one of the most significant tools in defining the age of Mississippian strata, and they are very useful for high-precision intercontinental biostratigraphic correlations. Based on samples from sections located in different blocks in China, this study achieves the following progress: 1) In traditional Chinese Carboniferous zonal schemes, Mississippian foraminiferal zones were broadly defined by genera, long-ranging species or local species, making it difficult to correlate to equivalent foraminiferal zones worldwide. A refined Chinese Mississippian zonal scheme of foraminifera is preliminarily established. New zones named for cosmopolitan species allow better international correlations. 2) Archaediscacean foraminifers are used as biostratigraphic marker microfossils from the early Viséan to early Serpukhovian. However, the ancestor of the archaediscids is still on debate. The specimens of *Lapparentidiscus* and *Viseidiscus* with continuous stratigraphic appearances from South China suggests that *Lapparentidiscus* is a unique pseudoamrnodiscid that gives rise to the archaediscids. The evolution trend of primitive archaediscacean foraminifers is: *Lapparentidiscus talasicus–Viseidiscus eospirillinoides–Viseidiscus monstratus.* The hyaline-radial layer of the archaediscids appears as a replacement instead of a filling. It replaces the dark, microgranular layer gradually, and extends from the umbilical area to the sides. 3) By investigating the foraminiferal succession of the Viséan/Serpukhovian boundary interval in China and its accurate correlation with conodonts from the Viséan/Serpukhovian boundary GSSP candidate section-the Naqing section and other auxiliary sections (such as the Narao section), the problem of basal Serpukhovian foraminiferal indices is discussed. The co-occurrence of typical Serpukhovian conodont *Lochriea ziegleri* and foraminfera *Janischewskina delicata* within the boundary interval provides important information of the correlation between conodont and foraminifera near the Viséan-Serpukhovian boundary.

Keywords: foraminifera, Mississippian, China

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Integrating the lower Carboniferous and older stratigraphy of the Netherlands with that of Belgium and Germany

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In spite of the fundamental changes occurring during the middle Paleozoic, the expression of this period in the subsurface of the Netherlands is difficult to disentangle. No sedimentary rocks older than Serpukhovian (Namurian) are exposed in the Netherlands, although many good outcrops are known from Belgium and Germany. In the Netherlands, pre-Serpukhovian sedimentary rocks are only known from 74 boreholes and inferred from seismic data. In the ultimate southwest and southeast of the country, this Paleozoic succession is found at relatively shallow depth (< 500 m). Going northwards, the depth rapidly increases, reducing the number of boreholes and seismic surveys reaching it.

During the last decades, both the amount of publicly available data and the interest in the lower Carboniferous and older succession have grown considerably. The Mississippian (Dinantian) succession is a target for geothermal energy exploration and energy storage. The Upper Devonian (Famennian) sandstone in the southeast of the Netherlands and bordering Belgium has gained interest for the construction of the subsurface gravitational wave observatory Einstein Telescope.

The renewed interest has resulted in new studies and boreholes, shedding new light on the sedimentology and stratigraphy. Both new and legacy data have been integrated into a new lithostratigraphic framework allowing for straightforward correlation to Belgium and Germany. The informal Frasnian-Famennian Bollen Claystone formation has been emended, while the Famennian Evieux Formation from Belgium, is adopted for equivalent deposits in the Netherlands. The Belgian Hastière Formation holds the Devonian-Carboniferous transition and has been identified in the Netherlands as well. Finally, the well-known Belgian Tournaisian Pont d'Arcole Formation can be traced over great distances in boreholes in the Netherlands and is introduced into the lithostratigraphic nomenclature. Apart from these successions straddling the Devonian-Carboniferous boundary, a new formation is introduced for the oldest known strata encountered in the Netherlands. These concern sediments deposited by turbidites during the late Silurian to earliest Devonian. The resulting updated lithostratigraphy embeds this part of earth history in the regional framework, allowing for better future integrated studies.

Keywords: Devonian, Tournaisian, Famennian, Frasnian, Silurian

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The Viséan-Serpukhovian boundary beds in the Beleuty Section (Zhezkazgan, Central Kazakhstan)

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The definition of the base of the Serpukhovian (Mississippian, Carboniferous) has for many years been a focus of global stratigraphic research. The official Viséan-Serpukhovian boundary at the base of the E1 ammonoid Zone in Europe (*Uralopronorites-Cravenoceras* ammonoid Genozone in Kazakhstan and the Urals) is difficult to precisely identify in many sections, as ammonoids are infrequent. Several alternative markers have been proposed, with the FAD of the conodont *Lochriea ziegleri* one of the primary candidates in northern hemisphere sections (Qi et al., 2018; Nikolaeva et al., 2020). However, its exact position needs to be accurately documented relative to the foraminiferal and ammonoid scales, especially in sections with boundary intervals lacking conodonts. The Beleuty section in Zhezkazgan Region, Central Kazakhstan (Litvinovich et al., 1969; 1985) is among the most complete successions spanning the Viséan-Serpukhovian boundary and containing foraminifers, ammonoids and conodonts. The foraminiferal-based Viséan-Serpukhovian boundary in Kazakhstan was traditionally drawn between the *Eostaffella ikensis - E. tenebrosa - Bradyina rotula - Howchinia gibba* and *Neoarchaediscus parvus-Kasachstanodiscus* Zones (Marfenkova, 1991; Zhaimina, 2002). However, *Neoarchaediscus parvus* (Rauser-Chernousova, 1948) (= *Asteroarchaediscus parvus*) is known from the uppermost Viséan (e.g., Kulagina, 2017), while *Kasachstanodiscus* first appeared in the Middle Viséan, and none of its species seem to be restricted to the Serpukhovian. Therefore, the base of the Serpukhovian defined by foraminifers is being revised in this section, with new zonal species proposed. There are several reported levels with ammonoids in the Beleuty section, the lower one with *Pachylyroceras*, usually found in equivalents of the P2 Zone (= *Hypergoniatites-Ferganoceras* Genozone in Kazakhstan) and upward in the section, several levels with *Cravenoceras*, usually restricted to the E1 Zone. Conodonts, including species of *Gnathodus,* are mostly confined to the Viséan. The Beleuty section is at the southern end of the Ulytau Uplift, 120 km south of Karsakbay. The Beleuty section is on the eastern flank of a trough. The Upper Viséan deposits (mostly Dalnenskian Regional Substage) are conformably overlain by the Beleutian Regional Substage (Zhaimina, 2007, 2010). The Dalnenskian uppermost unit includes limestones (dominant), sandy limestones, siltstones, and less commonly shales. Dalnenskian fossils include Late Viséan ammonoids, foraminifers, conodonts, brachiopods and ostracods (ammonoids: *Pachylyroceras newsomi*, nautiloids: *Endolobus litvinovichae*; conodonts:

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Gnathodus girtyi collinsoni, *G. girtyi girtyi*; brachiopods: *Ovatia jagovkini*, *Echinoconchus elegans, E. subelegans*, *Neospirifer nalivkini*, *Spirifer logani latus*, *Productus concinnus*, *Composita trinuclea*, etc.; ostracods: *Shishaella claytonensis*, *Healdianella darwinuloides*, etc. (Zhaimina, 2010). The Beleutian Regional Substage is composed of sandstones, siltstones, shales, various nodular, micritic and argillaceous limestones with ammonoids, foraminifers, corals, brachiopods, bryozoans, gastropods, bivalves, etc. (Litvinovich et al., 1985; Zhaimina, 2007; 2010). The base of the Beleutian was traditionally drawn near the earliest occurrence of *Cravenoceras*. Ammonoids from the lowermost unit are represented by *Cravenoceras beleutense, C. arcticum, C. malhamense, Kazakhoceras hawkinsi*, *Sudeticeras varians karagandense*, *Neoglyphioceras litvinovichae,* and *Beleutoceras carinatum.* Foraminifers include *Eostaffella minuta, Eostaffellina* cf. *paraprotvae*, *Pararchaediscus tumidus*, *P. convexus*, *Archaediscus* cf. *krestovnikovi*, *Howchinia gibba*, *H. gibba longa*, *H. beleutensis*, *Monotaxinoides* aff. *subplanus*, etc. The most informative foraminifer for fixing the base of the Serpukhovian in the section are *Monotaxinoides* aff. *subplanus* and *Eostaffellina* cf. *paraprotvae*, currently revised to be correlated with occurrences of *Pachylyroceras* and *Cravenoceras* in the same section.
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Keywords: Keywords: Viséan Carboniferous boundary, Beleuty Section, Zhezkazgan, Kazakhstan.

Late Pennsylvanian Tubiphytes reef in southern Guizhou Province, China: new insights into the peculiar reef-building association and the global environment change

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Hybrid carbonates are widespread and diverse throughout geological history and can reflect critical transformations in biosphere and earth surface processes. Late Pennsylvanian increase in microbial carbonates, together with the appearance of locally conspicuous sparry crusts, marked the inception of a significant interval of abiotic-microbial-skeletal triple hybrid carbonates formation that continued until the Middle Triassic (Riding and Virgone, 2020). Here, we present a new type of reef-building association from the uppermost Pennsylvanian (Gzhelian) strata of southern Guizhou Province, China. The reef is mainly composed of in situ *Tubiphytes* boundstone, *Tubiphytes*-cementstone, extensive synsedimentary cements, microbial bounsdstone, and coral framestone. The reef reported in this study is a peculiar reef-building association because of its extensive syndepositional marine cement, and was classified as abiotic-microbial-skeletal triple hybrid carbonates formed on the carbonate platform margin during the Late Pennsylvanian.

The main reef-building organisms are *Tubiphytes*, colonial rugose coral *Ivanovia* sp., encrusting calcimicrobes, and bryozoans in order of their content. Syndepositional marine cement is an important component of this reef, and locally forms cementstone. The following characteristics are found in the studied reef: (1) The primary reef-building organisms, including *Tubiphytes*, colonial rugose coral *Ivanovia*, and lamellar calcimicrobes, have a good encrusting habit; (2) Most of the bioclasts have micritized envelopes with a microbial origin. The lamellar encrusting calcimicrobes *Archaeolithoporella* is considered as the connecting bridge structure (linkage) between *Tubiphytes*, botryoidal cements, and clotted micritic microbialite; (3) Most of the biogenic components are surrounded by botryoidal radial fibrous cement, and remaining interstitial spaces are filled with blocky calcite cement; (4) Throughout the reef, allochthonous sediment is conspicuously absent; (5) The high proportion of early marine cement (especially botryoidal cement) in the reef indicates high original porosity. The massive coral *Ivanovia* could provide a protected environment for *Tubiphytes* and encrusting calcified microbes *Archaeolithoporella* to form the micro-frameworks in shallow marine with high energy conditions. Interstitial-filling

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radiaxial fibrous cement (syndepositional marine cement) were also formed under high energy conditions with good water circulation, enhancing the rigidity of the framework.

The widespread triple hybrid carbonates during Pennsylvanian and early Permian were considered as the result from extensive precipitation of synsedimentary cement, coinciding with climate cooling, sea level drop, increase continental washout, and slow-spreading seafloor intervals. In addition, the seawater chemistry was favorable for the aragonitic organisms and cement during these intervals. In the Late Pennsylvanian, the increase in microbial carbonates and the appearance of locally conspicuous sparry crusts marked the inception of a significant interval of abiotic-microbial-skeletal triple hybrid carbonates formation. The occurrence of the studied *Tubiphytes*-cement reef may indicate a significant change in the Pennsylvanian reef system of south China, consistent with a global environment during the Late Pennsylvanian (icehouse period). Thus, it also reflects an important development in the construction of shallow-water tropical reefs under late Paleozoic glaciation events.

Keywords: Reef, Tubiphytes, Hybrid carbonates, Late Pennsylvanian, South China

Late Paleozoic siliciclastics of the Changning-Menglian Belt: indications for the evolution of Paleo-Tethys in western Yunnan, China

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The Changning-Menglian Belt in western Yunnan, China, separating the Baoshan Block of Gondwana-affinity to the west and the Simao Block of Cathaysia-affinity to the east, is one of the key regions for deciphering the evolution of Paleo-Tethys. Late Paleozoic stratigraphic units with various ages, provenances and tectonic backgrounds blended in this orogenic belt of high complexity. Two types of siliciclastic strata with different characteristics, deposited almost simultaneously, can be identified. One is quartzose sandstone sequence represented by the Nanduan Formation in the east zone of the Changning-Menglian Belt. The other is lithic sandstone sequence represented by the Nanpihe Formation in the west zone of this belt.
The Nanduan Formation is mainly consisted of quartzose sandstones, silty mudstones and shales. Early Carboniferous ammonoids, like *Syngastrioceras* sp., *Somoholites* sp., *Epicanites* sp., *Stenopronorites* sp., *Prolecanites*? sp., accompanied with some bivalves and crinoids, were found in the shales. Sedimentary structures, petrographic indices and geochemical features indicate that these siliciclastic rocks were deposited in a neritic shelf to deep shelf environment on the passive continental margin. Detrital zircon geochronological analyses, showing significant age groups with peak age of ca. 550 Ma and ca. 950 Ma, suggest that these rocks are Gondwana-derived, and were possibly deposited on the east flank of the Baoshan-Shan Block with the metamorphosed Cambro-Ordovician siliciclastic successions in this belt.

The Nanpihe Formation located in the west zone of the Changning-Menglian Belt comprises lithic sandstones, silty mudstones, shales and bedded cherts. Late Devonian conodonts *Palmatolepis* spp. were found in the shales. And Late Devonian-Early Carboniferous sporo-pollen assemblages, *Retispora lepidophyta* and *Grandispora spiculifera*, were identified. Sedimentary structures, petrographic features and geochemical analyses of the clastics indicate they were near-source turbidity deposits and continental island arc related. Detrital zircon ages of these rocks, which record remarkable age clusters of ca. 435 Ma and ca. 950 Ma, show similar distribution patterns with those from the Simao and South China Blocks. These rocks were probably deposited along the western margin of the Simao Block, and then thrust onto the east flank of the Baoshan-Shan Block together with other rock units of the accretionary wedge during the closure of Paleo-Tethys.

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Keywords: orogen stratigraphy, Changning-Menglian Belt, Yunnan, Paleo Tethys, Devonian, Carboniferous

SC12: Devonian palaeoenvironments and time

Practical Sequence Stratigraphy of the Lower Devonian series Aoulef-Akabli axe (The occidental Ahnet basin, Saharian Platform, Algeria)

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Our study area is a part of the pre-Tassilian country of the Western Ahnet basin, located in the region of Aoulef and Akabli. The Lower Devonian series crops out with essentially clayey-sandstone lithology. It has allowed us to distinguish three formations: *Ain Ech-cheikh clay Formation*, *Sebkha Mekerrhane sandstone formation* and the *clayey-sandstone-carbonate formation.*
The lithostratigraphic study of two sections conducted in the Aoulef and Akabli sectors includes the analysis of the sedimentary structures generated by the hydrodynamic conditions and the facies. The results allowed us to identify four characteristic associations representing different bathymetric zones on a detrital platform ranging from *foreshore to offshore.*

The Ain Ech-cheikh clay Formation constitutes a distal mudflat presenting an *Offshore to Offshore*-transition environment. The Sebkha Mekerrhane sandstone formation was deposited in the proximal part of a detrital platform in the form of an alternation between an *Offshore-transition* environment to *Shoreface* in the lower member and another in the *foreshore* in the upper member. The clayey-sandstone-carbonate formation presents a distal to medium position oscillating between the *Offshore-transition to Shoreface.*
In terms of sequence stratigraphy the succession shows 4th Order transgressive-regressive (T/R) sequences grouped into two third-Order sequences determining two T/R cycles whose duration is estimated at approximately 9.5 Ma.

Keywords: Key words: Pre, Tassilian country, Aoulef, lithostratigraphy, Ain Ech, cheikh, Sebkha Mekerrhane, Lower Devonian, sequence stratigraphy.

*Speaker

La Mena Formation in the Compte Section (Famennian, Upper Devonian, Spanish Pyrenees)

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The Devonian sedimentary record in the Central Pyrenees is complex and widespread, and is divided into five main facies areas (North Pyrenean, Northern, Central, Western and Southern). The latter has been subdivided into four subfacies areas: Sierra Negra, Baliera, Renanué and Compte (Zwart, 1979; Valenzuela-Ríos & Liao, 2006). Diverse studies in different sections of the Compte Subfacies permit a compilation of the Devonian sequence (Boersma, 1973; Valenzuela-Ríos et al., 2005; Liao et al., 2008; Liao & Valenzuela-Ríos, 2013, Gouwy et al., 2013; Valenzuela-Ríos et al., 2017; Liao & Valenzuela-Ríos, 2017). Within this compilation, the various sections of the Compte area stand out (aforementioned reports). Lochkovian to lower Emsian and Givetian to lower Frasnian rocks have been accurately dated by conodonts. Recently our research group has started a thorough study of Upper Devonian strata in the Compte Section. There, the Upper Devonian consists of three main lithological units: Comabella Fm., La Mena Fm. and Barousse Fm. Silvério et al. (2021) have currently studied the Frasnian-Famennian transition, which falls within the upper part of the Comabella Fm. Herein, we continue these kind of studies further up in the stratigraphic column to include the La Mena Fm. and the lower part of the Barousse Fm. Our purpose is to date and characterize by means of conodonts the La Mena Fm. in the Compte Section.
In the Compte Subfacies, the La Mena Fm. chiefly consists of red nodular "griotte" limestone, is diachronic and is interpreted as deposited in a hemipelagic carbonate ramp environment. In the Compte Section, the La Mena Fm. measures 5.75 m and consists of red nodular, pseudonodular and well-bedded limestones, and red and grey nodular limestones with cephalopods. Our report focuses on a detailed study of the lower to middle Famennian conodont record from the uppermost part of the Comabella Fm, the La Mena Fm. and the lowermost part of Barousse Fm. 50 samples, in a bed-by-bed sampling, have been taken. The studied upper part of the Comabella Fm. consists of 4.53 m thick grey, dark and brecciated limestones. It comprises three conodont zones: *termini*, *glabra prima* and *glabra pectinata*, identified by their respective index conodont taxa. At the lowermost part of the La Mena Fm., the base of the *rhomboidea* Zone is recorded; higher strata document the *gracilis gracilis* Zone. In the upper part of La Mena

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Fm., the *marginifera marginifera* Zone is recognized by the conodont association *Palmatolepis marginifera marginifera*, *Pa. quadrantinodosa quadrantinodosa* and *Pa. quadrantinodosa inflexoidea.* The lower part of the Barousse Fm. consists of pink and grey nodular limestone, is 1.45 m thick and yields conodonts of the *marginifera marginifera* Zone.

Boersma (1973) situated the base of La Mena Fm. in the Compte section around the upper Frasnian *gigas* Zone (F13). However, Sanz-López (1995) reinterpreted these data and assigned the base of this formation to the Upper *triangularis* Zone (*minuta minuta* Zone). Our results differ from these interpretations, and the detailed conodont succession confirmed the position of La Mena Fm. in the Compte section between the *rhomboidea* and *marginifera marginifera* zones.
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Keywords: conodonts, Famennian, La Mena Formation, Spanish Pyrenees

Storm deposit characteristics and orbital cyclicity of the Xiejiawan Formation of early Devonian in the Longmenshan area, Sichuan Province, China

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The Xiejiawan Formation of early Devonian age in the Longmenshan area of Sichuan Province, China, is a shelf facies that consists of three types of carbonate-siliciclastic deposits: Mixed near-shore, clastic mixed shelf and carbonate mixed shelf facies. The variability of storm deposits in the Xiejiawan strata, based on tempestite sedimentary structures and sequences, was used to establish a storm abundance curve and a storm event-per-meter curve as climate proxies. A main long-eccentricity signal (405 kyr) and superimposed short-eccentricity signals (100 kyr) were identified by applying spectrum analysis, Fast Fourier Transform (FFT) and low-pass filtering to exact the orbital signals. There are seven main long-wavelength cycles in this record, and the implied 2.8 Myr span is nearly identical to the estimated ca. 2.5 Myr age span of corresponding conodont zones according to current Devonian conodont-zone timescale. Therefore, the storm frequency and magnitude were modulated by orbital forcing, in which eccentricity-induced climate cycles control the magnitude and frequency of tropical cyclones impacting the shelf, in addition to fluctuations in sea level.

Keywords: Early Devonian, Storm beds, Tempestites, Mixed shelf facies, Orbital cycles

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A new Konservat-Lagerstätte with putative early chordate from the Lower Devonian of Belgium

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The Lower Devonian siliciclastic succession of the southernmost part of Belgium, the Neufchâteau Synclinorium, recently yielded hundreds of enigmatic organisms during field campaigns in 2021 and 2022. The fossils were collected in slates of Pragian age and include various invertebrate taxa, mainly cephalopods and arthropods, and many unidentified specimens. Field campaigns followed the rediscovery of one fossil formerly identified as a cephalochordate, during a visit of local museum collections in 2020. The putative early chordate is preserved as calcite, quartz and pyrite mineralizations. A medial elongate structure is considered as a probable notochord. Most specimens collected from the locality are extensively pyritized with millimetre-sized pyrite crystals obscuring details of the anatomy. Other mineral phases, similar to those observed in the chordate, were identified. Most of the analysed specimens also contain organic matter. X-ray radiographies and CT scans showed that the fossils are highly compressed. The high degree of disarticulation of the fossils and the scarcity of large specimens indicate that they were probably deposited by turbidity currents, similar to those recorded in the Lower Devonian Hunsrück slate deposits of Germany. The Belgian locality constitutes a new Early Devonian *Konservat-Lagerstätte*, with the preservation of both bio- and non-biomineralized organisms. Future identification of problematic taxa should shed more light on the biodiversity of that new fossil locality.

Keywords: Devonian, Pragian, Konservat, Lagerstätte

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The Lochkovian-Pragian Boundary (Lower Devonian) in the Carnic Alps, Italy and Austria

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Lower Devonian rocks are widely exposed in the Carnic Alps representing diverse sedimentary environments from shallow water to relatively deep shelf. Six formations were discriminated in the upper Lochkovian and Pragian (Corradini et al., 2015). The lagoonal Polinik Fm. and the Seekopf Fm., mainly constituted by bioclastic limestone, sedimented in the shallower part of the basin. In intermediate conditions, the Rauchkofel Fm., represented by well bedded dark limestones alternated by calcarenite and thick breccia bodies, is followed by the Kellerwand Fm., represented by mudstone/ interbedded with packstone/grainstone. In the deeper settings the nodular ochraceous limestones of La Valute Fm. grades into the reddish nodular Findenig Fm. Several sections were measured along the Carnic Alps in order to obtain a precise age of the formation boundaries. In the shallower part of the basin, both the Polinik and the Seekopf fms span the boundary, but evident erosional surfaces are observable in the field at the Lochkovian-Pragian boundary; unfortunately, up to date, it was not possible to constrain chronostratigrafically the hiatus due to the missing of stratigraphically useful fossils. In correspondence of the Seekopf Fm. above the unconformity, at places the so-called megaclast horizon (e.g., Suttner and Kido, 2015) is present. The Rauchkofel/Kellerwand boundary is unconformable and different parts of the upper Lochkovian and the lower Pragian are missing in the various sections. The La Valute/Findenig transition is slightly diachronous from the latest Lochkovian to the earliest Pragian; however, conodonts and tentaculites are rare in the marly boundary beds, preventing a precise chronostratigraphic calibration of these levels.

In general, the hiatus seems to be larger in the western part of the Carnic Alps, in correspondence with the shallower parts of the succession, suggesting a sea level drop in the uppermost part of the Lochkovian, followed by a transgression in the lower part of the Pragian.

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Keywords: Devonian, stratigraphy, sea level variation, Carnic Alps

Sequence stratigraphy of the Middle Devonian of Belgium

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The Middle Devonian was a time of important carbonate sedimentation in the southern Laurassian shallow-water shelf, under tropical conditions. The important development of reefs and subordinate sediments was governed by eustatic fluctuations. The analysis of the geometrical relationships, the identification of trends and remarkable surfaces led to the identification of six third-order sequences in the Eifelian and Givetian stages.
The first sequence (MD1) starts in the uppermost Emsian (Saint-Joseph and Eau Noire formations), with the deposition of mixed siliciclastic-carbonate sediments then to purer stromatoporoid biostromes of the Viller-la-Tour Member of the Couvin Formation. The maximum flooding interval triggered the deposition of the black, fine-grained limestone of the Petigny Member, the stromatoporoid reefs returned when the sedimentation catch-up the eustatic increase (Cul d'Efer Member and Wancennes Formation). A subaerial erosive surface capping the dolomitic limestone of the Cul d'Efer Member can be traced within the Wancennes reef.

Above this surface, the Wancennes reef restarted whereas the Abîme Member of the Couvin Formation deposited. The latter two units forms the second sequence MD2, also capped by a major erosive surface.

The lowstand and transgressive system tracts of the sequence MD3 are dominated by the fine-grained siliciclastics of the Jemelle Formation (Vieux Moulin, Station, Cimetière and Chavées members). Its highstand recorded the development of small bioherms (Tienne Sainte-Anne Member) that grew as long as the accommodation space was available. When the sea level decreased, the latter emerged and were capped by a subaerial erosive surface. In proximal areas, this sequence is recorded in the Claminforge Member of the Rivière Formation.

The sequence MD4 straddles the Eifelian-Givetian Boundary. Locally, a lowstand system tract formed by the sandstone of the Lomme Formation deposited in the low areas between the Tienne Sainte-Anne bioherms. The transgressive system tract corresponds to the Hanonet Formation inside which the Kacak event was identified. The Givetian Trois-Fontaines Formation recorded the highstand (biostromal unit) and the falling-stage system tracts (lagoonal unit), capped by the next sequence boundary.

The sequence MD5 encompasses the Terre d'Haurs and Mont d'Haurs formations and passes in proximal settings to the Nevremont, Alvaux and Pepinster (p.p.) mixed and siliciclastic formations. The last sequence MD6 recorded a lowstand-transgressive system tract in the distal

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part of the basin (shaly limestone of the Flohimont Member of the Fromelennes Formation) and highstand system tract respectively in the Moulin Boreux and Fort Hulobiet members. In proximal areas, the Fromelennes Formation passes to the Le Roux and Mazy Members for which the record is rather hiatal. The sequence MD6 is terminated by emersion of the platform at the end of the Givetian and then by the deposition of the fine-grained siliciclastics of the Nismes and Presles Formations, with a hiatus increasing from south to north.

The sequence stratigraphic chart is constrained biostratigraphically and can be used as a correlation scheme throughout the shelf, notably to correlate lithologically distinct units.

Keywords: Middle Devonian, Givetian, Eifelian, eustacy, highstand, lowstand, trangression

The biostratigraphic and chemostratigraphic frameworks of Changtang section in South China: A continuous and complete section of the Frasnian-Famennian boundary

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The Late Devonian Frasnian-Famennian Boundary (FFB) witnessed a sharp decline of biodiversity of marine invertebrates, i.e., the F-F mass extinction, collectively known as the F-F mass extinction event, one of the big five mass extinctions in Phanerozoic. The F-F boundary may also experience an oceanic anoxic event, i.e., the Kellwasser Event (KE). To understand the biological turnovers and environmental changes in the F-F transition, it is critical to establish the high-resolution stratigraphic framework.
Here, we report the conodont biostratigraphy of the Changtang Section in South China, which transect the FFB. The Changtang section was located in the intra-platform basin of Yangtze Block, and is mainly composed of limestone. Compare to other sections in South China, the Changtang section records the most complete conodont zonation near the FFB, but lacks the direct geological evidence of KE, i.e., no black shale depositions. We integrate biostratigraphic and chemostratigraphic frameworks of the Changtang section, and compare it with other canonical sections in South China and the Global Stratotype Section and Point of FFB. Overall, the complete biostratigraphy of the Changtang section warrants its potential as a standard section of the FFB in China.

Keywords: Frasnian, Famennian Boundary, Kellwasser Event, South China, conodont belt, Changtang section, section assessment

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Are Devonian anoxic events astronomically paced? Cyclostratigraphy and numerical modeling as tools to assess potential relationships and causal mechanisms

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The Devonian Period witnessed 29 regional-to-global anoxic events, some of which are linked to major extinction episodes. Evidence of these abiotic and biotic events can now be found in the geological record and, for the Kellwasser Event, suggests a link between the pacing of ocean anoxia and astronomical forcing (2.4 Myr eccentricity nodes). However, a consensus on the mechanisms behind the Devonian events has not yet been reached. Commonly, Devonian anoxic events are characterized by a perturbation of the global carbon cycle (i.e. δ13C excursions) and are expressed as organic-rich black shales interbedded in carbonate-dominated sediment. However, expression of anoxic events as an unconformity, facies change, or hiatus have been reported as well – i.e. the expression of anoxic events is variable and depends on the paleoenvironment and paleogeography. In addition, most reports on Devonian anoxic events suffer from significant sampling bias, focusing mainly on the pantropical belt or being restricted to only a few localities. In the 'WarmAnoxia' project, we will attempt to consolidate existing and new observations from geological records with scenarios provided by numerical modeling to assess existing hypotheses and underlying mechanisms. Preliminary simulations with the model cGENIE indicate that the extent of the oxygen minimum zone is inversely proportional to the atmospheric CO2 concentration and, that part of the upper ocean is close to hypoxic/anoxic conditions at an atmospheric oxygen level of 70% of the current value. We also provide preliminary simulations of soil dynamics, nutrient fluxes, atmospheric oxygen levels and oceanic chemistry response by combining a complex atmosphere model with a module for soil dynamics and an ocean box model. A hierarchy of models will be used to assess a range of physical and biogeochemical hypotheses linking astronomical forcing to anoxia. On the other hand, application of cyclostratigraphy and carbon isotope stratigraphy will be used to constrain the temporal (phase) relationship between astronomical forcing and anoxic events recorded in the sedimentary record. Using a combination of numerical modeling and an integrated stratigraphic approach, it will be investigated whether complex multicausal factors and the 2.4 Myr eccentricity nodes can be associated with other Devonian anoxic events, either as a window of opportunity or rather the decisive trigger.

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Keywords: Devonian, Anoxic Events, Astronomical Forcing, Cyclostratigraphy, Modeling

Biostratigraphical correlation and palaeogeographic relations of the Middle-Upper Devonian carbonate successions in the Spanish Central Pyrenees

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The Devonian rocks of the Central Pyrenees are exposed in different facies settings. Pioneering stratigraphic studies carried out by Dutch geologists (University of Leiden) defined several *facies/subfacies areas,* which are distributed into four main facies areas (Mey 1967, Boersma 1973, Zwart 1979). Our main investigation is focused on the Southern Facies Area, which is located in the axial zone of the Central Pyrenees and comprises three of the four classical subfacies areas: *Sierra Negra*, *Renanué* and *Compte* (Mey 1967, Hartevelt 1970, Valenzuela-Ríos & Liao 2006).
Integrated conodont biostratigraphy and palaeogeographic relations of six successions from Middle to Upper Devonian (Givetian-Frasnian) in the Spanish Central Pyrenees are synthesized on the basis of published data (Liao 2014; Liao & Valenzuela-Ríos 2008, 2012 and 2022; Liao et al. 2002, 2008 and 2013; Gouwy et al. 2013).

These Devonian successions are Ampriú (Amp) and Ampriú II (*Sierra Negra Subfacies*), Renanué (*Renanué Subfacies*) and Compte, La Guardia d'Ares and Villech (*Compte Subfacies*).

In the Sierra Negra Subfacies, the *Renclusa limestone* comprises rocks from upper Givetian to Lower Carboniferous (Rios 1977). Pure, dark, grey and massive limestones interbedded by marly or lenticular calcareous shales compose Amp and Amp II sections. The conodont record in the Amp section indicates a late Givetian age and this limestone interval overthrusts middle Frasnian rocks. The precise age of the Amp II section could not be guaranteed by fossils, but litho- and sedimentologic characterization is very close to the upper Givetian part of the Amp section.

Mey (1967) introduced the *Renanué Subfacies*, which originally comprised a continuous succession spanning from Lower Devonian through Lower Carboniferous. This subfacies is composed of three main stratigraphical units: *Renanué Shales, Renanué Limestones* and *Sahún Shales.* Boersma (1973) defined the *Renanué Shales* alluding to the black shales below the *Renanué Limestones* and assigned late Emsian to Eifelian ages. Besides, he pointed out that the *Renanué Limestones* correspond to the dark and grey limestones interbedded with nodular limestones. In our investigations based on lithological characterization and faunal composition, the Renanué succession is composed of black shales (*Renanué Shales*) at the base, which is

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overlain by massive, bedded and nodular limestone (*Renanué Limestones*) and marly limestone in the upper part. Conodont data document a late Eifelian to early Frasnian age (Liao et 2001, Liao & Valenzuela-Ríos 2022).

The Compte Subfacies comprises four stratigraphic units: *Villech, Comabella, La Mena* and *Barousse formations.* The studied interval reaches the upper part of the Villech Fm. and mainly the Comabella Fm. The Villech Fm. extends widely and is mainly characterized by pink calcareous shales with thinner yellow limestones and lateral changes to red calcareous limestones. This lithological unit is bracket between the Basibé Fm. and Comabella Fm. Several authors assigned different ages for this unit. Our recent conodont investigation assigns an early Eifelian age for the Villech Fm. The Comabella Fm. is composed of nodular limestone (variable colours) with interbedded encrinitic limestones and shows a high diversity fauna. The age of this unit ranges from the upper Emsian to Frasnian/Famennian. Our studied area of this subfacies includes Compte, La Guardia d'Ares and Villech sections. Those sections exhibit the upper part of the Villech Fm. and the Comabella Fm. By means of conodonts, the age interval of the three sections ranges from lower Eifelian to middle Frasnian (Liao & Valenzuela-Ríos 2008, 2013; Gouwy et al 2013, 2016).
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Keywords: Middle, Upper Devonian, Central Pyrenees, conodonts, biostatigraphical correlation, paleogeography

Middle Devonian brachiopods and biostratigraphy in eastern Yunnan, China

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The Middle Devonian in eastern Yunnan consists of strata deposited under coastal to shallow-marine conditions. It contains many well-preserved plants and fishes, as well as benthic faunas. However, biostratigraphy and correlation among these sequences in the area remains poorly understood. The Middle Devonian in eastern Yunnan was re-investigated and updated in this study, with a special focus and discussions on the biostratigraphy of the Dongshan, Wutaishan, and Panxi sections.

The Middle Devonian Qujing Formation near the type area of Qujing City is exposed in the Wutaishan and Dongshan sections. The formation is characterized by limestones and marls containing brachiopods, corals, and stromatoporoids, with many intercalations of shales and sandstones that were possibly deposited in a frequent transitional environment from coastal zone to shallow shelf. The Qujing Formation near its type area is characterized by the *Meristella–Undispiriferoides* Brachiopod Assemblage, along with rugose corals *Temnophyllum*, *Spinophyllum*, *Endophyllum*, and the tabulate coral *Thamnopora*. The conodont *Bipennatus bipennatus* was recognized in bed NDS-CN01-2 in the Dongshan section. The species is especially abundant in the shallow-water facies of the lower to middle Givetian where coral- and stromatoporoid-bearing carbonates predominate.

Equivalent sequences in Panxi area are again represented by the Qujing Formation, which comprise bioclastic limestone–marlstone alternations with thick dolomite beds. Here, this formation has extremely diverse benthic faunas that contain the *Stringocephalus* Brachiopod Assemblage, rugose and tabulate corals and stromatoporoids from the lower and upper limestone members. This association is correlated with the middle part of the Qujing Formation in the type area. In the uppermost part of the Qujing Formation, carbonate deposits and benthic faunas are interrupted by massive input of clastic deposits. This could represent a global transgression associated with the Taghanic biocrisis that occurred in the middle–late Givetian. The biocrisis marked the end of extensive carbonate deposition and was characterized by the extinction of stringocephalids and the massive loss of biota of of the Phanerozoic reef ecosystem.

Keywords: brachiopod, Givetian, biostratigraphy, Taghanic biocrisis, South China

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The first discovery of Lochkovian (Lower Devonian) conodonts in central Guangxi, South China and its geological implications

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The Lochkovian, Pragian and basal part of the Emsian, which represent the post-Kwangsian Orogeny strata in the South China Block, are mainly composed of siliciclastic rocks. This lithology impedes the investigation of Pragian and Lochkovian conodont biostratigraphy in the South China Block, which results in a persistent controversy on the age of relevant lithological units. The present study provides new evidence by reporting for the first time Lochkovian conodonts obtained from the South China Block, specifically the Gaoling Member of the Nahkaoling Formation at the Lingli section, central Guangxi. The conodont fauna consisting of *Pandorinellina exigua lingliensis* n. subsp., *Pandorinellina exigua exigua* (Philip, 1966), *Zieglerodina*? *tuojiangensis* n. sp., *Amydrotaxis praejohnsoni* Murphy and Springer, 1989, and *Eognathodus* cf. *E. irregularis* Druce, 1971, dates the studied interval of the Gaoling Member as the lower or middle Lochkovian (contingent upon varying definitions of the base of the middle Lochkovian) to lower Pragian. Moreover, *Amydrotaxis praejohnsoni*, which was previously reported only in North America and eastern Australia, is herein also recorded in the South China Block, and thus may play an important role in the intercontinental biostratigraphical correlation. By shedding light on the age of the upper limit of the underlying Lianhuashan Formation at the Lingli section, the present study indicates that the Kwangsian Orogeny ended before the late Lochkovian. This age is slightly older than the previously estimated late Lochkovian based on the studies of fossil plants from the siliciclastic rocks deposited after the Kwangsian Orogeny.

Keywords: Lochkovian, Pragian, South China, Nahkaoling Formation, Kwangsian Orogeny

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Spore malformation, a terrestrial mass extinction and the definition of the Devonian-Carboniferous boundary

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Malformed land plant spores are abundant at the terrestrial Devonian-Carboniferous boundary in East Greenland. These are exactly coincident with spore extinctions with the lost of major clades that had dominated Mid and Late Devonian spore floras. These extinctions occur within the deepest, largest and most stable stratified lake within the East Greenland Devonian and Carboniferous succession. It is evident that this malformation results from the maturing spores being damaged by UV-B radiation whilst in the sporangium but before the protective spore wall was deposited. Alternative hypotheses of UV-B damage or poisoning during major eruptions is precluded by the absence of an Hg anomaly.
Now that we understand why the plants became extinct we can use this as a significant marker to define the Devonian-Carboniferous boundary in terrestrial and marginal marine sediments. This extinction can be identified worldwide including at high palaeolatitude in Gondwana.
In 2022 there was the rare opportunity to return to East Greenland and the Devonian-Carboniferous boundary on Celsius Bjerg during an expedition to collect latest Devonian tetrapods. The D-C boundary lake was cored using a backpack drill to acquire a complete record through the extinction event. This material is now being analysed for palynology, δ13C, TOC and carbonate % together with SEM backscatter imagery of fabrics. This provides a much better understanding of the relationship between the extinctions and development of the lake during the intense monsoon climate that accompanied the collapse of the terminal Devonian glaciation.

Keywords: Devonian, Carboniferous boundary, spores, malformation, UV, B, Greenland

*Speaker

Brachiopod-associated faunas in the Middle and Upper Devonian of the Baoshan Block: implications for biostratigraphy and palaeoenvironment

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The Baoshan Block constituted an important part of the Sibumasu Terrane which has a great palaeontological and palaeobiogeographical significance for the study of development of the Palaeotethys Ocean during the Palaeozoic. The block is defined by the Nujiang and Kejie-Nandinghe faults (the latter is a branching fault of the Jinshajiang Fault) in the western Yunnan Province of China. Devonian rocks in the Baoshan Block were named after the Heyuanzhai village of Shidian County, where thick fossiliferous successions of carbonate deposits were firstly investigated (Sun & Szetu, 1947). However, due to a lack of specific designation of the rocks and type section, the Heyuanzhai Formation was a matter of confusion regarding both stratigraphy and correlation. Herein the authors re-investigated the Devonian Heyuanzhai Formation in its type area in Shidian, with new discoveries on the sequences and their faunas in the Douyashan section.

The Heyuanzhai Formation in the Douyashan is mainly composed of greyish marls and limestone interbedded with yellowish calcareous shales and mudstones. A great number of fossils were collected from the successions, with detailed documentation of brachiopods, crinoids, and ostracods by the authors. In the lower and middle parts of the formation, the brachiopod Gypidula-Schizophoria-Spinatrypa assemblage is recognized and generally correlated to the Eifelian–Givetian. Whereas, in the upper part, the brachiopod Pugnax-Hypothyridina-Tenticospirifer assemblage is recognized for the first time, indicating an early-middle Frasnian age in terms of occurrences of new species of rhynchonellid and cyrtospiriferid brachiopods. The age determination was further supported by occurrence of the Middle and Late Devonian crinoids (Megaradialocrinus, Halocrinites, and Melocrinites) and ostracods (Palaeocopida, Platycopida, Metacopina and Podocopida).

The Heyuanzhai faunas from the Douyashan section are composed of abundant benthos (i.e., brachiopod, corals), along with long stems and well-preserved crinoid crowns as well as mixture of nearshore–offshore ostracod assemblages, demonstrating a relatively high-energy background. This is supported by sedimentary analyses, by which repeatedly well-bedded bioclastic packstone-floatstone generally demonstrating an overall high-energy background. Meanwhile, accumulation of shelly faunas in the upper Heyuanzhai Formation consists of unsorted brachiopods, crinoids, and coral debris, suggesting relatively turbulent condition of ramp. The presence of long stems and well-preserved crowns of crinoids in the muddy limestone of the

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Heyuanzhai Formation normally indicate nearly in-place degradation or relatively rapid burial subsequent to transport (as the discs and plates of crinoid are easily disarticulated after death). Alternatively, ostracods from the crinoid-bearing beds of the Heyuanzhai Formation demonstrating possible transportation and physical turbulence connected to storm wave or tempestite concentrations, in light of accumulation of both nearshore (type II) and offshore (type III) inhabitants. Overall, the facies association and fossil assemblages indicate that the faunas were possibly living in a ramp with high-energy setting between the fair-weather wave-base and the storm wave-base, and deposited in an environment that was typically derived from immediately adjacent habitats after short distance transportation.

Keywords: brachiopod, Devonian, Baoshan Block, Sibumasu, palaeoecology

Frasnian – lower Famennian stratigraphy and biota in the northern Gondwana margin preserved in Armenia

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The Upper Devonian sequences of Armenia consist of carbonate and siliciclastic sedimentary rocks, which deposited on a shallow water platform in the northern margin of Gondwana. Although they crop out only in a few places (Ertych, Djravank and Noravanak sections), they are rich in fossils (brachiopods, corals, bryozoans). These faunas were being studied since the 19th century and more systematically during the 1950s to 70s.
More particularly, the Frasnian–lower Famennian sequences of Armenia were subdivided into three 'formations' (Baghrsagh, Noravank and Ertych), which regrettably were mainly characterized by their fossil record, rather than distinct lithological differences. In practice, they have very similar lithological characteristics and they cannot be distinguished on the field without knowledge of their brachiopod assemblages.

Recent studies on brachiopods established that these benthic organisms are present essentially in two distinct limestone intervals, each one bearing a distinct brachiopod assemblage.

The lower limestone interval contains eleven brachiopod species; the assemblage is characterized by the presence of atrypides, in addition to some rhynchonellides and spiriferides. We establish a

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new brachiopod assemblage zone of Frasnian age, notably based on *Ripidiorhynchus gnishikensis.* Preliminary work on conodonts extracted from this limestone interval shows the presence of species including *Icriodus excavatus*, *I.*? *expansus*, *Polygnathus aequalis*, *P. praepolitus*, *P. webbi* and *P. xylus xylus* characterizing the Frasnian interval.

The upper limestone interval contains 24 brachiopod species; the assemblage is characterized mainly by the presence of spiriferide and rhynchonellide species and is assigned to the lower Famennian *Aramazdospirifer orbelianus–Tornatospirifer armenicus* brachiopod zone, which is correlated with the *crepida* standard conodont zone.
The limestone intervals are separated by 80-90 meters of terrigenous sediments, which are dominated by shales in its lower and upper parts and by mature sandstones in its middle part. Palynological preparations of shales coming mainly from the upper shales of the Ertych section allowed us to discover a miospore assemblage that may be correlated with the *triangulatus–catillus* and *langii–concinna* miospore biozones of northern Gondwana (late Givetian–late Frasnian). Most of the identified species, such as *Acinosporites lindlarensis, Geminospora lemurata*, *Kraeuselisporites ollii*?, *Samarisporties triangulatus, Ancyrospora langii*, *Cymbosporites caillus, Chelinospora concinna, Verrucosisporites nitidus?*, *Krauselisporites ollii*?, *Rugospora bricei* and *Teichertospora torquata* are similar to those coeval assemblages documented from Iran, Saudi Arabia, North Africa, Canada and Europe (Spain, Belgium). Moreover, the parent plants of miospores documented from the Ertych section mainly belong to different classes such as Rhyniopsida, Zosterophyllopsida, Lycopsida and Progymnospermopsida (Archaeopteridales and Aneuropthytales) assemblages, and the range of the latter varies from the late Givetian to the middle Frasnian.

Keywords: Frasnian, Famennian, stratigraphy, Armenia, Gondwana

Ostracod faunas from the Devonian-Carboniferous transitional intervals in Xainza and Nylam regions, Tibet

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Late Devonian to Early Carboniferous strata are well preserved in Tibet Plateau, China, but the fossils were poorly studied. Previous research on conodonts and spores from the Yali and Chaguoluoma sections enabled to approximately locate the Devonian-Carboniferous boundary in Xainza and Nylam regions. At Yali, three spore assemblages, including *Retispora lepidophyta–Verrucosisporites nitidus* (LN), *Vallatisporites verrucosus–Auroraspora incohatus* (VI) and *Cingulizonates bialatus–Auroraspora macra* (BM), and conodonts from the *Protognathodus kockeli* to *Gnathodus pseudosemiglaber* zones were reported, and the Devonian-Carboniferous boundary was placed at the base of the Goulongri Member of the Yali Formation. At Chaguoluoma, the occurrence of the conodont *Protognathodus* fauna was used to locate the DCB, but no photos of any specimen were provided. Our recent studies focus in the ostracod faunas from these two sections; 24 and 53 species were recognized at Yali and Chaguoluoma sections, respectively. Ostracods from the Yali section include *Bairdiocypris elliptica*, *Acratinella valida* and *Bairdiacypris wuxuanensis*etc. The *Bairdia magna* and *Paraparchites longmenshanensis*, which were firstly reported in Tournaisian, are found in the Goulongri Member of Yali formation. However, our new conodont collections recover both *Pr. kockeli* and *Siphonodella sulcata* below the Goulongri Member, lowering the DCB to the upper part of the Yalidonggou Member. Ostracods from the Chaguoluoma section include *Acratinella valid*, *Bairdia cestriensis* and *Microcheilinella cordata*, typically Late Devonian to early Carboniferous in age. Two early Carboniferous representative species, i.e. *Necrateria rectagona* and *Microcheilinella bushminae*, were firstly found 10.5 m above the base in the Chaguoluoma section. Moreover, major changes of ostracods abundance occur within the basal 8-10 m of the Chaguoluoma formation, more than 50 species are recorded within the lower 2-7 m while less than 5 species are found in the basal 8-10m. This change may be related to the Hangenberg extinction event in Tibet. In conclusion, the ostracod faunas have great potential to precisely locate the Devonian-Carboniferous boundary in theTibet Plateau.

Keywords: Ostracods, Devonian, Carboniferous boundary, Tibet

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The Pragian/Emsian boundary in the Huesca Province (Lower Devonian, Spanish Pyrenees): Biostratigraphic and magnetic data

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The different development of Lower Devonian strata and faunas lead to the extensive use of two different scales of difficult adjustment during the XIX and XX centuries (and even today). This situation prompted the IUGS and the corresponding International Subcommission on Devonian Stratigraphy (SDS) to establish an unified chronostratigraphic scale, which initially combined both scales. The resulting subdivision into three Stages: Lochkovian, Pragian and Emsian presented numerous difficulties, being the Emsian Stage one of the more complex and controversial. Based on the extensive work carried out by Yolkin and collaborators, the SDS decided to establish the base of the Emsian in 1994 with the entry of the conodont *Polygnathus kitabus* in the Zinzilban section (Kitab Geological Reserve, Uzbekistan). Numerous reports by Carls and Valenzuela-Ríos demonstrated the inaccuracy of this decision and the need to revise, as soon as legally possible, the boundary criterion.

In the SDS field conference held in the Kitab Geological Reserve in 2008, two major agreements were reached: 1) *P. kitabicus* is a good index but not for the base of the Emsian and we shall look for a different index. The proposed index was *Polygnathus excavatus* 114. 2) The intention to maintain the GSSP in the Zinzilban section, but in higher strata (those showing the entry of *Polygnathus excavatus* 114 within the phylogenetic branch of the *Polygnathus excavatus* group). Consequently, two international expeditions (2008 and 2015) searching for the new position of the boundary were launched in the Kitab Reserve. Unfortunately, results were not as expected and the SDS decided to expand the investigation to other potential areas.

One of them is the Spanish Pyrenees, were Pragian and Emsian strata crop out in several places. Two of these sections are Isábena 1 and Baliera 6 in the province of Huesca (Spanish Pyrenees). Both of them contain a rich conodont record spanning through the Pragian/Emsian boundary in both senses, the current and the proposed boundary (entries of *Pol. kitabicus* and *Pol. excavatus* 114 respectively). Besides, they

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also record taxa of the genus *Icriodus*, which allows direct correlations with those sections without polygnathids.
Taking into account these favourable conditions, we have started a combined comprehensive and multidisciplinary study of these two sections. In this report we present pioneer data of magnetic susceptibility aligned with the biostratigraphic ones.

Magnetic susceptibility trends and excursions are well characterised and dated and enable to start the construction of a multidisciplinary matrix of Pyrenean data, which in turn will confer the required stability for future decisions concerning the Devonian Time Scale and, in particular, the definition of the Emsian stage and its further subdivision.

This work is a contribution to IGCP652, to ICS program Regenerating the Time Lords: Towards the completion, calibration, digitization and outreach of the geological timescale, and the Research groups GIUV2017-395, GEOTRANSFER E32_17R and PERIGONDWANA UCM 910231. MIU-Next Generation EU (ZA21-005) supports J-C Liao research.

Keywords: Emsian, Spanish Pyrenees, conodonts, biostratigraphy, magnetism

Earliest Devonian marine environments and ecosystems of northeastern Gondwana: insights from lithofacies and trace fossils of the Lower Devonian Xiaxishancun Formation of Yunnan, China

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Strata deposited during the Silurian-Devonian transitional interval in the Qujing area, Yunnan, China, were assigned to the Yulongsi and Xiaxishancun formations. Unlike the underlying Yulongsi Formation, the Xiaxishancun Formation contains a large number of sandstones, indicating a significant increase in terrestrial input. Six sections of the Xiaxishancun Formation were studied, leading to the identification of three facies associations: mudstone-dominated facies association, heterolithic facies association and sandstone-dominated facies association. Storm deposits are common, indicating a shallow marine delta to shelf environment that was frequently affected by storm events. Sediments that were deposited with decreasing hydrodynamic energy after storm events and under the influence of fair-weather waves contain abundant trace fossils, including *Bergaueria*, *Chagrinichnites*, *Chondrites*, *Conichnus*, *Conostichus*, *Cruziana*, *Dactyloidites*, *Didymaulichnus*, *Diplichnites*, *Kouphichnium*, *Lockeia*, *Lophoctenium*, *Monomorphichnus*, *Oravaichnium*, *Olivellites*, *Palaeophycus*, *Parundichna*, *Planolites*, *Protovirgularia*, *Ptychoplasma*, *Rusophycus*, and *Selenichnites*. Our findings reveal a more flourishing benthic community than previously appreciated during the earliest Devonian, when storm deposits were common in low-latitudes of northeastern Gondwana.

Keywords: South China, Gondwana, Lower Devonian, Xiaxishancun Formation, trace fossils, storm deposits

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Variable paleoprecipitation in the Early Devonian Xujiachong Formation of Yunnan, China

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Elemental analyses of paleosol B horizons in the Lower Devonian Xujiachong Formation of Yunnan, China provide estimates of mean annual precipitation (MAP) and allow determination of humidity regimes. The chemical index of alteration minus potassium (CIA-K) and other proxies (CIA, CALMAG, Base/Al) were used to estimate paleorainfall. CIA-K values of the paleosols with high carbonate content indicate MAP estimates between 300 and 500 mm yr-1, with an average of 350 mm yr-1. CIA-K values of the paleosol with no or little carbonate indicate MAP estimates between 900 and 1400 mm yr-1, with an average of 1200 mm yr-1. Humidity provinces inferred from geochemical proxy-based estimates of evapotranspiration and energy influx from precipitation range from subhumid to perhumid, suggesting wetter conditions than the MAP estimates. Mass-balance reconstructions evaluate physical and chemical variations in the soil of the Xujiachong Formation, showing patterns of soil volume change (strain) and transport functions (translocation) of many major and trace elements. The upper portions of most pedons are characterized by net removal of K, Al and Si. Modest increases in Ca and Al are noted in the lower portions of the pedons. Quantitative estimates of paleoprecipitation and humidity provinces, together with mass-balance reconstruction, provide a deeper understanding of the paleoenvironment of the Lower Devonian Xujiachong Formation, which may provide insights into the habitat ecology of early vascular plants.

Keywords: South China, Lower Devonian, Xujiachong Formaiton, paleosol, paleoprecipitaion

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SC13: New stratigraphic insights into the Silurian story

The imprint of Astronomical cycles in the Ludlow part of the type-Silurian Cellon section in the Carnic Alps, Austria

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The Cellon section is the original section which forms the basis for the current Silurian conodont zonation on which the current Silurian timescale is based. The Cellon section including its conodont zonation has been thoroughly analyzed, reviewed and revised over the years, but no age constraints (absolute via U/Pb ash bed dating or relative via the construction of astrochronologies) are available for the Cellon section. It therefore remains unknown how much time the section actually encompasses. To get age constraints a cyclostratigraphic study was conducted on a new high resolution (_˜1cm) pXRF record of the Ludlow part of the Cellon section. Astronomical cycles ranging from the precession to long eccentricity can be visually recognized in the CaO, Al2O3 and Fe2O3 pXRF records. A clear bundling of cycles is observed in the record with 5-6 cycles contained within 1 small bundle and with 3-4 small bundles forming a larger bundle. This bundling results in a ratio of 21:3.5:1, which is akin to the 19,2:110:405 (21:3.6:1) ratio between precession, short eccentricity and long eccentricity. Of all the recognized cycles the small bundle (short eccentricity) is most pervasive in the record and is therefore chosen as the main astronomical cycles which is traced in the wavelet spectra of the CaO, Al2O3 and Fe2O3 pXRF records. The result is a short eccentricity-based age-model with uncertainties. Previous biostratigraphic studies indicated that there is a hiatus at 28.47m at the base of the Lau event. To estimate the duration of this hiatus first the 405kyr eccentricity cycle is extracted from the CaO, Al2O3 and Fe2O3 records split at the hiatus. The duration of the hiatus was then calculated by subtracting the sum of the duration between the last 405kyr eccentricity peak/through below the hiatus and the duration between the hiatus to the first 405kyr eccentricity peak/through above the hiatus from a complete 405kyr cycle which results in a duration of 123 +/-18 kyr for the Lau event hiatus. The resulting age model allows us to assign durations to the conodont zones, the Lau event, the different lithological units, the Ludlow Series and the Gorstian and Ludfordian Stages. One surprising results of the age model is that the Lau event has a relative short duration of only 444 +176/-47kys. The durations for the Ludlow, Gorstian and Ludfordian, (4622 +374/-306 kyr, 1432 +120/-95 kyr and 3190 +254/-210 kyr) are of similar duration as the current geological timescale however our astrochronological age model assigned durations are accompanied by significantly reduced uncertainties. The results from this study demonstrates that the imprint of astronomical cycles in the Ludlow part of the

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type-Silurian Cellon section is pervasive and of high quality allowing one to assign durations to different subdivisions contained within the studied section.

Keywords: Silurian Ludlow Cellon Austria cyclostratigraphy

An overview of black shales through the Ordovician–Silurian transition in South China: stratigraphy, distribution, and environment

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From late Katian (Late Ordovician) to early Telychian (Llandovery, Silurian), the Wufeng and Longmaxi (Lungmachi in Wade-Giles) black shales were widely distributed on the Upper Yangtze Platform, South China. They are the main intervals for shale gas production in China at the present stage. The stratigraphic research about these two formations started from the early 20th century, and after several decades of work, the graptolite biozonation sequence has been established and can be correlated globally. The Wufeng Formation includes four biozones, i.e., the *Dicellograptus complanatus*, *Dicellograptus complexus*, and *Paraorthograptus pacificus* biozones of upper Katian, and the *Metabolograptus extraordinarius* Biozone of lower Hirnantian. The Longmaxi Formation includes nine biozones, i.e., the *Metabolograptus persculptus* Biozone of upper Hirnantian, the *Akidograptus ascensus*, *Parakidograptus acuminatus*, *Cystograptus vesiculosus*, *Coronograptus cyphus* biozones of Rhuddanian, the *Demirastrites triangulatus*, *Lituigraptus convolutus*, *Stimulograptus sedgwickii* biozones of Aeronian, and the *Spirograptus guerichi* Biozone of lower Telychian. In recent years, with the exploration and production of shale gas from these two formations, biostratigraphic subdivision and correlation have been widely applied to many drilling cores in the Sichuan Basin. Meanwhile, three positive excursions of the organic carbon isotope are recognized, respectively in Hirnantian (HICE), around Rhuddanian and Aeronian boundary, and in late Aeronian. In addition, some preliminary cyclostratigraphic studies are carried out. The lithofacies paleogeography map, strata isopach map and paleotopography map for each graptolite biochrone of these two black shales were quantitatively reconstructed. The paleogeographic reconstructions revealed the circumjacent distribution pattern in the border area of Chongqing, Hubei, and Hunan provinces in the middle of Upper Yangtze Platform, and the stage-progressive distribution pattern from Guizhou to Chongqing in the south of Upper Yangtze Platform. Moreover, the migration routes of black shale depositional centers are described for exploring the preferred areas for shale gas. Comprehensive analysis shows that the formation of the Wufeng black shale was controlled by the regional restricted and stagnant marine environment formed by the connection of the southern old lands in South China during late Katian, while its disappearance resulted from the change of the global seawater circulation system due to the middle Hirnantian glaciation; the deposition of the Longmaxi black shale resulted from the anoxic environment at the bottom of the ocean due to the global sea level

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rise from the end of Ordovician to the earliest Silurian, and its diachronous facies change was controlled by the shallowing of seawater and the input of a large number of terrigenous clasts from middle Aeronian to early Telychian.

Keywords: Wufeng Formation, Longmaxi Formation, Biostratigraphy, Paleogeography, Shale gas

Silurian conodonts from western Yunnan and southern Xizang (Tibet), China

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The Wenlock to Pridoli conodont biozonation has been well established in many areas of the world, but has not yet been studied in China. The Silurian succession in western Yunnan and southern Xizang (Tibet) is relatively continuous and complete, but conodont biostratigraphy in these regions has not been extensively researched.
In this study, conodont samples were collected from the Laojianshan section in Baoshan of western Yunnan and the Yalai West II section in Nyalam of southern Xizang. In the Laojianshan section, seven conodont zonal units were recognized in the "Lichaiba" and Niushiping formations, including the *Pterospathodus amorphognathoides amorphognathoides* Zonal Group, the *Pterospathodus pennatus procerus* Superzone (probably only the Lower *Pterospathodus pennatus procerus* Zone), the *Ozarkodina sagitta sagitta* Zone, the *Kockelella ortus absidata* Zone, the *Kockelella crassa* Zone, the *Polygnathoides siluricus* Zone and the "*Ozarkodina*" *eosteinhornensis* s.l. interval Zone. Similarly, the Yalai West II section had five recognized conodont zonal units in the "Pulu Formation": the *Ozarkodina sagitta sagitta* Zone, the *Kockelella crassa* Zone, the *Kockelella variabilis variabilis–Ancoradella ploeckensis* Zonal Group, the *Polygnathoides siluricus* Zone and the "*Ozarkodina*" *eosteinhornensis* s.l. interval Zone. Based on these conodonts as well as the graptolites from the underlying strata, the "Lichaiba Formation" was assigned to the upper Llandovery (upper Telychian)-upper Wenlock (upper Homerian), the Niushiping Formation to the Ludlow-Pridoli, and the "Pulu Formation" to the upper Llandovery (upper Telychian)-Pridoli.
The late Telychian conodont fauna from the Laojianshan section indicates a distal, open-shelf depositional environment. The widespread distribution of Wenlock to Pridoli conodont species in the Baoshan and Nyalam regions suggests that the cosmopolitan characteristics of the conodont fauna from this period were due to the circulation of ocean currents.

Keywords: conodont, Silurian, Sibumasu, Tethyan Himalaya

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The mid-Homerian (Silurian) biotic crisis in offshore settings of the Prague Synform, Czech Republic: the links between the evolution of marine chemistry and changes in graptolite diversity

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The mid-Homerian crisis was recognized as a dramatic reduction of graptolite diversity by Koren' (1) and Jaeger (2) who called it the Lundgreni Event. This event has been documented globally in off-shore sediments from various regions located in temperate as well as tropical paleolatitudes (3). The mid-Homerian extinction was also recognized as a prominent overturn of conodont faunas in Gotland carbonate platform and named as the Mulde Event (4). The causes of the mid-Homerian crisis have not yet been fully elucidated. It has been suggested that the mid-Homerian biotic crisis is related to the global sea-level fall (5) which was associated with the Homerian glaciation (6, 7). Detailed study of this crisis is complicated by an incomplete sedimentary record on carbonate platforms due to global regression. For this reason, the offshore setting was chosen as a more suitable environment for a detailed analysis of the links between the evolution of marine chemistry and changes in graptolite diversity. The analysis was carried out on the shale-dominated Kosov Quarry section, central Bohemia, which preserves the most complete graptolite record across the mid-Homerian crisis in peri-Gondwanan Europe. Moreover, the evolution of graptolite assemblages of the Kosov Quarry section has recently been studied in detail (3,8). The results of geochemical investigations based on high-resolution sampling clearly demonstrate close links between the evolution of marine chemistry and changes in graptolite diversity during the mid-Homerian crisis. (1) Koren' (1991) Proceedings of the Estonian Academy of Sciences 40, 74–78 Geology. (2) Jaeger (1991) Neues Jahrb. Geol. Palaontol. Abh. 182, 303–354. (3) Manda et al. (2019) Palaeogeogr. Palaeoclimatol. Palaeoecol. 528, 14-34. (4) Jeppsson (1993) Proceedings of the Estonian Academy of Sciences 42, 23–27. (5) Loydell (2007) Geol. J. 42, 531–546. (6) Trotter et al. (2016) Palaeogeogr. Palaeoclimatol. Palaeoecol. 443, 34–48. (7) Grossman and Joachimski (2020) Oxygen isotope stratigraphy. In: Geologic Time Scale 2020, Elsevier, 279–307. (8) Štorch (2023) Bulletin of Geosciences 98(1). J.F. and B.F. acknowledge financial support from the Grant Agency of the Czech Republic (GA23-06198S).

Keywords: Silurian, Homerian biotic crisis, marine chemistry, graptolite extinction event.

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Evolution of Marine Chemistry during the Mid-Ludfordian Glaciation and the late Silurian Lau/Kozlowskii extinction events

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The Silurian was one of the most climatically unstable periods of the Phanerozoic as evidenced by several large positive carbon isotope excursions (CIEs) associated with extinction events. The primary triggers of these globally recognized CIEs and their links to the global carbon cycle and/or coeval changes in paleoenvironments, paleoecosystems, and palaeoclimate remain highly disputed. Attempts to test various hypotheses on the origin of the CIEs have been hampered by the lack of combined high-resolution geochemical/isotopic data and detailed sedimentological, paleontological, and biostratigraphic records from the same section.
One of the largest Phanerozoic CIEs, the mid-Ludfordian CIE (MLCIE; +8 to +12‰ in δ13Ccarb), was associated with the Mid-Ludfordian Glaciation, both recorded from different regions located in temperate as well as tropical paleolatitudes (1). The MLCIE was preceded by a globally recognized sea-level fall and the Lau/Kozlowskii extinction events. Based on new and published high-resolution geochemical records (δ7Li, δ13Ccarb, δ13Corg, δ18Oapatite, δ34Spy, δ44/40Ca, δ53Cr, 87Sr/86Sr, δ138Ba, 187Os/188Os, and redox-sensitive trace elements, (1,2,3,4)) from the Kosov section (Perunica, peri-Gondwana), which represents one of the most complete and well-studied MLCIE sections with detailed sedimentological, palaeontological and biostratigraphic records in the world, we explore the links between the evolution of marine chemistry and coeval changes in palaeoenvironment, palaeoecosystems, and palaeoclimate. Rapid and relatively short-term changes in marine chemistry and paleoclimate provide new tools for high-resolution global correlation of Ludfordian.
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Keywords: Silurian, Ludfordian Glaciation, Marine Chemistry, Lau/Kozlowskii extinction events

The mid-Homerian (Silurian) biotic crisis in offshore settings of the Prague Synform, Czech Republic: the links between the evolution of marine chemistry and changes in graptolite diversity

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The mid-Homerian crisis was recognized as a dramatic reduction of graptolite diversity by Koren' (1) and Jaeger (2) who called it the Lundgreni Event. This event has been documented globally in off-shore sediments from various regions located in temperate as well as tropical paleolatitudes (3). The mid-Homerian extinction was also recognized as a prominent overturn of conodont faunas in Gotland carbonate platform and named as the Mulde Event (4). The causes of the mid-Homerian crisis have not yet been fully elucidated. It has been suggested that the mid-Homerian biotic crisis is related to the global sea-level fall (5) which was associated with the Homerian glaciation (6, 7). Detailed study of this crisis is complicated by an incomplete sedimentary record on carbonate platforms due to global regression. For this reason, the offshore setting was chosen as a more suitable environment for a detailed analysis of the links between the evolution of marine chemistry and changes in graptolite diversity. The analysis was carried out on the shale-dominated Kosov Quarry section, central Bohemia, which preserves the most complete graptolite record across the mid-Homerian crisis in peri-Gondwanan Europe. Moreover, the evolution of graptolite assemblages of the Kosov Quarry section has recently been studied in detail (3,8). The results of geochemical investigations based on high-resolution sampling clearly demonstrate close links between the evolution of marine chemistry and changes in graptolite diversity during the mid-Homerian crisis. (1) Koren' (1991) Proceedings of the Estonian Academy of Sciences 40, 74–78 Geology. (2) Jaeger (1991) Neues Jahrb. Geol. Palaontol. Abh. 182, 303–354. (3) Manda et al. (2019) Palaeogeogr. Palaeoclimatol. Palaeoecol. 528, 14-34. (4) Jeppsson (1993) Proceedings of the Estonian Academy of Sciences 42, 23–27. (5) Loydell (2007) Geol. J. 42, 531–546. (6) Trotter et al. (2016) Palaeogeogr. Palaeoclimatol. Palaeoecol. 443, 34–48. (7) Grossman and Joachimski (2020) Oxygen isotope stratigraphy. In: Geologic Time Scale 2020, Elsevier, 279–307. (8) Štorch (2023) Bulletin of Geosciences 98(1). J.F. and B.F. acknowledge financial support from the Grant Agency of the Czech Republic (GA23-06198S).

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Keywords: Silurian, Homerian biotic crisis, marine chemistry, graptolite extinction event

Genicular structures of retiolitines (Graptolithina) as an indicator of the environmental changes across the lundgreni biotic crisis during the Homerian, Silurian

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Variable environmental changes during the Silurian are expressed in the adjustment of the graptolite plankton diversity. One of the most dramatic changes was caused by the *lundgreni* environmental crisis which was not survived by most of the monograptids and retiolitines. One of the best adaptations to the varying environmental conditions was shown by the retiolitines, diplograptid graptolites having an additional layer of periderm, built mostly by cortical bandages. The retiolitine *Gothograptus* lineage started to evolve successfully during the *lundgreni* Biozone. Some significant characters of these colonial animals are clearly visible in the *Gothograptus* lineage. The gothograptids were one of the first groups of retiolitids to have developed a genicular list, being a border between the protheca and metatheca. It gives the possibility of growing additional structures, named genicular structures. Short, cylindrical rhabdosomes (tubaria) of *Gothograptus* were ended by the appendix depicting the finite growth of colonies. The appendix probably represented a modified theca of the last zooid. The genicular structures in *Gothograptus* from pre-*lundgreni* event were some kind of apertural covers. One of the most spectacular genicular structures is the reticulated veil of *Gothograptus velo*, growing down covering the orifice and the metathecal part of the previous theca. Some of the veils are connected to the veil of the previous theca, forming an external layer above the thecal orifices and thecae. Thus the entrance to the thecal tube was long and narrow. Differently developed were the thick genicular hoods of the post-*lundgreni* *Gothograptus nassa* in the *nassa* Biozone, the survival time. This type of apertural structure appeared for the first time in *G. kozlowskii*, living during the *lundgreni* Biozone. All these structures were located close to the tubarium wall; they did not extend laterally. The apertural structures developed in the new retiolitine fauna of the recovery period after the *lundgreni* extinction event have a different aspect. They extended laterally from the tubarium and did not cover the thecal orifices. The largest, most developed apertural structures extending horizontally from the ventral wall of the tubarium were developed in *Papiliograptus retimarginatus* from the *praedeubeli/deubeli* Biozone. Their construction was made by two distinct thickened edges forming an obtuse angle with each other. Between the thick edges, the delicate reticulum was spread. The distance between the tips of the genicular processes (2.5 mm) is about twice as wide as the width of the lateral wall of the mature tubarium (1.1 mm). This comparison shows the great size of the extending genicular structures. The two types of colony development, the *Gothograptus* type vs. *Papiliograptus* type, show adaptations to the two extremely different environments occurring in the Homerian. The compact colonies of

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Gothograptus were adapted to highly turbulent water rich in oxygen and food: the surface layer of the oceans. This type of tubarium with the genicular hoods closely covering thecal orifices allowed hiding the zooids inside and surviving the high-energy environment. The new retiolitine fauna derived from the surviving gothograptids was able to develop new type of colonies during the recovery time, with extensive and delicate genicular structures as in *Papiliograptus*. This indicates calm and nutrient-rich waters. In summary, the development of the genicular list in retiolitines gave the possibility of surviving the big *lundgreni* environmental crisis and gave them an evolutionary advantage over other graptolites. Thus the large retiolitine diversity changes across the Homerian, the *lundgreni* extinction interval, provides some inside into environmental changes.

Keywords: Key words: Graptolithina, Retiolitine, genicular structures, environmental changes, adaptation, Silurian

The El Pintado section, Spain: replacement GSSP for the base of the Telychian

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Graptolites offer the best means of defining the base of the Telychian Stage, particularly as there are no major changes in chitinozoan or conodont faunas around this time. The most suitable section for the GSSP for the base of the Telychian Stage is that at the east end of El Pintado reservoir, Seville Province, Spain, which lies within the Sierra Norte de Sevilla UNESCO Global Geopark (Gutiérrez-Marco et al. 2021). Here, the base of the *Spirograptus guerichi* Biozone, 0.6 m above the top of a layer of decalcified nodules, in a continuously graptolitic, predominantly black shale section, is selected as the level for the "golden spike". The graptolite biostratigraphy and organic carbon isotope record of the El Pintado section were presented by Loydell et al. (2015). In addition to the changes in graptolite faunas in the lowermost Telychian (e.g. FAD of *Spirograptus guerichi*, FAD of *Pardiversograptus runcinatus*, major diversification of *Streptograptus*), a negative δ13Corg excursion (the Rumba low) close to the base of the Telychian offers a means of chemostratigraphical correlation.
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Keywords: Silurian, Telychian, graptolites, biostratigraphy, chemostratigraphy

*Speaker

Pridoli conodont and ostracod biostratigraphy from Hazro, SE Anatolia, Turkey

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This contribution is the result of a joint venture by the Research Center Julich and the Bundesanstalt f. Geowissenschaften u. Rohstoffe (BGR) established 2005 and extended with colleagues from Italy and Austria in 2022. Previous results were published by Kranendonck (2004), Luppold (2008), Dojen (2009) and Lupplod et al. (2012).
The Hazro area in SE Anatolia, Turkey, is part of the Arabian Plate which adjoined the Tauride Block at the northern border. Both tectonic units strike the Assyrian/Zagros suture. The investigated succession is situated within the Border Fold zone and is part of the Hazro anticline, where Palaeozoic non-metamorphic sequences with a low thermal stage are exposed. The total thickness of the sequence is 700 m thick and includes Palaeozoic to Tertiary sediments.

The investigated Silurian carbonate sequence was deposited in an eroded anticline, which was deposited in a near shore environment at the northern margin of Gondwana. New biostratigraphic investigation enabled a new subdivision of formerly lithostratigrphic units. The lower part of the sequence is characterized by the Silurian Middle Dadas Formation (64 m) with black marl- and siltstones (Kranendonck 2004). The upper part of these sequence shows a biocalcarenitic limestone which grades to dolomitic limestone/claystone succession (12 m). The upper part belongs to the Devonian Upper Dadas Formation (54 m) represented by marl-, silt- and claystones and the Hazro Formation on top.

Beside the key section (Fetlika I) another section has been investigated only few meters away from the first one (Fetlika II). In contrast to Fetlika I, in Fetlika II there are some additional fossilferous limestones above the biocalcareneitic limestone unit with frequent brachiopod shells which were preliminary determined as Pridoli/Lochkovian in age. The facies reconstruction comprises proximal to distal sequences of a middle to outer shelf (Kranendonck 2004).

The first report on conodonts in this area were made by Fontaine et al. (1980). Beside conodonts, our samples (3 to 11 kg) contains a rich well preserved ostracod-fauna of fine-grained pyrit. The preservation corresponds to the Colour Alteration Index (CAI) of less than 2, indicating a low-grade temperature. Most of the specimens show the white matter.

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Twelve conodont species, belonging to 7 genera (*Coryssognathus*, *Oulodus*, *Ozarkodina*, "*Ozarkodina*", *Panderodus*, *Wurmiella* and *Zieglerodina*) were collected. The association can be referred to the lower-middle Pridoli "*Oz.*" *eosteinhornensis* s.l. interval Zone and Lower *Oul. el. detortus* Zone.

Representatives of family Spatognathodontidae dominates the fauna, whereas conoform elements are very rare. The basal phosphatic quarz layers are of special interest, because the conodont faunas contain more frequent specimens, most of gerontic age as in other layers, so it seemed to be a horizon of assorting mechanism. Other comparable rich conodont faunas appear at the upper part of the section, in limestone layers of a distal environment. In these limestones ramiform elements are very common and of good preservation, because a quiet water environment is assumed.

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Keywords: Silurian, conodonts, ostracods, Turkey

Integrated stratigraphical study of the Rhuddanian-Aeronian (Llandovery, Silurian) boundary succession in the Rheidol Gorge, Wales: A proposed Global Stratotype Section and Point for the base of the Aeronian Stage

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The Rheidol Gorge section, approximately 17 km east of Aberystwyth, mid Wales, exposes a ca. 20 m-thick succession of Llandovery (Silurian) strata from the upper Rhuddanian *Pernerograptus revolutus* Biozone through the lower Aeronian *Demirastrites triangulatus* Biozone and basal *Neodiplograptus magnus* Biozone. The section records deposition under a range of bottom-water oxygenation states. The Rhuddanian-Aeronian boundary is located 0.8 m above an abrupt lithological change from predominantly organic-poor, bioturbated 'oxic' mudrocks to an interval of black, richly graptolitic 'anoxic' shales. The graptolite fauna through the boundary interval, including the local lowest occurrence of *D. triangulatus*, allows precise correlation with other parts of the world. Graptolite assemblages indicative of separate divisions in the underlying *revolutus* Biozone and of the lower, middle and upper parts of the *triangulatus* Biozone are also present. Chitinozoans are relatively well preserved in the section and indicate the *Spinachitina maennili* Biozone throughout the boundary interval, as is widely the case. The results of carbon isotope analyses from organic matter indistinctly show the weak interval of positive shift in δ13Corg values through the Rhuddanian-Aeronian boundary interval, as observed globally, though local or regional processes appear largely to overprint the global signal. Overall, the excellent biostratigraphical record, well-documented local and regional stratigraphical context, historical significance, as well as easy access and assured long-term preservation, mean that we propose the Rheidol Gorge section as a strong candidate for a new Global Stratotype Section and Point for the base of the Aeronian Stage.

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Keywords: Silurian, Rhuddanian, Aeronian, GSSP, Graptolites, Chitinozoa, Carbon Isotopes

Chemostratigraphy of the Silurian from Łupianka – 2 outcrop (Sudetes, Poland): A preliminary report

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Łupianka – 2 outcrop is located on Łupianka mountain in the Bardo Mountains of Central Sudetes (South West Poland) which belong to Saxothuringian Zone of Central European Variscides. The Saxothuringicum was a part of the Armorican Terrane Assemblage located on the southern hemisphere in the southern part of the Rheic Ocean near northern Gondwana margin during the Silurian Period. Present data is the first preliminary record of carbon isotope chemostratigraphy in the Silurian succession of the Saxothuringian Zone. Pelagic black, gray, grayish and greenish argillitic shales, about 7 m in thickness, crop out at the Łupianka – 2 section sampled for carbon isotope analyses. Samples for δ13Ccarb analyses have been collected approximately every 0.1 m. For the purpose of the δ13Corg analysis, the samples were powdered and dissolved using HCl acid for 24 hours to remove carbonate minerals. Dried samples were analyzed by isotope ratio mass spectrometer. Graptolite fauna is rare in the analyzed samples. However, such graptolites as *Cyrtograptus* cf. *centrifugus* Bouček from the lower part, and *Cyrtograptus* cf. *multiramis* Törnquist from the upper part of Łupianka – 2 section allowed for stratigraphic assignment of the section to the uppermost Telychian (Llandovery) – lowermost Homerian (Wenlock) interval. Sampled section can be divided in three parts according to δ13Corg values. The lower part comprising 7 samples is marked by δ13Corg values that vary from -29.63 to -29.95 ‰. In the middle part of the section (0.9–2.5 m) the δ13Corg values rise to -27.96 ‰ and then vary around -28 ‰. We assume that this part could be linked to the Ireviken positive carbon excursion with rise, stable and fall zones. The upper part of the sampled section (2.6–2.9 m) yields the lowest δ13Corg values that, with some fluctuations, vary around -31 ‰.

Keywords: δ13Corg, Silurian, Bardo mountains

*Speaker

Proposal for the subdivision of Přídolí Series based on stratigraphic markers defined in Central Bohemia

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The Silurian System consists of four series, three of them further subdivided into stages. The definition of the Přídolí Series as the fourth division has been the only major addition to the Silurian System in over the past 100 years (Kříž et al. 1986). Since then the Přídolí remains the only series recognized by the IUGS that has not been formally divided into stages. The Přídolí Series has been defined in the Prague Synform. The Series represents an interval of faunal changes, which strongly influenced the middle Palaeozoic transformation of marine ecosystem. Herein, the two-fold subdivision of the Přídolí Series is proposed into a lower Jarovian Stage and an upper Radotinian Stage. The base of the Jarovian Stage corresponds to the base of the Přídolí in its defined GSSP. The graptolite *Wolynograptus bouceki* is suggested as the critical marker to define the base of the upper Radotinian Stage. The conodont *Oulodus detortus* enters close to the base of the *bouceki* Biozone together with the cephalopod *Kopaninoceras fluminese*, which is abundant in the Přídolí strata across peri-Gondwana. Bivalves and the common brachiopod *Dayia bohemica* are useful for tentative interregional correlation. The appearance and proliferation of scyphocrinid crinoids represent a time specific biofacies in the Radotinian Stage. A shift to slightly positive $\delta 13$Ccarb values coincides with the base of the *bouceki* Biozone in sections of the Prague Synform. The Hvížďalka section with uninterrupted sedimentation and integrated graptolite and conodont biostratigraphy and geochemical proxies is proposed for potential stratotype of the Radotinian Stage.

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Keywords: Přídolí Series, Subdivision, GSSP, Stratigraphy, Prague Synform, Silurian

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Expansion of Reducing Marine Environments during the Ireviken (Silurian) Biogeochemical Event

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The Silurian was a dynamic interval in Earth's history with an overall high sea level and shallow epeiric seas covering large basins. There are several major biogeochemical events recorded globally in the extensive carbonate sections that formed during this period. One of these events, the Ireviken Biogeochemical Event (IBE), occurs across the Llandovery-Wenlock boundary and includes a major positive carbon isotope excursion, increased biotic turnover, and other significant geochemical perturbations. Recent work hypothesized that an expansion of reducing environments led to an increase in organic carbon burial – driving the Ireviken Carbon Isotope Excursion (ICIE). The IBE is recorded in the Altajme core from Gotland, Sweden, which provides a well-preserved and expanded stratigraphic section ideal for high-resolution sampling. Previous work on this core has resulted in the creation of the highest resolution record of the ICIE ever produced. Here, we present δ34Spy (pyrite) and δ34SCAS (carbonate-associated sulfate) data through this interval from the Altajme core that are indicative of a local signal of increased microbial sulfate reduction (MSR) and therefore an increase in the expansion of reduced environments locally. Additionally, δ34SCAS data compiled from nearby and distant basins provide further evidence for the global expansion of reducing environments throughout the oceans during the IBE.

Keywords: Silurian, Ireviken, Sulfur, Carbon

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Hlásná Třebaň section, Czech Republic: A proposed global stratotype for the base of the Aeronian Stage

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The Hlásná Třebaň section, approximately 17 km southwest of Prague fulfils all formal requirements for stratotype of a chronostratigraphic unit, and should be considered as a candidate for the new Global Stratotype Section and Point (GSSP) of the Aeronian Stage (Llandovery Series, Silurian System). The structurally simple section is somewhat condensed but there is a uniform succession of black shale without any evidence of disconformity in the broad Rhuddanian/Aeronian boundary interval. An abundant, well-preserved, diverse graptolite fauna occurs through the section and allows precise correlation with other parts of the world. The section comprises the lower–middle Aeronian (*Dem. triangulatus*–*Lituigraptus convolutus* graptolite biozones) along with underlying Rhuddanian (*Akidograptus ascensus*–*Coronograptus cyphus* biozones) and Hirnantian strata. The lowest occurrence of the graptolite *Demirastrites triangulatus*, 1.38 m above the base of anoxic black shale succession of the Želkovice Formation is proposed to mark the base of the Aeronian Stage. Several graptolite genera of primary importance in global correlation (*Demirastrites*, *Petalolithus*, *Rastrites* and *Campograptus*) first appear in the lower part of the *triangulatus* Biozone. A chitinozoan assemblage indicating the *Spinachitina maennili* Biozone, spans the boundary interval. The C*org* isotope record exhibits a minor positive excursion just above the base of the *triangulatus* Biozone, whereas TOC and N isotope and elemental geochemical records provide evidence for uninterrupted sedimentation under stable, anoxic conditions.

Keywords: biostratigraphy, chronostratigraphy, geochemistry, graptolites, GSSP proposal, Silurian

*Speaker

Graptolite-rich Ordovician-Silurian boundary and Rhuddanian reference section in the south-central Pyrenees, Spain: stratigraphy and correlation

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An Ordovician–Silurian boundary section described from the south-central Pyrenees of Spain, comprises the uppermost part of the quartzite-dominated Bar Formation and overlying black shales of late Hirnantian and Rhuddanian age which have been dated by graptolites to the *Metabolograptus parvulus* (upper *Metabolograptus persculptus*), *Akidograptus ascensus*–*Parakidograptus acuminatus* and *Cystograptus vesiculosus* biozones. The structurally simple Estana section is remarkable by an uninterrupted, relatively high rate black-shale sedimentation and abundant, diverse graptolites. The succession of graptolite assemblages and occurrence of several cosmopolitan taxa in its *parvulus* and lower *ascensus–acuminatus* biozones that are unknown elsewhere in peri-Gondwanan Europe suggest that strata immediately surrounding the O–S boundary are either absent, highly condensed, or oxic and barren of graptolites in many other sections of north-western peri-Gondwana. The whole succession of uni-biserial dimorphograptids (*Dimorphograptus elongatus*, *Dim. extenuatus*, *Bulmanograptus swanstoni/confertus*, *Bul. decussatus*, *Bul.*? *compactus*), associated with successive appearances of early monograptids (*Coronograptus praematurus*, *Atavograptus atavus*, *Huttagraptus acinaces*) is preserved in the *vesiculosus* Biozone. *Atavograptus atavus* and *Huttagraptus acinaces* subzones of the *vesiculosus* Biozone are recognized in the Estana section. Present succession is well correlatable with that described from Scotland and elsewhere in the UK. Absence of the former subzone in Bohemian sections, however, accounts for another, although less widespread gap in Rhuddanian black-shale sedimentation.

Keywords: Ordovician, Silurian boundary, graptolites, stratigraphy, Spain

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Review of the Silurian in Belgium.

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Since the last review on the Silurian in Belgium (Verniers et al. 2001), much new fieldwork and studies with detailed logging in boreholes and outcrops in the Brabant Massif and in the Condroz Inlier, increased our knowledge but often went unpublished in PhD's, MSc's and reports. Especially in the Condroz Inlier continuous lithologs could be recorded (Puagne area: Criptia and Genicot formations; Neuville-sous-Huy area: formations of Genicot, Neuville-S-H, Naninne, Jonquoi and Thimensart), and in the Orneau valley of the Brabant Massif: the Bois Grand Père, Fumal and Vichenet formations.
Detailed sampling in those sections produced moderately well preserved chitinozoan assemblages allowing to describe an accurate biozonation (Mortier 2014 Mortier *et al* subm.) and together with previous studies in boreholes of the Brabant massif (chitinozoans by Van Grootel 1990 unpublished, Zalasiewicz (in Van Grootel et al 1998) and more recent unpublished studies, for the first time a chitinozoan biozonation can be proposed for the entire Silurian of the Brabant massif (with14 assemblage biozones and 15 subzone) and another for the entire Silurian of the Condroz Inlier (with more than 12 assemblage biozones).

This biozonation and correlation with well dated sections in Avalonia and the Baltic area allowed a revision of the definitions of the Silurian lithostratigraphic units and propose a more accurate chronostratigraphical dating of the different subparts of the Brabant massif and the Condroz inlier. It appears that the Silurian sequence is thick in the Brabant Massif and less in the Condroz Inlier, which was already well known, but it appears that still many parts are missing in both areas. Several trends in oxic-anoxic cycles, sea-level change and facies change can now better be located in time.

In detail, it is shown that the late Hirnantian to lower Llandovery transition is well exposed in Tihange, Condroz Inlier (Pereira et al. 2021). The *convolutus* sea level drop followed by transgression well evidenced in the Llandovery area, Wales, proofs also to be present in the SW part of the Condroz: with Genicot Fm, covering a incision history and in the Brabant massif with a thin conglomerate in a borehole, a limited amount of missing strata below. The Corroy Formation (Brabant Massif, Sheinwoodian) is no more the time equivalent of the Naninne Formation (Condroz Inlier), as long postulated in literature: the latter is now dated upper Telychian (time slice Te5). The Ireviken extinction event observed in most fossil groups happens somewhat differently for the chitinozoans. The Corroy Formation is interpreted as deposited during a sea level low. In its top, already in the post-*riccartonensis* - *flexilis* biozone, an important extinction of the taxa occurs with nearly no changes lower down, Higher in the sequence the sea-level rises. The Mulde event is only visible with poorer chitinozoan assemblages. The

*Speaker

early Ludlow sea-level rise and maximum flooding surface is well visible sedimentologically low in the Ronquières Fm (Brabant Massif).

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Keywords: Silurian Belgium lithostratigraphy biozonation Chitinozoans graptolites

Chitinozoans of the GSSP candidate for the Rhuddanian-Aeronian (Silurian) boundary in the Hlásná Třebaň (Prague Basin, Czech Republic)

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The Hlásná Třebaň section exhibits a continuous, uninterrupted sedimentation with excellent graptolite biostratigraphic control across the Rhudanian-Aeronian boundary. For this reason, the section is proposed as a candidate for GSSP of the base of the Aeronian Stage (Štorch et al. 2018). To improve the biostratigraphic correlation potential of the section, a complementary study on chitinozoans has been conducted. In total 42 samples from identical levels as those for graptolite and carbon isotope studies have been analysed for chitinozoans by the standard palynological method (HCl & HF dissolution). Obtained organic residues show a high amount of organic matter. Chitinozoan preservation varies from moderate to poor. The main preservation bias on chitinozoans is most commonly present in the form of pyritization and as a lack of tiny ornamentation structures. Regarding genera, chitinozoans show a relatively diverse assemblage, including typical lower Silurian taxa such as *Angochitina*, *Ancyrochitina*, *Belonechitina*, *Conochitina*, *Cyathochitina* and *Spinachitina*, yet individual genera are unevenly distributed across the section. For example, *Belonechitina* specimens show an abundance peak in the lowermost part of the investigated section, i.e. in the *vesiculosus* and the *cyphus* graptolite biozones. On the other hand, *Spinachitina* specimens are most abundant in the *triangulatus* graptolite Biozone. Such a patchy occurrence suggests a possible ecological control on distribution of the respective chitinozoan genera. No significant turnover of chitinozoan faunas has been observed near the lowest occurrence of *Demirastrites triangulatus* – a proposed marker of the Aeronian Stage, neither across the whole sampled interval.
Spinachitina fragilis and *Belonechitina postrobusta* represent species commonly used for lower Silurian stratigraphy, however their ranges have been questioned recently. The presence of a global biozonal species *Spinachitina maennili* is suggested, yet not confirmed, due to the unfavourable preservation.

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Keywords: GSSP, Silurian, chitinozoa, Rhuddanian, Aeronian, biostratigraphy, Prague Basin, Hlasna Treban

δ13Ccarb isotope excursion through the lower Silurian of Ledai-179 borehole (Eastern Lithuania)

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Lithuania is located in the eastern part of the Silurian Baltic Basin, a region which was located near the equator during the Silurian. The Ledu -179 borehole is in the eastern part of Lithuania. The lower Silurian geological section of the Ledu -179 borehole is composed of carbonate and sulfate deposits and represents shallow-marine and lagoonal environments. Biostratigraphic and lithostratigraphic evidence indicate that the Adavere, Jaani, and the lower part of the Jaagarahu regional stages are present in the Ledu -179 borehole.
Samples were collected from the interval between 798.5 – 700 m of the Ledu -179 borehole for δ13Ccarb isotope analysis, at a rate of approximately one sample every 1 m. Stable carbon isotope values from carbonates were measured using a Thermo Gasbench II coupled with a Thermo Delta V isotope ratio mass spectrometer.

The δ13Ccarb values are moderately stable, ranging from 0.84‰ to 1.54‰ in the Švenčionys Formation. In the lower part of the Sutkai beds (783.6 m) values rise continually from 1.929 to 3.43 ‰ peaking at 763 m. Succeeding δ13Ccarb values are moderately stable (about 3 ‰) up to 750 m with a few minor spikes of 3.83 ‰ and 3.66 ‰. In the lower part of the Jonava Beds values decrease to 0.54 ‰ at 733 m. This positive δ13Ccarb excursion can be linked to the Ireveken Event of the lower Wenlock. The ranuliformis conodont Biozone is also documented in this interval of the Ledu-179 well core. δ13Ccarb values fluctuate slightly between 734 m and 700 m of the core profile in Birštonas Formation and vary around 0 ‰ (main spikes are -0.63 ‰ and 0.389‰).

In summary, δ13Ccarb values vary from – 0.96 ‰ up to 3.84 ‰ in the lower Silurian of the Ledu-179 well core. Such a large range of δ13Ccarb values could be related to shallow marine environments and local peculiarities in sedimentation. A more detailed biostratigraphic and lithological study is needed for better understanding of the stratigraphy of the Silurian geological section in the Ledu-179 borehole in the future.

*Speaker

Keywords: Lithuania, chemostratigraphy, lower Silurian

SC14: Ordovician: correlation of events

Back to the roots: basic biostratigraphy: Ordovician acritarchs from north-eastern Morocco and north-western Algeria

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Numerous early Palaeozoic sediments are poorly preserved, with metasedimentary sequences with no fossil preservation, except moderately to poorly preserved organic-walled microfossils. Acritarchs have often been the last chance to provide age indications, sometimes with little biostratigraphic precision, but nevertheless useful for first stratigraphical assignements.
A number of small tectonic inliers (traditionally named 'boutonnières') include Palaeozoic rocks in north-eastern Morocco and north-western Algeria. The area is commonly referred to as eastern Meseta by Moroccan geologists, or the Atlasic Domain ('domaine atlasique') by Algerian authors. The stratigraphical correlation of most units in the inliers remains problematical. The age of the inliers is very often uncertain, although Palaeozoic fossils have been recovered from several horizons. With the objective to provide better biostratigraphical information, a number of palynological studies have been carried out.
Our new investigations concern the Tazekka and Zekkara inliers in Morocco and the Tlemcen and Traras mountains in Algeria. Whereas the new investigations in the Zekkara inlier did not provide results, the 'Schistes de Tazekka' at the base of the succession (lower part of the Bou Chfâa Formation) of the Tazekka Inlier yielded an acritarch assemblage typical of the peri-Gondwanan margin, including the palaeobiogeographical index taxa Coryphidium and Striatotheca, pointing to a Floian age. Stratigraphically above these levels yielding Floian acritarchs, 'Llanvirn' graptolites were found in the upper part of the Bou Chfâa Formation.
In Algeria, the investigations in the Tlemcen Inlier remained unsuccessful. However, the discovery of acritarchs in the 'Formation des Psammites bioturbés' provides a first stratigraphic attribution (Middle to Upper Ordovician) of the oldest sediments in the Traras Mountains.

Keywords: Acritarchs, Tazekka Inlier, Tlemcen Inlier, Ordovician, Peri, Gondwanan

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The Crozonaspis incerta Biozone (Middle Ordovician) in the Iberian Peninsula: shallow water sands, storms and particular biofacies correlation

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The *Crozonaspis incerta* Biozone was first defined in Normandy (W France) by the vertical range of its eponymous trilobite, which occur associated with a particular assemblage of homalonotid trilobites of the genera *Eohomalonotus*, *Iberocoryphe*, *Kerfornella* and *Plaesiacomia*. It comprises a dozen species occurring exclusively in sandstones, being interpreted as representing a very shallow nearshore biofacies, the most proximal known in high-latitude Ordovician Gondwanan shelf. Given its environmental dependence, it is difficult to assess the biostratigraphic value of this association.

Unlike the scarce records in the Armorican Massif (Lower May and Mont de Besneville formations), this trilobite assemblage dominated by homalonotids, few representatives of *Crozonaspis* (*C. incerta, C. armata*) and a single *Neseuretus* species (*N. henkei*), is much more widespread in the Iberian Peninsula, as shown herein.

In a somewhat correlatable way with Normandy, the *C. incerta* Biozone reaches its maximum development in the southernmost part of the Central-Iberian Zone, coinciding with the shallowest part of the Iberian Gondwanan shelf. There, Dobrotivian (upper Darriwilian to lowermost Sandbian) strata are mainly represented by medium-grained sandstones bearing this homalonotid biofacies, but a similar assemblage is also recorded in a parallel belt dominated by siltstones and sandstones, following the gentle seaward slope of the Iberian shelf to the north and northeast (present-day coordinates). The record of *C. incerta* Biozone in this deeper area is limited to intercalations of sandstones or to lenticular coquinas evidencing short living conditions for homalonotid communities, removal by storms or transport by offshore currents. Certain

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widespread homalonotids, such as *Plaesiacomia* and *Kerfornella*, can also live in finer sediments. To the N and NE, there is the extensive muddy shelf that characterised the northern Central Iberian Zone, where coeval shales and siltstones are devoid of sandstone intercalations and these trilobites are unknown.

In Spain, the *C. incerta* Biozone has been recorded in El Caño and Botella formations of eastern Sierra Morena, Solana del Pino and Guadalmez synclines, the upper Elice-lowermost Torrico formations of the Cáceres and Santiago de Alcántara-Sierra de San Pedro synclines, and in the Iberian Cordillera (upper part of the San Marcos Formation and uppermost part of the Castillejo Formation), as well as in the Obejo-Valsequillo Domain (Belmez, Córdoba). In Portugal, *C. incerta* is known in the uppermost Cabril Formation of the Penha Garcia Syncline and, with doubt, in a correlatable unit from the Águeda inlier. Nevertheless, an homalonotid assemblage similar to that of the Botella Formation is also known in the uppermost Cabril Formation of the Amêndoa-Carvoeiro Syncline.

The trilobites recorded in Spain within *C. incerta* Biozone include *Eohomalonotus sdzuyi, E. brongniarti, E. vicaryi, Iberocoryphe verneuili, I. bonissenti, I.*? aff. *besnevillensis, Kerfornella brevicaudata, Plaesiacomia oehlerti, P. hesselinki, Neseuretus henkei, Crozonaspis incerta* and *C. armata*. Brachiopods are relatively common, and their representatives vary depending on the diachronic development of the sandy biofacies, from scarce occurrences of *Heterorthina morgatensis* in their earlier developments (e.g. El Caño Formation), to abundant *Heterorthina kerfornei* or *Tafilaltia valpyana* that characterize the younger records (e.g. Botella Formation). Other relatively frequent groups are rostroconchs and bivalve molluscs that also inhabit muddy environments, such as *Ribeiria pholadiformis*, *Cardiolaria beirensis* and *Hemiprionodonta lusitanica*, as well as bryozoans and disarticulated plates of pelmatozoan echinoderms. In Portugal, *C. incerta* only occurs with undetermined homalonotids, although *Tafilaltia* cf. *valpyana* and fragmentary bryozoans were reported from the homalonotid biofacies of the uppermost Cabril Formation.

Due to the environmental control of these species, biochronological markers to characterize this biozone are lacking. The age determination is relative, based on the dating of the units under- and overlying it: late Oretanian to early Dobrotivian fossiliferous shales and siltstones, and Berounian units, respectively. Here we present a direct attempt at dating this trilobite assemblage, through the first record of graptolites in the *C. incerta* Biozone, coming from SW of Alamillo (Ciudad Real), basal Botella Formation. This is represented by abundant specimens of *Oepikograptus bekkeri*, nicely preserved in sandstones and current-aligned. As this biserial form is highly characteristic of the early Sandbian *Nemagraptus gracilis* Biozone, their occurrence within *C. incerta* Biozone implies that corresponding trilobite biofacies, essentially developed in the late Darriwilian, also extends into the early Late Ordovician.
This research is a contribution to the projects PDI2021-125585NB-100 of the Spanish MICIN and IGCP 735 (IUGS-UNESCO).

Keywords: IberoArmorica, trilobite biofacies, Homalonotidae, Dobrotivian, Berounian

The Dawn of the Dapingian: the search for early radiations of Ordovician rhynchonelliform brachiopods

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The Middle Ordovician was a key time for the diversification and evolution of the Ordovician Brachiopoda. It marks the firm establishment of the Paleozoic evolutionary fauna, replacing that of the Cambrian dominated by lingulate brachiopods and some short-lived taxa. Previous studies on global palaeobiogeography have often grouped together the Dapingian and Darriwilian. The Dapingian is relatively short (c. 3 myr) and difficult to differentiate from the Darriwilian, particularly in successions in mountain belts commonly correlated with the Arenig. Improved stratigraphic correlations and some new brachiopod faunas are revealing a hidden diversity and distinctive bioregional patterns. Network Analysis of occurrences on the platforms, in more marginal continental settings together with those associated with oceanic terranes of the Celtic Province has identified a cluster of high-diversity faunas seaward of the platform provinces, revisiting the hypothesis that these areas were cradles for subsequent diversifications on adjacent shelves.

Keywords: Dapingian, brachiopods, rhynchonelliforms, network analysis, Celtic Province

*Speaker

Did the Late Ordovician mass extinction event trigger the earliest evolution of 'strophodontoid' brachiopods?

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As most majority of strophomenides during Silurian to Devonian, the 'strophodontoid' are typified with hinge line denticles, which is closely related to the origination of the clade. The evolution of hinge line denticles correlated with the disappearance of dental plates and teeth. In this study, the specimens of *Eostropheodonta parvicostellata* collected from the Kuanyinqiao Bed (Hirnantian, latest Ordovician) of Hetaoba Section, Meitan, Guizhou province, South China, displays clear population differentiation, capturing the process of the disappearance of dental plates and development of denticles from those anchored on the dental plates to form preliminary denticular plates. Three phenotypes of *E. parvicostellata* are recognized in the single fossiliferous bed, which may herald the progress of a speciation event. Among them, the Phenotype C could be assigned to a species of a younger genus, *Palaeoleptostrophia* but with more ancestral characters. Data on the distribution of species of *Eostropheodonta* in South China, may record a process of speciation. NMDS based on five key characters of the genera of the Family Leptostrophiidae shows the much larger morphospace of Silurian genera than that for Devonian taxa. For phylogenetic analysis of the Family Leptostrophiidae, 42 characters for 23 genera (coded based on type species) are coded. The result supports that of the NMDS and mostly tracks their geological history. The fossil population differentiation of *E. parvicostellata* discovered between the two phases of the LOME, may suggest the possible origination of 'strophodontoids' during the interregnum, and may link microevolution to macroevolution driving an adaptive radiation of the group. Cold environment during the glaciation of LOME might have triggered the origination of 'strophodontoids'.

Keywords: Microevolution, speciation, Late Ordovician mass extinction, morphospace, Leptostrophiidae

*Speaker

Late Ordovician beachrock as far-field indicator for glacial meltwater pulse

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Understanding ancient climate changes is hampered by the inability to disentangle trends in continental ice volume from records of relative sea-level change. As an unique coastal deposit in tropical and subtropical regions, beachrock has been proved to be reliable for constraining the glacial meltwater signal and, thus, the total volume of land-based ice in Quaternary. However, beachrock is rarely recognized in the fossil record due to (a) the 2-dimensional distribution of beach deposits, as opposed, for example, to extended platform sediments, and (b) the fact that specific environmental conditions are required in order to lithify sediments directly on the beach. By combining the stratigraphic architecture with petrography of characteristic cements, we demonstrate the first known Ordovician beachrock from the Tarim Block, northwestern China. According to biostratigraphy, a lower Katian (Upper Ordovician) palaeokarst surface is capped by a carbonate conglomerate beachrock, indicating a significant relative sea-level rise in late Katian. These beachrocks can be correlated with widespread subaerial exposure surfaces and a pronounced stratigraphical gap within the Katian in northwestern Tarim. We suggest that the beachrock 'fingerprinted' a strong melt-water pulse in high latitudes after a short-lived Katian glaciation, which has not received much attention in scientific papers so far.

Keywords: glaciation, palaeokarst, Katian, Tarim Block, northwestern China

*Speaker

Cyclostratigraphic study of the Middle-Late Ordovician Pagoda Formation on the Upper Yangtze Platform, China and the implications on palaeoclimate

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High resolution measurement of magnetism susceptibility (MS) in the Late Ordovician Pagoda Formation were performed in the northern, eastern, southern and central Upper Yangtze Platform, China. The MS variation and wavelengths of significant cycles correspond to long eccentricity, short eccentricity, obliquity and precession cycles. The continuous and well exposed sections of the Upper Ordovician on the Upper Yangtze Platform were surveyed and sampled for δ13C and δ18O isotope and conodont fossils. The geochem-stratigraphic-cyclostratigraphic work in the Pagoda Formation has resulted in the recognition of a positive δ13C excursion, the Pagoda Positive δ13C Excursion (PPCE). The PPCE is a distinctive positive excursion occurring in the Middle-Late Katian, consists of three minor excursions ranging from 1.5‰ to 3‰, which has been identified in all the study sections on the Upper Yangtze Platform. The PPCE interval ranges through the conodont *Hamarodus brevirameus* and *Protopandeordus inscrulptus* conodont zones in ascending order, which indicates that the PPCE develops in the Middle-Late Katian of the Late Ordovician, and is different from the Guttenberg δ13C Excursion (GICE) in the Baltoscandia and America extended from the Late Sandbian to the Early Katian. The strong signal of the astronomical forcing illustrates that the trigger of the PPCE was determined to be the combination of a sea-level transgression and long highstand in the Katian, which led to enhanced marine productivity and light-carbon burial on the flooded shelves causing an extended δ13C positive excursion. The MS signal in the limestones during the PPCE indicates that the orbital forcing, obliquity and precession impact the transgression and climate cooling. It reveals that the transgression occurs earlier in the southeastern Upper Yangtze Platform then the northwestern Upper Yangtze Platform.

Keywords: Cyclostratigraphy, Ordovician, palaeoclimate, sea, level, Katian, cooling event

*Speaker

Revising the depositional cycles of the Cambrian-Ordovician interval in the Tabuk Basin, Saudi Arabia.

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As a result of mapping and sedimentological analysis of the Lower Paleozoic succession, the detailed cyclicity of the Cambrian-Ordovician interval has been defined. This interval is considered a part of the mega-depositional cycles of the Paleozoic and was deposited over paleohighs of the Arabian Shield with an unconformity contact. The interval is subdivided into five formations, namely the Shig, Shigri, Al Ula, Risha, and Sajir, which are easily correlated across the Tabuk Basin in northwest Saudi Arabia. These formations provide important insights into the depositional environments and stratigraphic framework of the Paleozoic succession in the Arabian platform, which improve understanding of the geometry of transgressive-regressive (T-R) sequences at Tabuk Basin.
The Cambrian-Ordovician interval is overlain by the transgressive deposits of the Qasim Formation in the Ordovician.

A detailed study of the depositional environment and sequence stratigraphy of this cycle reveals a three-part cycle of marine transgression with marine pulses that formed flooding surfaces. Within the Cambrian-Ordovician sub-cycle, three sedimentary facies associations (fluvial, tidal, and coastal to open marine) have been identified, extending from the Saudi-Jordan border to the southeastern corner of the Jibal Al Misma quadrangle, west of Hail.
The cycle starts with a fluvial deposit and ends with a marine deposit. The Cambrian-Ordovician interval commences with an alluvial conglomeratic sandstone of the Shig Formation, which is overlain by a transgressive coastal to tidal flat environment exhibiting wavy bedding and sigmoidal cross-stratification of siltstone with vertical Skolithos burrows, with fine-grained sandstone at the top of the Shigri Formation reflecting the maximum flooding of this cycle. The second cycle begins with a conformable contact of fluviatile sandstone sequences of the Al Ula Formation, which exhibit a transgressive tidal environment with vertical Skolithos burrows and fine-grained sandstone in the upper part. The third sub-cycle commences with a thick fluvial sandstone sequence of the Risha and Sajir Formations of the Saq Group, showing tidal influences at the top. This study provides insights into the three-part cycle, fluvial-shallow marine sedimentation, and identification criteria for the Cambrian-Ordovician interval. A synthetic sequence stratigraphy is proposed from sequences analysis along the outcrop belt.

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Keywords: Tabuk Basin, Cambrian, Ordovician interval, cycles

Brachiopods from the Ordovician of southern Belgium (Avalonia): the end of a terra incognita

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Contrary to the well-exposed Devonian–Carboniferous rock sequence, the thick siliciclastic Cambrian–Silurian succession of Belgium is poor in macrofossils and, more especially, in brachiopods. These rocks mostly crop out in the Brabant and the Stavelot–Venn massifs, and in the Condroz Inlier. Occurrences of Ordovician brachiopods have been reported since the second half of the 19th century in the Brabant Massif but, until recently, only those from the Ashgill Fosses Formation (Condroz Inlier) have been properly taxonomically studied (Sheehan 1987). In the Early Ordovician, Belgium was located in high southern latitudes (it was part of Avalonia, a terrane with a Gondwanan origin), offshore from high latitude Gondwana (Amazonia–North-West Africa). During the Ordovician, Avalonia rifted from Gondwana and drifted northward, eventually docking Baltica in the Katian forming a block that collided with Laurentia in the Silurian and closing the Iapetus Ocean. The ongoing revision of the historical collections of the Royal Belgian Institute of Natural Sciences, complemented with newly collected specimens, has enables us to document the development of brachiopod faunas in this part of Avalonia from the Tremadocian. Early and Middle Ordovician brachiopod faunas are characterized by poor preservation leading to tentative identifications, low diversity and low to medium abundance assemblages, dominated by linguliformean taxa (Candela et al. 2021; Candela & Mottequin 2022, in press), from assemblages rooted in the Furongian (Popov et al. 2013). Middle to Late Ordovician brachiopod assemblages (e.g., Oxhe and Fosses formations) are characterized by a distinct shift towards rhynchonelliformean-dominated faunas that show stronger affinities with palaeo-equatorial faunas (Laurentia, Baltica), than with Early Ordovician peri-Gondwanan and Gondwanan faunas.

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Keywords: Ordovician, brachiopods, Belgium, Avalonia

Biostratigraphic subdivision of the Ordovician System in Australia incorporating water depths and facies

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During the Ordovician, the western two-thirds of the present-day continent of Australia consisted of numerous intracratonic sedimentary basins interspersed among the Archean and Proterozoic cratons forming the core of northeastern Gondwana. Eastern Australia, comprising the majority of the states of Queensland, New South Wales, Victoria and Tasmania, consisted of several extensive orogens including Ordovician sedimentary, volcanic and volcaniclastic rocks that accreted to the cratonic margins. To establish precise biostratigraphic correlations across an area equivalent to much of Europe, encompassing a variety of facies and water depths, has occupied the authors and their colleagues for much of the past 30 years. This project, focused on conodont biozonation, is now in its concluding stages.

The late Tremadocian to latest Floian conodont biozonation In shallow-water carbonate-dominated shelfal environments of the Canning, Arafura and Amadeus intracratonic basins has been established over the past two decades with revision and integration of previous systematic studies. The zonal succession, from oldest to youngest, comprises the *Paroistodus proteus*, *Prioniodus oepiki–Serratognathus bilobatus*, *Oepikodus communis*, and *Jumudontus gananda* biozones. Conodont biozonation of shelfal carbonate successions of the Delamerian Orogen along the cratonic margin in western NSW extends from the latest Furongian into the Floian but remains to be more finely resolved.

Middle Ordovician shallow-water conodonts were widespread across the Australian palaeocontinent, extending to New Zealand, with seven conodont biozones recognized. Dapingian and lower Darriwilian biozones are defined in the intracratonic basin sequences of the Canning, Amadeus and Georgina Basins, succeeding the *Jumudontus gananda* Biozone that ranges into the lower Dapingian. The *Histiodella altifrons* Biozone extends through the upper Dapingian into the basal Darriwilian. Younger biozones in the Darriwilian, in decreasing order of age, are the *H. holodentata–E. pseudoplanus* Biozone, *Eoplacognathus suecicus* Biozone, *Pygodus serra* Biozone and lower *P. anserinus* Biozone. Darriwilian 2 conodonts representative of the *H. holodentata–E. pseudoplanus* and three younger biozones are also found in carbonates of the Macquarie Volcanic Province in central NSW, and in limestones of the Takata Terrane in New Zealand.

The Late Ordovician shallow-water conodont biozonation of eastern Australia comprises seven biozones that are contiguous except in the middle Sandbian and upper Katian. The upper *Pygodus anserinus* biozone extends from the latest Darriwilian. Late Sandbian to middle Katian biozonation includes (from the oldest) the *Belodina compressa*, *Phragmodus undatus–Tasmanognathus careyi*, *Taoquopognathus philipi*, *T. blandus*, and *T. tumidus–Protopanderodus*

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insculptus biozones. The youngest biozone, of latest Katian age, is the *Aphelognathus grandis* Biozone. These conodont biozones have counterparts in North China, South China, and in the North American midcontinental faunas.
Utilising the widespread occurrence of conodont elements in cherts and siliceous mudstones of deep-water basinal environments, a conodont biozonal scheme has recently been established to subdivide the turbiditic successions of the Lachlan Orogen of eastern Australia into 12 superbiozones and biozones. In ascending order these are the *Paracordylodus gracilis* Superbiozone (including the *Prioniodus oepiki* Biozone), *Periodon flabellum* Superbiozone (including the *Oepikodus evae* Biozone in the lower part), *Periodon hankensis* Biozone, *Periodon aculeatus* Superbiozone (including the *Histiodella labiosa*, *H. holodentata*, *H. kristinae*, *Pygodus serra* and *Pygodus anserinus* biozones) and the *Periodon grandis* Biozone. This new conodont biozonation scheme spans the upper Tremadocian to middle Katian interval and permits precise age-dating and correlation of deep-water siliciclastic rocks that characterize the Ordovician Open-Sea Realm both regionally and internationally. The Darriwilian deep-water biozonation mirrors, but is not identical to, that defined in shallow-water carbonate successions, particularly in the succession of *Histiodella* species. The lower Darriwilian (Dw1) *H. labiosa* Biozone is succeeded by the *H. holodentata* Biozone (Dw2) and *H. kristinae* Biozone (Dw2). The subsequent two *Pygodus biozones* (*P. serra* and lower *P. anserinus*; Dw3) are the same as those recognised in shallow-water carbonates. The upper *Pygodus anserinus* Biozone extends into the basal Sandbian and is succeeded by the *Periodon grandis* Biozone.
The Ordovician graptolitic succession in Victoria, comprising 31 biozones covering the entire system, is globally recognised as the Pacific Graptolite Province. Occasional co-occurrence of conodonts with graptolites on bedding planes enables precise tie points to be established with the Victorian graptolite biozones, with the graptolite biozonation spanning facies of intermediate water depths between the shelfal carbonate environments and the deep-water basinal depths typified by cherts and siliciclastic sedimentary deposits.

Keywords: Ordovician, biostratigraphy, conodont, graptolite, biofacies, carbonate rocks, chert, Australia, New Zealand

Paleovalleys preserve new insights into the genesis of Upper Ordovician REE-enriched phosphorites

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Upper Katian and Hirnantian strata of the U.S. midcontinent are attracting attention for their rare earth element (REE)-enriched phosphorites. Constraining predictions about lateral variability in concentration and thickness of these units requires detailed knowledge of chronostratigraphy, paleogeography, paleo-sea water chemistry, and local paleotopography. Our previous examination of cores and surface exposures across thousands of square kilometers of the U.S. midcontinent provides regional context, but leaves much about localized conditions unknown. Therefore, we are studying one of the largest publicly available Upper Ordovician core collections on earth, those generated during the exploration and planning phases of the Tunnel and Reservoir Plan (TARP) and Superconducting Super Collider (SSC) projects of the greater Chicago area. The TARP and SSC cores archived by the Illinois State Geological Survey reveal new insights into the age and local depositional conditions of Upper Ordovician REE-enriched phosphorites. The 600+ cores provide an unprecedented sampling of midcontinent Paleozoic geology. Thus far we have generated new geochemical data through over 50 cores and additional synthesis though examination of photographs and engineering logs for the other 569 cores. We combined elemental (pXRF) and stable isotope analyses with sedimentological and paleontological data to: 1) characterize facies and contacts between stratigraphic units, 2) complete additional high-resolution study of possible karstic unconformities, especially those associated with phosphorites, 3) establish correlations of units between the cores within the collection and 4) correlate those units to age-equivalent strata in other portions of the basin. Utilizing these extraordinary data sets from northern Illinois, our study documents the complicated stratigraphy and paleogeography associated with incised and flooded paleovalleys advancing our understanding of the influence of local processes in the generation of REE-enriched phosphorites.

Keywords: Ordovician, stratigraphy, phosphorite, core, paleotopography, paleovalley

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Palaeobiological significance of chitinozoan clusters with parallel vesicles

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Chitinozoans are most commonly known to occur as isolated vesicles, and less commonly (but still regularly) in chains i.e. linear catenary structures. Chitinozoan clusters have been little studied, but are critical to the question of the biological affinity of chitinozoans. Bedding-plane assemblages and acid-digestion residues from Ordovician rocks of the Welsh Basin (Llanfawr, UK) and the Prague Basin (Beroun, Czech Republic) have yielded exceptionally preserved chitinozoan clusters of the family Conochitinidae arranged as parallel vesicles, with apertures either facing in the same direction or in opposite directions. Three genera (*Belonechitina*, *Eremochitina*?, and *Conochitina*) occur in the clusters, with each cluster being monospecific. This remarkable cluster arrangement is herein termed the P-cluster, in new terminology. Figured clusters available in the literature were analysed, and P-clusters are confirmed to occur in all three chitinozoan families. Modelling simulations of the relative abundances of different cluster morphologies suggest that P-clusters originated from a hypothetical, large cluster, functionally comparable with the already well-known *Desmochitina* clusters and interpreted as an egg mass. Our findings support the interpretation of all chitinozoans as metazoan eggs.

Keywords: Chitinozoa, Ordovician, Clusters, Chitinozoophoran, Egg Mass

*Speaker

A new framework for reinterpreting the Late Ordovician mass extinction on Anticosti Island (Québec, Canada): Sequence stratigraphic correlation within the eastern Ellis Bay Formation

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Anticosti Island (Québec, Canada) exposes a well-preserved and fossiliferous Ordovician–Silurian boundary succession that is one of the best-studied records of climatic, environmental, and biological events associated with the Late Ordovician mass extinction. Recent biostratigraphic, chemostratigraphic, and radiometric age studies have demonstrated that both the Ellis Bay Formation (*sensu* Copper et al., 2013) and lowermost part of the overlying Becscie Formation record the terminal Ordovician Hirnantian Stage, during which major climatic and oceanographic events are thought to have caused the Late Ordovician mass extinction. The stratigraphic succession on Anticosti Island thus contains one of the thickest, most fossiliferous records of the Late Ordovician mass extinction, making it critical to our understanding of the extinction event.

However, despite more than a century of work on the island, a comprehensive stratigraphic correlation framework for the Ellis Bay Formation remains elusive. Rapid lateral facies variability within the Ellis Bay Formation, particularly in the eastern half of the island, has hindered the establishment of a sequence stratigraphic correlation framework for the formation. Previous work has highlighted that a well-resolved sequence stratigraphic framework is necessary for differentiating stratigraphically-generated clusters of last occurrences from pulses of extinction to determine the underlying pattern and drivers of an extinction event (*e.g.*, Zimmt et al., 2021). The absence of a correlation framework for the Ellis Bay Formation therefore is a major impediment to understanding the expression of the Late Ordovician mass extinction on Anticosti Island.

Here, we combine sedimentological, stratigraphic, and chemostratigraphic data from seven continuous exposures of the eastern Ellis Bay Formation into a robust sequence stratigraphic framework, identifying six sequences in the eastern Ellis Bay Formation that are bounded by subaerial unconformities and maximum regressive surfaces. In contrast to previous studies, we find evidence that subaerial unconformities can be traced laterally across the entirety of the eastern Ellis Bay Formation. Subaerial unconformities are marked by a combination of microkarst, quartz

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pebble lags, negative carbon isotope excursions, and incised valleys. While often subtle, these indicators of subaerial weathering and erosion suggest that the Ellis Bay Formation records large, successive fluctuations in relative sea level that likely played a critical role in the presence and absence of species in the fossil record. Furthermore, the cryptic expression of unconformities in the Ellis Bay Formation suggests that other Hirnantian sections may record similarly subtle evidence of subaerial weathering and erosion throughout the Hirnantian Stage, with important implications for understanding the sequence of climatic, environmental, and biological events during the Late Ordovician mass extinction.

Keywords: Sequence stratigraphy, Ordovician, Mass extinction, Anticosti

SC15: Cambrian stratigraphy, palaeontology and depositional dynamics

The late Cambrian SPICE event as a chemostratigraphic tool for chronostratigraphic correlation of the base of the Furongian in Iowa, USA

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Excursions in stable isotope records function as critical nonbiostratigraphic tools in constructing viable, consistent frameworks for global chronostratigraphic correlation. The base of the international Paibian Stage (Cambrian) is placed to coincide with the first appearance of the cosmopolitan species *Glyptagnostus reticulatus*. Extensive studies of upper Cambrian strata across several paleocontinents document a global +4–5‰ shift in the carbon isotope record (δ13C) in an event now known as the Steptoean Positive Carbon Isotope Excursion (SPICE). The SPICE is closely associated with the first appearance of *G. reticulatus*, and, combined with its widespread nature, is valuable for globally correlating the base of the Paibian. A handful of studies additionally recognize coeval excursions in the organic carbon isotope record and in the carbonate-associated sulfur and pyrite records, all of which have the potential for use in correlating strata. Here, we collected high-resolution paired carbonate carbon (δ13Ccarb) and nitrogen (δ15NTN) isotope data of the SPICE from the Rhinehart A-1 drill core from central Iowa. The data reveal a transient negative δ15N excursion that begins at the onset of the positive δ13C excursion, thus providing another geochemical marker for potentially refining the base of the Paibian Stage and developing a clearer understanding of global ocean nutrient cycling during the SPICE Event.

Keywords: Paibian, SPICE, carbon, nitrogen, correlation

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Strenuaeva (Trilobita) from the Marianian (Cambrian Series 2) of Iberia: systematic assessment, biostratigraphy and palaeobiogeography

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Problems surrounding the identification and systematics of taxa belonging to the trilobite family Ellipsocephalidae have been highlightled for years. In this work we revise the ellipsocephalid *Strenuaeva* from Spain based on analyses of the type material of defined species together with newly collected specimens from the Ossa-Morena Zone and the Iberian Chains. Two species are recognized as valid for these regions, *S. sampelayoi* and *S. incondita.* The species *S. melendezi* and *Ellipsostrenua alanisiana* from Spain, as well as *S. marocana* from Morocco, are here considered junior synonyms of *S. sampelayoi.* Previous assignment of the Spanish species to *Issafeniella* is here rejected. The abundant available material of *S. sampelayoi* made it possible to evaluate the taphonomical role in the preservation of some characters and to recognize intraspecific variability similar to that described in *S. inflata* from Baltica, reinforcing its assignment to *Strenuaeva.* Biostratigraphically, *Strenuaeva* ranges from the uppermost Cambrian Stage 3 to the uppermost Cambrian Stage 4. In Iberia, it is restricted to the middle Marianian in the Ossa-Morena Zone, whereas it is known from the lowermost middle Marianian to the lowermost upper Marianian in the Iberian Chains. *Strenuaeva* is known from Baltica (Scandinavia and Holy Cross Mountains, Poland), Iberia (Spain), Morocco and, possibly, western Avalonia (Newfoundland).

Keywords: Trilobita, Ellipsocephalidae, Ossa Morena Zone, Iberian Chains, Cambrian Stages 3 and 4

*Speaker

Upper Marianian (Cambrian Series 2) trilobites from the Totanés–Noez area (Central Iberian Zone, Toledo province, Spain)

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In this work, we present a systematic study of the Marianian (Cambrian Series 2) trilobites from the area between the Totanés and Noez localities (Central Iberian Zone) and their biostratigraphical significance. Two different fossiliferous assemblages were recognized: the first is characterized by the presence of *Serrodiscus bellimarginatus*, *Chelediscus garzoni*, *Atops calanus*, and *Pseudatops reticulatus*. The second assemblage is composed of *Serrodiscus bellimarginatus*, *Triangulaspis* sp., *Andalusiana* aff. *cornuta*, *Termierella* (*Brevitermierella*) n. sp., and *Acanthomicmacca* sp., along with brachiopods and a small shelly fauna. These fossil assemblages indicate a late Marianian age in the regional stratigraphic chart for the Cambrian of the Iberian Peninsula, as *Serrodiscus*, *Chelediscus* and *Pseudatops* have been recorded in the upper Marianian stage, and *Triangulaspis*, *Andalusiana*, *Termierella*, *Atops* and *Acanthomicmacca* are characteristic of the middle to upper Marianian.
The taxa reviewed herein have a remarkable regional and international correlation potential: *Andalusiana* and *Termierella* occur in the Ossa Morena Zone, the Iberian Chains and Morocco; *Chelediscus*, *Triangulaspis*, *Acanthomicmacca*, *Atops* and *Pseudatops* have also been recorded from the Ossa Morena Zone, Morocco, Newfoundland, Siberia, and other regions, while *Serrodiscus* has a worldwide geographic distribution. In addition, the proposal made by the ISCS regarding the assemblage composed of *Hebediscus* Whitehouse, *Calodiscus* Howell, *Serrodiscus* and *Triangulaspis* as a potential marker for the base of the Cambrian Stage 4 may imply that the upper Marianian deposits of this area could be roughly correlated with the base of this stage.

Keywords: Trilobita, Central Iberian Zone, Cambrian stages 3 and 4, systematics, biostratigraphy, palaeobiogeography

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Large eddy simulations reveal skeletal adaptations of archaeocyaths

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As an extinct group of hypercalcified sponges, archaeocyaths are the first undoubted metazoan builders of abundant reefs and mounds in the Cambrian. Although the morphology of archaeocyaths has been well described in previous studies, the biomechanical significance of the archaeocyathan skeletal morphology remains incompletely explored. In the past decade, computational fluid dynamics (CFD) has been increasingly adopted for reconstructing the function and ecology of ancient and enigmatic fossils by numerical simulations of fluid flows. However, most of the earlier in silico experiments performed on extinct organisms are based on the Reynolds-averaged Navier Stokes (RANS) equations. In order to conduct reliable fluid dynamic simulations, we constructed simplified three-dimensional digital models of regular archaeocyaths by using SolidWorks based on typical specimens. With COMSOL Multiphysics, we performed a time-dependent analysis using the large eddy simulation (LES) turbulence model. As a comparison, the RANS model has also been applied to the same fluid dynamic settings. These CFD analyses reproduce the hydrodynamic conditions on the sea floor where archaeocyaths live. Both RANS and LES experiments reveal a rich, multifaceted role of the skeletal motifs of archaeocyaths on the flow physics within and beyond its central cavity. Compared to RANS model, the LES experiments resolved the eddy trail with more details exhibiting the classic pattern of swirling vortices. Overall, our computational results confirm the archaeocyathan models show passive entrainment of flow, on which modern sponges depend for suspension feeding. The flow direction through the models is consistent with predictions of the spongiomorph-affinity interpretation of archaeocyaths.

Keywords: archaeocyaths, hypercalcified sponges, paleoecology, biomechanics, computational fluid dynamics

*Speaker

Phosphatized calcified cyanobacteria from the latest Ediacaran and the early Cambrian

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Calcified cyanobacteria have only been sporadically discovered in the Neoproterozoic and did not appear widely until the early Paleozoic. It is proved that the abundance of calcified cyanobacteria is related to the change of atmospheric CO2 level and the calcium carbonate saturation of seawater. Description and systematic research of phosphatized calcified cyanobacteria in the Cambrian is rare, even though some phosphatized materials were reported. Anyhow, there is no report of phosphatized calcified cyanobacteria in the Precambrian except in the Gaojiashan biota. Both the Gaojiashan biota at the end of the Ediacaran and the Kuanchuanpu biota of the early Cambrian yield a variety of phosphatized calcified cyanobacteria assemblages. Especially the former fills the vacancy of calcified cyanobacteria all over the world during this period. These two biotas contain same calcified cyanobacteria such as *Girvanella*, *Obruchevella* and *Cambricodium*, and they are all phosphatized. Research on phosphatized calcified cyanobacteria of the Kuanchuanpu and Gaojiashan biotas, and a comparison of the similarities and differences, morphological features and occurrence modes of calcified cyanobacteria around the boundary provide important biological evidence for the calcification mechanism, the continuity of evolution of cyanobacteria and the changes of marine chemical conditions reflected by it during the critical transition period from the Precambrian to the Cambrian.

Keywords: Phosphatized calcified cyanobacteria, Gaojiashan biota, Kuanchuanpu biota, latest Ediacaran, early Cambrian

*Speaker

Geological evolution of northern South America during the Ediacaran to the Silurian

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In Colombia, the area to the east of the Andes is made up of the northwest of the Amazon Craton (the Rio Negro and Juruena provinces) and the Llanos Basin (sedimentary platform). During the Mesoproterozoic, the supercontinent Rodinia was formed, amalgamating Laurentia, Baltica and the Amazon Craton, among others. During this stage, new terranes were added (e.g. the Zapotec Terrane of Mexico) and a belt of rocks with a high degree of metamorphism (Grenville orogeny) was created in the collision zone. Much of the orogen and its suture lie to the south of the Eastern Cordillera (Garzón Massif) and under the sedimentary sequences of the Llanos Basin.
The rupture of Rodinia began in the Neoproterozoic. The zone to the west of the craton was intruded by syenites whose U/Pb ages are between 634 and 602 Ma. Simultaneously to this magmatic phase, a series of tectonic trenches (the Mantecal and Arauca Graben) were formed in which marine sequences with fossils ranging from the Ediacaran to the Cambrian were deposited. This stage of separation culminated at the end of the Ediacaran and the beginning of the Cambrian with the formation of recognized MORB gabbros to the east of the current Eastern Cordillera (Ariari region). The gabbros intrude calcareous platform sequences of the Ariari Formation and the turbiditic deposits of the Guape Formation. The Duda Formation is a diamictic type unit that unconformably covers the Guape Formation. Detrital zircons recovered from the Ariari Formation indicate ages ranging from the Mesoproterozoic to the Ediacaran. The separation of Baltica formed an oceanic basin (Iapetus) and left a series of continental remnants including the basement of the now Eastern Cordillera. In Cambrian rocks (Duda Formation) of the Llanos Basin, uplifted on the eastern Andean margin, *Paradoxides* and *Ehmania*, characteristic trilobites of the Avalonia continent, have been recovered. During the Ordovician, the western sector of the Llanos Basin behaved as a passive platform covered by siliciclastic sequences with graptolites.

By contrast, the geological history of the Andean zone differs substantially from that of the Llanos Basin. In the Santander Massif to the north of the Eastern Cordillera, the basement is made up of gneisses and schists (Silgará) with protoliths of Neoproterozoic age (Tonian). On these were deposited Cambrian protoliths of the Quetame and Chicamocha schists that were

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metamorphosed during the Ordovician. The Cambrian protoliths include tuffs and deposits of volcanic origin. The record of bioturbation structures visible in low-grade rocks of Quetame and Santander support the Cambrian ages indicated by the radiometric data. The basement is crossed by calc-alkaline granitoids of Ordovician age, which suggest the presence of a volcanic arc in these areas. This metamorphic phase is attributed to the Famatinian orogeny of South America or the North American Taconic orogeny. The position of the gabbroic intrusives, located on the Guaicaramo Fault, suggests that part of the Eastern Cordillera basement (including the Quetame, Santander and possibly Mérida massifs) constituted a part of a microcontinent that acted as a volcanic arc partially separated from South America by an oceanic basin.
Silurian marine sedimentary sequences cover both the Cambrian metamorphic rocks of the Eastern Cordillera and the Ordovician sedimentary rocks of the Llanos Basin. This suggests that these two sectors were amalgamated during the Silurian. These data are often ignored in early Paleozoic reconstructions for northern South America. It is frequently incorrectly assumed that the geology of the Andean zone for this interval is a mirror image of that of the Llanos Basin.

Keywords: Colombia, Rodinia, Ediacaran, Trench, Cambrian, Ordovician, Silurian, Terranes

Biodiversity across space and time in the Cambrian

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The fossil record is the primary source of information on how biodiversity has varied through deep time, providing unique insight on long-term dynamics of diversification and their drivers. Here we use fossil occurrence data from the Paleobiology Database (https://paleobiodb.org) to show diversity patterns during the Cambrian Radiation, particularly focusing on how the biodiversity varied along environmental and geographic gradients. The scope of this study refers to niche evolution and biogeography, and the aim of this study is to untangle ecological drivers of biodiversity changes at various spatial scales. We refined the biostratigraphic framework to delineate time slices for the Cambrian Period to improve the precision of temporal resolution. We applied several sampling-standardization methods to deal with taphonomic and sampling biases. By assessing how the overall increase in global diversity was partitioned between within-community (alpha) and between-community (beta) components and how beta diversity was partitioned among environments and geographic regions, we found that a rapid differentiation in faunal composition occurred at both local and regional scales in the early Cambrian, suggesting that global biodiversity during the Cambrian Radiation was driven by niche contraction at local scales. Using a compositional network, we outlined time-traceable provinces across the Cambrian Period and results confirm that abrupt biogeographic differentiation was facilitated by a decrease in by-species geographic distribution during the first three stages. A slight decreasing trend in biodiversity out-of-tropics is also evident in our results, indicating a latitudinal control on biodiversity in the Cambrian. By comparing our results with continental reconstruction and climate models, we concluded that both tectonic history and climate change may have played critical roles in driving spatio-temporal structure of biodiversity in the Cambrian.

Keywords: Biodiversity, Cambrian

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The success of Cambrian hyoliths in the "arms race" and their ecological significance

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Hyoliths were among the earliest biomineralized animals to emerge during the Cambrian Explosion, rapidly diversifying and radiating by the early–middle Cambrian. As vulnerable primary consumers, their high abundance and diversity made them significant members of the marine ecosystem. Knowledge of their ecology and survival strategies during the intensely competitive Cambrian "arms race" is increasing with more and more evidence accumulating from exceptionally well-preserved fossils. Hyoliths reached the epitome of their success in the Cambrian ecosystem, followed by a long progressive decline throughout the Palaeozoic until their Permian extinction. Cambrian hyoliths used a variety of life strategies, including their differing feeding habits, improvements in motility, and occupation of a wide range of habitats. They also had high rates of reproduction and other aspects of their palaeobiology. Calcareous hyoliths were particle-based energy transformers that played significant roles in the energy flow within a community, biological interactions, biogeochemical cycles, and ecological complexity of the Cambrian marine ecosystem.

Keywords: hyoliths, living strategies, ecology, ecosystem, Cambrian

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New U-Pb age from the Shuijingtuo Formation (Yangtze Gorges area) and its implications for the Cambrian timescale

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The Terreneuvian Series of the early Cambrian records the first major diversification phase of the canonical Cambrian explosion. However, a paucity of precise radio-isotopic ages for key stratigraphic horizons has resulted in a poor temporal calibration of fossil lowest occurrences (LO) and corresponding rates of evolution throughout the Terreneuvian. Here we present integrated SIMS and CA-ID-TIMS U-Pb analyses on zircons from the basal Shuijingtuo Formation in the Yangtze Gorges area, South China. The dating results provide a depositional age of 526.43 ± 0.54 Ma for the basal Shuijingtuo Formation, and compiled detrital zircon U-Pb dates from the Ediacaran-Cambrian transitional strata in the Yangtze Gorges area indicate their local provenances. The new high-precision date provides a minimum age constraint on the ZHUCE (Zhujiaqing positive carbon isotope excursion) and LOs of *Watsonella crosbyi* and *Aldanella attleborensis* in South China, and allows correlation of ZHUCE with either 5.5p or 5p/I' in Siberia and Morocco. We construct two models of the Ediacaran-Cambrian transitional timescale based on the two alternative correlations of the ZHUCE. The first model correlates the ZHUCE with 5.5p and yields significantly diachronous LOs of *W. crosbyi* and *A. attleborensis* between the Siberian Platform and South China. In contrast, the second and our preferred model equates ZHUCE with 5p/I' and implies relatively synchronous LOs of *W. crosbyi* and *A. attleborensis* between the Siberian Platform and South China. In the preferred model, the couplet of ZHUCE/5p/I' and LOs of *W. crosbyi* and *A. attleborensis* serves as a reliable combination to bracket the base of Cambrian Stage 2.

Keywords: Cambrian, Geochronology, Yanjiahe, Shuijingtuo, ZHUCE, South China

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SC16: Tonian to Cryogenian stratigraphy, palaeobiology and Earth system change

Towards a global chronostratigraphic framework for the Cryogenian non-glacial interval

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The Cryogenian Period (ca. 720–635 Million years ago, Ma) hosts sedimentary and geochronological evidence for two long-lived global-scale glaciations during the Sturtian (ca. 717–660 Ma) and Marinoan (ca. 650–635 Ma) cryochrons. Radiometric and chemostratigraphic data, in addition to climate modelling, support an approximately synchronous global deglaciation from the Sturtian cryochron (ca. 660 Ma), followed by a non-glacial interval with abundant globally-distributed marine sedimentary successions. The palaeontological record of Cryogenian non-glacial successions is dominated by microfossils and problematic macrofossils, some of which have been interpreted as possible sponge-grade organisms. Biomarker analyses also hint at the rise to dominance of green algae and the possible first appearance of demospongiae during this interval. Oxygen and nutrient availability can fuel biotic complexity, however Cryogenian non-glacial palaeoredox and palaeonutrient (e.g., phosphorus, P) dynamics are poorly understood. Furthermore, while regional lithostratigraphic and chemostratigraphic correlations of carbonate-dominated Cryogenian non-glacial sedimentary successions (ca. 660-650 Ma) are well documented, the temporal calibration of globally distributed carbonate and siliciclastic successions has not been attempted. Without a global chronostratigraphic framework, the regional versus global nature of geochemical responses to Earth System perturbations and the sequence of biotic events throughout this interval remain obscured. Here we present new geochemical data for the Cryogenian non-glacial interval, along with a new global chronostratigraphic framework for the calibration, in relative time, of geochemical and palaeontological data from carbonate and siliciclastic-dominated successions, including recently analysed drillcore. This enables our new data to be interpreted in the context of the highly dynamic global C and S cycles and

*Speaker

biotic record throughout this interval. This approach, in combination with new insights from climate models that constrain changes to atmospheric CO2 and temperature, sheds new light on the mechanisms for global changes to ocean redox and nutrients, and possible drivers that may have been partly responsible for an increase in biotic diversity during the Cryogenian non-glacial interval.

Keywords: Cryogenian, chronostratigraphy, non, glacial, geochemistry

A newly discovered Neoproterozoic diamictite-cap carbonate couplet from the Western Himalaya

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One of the central tenets of the snowball Earth hypothesis is the global recognition of the glacial diamictite-cap carbonate couplets in the Cryogenian sedimentary record. However, the scarcity of such peculiar stratigraphic elements in the Neoproterozoic successions of the Himalaya brings into question the severity and global extent of the snowball Earth event and likewise hampered glacio-stratigraphic correlation within the Himalaya and elsewhere. This study provides the first convincing evidence of the glacial diamictite-cap carbonate couplet from the Tanakki Member of the basal Kakul Formation, previously unknown from the Western Himalaya in North Pakistan. Detailed sedimentological analysis of the diamictite from the Tanakki Member reveals deposition in glacially-influenced proximal to distal subaqueous debris apron. The presence of glaciogenic clasts (striated, facetted and bullet-shaped) together with evidence of the ice-rafted dropstones in pervasive facies association provides credence to the glaciogenic affinity. The thin cap carbonate (herein referred to as Tanakki-cap dolomite; TCD) overlying the glacial diamictite record deposition in a deeper shelf (offshore) setting. The lithological, depositional and persistent negative C-isotope characteristics (ca. -3.2 to -5.8‰) combined with regional stratigraphic and available geochronological data allow us to interpret TCD as a 'Marinoan' cap carbonate and the underlying diamictite as an expansion of the terminal-Cryogenian (Marinoan) glaciation in the Western Himalaya. Moreover, the analyses of the tectonic and depositional history of the Tanakki Member coupled with the Neoproterozoic paleogeographic evolution of the northern margin of the Indian Plate argue against a previous interpretation of the culminating foreland basin orogeny and instead support deposition in an extensional fault-controlled rift basin. Finally, this study permits us to revise the Neoproterozoic stratigraphic framework of the Western Himalaya by describing the Cryogenian-Ediacaran boundary interval in the region that ultimately helps to overcome the previous glacio-stratigraphic discrepancies in the Neoproterozoic record of the Himalaya.

Keywords: Snowball Earth, glacial diamictite, cap carbonate, Neoproterozoic, Marinoan glaciation, Western Himalaya

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Marine euxinia during the melting of the Sturtian glaciation

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The Neoproterozoic snowball Earth events include the Sturtian (717-660 Ma) and the Marinoan glaciation (˜650-635 Ma). The snowball Earth hypothesis suggested that the global ocean was completely frozen during these glaciations. It is possible that global melting of ice sheets can cause significant marine stratification. In the aftermath of the Marinoan glaciation, this change has been tested. The Sturtian glaciation is the longest Snowball Earth event, but the marine redox conditions during the termination of the Sturtian glaciation remain unclear. Here we report massive pyrite from the top of the Sturtian Tiesiao diamictite from four drill cores in South China. Three types of pyrite are observed from the Tiesiao Formation: nodules, laminae and disseminated pyrite. Disseminated pyrite, including framboids, euhedral pyrite, are generally < 100 μm in size and are pervasively distributed in the matrix or within intergranular pores of diamictites and pebbly sandstones. The mean diameter of framboids ranges from 3.53 to 7.46 μm, and 59.20% of these framboid are < 5 μm. The proportion of framboids in all disseminated pyrites varies between 1.01–62.75%, with a mean value of 17.94%. Geochemical analysis of these pyrites shows low Co contents (mean=104.25ppm), low Co/Ni ratios (mean=0.79), but elevated sulfur isotope values (27.2–75.8‰). Iron chemistry shows FeHR/FeT > 0.38 in all samples and Fepy/FeHR > 0.8 in most samples. Meanwhile, there is a strong correlation between Fepy and FeHR. These results suggest that the ocean was stratified and H2S-enriched during the melting of the Sturtian glaciation. Since maintaining marine euxinic conditions requires enough seawater sulfate and organic matter, our results show that continental weathering increased and that the marine biosphere recovered quickly after the Sturtian glaciation.

Keywords: snowball Earth, Cryogenian, sulfur isotope, pyrite

*Speaker

The Garbh Eileach Formation, SW Scotland: A strengthened case for the Tonian–Cryogenian GSSP

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The boundary between the Tonian and Cryogenian periods (c. 720 Ma) represents a transition into one of Earth's longest and most extensive ice ages, the Sturtian glaciation. Owing to major global glacioeustatic sea level fall and the action of glacial erosion, the sedimentary record of this transition has commonly been erased. Missing strata at such a key juncture presents a significant challenge to both stratigraphic correlation of pre-glacial successions, and the establishment of a formal Global Stratotype Section and Point (GSSP) for the basal Cryogenian.
The Garbh Eileach Formation (GEF) is a $>$ 75 m succession of Tonian carbonates that directly underlies the 1.1 km thick glaciogenic Port Askaig Formation of Sturtian affinity. Fairchild et al. (2018) argued for a possibly unique transitional contact between Tonian and Cryogenian sediments on the largest of the Garvellach islands (Garbh Eileach) where the formation is best exposed. Amongst several lithostratigraphic observations for the gradual onset of ice (e.g. ice rafted sediment, gypsum pseudomorphs), their argument is poised on the preservation of the Garvellach carbon isotope anomaly and associated values of clasts in the overlying diamictite. The carbonate carbon isotope values defining the 'Garvellach anomaly' in the GEF, descend from -4‰ to -7‰, before recovering to +1‰ immediately beneath the overlying glaciogenic Port Askaig Formation. The GEF hosts the most complete known record of this global signal, where it is somewhat anchored chronologically by late Tonian 87Sr/86Sr signatures of 0.7066–0.7069 (Sawaki et al., 2010); however, the Garvellach anomaly is evidenced in at least two further global sections (Lamothe et al., 2019). In the absence of a reliable biostratigraphic framework for the Tonian, the point at which the carbon isotope values of the Garvellach anomaly become positive, 4 m below the first evidence for ice-rafted sediment, may offer a chronostratigraphic horizon suitable for the basal Cryogenian GSSP (Fairchild et al., 2018).

In 2013, Garbh Eileach was visited by the Cryogenian Subcommission to review its suitability for the placement of the basal Cryogenian GSSP within the GEF. The Scottish succession boasts a relatively thick and complete record of Sturtian glaciation as well as 100% exposure

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across the proposed Tonian-Cryogenian transition (Ali et al., 2018). Furthermore, the island of Garbh Eileach is relatively accessible and open to further research, all of which address criteria set out by the International Commission on Stratigraphy for future GSSPs. Although Garbh Eileach is considered to be a highly promising GSSP candidate due to its suitability as a chemostratigraphic type section, the lack of a direct radiometric age constraint still needs to be addressed (Shields et al., 2018). For this reason, we are focussing our attention on producing a more robust geochronological constraint for the GEF, while increasing the resolution of the Garvellach anomaly.

Here we present preliminary attempts at deriving a radiometric age constraint for the GEF by directly dating calcite using the U-Pb geochronometer. In-situ U-Pb carbonate geochronology has had recent success for Tonian carbonate successions to within 2.5% uncertainty (Lan et al., 2022) and it is hoped that further investigation will produce a meaningful age for this succession. These findings are coupled with a new high resolution carbon isotope curve ($>$ 200 data points) across the c. 75 m of exposed GEF on the island of Garbh Eileach. The new curve displays a similar form to that of Fairchild et al. (2018) and further refines the proposed chronostratigraphic horizon at which the GSSP could be placed.

Interrogating the links between coeval Earth system perturbations, climatic forcings, and the onset of the Sturtian glaciation, remains challenging. However, we consider that our high resolution, multiproxy study of the demonstrably transitional succession at Garbh Eileach will help to maximise the geological significance of any future Cryogenian GSSP, while shedding light on a remarkable episode in Earth's history.

Ali et al. 2018. Precambrian Res. 319, 65–78. https://doi.org/10.1016/j.precamres.2017.12.005

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Keywords: Basal Cryogenian GSSP, Dalradian Supergroup, Garvellach anomaly, U Pb carbonate geochronology

Towards a chronostratigraphic timescale for all Earth history

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The international geological time scale before 720 Ma uses rounded absolute ages (GSSAs) rather than specific events recorded in rocks to subdivide time. This has led increasingly to mismatches between subdivisions and the features for which they were named. A recent review by a working group of the International Commission on Stratigraphy (Shields et al., 2022) led to the following conclusions:
1) Division of Earth's history and geological record can be intuitively divided into its current four eons (Hadean, Archean, Proterozoic and Phanerozoic), whereby the Hadean-Archean boundary is taken to represent the onset of the terrestrial rock record at c. 4.0 Ga, pending establishment of a GSSP.

2) Two first-order (*Archean and Proterozoic eon*) and six second order (*Paleoarchean, Mesoarchean, Neoarchean, Paleoproterozoic, Mesoproterozoic, Neoproterozoic era*) stratigraphic intervals continue to provide intuitive subdivision of post-Hadean to pre-Phanerozoic time.

3) Major transitions in Earth's tectonic, biological and environmental history occurred at approximately 2.5-2.3, 1.8-1.6 and 1.0-0.8 Ga. Rock-based Proterozoic eras would therefore likely begin at or after c. 2.45 Ga, c. 1.8 Ga and c. 1.0 Ga, respectively, based around these major transitions, all of which occurred following orogenic peaks and during times of waning zircon production (post-acme, but not yet zenith) in line with major Phanerozoic boundaries.

4) A new Paleoproterozoic Era would therefore contain only three periods (instead of the current four), beginning at or after c. 2.45 Ga, c. 2.3 Ga and c. 2.05 Ga, respectively, so that the era begins near the end of major Archean BIF deposition, the onset of widespread glaciation and the Great Oxidation Episode, but ends close to the onset of a prolonged period of cratonic, climatic and isotopic stability.

5) As a result, the Statherian Period, currently the last period of the Paleoproterozoic Era, would likely become the first period of the Mesoproterozoic Era. The Siderian Period, currently the first period of the Paleoproterozoic Era, could be renamed the *Skourian* Period, after the Greek word for rust; while 'Siderian' could be retained for the final period of the Neoarchean Era.

6) A revised Mesoproterozoic Era would therefore contain four periods (Statherian starting at c. 1.8 Ga, Calymmian at c. 1.6 Ga, Ectasian at c. 1.4 Ga and Stenian at c. 1.2 Ga) so that it begins after major orogenic climax, but before putative eukaryote-grade fossil assemblages, in

*Speaker

the form of ornamented acritarchs and megascopic fronds, and ends after the Grenville Orogeny near to the final amalgamation stages of the Rodinia supercontinent.

7) A revised Neoproterozoic Era would likely contain four periods: a pre-Tonian period starting at c. 1.0 Ga, Tonian at c. 0.80 Ga, Cryogenian at c. 0.72 Ga and an Ediacaran Period, which has a ratified GSSP, dated at c. 635 Ma, so that it begins around the final amalgamation of Rodinia and ends traditionally at the Ediacaran-Cambrian boundary. The pre-Tonian period could be named the *Kleisian* Period, for closure, relating to the final amalgamation stages of Rodinia.

These and other proposals could be considered by future expert working groups or subcommissions to cover the 1) Tonian and Cryogenian periods, 2) Mesoproterozoic, 3) Paleoproterozoic and 4) Archean. Establshing a chronostratigraphic timescale, and essentially replacing all GSSAs with GSSPs, is not only a matter of academic interest for geologists. A robust, coherent and intuitive stratigraphic nomenclature will be of great importance for improving understanding of Earth's history in schools, universities and the wider community, too.
Shields, G.A., Strachan, R.A., Porter, S.M. and 33 others (2022) A template for an improved rock-based subdivision of the pre-Cryogenian timescale. Journal of the Geological Society, 179 (1), jgs2022-222.

Keywords: Geologic timescale, Precambrian, pre, Cryogenian, Chronostratigraphy

Positive carbon isotopes of synglacial carbonate from the Cryogenian Talisay Formation (northwestern China) suggesting synglacial active marine productivity

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The canonical Snowball Earth hypothesis argues that the Earth has been frozen globally for tens of millions of years, while the Slushball or Waterbelt hypothesis suggests incomplete freezing with the presence of a water belt in tropics. These two scenarios can be tested by synglacial (bio)chemical depositions, e.g., carbonate, which record the marine geochemical compositions during the global glaciation. The freezing over of the ocean, as proposed by the Snowball Earth hypothesis, prevented or dramatically retarded the surface ocean productivity, and thus the marine dissolved inorganic carbon (DIC) would have the carbon isotopic composition (δ13CCarb) of the mantle value (-5‰). As such, carbonate within glacial deposits, if not detrital or diagenetic, with higher δ13CCarb values would imply synglacial marine productivity and organic C burial, which is unlikely to have occurred in a Snowball Earth condition. In this study, we report bedded dolostone from the Talisay Formation in the Guozigou area of Xinjiang, northwestern China. The Talisay Formation is the youngest glacial deposition among the three glacial records in this area. Traditionally, it was interpreted as an Ediacaran glaciation, but a U-Pb zircon age of 642 +/- 5 Ma from an intrusive granite-porphyry vein in the top of Talisay Formation confirms a Cryogenian, likely the Marinoan glaciation instead. A _˜4-m thick carbonate layer is discovered within massive diamictite in the upper part of the Talisay Formation. Unlike Cryogenian cap carbonate, this carbonate layer within glacial diamictite has positive δ13CCarb values ranging from 0‰ to 1‰. It is suggested that the synglacial ocean might have sustained primary productivity as well as substantive organic C burial. Thus, our study strongly argues for the presence of open ocean during the Cryogenian global glaciation.

Keywords: Cryogenian, Marinoan ice age, snowball Earth, Guozigou, carbonatite carbon isotopes, biological activities

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The Ediacaran Ice-Age: The key node in the history of Earth system

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Glacial deposition is widely reported from late Ediacaran strata all over the world, but the temporal and spatial distributions of the Ediacaran glaciations remain poorly constrained, preventing our further understanding the nature and consequence of the Ediacaran Ice-Age. In this study, we reviewed global Ediacaran glacial depositions. We found that the Ediacaran Ice-Age might have extended from $>$ 580 Ma to $<$ 560 Ma, yet their paleogeographic distributions cannot be resolved by the non-Snowball Earth climatic model. In addition, the Ediacaran Ice-Age bracketed the Shuram Excursion (SE), the largest negative carbonate carbon isotope excursion in Earth's history, which has been attributed to the massive oxidation of dissolved organic carbon (DOC) or methane in the deep ocean, as well as witnessed the disappearance of large acanthomorphic acritarchs, the putative eukaryotic phytoplankton, and the diversification of Ediacaran biota. Termination of the Ediacaran Ice-Age after 550 Ma brought metazoans in the fossil records, starting the prelude of 'Cambrian Explosion'.

Keywords: Ediacaran Ice Age, Shuram Excursion, True power wandor

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An ecological rise of marine eukaryotes in the Tonian enabled by nutrient availability

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The diversification and ecological rise of marine eukaryotes is an impactful evolutionary event that transformed the Earth system. When did it occur? What were the driving forces? What were its impacts on the Earth system? Increasing paleontological and geochemical evidence indicates that the ecological expansion of marine eukaryotes occurred in the Tonian Period, earlier than previously thought. Further, emerging geochemical data indicate that increasing availability of marine nutrients (particularly phosphate and nitrate) may have enabled the ecological rise of photosynthetic eukaryotes, which in turn opened ecological opportunities for the diversification of eukaryotes overall. The transition from a prokaryote-dominated to a eukaryote-dominated marine ecosystem, particularly in terms of export bioproduction and global carbon cycles, had profound impact on the Earth system and in the long run may have contributed to snowball Earth glaciations in the following Cryogenian Period.

Keywords: Tonian, eukaryotes, nutrient availability, photosynthesis, nitrogen, phosphorus

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Widespread euxinia during the late Ediacaran ocean oxygenation event (Shuram) in South China

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The Ediacaran Period was a critical time in Earth history, connecting the "snowball Earth' Cryogenian glaciations and the emergence and rapid diversification of bilaterian animals. The largest negative d13Ccarb excursion in Earth history, the Shuram/DOUNCE event, occurred towards the end of the Ediacaran Period, and led into the Ediacaran-Cambrian radiations. In China, the DOUNCE excursion appears to have lasted about ten million years, beginning around ca. 570 Ma within Doushantuo Formation Member III, but extending into Doushantuo IV (the 'Miaohe' black shale), the top of which records the isotopic recovery in organic carbon isotopes. d13Ccarb turns positive in the immediately overlying dolomitic basal Dengying Formation. Previous studies suggested that anoxic ferruginous conditions in the deep marine environment gave way to more oxic conditions after the c.580 Ma Gaskiers glaciation in Newfoundland. However, over the South China Craton, the ocean seems to have been strongly redox-stratified, with some authors proposing an oxic surface layer resting above a sulfidic wedge that was sandwiched within ferruginous deep waters and some argue further for increasing water column oxygenation and deepening of the chemocline using abundance of framboidal pyrites in the Doushantuo Fm. Because the Doushantuo Fm can be traced widely across the craton and in evidently different depth settings, South China offers a unique opportunity to study the redox structure of the productive ocean margins of the Ediacaran ocean (Nanhua basin) during the DOUNCE excursion, which has been interpreted by some to indicate ocean oxygenation. A range of redox-sensitive elemental (e.g. Mo) and isotope (e.g. Mo, U, S) data from Doushantuo IV have been used to support this global oxygenation event. Fe speciation studies can shed light on the redox state of the paleo-ocean but have only been applied to a limited range of sections during this time interval. This study reports new Fe speciation data from the upper Doushantuo Fm. at seven different sections, ranging from shelf to slope settings throughout the Nanhua basin, and d98Mo from one slope section. With the data, we offer an attempted spatial reconstruction of the redox state of the Ediacaran ocean and our reconstruction confirms that pyrite deposition beneath euxinic waters was widespread along productive margins during the latter stages of the Shuram/DOUNCE excursion, and supports the idea that pyrite burial contributed to oxygenation during the late Ediacaran.

*Speaker

Keywords: Ediacaran, Shuram/DOUNCE excursion, Nanhua Basin, Iron speciation, Mo isotopes

SC17: The Early Precambrian: A Chronology of Invisible Time

The Eoarchean- Paleoarchean boundary: The current discussion

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The ICS Subcommission on Pre-Cryogenian Stratigraphy is currently discussing the Eoarchean - Paleoarchean boundary. During the 4.0 to 3.6 Ga Eoarchean era (by current definition), Earth had cooled down sufficiently to allow the development of increasing volumes of continental crust. The Archean igneous lithology is characterized by tonalite-trondhjemite-granodiorite (TTG) suites and ultramafic to felsic volcanic rocks. In the Eoarchean, TTGs were formed by episodic melting within a relatively thin basaltic oceanic crust. In the Paleoarchean (3.6-3.2 Ga), crustal growth by TTG formation continued and protocratons were thickened and stabilized by intracrustal granitoid magmatism. The Archean suprractustal rock assemblages are commonly

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associated with fluvial conglomerates, marine sandstones, mudstones, cherts and banded iron formations metamorphosed under low- to high-grade conditions. A low level of oxygen may have been present in the CO2- and CH4-rich Archean atmosphere. The oldest putative traces of life are C-isotopes and C–H–N–(P) elemental associations in the Isua Greenstone Belt, Greenland. Cherts in the Pilbara region of West Australia and in the 3.55 to 3.22 Ga Barberton Greenstone Belt, South Africa, include exceptionally preserved carbonaceous cells of prokaryotes and microbial mat fabrics of microbenthos once colonizing ancient oceans and hydrothermal systems. In the West Australian 3.48 Ga Dresser Formation, microbial mats colonizing a clastic coastal sabhka and silica hot springs formed stromatolites and microbially induced sedimentary structures (MISS). Sulfate-reducing metabolism is recorded by S-isotopes. Associated Ni suggests methanogenetic pathways, while aliphatic molecules document the presence of both Archaea and Bacteria. The already high diversity of biogenic structures and biogeochemical patterns indicates that microbial life at the end of the Eoarchean must have been complex, forming substantial microbial films and mats with similar structural and textural sedimentary expression like those on the modern Earth. The current discussion addresses the concepts and lithological, geochemical, geochronological and paleontological characteristics that might be used for a rock record-based definition of the boundary between the Eo- and the Paleoarchean eras.

Keywords: Precambrian, Hadean, Archean, stratigraphy, boundary

GP1: Advances in cyclostratigraphy – Reconstructing geologic time, palaeoclimate, and the Solar and Earth-Moon systems

Integrated stratigraphy and cyclostratigraphy reveal astronomical pacing of flint beds in type-Maastrichtian chalk (Upper Cretaceous, Europe)

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Northwestern Europe is the scene of many Upper Cretaceous chalk deposits, often containing interbedded flint nodules and bands. Yet, it remains unclear whether the pacing of these often seemingly rhythmically distributed flints is astronomically controlled. For this reason, we investigated a Maastrichtian chalk succession near Hallembaye (BE) in the type-area around Maastricht (NL). The Hallembaye section is characterized by a gradual change in lithology, which varies from greyish chalk with rare occurrences of flint nodules towards more pure, whitish chalk with clearly expressed flint bands. Powdered chalk samples were analyzed using micro-X-Ray Fluorescence to determine the concentration of major and trace elements. To quantify the distribution of flints in function of the stratigraphic height, 'Flint Scores (FS)' were attributed. Using an integrated stratigraphic approach, we applied cyclostratigraphy to assess a potential astronomical imprint in the FS and chalk elemental composition. Short-scale fluctuations superimposed on a gradually decreasing trend are observed in Ti/Al, a diagenesis-resistant proxy reflecting changes in the composition of detrital influx or the provenance thereof. Time-series and spectral analyses of the Ti/Al signal reveal a dominant 40 kyr obliquity component with its 173 kyr modulation, as well as a weaker precession-eccentricity signal. In addition, analyses performed on the FS strongly indicate astronomical pacing of the flint beds. The FS record is tuned using the stable 173 kyr obliquity modulation and 405 kyr long eccentricity cycles, yielding a high-resolution age model in absolute time. This age model is complementary to a floating astrochronology obtained after tuning the Ti/Al signal to the identified 40 kyr obliquity imprint. Even though the exact mechanism(s) behind the formation and astronomical pacing of flints remain to be constrained, evidence points towards a link to variations in the influx of detrital material (clays).

*Speaker

Keywords: Flint, Chalk, Astronomical, Cyclostratigraphy, type, Maastrichtian

Astronomically forced lake level fluctuations during the Toarcian Oceanic Anoxic Event (Sichuan Basin, China)

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The Toarcian Oceanic Anoxic Event (T-OAE) is characterized by one of the largest carbon cycle perturbations of the Mesozoic Era, with associated climatic and environmental change, most notably the widespread development of anoxia in epicontinental marine basins. On land, an enhanced hydrological cycle led to the development of major lakes, or significantly elevated lake levels, in continental basins in China, such as in the Sichuan, Tarim and Junggar Basins. Stratified lacustrine water columns and the development of anoxic–euxinic lake bottom- water conditions initiated a negative feedback mechanism in Earth's climate system through increased lacustrine (lake) carbon burial. The sheer size of these lakes possibly allowed for lacustrine carbon burial to have a significant impact on Earth's carbon cycling at that time. Here, we show new geochemical data from the Sichuan Basin and show that lake levels rose at the onset of the T-OAE. Importantly however, lake levels were likely not stable, but rather fluctuated on astronomical timescales, possibly in response to periodic changes in the hydrological cycle and the transport of moisture into continental interiors. Furthermore, the lacustrine climate records spanning the T-OAE provide crucial continental constraints on the duration of the T-OAE, which remains heavily debated, as based on marine climate archives.

Keywords: Astrochronology, Lake, level, Toarcian Oceanic Anoxic Event, Sichuan Basin

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GP2: From rock to time: evolutionary lineages and the calibration of the Chronostratigraphic Scale

Much more than a biostratigraphic tool: A geochemical and histological reappraisal of the conodont

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Conodont biostratigraphy, the backbone for much of the chronostratigraphic framework of the Paleozoic, is essential for understanding global patterns of geological and environmental change over much of Earth's history. Conodont apatite geochemistry is increasingly used as a proxy for measuring the chemical and isotopic composition of the ancient ocean. However, there is uncertainty about the source and timing of elemental enrichment in these fossils, with variable interpretations ranging from primary (in vivo) to postmortem recrystallization/exchange on the seafloor and during diagenesis/thermal maturation of the rocks. We have reduced this uncertainty by characterizing conodonts of different ages and thermal maturities using various geochemical and isotopic tools in combination with histologic studies.

The results show clear differences in the mineralogy, crystallinity, chemical and isotopic composition of morphologic components of individual conodonts which we interpret to reflect biologic growth. The highly crystalline components have not exchanged with the enclosing rock, while the less crystalline hard tissues are nearly completely exchanged. Geochemical maps of highly crystalline components also delineate wear/growth and resorption/regeneration surfaces, and ontogenetic differences that further support the hypothesis that the trace-element zones are a primary, and not diagenetic, record of biochemical uptake by the conodont organism.

These findings provide new insights into the biology, growth, and histology of the conodont animal, which may help identify the phylogenetic origins of this complex and enigmatic group. Moreover, the application of these new analytical tools and sampling methodologies in parallel with traditional biostratigraphic and chemostratigraphic approaches can improve the ability to correlate the global stratigraphic record at previously unattainable resolution. Therefore, when sampled correctly, conodont apatite biogeochemistry is an ideal proxy for measuring the chemical and isotopic composition of the ancient ocean.

Keywords: conodont, biostratigraphy, chronostratigraphy, chemostratigraphy, mineralogy, geochemistry, isotope, paleocean chemistry, biology, histology, ontogeny

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Cutting time in slices

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One of the main achievements of geology in the eighteenth-century was the conquer of time. The recognition that rocks could be older than previously supposed and that there was an order regulating their deposition radically changed the perspective in stratigraphy. Geological processes finally revealed to enclose a huge vastness of time, that had to be framed in a scale. Inevitably, attention moved to the criterion by which successions of strata could be identified and correlated throughout the world. The most immediate one was to stress on major discontinuities directly readable in the field and lithological features were soon applied to discriminate relevant time slices. However, while Earth was discovered to be older and older, it became evident that rocks were pullulated by a myriad of events, which were the most reliable for arranging in time the sequences of strata. Even with a biological approach, discussion arose on how to face time division and whether discontinuity (catastrophism) or continuity (uniformitarianism) should be the rule in cutting time in slices. The debate was extended in selecting the best combination of fossils (appearance, disappearance, range, abundance, etc.) and geographical distribution that could truly reflect a fraction of time. In any case, not even the best biozonation frame was able to perfectly match a chronological subdivision, and only the discovery of radioactivity and the application of radiometric dating enabled to put precise numbers on the geological scale and to create a rigid frame with horizontal time subdivisions that had now to be filled with names. The Chronostratigraphic Scale was further "nailed" with a series of Golden Spikes, the only points in which, according to Holland (1999), time-rock and rock coincide in space.
Chemostratigraphy, magnetostratigraphy and cyclostratigraphy have been later able to provide new tools for more accurate and easily comparable correlations. Together with an often-obsessive search of splitting time in thinner and thinner intervals, stratigraphers are now integrating diverse markers in order to increase the exactness, precision and reliability of the Chronostratigraphic Scale.

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Keywords: time, chronostratigraphy, biostratigraphy, history of geology

The influences in Geology of evolving evolutionary hypothesis in Italy between the XIX and XX Century

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The publication of Charles Darwin's work, *On the origin of species by means of natural selection, or the preservation of favoured races in the struggle for life* (1859) represented the birth of evolutionary biology in the proper sense. Theories on the evolution of organisms had already been discussed for some time. However, the specificity introduced by the Darwinian theory was the identification of possible mechanisms underlying evolutionary processes. His work constituted an event of unprecedented magnitude that radically altered the nature of the debate around these issues and went beyond biology, deeply influencing also geological interpretations of that time. Scientists from all over the world were involved in the discussion that followed, demonstrating on the one hand the growing interest in Darwin's own evolutionary idea and, on the other, the presence of perplexity regarding the causes of biological evolution, which according to some naturalists could not be traced back to random mutations and natural selection. In this panorama, a number of Italian scientists were also particularly active in the debate, either supporting the validity of Darwin's proposal or suggesting other theories. It is interesting to note how some elements proposed by theories at one time alternative to Darwinian ideas have actually found their way into the most current formulations of the theory of biological evolution. The aim of this study is to focus on the effects that the evolutionary debate had in Italy on contemporary geology, specifically on the evolving interpretation of the stratigraphy of the northern Apennines and on the creation of the first geological map following the birth of the Italian State, formally constituted as "Regno d'Italia" in 1861.

Keywords: evolution, stratigraphy, history of geology

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Mending the chronostratigraphic record

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Fossil range data are crucial for assembling the chronostratigraphic record, but their fidelity is limited by gaps and biases caused by environmental and paleobiological factors. Environmental volatility during major ocean-atmosphere perturbations may create further bias in the fossil record. Importantly, linked swings in eustatic sea level generate unconformities with durations of tens of thousands to millions of years that distort chonostratigraphic taxon range data and impart a false impression of temporal continuity.
Process-oriented sequence stratigraphy integrating facies analysis, biostratigraphy, chemostratigraphy, and geochronology is designed to identify chronostratigraphic distortions and provide corrections. In particular, carbonate carbon isotope chemostratigraphy is a powerful tool for identifying and characterizing unconformities, especially those that occur between biozone boundaries or within fossil species ranges. Iterative sampling both parallel and perpendicular to depositional dip is a novel aspect of our chronostratigraphic approach. Data profiles generated along depositional dip document diachroneity and thus mend chronostratigraphic knowledge gaps while depositional strike transects provide insights for subtle refinement of basin morphology and delineate the geometry and age of incised valleys.
Fully characterizing the spatial distribution and duration of unconformities is vital for identifying bias and knowledge gaps in the chronostratigraphic record. Mending those gaps through documenting diachroneity allows reconstruction of a more complete temporal continuum of the events that shaped Earth throughout its history, revealing linkages between eustatic sea level oscillations, the carbon cycle, ocean geochemistry, and the evolution of marine organisms.

Keywords: sequence stratigraphy, carbon isotope chemostratigraphy, geochronology

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GP3: Quantitative stratigraphic analysis using databases

OneStratigraphy: harmonizing global stratigraphic data

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The Deep-time Digital Earth (DDE) is the IUGS-recognized Big Science Program that aims to develop a platform to connect geoscience informatics efforts with the FAIR (Findable, Accessible, Interoperable, and Reusable) principles. This innovative, ten-year program plans to harmonize global deep-time geodata describing the various spheres of our globe (e.g., biosphere, lithosphere, hydrosphere) and further stimulate data-driven discoveries in our understanding of the deep-time Earth history (Wang et al., 2019). More specifically, new tools or services for data mining, knowledge discovery, and artificial intelligence will be developed to fulfill the multifaceted vision of DDE: open data, open infrastructure, open research, and open service.
OneStratigraphy, as part of the DDE system, was developed in early 2019 to share stratigraphic data and tools. To date, 1.3 million fossil occurrences from _˜13,000 sections/drill cores have been digitized and stored in the OneStratigraphy online platform, covering the major continents and oceans of the present. All data come from literature, stratigraphic reports or unpublished work and are digitized according to consistent standards to control data quality. Many tools have been integrated into the system, such as TS Creator for stratigraphic visualization and PaleoGIS and GPlates for paleogeographic visualization. The new system supports quantitative stratigraphic methods such as Graphic Correlation (Fan et al., 2013), Constrained Optimization (CONOP, Sadler et al., 2009), and Horizon Annealing (Sheets et al., 2012). Therefore, with its rapidly increasing data volume and efficient data analysis tools, OneStratigraphy can be used for innovative studies such as refined geologic time scales, high-resolution macroevolutionary history of life, and biotic/abiotic factors affecting the evolution and distribution of life.

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Keywords: Deep, time Digital Earth (DDE), Stratigraphy, Big data, Quantitative stratigraphy

Quantitative biochronology by unitary associations of late Albian ammonites from Europe and their biodiversity

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The chronostratigraphic subdivision into an Early and Late Cretaceous is preceded by a global turnover in marine faunas, called the middle–late Albian Boundary Bio-Event. Thus, the late Albian is a critical time interval, especially with respect to the evolution and radiation of ammonites, which are by far the most abundant nektic organisms at that time. In this context, achieving the best possible biochronological resolution has direct implications on the various geological, geochemical, palaeoclimatic and biotic hypotheses related to this period. Over the past decades, several quantitative biochronological methods have been developed to achieve more accurate biozonations and correlations. Using strict and well-defined algorithms allow for the processing of large datasets and ensure a rigorous, exhaustive, and consistent treatment of the biostratigraphic data. Here, by means of the Unitary Association Method (UAM), we perform a quantitative biochronological analysis on a substantial dataset of late Albian ammonite occurrences from western Europe (comprising 175 species among 13 sections). This led to the construction of a sequence of 23 UAs for the whole late Albian that corresponds to a higher resolution than the standard empirical interval-based zonations for northwestern and southwestern Europe (7 zones and 9 subzones, respectively). These UAs can also be merged into 9 more geographically reproducible association zones, which correlates very well with these two standard zonations. Based on our results, the UAM enables accounting for and highlighting the range of actually all taxa, and not just a few selected index taxa whose ranges very often extend before and/or after their eponymous interval zone. Finally, the UA quantitative biochronology enables us to measure western European ammonite diversity throughout the whole Albian in detail. Consequently, we identified a major and sharp diversity decrease during the uppermost Albian (UAZ 8/9 boundary; = *M. perinflatum*/*A. briacensis* zones boundary), concomitant with the well-known Oceanic Anoxic Event OAE1d.

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Keywords: Albian, Ammonoidea, Europe, quantitative biochronology, correlation, palaeobiodiversity

Newly designed CONOP program helps tackle the stratigraphic correlation problem of late Paleogene foraminifera

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Constrained optimization (CONOP), which uses a simulated annealing approach to iteratively find optimized matches to integrate sequences of stratigraphic datums via random perturbations (Sadler et al., 2009), is regarded as an effective method for handling global stratigraphic correlation problems, one of the nondeterministic polynomial time problems in computational complexity theory. However, the original CONOP program did not support parallel computing or high-performance computing (HPC), which may hamper the search for a global optimal sequence in the CONOP process. Therefore, Fan et al. (2020) developed a new program - CONOP.SAGA by combining simulated annealing and a genetic algorithm to overcome these limitations. Although this program provides the HPC function and works well with the China Palaeozoic dataset (Fan et al., 2020), it still followed the same procedure of CONOP to generate the initializing sequence and mutation, i.e., randomly placing the first and last appearance datums to the composite sequence and stochastically re-arranging these datums at the mutation stage, leaving opportunities for further improvement. Here, we employed a new method of generic population-based metaheuristic optimization algorithm, called CONOP.EA, which combines the original CONOP program with an evolutionary algorithm (Back, 1996). It is inspired by Darwin's theory of evolution to iteratively improve a set (i.e., population) of datum sequences via procedures of resembling or mimicking, recombination, mutation, and natural selection to generate a global sequence of stratigraphic datums of late Paleogene foraminifera. We construct a 28-Myr-long species richness history of foraminifera with an average temporal resolution of _˜26,000 years. This composite sequence uncovered the coupled foraminiferal diversity and environmental change pattern across the Eocene-Oligocene transition, a turning point in Earth's climate from "warmhouse" into "icehouse". The computation of this dataset was _˜17 times faster with CONOP.EA compared to CONOP.SAGA, and produced a better result with 520 less in penalty. Moreover, CONOP.EA has a new ability to evolve from previous results, and the evolved offspring sequences are proven to be better than their parent sequences by an average of 112 fewer penalties. This means that CONOP.EA is able to dig further to find a more globally optimized sequence than ever before.

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Keywords: CONOP, Evolutionary algorithm, Quantitative stratigraphic method, foraminifera

PalynofAIcies – a new artificial intelligence-assisted tool to analyse palynology slides

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Introduction

PalynofAIcies, a new tool for the automatic identification and quantification of organic particles in palynological slides is presented.

Many institutions, both public - Museums, Universities, Surveys - and private - oil and gas companies - have extensive micropaleontological collections. These are not always kept in optimal conditions (risking physical degradation) and generally this is stranded, unused data, despite its enormous value for stratigraphic context, source rock evaluation and paleoenvironmental interpretation.

The observation of palynological slides, and other microfossil groups, is based on the usage of optical microscopes by a specialist, commonly with a dedicated camera. Except for the introduction of digital cameras in the last decades, no significant technological advances have been made in over a century of micropaleontological studies. In recent years high-resolution slide scanners – initially used for cytology and other medical studies – have been introduced, allowing not only digitalization of the observation method, but opening the door to artificial intelligence (AI) applications.

Methods and materials

This new tool is based on the AI-assisted analysis of high-resolution images of scanned palynological slides, which are the inputs of the tool. The specialist-trained AI model is able to segment (isolate from the background), count and measure the area of up to 24 types of particles found in palynological slides:

Spores

Pollen

Bisaccate pollen

*Speaker

Monosaccate pollen

Non-saccate pollen

Acritarchs

Dinoflagellate cysts

Chitinozoans

Amorphous Organic Matter (AOM)

Fungal remains

Filaments

Foraminifera test linings

Other Zooclasts

Freshwater algae

Marine algae

Phytoclasts

Opaque equant (length: width ratio < 2)

Opaque lath (length: width ratio > 2)

Degraded

Translucent cuticle

Translucent structured

Translucent non-structured

Resin

Minerals

Fibres

Air bubbles

Additional particle types can be added. The training data set includes samples from Ordovician to Miocene strata, from diverse sedimentary settings and geographical locations.

Results and applications

The user can have local or remote access to the scanned slides on a computer screen and annotate the slide, measure and count particles and share the image and interpretation. The AI-model results are presented in a user-friendly graphical interface that allows the user to QC the interpretation, easily produce ternary diagrams (e.g. Tyson), and obtain several paleoenvironmental indexes and optical kerogen typing parameters. It can also be used as a tool to ease taxonomic identification, a stepping stone for biostratigraphic interpretation.

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Keywords: Palynology, Computer Vision, Artificial Intelligence, paleoenvironments

Building a high-resolution digital geological timeline: A perspective for stratigraphy

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The Earth has a history of approximately 4.5 billion years, leaving behind a myriad of geological records, and the geologic timeline is the only common language available to unravel the evolutionary history of the Earth. Since the 1960s, the International Commission on Stratigraphy (ICS) aims to establish a universal standard chronostratigraphy for intercontinental and regional correlations. The ICS currently uses the Global Stratotype Section and Points (GSSP) method to define geologic time boundaries. To date, 78 out of 102 GSSPs have been officially defined so far, which is an impressive achievement that is attracting worldwide attention. However, we have all recognized that there are some obstacles to precisely placing the stratigraphic horizon of a GSSP. The most common challenge is that all fossil records are far from complete, and it is theoretically impossible to identify the absolute first occurrence of an index fossil species, and thus the previously defined GSSP can be frequently overthrown by subsequent earlier "first" occurrences of index fossils. In addition, the GSSPs defined by biostratigraphy commonly contradict with other physical or chemical markers (e.g., volcanic ash beds, isotope excursions, geochemical anomalies, etc.) that are of isochronous significance. All geological records have temporal and spatial properties and thus should be valuable for intercontinental and regional correlations. The 21st century has entered an era of the widespread application of big data and artificial intelligence. Building a high-resolution geological timeline based on big data of all geological records is an urgent mission for stratigraphy in the next decade. The new geological timeline program we are expected to propose should bear the following characteristics: 1) Supported by global stratigraphic databases, we should comprehensively collect all stratigraphic sections containing fossil records. Once entered into the database, the data will be permanently stored and can be retrieved anytime to make full utilization of the comparative value of fossil records. 2) We could use applied statistics, artificial intelligence algorithms, etc. to correct the incomplete nature of fossil records and to obtain statistically optimal solutions for the ordering of stratigraphic information. 3) Combined with the geochronology, magnetostratigraphy, chemostratigraphy and cyclostratigraphy data, we could optimize the correlation between each profile and greatly improve the correlation accuracy. 4) The database can be updated at any time, and finally, a geological timeline of any time interval can be generated based on any selected or all data. The new digital timeline, once established, will greatly promote the quantitative study of the detailed timing, duration, and rate of a given event in Earth history, the integrated use of large environmental proxy data for numerical paleoclimate simulations, and the reconstruction of high-resolution biodiversity curves. It will promote and deepen research on the evolution of life, Earth materials, geography, and climate.

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Keywords: digital timeline, big data, GSSP, correlation

Confidence of taxonomic identification: the first step of biostratigraphy

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Fossils are the most important indices for stratigraphy, but the issue of fossil identification confidence or consistency has been discussed and debated for decades (i.e. Gradstein et al., 1985; Polly and Head, 2004). With the highly developed database technology in the last decade, millions of fossil data of varying quality have been accumulated through formal or informal databases (i.e. The Paleobiology Database, OneStratigraphy, World Register of Marine Species). After evaluation, these data have been used for high-resolution stratigraphic correlation (Fan et al., 2020; Deng et al., 2021). However, when tens of thousands of fossil data are used in one quantitative analysis, how accurate, confident, or consistent of their identification could we achieve? For millions of fossil data in the databases, how many could be re-examined and evaluated, and in what way?

Here, an AI-based machine learning approach for fossil image identification is proposed to test the influence of the training set consistency. Three different training sets, one with the original labels from various identifiers and the other two with revised labels from two different experts, are used for independent training with the same deep learning model and then perform identification for the same test set. The consistency among the training set, as well as the machine identification results, could provide arguments for the taxonomic identification confidence issue and the above-mentioned questions.

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Keywords: Fossil identification, Machine learning, Quantitative stratigraphy, Database

GP4: Palynology as tool of multidisciplinary researches applied to stratigraphy and palaeobiogeographical, palaeoclimatic and palaeoenvironmental reconstruction: advances and perspectives

Organic matter composition and thermal maturity assessment by the use of the Palynomorph Darkness Index method: a case study from the middle-upper Cenomanian OAE Black-Shales (Göynük-Sünnet section - NW Turkey).

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A palynological study from the Upper Cretaceous Uzumlu Member of Yenipazar Formation (NW Turkey) of the Mudurnu-Goynuk Basin was yielded with the aim to assess the organic matter composition and to evaluate the thermal maturity. For this purpose, in the pelagic succession of the Göynük-Sünnet section (north-western Turkey) located in a rift basin along the Sakarya continental margin twenty-seven black shale levels of middle-upper Cenomanian age were sampled. Such levels intercalated with marly shale/calcareous marl rhythmic alternations and chronostratigraphically constrained to Cenomanian stage by the planktonic foraminifer *Rotalipora cushmani*, Additionally, the planktonic foraminifer *Wheitenella archeocretacea* was recorded across the Cenomanian-Turonian boundary (Yilmaz, 2008) allowing to associate these black shales to mid-Cenomanian Oceanic Anoxic Event and to the Bonarelli Event OAE2. The organic matter content analysed was mainly of continental origin showing abundance of oxidised and partially oxidised ligneous particles, pollen, spores and less frequent marine elements as dinoflagellates and acritarchs. To evaluate the thermal maturity of organic matter, optical semi-quantitative method as the Palynomorph Darkness Index (PDI; *Goodhue and Clayton, 2010*) was used. PDI was measured on smooth, unfolded trilete spores and bisaccate pollens and calibrated with other thermal index as the Spore Colour Index (SCI; Waples, 1985; Marshall, 1991). PDI value varies based on the taxon measures. Generally, trilete spore shows PDI values ranging from 13% to 34%. The SCI observations (SCI 3.2 to 4.2) also indicate that organic matter content experienced a very immature stage with conversion vitrinite reflectance values (Clayton, et al., 2017) below 0.40%. In this study for the first time Palynomorph Darkness Index has been calibrated on Upper Cretaceous deposits thus opening new scenarios to other types of studies as sedimentary basins thermal history assessment. Moreover, further studies

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are in progress to rigorously calibrate the microflora with foraminifera biozones as well as with the OAEs.

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Keywords: Thermal marurity of Organic Matter, Palynomorph Darkness Index, Mid, Cenomanian, Turkey

Application of Palynomorph Darkness Index ('PDI') for thermal maturity assessment: a case study from the early Silurian Qusaiba Member of the Qalibah Formation, Saudi Arabia

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Organic-rich marine shales of early Silurian (Llandovery) age (also known as "hot shales") are developed regionally over the entire Gondwanan margin, where they constitute the primary source rocks for the Paleozoic petroleum systems especially in North Africa and the Middle East. In Saudi Arabia, early Silurian "hot shales" occur within the Qusaiba Member of the Qalibah Formation. In this study, we investigate the application of Palynomorph Darkness Index (PDI) for assessing the thermal maturity of the Qusaiba organic-rich shales. Usually the thermal maturity of vitrinite-lacking, pre-Devonian rocks, is assessed using various proxies for VR (Vitrinite Reflectance) such as pyrolysis-based Tmax determination, graptolite reflectance, palynomorph color, and Raman spectroscopy. The resulting values, expressed as 'Vitrinite Reflectance Equivalent' (VRE) all have limitations, including inapplicability to the full range of thermal maturity and imprecise correlation to VR. The Palynomorph Darkness Index (PDI) is increasingly used, in academia and industry, as an alternative, rapid, inexpensive and fully quantitative method of determining thermal maturity of pre-Devonian sediments. The PDI is based on the quantitative measurement of the degree of thermal-induced darkening of palynomorphs under transmitted light. In this study, PDI was determined on palynomorphs obtained from core samples from several sections in Saudi Arabia, spanning the maturity interval from sub-mature, through the oil, condensate and gas windows into the post-mature stage. In addition, qualitative fluorescence characteristics of the palynomorphs were investigated. The PDI values obtained were correlated to VRE derived from Tmax and graptolite reflectance. Results suggest that the *Veryhachium / Neoveryhachium* group of acritarchs are the most useful for PDI determination on the study rocks. PDI results based on the more diverse total acritarch assemblage proved very similar in most samples, except where significant numbers of thick-walled taxa were present. In terms of changes seen with increasing maturity, PDI (*Veryhachium / Neoveryhachium*) remains low (Veryhachium / Neoveryhachium) then increases more slowly through the Condensate Window and into the Gas Window to > 80 %, remaining at or above this value into the postmature zone.

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Keywords: Silurian, Saudi Arabia, Qusaiba Member, Palynomorph Darkness Index, PDI, Maturity, Vitrinite Reflectance Equivalent, Veryhachium, Hot Shales

THE CONTRIBUTION OF DINOCYSTS AND OTHER NON-POLLEN PALYNOMORPHS IN PALAEOENVIRONMENTAL STUDIES AT MAR PICCOLO (SOUTHERN ITALY; LATEST QUATERNARY)

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Dinoflagellate cysts and other Non-Pollen Palynomorphs (NPPs) assemblages from the S05B core documented the paleoenvironmental changes in the Mar Piccolo basin (MP, southern Italy) during the Late Pleistocene and Lower Holocene. During the Younger Dryas (latest Pleistocene) the NPPs contributed to detect, in prevalent lagoon settings, a high accumulation of organic matter (e.g., high presence of fungi) and nutrients (e.g., *Trachelomonas*-type). The absence of dinocysts suggests that at this time the connections with the Gulf of Taranto were not yet established. At the beginning of the Holocene, the high presence of algae such as Zygnemataceae documents freshwater inputs in the lagoon; the latter was always characterized by a high accumulation of vegetal organic matter (high concentration of carbonicolous/lignicolous). In addition, the presence of foraminiferal organic linings suggests an oxygenated bottom in a brackish water environment. The first appearance of dinocysts (e.g., *Operculodinium centrocarpum, Spiniferites belerius*) highlights the first connection between MP and the Gulf of Taranto. However, the non-continuous record of dinocysts pointed out quite rather unstable connections. Around the 8.2 ka BP event, the most significant environmental/climate change is attested by the disappearance of dinocysts. This work aims also to demonstrate that high palynological resolution of dinocysts and other NPPs can be used for a detailed analysis of aquatic paleoenvironmental changes (e.g., oscillations of the water column) in lithologically monotonous successions.

Keywords: dinocyst, Non, Pollens Palynomorphs, NPPS, Palaeoenvironmental changes

*Speaker

Palynology of the Early and Middle Jurassic and its evolution during the Sinemurian-Pliensbachian boundary event and the Toarcian Oceanic Anoxic Event (Sichuan Basin, China)

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The continental Jurassic System is well developed in China with a large thickness. Extensive research has corroborated that many geological events initially investigated by marine records are also documented in these terrestrial successions, such as the Early Jurassic Sinemurian-Pliensbachian boundary event (SPBE) and the Toarcian Oceanic Anoxic Event (TOAE). Both of them are characterized by a negative carbon-isotope excursion in bulk organic matter and carbonate carbon, and are supposed to be associated with climatic changes and biotic turnovers. Here, we report palynology analyses of the Early and Middle Jurassic in the Sichuan Basin (South China) which demonstrate that there are at least four evolution stages, the spore *Osmundacidites* dominant stage, the spore *Cyathidites* and pollen *Classopollis* co-dominant stage, the pollen *Classopollis* dominant stage, and the spore *Cyathidites* revival stage respectively. Both of the Early Jurassic events, SPBE and TOAE are observed in the third evolution stage whose components seemingly experience slight fluctuations. We attribute the contradiction that the spore and pollen widely known as the climatic indicator fail to detect the climatic and environmental changes associated with these Early Jurassic events to an actuality that the homology between palynology and vegetation is ambiguous and extremely complicated.

Keywords: Classopollis, palynological evolution, continental successions, TOAE, Jurassic

*Speaker

METHODOLOGICAL PRINCIPLES OF PALYNOLOGY APPLICATION IN STRATIGRAPHY

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Spores and pollen are allochthonous pelitic particles of biogenic origin, one of the most important floristic groups used for the dismemberment, and correlation of sedimentary sections. The main tool for sediment stratification by palynological data is palynozone. This is a specialized biostratigraphic subdivision - sediments containing a unique set of different categories of taxa (according to the peculiarities of vertical distribution key, characteristic, transit ones; on the content dominant, subdominant, accessory), that combined to zonal complex. The modernized method of definition of palynozone and the newest way of presenting biostratigraphic material in the form of a standardized and unified system of characteristics are offered.

Keywords: palynology, spores, pollen, palynozones, methodology

*Speaker

Chitinozoan contributions to unraveling the origin of rare earth element-enriched Upper Ordovician phosphorites in the eastern U.S.

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The Upper Ordovician Maquoketa Group and equivalents in the eastern U.S. contain at least two major rare earth element (REE)-enriched phosphorite packages, the total endowment of each dwarfing currently mined REE resources. Our multiyear effort to unravel the complex history of these phosphorites is providing new insights, including illumination of the sequence of events that led to the multi-phased Late Ordovician mass extinction. We have utilized an integrated biochemostratigraphic approach to study an extensive number of surface and subsurface sections. Remarkably, the Upper Ordovician has yielded exceptionally well-preserved chitinozoan assemblages across the region. The linchpin section that reduces uncertainty about temporal correlation of the Upper Ordovician Appalachians and Cincinnati Arch in the east with those of the Midcontinent in the west is a continuous core drilled at Fort Wayne, Indiana, referred to as F688.

The Upper Ordovician succession in the F688 core consists of a mixture of shallow- and deep-water facies containing abundant and well-preserved zonally important taxa and displays diagnostic chemostratigraphic patterns. The Maquoketa Group in the core is 210 meters thick and spans several lithofacies that are assigned to five lithostratigraphic units (Kope, Waynesville, Liberty, Whitewater, and "Fort Atkinson" formations). Detailed benchtop examination of the core revealed multiple phosphatic intervals, rich brachiopod faunas, and multiple graptolitic horizons. Elemental analysis of the entire Maquoketa Group, using portable X-ray fluorescence, was conducted at 60 cm intervals and powders drilled from the same horizons for carbonate carbon isotope data have revealed the positions of the Kope, Waynesville, and Elkhorn δ13Ccarb excursions. The Fairview δ13Ccarb Excursion is absent from the F688 core, suggesting that part of the Maysvillian (and perhaps the uppermost Edenian) sedimentary record is missing. Twenty samples were digested in buffered formic acid yielding abundant, well-preserved, low-diversity conodont assemblages that clearly demarcate the position of the Ordovician-Silurian boundary within the core. Laboratory study of more than fifty palynological samples targeted graptolitic intervals and produced important new insights

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The chitinozoan assemblage in F688 is well-preserved, rich, and stratigraphically varied. The lower Katian Kope Formation contains *e.g.* *Belonechitina kjellstromi*, *Hercochitina downiei*, and *Clathrochitina* sp. nov., and the top of the unit can be calibrated with a graptolite assemblage suggestive of the *Geniculograptus pygmaeus* Zone (upper Edenian and lower Maysvillian regional stages; approximately uppermost lower Katian, upper Ka1 Stage Slice). Samples from the overlying Waynesville Formation have produced graptolites indicative of the upper *pygmaeus* to *Paraorthograptus manitoulinensis* zones (upper Maysvillian and lower Richmondian regional stages; middle Katian, Ka2 and Ka3 stage slices). Chitinozoans from the Waynesville Formation include long-ranging species such as *Belonechitina micracantha* and *Plectochitina spongiosa*, together with several new species of the genera *Tanuchitina* and *Hercochitina*. Higher in the core, the Liberty, Whitewater, and "Fort Atkinson" formations yielded chitinozoan species characteristic of the upper Katian biozones of Anticosti Island (Canada) and Nevada (USA), such as *Tanuchitina anticostiensis, Hercochitina longi,* and *Eisenackitina ripae.* The Brassfield Formation (Silurian) overlies the "Fort Atkinson" Formation in the F688 core and here we infer a substantial stratigraphic gap that comprises at least all the Hirnantian Stage and likely the uppermost part of the Katian Stage.
The combination of these complementary methods has produced a high-resolution chronostratigraphic record for the Upper Ordovician succession in the F688 core. Not only is this suite of data from a pivotal locality in our emerging Upper Ordovician chronostratigraphic synthesis of the eastern U.S., but these results also highlight the promise of chitinozoan biostratigraphy to refine temporal correlations within Laurentia. Our integrated approach is yielding chronostratigraphic context for Maquoketa Group REE-enriched phosphate deposits allowing us to disentangle the signatures of the cryptic oceanic anoxic events from which they originated.

Keywords: Integrated stratigraphy, Palynology, Graptolites, Conodonts, Stable Carbon Isotopes, REE

Palynological changes across the Triassic/Jurassic boundary in the terrestrial basins in China

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There are four large terrestrial basins in China during the period of the late Triassic epoch to the early Jurassic epoch. They are the Junggar basin and the Tarim basin in NW China, the Ordos basin in north China, the Sichuan basin in south China.
According to previous research, the deposition of the top Triassic system and the base Jurassic system is continuous in the Junggar basin and the Tarim basin. The palynological succession of Haojiagou section in the Junggar basin shows a gradual evolution from Triassic zone to Jurassic zone, except several spore peaks (including *Densoisporites scanicus*, *Densosporites crassus* and *Cyathidites* sp.) at the base Jurassic.

It is generally believed that there is a big gap between the Triassic and the Jurassic in the Ordos basin. The Fuxian formation, the first stratigraphic unit of Jurassic in the Ordos basin, yields palynological zone with abundant *Classopollis* but no Triassic relict such as *Taeniaesporites*, *Aratrisporites*, which indicates the age of the late Early Jurassic.

In the past, the contact between the Jurassic and the Triassic in the Sichuan basin was thought to be conformable. Recently, however, we found a minor gap at the contact. The Xujiahe formation, the top Triassic strata, yields diverse Triassic-diagnostic taxa, such as *Dictyophyllidites*, *Aratrisporites*, *Kyrtomisporis* and *Taeniaesporites.* The Ziliujing formation, the bottom Jurassic strata, contains high proportion of *Cyathidites* and *Classopollis.* The two palynological zones shows an abrupt change, which means, we think, there is a gap. This view was supported by the study of flora and carbon isotope. Coniopteris, a plant firstly appeared at the middle Early Jurassic, was found near the base of The Ziliujing formation. The curve of organic carbon isotope lacks the negative shift of the earliest Jurassic which has been found at the Haojiagou section, NW China, St. Audrie's Bay section, SW UK, and Hochalplgraben section, Austria.

So, palynology is a useful tool of stratigraphy correlation, even identifying a stratigraphic gap.

Keywords: palynology, terrestrial, Triassic – Jurassic boundary, China

*Speaker

High-resolution statistical palynology reveals climatic changes in coastal wetlands of the Early Eocene proto-North Sea

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Long-term effects of present global warming on ecosystems on timescales beyond those covered by the human record are mostly a matter of speculation. However, the reaction of ecosystems to global warming on different timescales can be inferred from detailed studies of greenhouse periods and short-term warming events as repeatedly known from the geologic past. The Early Eocene Climatic Optimum (EECO) and its superposed short-term warming events such as the Paleocene-Eocene Thermal Maximum (PETM) represent the last greenhouse period before today. It is especially suited for comparisons to the presently developing greenhouse since fauna and flora had already reached an evolutionary state similar to today.
The sedimentary succession of the former Helmstedt Lignite Mining District in northern Germany includes the upper Paleocene to lower Eocene Schöningen Formation and the middle Eocene Helmstedt Formation in an estuarine setting at the southern edge of the proto-North Sea. It therefore covers the entire Paleogene greenhouse phase and its gentle demise almost continuously. Due to the interaction between changes in sea level, salt withdrawal in the subsurface and climate-related changes in runoff from the hinterland the area was subject to frequent changes between marine and terrestrial conditions.

A robust age model is now based on eustatic sea level changes, biostratigraphy, and radiometric ages as well as bulk organic carbon isotopic data. Negative carbon isotope excursions allow to identify long- and short-term hyperthermals of the early Eocene such as, e.g., the EECO and the PETM. Therefore, the more than 200 m thick succession with about 13 lignite seams of up to 15 m thickness offers the rare opportunity for tracing the effects of long-term changes and short-term perturbations of the climate on the diversity and composition of plant communities by using pollen and spores as proxies during ca. 10 million years of the late Paleocene to middle Eocene.
Here, we present high-resolution palynological analyses of several hundred samples from the lower part of the Schöningen Formation, which includes the PETM and other short-term warming events. Distinct changes in the palynoflora which are correlated with shifts in δ13C TOC values show that changes in the wetland vegetation can be attributed to known thermal events. However, multivariate statistical analyses also allow to identify successional stages within the peat-forming vegetation independent of climatic perturbations. They may have been related to changes in hydrologic conditions and/or nutrient resources and effects of peat aggradation. Therefore, the combination of a robust age model with high-resolution palynological analysis

*Speaker

and the application of multivariate statistics allows for a unique insight into the dynamics of a terrestrial ecosystem during the Paleogene greenhouse.

Keywords: Early Eocene, North Sea, palynology, carbon isotopes, PETM, EECO, Paleogene, greenhouse, multivariate statistics

Permian palynostratigraphy of Northern Namibia: new data from the Huab, Owambo and Waterberg Basins

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Hydrocarbon exploration in Northern Namibia in the last few years has sparked new interest in the Karoo Supergroup geology in the region. Several basins are known, outcropping and covered by Meso-Cenozoic sediments and volcanics.
Recent reanalysis of vintage wells in the Owambo and Waterberg Basins, together with field work and sample collection in the Huab Basin, have provided new data on the Lower Karoo Group stratigraphy in the region.

The historical ST-1 well in the Owambo Basin was resampled, spanning the Dwyka and Ecca Formations/Groups. Three cored wells (OK6-2, OK6-3 and OK9-3) from the Waterberg Basin were sampled, but only spot samples were taken due to the limited vertical span of the Lower Karoo in this area. The Huab Basin outcrops were sampled, both the Ecca equivalent (Verbrandeberg Fm.) and overlying formations (Tsarabis, Huab and Gai-As).

The ST1 well Karoo Supergroup samples showed a low thermal maturation degree (amber-yellow to brown colours) with abundant organic residue.

At the base of borehole ST1, the palynomorph assemblages recovered from the two samples assigned to the Dwyka Group show an abundant and well-preserved palynomorph assemblage, allowing taxonomic identification and biostratigraphic interpretations. These are dominated by abundant trilete spore palynoflora (52–55%), and some Filicopsida vegetation group also occurs. Gymnosperm pollen grains are frequent to rare and are assigned to the Glossopteridophyta group, including the monosaccate pollen (ca. 10%). Taeniate bisaccate pollen grains (13-14%) are common. Polyplicate pollen grains are also present (9-10%). In addition, non-marine algae groups are rare to frequent (6–14%), including *Botryococcus braunii*, *Leiosphaeridia* sp., *Ovoidites* spp., and *Tetraporina* sp..

This assemblage, assigned to the Dwyka Group, is characterised by the common occurrence of spores and monolete pollen grains, with *Vittatina* spp. and the presence of the FO and LO of

*Speaker

Hamiapollenites bullaeformis, suggesting an early Permian, Cisuralian, Asselian/Sakmarian age.

The assemblages recovered from samples assigned to the Ecca Group in ST-1 are dominated by trilete spore palynoflora (44–90%). Gymnosperm pollen grains are rare and are assigned to the Glossopteridophyta group, including the monosaccate pollen (ca. 1-10%). The rare non-taeniate bisaccate pollen grains are rare (ca. 0.6-1.5%). Rare Taeniate bisaccate pollen grains (of about 2-8%) are also rare in the assemblage. Rare to common polyplicate pollen grains (3-28%) are observed. Non-marine algae are rare to common (3-20%), similar to the deeper samples, while the fungi group is represented by *Portalites gondwanensis*.

The assemblages recovered in samples OK6-2 and OK6-3 are assigned to the Ecca Group and present a very poor spore assemblage. In borehole OK9-3, the Ecca assemblage is dominated by trilete spore palynoflora, with the Filicopsida vegetation group dominating. Gymnosperm pollen grains are rare, and Lycopsida microflora is common. Rare Taeniate bisaccate pollen grains occur in the assemblage with rare polyplicate pollen grains. Non-marine algae are rare to common and similar in composition to the ST-1 well samples.

Samples from the Huab Basin were mostly barren. The upper part of the sequence - Tsarabis and Gai-As Fms. – are composed of continental to transitional sediments, hampered organic matter preservation in most instances. The Verbrandeberg Fm. samples provided poorly preserved and poorly diversified sporomorph assemblages, indicating an Early Permian (probably Artinskian) age, following the regional interpretation for the Ecca unit. The sedimentation environment was lacustrine, as indicated by the presence of phytoclasts (vastly dominant), spores and, to a lesser degree, pollen. Non-marine algae – *Botryococcus* sp and *Tetraporina* sp. – support a lacustrine setting interpretation.

Abundant spores and a marked reduction of pollen grains characterise the Ecca palynology assemblages. The FO of abundant *Lundbladispora* spp. (even in tetrads) is a key taxa reference suggesting an Artinskian age.

Both assemblages contain key-species *V. costabilis* which is recognised as a late Carboniferous to early Permian marker, more abundant during the early Cisuralian (Asselian to Artinskian). In these continental successions, the absence of independent age constraints hampers the long-distance correlation of the Northern Namibia basins with other Karoo basins and other regions of the Gondwana paleophytogeographical province. However, similar assemblages can be identified at a sub-regional scale (northern Namibia, possibly Botswana and Paraná Basin), which can be used for correlation purposes and support regional exploration efforts.

Keywords: Permian, Namibia, Palynology

Palynology of the Devonian rocks of the Arabian Plate: the migration of the first forests

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Significant published information is now available on the Devonian palynology of the Arabian Plate. The Early and Mid Devonian was a key interval in land plant evolution as it was the time when the first forests diversified and spread across the continental land areas. The Arabian Plate was a key gateway on northern Gondwana where we can monitor the spread of these forests. The available data is also continuous range data from stratigraphic wells rather than the more typical random set of outcrop samples separated in time and space.
The earliest spore that we know comes from a forest plant is *Dibolisporites eifeliensis* that is related to tree sized Cladoxylopsid plants such as the Eifelian *Calamophyton* from Germany. This spore has a much earlier base Emsian inception in Saudi Arabia. This raises the problem that the rather simple spore *Dibolisporites* may be originating from an earlier smaller plant.

Arguably the most significant component of the Devonian forests was *Archaeopteris* with its deep and laterally extensive root system. *Geminospora* has first appearances in Saudi Arabia in the early Eifelian as *Geminospora svalbardiae* and then in the Givetian as *Geminospora lemurata*. This is a significant time separation as some workers place *G. svalbardiae* in synonymy with *G. lemurata* with the latter used as a pick for the base of the Givetian. This early inception of *G. svalbardiae* is anomalous and may represent a basal group with initial separation of the spore wall layers. Coincident with the inception of *G. lemurata* is that of *Rhabdosporites langii*, the spore of Aneurophytalean progymnosperms and probably the progymnosperm stem group. In Euramerica this appears low down in the Eifelian. Above the inception of *Geminospora lemurata,* and in the mid Givetian, is the inception of its megaspore *Contagisporites optivus*.
The final plant group that formed Mid Devonian forests are the lycopods. The forms that are known to form forests occur in the ever wet palaeo-equatorial areas such as northern China, Arctic Canada and Svalbard. These are represented by the microspore *Cymbosporites magnificus* and the megaspore *Verrucisporites submamillarius.* In Saudi Arabia these are represented by the *Cymbosporites catillus* morphon and *Verrucisporites yabrinensis*, the former having a late Givetian inception. In Western Australia, the closely related microspore is *Cymbosporites homiscoides* that also occurs in Western Gondwana (Bolivia). So, we can infer the migration of the tree sized lycopods as a somewhat different taxon along the northern margin of Gondwana passing through Saudi Arabia in the late Givetian. The Archaeopteridalean progymnosperms migrating in the opposite direction from Euramerica onto western Gondwana dispersing both eastwards to Arabia and southwards to southern South America.

*Speaker

Keywords: Devonian, palynology, Arabian Plate, forests

How the Mar Piccolo (Taranto, southern Italy) has changed from the Late Pleistocene to today: the evidence from organic matter and pollen analyses

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Palaeoenvironmental changes have been traced by palynological (pollen and organic matter) and sedimentological analyses of the S05B core (ca. 40 m; late Pleistocene to Holocene) retrieved from the Mar Piccolo (MP) basin (southern Italy). The palaeoenvironmental history of MP starts from MIS 2 with a fluvial incision and deposition of high-energy sediments. The successive instauration of a hypersaline anoxic saltmarsh has been inferred by the very high abundance of halophytes taxa (salty soils) and Dark Amorphous Organic Matter (DAOM, anoxic bottom). Steppe taxa are also abundant and possibly attest the Younger Dryas event. At the beginning of the Holocene, freshwater inputs support the establishment of a brackish lagoon with anoxic/disoxic bottom (high DAOM); in the area both freshwater and saltwater marshes are present. Solely from 23.91m, the evidence of an inner marine environment with oxygenated bottom is attested by the appearance, in the palynological record, of Clear Amorphous Organic Matter and dinocysts. Anoxic events are in coincidence with the increase of non-arboreal plant during rapid Holocene climatic changes (e.g., 4.2 ka BP event). In the upper portion of the sedimentary core, a marine environment with low hydrodynamics and a high burial rate of plant material is attested by the significant increase in cuticles and resins. The parallel study of the organic matter and pollen analyses from MP surface sediments provided an image of the present-day freshwater and saltwater marshes, around the basin. The comparison among fossil and sub-actual data is useful for a more comprehensive interpretation of the environmental and morpho-sedimentary changes in the past.

Keywords: palynofacies, structured organic matter, amorphous organic matter

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Palaeoclimate-induced stress and plant ecosystem demise across the middle to late Permian transition: a case study from Northern Gondwana

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One of the most significant climate changes in the Earth's history occurred during the late Palaeozoic, passing from a long and intense glaciation (i.e., the Late Palaeozoic Icehouse of Gondwana), marked by the lowest CO2 levels comparable to the preindustrial period, to a progressive global warming that profoundly changed the composition of the worldwide terrestrial biota. The late Palaeozoic can be considered a key time interval for the development and evolution of complex terrestrial environments and their related biota, culminating with two mass extinction events: the end-Guadalupian (middle Permian; 259.8 Ma) and the end-Permian (251.9 Ma). The end-Guadalupian biotic crisis has been recently hypothesized as the sixth mass extinction event ranked third in taxonomic severity, only surpassed by the end-Permian and end-Ordovician (Hirnantian) mass extinctions. The end-Guadalupian crisis occurred under combined controlling factors such as ocean anoxia and acidification linked to flood basalt volcanism from large igneous provinces. Abundant volumes of greenhouse gases (CO2, SO2and CH4) originated by magmatism triggered extremely warm global temperatures affecting marine and non-marine taxa.
In the present study, we analyse the microflora changes occurring throughout middle to late Permian of SW and NW Iran (Zagros Basin and Iranian Azerbaijan, respectively) to understand the response of palaeovegetation community to the end-Guadalupian biotic crisis.

The continuity and chronostratigraphically well calibration of these successions make them important key sections in the world to study this geological time interval. In SW and NW Iran, the middle Permian consists of mostly siliciclastic lithostratigraphic units (Faraghan and Dorud formations, SW Iran and NW Iran, respectively) passing to middle to late Permian units mainly dominated by marly limestone and limestone deposits. The Guadalupian microfloristic assemblages from SW and NW Iran show similar composition to that of coeval Northern Gondwana domain (Oman, Saudi Arabia, Southern Turkey, Iraq, Pakistan, etc.). In detail, the Roadian-Wordian microflora is dominated by monosaccate and bisaccate pollen grains (e.g., *Corisaccites*

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alutas, *Lueckisporites virkkiae*, *Potonieisporites* spp. and *Striatopodocarpites* spp.), mainly indicating a xeromorphic and xeromorpic-hygromorphic ecoclimatic affinity. The overlying Wordian-Capitanian microflora is characterized by the persistence of previous palynoelements and the occurrence of the monosaccate ?*Florinites balmei* and Lycopodiaceae trilete spores as *Indotriradites mundus*, *Kraeuselisporites* spp. and *Densoisporites* spp. and abundant monoletes as *Thymospora opaqua.* Aberrant sporomorphs are also present as sentinel forms announcing the end-Guadalupian ecosystem crisis. Palynoelements of hygromorphic ecoclimatic affinity and minor xeromorphic and xeromorpic-hygromorphic forms dominate the whole association.

The Lopingian palynoflora seems to be similar to the Guadalupian one. In the lower Lopingian (Wuchiapingian), hygromorphic monosaccate pollen grains are rare and mainly represented by ?*Florinites balmei,* while xeromorphic-hygromorphic bisaccates, as *Alisporites* spp. and *Hamiapollenites* spp. are abundant. These palynolelements continue to be present also in the upper Lopingian (Changxingian) in assemblage with a proliferation of hygromorphic trilete spore as *Kraeuselisporites* spp., *Densoisporites* spp. and monolete as *Thymospora opaqua.* Accordingly, the Lopingian microflora's morphological composition is marked by a continued period of biodiversification or relatively stable biodiversity after the end-Guadalupian crisis.
Based on our microfloristic analysis yielded from continuous and marine Guadalupian to Lopingian successions, at least in this region of Northern Gondwana, the land-plants can be confirmed as the 'great survivors' to the extinction events. Currently, there is no convincing evidence for a mass extinction among land plants at the end of the Guadalupian. Although the necessity for further palynological studies from coeval marine successions located in other areas, it appears that the 'sixth mass extinction' of the animal fossil record was not mirrored by a mass extinction in plants. The only signal of this crisis is supported by the presence of aberrant sporomorphs whose presence in this time interval has also been interpreted as the result of mutations due to high-levels of ultraviolet radiation.

Keywords: Palaeoclimate change, Permian extinction, Teratology, Floristic turnover, greenhouse gases

A taxonomic and stratigraphic database for Saudi Arabian Paleozoic palynomorphs

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Since 1990, the CIMP (Commission International de Microflore du Paleozoïque - International Commission on Paleozoic Microflora) has collaborated with palynologists from Saudi Aramco on the study of palynological assemblages, to define a detailed biostratigraphy of the Paleozoic successions of Saudi Arabia.
The Saudi Aramco-CIMP working group first met in Liège, Belgium, where renowned discipline experts gathered, such as Bernard Owens, John Richardson, Florentin Paris, Alain Le Hérissé, Maurice Streel, John Filatoff, and John Marshall, among others. Since the initial conference, that group has held numerous additional meetings, mostly special scientific sessions at international congresses, collaborated on countless studies, and published many scientific papers and special volumes devoted entirely to the palynology of the Arabian Plate. After more than three decades, a rather extensive body of literature on the Paleozoic Palynology of Saudi Arabia is now available in the public domain. This includes comprehensive studies of stratigraphically significant palynological assemblages as well as extensive taxonomic analyses with descriptions of many new taxa. However, the large number of papers published by different authors (some of which are now difficult to find) means that we are often confronted by opposing views and concepts especially on the systematics of certain groups of palynomorphs (e.g., acritarchs, cryptospores, chitinozoans). In this situation, it becomes difficult to integrate the large amount of available data into a consistent stratigraphic and taxonomic framework.

A summary of all data and results produced by the Saudi Aramco – CIMP collaboration is therefore necessary and timely. For this, we propose to establish a taxonomic and stratigraphic database of Paleozoic palynomorphs from the Arabian Plate based on all available data as well as published literature. A first attempt to build a global database of Paleozoic miospores, named PalyWeb, has been proposed in the past (Steemans & Breuer, 2007). This database was established using the free software Wikimedia, which is built on the Wikipedia model. However, the PalyWeb project has not evolved much beyond its initial stages and still remains unfinished due to the difficulties of collecting the enormous amount of data that exist in the literature on global occurrences of Paleozoic miospores. The experience of the PalyWeb project however

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can help now in the development of the herein proposed Saudi Aramco-CIMP taxonomic and stratigraphic database, which will have a more restricted scope, limited to the Paleozoic of the Arabian Plate. If successful, the Saudi Aramco-CIMP database could be successively expanded to include global, worldwide data on Paleozoic palynology.

Reference:
Steemans, P, Breuer, P., 2007.- PalyWeb: A palynomorph database project on the web. In: Steemans, P., Javaux E. (eds.), Recent Advances in Palynology.- Carnets de Géologie / Notebooks on Geology, Brest, Memoir 2007/01, Abstract 08 (CG2007_M01/08)

Keywords: Database, Saudi Arabia, Palaeopalynology, Palaeozoic

Identifying depositional units in complex clastic successions with palynology: understanding reservoir heterogeneity for CO2 storage

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An understanding of the heterogeneity of complex continental clastic successions is vital for CO2 storage and for the extraction of oil and gas. Heterogeneity caused by very low permeability mudstone units (baffles) can cause compartmentalisation of reservoirs impeding extraction or injection. The meter(s) scale of heterogeneity caused by mudstone baffles is also often subseismic, and so not visible in the subsurface, and may be poorly resolved on geophysical logs. The late Permian Umm Irna Formation outcropping along the Dead Sea shore in Jordan contains thick sandstone channels, palaeosols and mudstone units of various geometries and is an analogue for formations that are being targeted for CO2 storage in the North Sea (for example the Early Triassic Sherwood Sandstone Group), and for oil and gas bearing formations in the Middle East, for example the early Permian Gharif Formation.

Following fieldwork in December 2022, we show how chiefly palynology but also plant macrofossils and sedimentology can be used to reconstruct palaeoenvironments and geometry (thickness, lateral persistence, and form) of mudstones in the Umm Irna Formation giving rise to a 3D appreciation of the sources and character of heterogeneity. Individual mudstone units of different origins and geometries within the formation were sampled for their palynomorphs and plant fossils, and studied sedimentologically. The units revealed great variation in palynomorph assemblage type, but generally fell into two categories. The first category was found in laterally persistent argillaceous units such as migrating point bars or crevasse-splay deposits associated with the main river channels. This was high in palynological diversity, containing a wide variety of Permian pollen and spores that probably represent a regional snapshot of the vegetation on the floodplain and the higher ground around. The second category was from smaller, locally restricted argillaceous units like oxbow lake and channel plugs and was of lower diversity, but also varied almost uniquely from one unit to another with high proportions of one or two palynomorph species that appear to be related to plants growing very locally around features in the floodplain.

*Speaker

Thus, it is hypothesised that using palynomorph, plant fossils, and sedimentology, it may be possible to reconstruct the origin, form, and lateral continuity of mudstone baffles in the Umm Irna Formation and other similar formations. The distribution and lateral continuity of mudstone baffles may be relatively clear in outcrop, but the key is transferring what has been learned from the outcrop to the subsurface where 3D awareness will help to guide drilling and CO2 injection or hydrocarbon extraction strategies. Our work shows that detailed palynology, palaeobotany and sedimentology, preferably on core in fairly closely spaced boreholes, could allow reconstruction of mudstone geometry.

Developing methods like these may help understanding of CO2 storage targets like the Sherwood Sandstone Group in the UK, and co-eval formations in Europe, but also other continental successions which are the targets for aquifer geothermal and carbon capture and storage. Both of these low-carbon energy techniques rely on an understanding of fluid flow for injectivity and extraction.

Keywords: palynology plant fossils Permian carbon capture and storage heterogeneity mudstone baffles

A freshwater assemblage from the Hirnantian of Saudi Arabia

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A set of 11 samples from the Hirnantian of Saudi Arabia all of which contain the euglenid fossil, *Moyeria* Thusu, were examined for their organic-walled microfossil (OWM) content. Although these samples are dominated by sphaeromorph acritarchs of unknown phylogenetic and geographic provenance, they also contain members of both the Hydrodictyeaceae (*Proteolobus*, *Scenedesmus*) and the Zygnemataceae (*Gelastina*, *Lecaniella*, *Peltacystia*, *Zygnema*). The closest living members of all these green algae are restricted to fresh water settings. Their recovery here extends the geological record of first occurrences for several taxa, including members of the Zygnemataceae, the sister group to the embryophtyes. Cryptospores (*Quadrisporites*, *Velatitetras*, *Abiditusdyadus*, *Rimosotetras* and *Tetrahedraletes*) are common, but other than *Imperfectotriletes*, which are spores that were physically torn from permanent tetrads, there are no trilete spores recovered from these samples. The lack of trilete spores in this deposit is curious, especially given reports of their prior antiquity. The association of some envelope-enclosed tetrads and dyads with freshwater algae lends support of prior proposals that consider *Quadrisporites* and related forms to be classified with the chlorophycean green algae, not as cryptospores.

Keywords: cryptospores, NPP, Zygnema, origin of land plants, lacustrine deposits, freshwater, Hirnantian

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On-going studies on vegetative and encysted fossil euglenids.

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It is not uncommon for morphologically similar palynomorph types extracted from different stratigraphic horizons to receive different taxonomic names. There are, however, few examples of this phenomenon that are quite as prominent as the concentrically striated forms that go by the names *Chomotriletes* (Paleozoic), *Pseudoschizaea* (Mesozoic), and *Concentricystes* (Cenozoic – Recent). Due to their morphological similarity with a report of encysted *Euglena*, it has recently been proposed that these palynomorphs may have been produced by an ancient protist belonging to the Euglenophyceae. Based on the study of core samples from an Hirnantian (Late Ordovician) section in the subsurface of Saudi Arabia, we propose that these fossils represent the encysted form of the more stratigraphically restricted, but equally distinctive, taxon *Moyeria* Thusu. *Moyeria* is the vegetative (free-swimming) form of these ancient protists, and morphologically is clearly related to extant Euglenophyceae; this has been demonstrated by analysis using transmission electron microscopy. Establishing this link using solely extant euglenoids has been challenging since the taxonomy of the group is based exclusively on the vegetative forms, and knowledge of encystment in the group is practically non-existent. The discovery of both encysted and vegetative morphologies in a single horizon from the Hirnantian of Saudi Arabia provides a rare and crucial link in the ongoing effort to cement this relationship, and further expand upon the existing utility of these fossils as paleoenvironmental indicators.

Keywords: NPPs, Palaeozoic palynology, Chomotriletes, Pseudoschizaea, Concentricystes

*Speaker

Integrated stratigraphy (from radiolarians, conodonts, palynomorphs, ammonoids, ostracods) of the Early Carnian deepening upward sequence (the Huglu Unit) within the tectonic slices/blocks of the Mersin Mélange, southern Turkey: biochronologies and paleogeographic implications

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The Mersin Ophiolitic Complex in southern Turkey includes two different units as the Mersin Mélange (MM) and Mersin Ophiolite with metamorphic sole and is situated to the north and northwest of Mersin City, southern Turkey. The MM is a typical sedimentary mélange and contains slide blocks of oceanic and continental origin in a sheared and deformed olistostromal matrix of Late Cretaceous age. It has clear affinity to the allochthonous units (the Beysehir-Hoyran Nappes) originated from northern branch of Neo-Tethys. Two different blocks (the Tavuscayiri and the Kocatabur) are widely-exposed to the northern part of the MM.
Based on detail studies on the Tavuscayiri Block, samples along the Kilek Section have been investigated and they indicate that it contains two different parts. Lower part of the section characterized the Tavuscayiri Formation is represented by an alternation of conglomerates and sandstones at the basal part and followed respectively by sandy limestones, thick-bedded to massive limestones. This succession is interpreted as deeping upward sequence from fluvial / esturaine to marine conditions. Conglomeratic Sandstones at the base of sequence yielded palynomorphs indicating basal Julian age. Due to successive drowning of platform to the top of the Tavuscayiri Formation, red pelagic limestones with ammonoid remains appear. By correlating this part to the covealant beds with abundant ammonoid taxa around the Killik Hill, its age can be assigned that late Early Carnian.

*Speaker

Higher up-section follow the Huglu Tuffites which are carbonate-poor except for the uppermost part. Cherty limestones at the top of the exposed Huglu Tuffites include rich and diverse radiolarian fauna. Radiolarian fauna clearly reveals the late Early Carnian age corresponding to the *Tetraporobrachia haeckeli* Zone. This age assignment has also been confirmed by dating of associated fauna (conodont and ostracoda) obtained from adjacent beds.
We interpret the marked changes in the sedimentary environment as rapid prograding deepening in a back-arc basin setting of the Izmir-Ankara Ocean culminated in the high volcanic activity of the Huglu Tuffites.

Keywords: integrated stratigraphy, biochronology, Carnian, Mersin Melange

Palynology, lithofacies and stable isotopes reveal late Cisuralian terrestrial environments inside a megacaldera

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During the Permian, Earth's climate experienced a change from icehouse to greenhouse conditions. A stepwise aridification trend in low latitudes, which had started in the Late Pennsylvanian and continued until the Late Triassic, modified the composition of tropical Euramerican floras and the distribution of biomes during the Permian, from dominant wetlands to dryland biomes. Few multidisciplinary studies have investigated late Cisuralian (Early Permian) tropical terrestrial ecosystems and climate.

In the Southern Alps in northern Italy lies one of the reference areas for the study of terrestrial ecosystems at low latitudes during the Cisuralian. A megacaldera was formed in the Kungurian (_˜289-274 Ma) by the explosive volcanic activity recorded in the Athesian Volcanic Group. Intercalated in the volcanic units, sedimentary rocks were deposited during periods of volcanic quiescence. Some of these epiclastic units (i.e., in the Tregiovo Basin) are age-constrained by radiometric dating in the under- and overlying volcanic units and are well-known for their abundant plant macro- and microfossils as well as vertebrate and invertebrate remains and vertebrate traces. These epiclastic units represent an exceptional material to be studied with an integrated approach to reconstruct the different ecosystems and depositional environments developed within the megacaldera, together with the opportunity of detecting the impacts of the volcanic activity on the late Cisuralian ecosystems of that area.

Here, we present the results of the palynological, lithofacies, and stable carbon isotope analyses carried out on two fluvial-lacustrine successions, belonging to the same sedimentary formation, which corresponds to a quiescent phase of the Athesian volcanic activity that lasted approximately 2.1 Myr. Sedimentological analyses combined with palynofacies studies allowed the

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reconstruction of the depositional environments. The qualitative and quantitative study of the sporomorphs, the association to their parent plants (or plant groups) and the inferred plant ecoclimatic preferences (xeromorphic, xeromorphic-hygromorphic, hygromorphic) allowed us to reconstruct the vegetation composition, its distribution and the changes related to local climate conditions throughout the studied interval. The sections studied record two different depositional environments that were present in the megacaldera and occupied distinct depositional settings; one proximal and one more distal with respect to the source, distinguished by a slightly different composition of the sediments, palynofacies and organic carbon isotopes. Probably the megacaldera in that phase was subdivided into several more or less communicating basins with shallow water bodies influenced by the palaeotopography. The sporomorph assemblages show that the plant communities in the area were dominated by xeromorphic and xeromorphic-hygromorphic taxa, such as conifers and seed ferns. Hygromorphic elements like lycophytes and ferns were distributed mainly close to the margin of the lakes. The $\delta 13$Corg values are comparable with those of other Cisuralian continental organic matter and plants. The stable carbon isotope values evidence a small variability, which correlates weakly but significantly with the abundance of xeromorphic elements. All observations support deposition during semiarid to arid climate conditions, typical of the mid-late Cisuralian in the area without major climatic shifts. The same multidisciplinary approach will be applied to other sedimentary formations distributed within the megacaldera, in order to obtain new insights into the development of the ecosystems during the activity of the Athesian Volcanic Group.

Keywords: Palynology, Early Permian, terrestrial environments, megacaldera, Athesian Volcanic Group.

Palynology, lithofacies and stable isotopes reveal late Cisuralian terrestrial environments inside a megacaldera

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Keywords: Palynology, Early Permian, terrestrial environments, megacaldera, Athesian Volcanic Group

The early land plant fossil record from the Silurian of the Arabian Plate: palaeophytogeographical and palaeoclimatological implications

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The early land plant fossil record from the Silurian of the Arabian Plate is confined to dispersed spores present in palynological preparations. Due to deep desert weathering palynomorph recovery on the Arabian Plate is almost exclusively from boreholes. Nonetheless, rich palynological preparations containing abundant and well preserved palynomorphs of low thermal maturity are known from numerous boreholes in Saudi Arabia. These are all from marine strata and dominated by marine palynomorphs (acritarchs, chitinozoans, Scolecodonts etc.). However, they often also contain abundant dispersed spores that were transported into the ocean. This has enabled the sequence of dispersed spores to be established for the Silurian of the Arabian Plate. Analysis of the temporal and spatial distribution of these spores sheds light on the early evolution and palaeophytogeography of the Silurian vegetation of the Arabian Plate. Comparison with the dispersed spore record developed in coeval sequences from elsewhere demonstrates a similar sequence over the megacontinent Gondwana. However, smaller, isolated continents (e.g. Laurentia) and islands (e.g. Avalonia and Baltica) show different sequences of spore biotas. This talk will outline the palaeophytogeographical differentiation demonstrated by Silurian land plant spores and attempt to track migratory pathways. It will also consider the influence of climatic belts on Silurian plant distribution.

Keywords: Saudi Arabia, plants, spores, palaeophytogeography, palaeoclimate

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GP5: Integrated stratigraphy: methods and concepts

Building a pragmatic Phanerozoic eustatic sea-level curve from the rock record

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The depiction of Phanerozoic eustasy was given momentum in the 1970's and 1980's by the well-known publications led by Exxon researchers Peter Vail and Bilal Haq. Since then, further research has continued to develop our understanding. For the Cenozoic, where proxies (e.g., δ18O values) for glacio-eustasy are available, the timing and magnitude of short-term eustasy is reaching consensus. However, for the Mesozoic and Palaeozoic geochemical proxies are at best unreliable, causing dependence on interpretation of the rock record. As the isolation of the eustatic signal from the sedimentary record is challenging, this has led to a divergence of opinions. Herein we present a simplified workflow that allows for the construction of a pragmatic short-term ("3rd order") Phanerozoic eustatic curve, for which the results can be tested by process-modelling to determine plausibility. The mid-Cretaceous is chosen as an example of the approach.
In most sedimentary sections one can observe vertical facies trends and changes in palaeobathymetry indicators. Additionally, in the subsurface and in some large-scale outcrops it is possible to recognise sedimentary architectures indicative of changes in relative sea level. These sets of information can be interpreted using a consistent sequence stratigraphic approach, which reduces uncertainty in understanding sea-level trends. For a given short time interval (e.g., a stage), the examination of multiple suitable stratigraphic sections in a global dataset can be used to identify a commonality (overlap) in the timing of major transgressive and regressive events, although some residual uncertainty will remain. A prerequisite to this is detailed work on biostratigraphic calibration between different fossil groups and other chronological techniques (e.g., δ13C excursions).

Having established timings of synchronous eustatic rise and fall, eustatic magnitude limits can be estimated from stratigraphic observations (e.g., measurements derived from erosional and depositional relief, fossil assemblages, facies juxtaposition), geochemical proxies (e.g., δ18O values) or from a compilation of published magnitudes. These can then be integrated with an independently calculated long-term eustasy trend, derived from tectonic, onlap and geochemical models, and the resultant curve analysed for plausibility. Here forward stratigraphic modelling can be powerful for assessing the impact of uncertainties in timing and magnitude on the generation of a plausible eustatic curve. We show that many published eustatic curves fail to adequately create plausible sedimentary models in that the pace of eustatic change depicted is unable to generate the partitioning of different systems tracts observed in the rock record.
A plausible, pragmatic Phanerozoic eustatic curve provides a valuable tool for not only understanding Earth systems processes through time (e.g., assessing the presence of polar ice to drive

*Speaker

glacio-eustasy), but also for generating subsurface characterisation of lithological variation and heterogeneity. The latter is a major challenge of the 21st century energy transition, not least for identifying storage resource for CO2.

Keywords: Eustasy, sea level, sequence stratigraphy, Phanerozoic

GP7: Miscellaneous Session

Lithofacies and Sequence Stratigraphy of Saraburi Group Located in Na Din Dum Village, Mueang District, Loei Province, Thailand

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The platform carbonate rocks had been underlaid in northeastern Thailand are assessed as high petroleum potential. Accordingly, lithofacies and sequence stratigraphy were classified for providing more natural gases. Outstandingly, the Ban Na Din Dum section was petrographically studied in detail. Then 6 lithofacies were classified; intraformational conglomerate facies (FA1), dolomitic conglomerate facies (FA2), brachiopod rudstone facies (FA3), shale interbedded with thin-bedded micrite and grainstone facies (FA4), thin-bedded limestone and muddy siltstone facies (FA5), and fine-grained rocks with bioturbation and bivalve facies (FA6). That FA1-FA2 were indicated to outer ramp and further location respectively in process of low stand system tract (LST). FA3-FA4 were indicated to lagoon in system tracts of early and rapid transgression (TST). FA5-FA6 were specified to intertidal zone and sand shoal respectively during high stand system tract (HST). Lastly, the source rock potential was higher on FA3 due to unicellular organisms accumulated.

1. Introduction

Thailand is developing country that needs more energy distributing to all segments. The high petroleum potential was mainly focused on the northeastern part due to the platform carbonate rocks having been underlaid. These rocks can be formed as a source, reservoir, and seal rocks which can be provided more natural gases. So that the objective of this project is to classify the lithofacies and sequence stratigraphy as well as petroleum system evaluation of the carbonate Saraburi Group. Outstandingly, the carbonate rocks in area of Na Din Dum village, Muang district, Loei province are interesting.

2. Methods

The outcrops used for lithofacies and sequence stratigraphy were studied and described in detail emphasizing sedimentary structures, textures, and associated macrofossils. Then samples were collected and prepared as thin sections. Petrographically, they were looked through the polarized light microscope (Eclipes Ci-Pol) following Dunham (1962) and Flügel (2004) at Mahidol University (Kanchanaburi).

*Speaker

3. Results and discussion

The stratigraphical section was named as the Ban Na Din Dum that is mainly composed of intraformational conglomerates, brachiopod rudstone, bioclastic grainstone, micrite, shale, and marlstone, siltstone, and fine-grained sandstone with bioturbation and bivalve. Then 6 lithofacies were analyzed; intraformational conglomerate facies (FA1), dolomitic conglomerate facies (FA2), brachiopod rudstone facies (FA3), shale interbedded with thin-bedded micrite and grainstone facies (FA4), thin-bedded limestone and muddy siltstone facies (FA5), fine-grained rocks with bioturbation and bivalve facies (FA6). They were indicated to marine environment which FA1 was specified to outer ramp although the finer and rounder-grained conglomerate (FA2) was far away. They were the results of sea level fall during low stand system tract (LST). FA3 was indicated to inner ramp or lagoon because of sea level rise controlling by early transgressive system tract (TST). Then the sea level rapidly fluctuated rose which 7 sequences of shale, micrite, and grainstone (FA4) with oncolith, foraminifera, and radiolarian were indicated to outer ramp in TST process (high sediment influx). FA5 with cyanobacteria and spicule was specified to intertidal zone as well as subtidal zone. Lastly, finer-grained rocks with bioturbation, brachiopod, cyanobacteria, and lesser associated plant fragments (FA6) were indicated to coarsening upward sequence of sand shoal. FA5-FA6 were probably referred to high stand system tract (HST) in which slow sea level rise and wave dominance. Therefore, FA3 has good source rock potential that accumulates unicellular organisms such as algae, plant debris, and organic matter.

4. Conclusions

The Na Din Dum section has high petroleum potential which can be provided more gases by classifying lithofacies and sequence stratigraphy. Then 6 lithofacies were classified; intraformational conglomerate facies (FA1), dolomitic conglomerate facies (FA2), brachiopod rudstone facies (FA3), shale interbedded with thin-bedded micrite and grainstone facies (FA4), thin-bedded limestone and muddy siltstone facies (FA5), and fine-grained rocks with bioturbation and bivalve facies (FA6). That FA1-FA2 were specified to outer ramp during LST. FA3 was indicated to lagoon and changed to FA4 during seven cyclical rises in TST. FA5 and FA6 were specified to intertidal zone and sand shoal respectively during HST. Lastly, FA3 accumulating the unicellular organisms has good source rock potential.

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Keywords: petroleum system, source rock, carbonate rock, lithostratigraphy, faunal

Global warming and environmental changes across the Permian-Triassic boundary in Iran

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The end-Permian mass extinction event represents the most severe biodiversity loss of the Earth history which causes are still controversial. The present study aims to contribute to this debate providing data from two well-known and significant key sections for investigating the global phenomena occurred at the PTB: Abadeh (Central Iran) and Zal sections (NW Iran), continuously exposed for thousands of metres, spanning from Cisuralian to Lower Triassic. Robust multidisciplinary data from literature based on biostratigraphy (e.g., ammonoids, conodonts, brachiopods, bivalves, foraminifera among others) and chemostratigraphy (e.g, stable and radioactive isotopes) well constrain the PTB. The whole Permian sequence deposited under a transgressive event, linked to the opening of Neo-Tethys ocean along the eastern margin of Gondwana. In this scenario, Northwestern and Central Iran were part of the Cimmerian terranes which detached from northeastern Gondwana (Arabian margin), progressively drifting northward with the spreading of Neo-Tethys. In the two sections, the basal units are represented by Cisuralian siliciclastic deposits with thin- to thick-bedded sandstones and minor conglomerates and siltstones (Vazhnan and Dorud formations at Abadeh and Zal, respectively). The overlying stratigraphic units encompassing the Permian-Triassic interval, investigated for the purpose of this study, may be schematized, in ascending order, as follows. At Abadeh section, the Wordian-Capitanian Surmaq Fm (782 m thick) is represented by thin- to thick-bedded dark limestones and dolostones with chert intercalations. This unit is paved by the Capitanian Abadeh Fm (446m thick) which consists of fossiliferous massive limestones alternated with muddy limestones and rarer marly limestones. They pass upwards to dark shales interbedded with limestones and cherty limestones, followed by dark thick-bedded bioclastic limestones in the uppermost part. The overlying Lopingian Hambast Fm (35 m thick) comprises alternation of thin- bedded shales/marls and bioclastic limestones frequently containing ammonoids and conodonts. Brachiopod bearing beds are present at the lower part. At the Zal section, the Wordian Gnishik Fm (350 m) records the start of the carbonate sedimentation, being composed of dark-grey thin- to thick-bedded bioclastic limestones with marl and shale intercalations increasing at the boundary with the overlying late Wordian-early Capitanian Arpa Fm (320 m). This latter comprises light-grey medium- to thick-bedded bioclastic limestones grading to the Capitanian-earliest Wuchiapingian Khachik Fm (360 m) characterized by thin- to medium-bedded limestones and cherty limestones with shale intercalations. Nodular and marly limestones interbedded with

*Speaker

grey to reddish shales dominate the early Lopingian (Wuchiapingian) Julfa Fm (33 m). This is capped by the latest Permian (Changhsingian) Ali Bashi Fm (16 m) marked by a lower member (Zal Mb, 11 m thick), mostly consisting of red shales, followed by the *Paratirolites* Limestone Mb (5 m thick) with abundant ammonoids. At both sections, a thin (about 0.28 and 0.90 m, in Abadeh and Zal, respectively) reddish-greenish clay interval (Boundary Clay *Auctt*), represents the base of the Elikah Fm, marking the end-Permian mass extinction event. It is overlain by earliest Triassic yellow-grey, thin-bedded marly limestones, containing abundant bivalves and microbial bindstones (*Claraia* beds). The PTB lies at the base of this unit, as indicated by the first occurrence (FO) of the conodont *Hindeodus Parvus.* Based on integrated facies, microfacies, palynofacies and biostratigraphic data, the main results of this study are: 1) the depositional setting of the Permian units can be referred to homoclinal mixed carbonate-siliciclastic ramps evolving to more distal and deeper conditions upwards, characterized by different siliciclastic input according to their distance from the land masses; 2) the demise of carbonate sedimentation is characterized, in both cases, by a marked increase of fine siliciclastics approaching the PT transition; 2) the Lower Triassic microbial bindstones of the Elikah Fm represent the first stage of recovery of marine level-bottom communities in the immediate aftermath of the end-Permian mass-extinction; 3) the stacking facies and palynofacies vertical changes and microflora indicate a global warming event across the PT transition, related to the onset of the Siberian Traps, a potentially massive source of CO2; 4) a sequence stratigraphic interpretation is attempted and framed in the Permian-Lower Triassic paleogeographic scenario of this sector of the Gondwana domain. The overall results highlight the role of both global and regional climate changes as main controlling factors for the relative sea-level changes and, in turn, for the evolution of the depositional settings.

Keywords: Permian, Triassic, stratigraphy, paleoclimate, Iran

A new book on stratigraphical methods - Deciphering Earth's History: the Practice of Stratigraphy

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Deciphering Earth's History: the Practice of Stratigraphy is a new book designed to guide users in how to use and apply the wide range of stratigraphical tools now available. The distinctiveness of this book lies in its emphasis on 'how to do' stratigraphy. Each of the key stratigraphical methods are presented in a step-by-step fashion and illustrated with flow charts. Worked examples are used throughout to show how the methods have been used in practice. Shortcuts, possible pitfalls to avoid, and enhancements based on professional experience are provided as top tips. The strengths and limitations of each of the methods are also considered. For the theory behind each of the techniques the reader is directed to established and pioneering references.
As well chapters on the 12 key stratigraphical techniques, there are chapters on non-stratiform units, climate stratigraphy, recognizing incompleteness, and using and archiving stratigraphical data. The techniques are all brought together in the chapters on chronostratigraphy, constructing geological timescales, and two chapters on integrating and applying techniques to a range of problems. Extensive cross referencing throughout shows how the different techniques can be used to complement and enhance each other.

Stratigraphy has always played a key role in geology, one could say that the need to understand the sequence, rates and duration of events makes it the very backbone of geology. Alongside attempts to understand Earth's history at an increased scale of resolution and complexity there has been an increase in the range and sophistication of stratigraphical techniques that have developed. This development makes it is even more important that practitioners and users are well versed in the spectrum of stratigraphical methods. We hope that this book goes some way to helping to address this challenge.

Forty stratigraphers from industry, academia and the public sector contributed to this book, the first in a new book series, Geoscience in Practice (see Coe and Astley 2022). This presentation will focus on the scope and key features of the book and the aims of the book series which is open for book proposals.

Coe, A.L. (ed). 2022. *Deciphering Earth's History: the Practice of Stratigraphy.* Geological Society, London, Geoscience in Practice, 349pp., https//doi.org/10.1144/GIP1.
Coe, A.L. and Astley, C. 2022. The launch of a new practical book series: Geoscience in Practice.

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Geoscientist, **32** (4), 6. Available at: https://geoscientist.online/sections/news/the-launch-of-a-new-practical-book-series-geoscience-in-practice/ (Accessed 27 February 2023)

Keywords: stratigraphical methods, new book, techniques, chronostratigraphy, teaching, geological timescale

The International Chronostratigraphic Chart: Golden spikes or sticks in the mud?

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The ICS chart is a truly global enterprise reflecting the labours of many hundreds of committed earth scientists in the development of a global language for stratigraphy. The process, first developing the context and need for a boundary, then possible signals to correlate it, precede the definition of the Global Stratotype Section and Point and its recognition by a 'golden' spike. The point defined in rock is a fact and much else is interpretation. The process generates huge amounts of new data and stimulates research on many aspects of the evolution of earth systems, including major biotic radiations and mass extinctions. Decisions are made following discussion and votes by relevant working groups, the ICS subcommissions and finally ratified by the International Union of Geological Sciences Executive Board. It is a rigorous and robust process but unfortunately necessarily a lengthy one. The first GSSP, for the base of the Devonian System, was defined in a rock section at Klonk in the Czech Republic in 1972. Some 50 years on, about 80 of the available Phanerozoic GSSPs have been defined and a handful of further proposals are in progress. There are challenges, particularly around the correlations of boundary stratotypes, but GSSPs remain the standard for the definition of chronostratigraphic units, the basis for correlation and the construction of geological timescales

Keywords: Chronostratigraphy, GSSPs, correlation, golden spike

*Speaker

Histological investigation of gerontic conodonts

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Conodont elements represent the earliest mineralized feeding structures in the vertebrate fossil record. Elements grew through discrete episodes of lateral accretion of lamellae, and conodonts were able to remodel and repair elements during the lifetime of the organism. Both of these processes created histological signatures that can be analyzed to understand the growth history and dynamics of the organism. Gerontic elements are relatively common in collections of conodont elements, but they are typically overlooked because they represent atypical morphology of the species they belong to. They are characteristically large and variably deformed, e.g., thickened or with unusual sculpture, but not obviously pathological. It is unclear why some specimens become gerontic, although a greater than typical age for the individual is implied. This research uses multiple techniques to observe histological signatures of gerontic elements. Hypotheses investigated include: spatiotemporal changes in rates of growth, spatial relationships of damage and remodeling/repair, intensity and frequency of damage, and amount and spatial relationships of growth centers. The specimens studied are both normal and gerontic P1 elements of *Idiognathodus* species from the Late Pennsylvanian (Missourian; Kasimovian; *I. cancellosus* Zone) Hushpuckney shale of the Swope cyclothem. Constraining the specimen set to a single genus and cyclothem allows assessment of gerontic histology without potential confounding effects due to phylogenetic signals or evolution of seawater chemistry.

Keywords: conodont, microstructure, histology, scanning electron microscopy, ontogeny, tissue remodeling

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Keynote : Angiolini

The biomineral archive of Carboniferous and Permian climates and environments

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The Carboniferous and Permian witnessed rapid climate change and very varied environments in a time span of less than 100 my: from a protracted icehouse which produced the glacial events of the late Palaeozoic Ice Age (LPIA) (e.g. Montañez 2022) to the end-Permian hothouse, which lead to the most severe mass extinction of the Big Five (Dal Corso et al. 2022), through an enigmatic and still not well understood greenhouse at mid-Permian times.
Tectonics, volcanism and paleogeographic setting were among the main drivers of the change, in a tectonic scenario that forecasts a Pangea B supercontinent configuration in the Carboniferous-Early Permian, its northward latitudinal drift and transformation into the Pangea A configuration by the Late Permian, and the opening of the Neotethys Ocean (Kent & Muttoni 2020).

Several physical and chemical proxies have been used to interpret Carboniferous-Permian climate events and environmental changes, and one of the best archives of proxies is that of biominerals, hierarchically organized biocomposites resulting from controlled biological activity. Among biominerals, those produced by brachiopods provide high-resolution archives in the Carboniferous and Permian. These stenohaline sessile marine invertebrates are very abundant in most upper Palaeozoic sedimentary successions and they dominated benthic palaeocommunities at various depth and in different settings. In particular, brachiopods of the Subphylum Rhynchonelliformea have a low-Mg calcite shell with a characteristic microstructure, which is produced by periodical accretion, with temporary cessation of growth, in near-equilibrium with seawater. Their shell is resistant to diagenesis and can be screened by multiple methods (e.g. Garbelli et al. 2022): it is a faithful recorder of the environmental conditions in which the animal lived throughout its life span, lasting from a few years to several decades. Brachiopod shells can thus be used to reconstruct changes in seawater temperature and pH, seasonality, productivity and complex biotic relationships, even at a short-term scale.

Here, I offer several examples of how chemical (δ13C, δ18O, δ15N, δ11B) and physical (microstructure, morphostructure) proxies preserved in the brachiopod biomineral archive can be used to interpret climate and environments from Carboniferous glacial events to the hothouse at the end of the Permian. Starting from a farfield record of the LPIA in Visean-Serpukhovian brachiopods, I then show that the low-latitude Early Permian ocean waters did not undergo significant cooling during the apex of the late Palaeozoic glaciation, but the low-latitude warm belt and environments became narrower. Analyses of brachiopod shells from the Middle-Late Permian transition provide results that are more enigmatic with evidence of cooling also supported by other proxies (Gong et al. 2022). But the latest Permian record of the brachiopod biomineral archive is striking, with undisputed evidence for rapid warming and ocean acidifi-

*Speaker

cation. If global warming has been proven by multiple evidence, acidification is still debated (Foster et al. 2022). I also offer hints into the potential of detecting seasonality in deep time.

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Keywords: Carboniferous, Permian, brachiopods, microstructure, isotopes, climate

Keynote : Joachimski

Chemostratigraphy: Potential and Limitations

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Sedimentary geochemistry has long been used to understand the paleoenvironmental conditions during deposition. Since the late 1980s, stratigraphic geochemical variations have increasingly been applied to define specific geochronological or lithostratigraphic boundaries and since then have become a powerful stratigraphic tool.
Carbon isotopes measured on marine whole-rock carbonates have been shown to have the greatest potential for chemostratigraphic correlation, especially when recrystallisation and cementation have occurred in a closed diagenetic system (e.g. micritic carbonates). However, remineralisation of sedimentary organic carbon during diagenetic stabilisation can add isotopically light carbon (open system) and thus obscure the primary signal. The carbon isotopic composition of sedimentary organic carbon can be used as a complementary proxy, especially in carbonate-poor successions, but the taxon-specific and pCO2-dependent carbon isotope fractionation during photosynthesis and admixture of isotopically heavier terrestrial organic carbon can complicate the correlation with inorganic carbon isotope records. Records from epeiric seas may differ in absolute carbon isotope values and amplitudes of isotope excursions when compared to more open marine records (aquafacies). However, the relative changes in carbon isotope values generally allow chemostratigraphic correlations to be made between sections from different environments.

Strontium and oxygen isotopes are more sensitive to diagenetic resetting and should only be measured on pristine carbonate shells or biogenic apatite. Sr has a long ocean residence time of _˜2.4 Ma, so Sr isotope records are of limited use for high-resolution stratigraphy (10 - 100 kyr), but long-term variations in the Sr isotope record can be used for both stratigraphic correlation and dating. Instead, oxygen isotopes, which reflect changes in seawater temperature and global ice volume are a prime tool for high-resolution chemostratigraphy (e.g. Pleistocene benthic foraminiferal oxygen isotope record). In deep time, the use of oxygen isotopes measured on shallow-water fossil remains appears to be problematic because local sea surface water temperatures and salinities will result in spatial and latitudinal differences in oxygen isotope values. Nevertheless, oxygen isotopes are a useful chemostratigraphic tool during periods of global climate change.

Uranium isotopes in marine carbonates represent a new proxy for average global-ocean paleoredox conditions with secular variations in carbonate 238U/235U being interpreted in terms of changing proportions of anoxic versus oxic sinks for seawater U. A promising and newly developed indicator of ancient global weathering rates is represented by lithium isotopes derived

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from sedimentary carbonates. Due to the long residence time of both U and Li in the ocean, the ocean is well mixed in its uranium and lithium isotopic composition. Both proxies therefore have potential for chemostratigraphic correlation.

Carbon and oxygen isotopes have so far been successfully used for high-resolution correlation in Phanerozoic marine successions, whereas the relatively new proxies such as uranium and lithium isotopes have only been reported for specific time intervals. Proxy records used for chemostratigraphy must be calibrated by bio- or magnetostratigraphy and, importantly, checked for diagenetic overprinting. Trends or excursions in the geochemical signals should be documented by continuously increasing and/or decreasing values. Correlations of single data point excursions (wiggle matching) are not meaningful and need to be corroborated by additional analyses of samples collected at higher resolution.

Keywords: Chemostratigraphy, carbon isotopes, strontium isotopes, oxygen isotopes

Keynote : Scotese

The Earth System History Machine: A Dynamic Simulation of Plate Tectonics, Paleogeography, Paleoclimate and Paleobiogeography.

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Since the time of Nicholas Steno, more than 350 years ago, field geologists, paleontologists, stratigraphers, and geophysicists have fastidiously and painstakingly described and mapped the surficial and buried layers of the Earth's crust, revealing its detailed and exquisite history. This story emerged slowly at first, then accelerated as Earth Historians were able to calibrate their correlations using absolute radiometric age-dating. Using this robust chronometric framework, we now can tell the exciting story of the Earth, in all of its interwoven tectonic, geographic, oceanographic, atmospheric, geochemical, climatic, and biologic complexity. During the last 30 years, Energy companies and national geological surveys have compiled 3D exploration databases and have built 3D stratigraphic models covering the globe. An immense amount of high-resolution, digital stratigraphic data are now in-hand. So what does the future hold? The task before us is two-fold: first, a new Earth System History "Library of Alexandria" must be built from this great volume of digital Earth System History data to preserve it for future generations and, more importantly, to create a comprehensive, coherent and authoritative digital data source for the emerging artificial intelligence systems (e.g., GPT5). The second task, though daunting, is to use this Earth System History database, along with important geophysical data bases, to build an "Earth System History Machine". This Earth System History Machine will dynamically simulate the plate tectonic, paleogeographic, sedimentologic, paleoceanographic, geochemical, paleoclimatic evolution of the Earth since its beginnings, through to the present, and forward into the future Anthropocene. Numerous researchers, who span the globe, are now actively working towards this lofty goal They include researchers and students at the PALEOMAP Project (Northwestern University), EarthByte (University of Sydney), CEED (Norway), University of Geneva, University of Chicago, Leeds University, Chronosphere Project (Erlangen), University of Bristol, Texas A&M University, NMNH, DDE Project, Purdue University, Chinese Academy of Sciences, Peking University, University of Geosciences (Wuhan), Nanjing University, Paleobiology Database, Macrostrat (University of Wisconsin), Utrecht University, University of Western Australia, CNRS, ETH, University of Lisbon, and others.

Keywords: Earth system history, plate tectonics, paleogeography, paleoclimate, paleobiogeography

*Speaker

Keynote : Alegret

Global events of the Paleogene: towards a refined and complete record

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In order to better understand the evolution of the Earth, the International Commission on Stratigraphy pursues the unambiguous definition of a hierarchy of chronostratigraphic units, which provide the framework for global correlation. Consequently, the primary goals of the International Subcommission on Paleogene Stratigraphy (ISPS; https://www.paleogene.org/) include the formal definition of basal boundary stratotypes (Global Stratotype Section and Point, GSSP) of the Paleogene stages and series, the conservation of geologically and paleontologically important sites, and the facilitation of scientific cooperation in Paleogene Stratigraphy. The ISPS encourages international collaboration in understanding the evolution of the Earth during the Paleogene, a period of significant and extreme changes in Earth's climate and biota. The Paleogene began with the impact of an asteroid that triggered the fifth largest mass extinction of the Phanerozoic, and it was characterized by a two-fold, long-term warming and cooling trend, punctuated by short-lived warming events of different duration and magnitude. Holistic analysis of these global events, their nature and consequences, their biotic and stratigraphic expression, as well as the trends, rhythms and feedbacks of the Paleogene climate, is essential to understand how our planet works and how the Earth system will respond to the current climate change. These goals can only be achieved through increased precision of the dating of Paleogene events, the unambiguous definition of stages and series that allow global correlation, and through evaluation of the most continuous and complete stratigraphic records.

Within the Paleogene, the Bartonian is the only stage still pending formal definition of its basal GSSP. All the other stages of the Paleogene have official GSSPs, but the stability of some of them is questionable. In particular, the Ypresian GSSP at Dababiya section (Upper Nile Valley, Egypt) presents limitations regarding its continuity, potential for global correlation, and accessibility to the outcrop. The search for continuous sections spanning the Paleocene-Eocene transition continues, and future efforts should focus on selecting a better GSSP and a set of auxiliary stratotype sections and points for the base of the Ypresian.

The completeness and resolution of the stratigraphic record are equally important for the study of the events and the evolution of the Paleogene. Short-lived events such as the Late Lutetian Thermal Maximum are difficult to identify in deep-sea sediments due to their short duration (c.a. 10 kyr or less), and these events are to be identified in a wider range of localities and settings that allow global correlation with astronomically calibrated time scales. Unlike this global warming event, the impact of an asteroid at the Cretaceous/Paleogene (K/Pg) boundary is among the most intensively studied events of the geological history. This rapid, geologically instantaneous event has been identified in hundreds of land-based sections and ocean drilling sites, in terrestrial and marine settings, and it has been often studied at high resolution. Anal-

*Speaker

yses of apparently complete K-Pg boundary marine records show strong post-impact variability of marine productivity in space and time, supporting the existence of post-extinction heterogeneous oceans with regional plankton blooms. But this apparent variability might at least in part be due to variable incompleteness of the geological record at high time resolution, i.e., millennial resolution or less. Even incomplete records will document extinction, but detailed patterns of events (e.g., impact winter superimposed on long-term warming, short-term acidification superimposed on long-term CaCO3 oversaturation) can be understood from high-resolution records only. The completeness of the K/Pg record is therefore of vital importance in reconstructing the environmental consequences of the impact on short time scales, and sections traditionally considered to be continuous (such as the Bidart section in SE France, Alegret et al. 2004; or ODP Site 1262 in the SE Atlantic Ocean) due to the presence of all biozones may be incomplete in detail, requiring re-evaluation of the K/Pg records and their paleoenvironmental interpretation.

Keywords: Keynote speaker, Paleogene

Keynote : Laskar

The AstroGeo project. The interplay between space missions, celestial mechanics and the analysis of stratigraphic series

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According to Milankovitch's theory of climate, the great climatic variations of the past result from variations in the orbit and orientation of the Earth, themselves modified by gravitational interactions with the other planets and the Moon. Within the AstroGeo project, we propose to recover the past orbits of the planets and the Moon over geological times through the joint use of space missions data analysis, analytical and numerical methods in celestial mechanics and geophysics, and the analysis of sedimentary cyclostratigraphic data. What probably caracterise the AstroGeo approach, is that in the chain of necessary steps to perform this task, we are often using tools that we have developed. This is the case for the adjustment of the orbital solutions to the terrestrial observations and space missions data. This is also true for the celestial mechanics methods. We have developed a dedicated computer algebra system, TRIP, that allows to computed the averaged equations that have been essential to derive the first high accurate orbital and rotational solutions for the Earth (Laskar, 1988, 1990, Laskar et al, 1993), and to discover the chaotic motion of the solar system (Laskar, 1988, 1990). When relying on direct numerical integrations, in order to read the highest accuracy and stability, we had to devise some new high order integrators for the planetary motions (Laskar & Robutel, 2001, Laskar et al, 2004). Finally, in order to obtain, the first coherent scenario for the Earth-Moon evolution (Farhat et al, 2022), we needed the analytical understanding of the atmospheric and oceanic tides previously developed within the team (Desrotour et al, 2017, 2018, 2019). I will briefly describe some of these steps, focussing on the essential results that are of interest for the stratigraphic community.

Keywords: AstroGeo project, stratigraphic series

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Keynote : Holland

The interplay of stratigraphic architecture and ecological gradients: the oft-overlooked control on the stratigraphic occurrence of fossils

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Modeling and field studies have demonstrated the overarching control stratigraphic architecture has on the occurrence of fossils. Hiatuses and changes in sedimentation rate are the two most easily and widely understood of these controls. Intuitively, they are important for the formation of many shell and bone beds, the local abundance of fossils, but also simply the presence of fossils. As a result, first and last occurrences of species are strongly tied to hiatuses (e.g., subaerial unconformities) and intervals of greatly lowered sediment accumulation rates (e.g., downlap surfaces such as flooding surfaces and condensed sections).
Often overlooked and less widely understood is a third important control: the interplay of stratigraphic architecture and the distribution of species along ecological gradients that are correlated with water depth and elevation. In modern marine systems, benthic taxa are widely documented to form communities whose distribution is correlated with water depth. Although water depth itself does not control these communities, the physical and chemical factors that do exert this control are highly correlated with water depth. As a result, water-depth gradients in community composition are not only ubiquitous, they are also commonly the strongest gradient that describes the distribution of benthic marine species. Because many nektic taxa have ecologies that are tied to the seafloor (e.g., demersal fish), they are also commonly distributed along gradients correlated with water depth, and this is also observed in many ancient clades (e.g., ammonites and conodonts). Because many planktic taxa have distributions that reflect stratified water masses, they too often have stratigraphic occurrences correlated with water depth (e.g., graptolites).

The correlation with water depth is crucial because water depth changes predictably with stratigraphic architecture, with gradual shallowing during progradational and degradational stacking, gradual deepening within retrogradational stacking, abrupt shallowing at surfaces of forced regression, and abrupt deepening at flooding surfaces. Although numerous field studies have demonstrated these patterns, this ecological control on fossil occurrences is commonly overlooked.
Recent modeling also suggests a similar relationship in nonmarine settings, in which nonmarine gradients in community composition correlated with elevation, widely demonstrated in the modern world, may also be expressed in the stratigraphic record. For example, a net upward gain in elevation is expected during shoreline regression, whereas a net upward decline in elevation

*Speaker

is expected during transgression. Moreover, selective preservation of this nonmarine elevation gradient imparts a powerful and systematic control on the completeness of the nonmarine fossil record. The interplay of these community gradients correlated with water depth and elevation must be considered before any biological interpretation of the the stratigraphic occurrence of fossils can be made, such as at mass extinctions.

Keywords: stratigraphic paleobiology

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