EDITOR’S FOREWORD

The Conference « Across the End Permian “Great Extinction”: from Permian-Triassic Field Studies to Scientific Results » is to look back, celebrate, and pay tribute to Dr. Aymon Baud, fifty years of continuous Permian-Triassic field research and corresponding publications produced in part with the support of the Swiss National Science Foundation (SNSF), the Geological Museum of Lausanne and in association with the University of Lausanne, Switzerland. General scientific themes are organized in six plenary sessions over three days, starting August 30, 2023, with keynote talks and regular lectures, that will take place in the Auditorium 1216 of the Synathlon building on the campus of the University of Lausanne.

The Lausanne Organizing Committee comprise Profs Allison Daley, Michel Jaboyedoff, Jean-Luc Epard, TorstenVennenann, Thierry Adatte. Dr Aymon Baud is coordinator.

The Scientific Committee comprise the Profs Benoit Beauchamp (University of Calgary), Charles Henderson (University of Calgary), Hugo Bucher (University of Zurich), Nicolas Goudemand (ENS Lyon) and Sara Pruss (Smith College, Northampton, MA).

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COUPLING TIMING AND TEMPO OF VOLCANISM WITH THE MASS EXTINCTIONS THROUGH MERCURY AND TELLURIUM ANOMALIES

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With the contribution of Marcel Regelous, Hassan Khozyem, Jorge E. Spangenberg, Gerta Keller, Uygar Karabeyoglu, Blair Schoene and Syed Khadri

ABSTRACT

Mercury (Hg) and more recently tellurium (Te) are indicator of large-scale volcanism in marine sediments and provide valuable insights into relative timing between biological and environmental changes, mass extinctions and delayed recovery. Numerous studies have explored the connection between sedimentary Hg anomalies and Large Igneous Province (LIP) activity during mass extinction events (e.g., end-Devonian, Permian-Triassic, Triassic-Jurassic, and Cretaceous-Paleocene extinctions). This presentation will specifically focus on the Deccan volcanism, which is considered a key driver of the KPg mass extinction, alongside the Chicxulub impact. 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 located in France, Spain, Italia, Denmark, Israel and Tunisia. In all sections, our findings indicate that Hg concentrations are more than 2 orders of magnitude greater during the final 100ky of the Maastrichtian up to the early Danian P1a zone (first 380 Ky of the Paleocene). Notably, 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 being driven by 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 fallout from volcanic aerosols. Hg isotope data from Bidart (France) confirm a direct Hg fallout from volcanic aerosols. Furthermore, Te/Th ratios measured in the Goniuk (Turkey), Elles (Tunisia), Gubbio (Italy) 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 at the boundary cannot be excluded. Hg and Te maximum loadings coincide with time of maximum Deccan emission rates and volumes determined by zircon dating. Hg and Te concentrations within sediments in conjunction with Te/Th and Hg/TOC ratios are therefore robust and useful proxies to trace intensity of volcanism. These observations provide further support that Deccan volcanism played a key role in increasing atmospheric CO2 and SO2 levels that resulted in global warming and acidified oceans, increasing biotic stress that predisposed faunas to eventual extinction at the KTB

TAXONOMIC HOMOGENIZATION OF MARINE ECOSYSTEMS AFTER THE END-PERMIAN MASS EXTINCTION WAS PHYSIOLOGICALLY CONTROLLED

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ABSTRACT

In the wake of the end-Permian mass extinction, global terrestrial and marine ecosystems were depleted in taxonomic diversity and became more cosmopolitan. The causes of the diversity decline are increasingly understood but the explanation for taxonomic homogenization across space remains incompletely known. Here, we quantify changes in cosmopolitanism within the marine fauna across the Permian/Triassic boundary using three measures of taxonomic similarity: Biogeographic Connectedness, Jaccard Similarity and the semimetric Czekanowski's coefficient, each of which measures the degree of taxonomic similarity on a scale from 0 (totally endemic) to 1 (globally widespread). For our analysis, we downloaded fossil occurrence data for classes Bivalvia and Gastropoda spanning the Changhsingian (~254.4 - 251.9 Ma) and Induan (~251.9 -251.2 Ma) ages from the Paleobiology Database (2,140 occurrences of 240 genera) and grouped the occurrences into a global grid of 812 equal-area (~630,000 km^2) hexagonal cells. All three measures indicate that taxonomic similarity increased after the end-Permian mass extinction that persists even after accounting for the geographic distribution of available data. We further divided our dataset by survival status (victims, survivors, and originators). We find a greater degree of provinciality in victims than in survivors during the Changhsingian. However, the increase in similarity between the Changhsingian and Induan is much larger than the difference between victims and survivors within the Changhsingian data, indicating further biogeographic response within surviving genera. Genera that originated in the Induan had similarity indices similar to survivors during that age. Comparison of Permian/Triassic biogeography with environmental changes indicated by paleoceanographic models has the potential to further determine whether the taxonomic homogenization of the oceans was controlled by ecology, environment, or both.

CHANGES IN SEDIMENTATION ACROSS THE PERMIAN-TRIASSIC TRANSITION: RECORD FROM THE SAIQ FORMATION, OMAN

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ABSTRACT

A new stratigraphic record (~150 m thick) is introduced for the Permian-Triassic transition from previously unexplored sections of the Saiq Formation in Wadi Mijlas and nearby exposures of the Saih Hatat culmination, Oman. The succession reveals previously undescribed sedimentary features and demonstrates a significant shift in depositional processes, biota, and sedimentation patterns across the Permian-Triassic transition. Towards the late Lopingian, the record is dominated by m-scale shallowing-upward cycles within a Highstand Systems Tract, with oolitic facies at the top of each cycle. The sequence boundary is placed at the top of the last bioclastic oolitic grainstone. Carbon isotope ($\delta^{13}C$) values remain steady at ~4%–5% throughout the interval. This unit is overlain by a Transgressive Systems Tract of cm-scale, coarse-grained amalgamated beds with either normal grading or massive textures with erosive bases, inferred to be proximal tempestites. Intervals of wackestone-packstone interbedded with inferred tempestites with occasional hummocky cross-stratification and bioturbation follow, accompanied by a gradual decline in $\delta^{13}C$ values from ~4% to ~2.7%. In the upper part of this unit, there is a notable increase in heterozoan biota, such as sponges, bryozoans, brachiopods, and crinoids. At the Permian-Triassic transition a remarkably distinct ~20 m thick unit of yellowish, cyclic, turbidite-like cm-scale calcisiltite beds appears, which generally lacks fossils and contains disrupted slide-slump structures, but with rare ammonoids, bioturbations and reworked bivalve shells at the top part. While the transition is generally abrupt, some localities show an intraformational breccia comprising reworked cobbles-sized calcisiltite intraclasts. This interval shows an initial negative $\delta^{13}C$ excursion to -0.2%, followed by a short rebound peak of ~1.5%, then gradually decreasing values to -4%. Integrating changes in sedimentation with biota implies a change through the Permian-Triassic transition from mid-outer ramp to slope deposits. The abrupt transition along the boundary highlights a rapid change in depositional setting. We interpret this shift in sediments to be coupled with rapid sea level rise, and so argue that a regression event is not present across this Permian-Triassic transition.

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SIX MAIN FACIES IN THE POST-EXTINCTION BASAL TRIASSIC (GRIESBACHIAN) OF OMAN, FROM DEEP TO SHALLOW AND FROM EUXINIC TO WELL OXYGENATED

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ABSTRACT

This short sedimentological approach results from field works done first with Lausanne and later Zurich PhD plus PostDoc students and paleontologists, with colleagues from France, Austria, Italy, and Canada.

During the Permian-Triassic transition (PTt) the calcite compensation depth (CCD) is marked by a rise from deep to shallower depth in the paleo-oceanic Buda'yah section (Baud et al., 2012), showing a basal Triassic facies of light calcareous shale and platy lime mudstone beds overlying dark late Permian radiolarite chert beds and siliceous shales. The platy lime mudstone beds include an Upper Griesbachian bloom of calcite filled spheres (radiolarians?) that marks a potential world-wide event.

The next main facies occur on the continental-slope deposit of the Wadi Maqam section (Richoz et al., 2010, 2012) where we observe the same CCD rise, here from chert bands in Late Permian dolomite beds to 3 m thick boundary calcareous shales and up to 9 m of basal Triassic laminated papery limestones and stromatolite deposits in euxinic environment.

If apparently continuous deposits during PTt occur on shallow continental margin cropping out in the autochthonous, dolomitized Permian-Triassic water carbonate succession, gaps are present in the Saih Hatat (Weidlich & Bernecker, 2011) as in the Djebel Akhdar (North Oman mountains). The main basal Triassic facies on the Saiq Plateau sections consists of light thin bedded dolomudstone overlying brown azoique dolomudstone with disrupted and deformed beds (seismite, described in Baud et al., 2016).

During Triassic and Lower Jurassic times the Hawasina and Batain basins have been the sites of large-scale debris flows and olistostromes. Within the great number of reworked blocks, the discovery of basal Triassic highly fossiliferous boulders, revealed three new facies of Griesbachian limestones built, for two of them, by skeletal accumulations in well oxygenated water. These facies are in marked contrast with the euxinic muddy carbonate (dolomudstone) of the shallow water platform sediments. Their origins are from seamount or oceanic plateau, above fair-weather wave base.

The first of these three facies consist of a bivalve bioherm overlain by a Bivalve biostrome with rare Brachiopod, Gastropod and a new type of Crinoid, well dated by conodonts and characterize the Griesbachian Wasit block facies described by Krytsyn et al., (2003) and Twitchett et al., (2004). A similar Griesbachian coquina facies occur in the not yet described Naksi block in the Wadi Wasit and another coquina block in the Asselah area (Batain).

The second facies is a crinoidal lime-packstone discovered in an Asselah block described by Brosse et al. (2018) and showing among crinoids a rich assemblage of bivalves, gastropods and ammonoides.

The third facies show for the first-time a stromatactis pelagic Hallstatt-type limestone of Griesbachian age. It has been discovered by H. Bucher in a 30m thick reworked block (RAA) comprising Late Permian and Early Triassic carbonate succession in Djebel Rabat. After a preliminary sedimentological study, it is interesting to note the disrupted and deformed beds at the Permian-Triassic contact due to possible seismite.

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CARBONIFEROUS-PERMIAN LOW LATITUDE GLENDONITES: A RECORD OF EPISODIC UPWELLING IN ARAGONITE SEAS

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ABSTRACT

Ikaite (CaCO3.6H20) is a hydrated form of calcium carbonate mineral that grows in a variety of shapes at, or immediately beneath, the sediment-water interface in marine to non-marine environments. Ikaite grows as individual crystals or as variety of 2D and 3D arrangements of crystals, the most common of which are referred to as “hedgehogs”. Individual ikaite crystals display quasi-square transverse sections, and when well-preserved, bi-pyramidal oppositely canted crystal terminations, two “smoking gun” criteria indicative of its monoclinic crystal structure, which sets it apart from anhydritic forms of calcium carbonate. Ikaite is widely viewed as precipitating exclusively in near-freezing temperatures (1–7 oC) in cold climatic or oceanographic settings. Other conditions deemed necessary for ikaite growth, based mostly on laboratory experiments, are high alkalinity, provided in the environment by decaying organic matter, oxidation of seeping methane, or spring discharge, and the presence of an inhibitor of anhydritic calcite, such as orthophosphate, to prevent the thermodynamically favoured growth of low Mg calcite. Ikaite is inherently unstable and will quickly disintegrate when subjected to higher temperatures and will thus leave no trace in the rock record. However, given the right environmental and diagenetic conditions, ikaite transforms itself into a pseudomorph called glendonite, which maintains the megascopic and crystallographic shape of ikaite, while slowly dehydrating to calcite. The best preserved, and most abundant, glendonites in the rock record occur in high latitude areas, such as in the Cretaceous of Arctic Canada (75–80°N). Here, glendonites comprise a variety of well-preserved low Mg calcite phases that recorded the early transformation of ikaite to glendonite within the upper portion of the sedimentary column, and subsequent burial to a significant depth. Upper Paleozoic glendonites are also known from considerably lower paleolatitudes (~5–20°). These include typical glendonite rosettes and “hedgehogs” from: Lower Carboniferous of Alberta, Canada; Upper Carboniferous of Nevada, USA; Lower Permian of South China and New Mexico, USA; and the Middle Permian of Turkey and Oman. Albeit often smaller than their high latitude counterparts, these glendonites display the telltale signs of their monoclinic precursor ikaite, but they are variably preserved as complex arrangements of early to late diagenetic infills, including calcite, quartz, gypsum, anhydrite and, in some cases, celestite. The South China, New Mexico and Oman examples were studied in detail where the growth of ikaite on the sea floor was intimately linked to short-lived episodes of upwelling as shown by the replacement of prolific warm water photozoan carbonates by cool to cold water heterozoan carbonates. As best exemplified in Oman, episodic upwelling occurred at a frequency of ~500–2000 years, indicating some form of millennial climatic or oceanographic fluctuations that may be associated with recurring variations in the intensity of the mega-monsoonal system prevailing at that time. That said, the presence of glendonites at low-latitudes is problematic as modern upwelled water along low-latitude oceanic margins is rarely cooler than 10–15°C, which suggests either one of two things: the vertical thermal structure of late Paleozoic oceans may have been different than that of the modern oceans, or ikaite can form in considerably warmer waters than generally assumed, both of which have been suggested by some authors. Noteworthy, none of these low latitude glendonites are associated with high concentrations of either organic matter or phosphate. While the necessary high alkalinity may have been provided by the early dissolution of unstable carbonate minerals (e.g., aragonite), the low Mg calcite inhibition may have been provided by the high Mg/Ca ratio in the oceans, which is held responsible for the low-latitude aragonite sea that prevailed in the late Paleozoic. Low temperatures and high Mg/Ca would have worked in concert to inhibit authigenic low Mg calcite growth during the upwelling episodes, thus allowing ikaite to grow.

RAPID ENVIRONMENTAL IMPROVEMENT FOLLOWING LATEST PERMIAN MASS EXTINCTION IN MID-LATITUDE SVERDRUP BASIN (ARCTIC CANADA)

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ABSTRACT

One of the most widely accepted views about the Latest Permian Extinction (LPE) and its aftermath is that environmental mayhem and biological devastation occurred rapidly and endured for millions of years afterward well into the Early Triassic. The paleontological and sedimentological record of low latitude areas (e.g. peri-Tethys) supports that claim as shown, for instance, by the rapid eradication of prolific carbonate factories and their replacement by microbial communities. However, sediments that accumulated in the wake of the LPE at mid-latitudes, such as in the Sverdrup Basin, Arctic Canada, tells a much different story. The Sverdrup Basin was located along the northwest margin of Pangea at ~40-45° N during the Late Permian-Early Triassic transition. Earlier in that area, healthy Early Permian photozoan carbonate factories gave way to Middle and Late Permian impoverished heterozoan factories that became increasingly less productive and were progressively replaced by hyalosponge factories. By Wuchiapingian (Late Permian) time, carbonates were all but eradicated from the Sverdrup Basin and spiculitic chert occupied the entire spectrum of shallow to deep, inner to outer ramp environments. This has been explained by ocean acidification, fuelled by massive CO2 increase in the atmosphere and enhanced by upwelling, which led to shallow water areas falling below aragonite and calcite saturation. Only those organisms (siliceous sponges, phosphatic brachiopods) that could thrive in lower pH waters became preserved in widespread chert blankets that extended from the western USA to the Barents Sea (Permian Chert Event).
Wuchiapingian calcite-secreting brachiopods and bryozoans are extremely rare and corroded to varying degrees, while aragonite-secreting ammonites have never been observed. Conodonts too suffered major losses as only two long-ranging species (Mesogondolella rosenkrantzi and M. sheni) are known from chert-dominated successions. Furthermore, widespread anoxia started developing in the Late Permian, first in the deep axial area of the basin, but rapidly encroaching upon shallower ramp areas. By the early Changhsingian, anoxic, and even euxinic, conditions were established in all but the shallowest nearshore areas of the Sverdrup Basin. This led to even more biological devastation, as seen by a net reduction, and then virtual end, of bioturbation. It is important to note that this environmental devastation occurred BEFORE the latest Permian extinction event, which, contrary to generally held beliefs, led to a geologically instantaneous improvement in environmental conditions at mid-latitudes. This is shown by exceptional beds on NW Ellesmere Island that preserve a latest Permian (post-extinction/pre-Triassic) record at a time when clastic sedimentation was not quite established yet. These beds provide evidence for: 1) return to carbonate production; 2) near complete cessation of chert accumulation, heralding the Early Triassic Chert Gap; 3) re-establishment of bryozoan populations; 4) return of widespread bioturbation and production of faecal pellets; 5) deepening of the oxygen-minimum zone down to at least the basinal edge of the outer ramp; 6) incursion of large number of spherical radiolarians; 7) net reduction in the number, length and diameters of sponge spicules; 8) invasion and preservation of aragonite-secreting ammonites (e.g. Otoceras concavum, O. boreale); and 9) incursion of a diversified conodont fauna of tropical affinity, including several species of Clarkina. Clearly, environmental conditions improved on the mid-latitude shelves of northwest Pangea (much warmer, better oxygenized, less acidic waters) in the immediate aftermath of the LPE. Favourable conditions for marine life persisted well into the clastic-dominated Early Triassic as shown by widespread bioturbation, locally rich bivalve and bryozoan fauna, and diverse ammonite (e.g. Otoceras commune) and conodont (e.g. Hindeodus parvus, Clarkina spp.) populations. Clearly, the mid-latitude shelves of NW Pangea must have offered a refuge for benthic and pelagic/nektonic organisms at a time when extreme post-extinction conditions prevailed at low latitudes.

EXAMINING CARBON CYCLE PERTURBATIONS DURING THE SMITHIAN-SPATHIAN IN CENTRAL SPITSBERGEN

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ABSTRACT

The Smithian-Spathian boundary represents a critical time interval in the Early Triassic as it follows the largest mass extinction in Earth's history. This interval is characterized by global carbon cycle disturbances, decreasing sea surface temperatures, high turnover rates of marine nekton, and large shifts in terrestrial vegetation communities (Brayard et al., 2011; Goudemand et al., 2019; Schneebeli-Hermann et al., 2012; Widmann et al., 2020). Despite the geological importance of this epoch, comprehensive investigations focusing on multiproxy analysis from high latitude regions during the Early Triassic have been limited. Here we reconstruct local-to-regional dynamics of the carbon cycle alongside co-occurring paleoenvironmental change amid the Smithian and Spathian in a high latitude section from Spitsbergen. Our results suggest fluctuations in ocean oxygenation (oxic/anoxic) conditions throughout the Smithian and Spathian. Anoxia have also been noted for other Arctic basinsduring the same time interval, supporting a broader regional paleoenvironmental development (Grasby et al., 2013; Hansen et al., 2018). Anoxic bottom-water conditions would have promoted the preservation of organic matter and likewise restricted phosphorus remineralization, facilitating its recycling within the water column possibly influencing primary productivity. Coincident fluctuations in isostatic and eustatic sea levels likely played a role via influences on organo-mineral interactions, which in turn modulate organic carbon sequestration (Bianchi, 2011; Kennedy and Wagner, 2011). Based on the findings of this study we conclude that local organic carbon sequestration on the Barents Sea shelf was likely influenced by a combination of different factors, including sedimentology, redox conditions, nutrient availability, and primary productivity.

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LATE PERMIAN – EARLY TRIASSIC NON-MARINE RECORD IN WESTERN TETHYS, CLIMATIC IMPLICATIONS

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ABSTRACT

The aim of this presentation is to review our knowledge of the East Pangean intertropical domain from the end of the Middle Permian to the Middle Triassic, based on sedimentological data and paleoenvironmental reconstructions. In European and North Gondwana domain an angular unconformity is observed between deposits of the upper Permian and Triassic, except in the central part of the Germanic Basin. The sedimentation gap is more developed in the southern area where, in some basins, upper Permian sediment does not occur. At the scale of Europe, the large sedimentary supply, erosion and/or lack of deposition during the late Permian, as well as the variable palaeocurrent direction pattern between the middle–late Permian and the Early Triassic indicate a period of relief rejuvenation during the late Permian. During the Induan, the continental area was under erosion and sediment was only preserved in the northern, i.e. the central part of the Germanic Basin, and extreme southern domains. These sediments were preserved under the same climatic conditions as during the latest Permian, whereas in the extreme southern Europe, they were probably preserved in the Tethys Ocean, implying a large amount of detrital components entering the marine waters. The Early Triassic sedimentation began with the ephemeral fluvial systems indicate arid climatic conditions during this period. At the top of the Early Triassic, another angular unconformity is observed: the intra-Spathian Hardegsen unconformity. This tectonic activity created a new fluvial style, with marine influences at the distal part of the systems. During the Anisian and Ladinian, sedimentation was characterised by the fluvial system evolving into fluvio-marine environments with a direct influence of the Tethys Ocean in the southern and northern domains. Both at the end of the Olenekian (Spathian) and during the Anisian, the presence of palaeosols, micro- and macrofloras indicate less arid conditions throughout this domain. In North Africa, the fluvial sedimentation during the Early Triassic occurs in the Tunisian and Libyan basins, and is characterized by coastal plain deposits. In the Algerian Triassic basins, an angular unconformity at the base of the Triassic represents the boundary between pre-Triassic deposits and the Middle or Upper Triassic sedimentary succession, with lack of Early Triassic sedimentation. The Early Triassic deposits has been dated in the High Atlas Morocco Basin. In consequence, from a detailed sedimentological study, including palaeosol analysis it has been possible to characterize the beginning of Mesozoic sedimentation in the High Atlas area, which occur in endoreic basins, and to realize a comparison with Europeans basins.

EXCEPTIONAL AND UNEXPECTED EARLY TRIASSIC MARINE ASSEMBLAGES FROM THE WESTERN USA BASIN AND SOUTH CHINA

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ABSTRACT

After the Permian-Triassic mass extinction (PTME), Early Triassic marine assemblages are usually considered as highly depauperate and poorly diversified, especially benthic communities. The post-extinction biotic recovery was thought to be slow and trophically stepwise. Full re-establishment of complex marine ecosystems was assumed to have not occurred until ~8 million years after the PTME, being represented by the Luoping Biota. The recent discovery of new paleontological localities from the late Dienerian of South China and earliest Spathian of the western USA basin challenges this commonly assumed scenario. These assemblages –respectively the Guiyang Biota and the Paris Biota– unveil a spectacular and unexpected diversity and complexity showing a mix of primitive species from the early Paleozoic and first direct ancestors of modern forms, and indicate the rapid rise of modern-type marine ecosystems after the PTME. The Early Triassic is therefore a crucial interval in the development of modern-type marine ecosystems and these assemblages show key fossils records for the understanding of their establishment. Here we briefly present several new exceptional assemblages of similar or slightly younger age, and geographically distant within the western USA basin, allowing the determination of the spatio-temporal extent of the Paris Biota, as well as environmental conditions that influence its formation and preservation. The Guiyang Biota and the Paris Biota are probably not local exceptions and provide new information on paleobiology, paleoenvironment and the preservation of these organisms. They also question their actual diversity and abundance, which are obviously still largely underestimated although they are key parameters for developing accurate post-crisis rediversification scenarios.

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OMAN EXOTICS: NEW DIENERIAN, SMITHIAN AND SPATHIAN AMMONOID FAUNAS

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ABSTRACT

The presence of early Triassic ammonoids in the Hallstatt-type exotic blocks in Oman has long been known. In 2012 we published a first comprehensive study on the Smithian ammonoid taxonomy and biochronology from Oman. Here we present 4 new blocks that add significantly to the completeness of the Oman Early Triassic ammonoid record.

Block RAA (c. 30m) from Jebel Rahbat spans from the Griesbachian to the middle Smithian. Ammonoid-bearing beds are rare in this block, including three faunas from the middle Dienerian and the early Smithian. Block WAD2 (1.4m) from Wadi Ad Daffa contains a succession of 18 successive ammonoid associations ranging from the early Dienerian to the middle Smithian. Block RAC (2.5m) from Jebel Rahbat yielded three middle Spathian faunas corresponding to the *Procolumbites* beds and *Hellenites* beds. Block RAF (1m) from Jebel Rahbat contains several ammonoid-rich beds ranging from the *Hellenites* beds to the *Haugi* Zone.

Comparison of the new faunas with other, well-known basins such as South China, the Salt Range (Pakistan) and North America shows that most of the known ammonoid associations occur in the Oman exotics. However, faunas from the latest Smithian and the early Spathian are still missing. Despite low sedimentation rates no evidence of palaeontological condensation has been found. Several new ammonid genera and many new species will be described.

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INSIGHTS AND PERSPECTIVES FROM LIPID BIOMARKERS FROM THE PERMIAN/TRIASSIC BOUNDARY IN SVALBARD

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ABSTRACT

For estimating the magnitude and timing of the end-Permian mass extinction and the subsequent recovery in the Early Triassic, the fossil record provides a well-established source of information. However, while the record of micro- and macrofossils is biased by rarity, changing facies and sampling style, molecular fossils (lipid biomarkers) can complement the fossil data. Molecular fossils from various organisms can be preserved over geological timescales and are used to reconstruct environmental conditions in the water column of paleo-ecosystems (e.g., mode of primary productivity or redox conditions). Here, we analysed molecular fossils from Permian-Triassic sedimentary rocks from Lusitaniadalen, Svalbard, deposited in a boreal shallow marine environment. The studied molecular fossils are well preserved due to low degrees of diagenetic alteration and thermal maturation of the rocks. The total content of the *n*-hexane-soluble fraction (maltenes) increases more than 10-fold above the extinction horizon, either due to an increase of organic matter deposition from flourishing disaster taxa or improved conditions for biomarker preservation. Indeed, a decrease in the ratio of the chlorophyll-derived regular isoprenoids pristane to phytane (Pr/Ph) from 1.64 to 1.09 during the latest Permian indicates the development of a hypoxic to anoxic water column. This could have enhanced organic matter preservation and is consistent with anoxia as one of the main drivers of the end-Permian mass extinction. The extinction horizon at Lusitaniadalen coincides with a lithological change from fine sandstones to mudstones, potentially introducing a bias to the extinction signal. Interestingly, a similar lithological change is observed in the lower part of the section in the Permian Kapp Starostin Formation. However, changes in the biomarker inventory are apparently not correlated with changes in lithology, supporting the authenticity of the extinction signal. Among the compounds exclusively found in the post-extinction interval is C_{33} *n*-alkylcyclohexane (C_{33} *n*-ACH). This compound is produced by an unknown taxon that thrived in the aftermath of the extinction. C_{33} *n*-ACH is not associated with a certain lithology, and therefore probably represents a marker of post-extinction communities. While C_{33} *n*-ACH is present in all post-extinction samples, Pr/Ph values, and therefore water column oxygenation state, approach pre-extinction levels of 1.56 about 15 m above the extinction horizon. Therefore, the return to a fully oxic water column during the Early Triassic was possibly pre-dating the recovery of the biological community.

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MARINE SULPHUR ISOTOPE RECORDS AND ENVIRONMENTAL CHANGES DURING THE SMITHIAN-SPATHIAN TRANSITION: INSIGHTS FROM NEARSHORE AND OFFSHORE TETHYAN SUCCESSIONS

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ABSTRACT

The Smithian – Spathian transition (Early Triassic) was an interval of global marine and terrestrial environmental perturbations in the aftermath of the Permian-Triassic boundary mass extinction. Although documented from several spatially disparate sites, the causal mechanisms of these environmental disturbances remain debated. The current study provides a high-resolution middle Smithian to Spathian sulfur isotope record of carbonate associated sulfate (CAS) from three spatially dispersed marine successions representing deep-water nearshore (Qiakong, South China, PaleoTethys) and shallow-deep water offshore marine environments (Jebel Aweri and Wadi Musjah, Oman, NeoTethys). The aim is to disentangle local versus global controls on marine environmental changes as recorded in the Tethys region and thus, better constrain the causal factors of these perturbations during the studied interval. Results reveal differences in the expression, magnitude, and relative timing of sulfur isotope perturbations between the investigated successions. In contrast with previous studies, a negative $\delta^{34}S$ excursion for both CAS and pyrite is recorded between the middle Smithian to upper late Smithian for Qiakong. This middle Smithian negative $\delta^{34}S$ excursion is not recorded in the NeoTethyan sections. In addition, a pronounced positive $\delta^{34}S$ excursion, coeval with the global positive carbon isotope excursion (CIE) is recorded at the SSB for Qiakong. However, the offshore record displays a gradual positive excursion, with a factor of 3 smaller magnitude, spanning the middle to late Smithian and terminating at the SSB. For all sections, however, the basal Spathian is characterized by a prominent negative excursion, coincident with both climatic cooling and sea level regression. We interpret the variability in expression and magnitude of the recorded sulfur isotope excursions to reflect the influence of local effects on the Smithian – Spathian $\delta^{34}S$ record in nearshore depositional settings. Furthermore, we propose a model whereby increasing marine productivity, eutrophication, oxygen depletion, and enhanced organic carbon and pyrite burial, drove the global S-cycle during the middle Smithian to SSB, as expressed by a global overall positive (ca. 10 ‰) $\delta^{34}S$ trend characterizing this interval. At the same time, the negative middle to late Smithian excursion recorded in the nearshore PaleoTethys section was probably driven by elevated continental weathering fluxes facilitated by regional-scale volcanism. The weathering of buried pyrite in subaerially exposed continental shelves during the SSB and into the earliest Spathian, associated with glacio-eustatic sea-level regression, probably caused the negative $\delta^{34}S$ excursion recorded in the basal Spathian. Thus, although locally outpaced by riverine sulfate input fluxes, globally enhanced pyrite burial and/or microbial sulfate reduction were/was the major control(s) on the global sulfur-cycle until the SSB, after which continental weathering fluxes dominated the global sulfur isotope inventory. These results indicate that distance from the paleo shoreline greatly influences the record of marine environmental change archived in Early Triassic nearshore marine rock successions.

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QUANTIFYING THE CAUSE(S) OF THE END-PERMIAN MASS EXTINCTION IN SHALLOW MARINE ECOSYSTEMS

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ABSTRACT

The end-Permian mass extinction corresponds with numerous environmental changes, and the causes of extinction are often inferred from a seemingly synchronous timing of events. To improve our understanding of which environmental changes best explain the marine extinctions, we are collecting new, high-resolution geochemical, sedimentological and palaeontological data from around the world to statistically investigate the relationship between environmental changes and marine invertebrate extinctions. To investigate if this approach will work, a model study was undertaken using already published geochemical, sedimentological and palaeontological data from the most intensely studied Permian-Triassic section in the world, Meishan (China). The fossil database from this section includes 603 species, and the geochemical database includes 18 inorganic geochemical records. Firstly, we re-investigated the nature of the mass extinction in this section, and upgraded a pre-existing algorithm to handle large datasets, which quantifies the number of extinction pulses using the confidence intervals of taxa. Our investigation shows that at Meishan the mass extinction is best explained as an extinction interval that spans the Permian/Triassic boundary. In addition, the algorithm recognises that the nature of extinction varies between different fossil groups, most notably that ostracods have a unique timing of the mass extinction event. Subsequently, we used a regression model to explore the relationship with changes in diversity and the geochemical proxies, and then also investigated changes in faunal composition with the geochemical records using a partial distance-based redundancy analysis. Multiple proxies record a significant relationship with changes in diversity and composition, but $\delta^{18}O_{apatite}$, a proxy for palaeotemperature dynamics, and $\delta^{114}Cd$, inferred to reflect primary productivity dynamics, show significant relationships with the extinctions. This suggests that not only do our results agree with recent earth system models looking at changes in aerobic habitat as best explaining the cause of the marine extinctions, but also nutrient availability was a significant factor, at least in the equatorial, marine extinctions.

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OSTRACOD BODY SIZE AND COMMUNITY EVOLUTION ACROSS THE PERMIAN/TRIASSIC BOUNDARY AT THE SEIS/SIUSI SECTION, ITALY

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ABSTRACT

Body size can be a morphological characteristic that provides valuable insights into the biology, ecology, and evolutionary dynamics of organisms, both in the present and in the geological past. In the fossil record, a decrease in body size has been documented after mass extinction events and studied to better understand ecological selectivity. However, it is important to recognise that stratigraphic patterns and biases inherent in the fossil record can also influence the apparent pattern of body size selectivity. During the end-Permian mass extinction and recovery phase, a body-size reduction has been reported in different locations for several taxonomic groups, including gastropods, ostracods, foraminifera, brachiopods, ammonoids, and bivalves, with few exceptions. Ostracods, one of the most diverse and abundant metazoan groups during the Permian/Triassic boundary, provide an excellent opportunity to study the palaeoecological patterns associated with this event. In this study, we analysed the ostracod fossil record from the Seis/Siusi section in the Dolomites (Italy). The Seis/Siusi section consists of mixed carbonate-siliciclastic deposits accumulated in a shallow marine homoclinal ramp across the Permian/Triassic boundary. By analysing the ostracod record, we identified assemblages to quantitatively analyse community dynamics and measure the body size to investigate changes in body size at various taxonomic ranks. Our observations revealed a body size reduction of ostracod assemblages near the extinction horizon coinciding with a simultaneous faunal turnover. Furthermore, this body size change and faunal turnover correspond with a lithological change in the succession, where dolomitization influenced the preservation of fossils and, consequently, impacted the fossil record. Our evidence suggests that the body size reduction of ostracods at the Permian/Triassic boundary reflects the combination of ecological patterns such as the extinction of larger taxa, dwarfing of the survivors, and the diversification of smaller taxa.

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UPDATE ON PERMIAN CONODONTS IN WESTERN AND ARCTIC CANADA

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ABSTRACT

The most significant events of the Permian include the end of the late Paleozoic Ice Age (LPIA) and the end-Permian mass extinction (EPME) and yet the signature and timing of these events remain imprecisely understood, especially in western and arctic Canadian successions deposited on the north-eastern margin of the Panthalassic Ocean. The paleobiogeography, paleoecology, evolution, and extinction of conodonts can provide some useful insights. The Permian chert event (PCE) is associated with thermocline disruption and lysocline shoaling that led to the contraction of warm-water carbonate factories and expansion of silica factories. The PCE initiated in response to LPIA termination near the Asselian-Sakmarian boundary and continued until the EPME. During the LPIA conodonts are nearly cosmopolitan with biozones defined by *Streptognathodus* spp. on the shelf and by *Mesogondolella* spp. on the slope. During the early Sakmarian, *Streptognathodus* became extinct and was ecologically replaced by *Sweetognathus*. Species of *Sweetognathus* and descendant *Neostreptognathodus* were nearly cosmopolitan in distribution from the Sakmarian into the Kungurian. The last species of *Neostreptognathodus* in the Sverdrup Basin of the Canadian Arctic is *N. pnevi* that defines the base of the Kungurian. However, this genus ranges higher in lower latitudes continuing into the early Roadian in the Phosphoria and Delaware basins. The distribution of Permian conodonts becomes more provincial during the Middle and most of the Upper Permian. The last linkage to cosmopolitan distribution occurs during the early Roadian with the brief appearance of *Jinogondolella nankingensis gracilis* in the transgressive lower part of the Assistance Formation. This taxon is associated within a geographic cline with *J. nankingensis nankingensis* in the Delaware Basin of West Texas. Gene flow became restricted at this time leaving two distinct populations. Middle Permian conodonts in the north cool water province included relatively rare occurrences of longer ranging species of *Mesogondolella* (*M. phosphoriensis* and *M. bitteri*). In contrast, conodonts in the equatorial warm water province (EWWP), especially in the Delaware Basin and South China basins, included numerous shorter ranging species of *Jinogondolella* (*J. aserrata*, *J. postserrata*, *J. shannoni*, *J. altudaensis*, *J. xuanhanensis*, and *J. granti*). Distribution of species of *Mesogondolella* and *Jinogondolella* was likely restricted to a position below a thermocline whereas species of *Sweetognathus* continued to evolve above the thermocline in the EWWP. The abundant occurrence of gondolellids across most of the shelf areal extent and the restriction of *Sweetognathus* to proximal shelf margins suggests significant shallowing of the thermocline at this time. Tempestites delivered shallow-water taxa to mix with contemporaneous deeper water taxa providing a well-integrated high-resolution biozonation. The oceans became more acidic throughout the Late Permian and yet this did not affect conodont distribution. In the EWWP a new genus, *Clarkina*, evolved near the Guadalupian-Lopingian boundary in response to selection pressure associated with the major sea-level lowstand. Numerous species of *Clarkina* evolved rapidly in South China basins to provide a high-resolution biozonation within photozoan carbonate successions of the Wuchiapingian and Changhsingian, while *Iranognathus*, which evolved from *Sweetognathus*, continued into the early Changhsingian. In contrast, *M. rosenkrantzi* and *M. sheni* occur during the Late Permian in the Sverdrup Basin (Lindstrom Fm) and western Canada (Ranger Canyon and Fantasque fms); these formations were dominated almost exclusively by siliceous sponge assemblages leaving the impression that a major extinction event had already occurred. These sponges later became extinct near the end-Permian during a transgressive event when oceans warmed in association with Siberian trap greenhouse gas emissions. At this time, species of *Clarkina* migrated into the Sverdrup Basin and out-competed species of *Mesogondolella*. It has been suggested that this arctic extinction may predate the main EPME as recognized in South China where initial temperature spikes occur before the main hothouse. The PTB in the Sverdrup is associated with the occurrence of *C. taylorae* and *Hindeodus parvus* within the *Otoceras boreale* zone in the Blind Fiord Formation, Otto Fiord section. Conodonts were mostly unaffected through the EPME interval but underwent greater extinction at the end of the Griesbachian substage (early Induan) prior to an Olenekian adaptive radiation.

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UPDATE ON PERMIAN CONODONTS IN OMAN: RUSTAQ, WADI WASIT AND BATAIN

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ABSTRACT

The Lower Permian of interior Oman includes glaciogenic diamictites (Al Khlata Fm), sandy limestone with cold-water brachiopods (Saiwan Fm), and channelized sandstone sheets of fluvial origin (Gharif Fm). None of these facies have yielded conodonts since conodonts are not typically found in cold water deposits and only rarely in the peri-Gondwana Cool Water Province. Middle Permian conodonts are rare in overlying shelf carbonates of the Khuff Formation. However, Middle Permian conodonts are abundant in locations associated with the base-Roadian opening of the Neotethys Sea including the Al Jil Formation at Wadi Wasit and in the condensed red ammonoid bearing limestone overlying basaltic pillow lava at Rustaq. Middle Permian conodont biostratigraphy involves short-duration zones related to populations of *Jinogondolella* within the Equatorial Warm-Water Province (EWWP) and longer-duration zones related to populations of *Mesogondolella* in cooler water provinces to the north and south. The succession of EWWP zones is nearly identical between South China and the Delaware Basin of West Texas, which were separated by the Panthalassic Ocean. The Neotethys was dominated by *Mesogondolella*, but sporadic occurrences of *Jinogondolella* may relate to a migration filter across the Cimmerian terrranes adjacent to the Paleotethys Ocean. At Rustaq the occurrence of late Roadian to Wordian *M. siciliensis*, *J. aserrata*, and *Sweetognathus hanzhongensis* overlies pillow lava. The base of the succession at Wadi Wasit includes *M. saraciniensis* and *M. siciliensis* indicating a latest Kungurian or early Roadian age. A latest Roadian to early Wordian fauna is indicated by *J. nankingensis* transitional to *J. aserrata* as well as *M. omanensis*. Toward the top of the section and below a sub-Triassic erosional unconformity *J. shannoni* indicates Capitanian age. In addition, *M. omanensis* (? transitional to *Clarkina hongshuiensis*) and *J. altudaensis* indicate a late Capitanian age. Locally a Wadi Wasit block includes *Hindeodus parvus* and the Permian-Triassic boundary. Upper Permian conodont biostratigraphy involves short-duration zones of *Clarkina* in the EWWP and longer duration zones of *Mesogondolella* in cool water. *Clarkina* has been postulated to have evolved during the GLB from either a *Mesogondolella* or *Jinogondolella* ancestor, but apparatus reconstruction would favour the latter. *Clarkina* populations vary morphologically across the Tethyan region with differences noted among South China, Iran and Oman. It is possible that some degree of hybribization is occurring within these competing populations. An Upper Permian Qarari unit is part of a WNW directed nappe in the Batain area of NE Oman. It is dominated by medium-bedded rhythmites (spiculitic and radiolarian hemipelagic dark lime mudstone) that accumulated outboard of a productive shelf, interspersed with rare echinoderm-bryozoan turbiditic grainstone and shelf edge-derived reef debris. The unit recorded deep-water sedimentation well below the photic zone, indicating that all recovered conodonts were pelagic during life. Two levels of white quartzitic sandstone in the Asselah area are associated with tectonic slices of the Qarari Limestone. Conodont biostratigraphy suggests that the lower sandstone unit may be associated with the Guadalupian-Lopingian Boundary (GLB) sea-level lowstand, but it remains uncertain whether the units are genetically related or superimposed by tectonics. A distinctive early Wuchiapingian conodont fauna occurs immediately above the lower sandstone at Asselah includes *Clarkina* cf. *hongshuiensis*, *C*. cf. *dukouensis* and a few specimens of *Iranognathus movshovitchi* and *I. sosioensis*; the latter has been recovered from the Wargal Limestone at the Chhidru Nala section in Salt Range of Pakistan. A mid-Wuchiapingian fauna, including *C*. cf. *asymmetrica*, *C*. cf. *transcaucasica* and *C.* cf*. liangshanensis*, occurs within the limestone above the upper sandstone. The uppermost sample of this limestone includes three specimens of late Changhsingian *Clarkina* cf. *yini* suggesting a major gap. This mixture may be associated with microkarsting as a major sequence boundary separates this unit from an overlying transgressive succession. This latest Permian transgressive succession includes *C*. cf. *zhangi*, *C*. cf. *yini* and one specimen of *Mesogondolella sheni*. This Upper Permian Qarari unit is in fault contact with the Upper Triassic Zal unit.

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GENETIC MEMORY OF TRIASSIC CONODONTS

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ABSTRACT

This study investigates the importance of environment, paleoecology, and paleobiogeography in the evolution of organisms, specifically focusing on Triassic conodonts. The Triassic period experienced major mass extinctions, and the establishment of its stages was influenced by the biochronology of ammonoids in the 19th century. The Lower Triassic sub-stages (Griesbachian, Dienerian, Smithian, and Spathian) have been named by E.T. Tozer following his research in Canadian High-Arctic.

While 20th-century research relied on alternative biotic groups like conodonts and radiolarians for establishing the timing of open marine sequences, the 21st century has seen the dominance of isotopic excursion events. These events play a crucial role in the Early Triassic and can be categorized into five major events.Two of these events are negative (Permian-Triassic and middle-late Smithian transitions, while three are positive (Dienerian-Smithian plus Smithian-Spathian transitions and late Spathian-Early Aegean interval). These events are associated with environmental instability and sea-level changes, which are significant for understanding biological morphogenesis and evolution.

The Triassic period spans 51 million years and can be divided into the Induan–Olenekian, Anisian–Ladinian, and Carnian–Rhaetian intervals. The speciation rate varied throughout these intervals, with higher rates following the Permian extinction (13 S/Ma during the Induan–Olenekian) and decreasing over time (8 S/Ma during the Anisian–Ladinian and below 2 S/Ma during the Carnian–Rhaetian).

Triassic conodonts exhibit morphological adaptations in response to temperature and eustatic cycles. Speciation, radiation, and extinction events are non-random, and the processes of progenesis and neoteny (heterochrony) play significant roles in their evolution. Proteromorphosis and paedomorphosis are mechanisms that arise in response to sublethal environmental stress, often occurring after the radiation of fully developed forms during recovery stages following extinctions.

Keywords: *Atavistic reversal, Darwinian anagenesis, Triassic conodonts, proteromorphosis, rediversification*

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GURYUL RAVINE AND ITS TREASURES BEYOND THE PTB

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ABSTRACT

The late Smithian and Smithian-Spathian bounday (SSB) marked by stepwise extinction events for conodonts, occurring approximately 2.7 million years after the main Permian-Triassic boundary extinction. This study, based on high-resolution sampling, examines conodonts and $\delta^{13}C_{carb}$ at the renowned Guryul Ravine section in the Vihi district, Kashmir. Between the Smithian cliff forming platy limestone and the Spathian massive limestone forming wall build up by amalgamated distal turbidites of thin bedded lime mud without marked bedding plane, two facies' changes occur. The first shows a sudden fine terrigenous arrival of dark greyish clay between thin bedded laminated lime mudstone and records the well-known positive $\delta^{13}C_{carb}$ excursion. The overlying 6 m thick, light beige, thin nodular muddy limestone beds is characterized by the highest positive $\delta^{13}C_{carb}$ values. This Smithian-Spathian transition revealed exceptionally abundant and relatively well-preserved conodont elements, enabling a detailed regional biozonation.

A high-resolution $\delta^{13}C_{carb}$ curve was established for the entire Early Triassic interval, reliably concurring with previously documented carbon isotope excursions worldwide. By intercalibrating $\delta^{13}C_{carb}$ data with conodont biostratigraphy, a refined global correlation of the Smithian-Spathian transition is obtained. Analysis of the nekto-pelagic conodonts reveals a sharp faunal turnover during the late Smithian, followed by a rapid radiation in the early Spathian.

The late Smithian extinction event coincides with a well-known positive $\delta^{13}C_{carb}$ excursion recognized worldwide, although locally reaching an extraordinary amplitude of +12 ‰, which is interpreted as a diagenetic overprint. Our investigation of the Smithian-Spathian interval yielded over 1600 conodont specimens (P_1-elements), representing 53 species belonging to 17 genera. Within these faunas, subdivisions for the early, middle, and late Smithian, as well as a reliable bracketing of the SSB about which the exact definition has still not been conclusively clarified to this date.

Among the identified species, we describe 17 new taxa, with 13 assigned to open nomenclature. The remaining four new species are *Neospathodus aristatus* n. sp., *Neospathodus gulami* n. sp., *Icriospathodus reclinocrassatus* n. sp., and '*Neogondolella*' *prima*. Additionally, we classify *Borinella buurensis* and *Scythogondolella milleri* into five and two morphotypes, respectively. The conodont diversity observed during the Smithian and Spathian intervals at this study site represents the best documented in a Smithian-Spathian transition worldwide, encompassing both segminate and segminiplanate forms. This rich diversity enables the definition of 20 local biozones spanning the early Smithian to late Spathian interval.

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MORPHOLOGICAL EVOLUTION OF MARINE ANIMALS DURING THE PERMIAN-TRIASSIC MASS EXTINCTION

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ABSTRACT

The Permian-Triassic mass extinction (PTME), is the most severe biotic crisis in Earth's evolutionary history, with over 80% of marine species estimated to have gone extinct. The magnitude and duration of the biodiversity crisis during the PTEM have been thoroughly studied at both global and regional scales. Yet, the consequences of this mass extinction on the morphological disparity of marine animals and their evolution during this critical interval remains largely debated. Here we develop a new approach based on deep learning to extract morphological matrices (i.e., landmarks and semi-landmarks) from images of fossil specimens and use it to explore the evolution of disparity across the PTME. We apply our pipeline to a newly compiled high-resolution dataset of 730 species of six marine clades, spanning from the latest Permian to the earliest Triassic. We found that the mass extinction led to different disparity patterns across clades, with ammonoids and brachiopods showing a morphological reduction and selectivity, while extinctions in bivalves did not alter significantly their morphospace. We found that species with complex ornamentations and specialized shells were more vulnerable to extinction, while morphological generalist species were more resilient. Our approach offers new opportunities to study morphospace dynamics in deep time across large datasets. Our preliminary findings, show that the magnitude and selectivity of mass extinctions had nuanced impacts on morphological disparity among clades.

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RECONSTRUCTING LOCAL MARINE REDOX CONDITIONS OF TETHYS AREA DURING THE END PERMIAN MASS EXTINCTION USING I/CA

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ABSTRACT

The end-Permian mass extinction, occurring approximately 252 million years ago, stands as a pivotal event in the Phanerozoic era, resulting in a substantial loss of biodiversity on Earth. This catastrophic phenomenon witnessed 70 to 95 percent of terrestrial and marine species extinction. Extensive research spanning decades has aimed to uncover the primary trigger of this extinction event, with the expansion of anoxia emerging as a leading hypothesis for extinction in the marine realm. However, the spatiotemporal constraints of expanded reducing conditions in marine environments remain subjects of the ongoing investigation surrounding the end-Permian mass extinction. In a recent study conducted by Newby et al. (2021), compelling evidence (i.e., thallium isotopes) emerges of a brief period of global oxygenation occurring just prior to the main phase of the extinction event, a phenomenon not yet revealed by any other marine redox proxies. Among the suite of proxies developed for the reconstruction of ancient environmental conditions, the ratio of iodine-to-calcium (I/Ca) has recently gained prominence as a local to the regional indicator of oxygen contents of carbonate-dominated marine environments. Iodine is a redox-sensitive element, among the earliest elements to be reduced under low-oxygen conditions in marine settings. This study aims to apply the I/Ca proxy to carbonate-dominated Permo-Triassic successions within the Tethys Ocean region, which hosts continuous successions through this critical time interval. Some Permian-Triassic localities in Iran, Armenia, and China were selected due to their well-documented and nearly continuous successions that are ideal for testing this hypothesis of a brief marine oxygenation, but in shallow shelf environments. Through detailed integration of our new I/Ca records with existing paleontological and sedimentological datasets from these successions, our research aims to provide a comprehensive and nuanced spatiotemporal understanding of marine oxygen levels and the rates of end-Permian mass extinctions. Detailed and integrative studies such as ours have the potential to uncover crucial data that will enhance our comprehension of how marine redox evolution contributed to the end-Permian mass extinction at the local to regional scale. By deciphering the dynamics of oxygen levels on carbonate platforms during this period, we may also gain valuable insights into the interplay between environmental changes, climate, oceanographic conditions, and ecosystem collapse over deep time.

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THE PERMO-TRIASSIC FORMATIONS OF THE HELLENIDES DEVELOPED AT THE BASE OF CARBONATE PLATFORMS OR OCEANIC BASINS

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ABSTRACT

The Hellenides comprise Mesozoic shallow-water carbonate platforms developed above crustal fragments/terranes of Pre-Alpine continental crust (H1, H3, H5, H7) and oceanic basins (H2, H4, H6, H8) developed in between the drifted northwards carbonate platforms from Gondwana to Europe. The rifting phase of the continental terranes took place in the passive margin of Gondwana during Late Paleozoic - Late Triassic, comprising volcano-sedimentary sequences/complexes, with volcanic formations, clastic sediments, pelagic limestones and other more particular formations such as evaporites, conglomerates and olistholites from the marginal zones of the rifted basins. Immediately after the breakaway of the large continental fragments and their new isostatic equilibrium in the Tethyan realm the shallow-water carbonate platforms are established above the previous rifting complexes. Throughout the northward drifting of the terranes the carbonate sedimentation acquired thick successions of 1-2km thickness. The docking to the active European margin occurred during the establishment of flysch sedimentation on top of the carbonate platforms within the fore-arc basins of the Hellenic Orogenic belt from Jurassic to Early Tertiary. The age of the volcano-sedimentary Permo-Triassic formations differs in each terrane with older ages of Late Carboniferous – Permian observed in the northern terranes (H7, H5,)and younger ages of Permian to Scythian – Anisian (H3) and Permian to Karnian (H1) in the southern ones. Thus, Permian carbonates form the base of the platforms in the H7 (Pangeon) and H5 (Lesvos autochthon) terranes whereas Middle Triassic carbonates occur at the base of terrane H3 (Parnassos, SubPelagonian) and Late Triassic (Karnian) at the base of terrane H1 (Tripolis, Ionian). The same age differences are observed at the base of the pelagic/oceanic sequences of the intermediate oceanic basins (Karnian for the Pindos basin, H2, Scythian for Maliac/Vardar basin, H4). Some special cases of particular formations are observed: (i) in the case of the External Carbonate Platform H1 with Gypsum and related evaporites of Permian-Triassic age in the Tripolis, Ionian and Western Crete units. Additionally, a passive continental margin with Upper Paleozoic neritic limestones occurs beneath the relative autochthon unit of Mani in central Crete (Fodele). (ii) in the case of the Internal Carbonate Platform H3 with a distinctive formation of Permian-Lower Triassic clastics including olistholites/blocks of Permian neritic limestones with characteristic outcrops in Salamis Island, Attica and Evia. Another Permian-Lower Triassic formation with olistholites of Ordovician – Carboniferous formations is observed in the Chios autochthon, including both neritic and pelagic Paleozoic facies. (iii) Some cases of Permian shallow-water carbonate platforms are observed within the Subpelagonian and Pelagonian units of the Internal Carbonate Platform H3 in the outcrops of Hydra Island, where the platform if followed by Triassic volcanics and limestones and in the Chios Allochthon unit (H5), where the Permian platform was disconformably covered by the Upper Liassic carbonate platform with the whole Triassic missing.

INTERPRETING THE END-PERMIAN URANIUM ISOTOPE EXCURSION

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ABSTRACT

Ocean anoxia has long been hypothesized as a kill mechanism for the end-Permian mass extinction, the most severe biodiversity crisis of the Phanerozoic. Initially, support for this scenario came from proxies for local redox conditions, such as bioturbation levels, extent of black shales, sizes of pyrite framboids, and cerium anomaly values. Recently, advances in mass spectrometry coupled with recognition that uranium isotopes are fractionated in seawater and sediments during reduction of soluble U(VI) to insoluble U(IV) led to the development of uranium isotopes in sedimentary rocks as a paleoredox proxy. Because uranium should be well mixed in seawater, U(VI) incorporated into carbonate strata deposited under locally oxygenated conditions should function as a passive tracer of the $d^{238}U$ of seawater and, thereby, as a global paleoredox proxy. However, imprecise knowledge of some key parameters in the uranium cycle combined with noise in empirical records makes interpretation of uranium isotope data a challenge, both for producing best estimates of the extent of anoxia across time as well as estimating associated uncertainty. Here, we present an approach to quantifying the extent of anoxia and associated uncertainty using Monte Carlo simulations of the uranium cycle followed by model-data comparison using the Approximate Bayes Calculation (ABC). Following this approach, we estimate an increase in the extent of seafloor anoxia across the Permian/Triassic transition, reaching 18% of the seafloor (95% CI: [11%, 47%]), lasting anywhere from 20 kyr to 1.2 Myr. There is an inverse relationship between the extent and duration of anoxia in the set of best-fitting models. This initial pulse of pronounced anoxia is followed by a prolonged aftermath, which continues through the remainder of the study interval, of less extensive, yet still expanded, anoxia covering 7.8% of the seafloor (95% CI: [1.6%, 48.9%]). Both expanded and protracted anoxia are required to fit existing data, with no indication of full re-oxygenation during the study interval. An advantage of the Monte Carlo – ABC approach is that estimates can be updated as new data become available simply by repeating the ABC on the existing set of Monte Carlo runs, better illuminating the value of additional information and enabling more strategic collection of future data.

A NEW LOWER TRIASSIC FOSSIL RECORD IN THE WESTERN UNITED STATES: TINY FOSSILS HIDING IN PLAIN SIGHT

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ABSTRACT

The Lower Triassic is characterized by long-term environmental stressors, like low oxygen settings and exceedingly warm temperatures. While the biological consequences of Early Triassic environments have been examined in detail, the taphonomic implications of these settings have received less attention. Our work demonstrates a prevalence of small shelly-style fossil preservation in upper Lower Triassic carbonates of the Virgin Limestone in the western United States. In insoluble residues of carbonates across localities that span the nearshore to the middle shelf, fossils are replaced by apatite with minor glauconite and iron oxides. These minute fossils consist mostly of organisms also known from their macrofossil record, such as gastropods, bivalves, and echinoderms; however, novel occurrences, such as a new species of ophiuroid and previously unknown foraminifera have been identified. The presence of minerals such as apatite and glauconite in these samples is indicative of pore waters experiencing oscillating redox conditions, where the original skeletons are molded and occasionally replaced during early diagenesis. The size of the fossils plays an important role in this mode of fossilization; fossils > 300 microns are rarely preserved by these minerals. Our work reveals a hidden taphonomic pathway in Lower Triassic rocks, illustrating that the environmental stressors that led to long-term delayed recovery also aided in this mode of fossilization, allowing for the discovery of an unknown taphonomy and diversity among the smallest fossils. Future work examining Lower Triassic carbonates across the globe would enable an expansion of this important record.

STEADY STATES AND BIFURCATION DIAGRAM FOR THE PERMIAN-TRIASSIC CLIMATE

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ABSTRACT

General circulation models have been used to simulate climates of the past on the global scale, and to be compared to geological data collected in various localities in the world, representative of local or regional conditions. Initial and boundary conditions are set according to the geological reconstructions of paleogeography, surface temperature, atmospheric CO_2 content, solar energy input, *etc*. Then, the numerical model is run for several thousand years until it equilibrates, and the resulting climate is analysed. However, our knowledge of deep-time climates is subject to large uncertainties and in general a wide range of initial and boundary conditions needs to be explored.
A steady state is reached when a balance between energy received from the Sun, dissipation and feedbacks occurs. Because of the presence of several feedbacks, there are several ways for these mechanisms to equilibrate, and thus in general there is no unique resulting climate under the same forcing. Such situation, where there are different possible steady states and the final state only depends on the initial conditions, is referred to as 'multistability'. A transition between two steady states remains possible under a variation of the forcing (either smooth or brutal, *e.g.*, solar energy input, pCO$_2$ content, asteroid impact).
Here, we apply the multistability framework to simulate climates corresponding to the Permian-Triassic paleogeography. Simulations are performed with the MIT general circulation model in a coupled configuration including atmosphere, ocean, sea ice and land, and the paleogeographic reconstruction is provided by PANALESIS. First, we use a constant forcing (*i.e.*, fixed incoming solar energy and pCO$_2$ content). We explore a variety of initial conditions and let the numerical model evolve until a steady state is reached. This procedure allows us to identify the steady states. Then, we vary the pCO$_2$ content to construct the bifurcation diagram, which allows us to identify the stability range of each steady state and the position of tipping points. The required change in forcing to shift from one state to another helps to understand the oscillations in the climatic conditions observed during the Early Triassic. We finally couple offline the climate model with the vegetation model BIOME4. The two are run alternatively until convergence, and the obtained vegetation distribution can help discriminate which one of the steady states likely existed at the Permian-Triassic Boundary and its Early Triassic aftermaths.

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MICROBIALITES AND SPONGES: UNUSUAL FACIES AFTER THE END-PERMIAN MASS-EXTINCTION AROUND THE NEOTETHYS

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ABSTRACT

The end-Permian mass extinction greatly affected the sedimentary record, with the prolific upper Paleozoic skeletal carbonate factory replaced abruptly by a non-skeletal carbonate factory. During the earliest Triassic, microbialites and other microbial-influenced sedimentary structures flourished. Aymon Baud was a pioneer in the research on these peculiar sedimentary structures and published several seminal articles on this subject. I will here review the different microbial structures occurring around the Neotethys in Armenia, Turkey, Iran, Oman, Italy, and Hungary. The western margin of the Neotethys (Northern Italy) is dominated by extensive oolitic deposition, while the southern margin record oolitic levels followed mainly by thrombolite and some accessory stromatolites (Turkey, Zagros, Emirates). On the northern margin of the Neotethys, or following the reconstructions on the southern margin of the Paleotethys, the Cimmerian plates show a differentiated image with oolites followed by thrombolites and accessory stromatolites on the Central Iran and Alborz plates, whereas the ooids are completely absent from Sanandaj-Sirjan and Lesser Caucasus plates. There, dendrolites and thrombolites dominate with accessory stromatolites and some oncoidal levels. In deeper environments, the microbialites, if present, are generally dominated by stromatolites (Slovenia, Hungary). Over the years, an accumulation of sedimentological, palaeontological, and geochemical data has revealed a more complex image of these microbial-induced depositions with alkalinity, nutrient gradients, and wave energy as the main controlling factors of their forms, size, and repartition.

The recent discovery of the importance of non-spicular demosponges and sometime microconchids in the framework of these microbial structures highlights rather a metazoan-microbial association than purely microbial to build these bioherms. The non-spicular demosponges are, as non-biomineralized fossils, difficult to recognize and prone to debate. However, the careful application of identification criteria allows their identification in several thrombolites around the Neotethys. Their presence probably gives structure and stability to the growing microbialites and favored their growth in bioherm rather than in biostrome and thus an early recovery, even depauperate, of the reef ecological environment.

GEOHAZARDS SPECIALIZED GEOPARK OF ARMENIA, THE CHANAKHCHI GEOSITE WITH UNIQUE PERMIAN-TRIASSIC SUCCESSION

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ABSTRACT

The geology of Armenia is characterized by a diverse array of rock formations that record a long and complex history of geological events. Proposed Armenian geohazard-related Geopark will consist of twenty-six geosites, each of which represents evidence of different geological hazards. Geosites are concentrated in a relatively limited area of about 4.573 km^2, which represents about 15.3% of the total area of the Republic of Armenia (Avagyan et al., 2021). The area is prone to a range of geohazards, including earthquakes, landslides, and volcanic eruptions, which have shaped the landscape over millions of years. Here sedimentary sequences have preserved evidence of several mass extinction events that occurred at different points in the Erath's history in the Late Devonian (375-360 Ma), in the Permian-Triassic (~252 Ma), in the Paleocene-Eocene (thermal maximum, 56 Ma), in the Eocene-Oligocene boundary (abrupt cooling 33.9 Ma).

The Zangakatoun (Chanakhchi) section as a hazard-related geosite is also proposed for Armenian Geopark, which provides evidence of past geological hazard and environmental changes in the aftermath of the end-Permian mass extinction. This section is unique in terms of the development of the basal Triassic giant Sponge-microbial (SMB) build-ups up to 15m of vertical extension with asymmetrical sides due to steady bottom current. The overturned cone-shaped buildup geometry has a top head diameter up to 8m width that consists of numerous thrombolite domes. Changes in palaeoenvironments during the basal Dienerian *kummeli* conodont zone suddenly break-off the thrombolite's growth. The overall duration of these post-extinction SMB is estimated at 700'000 years (Baud et al., 2017).

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MASS EXTINCTION SURVIVAL GUIDE – PLANT FOSSILS FROM THE ARCTIC

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ABSTRACT

For marine animal life the Permian-Triassic mass extinction was devastating, the recovery patterns in its the aftermaths were quite complex and are still controversially discussed. Plants entered the stage of the Permian–Triassic mass extinction discussion rather late. But the discussion on how plants dealt with fundamental environmental changes associated with the extinction event is in no case less controversial. Have they been victims or heroic survivors? Here I present findings from Arctic palynology research that shed light on the dynamics of plant ecosystems and possible prerequisites for surviving a mass extinction. The Arctic has long been in the focus of palynological research. Initially, the exploration of Permian coal deposits was of interest, later the solution of stratigraphic questions and in the last decades also to answer questions concerning the Permian-Triassic mass extinction.

The Permian phytogeography included four main plant kingdoms. The Canadian Arctic, Greenland, the northern part of Norway, the Barents Sea, and the Russian Platform are combined in the Subangaran province. What is common to the palynological assemblages of these Subangarian regions is that those of the upper Permian and lowest Triassic are quite similar. A decline in diversity across the Permian–Triassic boundary was not observed. Basically, all lineages survived into the basal Triassic, but plant ecosystems remained not unscathed.

In some places (Greenland and Norway) significant short-term changes in the abundances structure of plant groups were documented. During the negative carbon isotope excursion that marks the extinction event globally, spore producing plants were dominant for a geologically short time interval. This event was also recorded on the Norwegian shelf and exemplifies that the plant ecosystems reacted to the environmental changes. There, abnormal morphologies of spores and pollen grains were also interpreted as consequence of the environmental changes.

Plants are primary producers and have therefore fundamentally different requirements for life compared to aquatic and terrestrial animals. The wide geographic distribution of plant lineages in the Arctic could have buffered environmental changes to some extent, providing enough refuge areas, whereas on the local scale changes in vegetation composition are evident and show the capability of plants to adapt to environmental changes from ecosystem level to plant level.

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THE PALYNOLOGICAL RESPONSE TO THE MIDDLE AND LATE PERMIAN EXTINCTION EVENTS ACROSS THE EQUATORIAL AND TROPICAL BELTS

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ABSTRACT

Recently, the end-Guadalupian (middle Permian) biotic crisis has been proposed as the sixth mass extinction event, ranking third in taxonomic severity after the end-Permian and end-Ordovician (Hirnantian) extinctions (Rampino and Shen, 2019). Drivers as ocean anoxia and acidification associated with flood basalt volcanism from large igneous provinces were invoked. The massive release of greenhouse gases such as CO2, SO2, and CH4, triggered by volcanic activity, led to extremely high global temperatures, profoundly impacting marine and terrestrial taxa.

In this study, we examine changes in microflora throughout the middle to late Permian period in the northern Gondwana margin: specifically in the Zagros Basin (SW Iran) and in the Zal and Ajabshir area (NW Iran). These well-preserved and chronologically calibrated Iranian successions serve as crucial reference sections for studying this geological time interval. Our aim is to understand the response of paleovegetation communities to the end-Guadalupian biotic crisis.

The Guadalupian microfloral assemblages from the studied areas displays a similar morphological composition to those documented from coeval Northern Gondwana regions, including Oman, Saudi Arabia, Southern Turkey, Iraq, Pakistan, and others (e.g., Stephenson et al., 2003; Stephenson, 2008; 2018; Stolle, 2007; Stolle et al., 2011). The Roadian-Wordian microflora points to a xeromorphic and xeromorphic-hygromorphic ecoclimatic affinity. The younger Wordian-Capitanian microflora is characterized by the persistence of previous palynoelements in assemblage with other specimens here firstly occurring. Aberrant sporomorphs also appear, serving as early indicators of the end-Guadalupian ecosystem crisis. The Wordian-Capitanian palynoelements indicate a predominance of hygromorphic ecoclimatic affinity and a minor presence of xeromorphic and xeromorphic-hygromorphic forms throughout the assemblage. After the end Guadalupian crisis, no floristic turnover was recorded in the early Lopingian (Wuchiapingian) palynoflora: the microflora consists of the same sporomorphs recorded in the Guadaluapian assemblages. It is predominantly characterized by a xeromorphic-hygromorphic flora. Going upward in the end of Permian, the microflora is also marked by a proliferation of Lycopodiaceae spore suggesting humid conditions. Nevertheless, the morphological composition of the Lopingian microflora points to a period of biodiversity stabilization or continued biodiversification after the end-Guadalupian crisis. Based on our microfloristic analysis of continuous marine Guadalupian to Lopingian successions, at least in this region of Northern Gondwana, land plants could be considered as the survivors of the extinction events. Currently, there is no compelling evidence of a mass extinction among land plants at the end of the Guadalupian. Although further palynological studies from coeval marine successions in other areas are necessary, it appears evident that the "sixth mass extinction" documented in the animal fossil record did not correspond to a mass extinction event in plants. The only signal of this crisis is supported by the presence of aberrant sporomorphs, which may have resulted from mutations induced by high levels of ultraviolet radiation during that time interval (Liu et al., 2023).

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OXYGEN ISOTOPE COMPOSITIONS AND TEMPERATURES OF EARLY TRIASSIC SEAWATER: A CLUMPED ISOTOPE PERSPECTIVE

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ABSTRACT

Recent studies have demonstrated that precise clumped isotope measurements of well preserved carbonates allows primary and diagenetic processes to be readily distinguished [1], both of which can influence the isotopic compositions of carbonates. In contrast to measurements of d^{18}O only, clumped isotope compositions (D$_{47}$) may provide absolute temperatures of crystallisation independent of the isotopic composition of the water that the carbonates crystallized from. This study summarizes the results of clumped isotope analyses of calcite from Early Triassic carbonate sequences. Samples include abiotic micritic limestones intercalated within highly fossiliferous, nectic and benthic fauna of the middle Dienerian (Wadi Ad Daffa and Ras Al Jin, Batain basin, Oman), individual fossil rhynchonelliform brachiopods and bulk carbonate rocks of the late Smithian and early Spathian (Hawasina nappes and Batain melange, Oman), all originally deposited in the Neotethys on offshore seamounts [2].

Absolute D$_{47}$-temperature estimates from three different Dienerian micrites in two sections reproduce well for RAJ at 29 ±2.0 °C (n=3), but give clearly diagenetic temperatures for WAD2-MC with 47 ±3.5 °C (n=59 and WAD2-MP with 50 ±13 °C (n=4); all calibrated against ETH-1, -2 and -3 standards [3]. The d^{13}C (VPDB) and d^{18}O (VSMOW) values are also homogeneous (RAJ: d^{13}C of +2.4 ±0.1 ‰, d^{18}O of 30.5 ±0.2 ‰; WAD2-MC: d ^{13}C of +2.0 ±0.4 ‰, d^{18}O of 28.9 ±0.3 ‰; WAD2-MP: d^{13}C of +1.4 ±0.3 ‰, d^{18}O of 27.7 ±0.1 ‰) and higher clumped isotope temperatures correlate well with lower d^{18}O values of the same carbonates. Clumped isotope thermometry supports Dienerian Neothethys subequatorial seawater temperatures within the range for the modern sea surface (25 to 32 °C) and hence gives calculated seawater d^{18}O for the RAJ section of between -0.4 to +2.3 ‰, also similar to the range of modern, evaporated sea-surface waters in subtropical oceans. The large range and higher average temperatures for the WAD sections but with lower d^{18}O values are likely due to diagenetic alteration in a rock-buffered system in the presence of seawater.

For the Smithian to lower Spathian absolute temperatures can be estimated from individual fossil rhynchonelliform brachiopods as well as bulk carbonates. Results suggest that sampling along individual brachiopod growth lines represents the best strategy to obtain clumped isotope temperatures. Best estimates support Early Triassic seawater temperatures in the equatorial realm within the range of modern equatorial sea surface temperatures of 27 to 32 °C. Furthermore, calculated water d^{18}O values for samples collected along growth lines are between -0.9 and +1.4 ‰, also similar to the range of d^{18}O values of modern seawater. Bulk rock carbonates, however, give higher clumped isotope temperatures of between 41 to 90 °C; as well as higher calculated water d^{18}O values at those temperatures. In general, higher clumped isotope temperatures correspond to high d^{18}O values calculated for water in both bulk rock and brachiopods, also indicative of diagenesis in a rock-buffered system in the presence of seawater or exchanged seawater. The results suggest that the oxygen isotope composition of Early Triassic seawater during the late Smithian to early Spathian was about –1 ‰. Using this brachiopod-based d^{18}O$_{seawater}$ value, the stable O-isotope analyses of oxygen in conodont phosphate (d^{18}O$_{PO4}$) from the same sequences provide temperatures of between 32 to 39 ºC for the late Smithian, but cooler temperatures of between 25 to 27 ºC for the Early Spathian.

These combined results for the Dienerian up to the Spathian are congruent with recent indications that seawater d^{18}O values remained relatively constant at about 0 ±2 ‰ throughout the Phanerozoic.

References:

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CONNECTING THE DOTS: TRACING THE IMPACT OF PERMIAN PALEOCLIMATE ON ENVIRONMENTAL CHANGES OF SOUTHERN GONDWANA'S TETHYS MARGIN (PAKISTAN)

Wadood Bilal

ABSTRACT

The formation of Pangaea supercontinent resulted in global warming and widespread development of dry-to-arid greenhouse climates during Permian. Tectonic upheaval shifted warm surface water from low to high latitudes and created cold-water upwelling on western coast of Pangaea. Massive mountain building processes severely affected regional and local climates, thus developing endemic biological realms. The southern Gondwana margin experienced climatic change due to tectonic expansion of Neo-Tethys and rifting induced basaltic extrusion. To better comprehend the Permian climate evolution and its impact on paleoenvironmental changes at the southern margin of Gondwana (NW margin of Indian Plate), here we utilize Middle to Late Permian strata exposed in Salt Range and Trans-Indus Ranges (Pakistan).The Middle Permian (Wordian) strata exhibit coarse-grained, ripple-marked, channelized sandstone and fossiliferous limestone suggesting deposition in a tide-influenced subaqueous delta under the fluctuating sea level. The compositionally mature sandstone in the lower part of the strata coupled with various geochemical proxieshintreworking of detritus from the adjacent rift shoulders under thewarm humid subtropical climate. The presence of a temperature-sensitive fusulinid fauna in association with photozoan-based ooidsand the deposition of limestone facies in the upper part confirms the Middle Permian warming.The overlying Capitanian-Wuchiapingian pure fossiliferrous limestone strata show diverse depositional environments ranging from mudflats and lagoon to sand shoal and middle shelf. Thus a marine Tethyan setting wasestablished at the margin of the rift flank basin with strong local intra-plate stresses. The outcrop studies of the overlying Changhsingian strata show laterally variable thicknesses of dominantly thick-bedded, calcareous and fossiliferous sandstone and sandy limestone. While the petrographic, geochemical, and SEM studiesdivulged lagoonal to delta dominated middle shelf evironment of deposition with an extremely arid and cold climate. The deposition of Changhsingian clastic-rich carbonates on the underlying pure carbonates (Capitanian-Wuchiapingian) hints strongly towards a sea-level fall on the NW margin of the Indian Plate. Such end-Permian regression tightly correlates with the stratigraphic record of the adjacent continents, including South China, the Persian Gulf, and northern Gondwana regions.

GRIESBACHIAN TO SMITHIAN AMMONOIDS FROM NORTHERN INDIAN MARGIN, WITH A REVIEW ON THE CURRENT STATE OF KNOWLEDGE OF EARLY TRIASSIC AMMONOID BIOSTRATIGRAPHY, EVOLUTION AND BIODIVERSITY DYNAMICS THROUGH THIS INTERVAL

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ABSTRACT

Until recently, most of our knowledge of Triassic biochronology and correlations was based on ammonoid faunas. Nowadays, conodonts also play a major role due to their more widespread, less facies-dependent occurrence. Nevertheless, recent investigations in the Griesbachian to Smithian of the Salt Range (Pakistan) and Spiti valley (Himalaya, India) have shown that ammonoid-based biostratigraphy provides higher time resolution than conodonts, and as such remain crucial for our understanding of the timing of the recovery following the Permian-Triassic mass extinction. Recently, the re-sampling of two previously known localities and sampling of two other new outcrops spanning this time interval in South Tibet allowed the validation and improvement of the biostratigraphic scheme previously proposed for the Northern Indian Margin, together with cross-correlation with conodont biostratigraphy and carbon isotope curves. The corresponding global correlations will be presented, together with some reflections on the corresponding stage and sub-stage boundaries.
The talk will be concluded by a short presentation of our current understanding of ammonoid taxonomy, evolution and biodiversity pattern through and following the Permian-Triassic mass extinction. Early Triassic, and particularly Induan ammonoids, remain to this day poorly known due to two reasons: the remote location of important expanded outcrops with well-preserved material (e.g. Siberia, Arctic Canada, NE Greenland, and central Himalaya) or to geopolitical complications (e.g. Pakistan, Afghanistan, central Himalaya, Madagascar). The perspective and priorities of these areas would be interesting to re-investigate in detail will be discussed.