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Mass extinctions, recovery and resilience

The change of microbialite forms associated with different fossil assemblages during the Early Triassic transgression: implication for the evolution of shallow marine ecology in the aftermath of end-Permian mass extinction

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Widespread microbialites developed at the carbonate platforms around the Tethys Ocean from the very beginning of the Early Triassic transgression. However, the microbialite forms have significant variation both temporally and spatially, reflecting diverse shallow marine environments in the aftermath of end-Permian mass extinction. Here we present a succession of the evolving microbialite forms and associated biotic assemblages with the sea-level rise in Early Triassic from the section at Chongyang in South China. Microbialite forms evolved from stratiform stromatolites to a sequence of tabular thrombolites, followed by domical thrombolites that were overlain, in turn, by oolites. The stromatolites contain more remains of calcified cyanobacteria but less metazoan fossils than the thrombolites, reflecting more supersaturated seawater condition during the formation of stromatolites that was favourable for the calcification of cyanobacteria but stressed for metazoans. Metazoan fossils increase from the deposition of tabular thrombolite and become more diverse within the domical thrombolite interval, reflecting increasing biodiversity with deepening of seawater. We suggest that with the development of domical thrombolites more complex seafloor relief created varied niches between and within the domes that harboured more ecologically diverse communities.

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Carbon isotopic excursion couples with sedimentary facies change from Wuchiapingian to Changhsingian of Late Permian in South China: caution for the application of geochemical parameters as global change

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The variation of carbon isotope signals in the geological record has widely been used as an indicator for global environment change. Previous studies found prominent negative excursions of carbon isotope near the Wuchiapingian-Changhsingian boundary (WCB) in some sections in South China, and suggested that the major global carbon cycle perturbations during the Paleozoic-Mesozoic transition may have occurred during Late Permian time, long before the end-Permian mass extinction. Here we present detailed carbon isotopic results throughout the Late Permian in South China. The results show that the variation of carbon isotope values is apparently related to sedimentary facies change. In shallow platform sections, both sedimentary facies and carbon isotopic values remain stable throughout the Late Permian. In contrast, there was a sudden sedimentary facies transformation near the WCB in the sections located in basin environments. Carbon isotopic values drop significantly from 3.61‰ to -1.11‰ along with this dramatic facies transition from shallow water to deep water facies, displaying coupling relationship between change of carbon isotope and sedimentary facies. Completely different isotopic excursion patterns in different water depth sections during the same stage of Late Permian suggest that the carbon isotopic excursions around the WCB recorded in these sections should have resulted from local environmental change and have no relations to the global carbon cycle perturbation happened across the Permian-Triassic boundary.

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Mass extinctions, recovery and resilience

Lowest Triassic anachronistic facies in the Cili region of South China and its palaeoenvironmental implications

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Anachronistic facies refers to unusual sedimentary deposits that are restricted to earlier history of the Earth but emerge again in the later periods. Various types of anachronistic facies developed immediately after the end-Permian mass extinction in shallow platforms of South China, and their depositional succession exhibits peculiar regularity. Microialites are often the first anachronistic sediments that formed above the mass extinction boundary, and are subsequently followed by oolites and oncolites, which are sometimes intercalated with vermicular limestones. Because different types of anachronistic facies represent different depositional environments, this succession pattern records the evolution of marine environments following the end-Permian mass extinction. Based on the sedimentological analysis of Yangjiawan section in Cili County of South China, this study suggests that the transition from microbialite to oolitic limestone was associated with earliest Triassic transgression and increasing of hydrodynamic energy. With continuous rise of sea level, the hydrodynamic became weaker, resulting in the shift from oolite to oncolite. The occurrence of vermicular limestone is considered to be the product of an ephemeral, restricted environment. Stratigraphic correlation between the Yangjiawan section and the GSSP Meishan reveals a much higher sedimentation rate in shallow platform than that in deeper setting. We suggest that the great thickness of anachronistic limestone in shallow platforms should have resulted from the high supersaturated marine conditions with respect to calcium carbonate as well as the world-wide transgression during Early Triassic which provides the necessary accommodation space for the rapid precipitation of anachronistic limestone.

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Mass extinctions, recovery and resilience

Complex causes of Australian megafauna extinctions during the Late Pleistocene

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The causes and mechanisms of megafauna extinctions during the Late Pleistocene are hotly debated because robust data are rare, and inferences are often biased owing to differential preservation of older evidence. Many mechanisms have been proposed to explain the causes of megafauna extinctions: (i) changes in climate conditions increasingly restricting habitats suitable for species; (ii) humans as a 'new and efficient big predator' dramatically impacting megafauna naïve to human hunting; (iii) a possible combination of human hunting pressure on populations already compromised by climate-driven environmental changes (or vice versa). Most contributions rely on chronological analyses, where the timing of both megafauna extinctions and the initial arrival of humans (associated with the age of the last and first fossil records and archaeological evidence, respectively) are compared to the reconstruction of climate variation at these times. Recent continental-scale modelling discarded climate variability and aridity as the main drivers of megafauna extinctions. However, such approaches have been criticised because they disregard spatial variation in extinction patterns, human colonisation trajectories, and palaeoclimate change. We combined a new statistical approach to infer the regional timing of megafauna extirpation and first human colonisation compared with palaeoclimate change simulated across south-eastern Australia over the last 120,000 years. We show that > 80% of regional megafauna extirpations were likely driven by a combination of human pressure and increasing aridity. These results provide new insights into how synergies between human pressure and past climate conditions profoundly affected the ecosystems of south-eastern Australia during the Late Pleistocene.

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Mass extinctions, recovery and resilience

Sedimentary markers of ocean plateau volcanism during the Cenomanian–Turonian Oceanic Anoxic Event

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The Cenomanian–Turonian transition (94 Ma) marked a major environmental and biotic crisis of the Cretaceous Period, featuring abrupt climate warming (with superimposed cooling pulses) and widespread marine anoxia/euxinia, from which it has been classed as an oceanic anoxic event (dubbed Cretaceous OAE 2). The cause of this event is widely believed to be linked to major volcanic activity during the emplacement of one or more oceanic plateaus (e.g., Caribbean Plateau, High Arctic Igneous Province). Because there are few radioisotopic dates for rocks on these ocean plateaus, demonstrating a precise coincidence between this volcanic activity and OAE 2 largely depends on utilisation of sedimentary proxies of volcanism in the stratigraphic records of the event. A globally recorded shift to unradiogenic osmium-isotope (specifically 187Os/188Os ratios) compositions is clearly indicative of enhanced ocean plateau volcanism at the onset of and during OAE 2, but other proxies have shown less clear trends. In this study, we present new geochemical data for a number of proxies for volcanism from sedimentary rocks of a near-shore shallow marine record of OAE 2 at Bass River (ODP Leg 174 AX, New Jersey, USA). This record represents a relatively rare example of a lithologically consistent (silty claystones) OAE 2 stratigraphic succession, allowing easier interpretation of geochemical trends. We find considerable variation in the studied proxies, and in some cases no indication of volcanism. These findings highlight the importance of eruption style and/or local marine conditions and sedimentological processes on many proxies of volcanism in records of OAE 2.

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Mass extinctions, recovery and resilience

Mercury anomalies across the Cretaceous-Paleogene mass extinction in northern China: Links to Deccan volcanism and palaeoecosystem impacts

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The Cretaceous-Paleogene boundary (KPB) mass extinction is commonly attributed to both the Deccan Traps volcanism and Chicxulub impact, although the exact mechanism is still controversial, the mercury (Hg) as a new proxy could help us to better interpret the relationship between large igneous provinces and mass extinctions. Here we present new Hg geochemical data from the terrestrial Songliao Basin, northern China. Our results show one significant Hg concentration anomaly which occurred ∼120 ky before the Chicxulub impact, is temporally corresponding to the second (main) phase of Deccan eruptions with maximum eruption rates and high losses of charophytes and ostracods in the Songliao Basin. There is no correlation between the Hg concentration and total organic carbon (TOC) & clay content, which suggests that the Hg anomaly was potentially caused by volcanic activities. We therefore suggest that the Deccan Traps volcanism triggered the latest Cretaceous warming ∼300 ky prior to the Chicxulub impact and then the initial KPB mass extinction ∼120 ky prior to the Chicxulub impact. We also speculate that the brief eruptions with extreme eruption rates (e.g. ∼66.1 Ma) would be tend to heavily disturb the ecosystem than those long-term eruptions with limited intensities (e.g. ∼66.3 Ma).

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Mass extinctions, recovery and resilience

Second-coming of the dinosaurs: Rapid diversification of birds following the end-Cretaceous mass extinction

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Insights from the fossil record and molecular phylogenies have converged on a dramatic evolutionary narrative: after narrowly surviving the end-Cretaceous mass extinction, crown birds rapidly radiated early in the Paleogene to fill a panoply of vacant niche space. The pattern and tempo of this radiation were structured by instrinsic biological factors (e.g., genomic substitution rates, correlated life history parameters) as well as extrinsic variables such as rates of habitat recovery. A coherent portrait of the near-demise, and rapid rise, of birds has begun to come into focus, drawing on an ever-improving avian fossil record integrated with genomic, palynological, and climatic data. Here, we summarise recent advances in all of these areas to provide an updated account of the impact of the end-Cretaceous mass extinction event on avian evolutionary history.

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Mass extinctions, recovery and resilience

High-resolution variation of ostracod assemblages from microbialites near the Permian-Triassic boundary at Zuodeng, Guangxi, South China

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After the end-Permian mass extinction (EPME), the marine environment was considered extremely toxic, which was mainly due to the anoxic, high-temperature conditions and ocean acidification. Thus, the ecosystem contained few organisms. We describes a new ostracod fauna from the microbialites-bearing Permian-Triassic (P-Tr) strata at Zuodeng, Guangxi, China. One thousand and seventy ostracod specimens were extracted from forty-eight samples. Fifty-three species belonging to fourteen genera were identified. Ostracods, primarily from the Family Bairdiidae, were extremely abundant in the microbialites and presented simultaneous Paleozoic and Meso-Cenozoic affinities overall the section, which suggests that the ostracods were opportunists able to survive within this special microbial ecosystem with sufficient food and scarce competitors and predators rather than undergoing a rapid and early recovery after the EPME. The similarities and differences among the ostracod faunas in the microbialites at the P-Tr boundary sections around the Paleo-Tethys indicate that there was a long-distance dispersion of ostracods. However, the faunas still maintained endemism at the specific level. Previous studies have regarded microbialites as whole units, and it is difficult to detect environmental changes within a microbialite interval based on paleoecological groups of (super) families. In this study, high-density sampling was applied to identify changes of abundance, diversity, and composition of assemblages of ostracods. The changes of five dominant species through the section exhibited an six-stage evolutionary trend, which indicates that the microbialite environment was not entirely constant but fluctuated during the post-extinction interval.

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Mass extinctions, recovery and resilience

The biotic recovery of the flora during the Early and Middle Triassic

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Plant communities were considered to recover slowly after the ecological disturbancies experienced during the end-Permian mass extinction, taking up to 14 million years for a complete recovery. The Early Triassic coal gap, with unknown Early Triassic and rare, thin Middle Triassic coal beds, supported the theory that the ecosystems remained unbalanced and unstable until the Middle Triassic. The stepwise recovery started with the proliferation of the lycopsid Pleuromeia during the Early Triassic, followed by the resurgence of the conifers in the early Middle Triassic (early Anisian), the return of cycadophytes and seed ferns in the late Anisian and the progressive evolutionary modernization of the subsequent plant communities. However, the last decades have seen the discovery and description of several new Early and early Middle Triassic floras in China (e.g., Yunnan province), Russia (e.g., Siberia), Europe (e.g. France, Germany) and Gondwana (e.g., Karoo Basin in South Africa, Bowen and Lorne basins in Australia). Those Early Triassic plant assemblages are often rich in but not dominated by Pleuromeia, and found in association with conifer and fern remains. The early Anisian plant assemblages are rich and diverse, with abundant lycophytes, conifers, cycads and seed ferns (some of which present already in the Early Triassic plant communities), whereas the late Anisian floras are very diverse with abundant representatives of all major plant groups. This suggests that the recovery of the plant communities was much quicker than previously considered.

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Mass extinctions, recovery and resilience

Timing and Paleoenvironmental Implications of Deccan Volcanism Relative to the KPg Extinction

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Several studies evaluated the relationship between Hg anomalies in sediments and LIP activity across mass extinction horizons. The bulk (80%) of Deccan Traps eruptions occurred over a relatively short time interval in magnetic polarity C29r. U-Pb zircon geochronology reveals the onset of this main eruption phase 250 ky before the Cretaceous-Tertiary (KT) mass extinction and continued into the early Danian suggesting a cause-and effect relationship. 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.

We present the first comprehensive high-resolution analysis of Deccan Traps Hg loading, climate change and end-Cretaceous mass extinction from a transect, which includes 25 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). These Hg anomalies are correlative with the main Deccan eruption phases. In several section, the highest Hg anomalies correlate with high shell fragmentation and dissolution effects in planktic foraminifera indicating that paleoenvironmental and paleoclimate changes drastically affected marine biodiversity especially during the last 25 ky preceding the KPg. These observations provide further support that Deccan volcanism played a key role in increasing atmospheric CO_2 and SO_2 levels that resulted in global warming and acidified oceans, increasing biotic stress that predisposed faunas to eventual extinction at the KPg

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Rapid biological recovery following the Cretaceous-Paleogene boundary catastrophe in the Maastrichtian type area

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Present-day marine biotas are increasingly subject to anthropogenically-forced extinctions. The study of the global mass extinction event at the Cretaceous-Paleogene (K-Pg) boundary can aid in our understanding of the patterns of selective extinction and survival and the dynamics of ecosystem recovery. Outcrops in the Maastrichtian type region (The Netherlands, Belgium) comprise an expanded K-Pg boundary succession, presenting a unique opportunity to study marine ecosystem recovery within the first thousands of years following the Chicxulub impact. We have reevaluated and studied the palynological, micro- and macropalaeontological record of this unique succession. Ecosystem changes across the K-Pg boundary in this region are rather limited, showing a general shift from epibenthic filter feeders to shallow-endobenthic deposit feeders. The fauna of the lowermost Paleocene still has many 'Maastrichtian' characteristics, a biological assemblage that survived the first hundreds to thousands of years into the earliest Paleocene. The shallow-marine oligotrophic carbonate sea of the Maastrichtian type area was inhabited by starvation-resistant, low nutrient-adapted taxa, that were seemingly less affected by the short-lived detrimental conditions of the K-Pg boundary catastrophe, such as darkness, cooling, food-starvation, ocean acidification, resulting in relatively high survival rates. The high survival rate allowed for a fast recolonization and rapid recovery of marine faunas in the Maastrichtian type area.

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Gulliver's Triassic Travels: Body size changes through the end-Triassic mass extinction and recovery

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Populations with small body sizes are widely reported in the aftermath of mass extinction. This is frequently regarded as the Lilliput effect, which is defined as a temporary reduction in body size in surviving species following a biotic crisis. However, there are several other possible causes behind these observations, including preferential loss of large species during the extinction or origination of small species in the immediate post-extinction interval. An organism's environment can impart a control on body size, factors such as temperature and oxygen availability are known to do this, and elevated temperatures and oxygen depletion of marine waters are players in many extinctions. During the subsequent recovery as these stressors ameliorate body size also increases to a pre-extinction norm.
Here we document body size of bivalves across the end-Triassic mass extinction event and ensuing recovery and attempt to relate these to changing environments. In the aftermath of the event marine bivalves are small and increase in size through the first two stages of the Early Jurassic. We assess the role of the Lilliput effect in the creation of these communities of small bivalves and propose a new term for species that originate at small body size and undergo a within-species size increase: the Brobdingnag effect. An effect which may prove to be more pervasive than the Lilliput effect, as a stipulation of a Lilliput is that the size reduction is seen within a surviving species, something that could be comparably rare across an extinction event.

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The impact of the end-Permian mass extinction on the global distribution of marine invertebrates

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While mass extinction events represent times of hardship for most of Earth's ecosystems, shallow marine reef communities have often been hardest hit during periods of extreme environmental change. This is particularly true of the end-Permian mass extinction (∼250 Ma), the most severe in Earth history, when up to 96% of marine species became extinct. High rates of taxonomic turnover across this event represent the transition between Sepkoski's 'Palaeozoic' and 'Modern' marine faunas.
However, the environmental changes which occurred during the Late Permian–Middle Triassic (∼260 – 237 Ma) are complex. Large-scale volcanic episodes drove extreme greenhouse temperatures, peaking in the late Early Triassic, alongside widespread ocean acidification and anoxia, compounded by feedbacks associated with the presence of the supercontinent Pangea. As such, the variation of climate with latitude may have driven spatially heterogeneous patterns of extinction severity and selectivity. Several recent studies have suggested that high latitude faunas suffered higher extinction rates during the end-Permian mass extinction than their counterparts at lower latitudes.
To examine the spatial nuances of the end-Permian mass extinction and recovery for marine invertebrates, we downloaded and reviewed Late Permian to Middle Triassic occurrence data for brachiopods and bivalves from the Paleobiology Database. We then calculated changes in origination, extinction and extirpation rates with latitude, and reconstructed the latitudinal diversity gradients (LDGs) of brachiopods and bivalves, with shareholder quorum subsampling (SQS) applied to compare richness between latitudinal bands. These results highlight the role of extreme climate change and continental configuration in driving Permo-Triassic spatial biodiversity patterns.

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Mass extinctions, recovery and resilience

Carbonate clumped isotope seawater temperature reconstructions from macrofaunal assemblages of the Campanian, Maastrichtian and Danian from the area around Maastricht

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The climatic conditions towards the end of the Cretaceous are expected to show a cooling trend from the Campanian to the Maastrichtian stage accompanied with several carbon isotope excursions (CIE) detected in the Atlantic, Pacific and Tethyan Oceans. The observation that these CIEs do not correlate with warming as for instance the Paleocene Eocene Thermal Maximum points on different causes that might relate to tectonic activity and/or changes in seawater circulation (e.g. Linnert et al., 2017).
The shallow and still relatively warm water conditions offered a fruitful environment for a wide range of marine organisms of which the fossil remnants are very abundant in the area around Maastricht, defining the type locality of the final Cretaceous stage, the Maastrichtian (72.1-66.0 Ma). We performed a low resolution seawater temperature record on fossil shell assemblages from the Maastrichtian type locality in southern Netherlands, which is based on carbonate clumped isotope thermometry. Our new seawater temperature record includes shell material from the Campanian, Maastrichtian and the Danian, thus provides background seawater temperatures around the Cretaceous Paleogene Mass Extinction event. With the analysis of a fossil assemblage we further hope to draw more accurate constraints on the local seawater oxygen isotope composition and eventual circulation patterns during that time.

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Mass extinctions, recovery and resilience

The nitrogen cycle and the Ammonium Ocean hypothesis for the end-Permian Mass Extinction

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The aftermath of end-Permian mass extinction was marked by a ∼5 million year interval of poorly-understood, extreme environments that likely hindered biotic recovery. Contemporary nitrogen isotope variations are considered, using a new conceptual model, to support a scenario that shows intensive nitrate-removal processes gradually depleted the global oceanic nitrate inventory during long-lasting oceanic anoxia. Enhanced nitrogen fixation shifted the oceanic nitrogenous nutrient (nutrient-N) inventory to an ammonium-dominated state. Ammonium is toxic to animals and higher plants but fertilizes algae and bacteria. This change in ocean chemistry could account for the intense and unexplained losses of nektonic taxa and the proliferation of microbial blooms in the Early Triassic. The transition from a nitrate ocean to an ammonium ocean was accompanied by a decrease in respiration efficiency of organisms and a shrinking oceanic nutrient-N inventory, ultimately leading to generally low productivity in the Early Triassic oceans. These unappreciated nutrient changes during episodes of prolonged ocean anoxia may be the key life-limiting factor at such times.

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Which impact had CAMP volcanism on the latest Triassic Earth System?

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In the latest Triassic, Earth's climate and biogeochemical cycles were severely perturbed by pulsed volcanic activity of the Central Atlantic Magmatic Province. Here, we present an effort to model aspects of the late Triassic climate and the impact of volcanogenic carbon and sulfur emissions.

The conducted simulations suggest that the simultaneous emission of carbon and sulfur during one pulse of volcanic activity could have caused strong interannual temperature fluctuations, overprinted by a transient cold period and followed by long-term global warming. The temperature changes at the locations of Late Triassic coral reefs are evaluated against the thermal limits of modern corals. A significant spread of marine anoxia, directly driven by warming, is not predicted for the examined scenarios. In contrast, the simulated ocean acidification and specifically the pronounced reduction of the carbonate saturation in the Tethys Sea would have hampered marine calcification.

We furthermore discuss work in progress on how the representation of characteristics of the Late Triassic marine carbon cycle can be improved in further modeling. This is also linked to ongoing investigations dealing with the question, how the Mesozoic revolution of the marine carbon cycle may have changed the Earth System's sensitivity towards perturbations similar to the end-Triassic volcanism.

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Mass extinctions, recovery and resilience

The terrestrial expression of the Late and End Devonian Mass Extinctions

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There were two mass extinction events in the Devonian (the Frasnian/Famennian and the End Devonian Mass Extinction at the Devonian-Carboniferous boundary. The Devonian has a well-developed terrestrial facies within extensional basins on the Old Red Sandstone Continent. This contains a direct record of climatic change within the Late Devonian that can be integrated with the palynological record. The Frasnian/Famennian section shows two interval of warming with a very active fluvial system, both succeeded by very arid episodes of stacked palaeosols. Palynological correlation shows these represent the Lower and Upper Kellwasser Events. Comparisons with other LIP driven extinction events show these as the comparable response to a LIP eruption with high CO_2 and a warm climate to produce a very active sedimentary systems that then causes excess drawdown and a cool arid climate.
The Devonian-Carboniferous boundary is a strong contrast with an intense arid interval that palynological correlation show equivalent to the terminal Devonian glaciation. This is followed by significant warming atypical for the basin and which produced intense seasonal rainfall that produced a deep stratified lake. Palynological extinctions are highly concentrated over a short interval within the lake.

EGU Galileo Conferences
GC5-Mass-22, 2019
Mass extinctions, recovery and resilience

Marine anoxia and mass extinction – a ubiquitous link?

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Ever since Hallam made the link between marine anoxia and extinction in the Early Jurassic nearly 60 years ago, the role of anoxia in the mass elimination of marine taxa has figured prominently in the literature. The spread of anoxic deposition acts to limit habitat area and even slightly dysoxic conditions are inimical to most marine forms. Marine anoxia is a principal contender for the Permo-Triassic mass extinction with the evidence including the widespread development of pyrite-rich facies and the extraordinary occurrence of black shales in all known occurrences of accreted deep-ocean sediments. The impact on ocean trace metal budgets was marked and seen in a decline in their enrichment factors. Widespread marine anoxia is also seen during other extinction events (e.g. Frasnian-Famennian, end-Devonian, Capitanian) but for others anoxia is either developed after the mass extinction crisis (end-Triassic) or there is no associated mass extinction at all (Bonarelli Event). The reasons for this hit-and-miss relationship will be considered.

EGU Galileo Conferences
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Mass extinctions, recovery and resilience

The end-Permian mass extinction in the Southern and Eastern Alps

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The end-Permian mass extinction event had a profound impact on terrestrial and marine ecosystems. Still not much is known about the exact effect and timing of this event in terrestrial ecosystems and about the possible influence of preservational/taphonomic bias on the apparent extinction patterns. The Southern Alps are one of the most important regions for the study of the end-Permian mass extinction, since the corresponding succession is continuous, fossiliferous, crops out in numerous places, and represents terrestrial, as well as coastal and marine settings. A three-year research project has now been conducted to examine the Permian–Triassic boundary interval in various outcrops across the Southern and Eastern Alps and across different palaeoenvironmental settings with a multidisciplinary approach. A main goal is to compare findings from different sections in order to identify taphonomic constraints. The study area includes the Dolomites and Carnic Alps of Northern Italy (Southern Alps) and the Lienz Dolomites and Gailtal Alps of Austria (Drau Range, Eastern Alps). Over the course of this project, we logged and sampled ten sections in the Dolomites (Bletterbach, Tramin/Termeno, Montan/Montagna, Gabbiolo, Seres, Laurinswand, Rotwand, L'Om Picol, Valfreda, Pizzo Forca), two in the Carnic Alps (Felempecle near Sauris di Sopra, Dierico) and two in the Drau Range (Simmerlacher Klamm, Riedgraben). Several more localities were sampled, but not logged (Seis, Würzjoch/Passo delle Erbe, Pufelsgraben, Naraun, Olang, Somor, Passo San Pellegrino). Samples were collected for isotope geochemistry (organic and inorganic), palynology, conodonts, microfacies and magnetostratigraphy. Macrofossils (invertebrates, tetrapod ichnofossils, plants, fishes) were collected where possible.

EGU Galileo Conferences
GC5-Mass-24, 2019
Mass extinctions, recovery and resilience

Is the rate of human-induced arthropod extinction comparable with diversity changes during the FIVE BIG mass extinctions?

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Human-induced biodiversity decline ("the sixth mass extinction") is often compared with the five big mass extinctions on Earth in the past 540 million years. It is thus surprising that arthropod biomass and biodiversity loss has only recently become a widely discussed topic based on the dramatic decline of insects, with no data being available presently for terrestrial arthropod groups other than insects (i.e. arachnids, millipedes). Assessment of diversity decline in arthropods is based on zoological collections, but these only span the last 200 years and the period in which ecosystems were already affected by human activity. We suggest that by comparing pre-Holocene change in arthropod diversity with current change, it will be possible to gain some insights into the rate of anthropogenic impact compared to background extinction rates, and on the extent of the current mass extinction compared to previous ones.

We discuss factors that may hamper the comparison of present-day insect diversity decline and extinction with past changes in insect diversity, i.e. hiatuses and gaps in the fossil record, imprecise dating methods, divergent fossilization potential of different groups. Moreover, we present case studies providing guidelines on how to avoid some of these effects and summarize ideas for future research projects allowing a comparison of present-day and fossil terrestrial arthropod diversity. These approaches comprise studies on groups with high fossilization potential and high taxonomical resolution, indirect indications for presence of taxa, e.g. via presence of trace fossils or specific parasites, and better interdisciplinary collaboration.

EGU Galileo Conferences
GC5-Mass-25, 2019
Mass extinctions, recovery and resilience

A new proxy for trophic and ecosystem-level responses to mass extinction events? The palaeoecology of conodonts.

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Conodonts, are an early and extinct group of jawless vertebrates; their teeth (elements) provide one of the most complete fossil records of any organism, with an evolutionary history spanning over 300 million years of the Palaeozoic and Triassic. However, despite the quality of their fossil record, their widespread occurrence, and the different forms of data encoded in their morphology and hard-tissues, conodonts have been underutilised as a palaeoecological resource. They survived the Late Ordovician, Devonian and Permian-Triassic mass extinction events, diversifying subsequently: robust palaeoecological analysis of conodonts thus has the potential to shed new light on biotic responses to these mass extinction events. Historically, analyses of spatial distributions have provided only limited constraints on conodont ecology. Nevertheless, it is widely accepted that variation in the size, morphology and differentiation of elements within the conodont dentition is indicative of differences in ecology between taxa. Bilaterally occluding P_1 elements, which functioned to process food, show clear morphological convergence both across coeval independent lineages and along lineages through time. Similarities in the morphology of the functional surfaces of P_1 elements are hypothesised to correlate with diet and represent trophic guilds. Using morphological, mesowear and biomechanical analyses of conodont P_1 elements, we aim to reconstruct the trophic ecologies of conodonts. We will investigate the differential likelihoods of extinction and diversification of trophic guilds through time, allowing us to evaluate the potential of conodonts as novel proxies for trophic and ecosystem-level responses to mass extinction events.

EGU Galileo Conferences
GC5-Mass-26, 2019
Mass extinctions, recovery and resilience

The onset of CAMP volcanism, environmental change, and the magnitude of carbon-cycle perturbation at the Triassic–Jurassic mass extinction (Neuquen Basin, Argentina)

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The end-Triassic mass extinction (at ∼201.5 Ma), approximately synchronous with the onset of Central Atlantic Magmatic Province (CAMP) emplacement, is associated with a global carbon-cycle perturbation.
We present data from a new Triassic–Jurassic boundary succession in the Neuquén Basin, Argentina, and show that Increased accumulation rates of sedimentary Hg (and Hg/TOC) began significantly before the end-Triassic mass extinction, and before the commencement of CAMP-related basalt emplacement, but contemporaneous with CAMP-associated dyke and sill formation, suggesting thermal alteration of intruded country rocks as a potential major source of elevated Hg fluxes to the atmosphere at this time.
We also show that despite significant increases in atmospheric pCO_2 across the Triassic–Jurassic transition, the magnitude of the associated carbon-cycle perturbation (and observed negative carbon isotope excursion (CIE)) was relatively modest (2–3‰. Furthermore, the Neuquén Basin was marked by oxygen-depleted marine conditions across the Triassic–Jurassic transition, enabling increased preservation of organic matter. Combined with similar observations across the Panthalassic margin and the north-western Tethyan seaway, burial rates of organic matter must have been relatively elevated in a global context. Using simple mass-balance calculations, we show that enhanced carbon burial rates, either during or directly succeeding the end-Triassic mass extinction, and in line with the major phase of CAMP basalt emplacement, can explain the observed evolution of the global exogenic carbon cycle at this time.

EGU Galileo Conferences
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Mass extinctions, recovery and resilience

Death defying morphologies: mass extinction and disparity in the order Harpetida

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This study seeks to better understand the phylogenetic relationships within the trilobite order Harpetida, with a view towards using this group to explore the relationship between extinction intensity and disparity. The harpetid response to the Late Ordovician mass extinction is of particular interest. A discrete morphological character matrix was created from the formal descriptions of harpetids in the published trilobite literature, and refined using first-hand observations of harpetid fossils. The final matrix consists of 76 discrete characters, including 69 cephalic characters, three thoracic characters, and four pygidial characters. This matrix is the first attempt of its kind to characterize the morphology of Harpetida as a whole, rather than focusing on individual harpetid genera.

Exemplar species from a broad selection of harpetid genera, along with ptychopariid and redlichiid out groups, are included in the matrix, coded according to published figures and direct observation of specimens held in the collections of the Yale Peabody Museum of Natural History. The matrix was used to generate a hypothetical tree of harpetid phylogenetic relationships, the topology of which indicates support for harpetid monophyly but throws doubt onto the previous hypotheses of the internal relationships of the group.

Disparity analysis of the group reveals a significant decline in morphological diversity across the Late Ordovician mass extinction boundary, with slow recovery beginning in the Silurian and continuing into the Devonian.

EGU Galileo Conferences
GC5-Mass-28, 2019
Mass extinctions, recovery and resilience

Correlated plant diversity and climate in North America during Earth system succession following the K-Pg mass extinction

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Western North America preserves a remarkable terrestrial record across the Cretaceous-Paleogene (K-Pg) boundary and provides an excellent framework in which to examine short- and long-term climatic, floral, and faunal change pre- and post- K-Pg mass extinction. Mega- and palynofloras from the Williston and Denver Basins (North Dakota and Colorado, respectively) suggest that ∼50% of angiosperm leaf species and ∼30% of palynomorph species disappear at the K-Pg boundary, demonstrating an instantaneous extinction and little evidence of preceding ecosystem stress. Plants from the immediate aftermath of the K-Pg extinction indicate rapid forest recovery. During this time, pulsed climatic warming correlates with increased plant species richness and the immigration of energy-rich fruit types, both of which may have supported the diversification of mammals in the earliest Paleocene. While these data suggest plants diversified in the wake of the K-Pg event, most megafloral data suggest forest diversity in North America did not recover until the Eocene, ∼10 Ma after the K-Pg boundary. However, the hyper-diverse Castle Rock rainforest (63.8 Ma) in the Denver Basin changed this paradigm. Continued analyses of this flora, particularly in the context of newer discoveries, give insight into food web recovery after the K-Pg extinction. Cast in the context of Earth system succession (global ecological succession following mass extinction events), these data suggest a staged and intrinsically linked pattern of recovery of the global ecosystem.

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GC5-Mass-29, 2019
Mass extinctions, recovery and resilience

Changes in dinosaur ecosystems leading up to the Cretaceous-Paleogene boundary in North America

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The Cretaceous-Paleogene (K-Pg) boundary is associated with Earth's third largest mass extinction. Despite being one of the best-studied intervals of time, there is considerable debate regarding the drivers and tempo of the extinction. The Deccan Traps flood basalt province and the Chicxulub bolide impact have both been suggested as drivers of the K-Pg mass extinction. With these drivers in mind, we provide a detailed and temporally constrained terrestrial fossil record that documents relative abundance of Hell Creek Formation dinosaur skeletons from the latest Cretaceous of North America.

The dataset consists of ceratopsians (65%), Edmontosaurus (23%), Thescelosaurus (5%), tyrannosaurs (4%), pachycephalosaurs (2%), and other taxa (1%). The relative abundance of skeletons is not distributed evenly through time or depositional environment. The lower third has a relatively even distribution of ceratopsians (31%), Edmontosaurus (38%), and Thescelosaurus (31%), while the relative abundance of ceratopsian dinosaurs increases to 58% and 73% in the middle third and upper third, respectively. In addition, ceratopsians are preferentially found in mudstone overbank deposits by a 2:1 margin, Edmontosaurus and Thescelosaurus in sandstone riverine deposits by a 16:1 and 8:1 margin, respectively. The preferential occurrence of taxa with lithology, combined with a general lithologic change from a sandstone-dominated base to a mudstone-dominated top suggests depositional environment changes, likely a result of marine transgression, is a primary driver for observed changes in Hell Creek dinosaur ecosystems. The occurrence of all large, common dinosaurs within the uppermost Hell Creek suggests a rapid demise as a result of the bolide impact.

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GC5-Mass-31, 2019
Mass extinctions, recovery and resilience

An orbital time scale of environmental perturbations across the Cretaceous – Paleogene boundary section of Nye Kløv (N. Denmark)

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The Cretaceous-Paleogene boundary (K-PgB) section of Nye Kløv, (N. Denmark) has been the subject of important past contributions for understanding of this mass extinction. Although it is less emblematic than the Stevns Klint section, due to its poor exposure in a farm field, this section presents many advantages. For instance, calcareous microfossils are well preserved, and none of the hardgrounds documented at Stevns Klint are observed there, thus arguing for better continuity. Here, we focus on environmental changes occurring across the K-PgB as documented from various, high-resolution geochemical analysis coupled with paleontological data. Bulk carbonate carbon and oxygen isotopes, elemental data from XRF, XRD mineralogical data, mercury content and rock-EVAL analysis provide a robust environmental framework. The late Maastrichtian Kjølby Gaard marl is an event of particular importance, characterized by the most negative values in oxygen isotopes and a transient mercury anomaly, suggesting a strong imprint of a latest Maastrichtian volcanic event and associated greenhouse warming. Oxygen isotopes delineate the end-Maastrichtian warming, followed by an end-Maastrichtian cooling and by a last pulse of warming immediately below the K-PgB. Moreover, oxygen isotopes show a well-pronounced orbital cyclicity throughout the section with strong influence of both precession and short-eccentricity that permit a detailed astronomical calibration of the K-Pg transition. Two early Danian mercury anomalies are found, one of which may be related to the Dan-C2 event. Altogether, our new data draw a precise timing of K-Pg environmental perturbations (volcanism and impact) and their effects in the Boreal Chalk Sea.

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GC5-Mass-32, 2019
Mass extinctions, recovery and resilience

Simulations of the environmental effects of the Chicxulub impact imply important contribution to the end-Cretaceous mass extinction

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During the end-Cretaceous mass extinction 66 million years ago, non-avian dinosaurs and many other organisms became extinct. Whether this most recent of the five largest mass extinctions was caused by flood-basalt eruptions or the impact of a large asteroid impact is still under debate. Modeling the climatic effects of the Chicxulub impact can therefore help to assess the possible contribution of an impact to the end-Cretaceous mass extinction.
We investigate the climatic effect of sulfate aerosols and carbon dioxide using a coupled ocean-atmosphere model. Additionally, we explore the biogeochemical effect of sulfur, carbon, iron and phosphate added into the ocean during the impact using a marine biogeochemistry model.
We find a strong decrease of global surface air temperatures by at least 26°C, returning to pre-impact temperatures after about 30 years. The strong ocean mixing induced by the cooling leads to changes in the oxygen distribution, with significantly higher concentrations in the deep ocean 30 to 300 years after the impact. Net primary productivity ceases in the first years after the impact. However, with light returning it exceeds the pre-impact value already after less than 10 years due to the higher availability of iron and phosphor.
The strong environmental perturbations found in our simulations indicate a significant contribution of the impact to the end-Cretaceous mass extinction.

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Mass extinctions, recovery and resilience

Potential impact of the end-Permian pelagic deep-sea anoxia

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Sedimentary rocks in the Japanese accretionary complexes are rare and important material which record the pelagic oceanic region at least several thousands of kilometres far from the main continents. Using these materials, we have reported the pelagic deep-sea environmental records of the palaeo-superocean Panthalassa during this mass extinction event and its aftermath. In this presentation, we will present some latest findings based on one of the best deep-sea Permian-Triassic boundary sections (Akkamori section; Takahashi et al., 2009; 2014; 2019).
The strong sulphidic condition was estimated by the highest peaks of Mo coinciding with the onset of the black organic matter enriched claystone, in accordance with the end-Permian mass extinction event which associated with a significant decrease in silicic microfossils. The reactive Fe hosted in pyrite mineral decreased toward this horizon suggesting a decrease in reactive Fe in the sediments and contemporaneous seawaters under sulphidic conditions. After that, Mo decreased despite high total organic carbon contents and temporal increases in pyrite. This trend implies drawdown of seawater Mo after the massive Mo deposition during sulphidic water condition. Therefore, it was revealed that the redox changes in the pelagic Panthalassa at the end-Permian mass extinction have a great impact on the seawater composition. The decrease in reactive Fe from pelagic seawater would promote sustainable anoxic water development, because of the limited H2S consumption by pyrite formation. Depletion of Mo as a bio-essential nutrient could have had a considerable effect on primary producer turnover and marine animals.

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Mass extinctions, recovery and resilience

Conodont natural assemblages in lowermost Triassic deep-sea claystone from northeastern Japan, with probable soft-tissue impressions

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We report the first discovery of Lower Triassic platform-type conodont (Clarkina sp.) assemblages: four natural conodont assemblages from Lower Triassic pelagic black claystones of the North Kitakami Belt in northeastern Japan (Akkamori section; Takahashi et al., 2009, 2019). The fossils were obtained from the black claystone horizon. This horizon has been dated to the earliest Triassic (Griesbachian) by the occurrence of Hindeodus parvus, which is the index species for the base of the Triassic, in the same and subjacent horizons. These four fossil assemblages include a paired segminiplanate-formed P1 element, which was identified as the genus Clarkina, and have fully or partially preserved the original components of conodont elements. The most complete assemblage among them includes 15 distinctive elements, namely S0 and pairs of M, S1, S2, S3, S4, P1, and P2.

It is noteworthy that these fossil assemblages preserve probable impressions of soft tissue which is possibly sensory organs 'eyes,' which were replaced by aggregations of silicate, phosphate, and sulphide minerals. The occurrence of several sets of fossils that retain the original positioning of the conodonts' elemental apparatuses, as well as the original presence of soft tissue, may be attributed to the process by which the conodonts' bodies were transported to the deep seafloor, and by which the activity of agents of decomposition was inhibited in near-abiotic sediments under anoxic conditions in the pelagic deep sea during the earliest Triassic.

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GC5-Mass-35, 2019
Mass extinctions, recovery and resilience

Rapid ecological succession of pioneering fern species at the John's Nose Cretaceous–Paleogene boundary section (North Dakota, USA)

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Southwestern North Dakota offers some of the best terrestrial Cretaceous–Paleogene (K–Pg) boundary exposures, associated with many plant and vertebrate fossils. The John's Nose section, North of Marmarth, exhibits an organic-rich shallow lacustrine mudstone sequence that preserves a white, 2-3-cm-thick boundary claystone. We have conducted an unprecedentedly high resolution (1 cm) palynological sampling of the boundary interval. The onset of the boundary clay is associated with the sharp extinction of typical Cretaceous palynomorphs (K-taxa, from 20-30% total abundance down to <1%). Immediately above the boundary clay, we observe evidence for a rapid and sequential recolonization of the devastated landscape by pioneer species. Fern spore species typical of the K–Pg « fern spike » appear first (Cyathidites spp., ∼80%, then Laevigatosporites spp., ∼40%), followed by Deltoidospora spp. (∼20%), Reticuloidosporites pseudomurii (∼11%), and Gleicheniidites spp. (∼9%). Two disaster angiosperm taxa are also spiking within the same interval (Kurtzipites circularis, ∼11%, and Ullmipollenites krempii, ∼8%). This ecological succession of ferns is similar to those observed today following disturbances associated with landslides, wildfires, lava flows and human deforestation, in which different ferns species replace each other over a ∼100-year time span. In light of these similarities in both tempo and ecological signature, we propose that the K–Pg vegetation dynamics and associated impact on faunas could serve as a methodological model to better understand the impact of anthropogenic landscape disturbances.

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GC5-Mass-36, 2019
Mass extinctions, recovery and resilience

Timing and causes of early Triassic climate disturbances; Linking U-Pb dates and $\delta^{13}C_{carb}$ record

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Following the Permian/Triassic mass extinction (PTME), the Early Triassic biotic recovery underwent several setbacks of the nekton and terrestrial plants during its 5 myr time span. The first ~3 myr are characterized by high amplitude fluctuation in the δ^{13}C and δ^{18}O records, associated with changes in global climate and their consequences in terms of sea level, weathering rates, redox conditions, and organic carbon burial. Episodic pulses of volcanism of the Siberian Traps Large Igneous Province (STLIP) are commonly proposed as a trigger for these Early Triassic disturbances, but lack a confirmation by reliable radio-isotopic dating. A direct temporal link is difficult to make, since the geochronological database consists of partly imprecise and inaccurate ^{40}Ar/^{39}Ar, ^{40}K-^{40}Ar and U-Pb data. Yet, it is uncertain how the declining magnitude and frequency of STLIP volcanic episodes may have contributed to these Early Triassic climatic disturbances and associated biotic setbacks.

We present new high precision zircon CA-ID-TIMS U-Pb ages from volcanic ash layers associated with marine sediments of the Loulou Fm. in the Nanpanjiang Basin (South China) that offer a high resolution ammonoid and conodont biochronological age control. The U-Pb-ages are integrated into a Bayesian age-depth model that establishes a precise timeframe for substage-level early Triassic stratigraphy and infers the durations for the different $\delta^{13}C_{carb}$ isotope excursions. Hafnium isotope analysis of the dated ash bed zircons reveals fluctuations in εHf values over time, interpreted as periods of more juvenile magma compositions erupted to produce the studied ash beds.

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Mass extinctions, recovery and resilience

Mis-shapes, mistakes, misfits: aberration & mutations in terrestrial palynomorphs

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Since 2005 and the recognition of lycopsids permanent tetrads being associated with the end-Permian mass extinction and their potential linkage to an increase in UV-B flux there has been the suggestion that aberrations in the palynomorph record might be used to detect episodes of environmental stress. Our understanding of pollen aberration is chiefly derived from laboratory studies, typically on model plants e.g. Arabidopsis thaliana where malformations are induced by exposure of seeds to mutagenic compounds such as ethyl methanesulfonate or exposure to neutron radiation. The end result is the production of abnormal of pollen and an understanding of the developmental pathway that is responsible for pollen formation. Further data on non-model plants is available from fieldwork carried out in areas of high pollution. These studies have enabled background levels of aberration to be detected and have been used to demonstrate a link with air pollution from heavy industry and thus a possible link to volcanic eruptions during mass extinction events.

The detection of aberrations in fossil pollen and spore assemblages are essentially a morphological representation of a break down in normal pollen development and are an indication that the parent plant has been exposed to abiotic stress. From a palynological/ palaeoclimate standpoint the challenge is to establish what this record actually means and from there how we can interpret variation in mutation. In this presentation I will outline how these disparate fields can be integrated and outline how this information could be used to aid our understanding of mass extinctions.

EGU Galileo Conferences
GC5-Mass-40, 2019
Mass extinctions, recovery and resilience

Response of high southern latitude herbivorous arthropod guilds to the collapse of glossopterid forests during the end-Permian biotic crisis

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The upper Permian to Middle Triassic continental succession of the Sydney Basin, Australia, is rich in plant fossils, well constrained by radiometric dating of tuffs and palynostratigraphy, and has been subjected to detailed sedimentological and geochemical studies. This succession represents an ideal testing ground for assessing plant-arthropod interactions through the Permian–Triassic extinction and recovery phases. Broad-leafed glossopterid gymnosperms overwhelmingly dominated the high-palaeolatitude wetland communities of the Sydney Basin during the Permian. The abrupt collapse of glossopterid ecosystems and cessation of peat accumulation characterizes the end-Permian extinction in the Sydney Basin. Succeeding plant assemblages from a <5 m package of dark shales immediately overlying the uppermost coal seam are characterized by peltaspermalean seed-ferns and voltzialean conifers with small sclerophyllous leaves together with herbaceous pleuromeian lycophytes, ferns and sphenophytes. Plant assemblages progressively diversify through the Lower Triassic succession, with corystosperm taxa becoming dominant during the Olenekian. A general increase in leaf size among the dominant plants and the re-appearance of coaly laminae suggests a return to more humid conditions near the end of the Early Triassic. Arthropod damage is common and diverse on Late Permian glossopterid plants across Gondwana. Damage features on immediate post-EPE plant remains are sparse and dominated by simple margin-feeding injuries. A stepwise increase in insect damage abundance and complexity is evident through the Early Triassic, attesting to the tandem recovery of plant and terrestrial arthropod communities.

EGU Galileo Conferences
GC5-Mass-41, 2019
Mass extinctions, recovery and resilience

Platinum-group elements link the end-Triassic mass extinction to volcanism

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Elevated concentrations of iridium (Ir) and other platinum-group elements (PGE) have been reported in both terrestrial and marine sediments associated with the end-Triassic mass extinction (ETE) c. 201.5 million years ago. The source of the PGEs has been attributed to condensed vapor and melt from an extraterrestrial impactor or to volcanism. Here we report new PGE data for volcanic rocks of the Central Atlantic Magmatic Province (CAMP) in Morocco and show that their Pd/Ir and Pt/Ir ratios are similar to marine and terrestrial sediments at the ETE, and very different from potential impactors. Hence, the PGEs provide a new temporal correlation of CAMP volcanism to the ETE, corroborating the view that mass extinctions may be caused by volcanism.

EGU Galileo Conferences
GC5-Mass-42, 2019
Mass extinctions, recovery and resilience

Refined Permian–Triassic timeline reveals early collapse and delayed recovery of the south polar terrestrial ecosystem

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The collapse of late Permian Gondwanan floras, and extinction of glossopterids, heralded the end of one of the most enduring and extensive biomes in Earth's history. The Sydney Basin, Australia, hosts a near-continuous, age-constrained succession of high southern palaeolatitude (~65–75°S) terrestrial conditions spanning the end-Permian extinction (EPE) interval. Sedimentological, stable carbon isotopic, palynological and macrofloral data were collected from two cored coal-exploration wells and correlated. Six spore-pollen biostratigraphic zones were identified within the uppermost Permian to Lower Triassic succession, corresponding to discrete vegetation stages developed before, during and after the EPE interval. Collapse of the glossopterid biome marked the onset of the terrestrial EPE and significantly predated the marine mass extinctions and conodont-defined Permian–Triassic Boundary. The EPE was characterized by collapse of the dominant Permian taxa; the immediate aftermath witnessed high abundances of opportunistic fungi, algae and ferns. This transition is coeval with the onset of a gradual global decrease in δ13Corg and the primary extrusive phase of Siberian Traps Large Igneous Province magmatism. Primary gymnosperm groups of the Gondwanan Mesozoic all appeared in the region soon after the collapse, but remained rare throughout the immediate post-EPE succession. Faltering recovery was due to a succession of rapid and severe climatic stressors until at least the late Early Triassic. Concurrent with the Smithian–Spathian boundary (~249 Ma), indices of increased weathering, thick redbeds, and abundant pleuromeian lycophytes likely signify marked climate warming and intensification of the Gondwanan monsoon climate system.

EGU Galileo Conferences
GC5-Mass-43, 2019
Mass extinctions, recovery and resilience

Paleoenvironmental and paleoecological trends leading up to the end-Triassic mass extinction event: story of two sites from northeastern Panthalassa.

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Conditions leading up to the end-Triassic mass extinction (ETE) event during the Rhaetian are not well understood. This study investigates pre-extinction intervals at two sites, Ferguson Hill, Nevada and Williston Lake, British Columbia. The Ferguson Hill section records the initial negative carbon isotope excursion (INIE) of 1.7 ‰ occurring worldwide in association with the ETE. A precursor carbon isotope excursion (PCIE) of 1.6 ‰ is identified 7 m below the extinction interval at this site. Lack of macrofaunal bioclasts within bulk samples as well as thin sections is coincident with precursor and INIE intervals illustrating negative effect of carbon shifts on benthic metazoa. An identical PCIE is documented in Austria, UK and Germany by Ruhl and Kurschner (2011) suggesting that observed shifts in the carbon cycle occurred globally. Petrographic investigation reveals an elevated amount of sulphide pseudomorphs (goethite framboids after pyrite) within the PCIE interval followed by episodic re-occurrence up the section and by steady increase starting 2m below the extinction interval. The presence of sulphide pseudomorphs suggests episodic dysoxic conditions within the sediment and potentially within the water column preceding the ETE. Three sites at Williston Lake record phosphorite deposits in the interval immediately preceding the ETE. Fluctuating redox conditions play a crucial role in phosphogenesis therefore providing direct biosedimentary evidence that episodic shelf euxinia at Williston Lake existed leading up to the ETE. Both sites record stressed conditions before the global environmental collapse which possibly were precursors for reduced environmental stability during initial CAMP volcanism in northeastern Panthalassa.

EGU Galileo Conferences
GC5-Mass-44, 2019
Mass extinctions, recovery and resilience

Biomarker evidence for the origin and crisis of early angiosperm during late Permian–early Triassic

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Des-A-mono-aromatic oleanane (DAMAO) was detected and identified in the Changxing section bearing GSSP of Permian-Triassic boundary and GSSP of Wuchiapingian–Changhsingian boundary. This could be an important evidence for the early origin of angiosperm. DAMAO reaches its highest content at the top interval of the Changxing Fm. just below the Bed 25, but it becomes extremely low or under detection in the Yinkeng Fm. DAMAO also shows a stratigraphic trend that is highly consistent with phenol compounds diagnostic of woody plants. This indicates that the Changxing section well records the collapse of terrestrial ecosystem at the end-Permian, coupling with the marine mass extinction event. This means that the early evolution of the angiosperm must have been delayed by the end-Permian mass crisis.

EGU Galileo Conferences
GC5-Mass-46, 2019
Mass extinctions, recovery and resilience

Archives from the past: characterization of oolites deposited in the early aftermath of mass extinctions

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Ooids were intensively investigated both petrographically and sedimentologically in the past decades; but only recently, scientists concentrated on their potentialities as archives for the original chemical composition of the oceans where they formed. The deposition of ooids is atypically high in the direct aftermath of major and minor extinction events occurring during the evolution of Life. We used a morphological and geochemical approach to better understand peculiar seawater chemistry just after major biodiversity breakdowns, in particular the end-Permian and end-Triassic mass extinctions, and two Silurian events (Mulde and Lau events). Here, I will present the first results from an end-Triassic section from the Emirates and four end-Permian sections from Italy. Petrographic analyses provided a detailed morphological classification of coated grains. FE-SE-EDX imaging unraveled peculiar μm-scale features linked to diagenetic processes and microbial interaction in the cortex. LA-ICP-MS analyses were performed for specific major and trace elements. Post-extinction oolites show high variability in size and development of the cortex. They range from small ($\sim$ 300 μm) and superficial coating, to bigger (up to 800 μm) and well developed. The degree of micritization highlights different oxic conditions in the diagenetic environment. Moreover, LA-ICP-MS analyses give insights into seawater redox conditions during ooids formation, siliciclastic contamination and the role of bacterial strain in shaping the ooids. These first observations look promising to understand why oolites were so widespread in this geological context and to trace back some of the active factors during mass-extinction events.

EGU Galileo Conferences
GC5-Mass-47, 2019
Mass extinctions, recovery and resilience

Sedex brine expulsions to the ocean: The underling culprit of catastrophic global change and mass extinctions

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Increasingly, chemostratigraphic studies show dramatic episodes of global climate-oceanic instability that are denoted by isotope disturbances in oceanic C, O, S and Sr and trace element cycles. It is now clear that these reorganizations of global Earth systems form the nodes in the evolutionary trajectory of life. Yet, while our understanding of these phenomena is advancing, the underlying trigger(s) remain poorly understood.

We integrate new palaeontological and chemostratigraphic tools to advance an alternative hypothesis for the trigger of these dramatic events. Specifically, we propose that massive releases of sedimentary brines, analogous to those that form sedimentary-exhalative (sedex) ore deposits, induced runaway fertilization and eutrophication that through a series of positive feedbacks resulted in these perturbations of global ocean-climate systems. Central to this new model are new ore genesis and fluid flow studies that demonstrate these brine discharges supplied quantities of metals, radiogenic Sr and biolimiting nutrients to the oceans surpassing that of the total modern riverine flux to the ocean. Strong temporal correlations between brine releases, combined with mass balance evidence and oceanographic box modelling, suggest that the flux of radiogenic Sr-rich sedex brines was sufficient to cause observed positive excursions ("spikes") in the global marine Sr-isotope record that correspond with global δ13C and δ18O, global anoxia, metal-rich black shale deposition, climate change, metal-induced teratology of marine organisms, and significant biotic extinctions - suggesting that these massive brine exhalations may be for the ultimate culprit of these catastrophic global events.

EGU Galileo Conferences
GC5-Mass-48, 2019
Mass extinctions, recovery and resilience

Metal-induced malformations in fossil plankton ground-truth a sedex-fueled mechanism for early Palaeozoic mass extinctions

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Upper Ordovician and Silurian (mass-)extinction events are no longer considered a direct consequence of glacial episodes. This once-popular cause-and-effect relationship has been critically challenged by an accumulating body of stratigraphic and proxy data that demonstrate misalignment between the faunal turnovers and the climatic perturbations. Proposed alternative triggers of these catastrophic extinctions, such as sedex-induced ocean anoxia and the associated remobilisation of toxic metals, though seemingly plausible, must be ground-truthed against the fossil record.

Our collaborative research has repeatedly demonstrated that malformed (teratological) fossil microplankton occur throughout the early phases of several Ordovician-Silurian extinctions. By analogy with metal-induced malformations in modern plankton, teratology in these ancient organisms might be a new, independent proxy for monitoring the metal concentration of Palaeozoic oceans. In order to test this supposition, we are using a suite of analytical techniques, including ToF-SIMS, LA-ICP-MS, electron microprobe analysis and multiscale XRF to quantify the major and trace element composition of microfossils and their host rocks through Ordovician-Silurian events.

This presentation summarises data from multiple stratigraphic sections, including through the end-Ordovician mass extinction, that support the hypothesis that global anoxia and the associated cycling of toxic metals was a key factor during these events. Moreover, the suite of metals observed, their stratigraphic order of appearance, their correspondence with other isotopic systematics and, crucially, their effects on the biology support our model that this flood of redox-sensitive metals in the ocean can be traced back to dramatic brine exhalations that also deposited the world's largest mineral deposits on the seafloor.

EGU Galileo Conferences
GC5-Mass-49, 2019
Mass extinctions, recovery and resilience

Teratology in fossil spores and pollen - A result of chance, a genetic pattern or a result of ecological upheaval?

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The end-Triassic biotic crisis is considered as one of the five most severe extinction events. However, it is often argued that flora, in contrast to fauna, depicts different patterns of change and lower degrees of disturbance in times of extinction. Indeed, given that plants cannot "runaway" (or escape) like animals do in an abruptly changing environment, their responses in times of intense stress might manifest in other ways than in mere taxonomical extinction.

Recently, teratological studies, i.e. studies investigating the occurrence of 'abnormal' structures, are increasing along mass extinctions, especially the presence of 'aberrant' spores and pollen grains along the P/T- and T/J-boundary. They are also getting more attention because they might provide new insights on the different response of the plant kingdom to ecological crisis.

Here we present unpublished data on teratological spores and pollen grains from the Bonenburg section in the Central European Basin from the Triassic-Jurassic transition, and using arguments from extant plant lineages, provide potential explanations for their occurrence. Specifically, we review intrinsic genetic processes naturally causing such variation, and which can be triggered by extrinsic ecological causes, such as a changing environment typical for times of biotic crisis. We thereby provide new interpretations on the potential significance of the occurrence of aberrant terrestrial palynomorphs and discuss the potential value of teratology as a signal of ecological disturbance, and its significance to re-evaluate the severity of mass extinctions in the plant kingdom.

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GC5-Mass-50, 2019
Mass extinctions, recovery and resilience

Mutagenesis in land plants during the end-Triassic mass extinction

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During the last 600 million years of Earth history, four out of five major extinction events were synchronous with volcanism in large igneous provinces. Despite improved temporal frameworks for these events, the mechanisms causing extinctions remain unclear. Volcanic emissions of greenhouse gases, SO_2 and halocarbons are generally considered as major factors in these biotic crises, resulting in global warming, acid rain and ozone-layer depletion. The occurrence of increased abundances of malformed land plant spores and pollen during the end-Permian and end-Devonian events have mainly been attributed to increased UV-B radiation due to ozone layer depletion. Here, we report exceptionally abundant malformed fern spores in Triassic–Jurassic boundary successions in Denmark, Sweden, and Germany. The high occurrences of abnormal fern spores during and after the mass extinction interval indicate severe environmental stress and genetic disturbance in the parent plants. This coincides with increased levels of mercury – the most genotoxic element on Earth – in both marine and terrestrial Triassic–Jurassic boundary successions, and offers compelling evidence that emissions of toxic volcanogenic substances contributed to the end-Triassic biotic crisis.

EGU Galileo Conferences
GC5-Mass-51, 2019
Mass extinctions, recovery and resilience

First record of the end-Triassic mass-extinction in the Netherlands

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The town of Winterswijk is well-known for its commercially exploited limestone quarry that represents the sole outcrop of Muschelkalk (Anisian, Triassic) in the Netherlands. Perhaps less well-known is that the Muschelkalk is overlain by a thin band of around 8 meters of black to brown laminated clays that have been dated to be of Rhaetian age based on a characteristic assemblage of Late Triassic pollen and spores. The Rhaetian is truncated towards the top and overlain by Oligocene marine clays rich in dinoflagellate cysts. Here, we use the WINT15-02 core drilled by Sibelco in 2015 to examine in detail the Rhaetian palynological assemblage. The Rhaetian clays of Winterswijk can be subdivided into two intervals; the lower part is dominated by high abundances of Classopollis and other typical Rhaetian pollen, including Ovalipollis ovalis. The upper part is a spore-dominated interval with high spore diversity and a dominance of the Concavisporites-Deltoidospora complex and Polypodiisporites polymicroforatus. We also observed aberrant forms of Classopollis in this interval. The WINT15-02 core thus preserves a transition from the latest Triassic Contorta to the Triletes Beds, representing the onset of the end-Triassic mass-extinction. Using the Spore Ecogroup Model, the Triletes Beds show a strong increase in lowland plants and pioneer species indicating warm and wet climate conditions. A strong decrease in palynomorph concentration and pollen diversity indicates an overall decrease in tree coverage as has also been observed in other nearby sites in the Germanic Basin.

EGU Galileo Conferences
GC5-Mass-52, 2019
Mass extinctions, recovery and resilience

Soil loss and resilience associated with end-Triassic deforestation

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Soils are a crucial link between the atmosphere, biosphere, and geosphere and disturbances to the health of soils will severely impact plants as well as a multitude of organisms living in or on soils. Catastrophic soil loss is thought to have played a pivotal role during mass-extinction events as a result of major deforestation, but the exact feedbacks remain elusive. Here, we assess the role of soil loss into the end-Triassic mass-extinction event based on proxy data obtained from core material from France, Germany, England, Denmark, and Sweden. Clay mineral and palynological data indicate a strong increase in chemical weathering and mechanical erosion during the latest Rhaetian with the influx of kaolinite and abundantly reworked Palaeozoic organic matter. Based on a new timeline, these changes were coeval with intense volcanic activity in the Central Atlantic Magmatic Province (CAMP), which released large quantities of volatiles that contributed directly and indirectly to enhanced weathering. Erosion rates likely also rose in response to deforestation, repeated forest fires, and seismic activity related to CAMP emplacement. Using a novel proxy based on biological degradation of fern spore walls, the intensity of biodegradation by fungi and bacteria, a process coupled to organic matter decay in soils, strongly decreased across the T/J boundary. We interpret this as evidence for the widespread removal of soils. Taken together, CAMP induced environmental changes led to profound changes in weathering and erosion and removal of soils, while soil resilience during the Hettangian proceeded hand in hand with recovery in Jurassic seas.

EGU Galileo Conferences
GC5-Mass-53, 2019
Mass extinctions, recovery and resilience

Ammonite death and nautilus survival at the Chicxulub massacre: here's what we know so far

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The differing faith of ammonites and nautiluses across the Cretaceous/Paleogene boundary has puzzled scientists for decades. In the past 20 years, our understanding of the death of the ammonites has largely moved forward, and we now have many more insights in the exact timing, rate and pattern of the ammonite extinction, and its most probably trigger.

In a nutshell, ammonites were still abundant, diverse and widespread at the moment of the Chicxulub impact, and disappeared abruptly from the fossil record within the following tens of thousands of years. Diversity changes prior to the impact were minor, and cannot be held accountable for their final extinction. As an example, generic diversity slowly declines throughout the Maastrichtian, but only accounts for a ten percent loss. And although Deccan warming may have initiated some migrations, it cannot (yet) be linked with (major) ecosystem failure.

At present, 33 sites are known to document 30 genera and at least 62 species alive within the ultimate 0.5 million year of the Cretaceous. Among them are representatives of all major evolutionary lineages and shell shapes. Interestingly, community structures and diversity patterns differ between different environments and paleogeographic realms.

Contrasting with the progress in the understanding of the ammonite death, the survival of the nautiluses currently remains one of the last unexplored issues of the 5th mass-extinction. Ongoing research indicates that their survival is a complex story, which may be better characterized by a turnover, composed of a combination of extinctions, migrations and radiations.

EGU Galileo Conferences
GC5-Mass-54, 2019
Mass extinctions, recovery and resilience

Palynology across the pristine spherule layer marking the Cretaceous-Paleogene boundary at Gorgonilla Island, Colombia

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A few cm thick spherule bed representing Chicxulub impact ejecta depos¬its and marking the Cretaceous-Paleogene (K-Pg) boundary was recently discovered on the Gorgonilla Island, Colombia. The deposit consists of extraordinarily well preserved glass spherules reaching 1-3 mm in diameter. Importantly, the Gorgonilla spherule bed is unique with respect to other K-Pg boundary sites in that up to 90% of the spherules are intact and not devitrified, and the bed is virtually devoid of lithic fragments and microfossils. The spherules were deposited in a deep marine environment, possibly below the calcite compensation depth. 40Ar/39Ar dating and micropaleontological analysis reveal that the Gorgonilla spherule bed was a result of the Chicxulub impact (the weighted mean of all plateau ages is 66.051 $\pm$ 0.031/0.054 Ma).

The vegetation recovery is represented by fern spores, more specifically by ground fern taxa such as Gleicheniaceae and Dictyophyllum, together with abundant occurrence of the aquatic fern Azolla. These interestingly co-occur with fungal spores and hyphae. A so-called fern-spike has previously been described from New Zealand K/Pg boundary clay coincident with the iridi¬um-enriched layer and interpreted as a response to short term darkness. The genus Azolla consistently characterizes warm-climate lacus¬trine environments and ranges of many Azolla species span the K/Pg boundary at other sites. The identification in Colombia of Azolla microspores and massulae directly above the K/Pg boundary at the Gorgonilla locality shows their potential to endure altered environmental conditions.

EGU Galileo Conferences
GC5-Mass-56-1, 2019
Mass extinctions, recovery and resilience

Survival of arid-adapted plants over global biotic crises is influenced by their pollination biology

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Terrestrial vegetation response over mass extinctions is controversial, and in particular, the role of pollination biology in biotic reorganisation remains largely unexplored. The xerophyte *Ephedra* (Ephedraceae, Gnetales) harbours remarkable variation in pollination biology, but this is not reflected in the low morphological and genetic divergence of the extant clade, prompting questions regarding its origins. Ultrastructural and experimental work on living *Ephedra* suggest insect pollination is actually ancestral in the Gnetales, which originated at least in the Early Cretaceous. This extended record indicates much higher ephedraceaen diversity in the past, particularly in steppe environments. Here we explore the palynological record of *Ephedra* on the Central Asian steppe with two aims: 1) pinpoint drivers underlying a pollination syndrome shift in the Asian clade, and 2) improve understanding of arid biome response to rapid climate transitions. We find that perturbations at the Cretaceous–Paleogene (K–Pg) and Eocene–Oligocene (EO) boundaries forced catastrophic shifts in Asian steppe ecosystems, with permanent negative effects on ephedraceaen abundance and diversity. The group may have survived through an evolutionary shift to wind pollination, but not in direct response to either biotic crisis; rather it permitted wind-pollinated species to persist by decreasing their vulnerability to disturbances in plant-pollinator mutualisms. Gradual changes prior to the K–Pg and EO events also contributed to ephedraceaen demise by eroding ecosystem resilience, but in the latter crisis this was masked by a positive vegetation feedback loop. This suggests that current ecosystem monitoring may underestimate long-term arid biome susceptibility to anthropogenically-induced global change, especially for insect-pollinated plants.

EGU Galileo Conferences
GC5-Mass-57, 2019
Mass extinctions, recovery and resilience

Building an accurate and precise chronological framework for the British Palaeogene Igneous Province

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Radioisotopic geochronology has provided a means to interpret the temporal coincidences of Large Igneous Provinces (LIP) (e.g., Deccan Traps, Columbia River Basalts, North Atlantic Igneous Province) with catastrophic global events, such as the late-Cretaceous mass extinction and the Palaeocene-Eocene Thermal Maximum. However, in addition to establishing cause-and-effect relationships, which require an age for an event, advances in geochronology are now allowing for the dissection of LIPs on sub-100 ka timescales. The ability to resolve the distribution of time within a LIP allows us to examine individual eruptive events, the frequency of eruptions and changes in eruption rate. Here we demonstrate the levels of precision that can be obtained using the $^{40}Ar/^{39}Ar$ dating technique for the dating of the British Palaeogene Igneous Province (BPIP). Despite being one of the most intensely studies regions in the world, the current geochronology for the BPIP is poor. $^{40}Ar/^{39}Ar$ data collected using a HELIX-platform noble gas mass spectrometer achieve total precisions of ca. 50 ka (2-sigma) for 60 Ma basalts and are revolutionising our understanding of the geodynamic setting of the region. This contribution will detail a study of the Staffa Formation, a basal lava sequence within the BPIP and highlight the potential of using $^{40}Ar/^{39}Ar$ geochronology to dissect other LIPs.

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GC5-Mass-58, 2019
Mass extinctions, recovery and resilience

Palynofloral turnover across the Triassic–Jurassic transition in the Sichuan Basin, southwestern China

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The end-Triassic mass extinction is considered as one of the five largest Phanerozoic extinction events, major biotic turnover occurred in both the marine and terrestrial realms. Here we present results from detailed palynological studies on the Late Triassic–Early Jurassic successions from the Sichuan Basin, China, revealing palynofloral changes across the Triassic–Jurassic transition. Based on palynological analyses, the Late Triassic flora was dominated by ferns mainly represented by Dipteridaceae/Mantoniaceae together with conifers. During the latest Triassic, a change to a flora dominated by cycads/bennettites/ginkgophytes and conifers occurred, while ferns decreased in relative abundance. The earliest Jurassic assemblages were dominated by fern spores, so-called fern-spike, and the Cheirolepid-conifers began to develop. The fern-spike is accompanied by common occurrence of *Classopollis* tetrads, some of which exhibit possible polyploidy, indicating an end-Triassic terrestrial ecosystem. This study presents data on changes within the terrestrial palynoflora across the Triassic–Jurassic boundary in the Sichuan Basin, providing important evidence for vegetation changes and ecosystem collapse within the eastern Tethys.

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GC5-Mass-59, 2019
Mass extinctions, recovery and resilience

Sedimentological and geochemical facies changes in the NE Paris Basin linked to the end-Triassic mass extinction event

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In the NE Paris Basin, upper Triassic and lower Jurassic sediments are widespread. The area, in which the sediments were deposited, was sensitive for changes of the sea level, paleogeography and paleoenvironment. A large number of complete sections from Luxembourg, NE France and W Germany show a wide variation of rapidly changing sediment facies from shallow marine to terrestrial. Detailed multidisciplinary studies have been conducted on these different sections to observe the variations of critical parameters characterizing the dramatic environmental changes, leading to the end-Triassic mass extinction. During this period, the opening of the Central Atlantic Ocean was accompanied by massive volcanism which released CO_2 and other gases in extreme volumes, leading to a greenhouse and negatively affected atmosphere, hydrosphere and biosphere. In the Paris Basin the asteroid impact of Rochechouart additionally deteriorated the ecological environment.

The geochemical composition reflects the lithology and allows furthermore a chemo-stratigraphical subdivision. The element patterns are also depending of the local depositional environment. Terrigenous elements can be discerned from biogenic, heavy mineral bound or diagenetically enriched elements. Redox-sensitive ratios play a significant role in the description of the redox-conditions in the sediment and water column. δ18O- and δ87Sr-analyses were used to give information about the temperature and salinity of the Rhaetian Sea.

Our δ13Corg vertical distribution data show prominent negative excursions occurring globally. They permit a worldwide stratigraphic correlation. A major negative peak is observed at the T/J boundary, above which stronger anoxic conditions replace the red beds of the uppermost Rhaetian.

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GC5-Mass-60, 2019
Mass extinctions, recovery and resilience

Vegetation changes during Early Jurassic global warming with impacts on oceanic anoxia

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Global warming and oceanic oxygen deficiency during the Early Jurassic Toarcian Oceanic Anoxic Event (T-OAE; ~183 million years ago) is associated with mass extinction in the oceans linked to volcanic activity. However, the effects of this warming event on land-based ecosystems have remained poorly understood. Here we present spore-pollen and marine palynological data from Yorkshire, UK, that reveal substantial changes in vegetation on land and plankton communities in the oceans. Forest ecosystems shifted from a diverse mixture of conifers, seed ferns, ferns and lycophytes, to a low-diversity community dominated by cycads and *Cerebropollenites*-producers during the event. After temperatures returned to normal, forest ecosystems recovered, however the dominant tree groups were notably different after the event, signifying long-term consequences for continental ecosystems. In the oceans, dinoflagellates disappeared – this is a widespread signal noted from several localities previously – and the warming led to massive algal blooms and eutrophication in shelf seas. The substantial initial ecosystem response on land compared to the relatively minor marine response at the Pliensbachian/Toarcian boundary (before the T-OAE) suggests that the early stages of warming were more severe on the continents than in the oceans.

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Mass extinctions, recovery and resilience

New Evidence for Canopy Collapse at the Cretaceous-Paleogene Boundary from Leaf Cuticles

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Since the discovery of the massive bolide impact at the Cretaceous-Paleogene Boundary (∼66 Ma), there has been much speculation on how the impact event affected terrestrial landscapes. A sudden shift to an over-dominance of fern spores – the “fern spike” –immediately above the K-Pg boundary clay indicates a substantial disruption to terrestrial plant communities. We present new data to assess canopy dynamics across the K-Pg event using the morphology of leaf epidermal cells, which respond to the amount of sunlight leaves receive during development. We reconstructed a high-resolution record (∼1 cm) of canopy density quantified as Leaf Area Index (LAI–the area of foliage/area of ground) from dispersed leaf cuticles preserved in palynological samples from the K-Pg John’s Nose locality near Marmarth, North Dakota, USA. The results show the presence of consistently dense forest canopies prior to the K-Pg event, but an opening of the canopy abruptly following emplacement of the boundary clay. This open signal occurs during the peak of the fern spike and is brief in duration. After the fern spike, the LAI rebounds to pre-event levels within ecological timescales. These data are concordant with previous interpretations of the fern spike that suggest forest canopy collapse. In addition, they permit the estimation of recovery time for forests to regain their original structure (though compositionally different from pre-impact floral communities), and they provide additional evidence of habitat loss and a breakdown in terrestrial primary production.

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Mass extinctions, recovery and resilience

Early Triassic nutrient crises limited marine productivity

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The Early Triassic represents a prolonged period of ecologic recovery following the latest Permian mass extinction. Factors that delayed biotic recovery are under debate and partly revolve around impacts of volcanic induced global warming on primary marine productivity. We examined N isotope records from the Festningen section, Spitsbergen, to study changes in nutrient availability through the Early to Middle Triassic along the northern margin of Pangea. Results show progressive shift from high to low nitrogen isotope values throughout the Griesbachian, that we interpret to reflect reduction in N availability, and in response increased atmospheric N2 fixation. This nutrient limitation occurred throughout the remainder of the Early Triassic and in conjunction with decreased organic matter in the sediments as well as declines in paleoproductivity proxies, suggesting stressed primary productivity along northern Pangea during that time. There was a return to a highly productive continental margin in Middle Triassic time coincident with final cooling of global oceans. Results are consistent with other studies from northern and western Pangea and thus show regional nutrient limitations occurred in what should have been a major zone of marine primary productivity. We suggest this was driven by Siberian Traps induced global warming, creating high ocean temperatures that depressed the marine nutricline below the zone of upwelling. As such not only did the Siberian Trap LIP likely cause the worst mass extinction of the Phanerozoic, but also impacted marine producitivty for the subsequent several million years, limiting the recovery of life.

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Mass extinctions, recovery and resilience

Elucidating human-megafauna interactions in South America: The archaeological and paleontological potential of the archaeological site of Santa Elina, Brazil

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Evidences for the interaction between humans and megafauna during the Pleistocene are abundant in several places worldwide (e.g. North America, Eurasia). In striking contrast to this, only few and very controversial claims exists for the entire South American continent. In this context, the Santa Elina archaeological site (Mato Grosso State, Brazil) stands out as a key site for shedding new light on this topic. Previous works demonstrated the presence of skeletal remains of the giant sloth Glossotherium sp. occurring together with vestiges of human occupations (e.g. lithic materials). Some of these osteoderms found in a layer dated from 27,000 years B.P were highly modified. Here we show new data obtained through Stereomicroscopy and Scanning Electron Microscopy. The results revealed regular micro-morphologies attributable to human intervention on these materials. It is possible to observe a superficial surface covered by striations, a set of parallel marks with equally sizes, following the same direction, and central tiny holes. These results enable now more detailed investigations, in order to determine if these modifications were made in fresh or fossilized bones, so more analyzes are being performed. This may help to elucidate the possibility that South American human populations have interacted with megafauna, the chronology of peopling of the South America, and also elucidate the debate about South American megafauna extinction.

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Mass extinctions, recovery and resilience

Microbial Mats and Seafloor Recolonization following Mass Extinctions

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Microbial induced sedimentary structures are produced by the interaction between microorganisms, the compounds they produce and the host sediment. These include Kinneyia structures which are produced by the growth of microbial matgrounds; blanket-like communities of microbes that glue sediment and themselves together by secreting Extracellular Polymeric Substances).

Matgrounds, and the Kinneyia structures they produce, are prevalent throughout the Proterozoic (2500-541Ma), However matgrounds decline rapidly during the Cambrian (540-485 Ma) as new species of burrowing animals (infauna) evolved. These animals disrupted the matgrounds, mixing dissolved oxygen into the sediment and redistributing deposited material, thus establishing modern-like animal-dominated mixground assemblages.

Mixgrounds are dominant on the seafloor today and throughout the Phanerozoic, however Kinneyia structures do see several resurgences in the fossil record. These are usually associated with oceanic anoxia and marine extinction events (Mata and Bottjer, 2009) and indicates a return to Proterozoic-like matgrounds following mass extinctions, before the eventual recovery of mixground assemblages. As a result, post-extinction recovery mimics the initial early Cambrian colonization of the seafloor.

This research combines fieldwork, examining the fossilized relationship between infauna and matgrounds, and experimental work, using modern animals in anoxic and matground-dominated sediments as a model for infauna during the Early Cambrian. This will allow us to better understand the infaunal conditions that allowed the sediment to be colonized and could provide an important insight into the recovery of ecosystems following mass extinctions.

Reference

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EGU Galileo Conferences
GC5-Mass-66, 2019
Mass extinctions, recovery and resilience

Constraining end-Triassic carbon cycle perturbations from single fern spore carbon isotope records

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The end-Triassic mass extinction event and related global climate changes are linked to the emplacement of the CAMP (Central Atlantic magmatic province). The release of large amounts of volatiles, such as CH4 and CO_2, are thought to be responsible for carbon cycle perturbations across the Triassic-Jurassic boundary. In particular, the main phase of the biotic crisis and the environmental changes were marked by two negative Carbon Isotope Excursions (CIEs) and it was preceded by a precursor negative carbon isotope shift. Many carbon isotope records are based on bulk organic matter analyses due to a paucity in carbonate deposition. However, bulk organic carbon isotope records can be strongly influenced by changes in composition, compromising global carbon cycle signals. Here, we investigate whether individual spores track these carbon isotope shifts. We use palynological preparations of the Schandelah core (northern Germany) spanning the Triletes Beds (Upper Triassic) and Hettangian Alpha-1 (Lower Jurassic). Individual spores of the Deltoidospora-Concavisporites complex were hand-picked using an inverted microscope. Analyses were performed with a laser-ablation nano-combustion gas chromatography/isotope ratio mass spectrometer present at Utrecht University. Preliminary results indicate that single spores can be used to better understand fluctuations in bulk organic the δ13Corg records.

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Mass extinctions, recovery and resilience

The assessment of end-Permian ozone shield strength using Fourier transform infrared spectroscopy to investigate sporopollenin chemistry

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Sporopollenin is a primary constituent of pollen and spore walls, that is extremely recalcitrant and which allows the identification and study of palynomorphs hundreds of millions of years after they formed. Sporopollenin typically contains ultraviolet (UV) absorbing compounds (UACs) that protect the genetic contents of the palynomorph from UV-B radiation. As plants can regulate UAC production according to UV exposure, abundances of UACs have been used as a proxy for historic UV and ozone shield health.
A large proportion of palynomorphs from the end-Permian mass extinction (EPME) are malformed and it has been hypothesised that these malformations resulted from high levels of UV-B. High levels of UV-B suggest that the Earth's ozone shield was severely compromised during this time, which may have been caused by extensive magmatism at the Siberian Traps large igneous province. We are using chemopalynology to seek more direct, chemical evidence of catastrophic ozone collapse during the EPME by investigating end-Permian sporopollenin with a view to linking changes in UAC abundance to Siberian Traps magmatism.
We will discuss the cutting-edge Fourier Transform infrared (FTIR) spectroscopy imaging we have employed to investigate the effects of end-Permian levels of UV exposure on the sporopollenin chemistry of extant plants. This work has provided a reference from which we can estimate prehistoric ozone shield strength at biologically catastrophic UV doses. Further we will explore the sporopollenin chemistries of End-Permian palynomorphs sourced from areas that would have spanned the supercontinent, Pangea.

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Mass extinctions, recovery and resilience

Temporal analysis of Early Jurassic large igneous province activity and its relationship to environmental perturbations

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Volcanism in Karoo-Ferrar Large Igneous Province (LIP) is considered to be the trigger for major environmental changes in the Early Jurassic associated with the Toarcian Oceanic Anoxic Event and carbon isotope excursion (CIE), as well as the Pliensbachian-Toarcian Event and CIE. This environmental change is characterized by carbon cycle perturbations that affected the whole ocean-atmosphere system, as well as mass extinction in the marine realm. Significant work has been undertaken to understand the impact, absolute age and duration of these events in relation to LIP activity. Despite the plethora of vintage and recent geochronological datasets that have been generated for the large igneous provinces of the Early Jurassic, no rigorous statistical analyses of all of the published data have been undertaken to assess the temporal relationship between igneous province activity and environmental changes. Here we provide a compilation of over 200 ages for the entire large igneous province and statistical analyses of these ages. The analyses highlight peak volcanism in Karoo at the onset of the OAE and peak volcanism in Ferrar at the climax of the carbon isotope excursion that demarcates the OAE.

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Mass extinctions, recovery and resilience

Photic zone euxinia in North East England following the end-Triassic mass extinction

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Pulsed CO_2 degassing from the giant flood basalt eruptions of the Central Atlantic Magmatic Province (CAMP) is thought to have triggered the end-Triassic mass extinction (ETE) ∼201.6 million years ago. This rapid atmospheric pCO_2-driven global warming is linked to positive feedbacks via weathering, oversupply of nutrients, anoxia and sulphate reduction, culminating in at least regional H2S poisoning of the water column (e.g., euxinia) that acted to restrict the habitable zone to a narrow mid-water refuge.

As part of our study of a transect across the Channel between modern day England and Germany, we present a multiproxy dataset from analysis of a 6 m section of a drillcore from Felixkirk, located on the western margin of the Cleveland Basin, NE England. Throughout the latest Triassic and early Jurassic, the Cleveland Basin comprised a swathe of low-lying islands surrounded by a warm, shallow epicontinental sea, making it susceptible to adverse climatic effects (e.g., dramatic sea level change, etc.).

We use lipid biomarkers, bulk δ^{13}Corg data and published palynological data to reconstruct a continuous high-resolution record of environmental conditions across the ETE, marked in the Felixkirk sediments by an abrupt, large magnitude negative carbon isotope excursion. We show that fossil derivatives of the pigment isorenieratene (derived from green sulphur bacteria Chlorobiaceae) in conjunction with a suite of redox-sensitive biomarkers indicate widespread photic zone euxinia following a dramatic relative sea level fall coincident with the extinction event.

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Mass extinctions, recovery and resilience

Ecosystem Pressure in the Early Eocene Lake Uinta, Green River Formation, Utah: Hydrological and Biogeochemical Cycling During Rapid Warming Events

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Understanding past climatic states and ecological modes, especially in times of extreme warmth, is crucial for future predictions of biotic change during the new warm mode we have created. The Early Eocene Climatic Optimum (EECO, 53-50 Ma) provides a natural experiment of the impacts of extreme global warming on the Earth system.

The Early-Eocene aged Green River Formation is world-famous for its fossils including some of the best-preserved examples of early Cenozoic flora and fauna. However, this otherwise fossiliferous deposit has a 120-metre-thick interval of lacustrine strata devoid of macroscopic animal fossils, but extremely rich in organic matter (up to 50% TOC) known as the Mahogany Zone. To investigate the response to a prolonged hot-house climate in a lacustrine basin and extreme biotic stress, we used molecular fossils extracted from the Mahogany Zone from a transect of cores through the margin and centre of Uinta Basin, Utah. Quantitative δ13C data from this terrestrial succession can be correlated to marine sections through astrochronology tied to 21 U-Pb and 40Ar/39Ar dates from ashes.

Our results of compound-specific hydrogen isotopic analyses of n-alkanes, isoprenoids and hopanes, in concert with high-resolution sedimentary logs, additional lipid biomarker profiles, and organic petrographic data, allow the differentiation of hydrological change from broader ecosystem change during the EECO. We conclude that lake conditions experienced lethally warm waters optimal for algal productivity, enhancing anoxia in the water column to the point where conditions in the habitable area were too extreme for macrofauna to thrive.

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Mass extinctions, recovery and resilience

Parallel pCO$_2$, Hydrologic and Conifer Physiognomic Trends across the end-Triassic extinction

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Although the end-Triassic extinction (201.6 Ma) had modest effects on plant diversity, we have found a strong effect in plant physiognomy. We describe trends in cheirolepidaceous conifer leaf and stomatal morphology from tropical Pangean great rift lake deposits (present northeastern USA) that broadly parallel orbital-to-seasonal scale pCO$_2$ and hydrological cycle changes recorded from the same strata. The physiognomic changes appear at an abrupt (<10 ky) negative δ^{13}C excursion in n-alkanes synchronous with a palynological turnover and fern spike and continue through a prolonged negative δ^{13}C excursion that tracks the pCO$_2$ and n-alkane hydrogen isotope records, lasting 900 ky (through all 3 basaltic extrusive events of CAMP), encompassing most of the Hettangian age. During intervals of elevated pCO$_2$, cheirolepidaceous conifer leafy shoot forms *Brachyphyllum* and *Pagiophyllum* develop microphyllous leaves with thickened cuticle and sunken papillate stomata. Subsequently, a 2- to 5-fold increase in the area of leafy shoots in strata of latest Hettangian age suggest a return to lower thermal stress levels from lower pCO$_2$, despite the fact that eastern North America continued to drift into more arid latitudes. The lower pCO$_2$ is also associated with limestone deposits that are otherwise unusual and suggest that extremely elevated pCO$_2$ drove extreme weathering of exposed local and new CAMP lavas. The floral physiognomic changes associated with the negative δ^{13}C excursion, very elevated pCO$_2$ levels, and abrupt transitions in arid and humid conditions is a microcosm of the Mesozoic in which the dominance of cheiroleps overlaps with the highest pCO$_2$ levels of the Phanerozoic.

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Mass extinctions, recovery and resilience

A biomarker and compound specific isotope investigation into the end-Triassic extinction; implications for CIEs and extinction

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The end-Triassic mass extinction (ETE), driven by the large igneous province the Central Atlantic Magmatic Province (CAMP), is characterised by negative excursions in the organic carbon isotope record (CIEs). Because the leading hypothesis behind the CIEs is CAMP induced methane clathrate release, the precursor, initial, and main CIEs are used as chemostratigraphic markers to correlate globally dispersed sections during the ETE. One focal section to which many organic carbon isotope records are correlated too is St. Audrie's Bay in the SW UK. However, high-resolution biomarker and compound specific isotope investigations here implicates correlations and extinction. We find the precursor CIE is instead related to organic matter change, not CAMP activity. Similarly, there is strong evidence the initial CIE said to represent the ETE is instead related to the emergence of microbial mats containing purple and green-pigmented green sulfur bacteria. Here, the proposed extinction event and "dead zone" is simply explained by changes in salinity and water depth, well evidenced by brackish to freshwater organisms and sedimentary features. Better placement for the ETE in the SW UK is with return to fully marine conditions in overlying strata. Here, conodont, phytosaur, and bivalve extinctions are observed, above which a biocalcification crisis is evidenced by poorly preserved and decalcified shelly taxta with lack of ammonites and corals. During the biocalcification crisis strong evidence of anoxia and persistent photic zone exunia, a process important in other mass extinction events, in conjunction with acidification may better account for the ETE and lack of sedimentary carbonates.

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Mass extinctions, recovery and resilience

Catastrophe at the end of the Cretaceous? Shallow marine biodiversity, palaeoecology, and the complexities of the Cretaceous-Paleogene (K-Pg) mass extinction event

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The Cretaceous-Paleogene (K-Pg) mass extinction event 66 million years ago is the most recent of the 'Big Five' Phanerozoic extinction events and is associated with the loss of non-avian dinosaur-dominated ecosystems on land, and marine reptiles and ammonoid cephalopods (ammonites) in the oceans. It is now almost forty years since Alvarez et al. proposed this extinction was caused by a catastrophic bolide impact (now known to be responsible for formation of the Chicxulub crater in the Yucatan Peninsula, Mexico), and a vast body of work supports this hypothesis. However, the extinction also coincides with the emplacement of the large Deccan Traps Large Igneous Province (LIP) in India, which based on high-precision dating, occurred over a <1 million-year period coinciding with the K-Pg boundary. Given the evidence that LIP volcanism is ultimately responsible for at least three of the other 'Big Five' extinctions, disentangling these phenomena is critical to understanding the fate of various groups at the K-Pg boundary. Did volcanism cause extinctions and instability prior to the Chicxulub impact? How were common groups like ammonites faring during the latest Cretaceous? What processes led to the formation of complex sedimentary deposits coincident with the K-Pg boundary? And did sea level change play a role in the record of the extinction? We are investigating these questions using faunal and geochemical data from K-Pg successions in the United States Gulf Coastal Plain, which demonstrate the complexities of the extinction event and recovery in shallow marine settings proximal (∼1500 km) to the Chicxulub crater.

EGU Galileo Conferences
GC5-Mass-74, 2019
Mass extinctions, recovery and resilience

The abnormal marine ecosystems after the Permian-Triassic mass extinction

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The Permian-Triassic boundary (PTB) crisis, representing the largest mass extinction of the Phanerozoic, was linked to major perturbations of the ocean-atmosphere system. Recently, we found some new interesting phenomenon from fossil and sedimentary records in the Early Triassic. Our results show that the PTB mass extinction resulted in the appearance of an abnormal marine ecosystem. Normally, marine ecosystem was dominated by non-motile animals with normal body sizes in the Paleozoic. However, following the PTB mass extinction, the Early Triassic marine ecosystem was dominated by nektons, small and opportunistic taxa.
We found two new "anachronistic" sedimentary events associated with the changes in the seawater system during/after the PTB crisis, i.e. 'dolomitization event' and 'marine red beds event'. Ten of twenty-two sections show high Mg/(Mg + Ca) ratios bracketing the PTB, indicating a global dolomitization event during the PTB crisis. We hypothesize that dolomitization event was triggered by enhanced microbial sulfate reduction within the oceanic chemocline. We found dozens of Early Triassic sections containing red carbonates (called marine red beds event). These red beds coincide closely with intervals immediately following periods of ocean anoxia as well as negative δ^{13}C excursion. We propose that displacement of Fe^{2+}-rich anoxic deeper waters into oxic shallower waters during the termination of oceanic anoxic events led to precipitation of hematite, coloring the red carbonates.

EGU Galileo Conferences
GC5-Mass-75, 2019
Mass extinctions, recovery and resilience

Cambrian extinctions

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The first Phanerozoic mass extinction happened soon after the beginning of the Cambrian Explosion. This extinction being coined the Sinsk Event occurred about 513 million years ago (Ma) and was ascribed to a global anoxia judging by facies analysis (Zhuravlev and Wood, 1996). By the gross, about a half of standing generic and species diversity was cut out. Despite a smaller scale by comparison with the infamous Big Five mass extinctions due to much less taxa existed then, its influence on the evolution of the biota was as severe as that of the Permian-Triassic catastrophe. The Sinsk Event reduced drastically a number of basal metazoan groups giving a pass to the radiation of more advanced taxa proliferated during the later Palaeozoic. These newly diversified groups were much less devastated by the extinction. A quantitative comparison of] 'underdogs' and 'lucky beggars' revealed that the latter were relatively widespread geographically and adopted to a larger spectrum of conditions.
Recent elemental and isotope data confirm a connection of the Sinsk Event with a global anoxia but, in addition, indicate general low oxic conditions in principal Cambrian marine basins accounted for a number of less pronounced extinctions triggered by frequent oxycline fluctuations. The effect of the Sinsk extinction could be amplificated by the eruption of the Kalkarindji continental flood basalts (512–498 Ma) and contemporary global warming due to a release of a significant carbon dioxide volume.

EGU Galileo Conferences
GC5-Mass-76, 2019
Mass extinctions, recovery and resilience

New constraints on the disappearance of archaeocyathan reefs in the western United States

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Archaeocyathan reefs have been well described from the western United States, particularly in the lower Cambrian stratigraphy in the White-Inyo Mountains of California and Esmeralda County, Nevada. Reefs in the Lower Cambrian Harkless Formation, argued to be some of the youngest archaeocyathan reefs in the world, are a consortium of archaeocyaths and microbial fabrics, with rare occurrences of early Cambrian corallomorphs. Although archaeocyathan reefs are not known from any stratigraphic unit that overlies the Harkless Formation, it remains unknown how and when these reefs finally disappeared from western Laurentia, and if this timing matches with the global record of their disappearance. Here, we show the first evidence for a negative carbon isotope excursion stratigraphically above the uppermost Harkless archaeocyathan reefs, preserved in ooid and quartz-rich carbonates that overlie the reefs. At all measured localities, carbon isotopes veer from 0‰, to more negative values, reaching the lowest value of -4‰ at one locality, and then recovering to more positive values (1‰) in overlying carbonates. We interpret this as the negative AECE excursion (archaeocyath extinction carbon isotope excursion); the presence of this excursion in strata within 30 m of the last archaeocyathan reefs in the Harkless Formation suggests that the global extinction excursion is present here and links the disappearance of archaeocyathan reefs from the western United States with their global demise.

EGU Galileo Conferences
GC5-Mass-77, 2019
Mass extinctions, recovery and resilience

Disentangling the adaptive radiation ('Siluro-Devonian Explosion') of land plants, environmental change and extinction events

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Land plants (embryophytes) appear to have originated in the Ordovician and rapidly colonised the exposed land surfaces. However, this initial invasion of the land does not appear to have been associated with major anatomical/morphological innovation. Following this 'slow fuse', that lasted at least 40 million years, the major adaptive radiation of land plants occurred in the Late Silurian to end Devonian. Plant maximum height increased a staggering four orders of magnitude, from a ground-hugging few millimetres to trees dozens of metres tall, with similar below ground impact. This was accompanied by a bewildering exploration of morphospace as all of the major groups of plants (except the flowering plants) appeared. During the time period in which land plants underwent this adaptive radiation the planet witnessed a high degree of environmental turbulence and numerous extinction events (including at least one of sufficient magnitude to be classed as a mass extinction). How did the land plants fare during these turbulent times? In this presentation I will attempt to unravel the rapid evolution of land plants (high species turnover coupled with innovation) and the concomitant environmental changes and extinctions. Was the adaptive radiation of land plants retarded or promoted by these environmental perturbations and extinction events?–or was the adaptive radiation of land plants actually responsible for them?

EGU Galileo Conferences
GC5-Mass-78, 2019
Mass extinctions, recovery and resilience

The functional consequences of extinctions: from giant sharks to small mollusks

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We used to think that the threats that marine vertebrates are experiencing today had no precedent. Based on an analysis of the fossil record, we overturned this assumption by showing that one third of the marine megafauna became extinct in the Pliocene. To gauge the potential consequences of this extinction for ecosystem functioning, we evaluated its impacts on functional diversity and found that 17% of their functional space was lost. This level of erosion contrasts with previous studies that have reported negligible functional changes after the (mass) extinction of marine invertebrates. A new study of a well-known extinction in the Caribbean reveal the mechanisms driving functional vulnerability and resilience: small, specious invertebrates can be persistently redundant (large number of taxa performing similar functions) through time, which in turn buffers them against extinction. Large vertebrates, on the other hand, tend to be functionally unique, thus highly vulnerable. After the extinction event that the marine megafauna experienced in the recent geological past, they would likely still be recovering today. Nevertheless, 30% of their species are currently deemed at risk of extinction by the IUCN. We forecasted how the eventual extinction of threatened species would affect marine megafauna functional diversity. Our simulations suggest that between 50% and 70% of their functional space would be lost. Therefore, the fate of marine megafauna in the Anthropocene has no precedent in the geological history.

EGU Galileo Conferences
GC5-Mass-79, 2019
Mass extinctions, recovery and resilience

Permian–Triassic biotic and abiotic facets

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The marine record of the Permian Triassic transition reflects the severest extinction event in Earth history, followed by a phase of continued environmental change and disrupted recovery during the Early Triassic. It is widely accepted since long that there had been a significant mass extinction and even the culprit seem to have been captured - the Siberian trap volcanism.
Currently, the focus of research is centered around the consequential network of environmental changes triggered by the Siberian Traps volcanism. Permian-Triassic environmental changes are reconstructed using a plethora of geochemical proxies such as carbon and oxygen isotope data, calcium isotopes, main and rare elements, mercury, and many more.
A second field of research opened up with increased dating accuracy. Thus, the timing of biotic and abiotic events are progressively unraveled in detail. Obviously, paces and patterns of destruction and recovery differ in among various faunal groups. Furthermore, the patterns of changes in terrestrial ecosystems appear to be different from those in the marine realm, but they are never completely decoupled.
Most plant groups survived the Permian-Triassic extinction event. Despite the taxonomic loss has been mild compared to the marine realm, significant changes are documented in the evenness of certain plant communities. Additionally, malformed sporomorphs gained attention as potential bioindicator for environmental hazards, so far documented by aforementioned geochemical proxies.

EGU Galileo Conferences
GC5-Mass-80, 2019
Mass extinctions, recovery and resilience

Sulfur and Mercury geochemistry of end=permian successions in China reveal terrestrial mass extinction timing and mechanisms

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The end-Permian mass extinction (EPME) is the most severe biological crisis of the Phanerozoic. The EPME was coincident with the eruption of the Siberian Traps LIP, which volcanic gases injected into the atmosphere–ocean system likely triggered a series of environmental changes that led to the biological crisis. The vast majority of the literature on the EPME is focused on marine environments whilst far less is known about the mechanisms and timing of the terrestrial EPME, and its links with the LIP eruption, due mainly to the less well-developed chronostratigraphy and poorer fossil preservation. Here we report organic C-isotope, TOC, Hg, and S-isotope data from coastal-lagoonal successions in western Guizhou – eastern Yunnan (South China), and lacustrine successions in Xinjiang (Northwest China). In the studied sections, a negative C-isotope excursion (CIE) is recorded coincident with the extinction of the terrestrial fauna and flora. Hg concentrations and Hg/TOC show a sharp peak correlated with the negative CIE, displaying a pattern similar to that of marine records. The S-isotope data of total-S and palaeosol-carbonate-associated sulfate from Xinjiang are consistent with the addition of volcanic S into the lake system as acid rain. We ran a biogeochemical box model that incorporates C and Hg cycles to test different gas injection scenarios into the end-Permian ocean–atmosphere–land system. The new geochemical and modelling results reveal the temporal and cause-and-effect relationships between the eruptions of the Siberian Traps and the terrestrial EPME, improving our understanding of the EPME mechanisms in continental ecosystems.

EGU Galileo Conferences
GC5-Mass-81, 2019
Mass extinctions, recovery and resilience

Climate Related Stressors and Mass extinctions

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Phanerozoic Mass extinctions were shown to coincide with Large Igneous Provinces (e.g. Late Devonian, Permian-Triassic, end-Triassic, end-Cretaceous). These catastrophic volcanic events may have been a potential source for greenhouse gases by volcanic CO_2 degassing and more importantly by thermogenic heating of organic carbon-rich sediments. Global warming, a decrease in marine dissolved oxygen concentrations culminating in anoxia/euxinia and lowered oceanic pH were potential consequences. These climate related stressors (CRS) may have affected marine life and contributed to mass mortality.

Proxy records have been used more or less successfully to document CRS in the fossil record. The palaeosol CO_2 barometer was applied to document changes in atmospheric CO_2. Addition of thermogenic CO_2 and thus changes in the global carbon cycle were identified by carbon isotopes measured on inorganic or organic carbon. Oxygen isotopes measured on biogenic calcite or apatite were used to reconstruct changes in marine palaeotemperatures while boron isotopes served as a pH proxy.

The proxy records for $p\mathrm{CO_2}$, global carbon cycle changes and climate warming as well as the temporal coincidence of climate related stressors with LIP volcanism will be reviewed for the Late Devonian, Permian-Triassic and end-Triassic mass extinctions with special emphasis given to the Permian-Triassic event.

EGU Galileo Conferences
GC5-Mass-82, 2019
Mass extinctions, recovery and resilience

Redox-dependent phosphorus cycling sets-off a cascading biogeochemical crisis during the end-Permian

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Multiple indices link the devastating end-Permian mass extinction to the global-scale spread of marine anoxic regions. Recent studies have postulated that the continental influx of nutrients might have played a critical role in eutrophication-induced oxygen depletion and hydrogen-sulfide build-up in the water column. However, advances in geochronological dating schemes and lithium isotope records suggest that the proximal causes, such as volcanic activity and continental weathering pre-date the main extinction pulse. In order to resolve these temporally misaligned signals of environmental deterioration and biotic response, we assess current understanding of local- to global-scale redox changes in marine conditions in conjunction with the fossil record. A primary observation is that a precise reconstruction of ocean redox conditions (i.e. the differentiation between euxinic, ferruginous or oxic conditions) is still largely lacking, which is essential to evaluate the role of redox-dependent sedimentary P retention. By constructing sedimentary P records within the context of local redox conditions across a bathymetric transect, we show that phosphorus might bridge the gap between disparate sedimentological, geochemical and palaeontological observations. This combined approach suggests that phosphorus could have acted as a primer, which pre-conditioned the inner-shelf to an unstable oxygen-restricted state. Only moderate changes in the external forcing were needed to induce an amplification, where phosphorus was extensively recycled under euxinic conditions, increasing productivity and tipping large stretches of the shelf into a reduced state. This killing mechanism also explains why benthic taxa with a high tolerance to low oxygen conditions and a planktotrophic larval stage dominated post-extinction marine communities.

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GC5-Mass-83, 2019
Mass extinctions, recovery and resilience

Mass loss of stable hypoxic habitats in the end-Ordovician

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Animal diversity was dramatically altered during two extinction pulses in the end-Ordovician, where causes for particularly the first pulse appear contradictory. A range of geological models now support scenarios of both increasing marine anoxia[e.g.1,2] and cooling-driven oxygenation[e.g.3−5]. The scenario of cooling is problematic since, for example, reduced temperatures in a greenhouse world[6] would rather appear a relief of stress than a kill mechanism. The scenario of increasing anoxia is also problematic since, for example, the mid-Ordovician and early Silurian oceans were also prone to develop anoxic water column conditions[2,7] in the low-oxygen Paleozoic world[11]. However, the two scenarios make some sense together when considering that a) the synchronous expansion of the oxic and anoxic niches would reduce the hypoxic niche, and b) that stable hypoxic niches could be argued important for invertebrate animals to manage their tissue renewal and, thus, regeneration8. If invertebrate animals indeed require hypoxia – internally or externally – for tissue renewal, the loss of hypoxic habitats could be a significant biotic challenge during both sea-level rise and fall. We evaluate the loss of hypoxic shelf area (0.5-1.5 mg/l) through a combination of models at sea-level fall of 100 m, as possibly associated with the first extinction pulse[9,10]. A mass loss of hypoxic habitats would add to the ongoing gradual modernization of Earth's atmospheric oxygen concentrations[11]. Collectively, these geobiological observations requires us to consider whether the trajectory of animal evolution was defined also by the loss of hypoxic habitats and of the hypoxic Paleozoic world.

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EGU Galileo Conferences
GC5-Mass-84, 2019
Mass extinctions, recovery and resilience

Mesozoic plants in palaeo-atmospheric and climate change research

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Plants typically have longer temporal lineages and are more resilient to ecosystem perturbations than animals, often undergoing mostly turnover of taxa when animals suffer mass extinctions. This makes plants highly suitable to track environmental changes across intervals of ecological upheaval, since the same taxa can often be recorded before, during and after the mass extinction event occurred. Plant leaf cuticle in particular is a powerful tool when researching the causes and consequences of mass extinctions episodes in the past, since these are highly resistent to taphonomic processes, and can almost always be obtained from sediments as leaf fragments, even when visible macro-leaf fossils are missing. Fossil leaves can be utilised for isotope analysis, $p\mathrm{CO}_2$ reconstruction and may give indications about SO_2 air pollution in the past. Since most mass extinction events are thought to be associated with greenhouse gas-driven global warming, in some cases in combination with transient global dimming/cooling episodes, this information is extremely pertinent. Here, a few examples will be listed of how fossil plants have tracked the pace and mechanisms behind two major Mesozoic mass extinctions - at the Tr-J and K-Pg boundaries.

EGU Galileo Conferences
GC5-Mass-85-1, 2019
Mass extinctions, recovery and resilience

Timing and pacing of the Late Devonian mass extinction event regulated by eccentricity and obliquity

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The Late Devonian envelops one of Earth's big five mass extinction events at the Frasnian–Famennian boundary (374 Ma). Environmental change across the extinction affected Devonian reef-builders, besides many other forms of marine life. Yet, it remains unclear which cause-and-effect chains led to the extinction, mainly because Devonian stratigraphy is poorly resolved. During this talk, I will present a global orbitally-calibrated chronology across this momentous interval, integrating cyclostratigraphy and high-precision radio-isotopic dates.

Our timescale stipulates that 600 kyr separate the lower and upper Kellwasser positive $\delta^{13}C$ excursions. In the Steinbruch Schmidt section (Germany), the black argillaceous interval of the Lower and Upper Kellwasser last respectively 80 and 110 kyr, but the $\delta^{13}C$ excursions are more extended in space and time. The UKE carbon isotope excursion is paced by obliquity and is therein similar to Mesozoic intervals of environmental upheaval, like the Cretaceous Ocean-Anoxic-Event-2 (OAE-2). This obliquity signature implies coincidence with a minimum of the 2.4-Myr eccentricity cycle and highlights the decisive role of astronomically-forced "Milankovitch" climate change in timing and pacing the Late Devonian mass extinction. To conclude, I will comment on the new set of questions that can be assessed thanks to this high-resolution timescale. One can, for example, identify time-lags between different proxies and therewith differentiate between the responses to astronomical forcing of different components of the Earth's system. Indeed, we report a delay of about 100 kyr between the $\delta^{13}C$ and the Ti/Al ratios, reflecting the slow response of carbon reservoirs to astronomical forcing.

EGU Galileo Conferences
GC5-Mass-86, 2019
Mass extinctions, recovery and resilience

Mammalian extinctions in the age of humans

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Currently approximately 1 million species are at risk of extinction because of human impacts. While these impacts have increased considerably since the industrial revolution, hominins have been having outsized effects on ecosystems for far longer. As hominins dispersed out of Africa and increased in abundance, extinctions that were spatially and temporally transgressive followed. They were highly size selective and unlike mammalian extinctions in the rest of the Cenozoic. Life history traits associated with large size and difficulty responding to perturbations (e.g., small litter size) are good predictors of late Pleistocene extinctions. By the terminal Pleistocene, large bodied mammals were extirpated from most of the globe with the few remaining species found in Africa and southeast Asia. Species of all sizes are at risk today including almost all large bodied mammals. Thus, understanding the consequences of these extinctions is important not simply for ecological theory, but also for conservation efforts. After the terminal Pleistocene extinctions, we find significant changes to many macroecological patterns including continental body size distributions, the relationship between geographic range size and body size, and maximum body size and land area. We also find significant changes in community structure including decreased beta diversity, shifts in pairwise co-occurrence of species, changes in the role of functional traits in mediating co-occurrence, and decreased importance of biotic interactions relative to abiotic factors. Mammalian extinctions in the age of humans are unlike extinctions at other times in evolutionary history and understanding their effects can help us predict how species and ecosystems will respond to future perturbations.

EGU Galileo Conferences
GC5-Mass-88, 2019
Mass extinctions, recovery and resilience

Volatile elements in CAMP basalts at the Triassic-Jurassic boundary

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The Central Atlantic magmatic province (CAMP) was emplaced during the latest Triassic and earliest Jurassic with peak activity between 201.6 and 201.1 Ma. Geochronologic and biostratigraphic data show that volcanism and shallow level intrusions (sills) were formed in short-lived pulses. Emission of volcanic gases and degassing of sediments intruded by the basalts probably triggered the end-Triassic mass carbon isotope excursions, substantially modified the composition of Earth's atmosphere-ocean system, and ultimately caused the end-Triassic mass extinction. Constraints on the magmatic volatile element budget is given by micro-analytical data both on melt inclusions within the basalts and on magmatic minerals formed at depth within the magmatic plumbing system. Here, we will discuss the origin of carbon and sulfur gases entrapped and emitted by CAMP magmas as well as the importance of volatile elements in controlling the tempo of magma rise through the continental crust.

EGU Galileo Conferences
GC5-Mass-90, 2019
Mass extinctions, recovery and resilience

Pulses of ocean acidification at the Triassic Jurassic boundary recorded by boron isotopes

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Ocean acidification driven by the emplacement of the Central Atlantic Magmatic Province (CAMP) has been suggested as a kill mechanism for the end-Triassic mass extinction. Although preferential extinction of heavily calcified groups and changes in shallow carbonate deposition hint at acidification as a causal mechanism, these observations can also result from other factors. Furthermore, depending on the rates of volcanic input and the efficiency of buffering by the carbonate system, volcanic emissions may not result in appreciable carbonate undersaturation. Here we present the first pH reconstruction over the Triassic-Jurassic boundary to test whether ocean acidification was a feature of environmental change at this time. These data, generated using the boron isotope composition of well-preserved fossil oyster shells, reveal a pronounced acidification pulse in the aftermath of the end-Triassic extinction, coincident with input of isotopically light carbon and ocean warming. This signal is consistent with ocean acidification due to pulses of volcanic carbon input from the CAMP, supporting the hypothesis that ocean acidification was an important component of large igneous province-associated mass extinctions.

EGU Galileo Conferences
GC5-Mass-91, 2019
Mass extinctions, recovery and resilience

Milankovitch forcing of Early Jurassic wildfires

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The Early Jurassic was characterized by major climatic and environmental perturbations which can be seen preserved at high resolution on orbital timescales. The Early Jurassic is a period of overall global warmth, and therefore serves as a suitable modern-day analogue to understand changes in the Earth System. Presently, Earth's climate is warming and the frequency of large wildfires appears to be increasing. Recent research has indicated that Quaternary deposits reveal that wildfires respond to orbital forcings; however, to date no study has been able to test whether wildfire activity corresponds to changes over Milankovitch timescales in the deep past.
A high-resolution astrochronology exists for the Upper Pliensbachian in the Llanbedr (Mochras Farm) borehole (NW Wales). Ruhl et al. (2016) show that elemental concentration recorded by hand-held X-ray fluorescence (XRF), changes mainly at periodicities of ∼21,000 year, ∼100,000 year and ∼400,000 year, and which can be related to visually described sedimentary bundles.
We have quantified the abundance of fossil charcoal at a high resolution (10-15 cm) to test the hypothesis that these well-preserved climatic cycles influenced fire activity throughout this globally warm period. Preliminary results suggest that variations in charcoal abundance are coupled to Milankovitch forcings over periods of ∼21,000 and ∼100,000 years. We suggest that these changes in fire relate to changes in seasonality and monsoonal activity that drove changes in vegetation that are linked to variations in the orbital forcing. Supplementary to the charcoal record, a high-resolution clay mineralogy dataset has been generated to further explain the climatic cyclicity observed in the wildfire record regarding the hydrology on land.