PERMIAN-TRIASSIC ECOSYSTEMS
IGCP572: Restoration of marine ecosystems
following the Permian-Triassic mass extinction

LESSONS FOR THE PRESENT

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Abstract volume
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Field Guide – Bükk Mountains


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SIGNIFICANCE OF SPATIAL VARIATION IN OCEAN REDOX CONDITIONS AT THE PERMIAN-TRIASSIC BOUNDARY

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Marine redox conditions varied greatly in time and space during the latest Permian-Early Triassic global crisis. Although models of a pervasively anoxic deep ocean have been proposed[1], reevaluation of oceanic sections suggests a modest shift toward mainly suboxic conditions on the deep seafloor accompanied by strong expansion of the oxygen-minimum zone at intermediate water depths[2-4]. In contrast to the relatively stable redox conditions in the deep ocean, shallow-marine sites were subject to frequent shifts between oxic and euxinic conditions for at least a million years[5-6]. Such fluctuations resulted from recurrent expansion of a shallow oxygen-minimum zone into the ocean-surface layer[7-8] in response to several types of environmental perturbations. First, global climates warmed abruptly during this interval[9], leading to lower dissolved oxygen levels in seawater and a reduced latitudinal temperature gradient[10] that suppressed overturning circulation and deepwater formation[4]. Second, enhanced continental weathering led to enhanced erosion[11] and higher nutrient fluxes, stimulating marine productivity and the sinking flux of organic matter[12]. However, the effects of terrestrially sourced nutrients on marine productivity were spatially variable[2,13], and some low-lying regions (such as South China) received few nutrients, triggering a productivity crash during the Early Triassic[14]. Changes in oceanic redox conditions during the Permian-Triassic boundary crisis may provide insights concerning the consequences for modern oceans of global warming and nutrient flux changes wrought by human activities[15].

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UPPER PERMIAN TO LOWER TRIASSIC STROMATACTIS LIMESTONE, A CONTINUUM?

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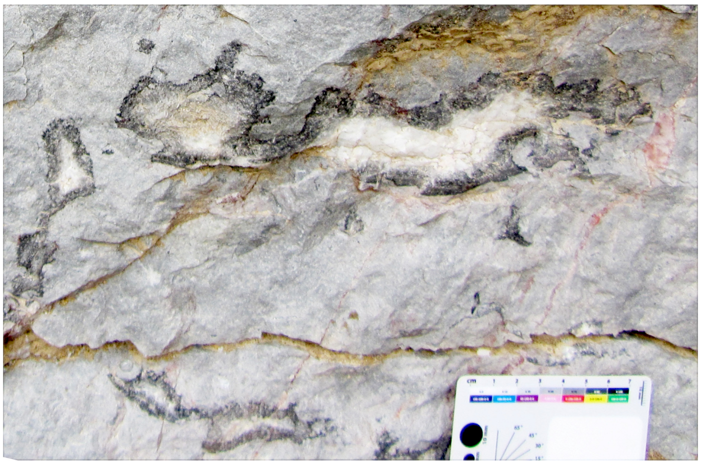
It is interesting to note that the stromatactis limestone has been recognized and described mainly in Paleozoic mud-mounds, but it is also represented in middle and upper Triassic drowning reefs.

A new quarry in the upper Permian to basal Triassic carbonate succession near Shanggan (Leye County, NW Guangxi, China) shows an upper Permian stromatactis mound which developed above a coral reef. The top of this Permian stromatactis buildup is cut by high-energy laminated lime grainstone, followed by a 5 m thick basal Triassic stromatolite facies. The upper, domal part of this microbial buildup displays centimetric cavities of stromatactis type cemented by blocky calcite. Abundant and larger stromatactis type cavities with fibro-radial calcite cement occur in the overlying upper Griesbachian coquina limestone. Just above, within the lower Dienerian lime siltstone, elongated stromatactis cavities and sheet cracks type filled by gray lime mud and microlayered isopachous cements are recorded.

In Oman, a younger lower Triassic occurrence (Smithian) of red stromatactis limestone has recently been described. Spathian red stromatactis limestones are also reported from areas in Dobrogea (Rumania).

The Shanggan section fills a gap between previously known occurrences and bridges Paleozoic and Mesozoic stromatactis limestone. This continuum was favored by the local persistence of open marine carbonate deposition from the Permian into the Triassic, on top of a tectonically uplifted block.



THE EARLY TRIASSIC OCEAN AS A MODEL FOR THE FUTURE GLOBAL WARMING OCEAN

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In the next 100 years it is projected that the Earth will move from an icehouse to a greenhouse climate state. The future global warming ocean will include increases in the extent of the oxygen minimum zone and ocean acidification. Through study of the past we can predict what the Earth and its biota will be like in this new greenhouse state, and what the journey to that state will entail. The interval marked by the end-Permian mass extinction and the subsequent Early Triassic experienced significantly increased warming due to the eruption of the Siberian Traps, with intrusion and eruption through coal and other organically-enriched deposits which when baked and burned enhanced the volcanic contribution of greenhouse gases to the atmosphere, particularly carbon dioxide. Although palaeogeographic, climatic, and geochemical conditions as well as evolutionary state of biological systems on Earth were different then than now, results from this natural experiment on the Earth system can be observed from the fossil and stratigraphic record and potentially provide information to manage our future global warming ocean. The ocean then was characterized by widespread anoxia, which impinged from deep into shallow environments, and typically was euxinic. The effects of the mass extinction on land led to a significant increase of terrigenous runoff to shallow-marine systems. The development of microbial structures, such as stromatolites and wrinkle structures, was unusually abundant, implying an ocean more dominated by microbes than is typical of the Phanerozoic. These stressful environmental conditions also led to an Early Triassic metazoan reef gap followed by a reef eclipse interval. Similarly, level bottom benthic environments were characterized by low biodiversity, cosmopolitan taxa, and reduced depth and extent of bioturbation. Significant opportunity thus exists to examine ecological questions relevant to the modern ocean. The decrease in bioturbation provides perhaps the best case for study in the Phanerozoic of how shallow seafloor communities with reduced bioturbation assemble and operate. Similarly, the predominance of a few abundant and cosmopolitan benthic taxa during this time provides an opportunity to understand the ecology and geographic variability of such widespread communities. The effects of a resurgent microbial world upon surviving metazoans can also be addressed as well as the character of microbial reefs under these conditions. Much can also be learned on the extent to which episodes of severe environmental change lead to the development of alternative ecosystems in the global ocean. Although not a perfect analogue, the Early Triassic ocean has much to teach us about the future global warming ocean.

TWO MAJOR EVOLUTIONAL CHANGES IN LATEST OLENEKIAN TO ANISIAN CONODONTS FROM THE UPPER GUANDAO SECTION, SOUTH CHINA: FINAL STEPS OF THE RECOVERY?

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Upper Guandao section is one of the most continuous and well exposed Middle Triassic section located in Guizhou Provice, South China. Based on the new conodont samples and previous studies, twelve conodont zones were revised or newly established according their first appearance data. In ascending order: *Neospathodus homeri* Zone, *Chiosella gondolelloides* Zone, *Chiosella timorensis* Zone, *Neogondolella regalis* Zone, *Nicoraella germanicus* Zone, *Nicoraella kockeli* Zone, *Paragondolella bulgarica* Zone, *Neogondolella constricta* Zone, *Paragondolella excelsa* Zone, *Budurovignathodus hungaricus* Zone, *Budurovignathodus mungoensis* Zone, *Metapolygnathodus polygnathiforms* Zone.

A statistical analysis of the conodont diversity reveals two important evolutionary events in this section, parallel of the ammonoids diversity curve. Event 1 occurred close to Olenekian-Anisian boundary, and is characterized by the disappearances of *Neospathodus* elements, including *Neospathodus homeri*, *Neospathodus spathi*, *Neospathodus symmetricus*, *Neospathodus brochus*, *Neospathodus triangularis*, and the recurrence of *Neogondolella* element: *Neogondolella regalis*. Event 2 occurred in *Neogondolella constricta* Zone (Illyrian) and is characterized by the radiation of diversiform *Neogondolella* elements, such as: *Neogondolella constricta*, *Neogondolella bifurcata*, *Neogondolella constricta cornuta*. *Neogondolella* elements dominated the conodont records during the Changhsingian, but they became rare during the Early Triassic. As *Neogondolella* is interpreted as deep water nektobenthic taxon, its new dominance after the event 2 could indicate the complete recovery of the deep water life conditions.

PERMIAN-TRIASSIC MARINE ECOSYSTEMS: COLLAPSE AND REBUILDING

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Life came closest to complete annihilation during the end-Permian mass extinction (EPME), which is also responsible for much of the structure of marine ecosystems today. However, whether the Permian biota has experienced one-episode extinction pattern or multiple-episode extinction model is still disputed. There is also some debate on the recovery rate and pattern of marine organisms in the aftermath of the EPME. Some clades recovered rapidly, within the first 1–3 Myr of the Triassic. For example, ammonoids and conodonts diversified in the first 2 Myr of the Early Triassic, reaching apparently stable local diversities. Further, some earliest Triassic body and trace fossil assemblages are more diverse than predicted. The best example comes from foraminifera in the South China sections, where recovery began 1 Myr into the Triassic, and was not much affected by Early Triassic crises. Others, ie. Brachiopods, corals etc., however, did not rebound until the early Middle Triassic. In addition, although ammonoids recovered relatively rapidly, reaching a higher diversity by the Smithian than in the Late Permian, much of this Early Triassic radiation was within a single clade, the Ceratitina, and their morphological disparity did not expand until the end-Spathian.

Here, I like to broaden the modern ecological network model to explore the complete trophic structure of fossilized ecosystems during the Permo-Triassic transition as a means of assessing the recovery. During the Late Permian and Early Triassic, primary producers, forming the lowest trophic level, were microbes. The middle part of the food web comprises primary and meso-consumer trophic levels, the former dominated by microorganisms such as foraminifers, the latter by opportunistic communities (i.e. disaster taxa and some tracemakers), benthic shelly communities, and reef-builders. These were consumed by invertebrate and vertebrate predators, the top trophic level.

Latest Permian ecosystems usually had a healthy trophic structure from primary producer to top predator. These ecosystems seem not to be completely destroyed within one event, but collapsed following a stepwise model. Marine ecosystems immediately after the extinction were either microbialite buildups, formed from microbes associated with tiny gastropods and ostracods or high-abundance, low-diversity communities dominated by disaster taxa. Thus, marine ecosystems were degraded to a low level, typified by primary producers or opportunistic consumers.

In the Spathian, marine ecosystems comprised ever more diverse trace fossil assemblages, as well as biodiversity increases of some clades, coupled with the emergence of some high-tiering organisms such as crinoids, as well as rare predatory fishes and the first ichthyosaurs. However, benthic communities were still of low diversity and high abundance. In the middle-late Anisian, marine ecosystems were characterized by the common occurrence of reptile- and fish-dominated communities such as the Luoping biota in Yunnan, Southwest China, in which marine reptiles (ichthyosaurs, pachypleurosaurs, thalattosaurs, prolacertiforms) diversified as top predators. With these top predators, Middle Triassic ecosystems added a new trophic level not seen in the Permian, when sharks, and not reptiles, had been top predators. Thus, ecosystems were constructed step by step from low level to top trophic levels through the early to middle Anisian, some 8–9 Myr after the crisis. Importantly, this was the time when the ‘coral gap’ and the ‘coal gap’ ended.

EARLY TRIASSIC REDOX STRUCTURE OF THE NEO-TETHYS MARGIN (OMAN)

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Poster

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This work presents the first results from a shelf-to-basin transect of the Arabian Platform and Hawasina Basin, aiming to reconstruct the temporal and lateral changes in redox conditions across the PTB and during the Early Triassic. The first results are from the slope section at Sumeini (Wadi Maqam, Shuyab and Mayah) from Oman.

I use a full Fe-speciation technique to characterise the water column redox conditions during this time period. The PTB section at Maqam shows a distinctly anoxic signature across the PTB carbon isotope excursion (CIE). The Smithian/Spathian boundary sections of Wadi Shuyab and Mayah show a shift from oxic to anoxic conditions coinciding with the positive CIE. Conditions then returned to fully oxic following the CIE in the Spathian.

PALEOCLIMATIC IMPLICATIONS OF PALAEONTOLOGICAL AND GEOCHEMICAL DATA FROM THE UPPER PERMIAN AND LOWER TRIASSIC CARBONATES OF THE VELEBIT MT. (CROATIA)

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Poster

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Permian deposits in the Velebit Mt. area (Croatia) derive from the epeiric platform which existed in equatorial area along northern Gondwana. Late Permian is characterized by dolomites encompassing three relatively thin zones of dark limestones (together named as Velebit Fm., Flügel, 1977). Late Permian dolomites in the Velebit Mt. area are mostly early-diagenetic. The deposition took place in subtidal, intertidal and supratidal environments, as a result of global trends in sea level oscillations. Latest Permian Transitional Dolomite (TD) includes complete remains and bioclasts of algae (dasycladales, solenoporaceans, gymnocodiaceans), foraminifera (*Earlandia*, *Ammodiscus*, *Glomospira*, *Tuberitina*, *Pachyphloia*, *Globivalvulina*, *Permodiscus*, *Staffela*, *Hemigordius*, Lagenidae), with fragments of sponges, ostracods, gastropods, echinoderms and brachiopods. Conodont remains have not been found. The lithologic boundary between Transitional Dolomite and overlying Sandy Dolomite (SD) is marked by a sudden occurence of ooids and siliciclastic grains. Even though it was previously considered as the chronostratigraphic PTB, it represents latest Permian regressive phase marked by an enrichment in concentrations of most major, trace and rare earth elements, followed by the Last occurence of the Permian fossils (LPE) in the lower part of the SD unit (Fio et al., 2010). Chemostratigraphic Permian–Triassic Boundary (PTB) is set within the SD unit marked by the parallel negative carbon isotope excursions in carbonate and organic carbon and changes in element concentrations.

First fossil remains after the PTB belong to foraminifera *Earlandia* sp., which is found together with the pyrite framboids just above the chemostratigraphic boundary (Fig. 1), pointing to suboxic and anoxic conditions (Fio et al., 2010). Up in the column, only probable cyanobacterial mats and juvenile mollusc remains have been found within the SD.

Decreasing carbon isotope values through the latest Permian, with considerable negative shift in $\delta^{13}C_{carb}$ at the Permian–Triassic Boundary (PTB), demonstrate that the Earth was significantly warmer, and that oceans were in the latest Permian globally warmer than present (e.g., Kidder &Worsley, 2004; Kiehl and Shields, 2005). Stable isotopes of oxygen can be used for palaeoclimatic and palaeoecological estimations, but for reliable data this estimations have to be done carefully, since oxygen isotopes are easily prone to diagenetic changes. For Rizvanuša section (Central Velebit Mt.), Late Permian whole rock $\delta^{18}O_{carb}$, with respect to V–PDB, vary from –3.2 to –1.3‰ (average–2.6±0.4‰), and Early Triassic from –3.2 to –2.2‰ (–2.7±0.3‰). According to formula $t\ (°C) = 16.1 - 4.64\ (\delta_c - \delta_w) + 0.09\ (\delta_c - \delta_w)^2$ (Kim and O'Neil, 1997; Bemis et al., 1998), and assuming seawater $\delta^{18}O$(V–SMOW) = 0‰ (Korte et al., 2005), we presume that Late Permian temperatures ranged from 21 to 31°C, with average 27°C, while Early Triassic ranged from 25 to 31°C (average 28°C).

These results correspond well to determined fossil community, but also to palaeotemperature estimations made by Polšak & Pezdič (1978), suggesting Late Permian mean sea-temperatures in the Dinarids–Alps area to be up to 26°C, Kiehl and Shields (2005) palaeotemperature models who proposed western Palaeotethys temperatures from 28–30°C, and results of Kearsey et al. (2009) estimating latest Permian temperatures between 26 and 29°C.

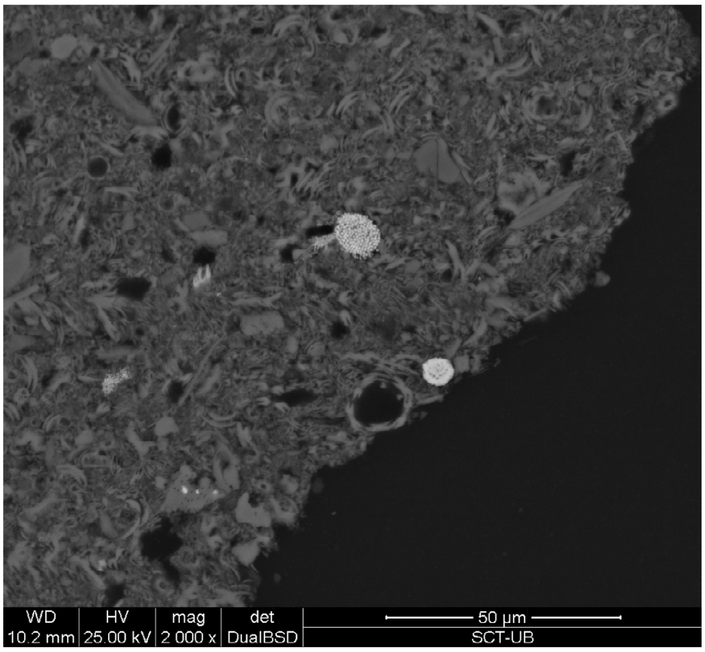

Fig. 1. First fossil remains after the PTB, probably *Earlandia*, found together with the pyrite framboids just above the chemostratigraphic Permian–Triassic Boundary

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UNEXPECTED OSTRACOD (CRUSTACEA) SURVIVAL IN THE AFTERMATH OF THE END-PERMIAN EXTINCTION: THE EARLY GRIESBACHIAN RECORDS

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Ostracods (Crustacea) were deeply affected by the end-Permian extinction (EPE), with specific extinction rate ranging from 74 to 100% according to localities (Crasquin & Forel, submitted). Their recovery is assumed to be complete during the Rhaetian when they are well known in the Tethyan domain. However, rare faunas are described from Early Triassic so that survival and refuge zones at the origin of this upper Triassic diversity stay unclear.

Intensive analysis of lower Triassic deposits allows us to describe two unexpected survival phases for ostracods:

In the earliest Griesbachian of Palaeo-Tethys (Hungary and South China), Neo-Tethys (Turkey) and Panthalassa (South China) (Forel, in press; Forel *et al.*, submitted). Biotic characteristics of abundant ostracod faunas associated with microbialites reveal that microbial mats would have been refuges by providing an unlimited food supply and O_2 to the supposedly anoxic environment following the EPE. They are dominated by typical Palaeozoic forms and disappear together with microbialites during the Griesbachian traducing brief survival phenomenon.

In the late early Griesbachian of the Meishan section (South China), low species richness/high abundance assemblages are described (Forel & Crasquin, 2011; Forel, in progress). This interval is the unique occurrence of ostracods not associated with microbialites after the EPE. Informations on environmental requirements of the encountered forms are few but their thriving is interpreted as environmentally driven. These faunas are also dominated by Palaeozoic representatives exemplifying a new survival interval.

BIOTIC RECOVERY FROM THE END-PERMIAN MASS EXTINCTION: CASE STUDIES FROM LOW PALEOLATITUDES

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The end of the Permian period is demarcated by the largest Phanerozoic mass extinction, and some evidence suggests that at least 5 million years elapsed before life on Earth returned to pre-extinction complexity in the Middle Triassic (e.g., Lehrmann et al., 2006). It is generally accepted that the Early Triassic is an interval characterized by low biodiversity and ecological complexity, but emerging research suggests that marine ecosystem recovery was not uniform around the globe following the extinction. Paleolatitude (e.g., Wignall et al., 1996), length of time after the mass extinction (Twitchett and Barras, 2004), and shoreface architecture (Beatty et al., 2008) are proposed to have had roles in shaping the biotic recovery after the end-Permian mass extinction. Despite recent developments, the nature and timing of full biotic recovery is not completely understood. Lack of such knowledge of ecosystem restoration is an important problem because it hampers our ability to more completely understand the inter-relatedness between environmental conditions and evolutionary processes.

To test the hypothesis that biotic recovery following the mass extinction was spatially and temporally varied, we conducted field studies on Lower and Middle Triassic strata exposed in Nevada and Utah, USA and Ghuizhou Province, SW China that were deposited in eastern Panthalassa and eastern Paleotethys, respectively. Preliminary results indicate: 1) biotic recovery in low latitudes in eastern Panthalassa was protracted in deep marine environments; and 2) that while Middle Triassic benthic marine communities in eastern Paleotethys were characterized by high diversity, tiering, evenness, and organism size were not comparable to those of pre-extinction (Permian) communities. These case studies demonstrate that full biotic recovery may have taken longer than previously recognized in certain regions and environments.

COMPARATIVE ANALYSIS OF PERMIAN–TRIASSIC AND TRIASSIC–JURASSIC BOUNDARY SECTIONS IN HUNGARY

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The stratigraphic record in Hungary includes sections that record mass extinction events, which have been in the focus of recent studies, in conjunction with international research projects. Both the Permian-Triassic (P-T) and the Triassic-Jurassic (T-J) boundary are well represented in Hungary and have been subjected to multidisciplinary investigation, largely by the same research team, using the same approach and methodology. Thus the major extinction events at the beginning and the end of the Triassic period are directly comparable using the Hungarian stratigraphic sections, in order to reconstruct the changes and sequence of events, discuss similarities and differences between the end-Permian and end-Triassic events, and attempt to infer their causes.

The studied marine strata were deposited at the Tethyan margin, on shallow to moderately deep parts of a ramp at the Permian-Triassic transition (Bálvány section, Bükk Mts.), and in a partly restricted basin which became gradually more open at the Triassic-Jurassic transition (Csővár section, Transdanubian Range Unit). It is crucial to distinguish between local effects, Tethys-wide and global phenomena controlling the observed sedimentary and paleobiological patterns. Therefore the Hungarian sections need to be further compared with other well-studied boundary sections worldwide.

Marine P-T boundary sections are known in the Bükk Mountains in northern Hungary. The outer ramp–shallow basin facies of the Bükk Mountains represents the deeper offshore zone of the Tethys shelf. Based on our detailed studies, especially in the Bálvány North section, the series of changes in the P–T boundary interval can be summarised as follows:

- onset of $\delta^{13}C$ negative shift in the latest Permian (*praeparvus* Zone);
- significant reduction of amount of skeletal detritus;
- significant decrease in the carbonate content, appearance of amphibolite rock fragments, large amount of pyrite;
- last occurrence of the Permian bivalves and brachiopods, significant reduction of amount of skeletal detritus, negative $\delta^{13}C$ peak;
- appearance of microbial carbonates, stabilisation of $\delta^{13}C$ values at about -1‰ in the earliest Triassic (*parvus* Zone).

A continuous marine T-J section is exposed near Csővár, at the northeasternmost end of the Transdanubian Range Unit. Slope, toe-of-slope and basinal facies of an intraplatform basin, related to the extensive late Triassic Dachstein carbonate platform, exhibit the following changes in the T-J boundary interval:

- stepwise disappearance of conodont species and last occurrence of Triassic choristoceratid ammonoids;
- major reduction in the amount of bioclasts and skeletal detritus;
- last occurrence of Triassic foraminifera;

-major negative $\delta^{13}C$ excursion;
-reappearance of resedimented biodetritus.

Locally, both the P-T and T-J transitions share gross similarities of the prominent negative carbon isotope anomaly and the stepwise biotic decline, observed in the micro- and macrofossil record and the biogenic sedimentary components. Leading hypotheses for both the P-T and T-J extinction and environmental change invoke a cascade of events triggered by volcanism of large igneous provinces (LIPs), i.e. the Siberian Trap and the Central Atlantic Magmatic Province. Similarities thus largely reflect the common driving force, LIP volcanism. Differences are partly explained by the local sedimentary environment, e.g. the deeper setting of the Csővár basin, and partly related to the greater magnitude of the P-T event. An obvious difference is the presence of microbial carbonates and the significantly longer recovery after the P-T event.

NO RULES OR JUST MANY EXCEPTIONS? SPATIAL AND TEMPORAL TRENDS IN BENTHIC RECOVERY FROM LOW-LATITUDE SETTINGS

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Recent advances in the understanding of Early Triassic ecosystems suggest that the recovery from the end-Permian mass extinction was much more variable than traditionally suggested. By comparing low-latitude settings of the western Tethys (Werfen Formation of northern Italy) and eastern Panthalassa (Dinwoody Formation and Thaynes Group of the Western US) using quantitative palaeoecology, we aim to reconstruct ecosystem evolution in different palaeo/ geographical areas and to identify differences and general patterns in the recovery from the greatest mass extinction in Earth's history.

In the Werfen Formation, the immediate aftermath of the extinction records relatively diverse and balanced communities. In the course of the Griesbachian, simple, high-dominance communities predominate although some samples may show comparatively high diversities and low dominance values towards the upper Griesbachian. This trend culminates in the presence of moderately diverse and balanced faunas around the Griesbachian-Dienerian boundary interval and is mirrored in the ichnofaunas as well. In the course of the Dienerian, dominance, alpha diversity and community composition strongly fluctuates. In the lowermost Smithian interval, shelly fossils are virtually absent apart from some low-diverse shell pavements. Bioturbation is again significantly reduced. The remaining part of the Smithian is dominated by very low-diverse communities that strongly fluctuate in dominance values. The basal Spathian shows a remarkable increase in new species and the establishment of more balanced communities. Bioturbation becomes again abundant and the return of some "high recovery" ichnotaxa is observed. Alpha diversities rebound to the highest values recorded in the Werfen Formation.

In the Griesbachian and Dienerian rocks of the Dinwoody Formation of the western U.S., faunas locally exhibit relatively high alpha diversities and low dominance values. However, most samples of this time interval record rather highly-dominant, low-diverse communities. During the Smithian (Thaynes Group and the Sinbad Formation), more balanced and slightly more diverse communities became established in outer and inner shelf settings with local occurrences of small, reef-like structures. The near shore habitats of the lower Spathian Virgin Formation record the most diverse and most balanced communities of the western U.S. of the Early Triassic.

It becomes apparent that the recovery patterns differed significantly between the two low-latitude settings. The western Tethys shows several pronounced ups and downs. A relaxation phase is observed at the base of the Griesbachian, which is related to the temporary presence of short-term survivors. A next strong recovery signal is observed around the Griesbachian/ Dienerian-boundary. The communities of the same interval from Eastern Panthalassa indicate more stressed conditions except for some near-shore settings. In the western Tethys, a dramatic drop in benthic ecosystem complexity is recorded at the base of the Smithian. The subsequent "low" is likely related to high siliciclastic input, which was possibly accompanied by fluctuations in salinity. Smithian sections from Eastern Panthalassa do not show strong evidence for pronounced environmental stress and the ecological conditions improved with respect to the bulk Griesbachian and Dienerian record. The Spathian of the western Tethys marks a next notable restoration signal, which was, however, not fundamentally different to the first Griesbachian pulse in terms of alpha diversity and dominance of taxa. In eastern Panthalassa, this recovery signal is much more pronounced and the ecological and taxonomical recovery exceeds everything observed in earlier in the Triassic. In both palaeogeographic regions, the Early Spathian marks the establishment of many new taxa that add to the inherited diversity from the Smithian interval. With only little loss on the species and virtually no loss on the genus level, the Smithian-Spathian boundary was no caesura for benthic ecosystems.

In summary, restoration signals varied in their magnitude and stratigraphic position between both regions. To extract a general recovery pattern, additional data from other regions are necessary in order to factor out the local facies controls over the ecological structures of the benthic assemblages. It is furthermore noted that the well documented end-Smithian crisis of nektonic clades are not found in benthic ecosystems. By carefully integrating the variations in the recovery pattern among different clades and different regions, improved models on for environmental disturbances during the Early Triassic will be ultimately achieved.

LUKAČ SECTION – A KEY FOR A DEFINITION OF THE PERMIAN-TRIASSIC BOUNDARY IN THE DINARIDES

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The Lukač section situated in NW Slovenia is a part of the External Dinarides geotectonic unit. The Upper Permian and Lower Triassic strata of the External Dinarides in Slovenia were formed on an extensive Slovenian Carbonate Platform which became established during the Late Permian, and it remained stable until Middle Triassic time when it was split to the Julian Carbonate Platform in the north, and the Dinaric Carbonate Platform in the south.

The Permian-Triassic interval of the Lukač section in western Slovenia was studied sedimentologically and micropaleontologically by using conodonts and foraminifers (Kolar-Jurkovšek et al., 2011a,b). The analyzed section is composed of the Bellerophon Formation (Bellerophon Limestone and Evaporite-dolomite Members) and the Lukač Formation (Transitional Beds, Streaky Limestone Member and Carbonate-clastic Member).

The overall sedimentary characteristics reflect shallow marine conditions that began with the Permian Bellerophon Member where micritic microfacies prevail. A deposition of micrites/biomicrites in a lagoonal, possibly back reef conditions, continuously change to hypersaline very shallow, possibly supratidal conditions depicted as Evaporite-dolomite Member. The conformable boundary with the Transitional Beds suggests maintaining of a shallow marine condition during the depositon of the Transitional Beds. Deposition of laminated mudstone and laminated micrites/biomicrites (with abundant ostracod detritus) suggests a restricted marine conditions, but the presence of grainstone implies periodically established higher energy condition and deposition of oolitic detritus by oscillatory and/or tidal currents. Streaky limestone beds were deposited in strictly subtidal conditions by oscillatory and/or storm currents in a shallow sea. Predominantly subtidal deposition implies deepening of the environment associated with increased terrigenous influx at the beginning of the Early Triassic. Sedimentary rocks of the Carbonate-clastic Member are also characterised by shallow marine deposition of ooid or bioclastic detritus by oscillatory currents. A prevailing deposition of carbonate was periodically punctuated by terrigenous input of silty siliciclastic material. A deposition of the Lukač Formation implies a general deepening of the environment associated with the increased terrigenous influx during Early Triassic time.

The importance of the Lukač section for the definition of the Permian-Triassic Boundary in Slovenia is the recovery of conodonts in the boundary interval beds. Conodont faunas are characterized by shallow water elements with prevailing *Hindeodus* and *Isarcicella* that are in the higher part of the section accompanied by representatives of *Hadrodontina* and ellisonids. The absence of gondolellids is obvious. The following conodont biozones have been recognized: the latest Changhsingian (uppermost Permian) *praeparvus* Zone, and the Griesbachian (lowermost Triassic) *parvus, lobata, staeschei-isarcica, postparvus* and *anceps* Zones. The first appearance of *Hindeodus parvus* in the sample L1 in the Transitional beds marks the systemic boundary.

A foraminiferal study resulted description of four new species: *Multidiscus zhiriensis*, *M. dinaridicus,* and *Globivalvulina lukachiensis* from the Upper Permian and *Lingulonodosaria slovenica* from the lowermost Triassic.

The Late Permian assemblage is represented by 43 species of 22 genera, including 2 genera of fusulinaceans: *Reichelina* and *Nankinella* that consists of species characteristic for the Changhsingian of many regions in the Tethys (Nestell et al., 2011).

Younger foraminifers also co-occur with conodonts and were recovered from the Transitional beds deposited in shallow restricted marine conditions. The assemblage of Early Triassic foraminifers is very poor and it is represented by seven species of four genera. Among them is important the recognition of the species "*Cornuspira*" *mahajeri* and "*Earlandia*" spp., marking the lower boundary of the Triassic worldwide based on foraminifers. These species are found below the first appearance of the conodont species *Hindeodus parvus* which officially marks the lower boundary of the Triassic, and they are considered to be ecological species and their appearance coincides with a stressful shallow water environment. The first interval with nodosariid foraminifers appear 2m above the Permian-Triassic boundary and second one is approximately 5m above the boundary.

The conodont biozonation of the Lukač section is the first introduced for the PTB interval in Slovenia as well as in the entire Dinaride region and thus it represents a key section for definition of the PTB in the Dinarides. The recovered conodont faunas can be well correlated with the Global Stratotype Section and Point (GSSP) at the Meishan section and the Southern Alps, as well as with other coeval sections of the adjacent areas in neighbouring areas of Austria, Hungary and Croatia.

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MORPHOLOGICAL EVOLUTION AND EXTINCTION PATTERNS OF THE AMMONOIDEA AT THE PERMIAN-TRIASSIC BOUNDARY OF IRAN

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The classical Permian-Triassic (P-Tr) boundary sections in the vicinity of Julfa (NW Iran) have high potential for the study of the end-Paleozoic extinction event. The lithostratigraphic record of the P-Tr boundary beds in the Julfa area is rather uniform over a distance of 35 km. It comprises the *Paratirolites* Limestone (four meters of red nodular limestone), Boundary Clay (60-190 cm), and Elikah Formation (400 m gray platy limestones). Sections in the Aras Valley and at Kuh-e-Ali Bashi display very similar successions of latest Permian ammonoids. Sections in the vicinity of Abadeh in Central Iran show a similar succession and faunal composition.

Excellent correlation of the sections can be achieved and enables the detailed documentation of the demise of the Paleozoic faunas. The *Paratirolites* Limestone, the youngest Permian carbonate formation that represents about the upper half (appr. 1.2 Ma) of the Changxingian stage, can be subdivided in terms of ammonoid biostratigraphy, complementing lithostratigraphic, carbonate microfacies, stable isotopes, and conodont data.

The unit can be subdivided into at least four clearly separable ammonoid zones, allowing discrimination into ~300,000 year intervals. The study region can therefore serve as a standard for the Tethyan development of the P-Tr boundary. A stepwise temporal development of the Late Permian ammonoid faunas is observed. In contrast to earlier studies, the *Paratirolites* Limestone is not uniform in its ammonoid faunas but shows some distinct patterns:

(1) The abundance of ammonoids decreases towards the top of the *Paratirolites* Limestone; only the top part of this rock unit shows sometimes a mass occurrence of small ammonoids.

(2) A morphological development from simpler suture lines (with unserrated prongs of the external lobe) at the base of the *Paratirolites* Limestone towards more complex sutures with stronger frilled external lobes in the middle portion of the rock unit, and finally a rebound towards simpler suture lines (succession of the genera *Dzhulfites*, *Paratirolites*, and *Abichites*).

(3) A general simplification of the conch geometry from trapezoidal to compressed whorl cross sections.

(4) A smoothing of the shell ornament (loss of coarse sculpture such as ventrolateral nodes with a development to faint ribs).

(5) A conspicuous size decrease of the ammonoid conchs (from up to 200 mm diameter to 30 mm). This size reduction can be seen in the paratirolitid lineage (genera *Paratirolites* and *Abichites*) but also in the immigration of small-sized ammonoids such as *Neoaganides*.

The top of the *Paratirolites* limestone shows the extinction horizon with numerous small ammonoids with simplified suture lines. These data indicate that the evolution of the ammonoids has severely been affected already within the Changxingian. The data demonstrate the complex morphological evolution of the latest Permian ammonoids prior to the mass extinction event.

CARBON AND OXYGEN ISOTOPE CHANGES ACROSS THE PERMIAN-TRIASSIC BOUNDARY AND DURING THE EARLY TRIASSIC

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The Palaeozoic-Mesozoic transition, one of the most remarkable turning points in Earth's history that included a severe biotic crisis, was accompanied by major perturbations in the global carbon cycle and climate fluctuations. Changes in the carbon cycle have been inferred from strong temporal oscillations of the carbon isotopes, pronounced in marine carbonates as well as in marine organic matter and land plants. Both, distinct negative and positive excursions occur for the Permian-Triassic boundary and for the Early Triassic, indicating large scale carbon dioxide injection and drawdown, and that environmental and biotic changes lasted over a prolonged period of some million years. Reliable oxygen isotope data from phosphate fossils exist for some P-T boundary successions, suggesting a general warming trend from the latest Permian to the earliest Triassic, but for the period between the low-latitude marine extinction event and some 10,000 years afterwards, as well as for most of the Early Triassic the dataset is still sparse.

EARLY TRIASSIC DISASTER BIVALVES: EXPLORING THEIR RISE TO ECOLOGICAL DOMINANCE IN THE AFTERMATH OF THE END-PERMIAN MASS EXTINCTION

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As a consequence of the end-Permian mass extinction, many marine invertebrate groups suffered decreased diversity and abundance, except for a few genera that instead thrived during the Early Triassic recovery period. Four bivalve genera that have been historically labeled as "disaster bivalves" (*Claraia, Eumorphotis, Promyalina,* and *Unionites*) have been qualitatively observed to dominate marine benthic communities to a degree not seen before or after the extinction (Hallam and Wignall, 1997). Presented here is preliminary work on Western US Early Triassic assemblages quantifying disaster bivalve dominance that reveals previously unknown complexities in degree and timing. We expect to find a greater dominance of the disaster bivalves in earlier assemblages and a decrease of their importance in communities further into the recovery period of the Early Triassic, mirroring the progressive recovery of marine communities and the exclusion of opportunistic taxa. Early Triassic collections including abundance counts of bivalves, brachiopods, and gastropods were downloaded from the PBDB (paleodb.org). PBDB collections used for this study met two requirements: 1) all brachiopod, bivalve and gastropod abundances were reported accurately, estimates were not accepted, and 2) more than one genus was reported. Mean rank (the average rank based on relative abundance of each genus in all collections of a certain time bin), breadth of distribution, (the percent of total collections in which that genus occurs), and overall assemblage evenness (based on Simpson's Dominance Index) were calculated for the four genera using the methods of Clapham et al. (2006). Preliminary analyses reveal differences in the timing and degree of dominance between the four genera in Western U.S. collections. Griesbachian assemblages show more overall occurrences and dominance by the four disaster bivalves, while later assemblages show greater diversity, evenness, and dominance of other taxa in addition to the disaster bivalves. *Claraia* is most widespread and abundant in the beginning of the Triassic, but largely disappears in Smithian and Spathian assemblages (Figure 1). *Unionites* decreases in mean rank and breadth of distribution over time. *Promyalina* increases in both mean rank and breadth of distribution, and along with *Eumorphotis*, becomes the most dominant and widespread disaster bivalve in the Spathian. Compared to assemblages in the beginning of the Early Triassic, later assemblages show only a slight decrease in overall dominance index (greater community evenness), but show more diversity of dominant genera in individual communities. For example, *Neoschizodus, Leptochondria, Protogusarella,* or *Piarorhynchella* are commonly observed as the dominant genus in addition to *Promyalina* or *Eumorphotis* in many Spathian assemblages. Though communities in the later Early Triassic lack evenness levels characteristic of pre-extinction communities, the greater diversity of dominant genera in these assemblages suggests increasing competition or changing environments may have excluded *Claraia* and *Unionites* from these communities. The phenomenon of the four "disaster bivalves" as the only dominant genera is largely restricted to the beginning of the Early Triassic, but opportunistic taxa remain an important part of these communities throughout the Early Triassic. Determining the ecological significance of these results requires more detailed analysis, but reveals a previously unknown complexity to the nature of disaster bivalve dominance. Future work with European assemblages will allow a global comparison between the Panthalassa and Tethys Oceans of the Early Triassic.

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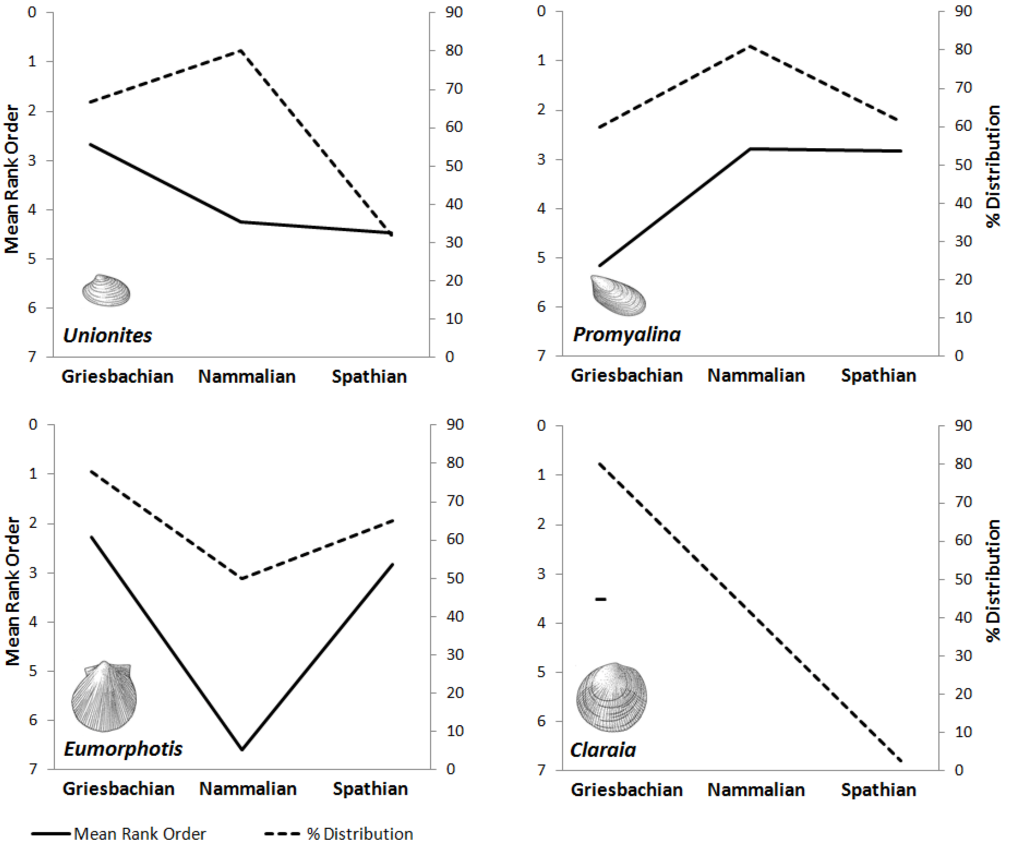

Fig. 1 Mean rank order and breadth of distribution of the four disaster bivalve genera from Western USA PBDB entries. Images modified from Hallam and Wignall (1997).

A GLOBAL COMPARISON OF DEPOSITIONAL ENVIRONMENTS IMPACTING THE TIMING OF RECOVERY FROM THE END-PERMIAN MASS EXTINCTION

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The end-Permian mass extinction 250 million years ago devastated life on Earth with the loss of 95% of the species on the planet (Erwin 2006). The recovery that followed took up to five million years, the duration of the Early Triassic. Various authors have determined different patterns of benthic macrofaunal recovery for localities across the globe. It remains to be seen whether global environment dictated recovery from the extinction event or whether more localized mechanisms or some combination of both were driving the taxonomic and ecological patterns we observe in the fossil record. Current research on the Early Triassic fossil record covers the Tethys, Panthalassic, and Boreal Oceans and spans a range of shoreface geometries and depositional environments. We predict that differences between Early Triassic ocean basins, although important, were not the primary driver of disparate recovery rates. Instead, we hypothesize that depositional environment was most significant in structuring the re-diversification of the benthic macrofauna. The Early Triassic is known for wide-spread ocean anoxia in the form of deep water anoxia or as mid-depth oxygen minimum zones. The shoreface geometry of different localities may have controlled the spread and strength of anoxic upwelling events either exposing the recovering benthic fauna to deleterious conditions or protecting them. Carbonate platforms near the ocean surface may have experienced the least amount of harmful anoxia and therefore experienced more rapid recovery. Broad epicontinental seas would also provide a refuge from anoxia looming farther offshore. Shelves and ramps in closer proximity to deep offshore anoxia could have been more exposed resulting in delayed benthic recovery. A habitable zone may have developed on high energy shelves and ramps resulting in increased oxygenation by wave aeration of the water column producing a buffered environment for benthic recovery (Beatty et al. 2008).

Using data from the literature four major depositional environments from the three major Early Triassic ocean basins were compared (Figure 1). The four depositional systems considered are; carbonate platforms, carbonate ramps, and siliciclastic or mixed shelf systems and epicontinental seas. Panthalassic localities include the Southwestern United States and British Columbia. Spitsbergen is used to represent the Boreal Ocean. Tethyan localities include Lower Triassic deposits from Italy, Hungary, Pakistan, Oman, and South China (Figure 1). Well documented stratigraphy for each site allowed for precise interpretation of energy level variations for the depositional environments represented in each section. The benthic fauna has been moderately well studied allowing for basic comparisons between each locality of diversity and abundance as well as stage by stage timing and patterns of benthic recovery.

Preliminary results show similarities and differences in recovery timing and benthic diversity for various depositional environments. The carbonate ramp and epicontinental environments of the Southwestern United States (Panthalassa) and the shelf environments of the Italian Dolomites (Tethys) both show a slow increase in diversity through the four stages of the Early Triassic. The benthic fauna for these geographically distant localities is composed of high dominance paleocommunities with 5 to 12 genera representing disaster bivalve fauna and microgastropods (Schubert and Bottjer 1995, Frasier et al. 2005, Posenato 2009). In the platform carbonates of Oman and South China the extinction and recovery progress very differently. In Oman, the Griesbachian, contains a high diversity fauna of 17 genera comprising a range of gastropods, bivalves, echinoderms, and brachiopods (Twitchett et al. 2004). In South China the Griesbachian fauna of the Great Bank of Guizhou is composed of molluscs and some remnant Permian brachiopods (Payne et al. 2006). Based on these initial results the two Tethyan localities, Italy and China, show disparate recovery patterns. Early Triassic carbonate platforms contained a highly diverse and even fauna compared to the high dominance, low diversity fauna of the shoreface and epicontinental sea deposits.

This study highlights the importance of depositional environment in the recovery from the end-Permian mass extinction. Continued research will lead to a better understanding of the role that depositional environment played in local recovery patterns, such as the difference between carbonate platforms and shelf environments. Detailed study suggests that global improvement of ocean chemistry and circulation were not the only contributors to recovery.

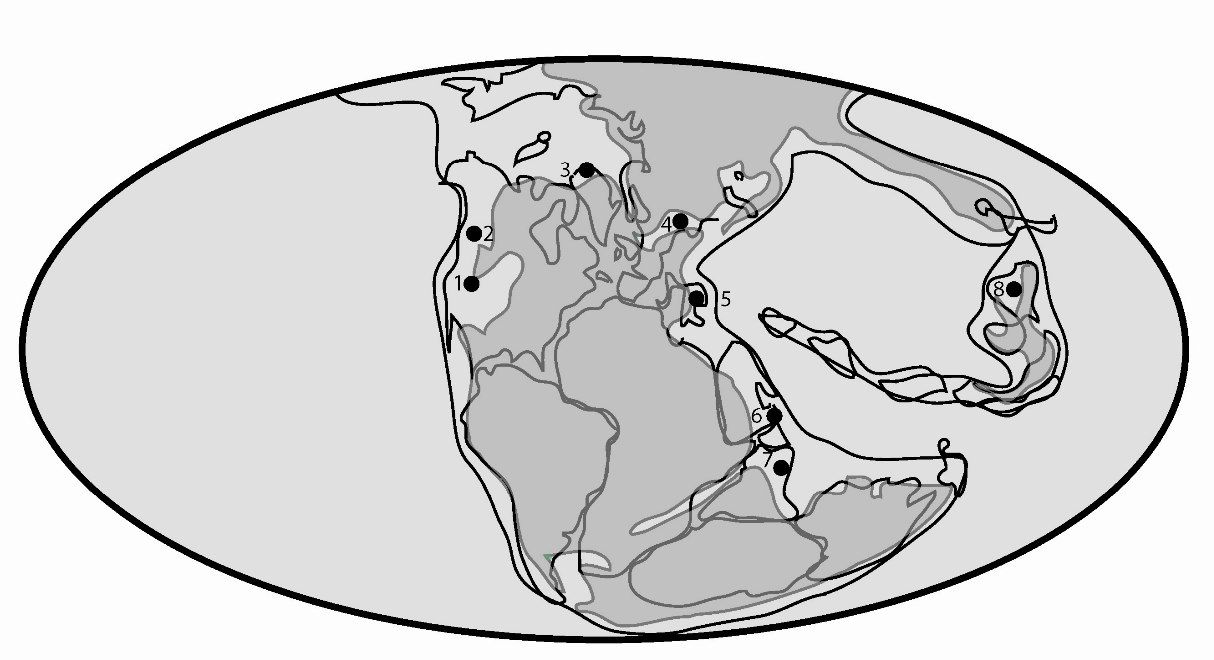

Fig. 1: Eight localities from three Early Triassic ocean basins that will be the focus of this study. Panthalassa; Southwestern United States (1), British Columbia (2). Boreal; Spitsbergen (3). Tethys; Hungary (4), Italy (5), Oman (6), Pakistan (7) and South China (8). Modified from Scotese 2011.

RELATED CHANGES IN WATER REDOX CONDITIONS AND PELAGIC FAUNAL RECOVERY DURING THE EARLY TRIASSIC IN THE INDIAN HIMALAYA

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The Mud section in Spiti valley, Western Himalaya, India is a candidate section for the GSSP of the Induan-Olenekian Boundary (IOB). The section contains abundant fossils allowing a very precise biostratigraphy and displays no signs of sedimentary breaks. Analysis of pelagic faunas proves a significant, two-step radiation phase in ammonoids and conodonts close to the Induan-Olenekian boundary. These diversifications are coupled with short-termed, prominent, positive $\delta^{13}C_{carb}$, $\delta\ ^{13}C_{org}$ and $\delta\ ^{15}N_{org}$ excursions and a shift from an-/dysoxic to fully oxic sea-floor conditions as shown by geochemical (major, minor and trace elements, $\delta\ ^{15}N_{org}$) and sedimentological evidence. Below Prior to the first step, significantly heavier $\delta\ ^{13}C_{carb}$ values in shallow tempestite beds relative to lighter values for authigenic deepwater carbonate is interpreted as a sign of a well-stratified water column. This effect disappears with the onset of better oxygenated conditions at the time of the ammonoid-conodont radiation. The second step coincided with the change from terrigenous to almost pure carbonate sedimentation and is causally linked to the start of the Smithian carbonate factory leading to the widespread onset and progradation of carbonate ramps along the tropical shelves of the Tethys and Panthalassa oceans. This new set of data demonstrates the rapidity of radiation of the pelagic fauna in the aftermath of the Permian-Triassic extinction as soon as environmental conditions were favourable again.

EXTREME EUXINIA AT THE END OF THE EARLY TRIASSIC

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The greatest mass extinction occurred 252 million years ago at the end of the Permian. Complete biotic recovery took an extraordinarily long time (about 5 million years). This is probably because harsh conditions for life (e.g., an euxinic ocean) developed repeatedly during the Early Triassic. Here, we show that the most severe euxinic conditions occurred at the latest Early Triassic, just prior to biotic recovery from the end-Permian mass extinction. The euxinia may have been caused by the anaerobic oxidation of methane (AOM) triggered by the melting of methane hydrates. Okenane, a biomarker for photic zone euxinia at ~25 m water depth[8], and crocetane, a biomarker for anaerobic methanotrophic Euryarchaeota (ANME) and green sulfur bacteria (GSB), were detected from the latest Early Triassic samples in South China. The latest early Triassic euxinia is a global event comparable to the euxinic oceanic state of 1.6 billion years ago rather than that at the latest Permian. Our data suggest that melting of methane hydrates is not only a driver of global warming but could also facilitate oceanic euxinia.

NEW RECORDS OF EARLY TRIASSIC CONCHOSTRACANS IN THE LOWER BUNTSANDSTEIN OF CENTRAL GERMANY

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The Early Triassic terrestrial Bernburg Formation (Lower Buntsandstein, central Germany) of the Germanic Basin mainly consists of siliciclastics with intercalated oolitic limestone and dolomite deposited within a playa-lake environment. The oolitic horizons are used for lithostratigraphic subdivision of the Bernburg Formation in central parts of the Germanic Basin (Schulze, 1969). The Lower Buntsandstein strata yield a fauna of crustaceans (conchostracans, triopsids, limulids; e.g. Kozur & Weems, 2010; Voight et al., 2008; Hauschke & Wilde, 2000) and fish remains (e.g. Scholze, 2011). Since conchostracans represent most frequent faunal elements in the Lower Buntsandstein, they are most suitable for biostratigraphy.

In the present study three sections of Lower Buntsandstein of central Germany were investigated on sedimentary facies and fossil content. The first section is exposed in an abandoned quarry at Beesenlaublingen (2.5 km NW of Könnern, Saxony-Anhalt), showing 64 m interbeddings of fine-grained siliciclastics with oolitic and dolomitic horizons deposited in central position within the Buntsandstein basin, and interpreted as playa-lake facies (Scholze, 2011). The conchostracan fauna consists of *Cornia germari* (Beyrich, 1857), *Liograpta (Magniestheria)? malangensis* (Marlière, 1950), *Estheriella bachmanni* Kozur & Hauschke, 2008, and *Estheriella costata marginostriata* Kozur, 1980. The second section was mapped in a temporary outcrop during A 38 highway construction in 2010/11, 3 km SE of Sangerhausen (Saxony-Anhalt). The 9 m of section is characterized by fine- to coarse-grained siliciclastics with internal cross bedding, load casts, desiccation cracks, and syneresis cracks as well as with an intercalation of a single 60 cm thick dolomite horizon (Scholze, 2011). The succession is interpreted as transitional of fluvial to playa facies. The conchostracan fauna is represented by *Cornia germari*, *Estheriella nodosocostata* (Giebel, 1857), and *Estheriella costata* Weiss, 1875. The third section, located 1 km SE of Bücheloh (Thuringia), was temporary exposed in road cuts up to 17 m thick in 2011/12. There, coarse grained siliciclastics with flaser- to ripple bedding of fluvial shallow channel deposits of a braided plain are regarded as marginal deposits of the southern Buntsandstein basin. On distinct layers *Estheriella bachmanni*, *Cornia germari*, *Estheriella nodosocostata*, and *Euestheria gutta* (Ljutkevitč, 1937) were identified.

Conchostracan biozones of Kozur & Weems (2010) indicate an Early Triassic (Induan) age of all three investigated sections. In the Beesenlaublingen section the first occurrence of *Estheriella costata marginostriata* is located between oolite horizons Eta and Theta (Bernburg Formation), indicating a slightly deeper position of the *Estheriella marginostriata* zone Kozur & Weems, 2010. The temporary outcrops at Bücheloh and Sangerhausen containing *Estheriella nodosocostata* belong to intervals of middle Bernburg Formation, due to calibrations with the *Estheriella nodosocostata* zone Kozur & Weems, 2010. *Estheriella bachmanni* is recorded for the first time from southern Thuringia.

Despite the described differences between fluvial, fluviolacustrine and playa-lake facies all three sections are characterized by a *Cornia-Estheriella* assemblage. Occurrences of this assemblage are not confined to distinct sedimentary environments. This strongly supports the practicability of the conchostracan biostratigraphy in Triassic continental clastics.

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STABLE CARBON AND NITROGEN ISOTOPES OF PERMIAN-TRIASSIC BOUNDARY SECTIONS IN THE REGIONS OF JULFA (NW IRAN) AND ABADEH (CENTRAL IRAN)

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The Permian-Triassic (P-Tr) boundary sections in the regions of Julfa (NW Iran) and Abadeh (Central Iran) have high potential for the study of the most dramatic extinction event in Earth's history. As part of a multidisciplinary project, we have conducted high-resolution carbon isotope analysis of bulk carbonate rocks ($\delta^{13}C_{carb}$), coupled with preliminary carbon isotope analysis of bulk organic matter ($\delta^{13}C_{org}$), and nitrogen isotope study of bulk sediment ($\delta^{15}N_{bulk}$), for three fossil-rich, pelagic P-Tr boundary sections in NW Iran (Ali Bashi, Aras Valley, and Zal) and one in the Baghuk Mountain area in Central Iran.

The Permian-Triassic boundary sections in Iran display three characteristic rock units: (1) the *Paratirolites* Limestone (4 m thick) with the mass extinction horizon (P-Tr extinction event) at the top surface, (2) the Boundary Clay (0.5–2 m thick), and (3) the Elikah or Shahreza formations with the conodont P-Tr boundary near the base. The well-known negative $\delta^{13}C_{carb}$ excursion begins in the middle of the *Paratirolites* Limestone and culminates at the base of the Elikah and Shahreza formations; it is interrupted by a weak positive $\delta^{13}C_{carb}$ excursion within the Boundary Clay. The bulk $\delta^{13}C_{org}$ values and time-equivalent bulk $\delta^{13}C_{carb}$ values show different trends. The $\delta^{13}C_{org}$ curve reveals highly oscillating values throughout the entire section. A negative $\delta^{15}N_{bulk}$ trend begins in the topmost part of the *Paratirolites* Limestone and culminates at the base of the Boundary Clay.

The $\delta^{13}C_{carb}$, $\delta^{13}C_{org}$, and $\delta^{15}N_{bulk}$ isotope data, together with TOC and TN concentrations as well as C_{org}/N_{tot} ratios, provide evidence for significant environmental changes around the P-Tr boundary. The beginning of the negative $\delta^{13}C_{carb}$ excursion correlates well with the largely explosive Siberian Trap volcanism, and the $\delta^{13}C_{carb}$ peak at the top of the *Paratirolites* Limestone corresponds to the strong explosive felsic volcanism in southern China. The oscillation of the $\delta^{13}C_{org}$ curve is attributed to a varying prominence of the input of marine and terrestrial organic matter, and/or the preservation mode of the organic matter. C_{org}/N_{tot} values and the $\delta^{15}N_{bulk}$ signatures of the entire *Paratirolites* Limestone and of the base of the Elikah Formation reflect normal marine conditions controlled by biotic factors. In contrast, a dominance of abiotic factors appears to be recorded within the Boundary Clay, where the low TOC and C_{org}/N_{tot} ratios, the negative $\delta^{15}N$ excursion, and the enhanced concentration of total nitrogen are observed. The low $\delta^{15}N$ values within the Boundary Clay reflect the terrestrial origin of nitrogen and speak for an introduction of atmospheric nitrogen into the marine nitrogen cycle. We conclude that low C_{org}/N_{tot} ratios within the Boundary Clay reflect the low organic matter accumulation ratios, coupled with a high content of inorganic nitrogen fixed within clay minerals. The enhanced TOC concentration and high C_{org}/N_{tot} ratios in the aftermath of the P-Tr mass extinction in the Elikah

Formation may reflect a time of high primary organic productivity with elevated proportions of land-derived organic matter.

The stable isotopes show that the environmental changes started in the Late Permian *Paratirolites* Limestone, below the actual P-Tr extinction event, and before the conodont P-Tr boundary.

ILLYRIAN PLATFORM MARGIN REEF FROM THE WESTERN TETHYS (AGGTELEK, NE HUNGARY)

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The end-Permian extinction event caused a worldwide disappearance of metazoan reefs. Their recovery started only after a considerable gap. The oldest Triassic platform margin reef (Illyrian–Ladinian) of the Western Neotethys can be found in the Aggtelek platform (Silica Nappe, Western Carpathians, NE Hungary).

The sediments of the Gutenstein ramp are overlain by the open lagoonal, thick-bedded, laminitic, dasycladalean and oncoidal Steinalm Limestone. Its Pelsonian age was determined by *Poncetella hexaster*, *Anisoporella anisica*, *Meandrospira dinarica* and *Glomospirella semiplana.*

In the late Pelsonian, the uniform Steinalm Platform was drowned and dissected due to the Reifling event, represented by the base of the ammonite layer. Its base was dated as Binodosus Subzone on basis of conodonts. A connection with the open sea was established, indicated by the appearance of gladigondolellid conodonts from the early Illyrian. The Reifling event had a striking effect on the conodont evolution as well. Immediately after the drowning of the Steinalm Platform, the typical Pelsonian conodont species (*Gondolella bulgarica, G. hanbulogi* and *G. bifurcata*) still appear, but a few metres above two out of the three species died out (*G. bulgarica* and *G. hanbulogi)* and new species appear (*Gondolella liebermani, G. szaboi, G. excelsa*).

Due to the Reifling event, basins and highs were formed. In the NW part of the studied area, the lower - middle? Illyrian, 40-80 m thick basinal carbonates (Jenei Formation) were followed by a platform margin reef (reef stage 1). It is 700 m thick and can be followed over a distance of 3.5 km on the edge of the platform next to the basin.

Thanks to the outcrop conditions, the birth of the reef can be studied step by step in two sections, one in a cave and one on the surface.

The reef development starts with a crinoidal member less than 80 m thick, which corresponds to the stabilisation stage.

The reef community consists mainly of segmented sponges (Sphinctozoans: *Celyphia? minima*, *C. zoldana*, *Colospongia catenulata, Follicatena cautica*, *Olangocoelia otti*, *Solenolmia manon manon*, *Sollasia*? *baloghi*, *Thaumastocoelia dolomitica*, *Vesicocaulis oenipontanus*) and microproblematica (*Baccanella floriformis*, *Bacinella ordinata, Ladinella porata, Plexoramea* *cerebriformis, Radiomura cautica, "Tubiphytes" gracilis, "T." multisiphonatus, Tubiphytes* sp.), porostromata algae, bryozoans, gastropods and foraminifera.

The fossils are characteristic of the Wetterstein – type reef communities, although several typical Wetterstein sphinctozoan taxa (*Alpinothalamia bavarica, Uvanella irregularis, Stylothalamia dehmi, Cryptocoelia zitteli,* and all species of *Vesicocaulis* except for *V. oenipontanus*) have not been found in the studied association.

The reef development was twice interrupted by deeper water events resulting in dark-grey crinoidal-brachiopodal limestones. The conodonts (*Gondolella fueloepi, G. trammeri*) from the lower intercalation indicate an age interval between the Avisianum Subzone and the end of the Illyrian, while the brachiopod assemblage (*Decurtella decurtata, Dinarispira dinarica)* restricts its age to the late Anisian.

After the first deep water event, the reef recovered for a short time until it was finally terminated by a second deep-water horizon, the age of which is unknown. It is overlain by upper Illyrian – earliest Fassanian lagoonal limestone (*Diplopora annulata* with *D. annnulatissima).*

Differently from this, in the SE part of the studied region, a basin existed from the late Pelsonian (*G.* gr. *bulgarica*) until the early Ladinian *(G. transita/pseudolonga, G.* gr. *bakalovi)*. During the late Illyrian – Early Ladinian the reef prograded to the SE, where reef stage 2 was established. Meanwhile, on the NW part of the platform a lagoon was formed behind reef stage 2.

In reef stage 2, the reef association is the same as in reef stage 1, but the reef cores are much larger and densely packed with reef-building organisms. The thick, coarse crinoidal member forming the base of the reef stage 1 is absent here. Neptunian dykes were not found in reef stage 2.

Based on conodonts from the neptunian dykes dissecting the platform, the three main periods of tectonic activity are (1) latest Pelsonian (Binodosus Subzone), (2) early-middle Illyrian (Trinodosus Zone – most part of Reitzi Zone), and (3) uppermost middle Illyrian (Avisianum Subzone).

Coeval volcanic activity is documented in two stratigraphic levels: 1. Binodosus Subzone, and 2. middle Illyrian.

RECOVERY IN EARLY TRIASSIC OCEANS – GOOD TIMES OR BAD?

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The apparent failure of marine communities to radiate in the aftermath of the end-Permian mass extinction has long been a cause of comment and debate because it was not until the Middle Triassic, 7-8 million years after the crisis, that rapid diversification apparently began. The Griesbachian Stage in particular is marked by an extraordinarily widespread, truly pandemic community consisting of the same few species of bivalves, conodonts and ammonoids (ophiceratids). The marine recovery rate is much slower than seen in terrestrial tetrapod communities and has lead to the suggestion that the Early Triassic oceans saw the prolongation of harmful conditions (such as global marine anoxia) that caused the original mass extinction (Hallam 1991). The alternative – that the mass extinction was so enormous and diversity so reduced that it took millions of years to accrue sufficient species for radiation to be noticeable (Erwin 1993) – implies that marine habitats returned to normal in the Early Triassic but were simply uninhabited. These uninhabited versus uninhabitable scenarios have been at the heart of the debate about Early Triassic times ever since. Intense research activity over the past decade has added many new facets including: the discovery of large oscillations in the carbon isotope record, a major extinction around the Smithian/Spathian boundary, a significant holdover effect of radiolaria until the end of the Griesbachian, several discrete oceanic anoxic events, evidence for rapid recovery of nekton (Brayard et al. 2009) and the onset of benthic recovery in the later Early Triassic (Spathian Stage) rather than in the Middle Triassic (Song et al. 2011). Current knowledge suggests Early Triassic oceans record a range of conditions and phases:

1. Griesbachian (~600 kyr). Following onset of whole ocean anoxia at the end of the Permian, this redox state remained intense and widespread throughout this interval causing, amongst other things, the severe drawdown of the dissolved oceanic uranium inventory. Calcimicrobial activity becomes important in the equatorial realm. There as a rapid recovery of C isotope values back to pre-extinction values of around 3 permil. Neotethyan shelf seas shows the most favourable conditions at this time and harbour Permian holdovers. Only ammonoids and flat clams show significant radiation but the end of this stage was a significant extinction amongst pelagic taxa: ammonoids, conodonts and surviving “Permian” radiolaria.
2. Dienerian-late Smithian (~800 kyr) Improvement in oceanic ventilation (Wignall et al. 2010), major radiation of ammonoids and conodonts but not benthos. Stable plateau of C isotope values before they begin to fall again in the Smithian.
3. Smithian/Spathian extinction (Stanley 2009) (conodonts, ammonoids), lowpoint of C isotope values. Possible shelf anoxic event.
4. Spathian long (3 myr), slow radiation of most marine groups, recovery of C isotope values to a stable value around 2 permil. Return of intense anoxia in the oceans late in the Stage

The Early Triassic oceans reveal both good and bad times for marine life. The radiation delay is to some extent taxon specific. Thus, those groups with intrinsically high evolutionary rates, such as ammonoids and flat clams radiated fast, suggesting that marine conditions were often good or at least not too stressed to suppress normal rates of origination. On the other hand, there were clearly intervals of the Early Triassic when further crises affected the marine realm (end

Griesbachian, late Smithian). Perhaps the remaining enigma for the interval still remains at the Spathian/Anisian boundary: why did origination suddenly increase at this moment?

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