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Biostratigraphy and Event Stratigraphy Around the Permian-Triassic Boundary (PTB) in Iran and Implications for the Causes of the PTB Biotic Crisis

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In several sections of four areas with pelagic open sea deposits in Iran (Abadeh and Shahreza in Central Iran, Jolfa and Zal in NW Iran) the conodont succession and events around the PTB were investigated in detail. A very detailed conodont zonation was elaborated from the *Clarkina nodosa* up to the *Isarcicella isarcica* Zone. All events could be very well dated and by cross correlation with continental lake deposits with well recognisable Milankovitch cyclicity not only the numerical age of the events could be well recognised but also the duration of most of the conodont zones could be calculated. The following 9 conodont zones were discriminated: *C. nodosa*, *C. changxingensis-C. deflecta*, *C. zhangi* (~ 70 000 years), C. *iranica* (~ 60 000 years), *C. hauschkei* (~ 15 000 years), *C. meishanensis-Hindeodus praeparvus*, *Merrillina ultima-Stepanovites*? *mostleri* (the two zones together ~ 120 000 years), *H. parvus* (~ 100 000 years) and *I. isarcica* (~ 0,5 Ma) Zones. No detailed cross correlation is possible for the *C. nodosa* and *C. changxingensis-C. deflecta* Zones but comparing the thickness of the two overlying zones in unreduced sections, under assumption of probably constant sedimentation rate, the *C. nodosa* Zone is about as long as the *C. iranica* Zone or a little shorter (~ 50 000 to 60 000 years) and the *C. changxingensis-C. deflecta* Zone is about as long as the *C. zhangi* and *C. iranica* Zones together (~ 130 000 years). The unusual short duration of all conodont zones in the interval from the *C. nodosa* up to the *H. parvus* Zone indicates high ecologic stress. The extremely short *C. hauschkei* Zone Is the uppermost zone with warm water conodonts and it is cut by the extinction even for warm water conodont faunas at the top of that zone. In Abadeh section, situated about at the tropic of capricorn only a poor cool water conodont fauna is present in the *C. hauschkei* Zone. In the more northern sections, closer to the equator in that time, the poor cool water fauna begin only at the base of the *C. meishanensis-H. praeparvus* Zone.

The *C. zhangi* Zone, *C. meishanensis-H. praeparvus* Zone and *H. parvus* Zone can be directly correlated with the same conodont zones in South China. The *C. changxingensis-C. deflecta* Zone can be roughly correlated, but the underlying *C. nodosa* Zone is not present in South China. The *C. hauschkei* Zone may be present in South China but not in Meishan, where both the *C. iranica* and *C. hauschkei* Zones are missing. The *M. ultima-S.*? *mostleri* Zone can be well correlated with the *C. zhejiangensis* Zone at Meishan. The *C. hauschkei* Zone can be correlated until Greenland, where *C. hauschkei borealis*, which is also present in Iran, occurs in the lowermost *Otoceras boreale* Zone. The *C. meishanensis-H. praeparvus* and *H. parvus* Zones can be also directly correlated with the same zones in the Boreal realm.

In three horizons, the Dorashamian warm water conodont fauna is replaced by a cool water fauna with *H. typicalis* and few *Merrillina* sp. Especially well recognisable is the uppermost horizon in the lower *C. zhangi* Zone. This level can be well correlated with continental beds by a short reversed interval which comprises the upper *C. changxingensis-C. deflecta* Zone and most of the *C. zhangi* Zone. In the Germanic Basin it occurs in the uppermost Zechstein lower Fulda Formation and lowermost upper Fulda Fm. On the Russian Platform it corresponds to the Nedubrovo Formation, in which a fallout of mafic tuffs from the Siberian Trap is present several 1000 km away from the eruption centres. In the Germanic Basin and in Iran this horizon contains volcanic microsphaerules. Thus, a direct connection of the immigration of cool water fauna into the tropical realm with an especially strong explosive activity of the Siberian Trap volcanism can be recognised. As these faunal changes are the same as at the base of the Boundary Clay also for this horizon a short cooling event due to strong volcanism can be assumed. Additional influence by an impact cannot be excluded.

The following events can be observed close to the PTB in the Iranian sections (1) A continuous drop of $\delta^{13}C_{carb}$ can be observed which starts with values around 3 ‰ in the *C. nodosa* Zone and goes to values slightly below 0 ‰ at the base of the *H. parvus* Zone. After a short recovery in the upper *H. parvus* Zone, mostly a second negative excursion can be observed in the lower *I. isarcica* Zone. Within the continuous drop from the *C. nodosa* Zone up to the base of the Triassic only a short recovery to values maximally around 2 ‰ was in the uppermost *C. meishanensis-H. praeparvus* Zone. The strong and abrupt negative excursion in the Boundary Clay of Meishan is a secondary signal, which we found also in Iran, when weathered Boundary Clay with very low carbonate content (as in Meishan) was investigated as in Abadeh and Jolfa. However, if unweathered Boundary Clay was investigated, like in Shareza, Zal and Gerennavár of Bükk Mountains, Hungary, this negative excursion is not present. It is very interesting that the interval with strong ecologic stress indicated by the very short conodont zones coincides with the continuos drop in $\delta^{13}C_{carb}$. (2) Short reversed horizon (duration according to cross correlation with continental beds ~ 110 000 years) in the upper *C. changxingensis-C. deflecta* Zone and in the largest part

of the *C. zhangi* Zone. (3) Sudden facies change at the base of the Boundary Clay which is accompanied by a strong extinction event of the warm water fauna (and therefore related to a strong climatic change) which did not much affect the eurytherm benthos (small foraminifers, ostracods),. Whereas the base of the Boundary Clay is a synchronous event which indicates rapid drop in biogenic carbonate production (most probably because of blocking of sunlight), the extinction of the warm water faunas is diachronous, and lies at the tropic of capricorn (Abadeh section) at the base of the *C. hauschkei* Zone, 1000 km closer to the palaeoequator and at the palaeoequator themselves at the base of the *C. meishanensis-H. praeparvus* Zone. (4) Strong climatic change at the base of the Boundary clay (see 3). (5) High energy event at the base of the Boundary Clay which can be also observed in the several 1000 km away Bükk Mountains. It is probably related to huge tsunamies. (6) Rapid, but stepwise extinction of the eurytherm benthos in the interval from the base of the *M. ultima-S.*? *mostleri* Zone up to the very base of the *H. parvus* Zone, which occurs in the southern sections earlier than in the northern sections closer to the palaeoequator. (7) Maximum of microbialites, in shallower sections also large stromatolite or thrombolite bodies in the *H. aprvus* Zone which begins already in the *M.ultima-S.*? *mostleri* Zone. (8) Presence of an about 300 000 years long interval with more frequent than average microsphaerules with a first maximum in the cool water horizon of the lower *C. zhangi* Zone (mostly volcanic microsphaerules) and a second strongest maximum in the lower but not lowermost Boundary Clay (cosmic and volcanic sphaerules). Except event 6 all events can be traced also in other marine and continental sections.

Especially important is the fact that the PTB in the investigated Iranian sections lies in red sediments or, if it lies in light grey sediments as in Abadeh, the ostracod fauna indicates high oxygen content in the bottom water. Therefore, the anoxia cannot be the reason for the extinction event but they only locally or regionally overprint the extinction event, where they are present.

Correlation of the Continental Uppermost Permian and Lower Triassic of the Germanic Basin with the Marine Scale in the light of New Data from China and Iran

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The correlation of pelagic sediments with high-resolution biostratigraphic control with continental beds belongs to the most difficult stratigraphic questions. For detailed correlation not only interfingering of marine and continental beds must be used but also abiotic events. Yin Hongfu and co-workers made very important and excellent studies on the eventostratigraphy around the Permian-Triassic boundary (PTB) in Meishan and other South Chinese pelagic sections, and correlated all events very precisely with the high-resolution biostratigraphy of these sections (e.g. Yin Hongfu & Zhang Kexin, 1996, Yin Hongfu et al., 1996a, b, 2001). All events around the PTB can be found also in Iran, where they were correlated very detailed with the conodont biostratigraphy (Kozur, 2004 and in press, Korte et al., 2004 a, b, c). The detailed conodont zonation is shown in Fig. 1. All these events are also present around the PTB in continental beds of the Germanic Basin, and allow a very precise correlation of the PTB and eventostratigraphic markers below and above this boundary (Fig. 2). Detailed bio- and eventostratigraphic data were also published around the Olenekian base from the proposed GSSP of the Olenekian base at Chaohu (Tong et al., 2004, 2005). Further important data about the Gangetian to Smithian ammonoid and conodont chronology were reported by Bhargava et al. (2004) and Krystyn et al. (2004) from extremely ammonoid- and conodont- rich sediments of Spiti (India).

The PTB in continental beds of the Germanic Basin lies at the top of the *Falsisca postera* Zone. It is confirmed by a minimum in $^{13}C_{carb}$ and $^{13}C_{org}$ in the same bed and the same event succession as in Meishan and the Iranian sections. The boundary between the *F. postera* and the *F. verchojanica* Zone can be also found in Dalongkou close to the LOD of *Dicynodon*. The co-occurrence of *Dicynodon* with *Lystrosaurus* is therefore uppermost Permian and not lowermost Triassic. Most of the Lystrosaurus fauna (without Dicynodon) is, however, Triassic in age and coincides with the Gangetian Substage. The Gangetian-Gandarian boundary in continental beds is characterised by the disappearance (LOD) of *Falsisca* and the roughly contemporaneous LOD of *Lystrosarus* and the first occurrence (FAD) of spined conchostracans (*Molinestheria*, *Vertexia*, *Cornia*). It lies in the uppermost Calvörde Formation in the middle of magnetozone 1r (both in marine and continental beds). The base of the Olenekian in continental beds of the Germanic Basin was mostly placed at the base of the Hardegsen Fm. (Menning, 1995) or at the base of the Volpriehausen Fm. (Menning, 2000), but this was not supported by biostratigraphic or magnetostratigraphic evidences. Szurlies (in press) and Szurlies et al. (2003) used the magnetostratigraphic data of Scholger et al. (2000) from the Southern Alps and put the base of the Olenekian inside the Volpriehausen Fm., but such magnetostratigraphic correlations made only a sense, if not only reliable magnetostratigraphic data are used but also the correlation of the magnetozones within the marine Triassic must be checked in the sections, where they were measured. The palaeomagnetic data of Scholger et al. (2000) are reliable, but these authors did not regard the well known biostratigraphic data summarised in Farabegoli & Perri (1998) from the same Pufels (Bulla) section, where the magnetostratigraphic investigations were made. The top of the normal zone 2n is close to the base of the Olenekian (Tong et al., 2005) and not in the middle Gandarian (Dienerian) as shown by Scholger et al. (2000). The top of magnetozone 2n in Pufels (Bulla) is close to the top of the upper Gandarian *Claraia aurita* Zone and about 3 m below sample Bu 45 of Farabegoli &