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Biotic carbonate precipitation inhibited during the Early Triassic at the rim of the Arabian Platform (Oman)

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ABSTRACT

Sedimentological, palaeontological, and geochemical data of a 152-m thick composite section of the Saiq Formation were used to describe the facies associations and the nature of carbonate precipitation during the Late Permian–Early Triassic at the eastern rim of the Arabian Platform (Sultanate of Oman, Saih Hatat, Wadi Aday). Changhsingian (Late Permian) platform carbonates, dominated by bryozoans, brachiopods and crinoids, are truncated by a mineralized discontinuity surface. The disappearance of Permian calcified metazoans, a negative $\delta^{13}C_{carb}$ excursion, and a sharp facies contrast collectively suggest that the Permian–Triassic boundary lies in this interval. Unfossiliferous siliciclastics with nodules of iron and manganese minerals on top of the unconformity were probably deposited during a phase when sea water was undersaturated with respect to calcium carbonate. After a gap, late Dienerian carbonate deposition started with abiotically precipitated lime mudstone and biotically induced microbialites having the lowest observed $\delta^{13}C_{carb}$ values (facies association A). Further up, 1–2 m of bioclastic wacke- and grainstones with a positive $\delta^{13}C_{carb}$ excursion indicate a short-lived interval of biotically controlled carbonate precipitation (facies association B). The overlying sequence of siliciclastics, laminated or bioturbated dolomitized mudstone, microbialites, dolomitic siltstone, and black calcite, which is characterized by a 2nd negative $\delta^{13}C_{carb}$ shift, marks the return to biotically induced carbonate precipitation (facies associations C–D). The recrystallized black calcite at the top of the sequence is capped by a thick palaeosol and overlain by late Early to Middle Triassic cycles consisting of biotically precipitated carbonate. The facies development of the rim of the Arabian Platform differs from that of the interior in having a pronounced discontinuity at the Permian–Triassic boundary and an Early Triassic bioclastic carbonate unit sandwiched between abiotically precipitated carbonates. The observed lateral changes in carbonate precipitation across the Arabian Platform could have been caused by changes in oceanic circulation, such as episodic upwelling of deep water.

1. Introduction

The mass extinction in the latest Permian was the most severe event affecting terrestrial and marine life during the Phanerozoic Eon (Erwin, 2006 and references therein). A variety of abrupt mechanisms have been considered, including ocean hypercapnia (CO_2 poisoning, Knoll et al., 1996), oceanic anoxia (Wignall and Twitchett, 1996; Isozaki, 1997; Wignall and Twitchett, 2002), volcanism (Reichow et al., 2002), methane expulsion (Krull and Retallack, 2000), bolide impact (Becker et al., 2001) and perturbations of the carbon cycle (Berner, 2002, 2005). Repetitive $\delta^{13}C_{carb}$ excursions observed in Early Triassic marine carbonates have fuelled the discussion of disturbances of the carbon cycle during the aftermath of the Permian–Triassic mass extinction (Payne and Kump, 2007) and affected carbonate production of tropical shallow-water platforms. So-called "anachronistic" carbonates, which differ from Late Palaeozoic to Mesozoic carbonates by the presence of thrombolitic bindstones and the low diversity of calcified metazoans, were described from the Early Triassic of the Great Bank of Guizhou, South China (e.g., Lehrmann et al., 1998, 2001) and from carbonate platforms of the Neo-Tethys (e.g., Baud et al., 2007). These unusual Early Triassic precipitates have to been seen in the context of shallow-water carbonate precipitation as a continuum of processes with abiotic, non-enzymatic biologically induced and enzymatic biologically controlled precipitation as end members (Webb, 2001; Schlager, 2005). Biologically controlled carbonates are dominated by photozoan or heterozoan production modes. Permian photo-autotrophic carbonate production is governed by a variety of organisms including, calcisponges, calcareous algae, calcified invertebrates with symbiotic zooxanthellae (e.g., fusulinids or alatoconchid bivalves) and heterotrophic metazoans (Beauchamp and Desrochers, 1997). Conversely, carbonate production of the heterozoan association lacks the aforementioned warmwater components of the photozoan assemblage and is maintained by calcified metazoans like brachiopods, crinoids and bryozoans.

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Modes of carbonate precipitation in combination with stable carbon isotope data of a well exposed three-dimensional Permian–Triassic boundary section of the rim of the Arabian platform (Fig. 1) were investigated (1) to describe the Permian–Triassic boundary interval and the Early Triassic facies associations, (2) to discuss the data under consideration of sections of the interior Arabian Platform and (3) to interpret the data under consideration of a possible differential severity of the Early Triassic recovery phase.

2. Geological setting

2.1. General overview

With a width of more than 2000 km, an epeiric Middle Permian–Late Triassic platform extended from the Arabian Shield eastwards and southeastwards and passed into slope facies of the Sumeini Group in the Neo-Tethys. Shallow-water carbonate-dominated platform deposits of Middle Permian to Early Triassic age are called the Khuff Formation in Kuwait, Saudi Arabia, Qatar, Bahrain, and the subsurface of the UAE and Oman (Alsharhan and Nairn, 1997) and represent the most prolific gas reservoirs in the Middle East. Outcrop analogues can be studied in the northern Oman Mountains (Bih Formation), in the eastern Oman Mountains (Saiq Formation), in the Huqf area of central Oman (Khuff Formation), in Saudi Arabia and in the Zagros Mountains (Dalan and Kangan Formations). Outcrop and subsurface data have been used in many papers to characterize the facies heterogeneity and architecture of these formations (e.g. Alsharhan, 1993; Weidlich and Bernecker, 2003; Osterloff et al., 2004; Vaslet et al., 2005; Alsharhan, 2006; Insalaco et al., 2006; Weidlich and Bernecker, 2007; Weidlich, 2007; Maurer et al., 2009; Koehrer et al., 2010) or were synthesized in facies maps (Murris, 1980; Al-Jallal, 1995; Konert et al., 2001; Ziegler, 2001).

2.2. Large-scale facies patterns

The aforementioned studies have documented a large-scale pattern of facies change across the Arabian Platform (Fig. 2). The widely accepted facies model for the platform interior is a homoclinal ramp with gentle facies transitions from marginal marine siliciclastics to inner platform carbonate–anhydrite cycles and to open-marine platform carbonates. Typical facies associations of the ramp comprise supra- to intertidal sabkha and salina anhydrites and mudstones, inner-ramp bioclastic wacke- and packstones, high-energy shoal pack- and grainstones as well as outer-ramp muddy, argillaceous carbonates (see, for example, Alsharhan (2006), Insalaco et al. (2006), Maurer et al. (2009) or Koehrer et al. (2010) for details). Based on measured sections and sedimentological and petrographic analyses of samples from Wadi Aday, Saih Hatat, the depositional history of the rim of the Arabian Platform was addressed by Weidlich and Bernecker (2003, 2007) and Weidlich (2007). Here, carbonates differ from the inner- to mid-ramp facies associations in exhibiting a characteristic succession from Guadalupian photozoan wackestones and grainstones to Lopingian open-marine heterozoan mudstones and floatstones and to Early Triassic predominantly abiotic and biotically induced carbonate and siliciclastics. Carbonates of the Middle to Late Triassic Mahil Formation are dominated by photozoan carbonates. The base of slope of the Arabian Platform, the so-called Maqam Formation of the Sumeini Group, is a deep-water succession from Lopingian thin cherty lime mudstones, bedded dolomitized calciturbidites, and debris flows (Maqam B) to Early Triassic deep-water mudstones and calciturbidites.

2.3. Landward to seaward facies changes

Focusing on the Permian–Triassic boundary interval and the earliest Triassic, the following changes can be observed along an ideal landward-seaward (W–E) transect across the Arabian Platform.

2.3.1. Western Interior Arabian Platform

Vaslet et al. (2005) in their summary of the inner-ramp Khuff outcrops in Saudi Arabia did not focus on the Permian–Triassic boundary in detail, but illustrated in their logs Early Triassic oolites and microbialites. Regarding the interior of Arabian Platform, Insalaco et al. (2006) observed in the subsurface (South Pars field) and the Zagros Mountains (Iran) no major unconformity or disconformity at the boundary interval. The extinction level occurs within an oolitic and bioclastic grainstone unit and is overlain by a 1–3-m thick ‘azooic interval’ followed by Early Triassic microbialites. Ehrenberg et al. (2008) reported from a core covering the Permian–Triassic boundary interval a long-lasting decrease in bulk-rock uranium, a negative $\delta^{13}C_{carb}$, and microbialites. Maurer et al. (2009) described from the Bih Formation the Permian–Triassic Boundary interval as a ubiquitously present zone with a thickness of about 15 m which is characterized by a bulk-rock uranium depletion. An Early Triassic thrombolite bed is bracketed by ooid grainstone.

2.3.2. Eastern Arabian Platform rim to slope

Close to the rim of the Arabian Platform, in the Saih Hatat, the Lopingian–Early Triassic was a phase of intense tectonic activity during rifting of the Neo-Tethys, as indicated by synsedimentary faults, laterally rapid facies changes, breccias with a high fitting of the clasts and slumping structures (Weidlich and Bernecker, 2003, 2007). Lopingian floatstones with crinoids, brozoans and brachiopods were truncated by an unconformity and overlain by carbonate-free siliciclastic sediments. The base of slope deposits of the Arabian Platform (Maqam Formation, Sumeini Group) also recorded tectonic inquiescence during the deposition of Changhsingian cherty limestone with sponges, bryozoans and crinoids. The Permian–Triassic boundary interval is a silicified hardground, overlain by a sequence comprising yellow shale, Griesbachian–Dienerian thin bedded platy limestone and debris flows (basal Maqam C), a 7 m thick unit of Lower Smithian vermicular (intensely bioturbated) limestone and middle to upper Smithian platy limestone, debris flows and calciturbidites (Watts, 1987; Richoz et al., 2005).

2.4. Biostratigraphic age control

Smaller foraminifera, fusulinids and ostracods are important biota for biostratigraphic zonations of the Khuff and Mahil carbonates of the Arabian platform. The basal limestones of the Saiq Formation, with a Wordian age (*Neoschwagerina schuberti* Zone), are well dated and contrast to Changhsingian carbonates, which are generally characterized by a poor stratigraphic control. Precise biostratigraphic dates are especially challenging for the Permian–Triassic boundary on the Arabian platform due to the absence of conodonts and ammonoids. Since conodont samples collected from Late Permian to Early Triassic carbonates and siliciclastics in the study area failed to deliver age-diagnostic microfossils, foraminifera were used to establish biostratigraphic data points. These markers are the Changhsingian smaller foraminifer *Colaniella minima* and the Early Triassic smaller foraminifer *Pilamminella* sp. (see Fig. 3). Early Triassic boundaries of substages are preliminary and were inferred from facies correlation with measured sections from Jabal Akhdar (A. Baud, S. Richoz and L. Krystyn, pers. comm.).

3. Methods

In this study, we investigated Lopingian–Early Triassic strata along the northwest–southeast-oriented and north–south-oriented transects (Figs. 4, 5, 11A, B) east of Wadi Aday, Saih Hatat, eastern Oman Mountains (Fig. 1C, D). The textures and microfabrics of the sedimentary rocks have been mostly well preserved despite pervasive dolomitization and metamorphism. The limestones had been almost completely replaced by mimetic non-planar equidimensional