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Sequence stratigraphic and sedimentologic significance of the trace fossil *Rhizocorallium* in the Upper Triassic Nayband Formation, Tabas Block, Central Iran

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ABSTRACT

This study analyzes in detail the beds bearing *Rhizocorallium* in the Upper Triassic Nayband Formation (Tabas Block, Central Iran) and shows their potential in interpreting depositional settings, ecological features and sequence stratigraphy. An integrated approach combining ichnological, sedimentological and stratigraphic methods has significantly enhanced our understanding of the changes in the spatial distribution style and morphological differences among the same ichnospecies of *Rhizocorallium*. The Upper Triassic *Rhizocorallium* assemblages from the Nayband Formation reveal significant spatial variations in the orientation and dimensions (i.e., length, width, limb diameter), the tiering pattern, and the colonization style throughout systems tracts and at erosional discontinuities or omission surfaces. Based on the wide variety of forms and orientation, numerous morphotypes of *Rhizocorallium* are grouped into two main types, i.e., those that are mostly facies controlled and those that appear abundantly in a confined stratigraphic interval and are facies independent. In this respect, three paleoichnocoenoses or habitats for the rhizocorallid producers could be differentiated according to the burrow morphology and the nature and consistency of the substrate: (1) stable habitat, represented by soft substrates including horizontal, long, straight or slightly sinuous, spreite-bearing, U-shaped protrusive burrows of *Rhizocorallium irregulare* (= *R. commune* var. *irregulare*). This habitat resulted from processes operating in settings that are characterized by soft substrates, reduced sedimentation rates, and abundant food supply, typical of low- to moderate-energy, fully marine conditions; (2) unstable, physically-controlled habitat, represented by a suite of shifting substrates with low- to high-energy settings, including short, U-shaped protrusive spreiten-burrows of *R. jenense* (Type 1). In this habitat alternating and contrasting energy conditions did exist due to repeated storm events that were the main controlling factor in the distribution and preservation of *Rhizocorallium*; (3) substrate-controlled habitat represented by a suite of stiff-to-firm substrates including oblique to vertical protrusive or retrusive spreiten U-shaped burrows of *R. jenense* (Type 2). The erosional discontinuities or omission surfaces related to this habitat include parasequence-bounding transgressive surfaces of erosion (TSE) and parasequence-bounding flooding surfaces (FS) and are mainly associated with the *Rhizocorallium*-dominated *Glossifungites* ichnofacies. Complementary ichnological information indicates that the shift in the orientation and the morphological features of rhizocorallid burrows point to broad changes of environmental parameters, which are, in turn, controlled by the rate of sea-level changes.

1. Introduction

Rhizocorallium, a common trace fossil mostly found in the Mesozoic carbonate or mixed carbonate-siliciclastic basins all over the world, has been reported from marginal marine to deep marine environments and ranges from the Early Cambrian to the Recent (Fürsich, 1974, 1975; Uchman, 1992; Schlirf, 2011; Knaust, 2007, 2013). The recognition of the lifestyle of the *Rhizocorallium* tracemaker with the considering the

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of morphological changes of the burrows can help significantly as key environmental indicator, especially in evaluating the effects of energy level, substrate consistency, and organic matter distribution or nutrient supply (Basan and Scott, 1979; Rodriguez-Tovar and Pérez-Valera, 2008; Kowal-Linka and Bodzioch, 2011; Bayet-Goll et al., 2017). As proposed by Rodriguez-Tovar and Pérez-Valera (2008), the various morphological features of *Rhizocorallium* suggest evidence of the different modes of ethology of their tracemakers. Moreover, tiering pattern, penetration depths, size of the U-shaped spreiten-burrows together with variations in the orientation of the movement during construction of the burrows could be influenced by changes in ecological conditions. Nevertheless, the ethology of the *Rhizocorallium* producer and colonization style modifications triggered by changes in different physical, chemical and biological parameters are still poorly understood (see Knaust, 2013). The distribution and morphological differences of ichnospecies of *Rhizocorallium* in shallow-marine deposits is mostly facies-controlled. However, in many cases rhizocorallid burrows appear abundantly in confined stratigraphic intervals, independent of the facies (Uchman et al., 2000). Erosional discontinuities or omission surfaces in rock units include surfaces that are attributed to bounding surfaces of stratal units, including regressive surfaces of erosion (RSE), sequence boundaries (SB), transgressive surfaces of erosion (TSE) and amalgamated sequence boundaries, and other surfaces such as marine flooding surfaces (FS/SB), maximum flooding surfaces (MFS) and parasequence-bounding flooding surfaces (FS), which both are mainly associated with the *Glossifungites* ichnofacies (Bromley, 1975; MacEachern et al., 1992; Gingras et al., 2000, 2001; Savrda et al., 2001a, 2001b, 2016; Savrda, 2012; Rodríguez-Tovar et al., 2006, 2007; Abdel-Fattah et al., 2016; Bayet-Goll et al., 2016a). The association between *Rhizocorallium* and erosional discontinuities or omission surfaces has commonly been used to determine the types of bounding surfaces of stratal units (Pemberton et al., 2001).

The Upper Triassic, shallow-marine Nayband Formation of the Tabas Block, Central Iran, hosts sparse to profuse various types of ichnofossils (Fig. 1). *Rhizocorallium* assemblages are one of the most common and widely known marine trace fossils from the Upper Triassic sediments of the world (e.g., Rodríguez-Tovar et al., 2007). This study analyzes in detail the abundant *Rhizocorallium* found in the Nayband Formation, and shows their potential in interpreting depositional settings, ecological features and sequence stratigraphy. The common occurrence of well-preserved *Rhizocorallium* assemblages in this formation provides an opportunity to document paleoecological, taphonomic and environmental controls on the distribution, colonization styles, and morphological differences of the ichnospecies of *Rhizocorallium*. The aims of this paper are: (1) to provide a detailed analysis of a unique occurrence of *Rhizocorallium* displaying a wide variety of forms and orientation in open marine facies of the Nayband Formation, (2) to deduce paleoichnocoenoses or habitats of the rhizocorallid producers according to the morphology of burrows and the nature and consistency of the substrate, and (3) to show how the association between *Rhizocorallium* and erosional discontinuities can document the internal organization of a depositional sequence, especially in defining bounding surfaces of stratal units.

2. Geological setting

The study area is located within the Tabas Block, in central part of the Central-East Iranian Microcontinent (CEIM). The CEIM can be divided into several tectonic blocks separated by major faults, including the Lut Block (LB), Tabas Block (TB), Posht-e-Badam Block (PBB) and Yazd Block (YB) (Alavi, 1991) (Fig. 1). The Tabas Block is an intracontinental depression (Takin, 1972) is limited to the east by the Nayband fault and to the west by the Kalmard fault (Alavi, 1996) (Fig. 1). From the Precambrian to the Permian, the Central Iran was part of the northwestern Gondwana (Alavi, 1991; Stampfli et al., 1991; Fürsich et al., 2009). During Early Triassic time, the Tabas Block underwent slow and steady subsidence, which resulted in the deposition of shallow-marine sediments of the Sorkh Shale and Shotori Formations (Aghanabati, 2004). According to Aghanabati (2004), the Early Triassic rocks were deposited on a passive margin and are dominated by carbonate lithology with subordinate interbedded clastics. After the collision of the CEIM with the Eurasia during the Middle-Late Triassic time (Early Cimmerian tectonic phase), the Upper Triassic, Nayband Formation was deposited on a siliciclastic shelf over covering the Shotori platform carbonates (Seyed-Emami et al., 2004; Wilmsen et al., 2009). According to the studies of Fürsich et al. (2009), the Early Cimmerian tectonic phase had a key role in the deposition of the Middle-Late Triassic successions of the Cimmerian terranes of Iran. In other words, the thick siliciclastic sediments of the Nayband and Shemshak Formations of the Cimmerian terranes were originated from the highlands, that recycled from tectonic phase.

The Upper Triassic (Norian-Rhaetian) deposits of the Nayband Formation have a widespread distribution in central and eastern Iran with an increasing thickness toward the east/southeast (Seyed-Emami, 2003). In the area of the type locality of the Kuh-e Nayband, four members are recognized in the Nayband Formation, which in stratigraphic order are: (1) Gelkan Member (silts, sandstones), (2) Bidestan Member (carbonate rocks), (3) Howz-e-Sheikh Member (silts, sandstones) and (4) Howz-e-Khan Member (carbonate rocks) (Senowbari-Daryan et al., 1997; Fürsich et al., 2005; Senowbari-Daryan, 2005).

The major focus of the present study is the Nayband Formation spreading out over a large area in the northern of Kerman Province at the east City of the Zarand. Here the formation can be subdivided into: (1) the Gelkan Member composed of thick layers of sandstone and shale and (2) the Howz-e-Sheikh Member containing shale and sandstone, dark-green silty calcareous shale, siltstones and limestone (Fig. 1C). The Bidestan and Howz-e-Khan Members are not recorded in this area. The formation overlies, with an unconformity, the shallow-water carbonate platform sediments of the Middle Triassic Shotori Formation and is overlain by the Lower Jurassic Ab-e-Haji Formation. The Nayband Formation contains a rich benthic macrofauna, particularly of bivalves, corals and various groups of sponges, and some brachiopods, echinoderms and gastropods (Fürsich et al., 2005). However, in most areas, the macrofauna is mainly restricted to the Bidestan and Howz-e-Khan Members. In contrast, trace fossils are fairly common in the Gelkan and Howz-e-Sheikh Members, but not yet studied in detail (Fürsich et al., 2007). A series of studies were recently undertaken on the Nayband Formation, providing valuable biostratigraphic information and dating this sequence from the Norian to Rhaetian (Nützel and Senowbari-Daryan, 1999; Nützel et al., 2003; Cirilli et al., 2005; Fürsich et al., 2005; Fürsich et al., 2005; Senowbari-Daryan, 2005).

3. Methodology

The Nayband Formation has been studied and measured in one section (a parallel-to-strike transect, 30°44′12″N, 56°51′4″E), where this formation is well accessible and continuously exposed (Fig. 2). This section was logged and evaluated using sedimentological and ichnological data as the basis for a detailed analysis of sedimentary processes (facies) and depositional systems (facies associations). This paper concentrates on sequence stratigraphic and sedimentologic significance of the trace fossil *Rhizocorallium* within the Howz-e-Sheikh Member that was interpreted as a wave-dominated shoreface-offshore complex (Bayet-Goll and Neto de Carvalho, 2017). No *Rhizocorallium* was observed in the siliciclastic rocks of the Gelkan Member that was interpreted as a river-dominated succession (Bayet-Goll and Neto de Carvalho, 2017). Sedimentary facies were identified based on field data and petrographic analysis (Table 1). The standard environmental zonation of the landward and seaward parts of open marine wave-dominated deposits has been adopted with the criteria and nomenclature introduced by MacEachern and Pemberton (1992) and MacEachern et al. (1999). During the field study, paleocurrent data were collected