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Evidence for seagrass meadows and their response to paleoenvironmental changes in the early Eocene (Jafnayn Formation, Wadi Bani Khalid, N Oman)

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ABSTRACT

The recognition and understanding of vegetated habitats in the fossil record are of crucial importance in order to investigate paleoecological responses and indirectly infer climate and sea-level changes. However, the low preservation potential of plants and macroalgae hampers a direct identification of these environments in the geological past. Here we present sedimentological and paleontological evidences as tool to identify the presence of different seagrass-vegetated environments in the shallow marine settings of the lower Eocene Jafnayn platform of Oman and their responses to paleoenvironmental changes. The studied lower Eocene deposits consist of well bedded, nodular packstones dominated by encrusting acervulinid and alveolinid foraminifera passing upward to an alternance of packstones with echinoids and quartz grains and grainstones rich in *Orbitolites*, smaller miliolid foraminifera and quartz grains. The presence of seagrass is inferred by the occurrence of encrusting acervulinids and soritid *Orbitolites*, as well as by their test morphologies together with further sedimentological criteria. The clear shift observed in the faunal assemblages and sedimentary features may be related to a major reorganization of the carbonate system passing from a carbonate platform to a ramp-like platform with increased terrigenous sedimentation. Heterotroph tubular acervulinids and oligotroph alveolinids of the carbonate platform were replaced upward by more heterotroph organisms such as large, discoidal *Orbitolites* and smaller miliolids, most likely due to enhanced nutrient levels which would have led to a change of phytal substrate, from cylindrical-leaf dominated grasses into flat-leafed ones.

1. Introduction

In the photic zone of tropical and temperate carbonate settings, seagrass meadows represent a very influencing environment, playing an important role in the oceanic carbon budget as one of the most productive marine habitats. The high productivity of seagrass habitats and their role as carbonate factories result from the direct calcification of the grasses (Enríquez and Schubert, 2014), from the sediment retention promoted by the plant canopy (Scoffin, 1970; Gacia and Duarte, 2001; Agawin and Duarte, 2002; Mateu-Vicens et al., 2008) and more significantly from the great abundance of calcifying epiphytes, infaunal and epifaunal organisms associated with the grasses (Brasier, 1975; Perry and Beavington-Penney, 2005; Corlett and Jones, 2007; James et al., 2009; Mateu-Vicens et al., 2012; Brandano et al., 2014). Additional important ecological roles of seagrasses include nursery and food source for other marine organisms, sediment stabilization and shoreline defense, and nutrient cycling (e.g. Costanza et al., 1997; Hemminga and Duarte, 2000; Hein et al., 2006; Orth et al., 2006; Vassallo et al., 2013). Moreover, seagrasses are one of the most common habitats in the shallow-water, soft bottoms during the Cenozoic, particularly from the Miocene, a time where many seagrass genera diversified and expanded geographically. Therefore, in order to preserve this valuable ecosystem, numerous studies have focused on understanding the interactions and responses of seagrasses to environmental changes and stressors such as increased light, eutrophication, sedimentation and turbidity, climate change, and water quality. Seagrasses can respond to these changes in different ways such as regulating the physiological activity of the plant, changing the plant morphology, and/or the species composition and biomass (e.g. Duarte, 1991; Short and Neckles, 1999; Gacia et al., 2002; Lirman and Cropper, 2003; Koch et al., 2007, 2013; Ralph et al., 2007; van Katwijk et al., 2011; Jordà et al., 2012; Govers et al., 2014). Furthermore, seagrass-associated organisms, especially of epiphytic foraminifera, are widely used as proxies to characterize specific habitats

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and to reflect present and past environmental changes such as climate change, sea-level fluctuations, changes in light and nutrient levels and/or substrate type (e.g. Langer, 1993; Wilson, 1998; Fujita and Hallock, 1999; Semeniuk, 2005; Richardson, 2006; Moissette et al., 2007; Brandano et al., 2009; Mateu-Vicens et al., 2010, 2014; Reuter et al., 2011).

Seagrasses have been considered to originate in the Tethys Ocean and their fossil record extends back to the Late Cretaceous (Den Hartog, 1970; van der Ham et al., 2007). It was only during the early Eocene when this ecosystem became well established and spread throughout the Tethys (Brasier, 1975) and the Western Atlantic-Caribbean (Vélez-Juarbe, 2014). However, the understanding of the functioning of seagrass ecosystems in the geological record is limited, with only few studies focusing on the distribution of seagrasses and their response to environmental changes during the Cenozoic (e.g. Brasier, 1975; Eva, 1980; Domning, 2001; Moissette et al., 2007; Vélez-Juarbe, 2014). This is likely a consequence of the scarcity of fossil remains of seagrasses, due to the low potential of preservation of these plants (Brasier, 1975; Reich et al., 2015 and references therein). Therefore, commonly, the identification of paleo-seagrasses can only be done through the recognition of indirect sedimentological and biological indicators, by comparison with modern seagrass habitats. Common indirect criteria are: specific benthic foraminiferal assemblages, specific composition and growth morphology of crustose coralline red algae, bryozoans, ostracods and mollusks, occurrence of specific taxa of echinoderms, and the presence of unsorted sediments with micritic matrix (for a complete review of these and further indirect indicators of past seagrass habitats the reader is referred to the reviews of Beavington-Penney et al. (2004) and Reich et al. (2015).

Here we provide evidence for the presence of different seagrass environments in the shallow water carbonates of early Eocene age (Jafnayn Formation) in Wadi Bani Khalid (N Oman). To our knowledge, this is the first time that seagrass environments are reported in Oman during the early Eocene. Also, this study documents the capacity of seagrasses and their associated communities to respond to environmental changes such as enhanced runoff, suggesting that seagrasses ecosystems were well evolved and relatively complex already at the early times of the history of the group.

The main objectives of this paper are to: (i) describe in detail and interpret the facies and depositional conditions of lower Eocene deposits in the Wadi Bani Khalid section, (ii) document and critically revise the variety of indirect indicators (sedimentological and paleontological) of the presence of ancient seagrass-dominated settings, (iii) characterize the epiphytic foraminifera associated with the seagrasses, and (iv) unravel the responses of the seagrasses and associated communities to environmental changes related to the influx of terrigenous.

2. Setting

2.1. Regional geological setting

The study section is located in the Wadi Bani Khalid, 36 km west of the city of Sur, in the south-eastern end of the Oman Mountains (Fig. 1A). From the Paleocene to the early Miocene, up to 2 km of, predominantly, platform carbonates accumulated in the Oman Mountains (paleolatitude 10°N) after the transgressive Maastrichtian deposits (i.e. fluvialites, shallow marine clastics and shallow shelf carbonates) that followed the obduction of the Semail Ophiolites (Nolan et al., 1990; Racey, 1995). This thick Cenozoic interval represents the most complete succession of Paleogene depositional sequences in the Middle East. Particularly, the Sur region comprises one of the most complete succession with shallow-marine deposits, represented by the Jafnayn, Rusayl and Seeb Formations (defined by Nolan et al., 1990), accumulated in the western part, the so-called Tiwi Platform. Part of these Paleogene shallow-marine facies are well exposed in Wadi Bani Khalid, a narrow valley located 140 km W of the city of Sur in the southern most

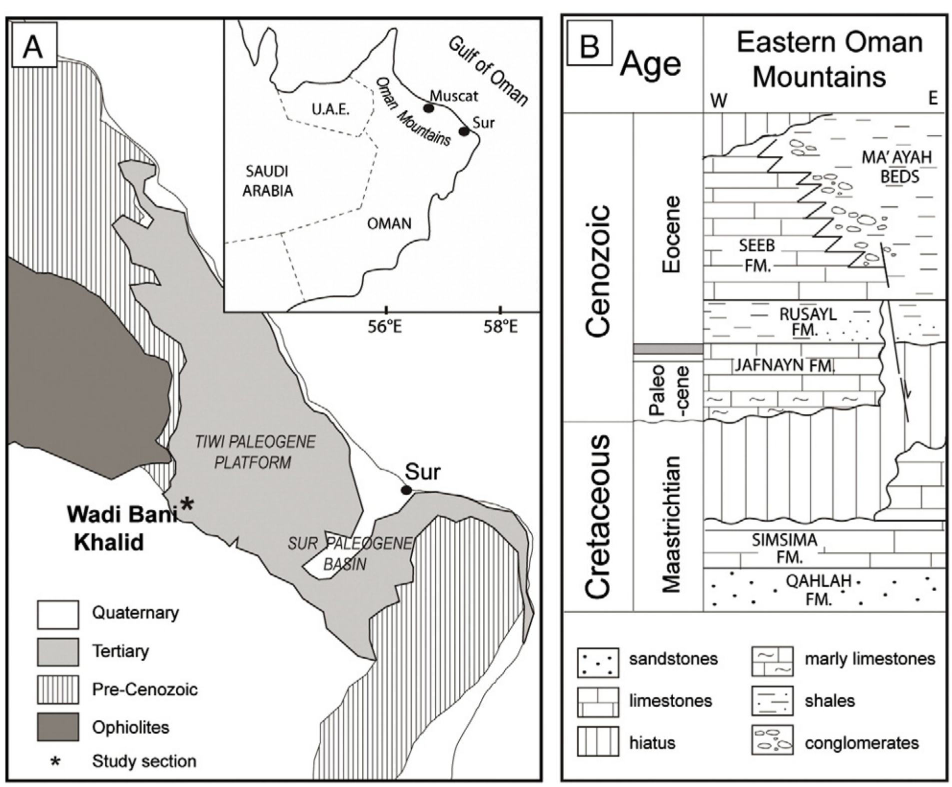

Fig. 1. Geological map and lithostratigraphy of the study area. A) Simplified geological map of the Sur Region (south-eastern Oman Mountains) and location of Wadi Bani Khalid section (modified from Razin et al., 2005). B) Regional chrono- and lithostratigraphy of the eastern part of the Oman Mountains (after Nolan et al., 1990). The study interval (upper part of the Jafnayn Formation) is highlighted in gray.