

Bioerosive structures in orbitolinid foraminifera: examples from the Lower Cretaceous of Central Iran

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Abstract. Lower Cretaceous orbitolinid assemblages from Central Iran yield various bioerosional structures. The omnipresent traces of different boring taxa and groups (*e.g.*, sponges, calcimicrobes, incertae sedis) represent a characteristic feature of the investigated thin-section material. The assemblage can be attributed to the *Entobia* ichnofacies dominated by borings assigned to the activity of sponges. The boring galleries are often concentrated in a plane parallel to the test surface, along the boundary of the marginal and the central zone of the orbitolinid tests. The borings are observed in foraminiferan-dasycladalean wackestones to poorly washed-out packstones, which can be referred to a subtidal palaeoenvironment.

Key words: bioerosion, ichnology, orbitolinid foraminifera, bacinellid fabrics, *Entobia* ichnofacies, Iran, Lower Cretaceous

INTRODUCTION

Bioerosion, the decomposition of hard substrates of biogenic or abiogenic origin by biological processes such as grazing, etching or boring, is a well known phenomenon in both ancient and modern shallow marine carbonates (*e.g.*, Neumann, 1966; Golubic et al., 1975; Taylor and Wilson, 2003). Numerous organisms are able to actively excavate (or bore) substrates on a macroscale, such as certain bivalves, gastropods, echinoids, sponges, polychaetes, arthropods, bryozoans or benthonic foraminiferans (*e.g.*, Bromley, 2004). Certain groups of cyanobacteria, green and red algae as well as fungi bore on a microscale and are therefore termed microborers. The terminology to separate microborings from macroborings is not uniformly used in the literature. Some consider borings with a diameter of less than a millimetre as microborings (*e.g.*, Flügel, 2004: p. 387; Wilson, 2007), while others take a maximum width of 0.1 mm as the boundary between micro- and macroborings (*e.g.*, Golubic et al., 1975; Glaub, 1994). Borings are treated ichnotaxonomically even in cases where the producers are known (*e.g.*, Mägdefrau, 1932; Taylor and Wilson, 2003; Bertling et al., 2006, with further references therein). Generally, endoliths within host skeletons sometimes are divided into active borers (euendoliths) or passive settlers (paraendoliths and cryptoendoliths) that thrive in fissures or nestle in pre-existing borings, respectively (*e.g.*, Golubic et al., 1981; Scoffin and Bradshaw, 2000). This distinction may be sometimes difficult in fossil material especially in cases where recent observations are not available.

In Mesozoic to Cenozoic shallow water carbonates, the tests of larger benthonic foraminifera often represent typical substrates

for both macro- and microborers (Banner, 1971; Matteucci, 1978; Golubic et al., 1984; Nielsen, 2002; Nielsen and Görmüş, 2004; Sen-Gupta and Nielsen, 2009; Nebelsick et al., 2011; Čosović et al., 2012). For orbitolinids, especially the presence of small cryptoendolithic foraminifera inside borings was recorded repeatedly (*e.g.*, Cherchi et al., 1990). The present paper addresses several examples of bioerosional patterns observed in the tests of orbitolinids from the Lower Cretaceous (Barremian-Aptian) of Central Iran.

GEOLOGICAL SETTING

The mountainous region around Anarak (Nain County, Isfahan Province) belongs to the Yazd Block of Central Iran (Berberian and King, 1981; Aghanabati, 2004, for overviews). Lower Cretaceous shallow-water limestones occur transgressively upon conglomerates and sandstones which in turn are underlain by the Late Paleozoic to Triassic Anarak metamorphic complex (*e.g.*, Torabi, 2011; Buchs et al., 2013). For a geological sketch map of the Anarak region see Torabi (2011, fig. 2).

The Lower Cretaceous shallow-water carbonates of the Yazd Block, which are generally assigned to the Barremian-Aptian interval (*e.g.*, Chahida and Djafarian, 1977), were investigated with respect to microfacies, sedimentology and micropalaeontology by Bucur et al. (2012) and Wilmsen et al. (2013). Three sections are currently under study in the area of Anarak-Naien-Ardakan (Fig. 1): the Anarak section near Anarak and the Herisht sections (T and H) close to Ardakan. First results indicate that the stratigraphy of these carbonates, in Iranian geology often designated as “*Orbitolina* limestones” (*e.g.*, Stöcklin, 1971), may be highly different (*e.g.*,

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Schlagintweit et al., 2013). In fact, orbitolinid foraminifera represent frequent constituents in these carbonates, mostly wacke- to packstones, where bioerosional processes may affect their tests. In the orbitolinid-dominating samples, other bioclasts acting as hard substrates for the boring organisms are represented mostly by remains of dasycladalean algae only. The purpose of the present paper is to illustrate and briefly describe and comment the observed boring traces affecting the orbitolinids. Most of the examples shown are from the Early Barremian of the Anarak section (Fig. 1) where the dating is based on the occurrence of *Eopalarbitolina charollaisi* SCHROEDER and other taxa (Schlagintweit et al., 2013, for details). Only some examples are from the Early Aptian (*Praeorbitolina cornyi* zone of Schroeder et al., 2010) of the Herisht section.

DESCRIPTION OF ENDOLITHS, ICHNOTAXA AND BORING PATTERNS

In the thin-sections studied different types of boring galleries can be observed. Most of them are empty and filled with cement. In

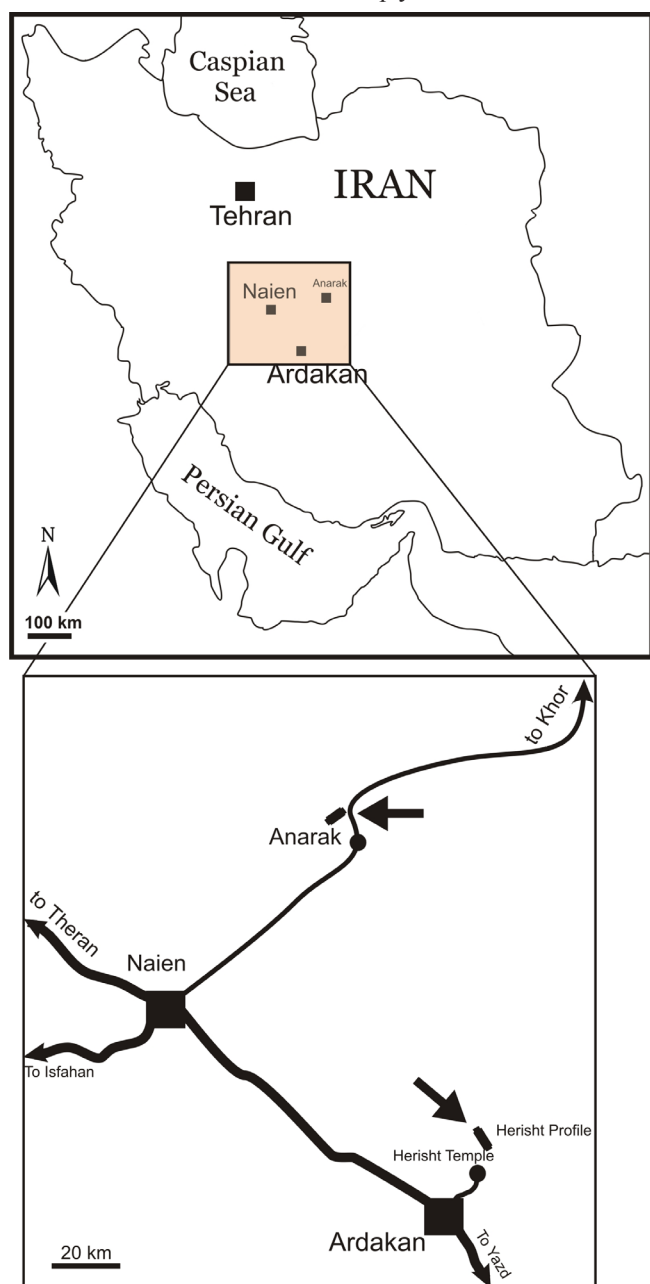


Fig. 1. Locality map of the study area in Central Iran, indicating the position of the Anarak and Herisht sections (arrows).

some cases, (micro)organisms can be observed inside the borings. These can be either related to the producer itself (= euendolith) or to a secondary nestler (= cryptoendolith) that entered the borings, for instance as a protective site (Golubic et al., 1981, for terminology). Abundances in the thin-sections were not quantified. The order of the description does not imply abundances or other attributes.

Bacinellid crusts

Crustose masses of pseudocellular bacinellid textures (*sensu* Maurin et al., 1985 and Schlagintweit and Bover-Arnal, 2011) are observed enveloping the orbitolinid tests, occasionally also forming bridges between adjacent specimens and thus binding them together (Fig. 2a). The crusts may penetrate deeply into the orbitolinid tests, thereby replacing the original chamber structures. Due to their diffuse outline, these structures most likely represent an active penetration by dissolution/etching processes.

For these textures, a calcimicrobial origin is generally assumed based on rare findings of various types of filamentous structures within the pseudo-cells (Schäfer and Senowbari-Daryan 1983; Maurin et al., 1985; Vachard et al., 2001; Granier, 2003; Uță and Bucur, 2003; Schlagintweit and Bover-Arnal, 2012). In most cases, however, arguments for such an interpretation were not further substantiated, e.g., by thin-section photographs. To illustrate this, two further examples from Lower Cretaceous (Aptian) bacinellid crusts of Spain and Oman are shown in Fig. 3. The relevance of these rare finds is of importance here as an etching potential of these structures was already envisaged by some authors (Neuweiler and Reitner, 1992; Kolodziej, 1997; Granier, 2003). The modern microflora actively penetrating hard substrates has been studied since many decades (e.g., Ercegovic, 1927; Tribollet, 2008; and many others). The taxonomy of fossil counterparts, however, is still poorly known.

Ichnogenus *Entobia* Bronn

In the thin-sections studied, *Entobia* represents the most widespread ichnotaxon within the orbitolinid tests. Due to the random sectioning, different types (that might exist) were not distinguished, as the three-dimensional form remains unknown. Rather, these are collectively attributed to *Entobia* isp. This *Entobia* ichnofacies is usually reported from rocky shores and cliff-bound carbonate deposits (e.g., de Gibert et al., 1998; Titschack et al., 2005), the Lower Cretaceous occurrences instead are from subtidal shelf environments of only moderate hydrodynamic energy.

Some perforations are cutting the tests without preferred orientation, while others are arranged in a plane parallel to the test surface, often at the boundary of the marginal zone to the central zone. Single chambers with radiating unbranched canals (Fig. 4d) are present as well as forms exhibiting several smaller chambers with interconnected canals (for terminology see Bromley and D'Alessandro, 1984). Similar structures affecting orbitolinid tests were illustrated by Schroeder (1997, pl. 1, fig. 5) from the Early Barremian of Switzerland as "traces of dissolution at the boundary marginal to central zone" (translated).

Boring of an unknown producer

This boring pattern is characterized by straight to slightly undulating canals that exhibit a continuous increase in diameter starting from the entrance point at the foraminiferan test (Fig. 5a). Later, the diameter remains constant and branching may occur as well (Fig. 5b). Due to the absence of chambers in the sections

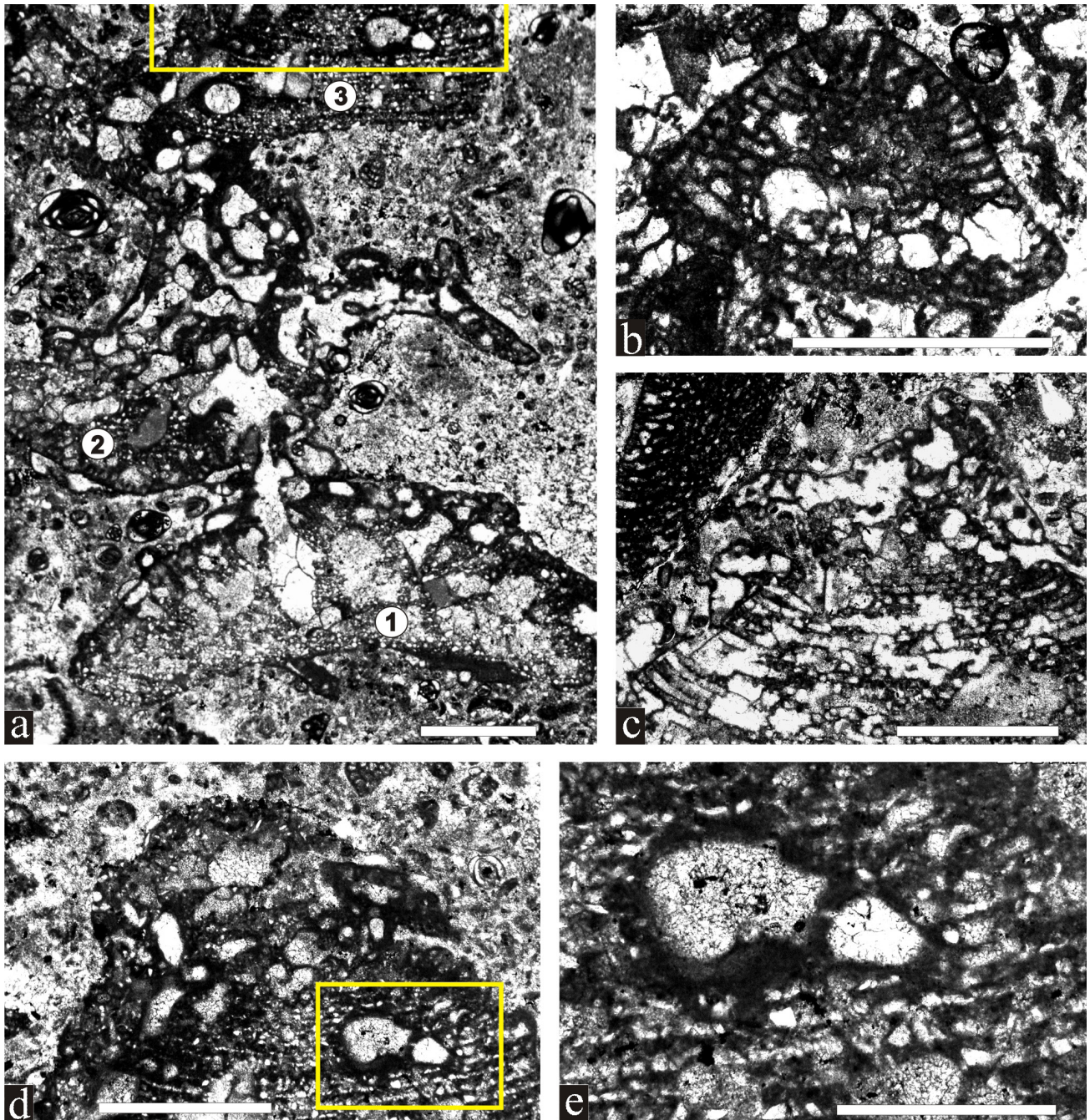


Fig. 2. Bioerosion of orbitolinids by bacinellid crusts; **a)** Three tests of orbitolinids (1-3) encrusted and thus connected by the crusts. Note the penetration and etching from all sides. The yellow rectangle marks part of the detail shown in **d**. Anarak section, thin-section AQn 24; **b-c)** Test filled partly with irregular bacinellid-type pseudocells replacing the chamber structures of the orbitolinid. Herisht section, thin-section H 43 and Anarak section, thin-section AQ 23; **d-e)** Details from **a**, showing the external encrustation and an unknown bioeroding taxon. Note the micritic filling. Anarak section, thin-section AQn 24. Scale bars = 1 mm, except e = 0.5 mm.

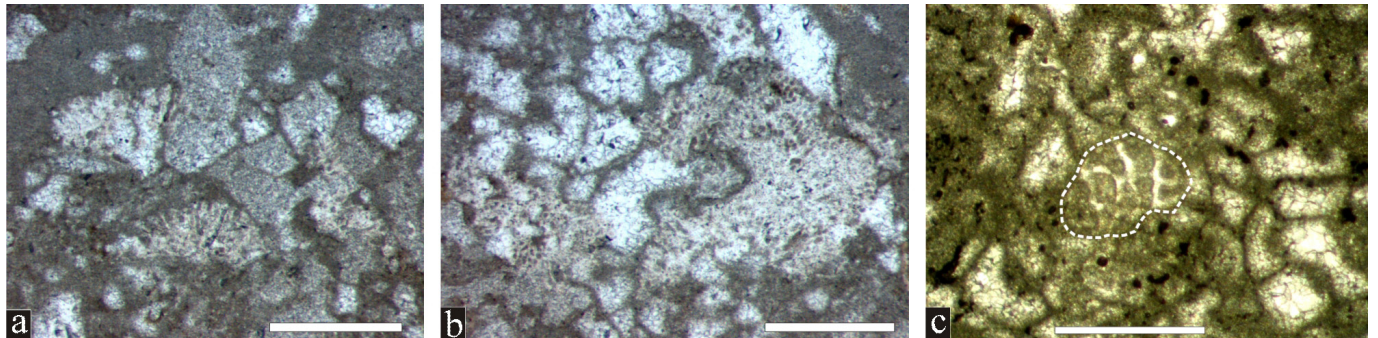


Fig. 3. Filaments of assumed cyanobacterial origin within pseudocells of bacinellid fabrics (see also GRANIER, 2003: Fig. 6); **a-b)** Bushy filament type (diameter 4 - 10 μm) (?Nostoclean-type), Late Aptian of Spain (leg. S. Huck). (**a** vertical section, **b** horizontal oblique section); **c)** Vertical oblique section of filament-like arrangement of cells (?Chroococcalean-type), Early Aptian of Oman (leg. A. Immenhauser). Scale bars = 0.3 mm.

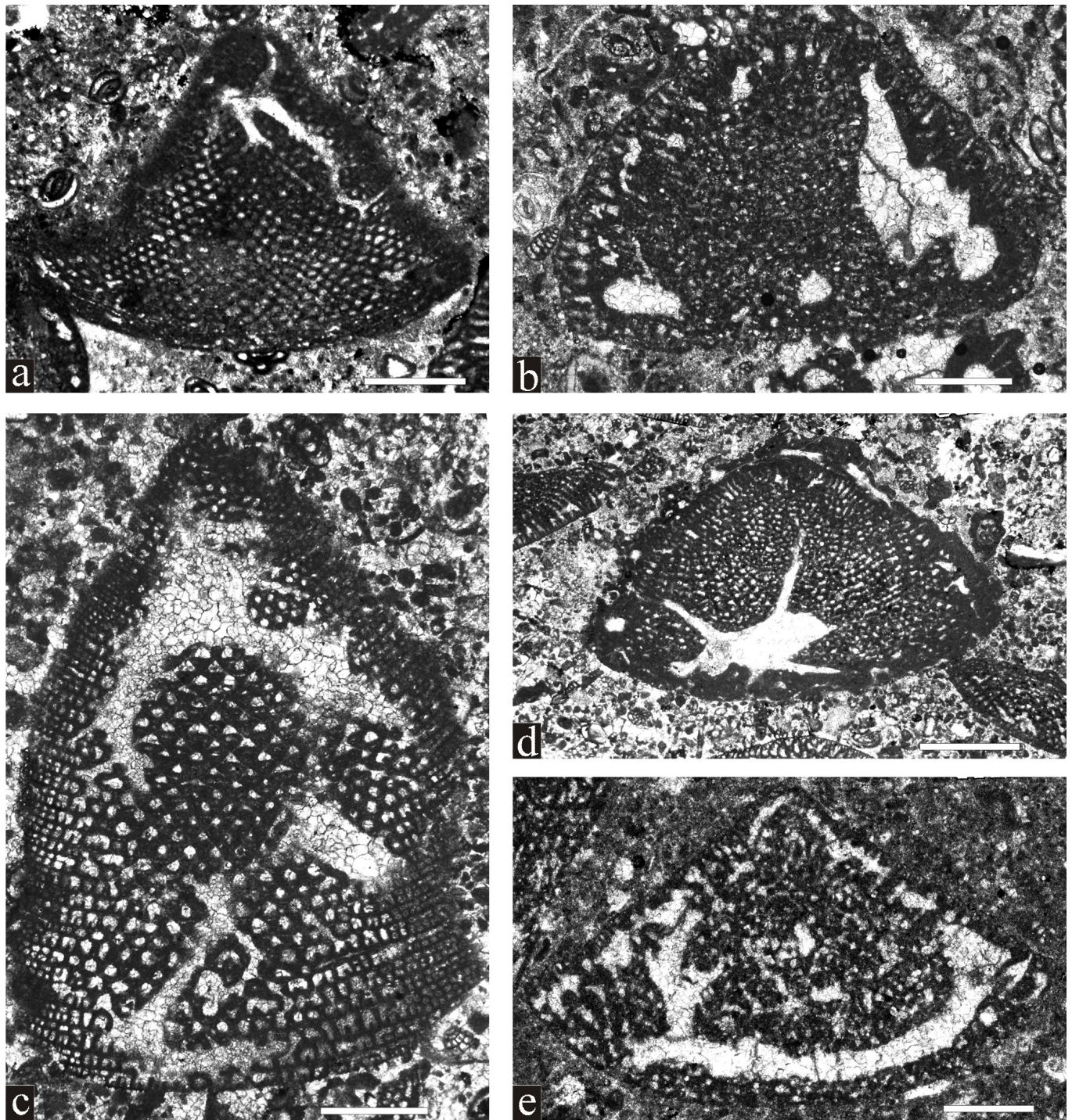


Fig. 4. Different sparite-filled traces (ichnogenus *Entobia*) ascribed to boring sponges from the Anarak section, Central Iran; **a)** Branching gallery of variable diameter. Note the thin micritic wall structure of unknown affinity. Thin-section AQ 24; **b)** Bioeroded orbitolinid test showing a large cavity (chamber). Thin-section AQ 25; **c)** Boring gallery with swollen parts (chambers) and connecting canals. Thin-section AQ 49; **d)** Bioeroded test with one large chamber and radiating canals. Thin-section AQ 48; **e)** Bioeroded test with a thick cylindrical canal running subparallel to the foraminiferan dorsal side. Thin-section AQ 58. Scale bars 1.0 mm = a, d, 0.5 mm = b, c, e.

in question, however, they cannot be referred to the ichnogenus *Entobia* Bronn with certainty. However, endolithic sponges might cause these boring canals.

Borings associated with thaumatoporellaceans

In the Lower Cretaceous material from Iran, thaumatoporellaceans are common though not frequent. They occur within the micritic matrix or attached to the orbitolinid tests (Fig. 6b). Irregular ovoidal specimens are observed in shallow borings affecting the orbitolinid tests. The occupation

of pre-existing cavities cannot be excluded so that a final conclusion about the status of these endoliths is not possible. Both thaumatoporellaceans within the matrix and borings exhibit rather thin walls (with poorly if ever visible pores) compared with, e.g., the Upper Cretaceous type-material (Pia, 1938; De Castro, 1990).

Endolithic tube of unknown affinity

A single section of a tube of unknown biogenic affinity was observed inside the central zone of an orbitolinid. The outer tube diameter is 5 μ m and the tube length may go up to 500 μ m. The

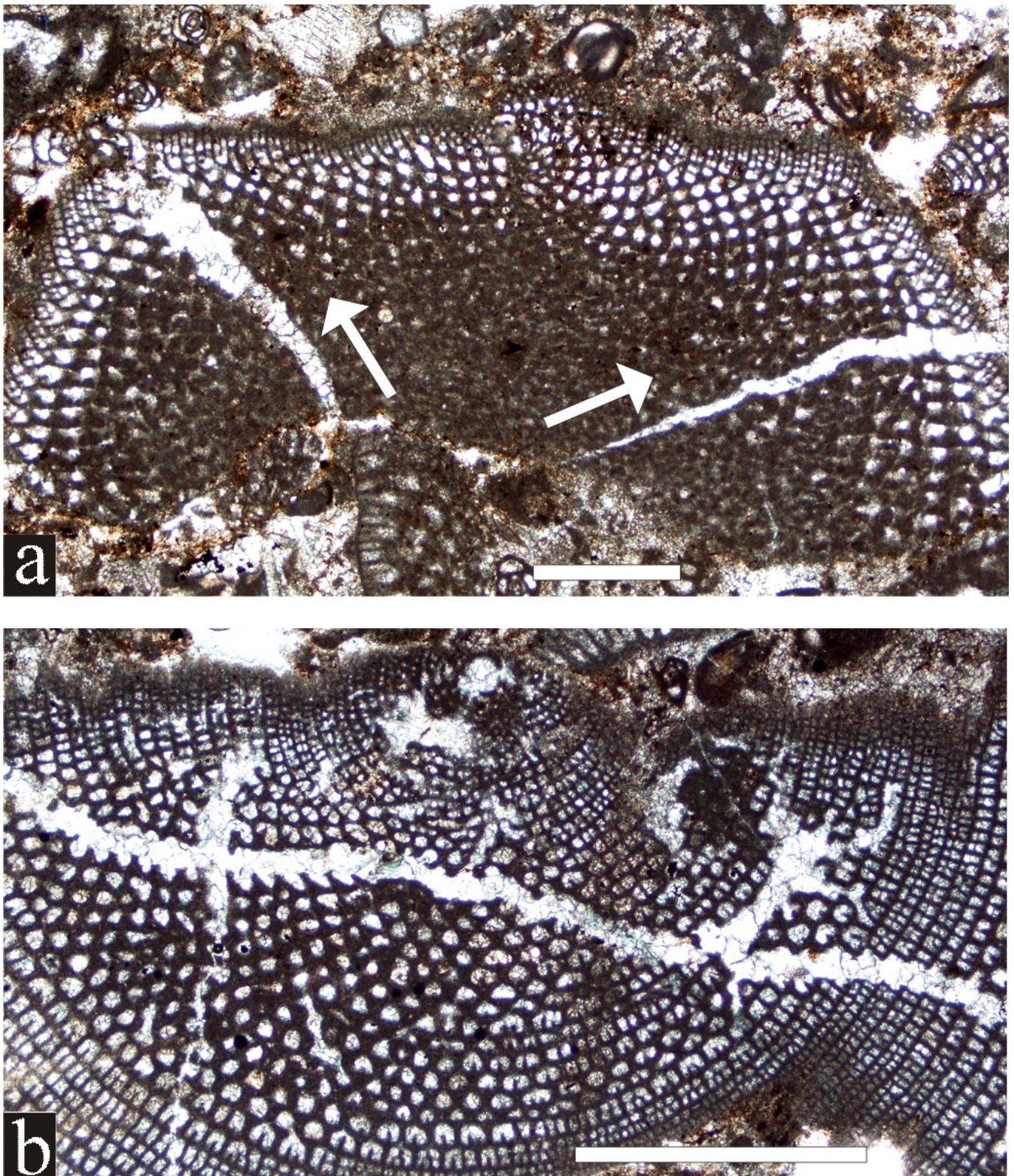


Fig. 5. Tubular, straight to slightly bending borings of unknown producer exhibiting increasing diameter and branching in **b**. The assumed boring direction (starting from the test ventral side) in **a** is marked by the white arrows. Thin-section AQ 23. Scale bar = 0.5 mm.

wall thickness is about 7 μm . The tube is similar to epibionts on orbitolinid tests (? sessile miliolids) (Fig. 7b).

CONCLUSIONS

Thin-section studies of Barremian-Aptian shallow-water carbonates from central Iran have yielded different bioerosional structures within orbitolinids. The observed traces can be related

to the activity of calcimicrobial bacinellid crusts, the ichnogenus *Entobia*, endolithic tubes of unknown origin and possibly also thaumatoporellaceans. In several cases, the distinction between euendoliths and cryptoendoliths is not possible. The identified bioerosional structures were observed in foraminiferal-dasycladalean wackestones to poorly washed packstones, a palaeoenvironment of supposedly relatively low rate of

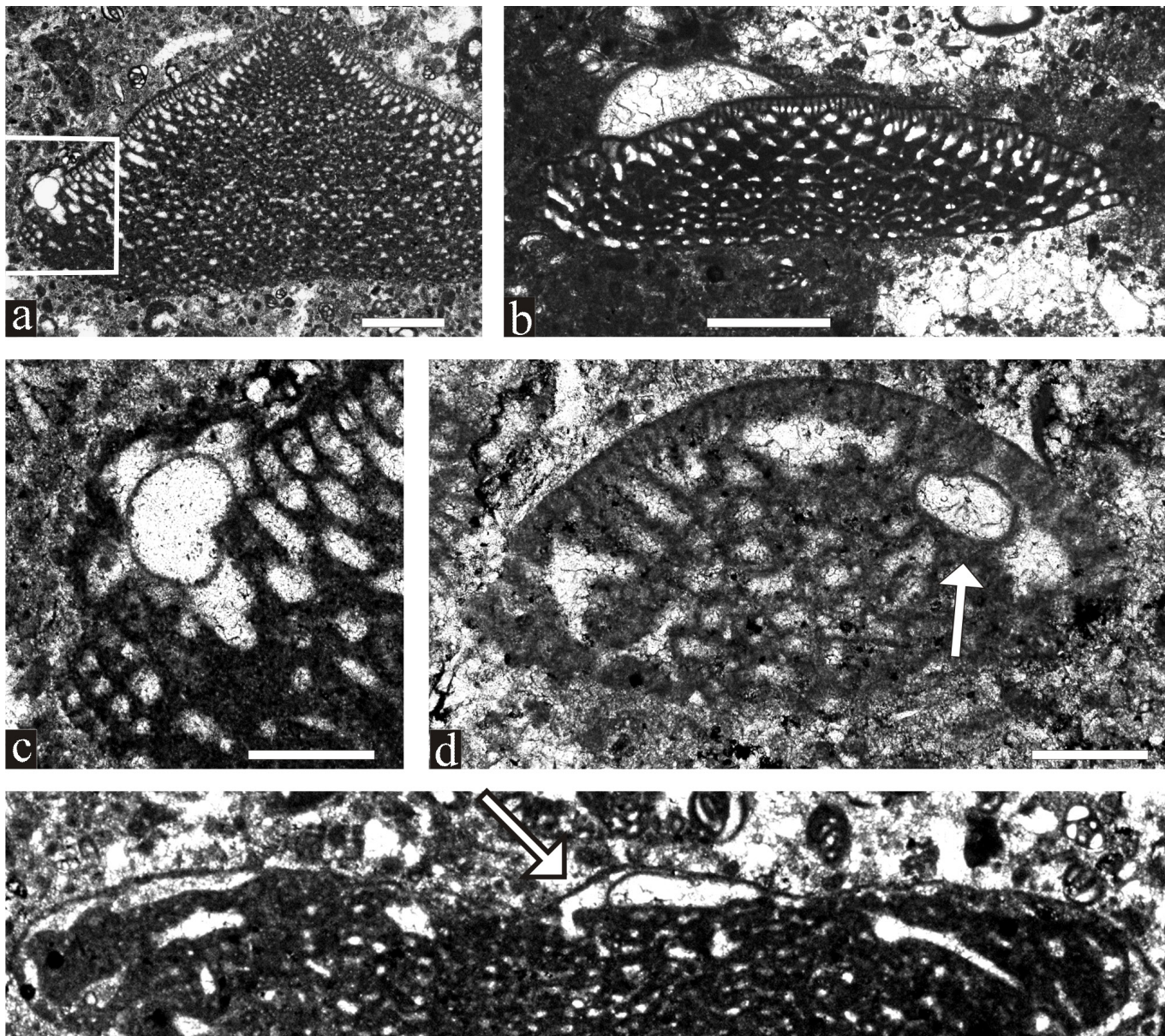


Fig. 6. Epi- and endolithic (euendolithic or cryptoendolithic) thauroporellaceans; **a)** Irregular spheroidal specimen inside a cavity affecting the orbitolinid marginal zone. Thin-section M 3; **b)** Epilithic specimens attaching to orbitolinid test. Thin-sections AQ 8; **c)** Detail from **a**; **d)** Euendolithic or cryptoendolithic specimen inside a bored cavity. Thin-section AQ 25; **e)** Flat conical orbitolinid test affected by various borings. Note the attaching thauroporellacean (arrow) at the ventral side stretching into a boring. Thin-section AQ 18 small; **f-g)** Specimens inside borings. Thin-section AQn 24, AQ 18 small. Scale bars = 0.5 mm, except c-d = 0.2 mm.

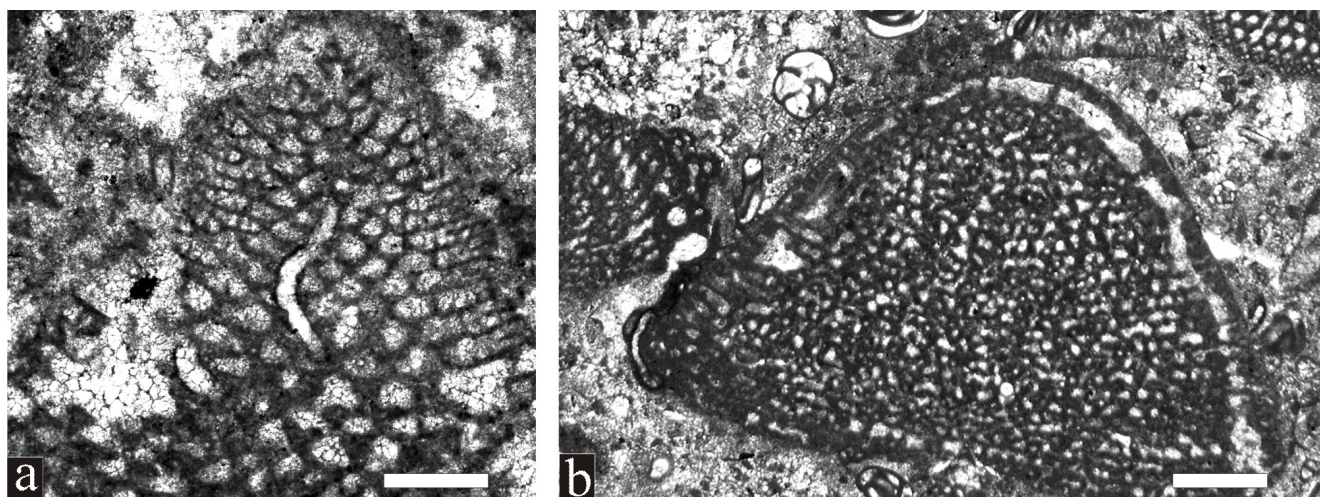


Fig. 7. **a)** Tubiform euendolith of unknown taxonomic position. Thin-section AQ 20; **b)** Epibiont (milioid foraminifer?) attached to an orbitolinid test (lower left margin) showing some similarities to the specimen in **a**. Thin-section AQ 23. Scale bars 0.2 mm for **a**, 0.5 mm for **b**.

sedimentation allowing these organisms to act as bioeroders. The most common ichnotaxon is *Entobia* (*Entobia* ichnofacies). Preliminary results show that the intensity of bioerosion is much more intense in the Early Barremian than in the Lower Aptian samples. This observation might reflect the influence and possible change of longer-term environmental conditions (nutrients?). Such a link between evolutionary trends (e.g., abundances, speciation) and nutrition influx was discussed recently by Schroeder et al. (2010) for the orbitolinid fauna of the eastern Arabian plate (including southwest Iran).

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