Acta Geologica Polonica, Vol. 60 (2010), No. 1, pp. 39–44

Unusual preservation of *Ophiomorpha* in middle Miocene rocks of Wadi Zablah, east Matruh area, northwestern Egypt

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ABSTRACT:

Gameil, M. and Sadek, S. 2010. Unusual preservation of *Ophiomorpha* in middle Miocene rocks of Wadi Zablah, east Matruh area, northwestern Egypt. *Acta Geologica Polonica*, **60** (1), 39–44. Warszawa.

Unusual biogenic structures in the form of hollow burrows are preserved in middle Miocene sandy limestones (calcarenites) exposed in Wadi Zablah, east of the town of Mersa Matruh along the Egyptian Mediterranean coast. This calcarenite unit is about 30 m thick and lies in the middle part of the Marmarica Formation. The burrows commonly are up to 2.5 m long and can reach a length of 3 m in some outcrops. The internal diameter ranges from 1 to 5 cm. In most cases there is a hard cemented zone surrounding the hollow burrows that ranges in thickness from 0.2 to 0.4 cm.

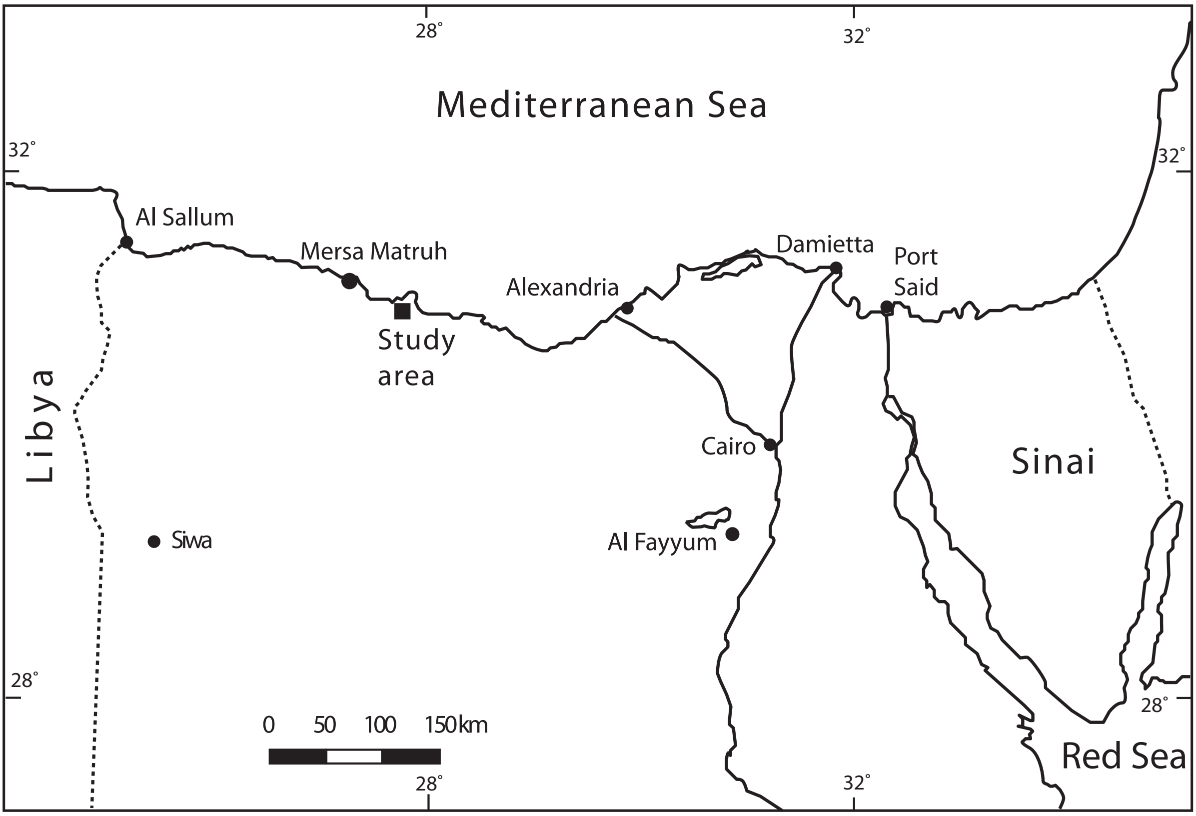
In several burrows where the hard cemented zone is preserved, a knobby sculpture is visible on the internal surfaces of the burrows. This is considered to be a negative mold of the pelleted wall of *Ophiomorpha*. This inverted knobby sculpture is formed by the cemented zone, which permitted the trace fossils' preservation, the original *Ophiomorpha* wall having been dissolved away during or subsequent to lithification by subsequent weathering processes. The presence of these burrows in association with marine fossils suggests a littoral to very shallow shelf environment.

Key words: Trace fossils; Taphonomy; *Ophiomorpha*; Miocene; Egypt; Diagenetic concretion.

INTRODUCTION

In the middle Miocene rocks of Wadi Zablah unusual examples of *Ophiomorpha* occur in the middle part of a succession of alternating shale, marl and limestone. The specimens occur as vertical, inclined and horizontal burrows. Unusual in the occurrence of these burrows is their length, which may reach three metres, and their concretionary preservation. The purpose of this paper is to describe their morphologic features and to suggest probable interpretations concerning their origin.

Generally, the Miocene rocks that crop out along the northern part of the Western Desert form a plateau that parallels the Mediterranean coast from Alexandria to Mersa-Matruh and onto the Egypt-Libya borderland. Wadi Zablah is one of the valleys that intersect this plateau, located about 45 km east of Mersa Matruh (Text-fig. 1). The rocks are composed of shallow-marine deposits containing a variety of macro- and microfossils (Text-fig. 2) and have been given the formal name Marmarica Formation (Said 1962).



Text-fig. 1. Location map of Wadi Zablah, Matruh area

STRATIGRAPHIC OCCURRENCE OF THE BURROWS

The lower part of the middle Miocene succession at Wadi Zablah consists of argillaceous limestone that is greenish-grey in color and rich in echinoids and pectinid bivalves. This limestone is overlain by white sandy limestone (calcarenite) composed entirely of rounded algal particles and fossil fragments cemented by sparite (Text-fig. 3). The upper 30 m of this limestone contains abundant dark brown burrows of *Ophiomorpha*.

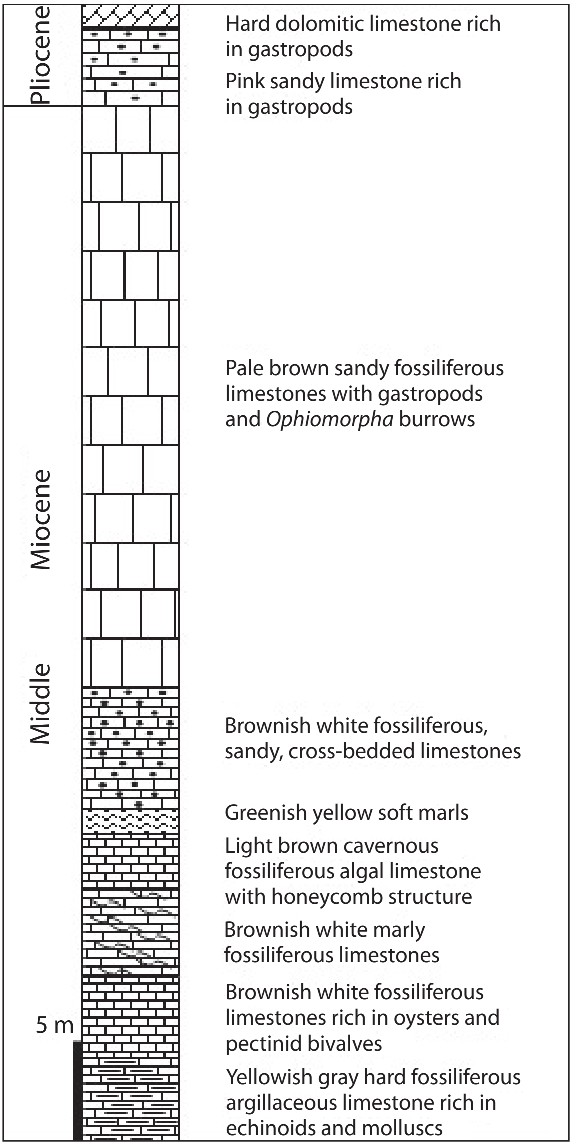
The burrows are exposed as complete tubes parallel to one another (Pl. 1, Figs 1, 2, 6). From these burrows circular to elliptical openings extend horizontally and appear as rounded holes on the cliff surface in some outcrops (Pl. 1, Fig. 3; Pl. 2, Figs 1, 2). In some cases the burrows are broken as a result of weathering processes and hang from the roof of the rock (Pl. 1, Fig. 4).

Where a cliff surface is exposed the burrows resemble brown carvings on the cliff surface. The interior of these burrows is filled with friable silt and clay (Pl. 1, Fig. 5) and they extend downward in a vertical or inclined position. Some burrows extend downward then incline upward and again downward. Other burrows extend downward and turn horizontally along bedding planes (Pl. 2, Figs. 1, 2). Primary lamination is preserved except where crossed by burrows.

DESCRIPTIVE ICHNOLOGY

The trace fossils consist of hollow vertical shafts and many horizontal galleries that spread along bedding planes. Most of the shafts extend perpendicular to or at high angle to bedding planes with no change in burrow orientation. Where free specimens are collected, one observes many small openings arising laterally from the main burrows (Pl. 3, Figs 1, 2; Pl. 6, Fig. 2). Around the hollow cavity in several specimens, there is a dark gray, thin, hard cemented zone (Pl. 5, Figs 1-4). In cases where the hard cemented zone is preserved the interior of the burrows bears a knobby sculpture similar to the pelleted wall of *Ophiomorpha* (Pl. 3, Fig. 2; Pl. 5, Figs 1-4; Pl. 6, Figs 1, 2).

The burrows generally range in length from 1 to 2.5 m and can reach 3 m. The internal diameter of well preserved burrows that have knobby mold linings is uniform within each specimen but ranges among specimens from 1 to 5 cm. Measurements of concretionary



Text-fig. 2. Stratigraphic section of the Marmarica Formation showing the position of the trace fossil

burrows that lack knobby mold linings are not taken into consideration as they are likely enlarged by dissolution and so do not accurately reflect original burrow diameters.

The thickness of the concretionary burrow ranges from 0.5 to 5 cm and the cemented rim around the hollow burrow is about 0.2 to 0.4 cm thick. This thin rim is not knobby, so it is probable that it is a secondary halo produced during an initial phase of concretionary development.

The trace fossils occur as isolated vertical burrows and systems that ramify into many tunnels (Pl. 3, Figs 3, 4; Pl. 4, Figs. 1, 2). Small horizontal openings extend from both burrow types (Pl. 4, Figs 3, 4).

ORIGIN OF THE BURROWS

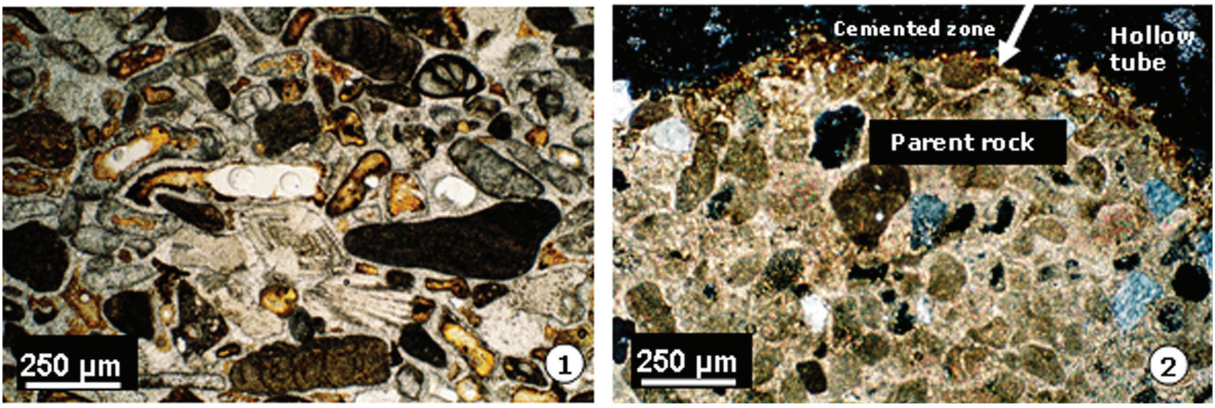
The inverted knobby sculpture seen on the interior of some burrows is very similar to the pelleted exterior wall pattern of the trace fossil *Ophiomorpha*. For this reason the burrows are interpreted as concretionary molds of *Ophiomorpha* burrows. *Ophiomorpha* is defined, apart from general burrow morphology, on the basis of the characteristic knobby or pelleted exterior of their linings (Frey *et al*. 1978).

Ophiomorpha shafts and galleries commonly remain open or are later washed clean or cleared of fill via dissolution. With dissolution, *Ophiomorpha* segments may lose part or all of the burrow lining, usually from the inside outward (Cunningham *et al*. 2009). Therefore each of the exposed burrows at Wadi Zablah is considered to be a concretionary halo outside the original walls of the trace fossils. Subsequently both infill and pelleted wall of the burrow were removed by terrestrial weathering processes, chiefly dissolution by ground water.

Three stages are proposed for the formation of the empty concretionary burrows (Text-fig. 4). The first stage involves the formation of *Ophiomorpha* burrows by callianassid shrimp. After the death of the producers, the burrows were buried and filled partially or completely with sediment. Diagenetic processes formed a hard cementing zone around the *Ophiomorpha* burrows. Finally, dissolution removed both infill and the pelleted wall, exposing only hollow concretionary burrows with a knobby mold on their internal surface surrounded by the hard cemented rim.

Corroborating the attribution of the investigated burrows to *Ophiomorpha* is the abundance of well preserved *Ophiomorpha* in the underlying lower Miocene sandstones of the Moghra Formation. The difference lies in the state of preservation, which makes the explanation of the origin of the studied burrows somewhat uncertain. Dissolution could affect these sediments more quickly than the underlying lower Miocene sediments. Moreover, these rocks are the youngest exposed strata whereas post-Miocene sediments are absent over most of the Marmarica Plateau. Consequently the empty burrows are interpreted as relicts of *Ophiomorpha*. The burrows intersect bedding planes and continue without interruption above and below it, indicating near-continuous deposition.

One of the best documented modern tracemaker-trace relationships is that of the ghost shrimp *Callichirus* (formerly *Callianassa*) *major* as one of the makers of *Ophiomorpha nodosa* burrow systems (Weimer and Hoyt 1964). Several species of tha-



Text-fig. 3. Photomicrographs of the rock surrounding the trace fossils. **1** – Calcarenite composed of algal grains and other bioclasts cemented by sparite; **2** – A hard cemented zone surrounding the central opening and followed by the parent rock

lassinideans are known to construct burrows with pelleted linings (Frey *et al.* 1978; Bromley 1996). Other decapods such as some brachyurans (crabs) and astacids (crayfish) build pelleted chimneys protruding above the surface, but their dwellings within the sediment are unpelleted (Chamberlain 1975). Hence, pellet-lined burrows today seem to be exclusively the product of thalassinidean shrimps. Three ichnogenera are widely recognized and attributed to the work of thalassinidean or similar crustaceans: *Ophiomorpha, Thalassinoides* and *Spongeliomorpha* (Fürsich 1973; Schlirf 2000). In *Ophiomorpha* the wall is pelleted and in *Thalassinoides* the wall is smooth, whereas in *Spongeliomorpha* the wall displays distinct bioglyphs (scratches).

Thus, the *Ophiomorpha* burrow systems at Wadi Zablah were likely formed by a callianassid shrimp. The burrows functioned as dwellings in a grainstone substrate and therefore required wall stabilization. Callianassid shrimps are the principal burrowers in tropical, shallow subtidal carbonate sand environments (Curran and Martin 2003).

A COMPARISON OF THE HOLLOW BURROWS WITH OTHER BIOGENIC STRUCTURES

Confusion regarding the origin of these burrows may arise because of similarity with other structures of similar morphology such as tree stump casts and rhizoliths. Alonso-Zarza *et al.* (2008) described mega-rhizoliths from the Pleistocene aeolian deposits of Spain. Although their tubes superficially resemble the middle Miocene tubes described herein, several differences distinguish the two types of tubes. The Egyptian tubes are found in shallow marine sediments rich in foraminifera, algae, bivalves, gastropods and echinoids (Text-fig. 3), and they show downward ramification (Pl. 2, Fig. 1) but do not have a root-like pattern. In addition, the tubes have a nearly fixed diameter along their length, not tapering as is characteristic for root traces (Pl. 2, Fig. 2). The preservation of knobby sculpture is clear proof that the tubes are of animal origin.

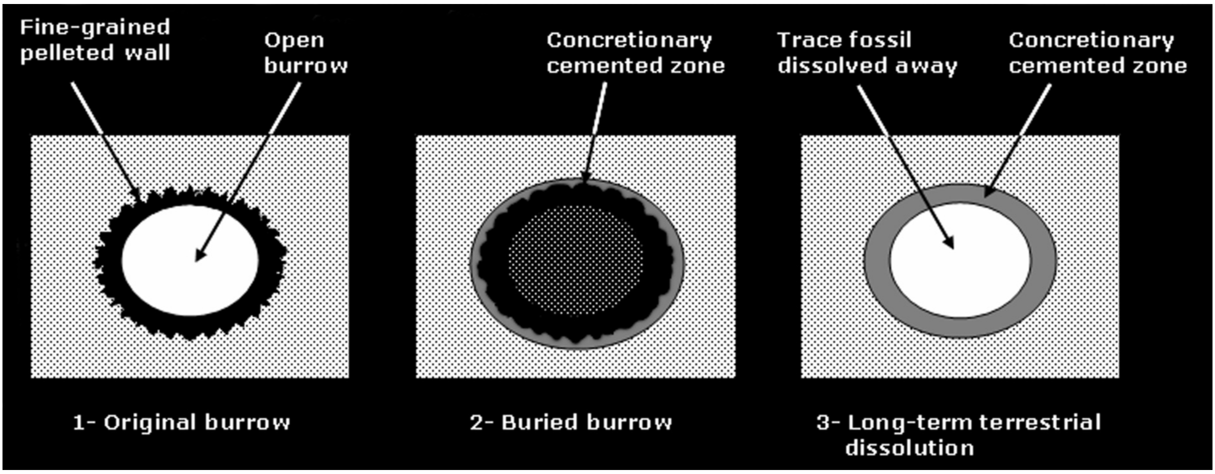
A cross section of rhizoliths as described by Alonso-Zarza *et al.* (2008) shows five zones of different mineralogy and microfabric. In the Egyptian tubes these zones are not recognized and only a cemented zone surrounds the central opening of the burrow (Text-fig. 3. 2).

DEPOSITIONAL ENVIRONMENT

The trace fossils are found in well sorted, sandy limestone (calcarenite) composed mainly of sand-sized algal particles and containing small, broken bivalve shells (Pl. 6, Fig. 3). This suggests that the animals responsible for the structure lived in an energetic environment. The associated macrofossils such as barnacles, echinoids, bivalves, gastropods and bryozoans are characteristic of littoral to very shallow subtidal environments (Gameil and Sadek 2007).

Ophiomorpha is a well-established and conspicuous trace fossil occurring in shallow marine sandy facies from the Mesozoic onward, characteristic of the Skolithos ichnofacies (Seilacher 1967).

Field observations show that the studied trace fossils extend for 2.5 m above and below bedding planes without any evidence of truncation (Pl. 2, Figs 1, 2). On the other hand bioturbational structures is sparse and accompanied by primary horizontal lamination. This indicates that the rate of deposition was continuous. The callianassids must have kept pace by moving upward in the newly deposited sediments, with no time for extensive bioturbation.



Text-fig. 4. Steps of formation of *Ophiomorpha* concretionary burrows

CONCLUSION

The seemingly enigmatic burrows found in the middle Miocene sandy limestone (calcarenite) of Wadi Zablah, Egypt represent an unusual style of preservation of *Ophiomorpha*, produced most likely by callianassid shrimp.

The unusual mode of preservation of the trace fossils in the form of long hollow burrows preserving a knobby mold of the original pelleted wall may have developed as a result of both constructive and destructive processes. The constructive process is the diagenetic process that formed a hard concretionary layer around the burrows. It was followed by dissolution which removed the original wall and the sediment that may have originally filled the *Ophiomorpha* burrows.

Acknowledgements

The authors would like to thank Franz Fürsich (Erlangen University) and Richard G. Bromley (University of Copenhagen) for their helpful suggestions. The authors are also grateful to Alfred Uchman (Jagellonian University) for his valuable discussions and his help in revising a primary draft of the work. Many thanks to H. Allen Curran, Andrew K. Rindsberg and Christian Gaillard for their great efforts and valuable suggestions in reviewing the manuscript and bringing it to its present form.

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Manuscript submitted: 5th January 2009
Revised version accepted: 12th November 2009

PLATES 1–6

PLATE 1

1 – Several parallel burrows with horizontal openings arising from them (shown by the arrow).
2 – Cross section of three burrows showing circular outline
3 – Outcrop showing a vertical burrow and two horizontal burrows
4 – Outcrop showing several broken burrows hanging down from the roof of the rock
5 – Cliff face showing the limestone cut by several burrows that are highly weathered
6 – Outcrop showing vertical burrows with hollow interior and other horizontal openings. Notice the nearly constant diameter of the burrows along its length

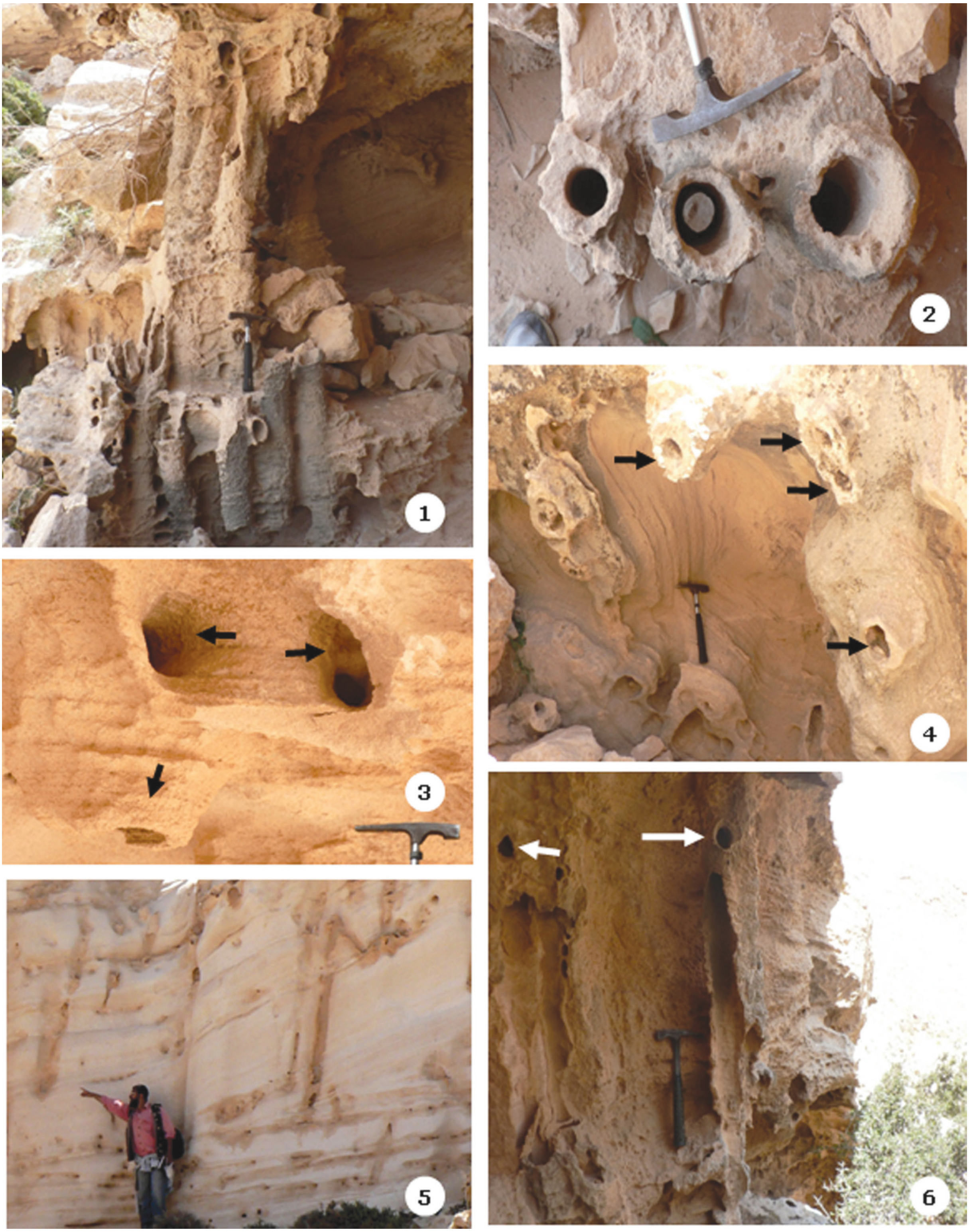
1
2
3
4
5
6

PLATE 2

1-2 – Cliff face showing the limestone beds cut by several burrows that are highly weathered. Notice the ramified burrows shown by the arrow in Fig. 1 and the abundant rounded holes which represent horizontal galleries spread along the bedding planes and radiating from the hollow vertical shafts in Fig. 2


1


2

PLATE 3

1 – Side view of a hollow burrow
2 – Cross section of the same burrow showing interior of the burrow with a knobby sculpture and a small horizontal opening (shown by arrow)
3-4 – Branching burrows showing two inclined branches radiating from the main burrow

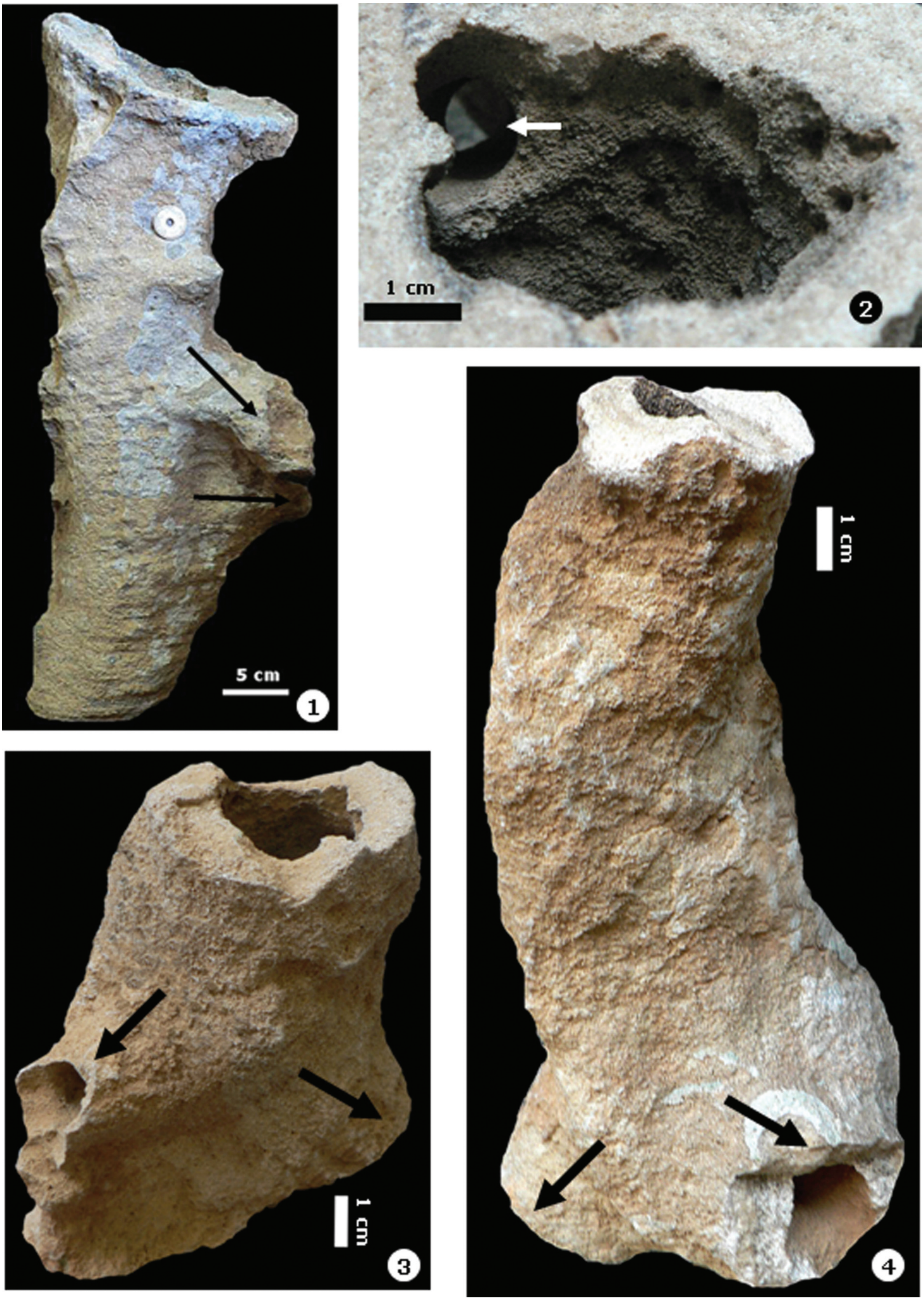
5 cm
1
1 cm
2
1 cm
3
1 cm
4

PLATE 4

1 – Side view of a hollow burrow
2 – Cross section of the same burrow showing elliptical and wide cross section probably due to multi-burrowing stages
3-4 – A broken piece of rock showing several burrows of varying diameter, notice the horizontal opening arising from the large opening (shown by arrow)


1 cm
1
1 cm
2
3
1 cm
1 cm
4

PLATE 5

1 – Side view of a hollow burrow
2 – Cross section of the same burrow showing interior of the burrow with knobby sculpture and a hard cemented zone
3-4 – Another burrow with knobby sculpture and hard cemented zone

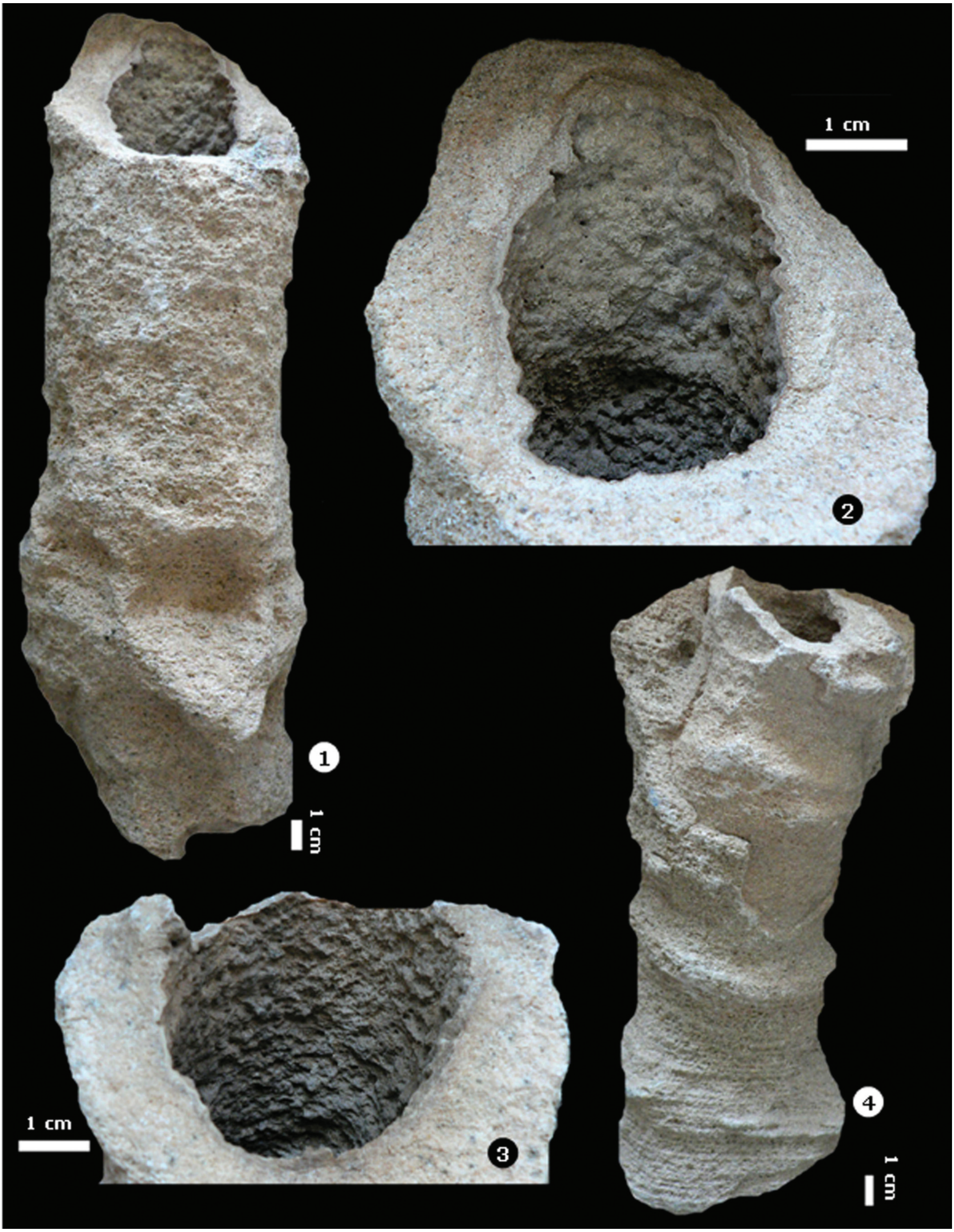
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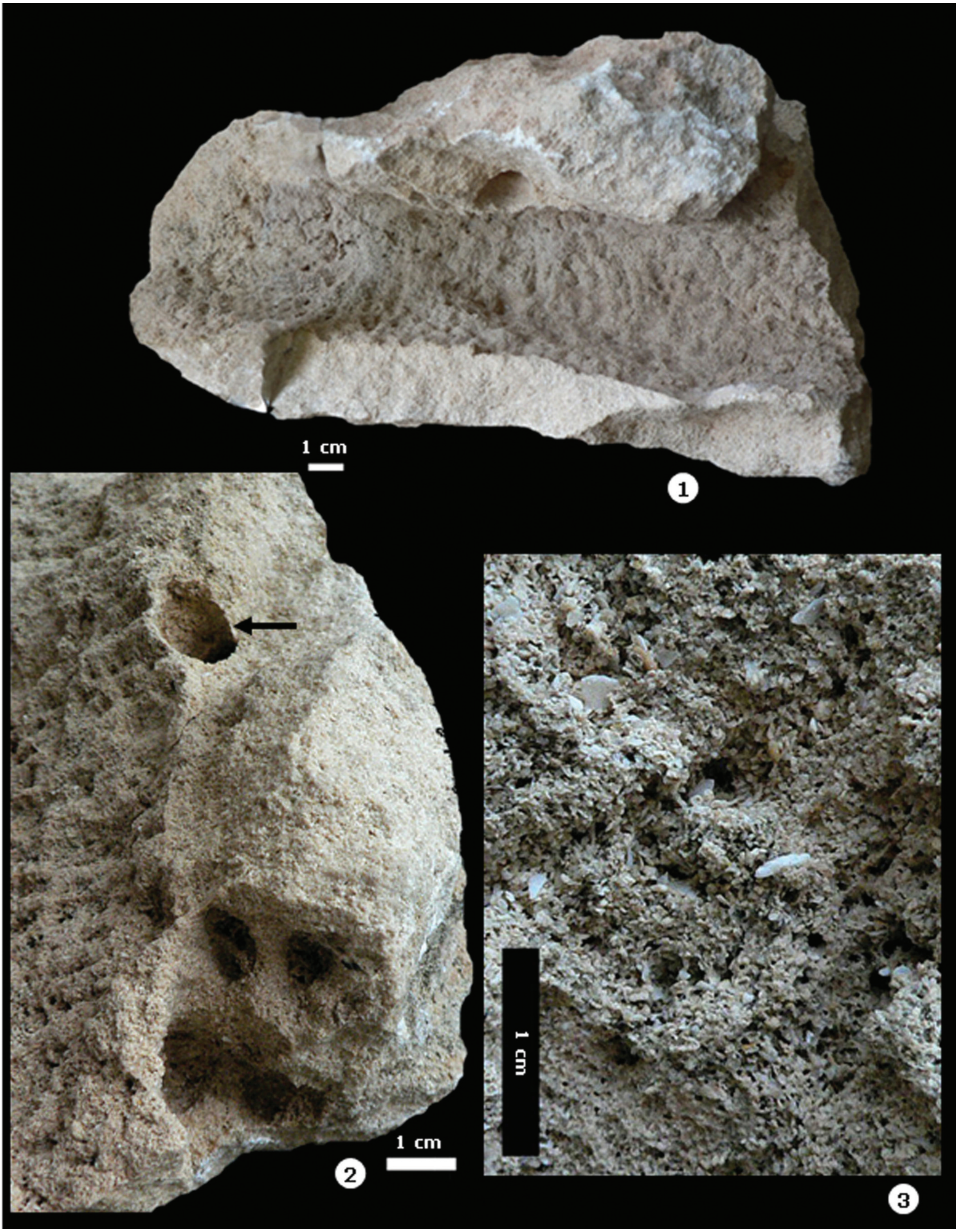
PLATE 6

1 – Longitudinal section of a broken burrow showing the burrow interior with knobby sculpture

2 – Magnification of the same specimen showing a horizontal opening (shown by arrow) and four incomplete burrows

3 – Enlarged part of the same specimen showing the interior composed of bioclastic grains dominated by small shell fragments of bivalves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