NATURAL CASTS OF *ENTOBIA* FROM THE LATE CAENOZOIC OF SICILY

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Abstract. As with other ichnofossils, the study of the ichogenus *Entobia* Bronn, 1837, attributed to the activity of boring sponges, is useful to understand taphonomic processes and reconstruct paleoenvironments. Here we delineate a diverse *Entobia* assemblage from Sicily, the first described from this Mediterranean island, based on the discovery of well-preserved natural casts. The studied association is represented by seven ichnotaxa, *Entobia cateniformis, E. cateniformis* form A, *E. geometrica, E. laquea, E. ?megastoma, E. ovula, E. ?paradoxa*, which come from the late Caenozoic sites of Altavilla Milicia and Sferracavallo, in north-western Sicily. Aragonitic bivalves, mostly veneroids, served as substrate for the boring organisms responsible of producing these ichnotaxa. *Entobia* was also found associated with natural casts of the boring *Caulostrepsis taeniola*, produced by polychaetes. Ichnology and shell-bed taphonomy indicates that investigated deposits formed in conditions of low rate of sedimentation; post depositional processes involved chemical conditions favorable to the preservation of calcite shells.

INTRODUCTION

Ichnology represents an important interface between sedimentology and palaeontology, thus providing useful tools for palaeoenvironmental reconstruction and understanding taphonomic processes. This concept is also applicable to the ichogenus *Entobia* Bronn, 1837, which represents hard substrate-dwelling structures (domichnia), made by boring (Bromley & Asgaard 1993a; Gibert et al. 1998, 2007; Uchman et al. 2002). *Entobia* is generally produced by marine sponges of families Phloeod-

ictyidae Carter, 1882 (Schönberg & Tapanila 2006; Bromley & Schönberg 2007) and Clionaidae d'Orbigny, 1851. Within the latter family, the genus *Cliona* Grant, 1826 (Bromley 1970; Bromley & D'Alessandro 1984) certainly is the most widespread boring sponge. This genus comprises species that are efficient excavators and destroyers of lithified calcareous substrates, including corals and carbonate skeletons of molluscs, such as oysters, scallops and gastropods, as well as relatively thick barnacles (Mikuláš 1992; Holmes 2000; Radwańska & Radwański 2008; Duckworth & Bradley 2013, Dávid et al. 2017, 2021). *Cliona* sponges bore by chemical processes, producing new or widening existing cavities that communicate with the surface by exhalant

and inhalant canals terminating in pores (Schönberg 2008). They simultaneously produce considerable amount of sediment (Holmes 2000; Nava & Carballo 2008, and references therein; Calcinai et al. 2011). In general, evidence of boring sponges in the fossil record is very common and extends back to the lower Cambrian (Ward & Risk 1977). Fifty-two ichnospecies have been described to date within *Entobia* (Wisshak et al. 2019 and references therein). Whereas most *Entobia* records concern holes produced by the boring activity, finds of *Entobia* natural casts (Marcinowski & Radwański 2009; Radwański et al. 2011; Gurav & Kulkarni 2018; Belaústegui et al. 2018; Dávid et al. 2021; Łaska et al. 2021) are very rare, although this ichnogenus extends back to the Palaeozoic (Schönberg & Tapanila 2006) and is common from the latest Jurassic onwards (Bertling 1999; Taylor & Wilson 2003 and references therein). The knowledge of the *Entobia* association for Italian sites is rather scarce and almost limited to the study of late Caenozoic calcarenites from Puglia, in South Italy (Bromley & D'Alessandro 1984). To our knowledge, nothing is known on fossil sponge traces from Sicily, except for a doubtful Mesozoic case (Cherchi & Schroeder 2012) and Plio-Pleistocene borings found on Mesozoic limestone blocks and in an oyster shell bed (Dávid et al. 2017; Dominici et al. 2020).

The main purpose of the present article is to report for the first time from Sicily an association of *Entobia* ichnospecies determined on the basis of natural casts. The findings reported here, associated with shelly substrates, are also discussed in terms of shell-bed taphonomy, useful to reconstruct the dynamics of fossil formation and the environment of deposition. The stratigraphic intervals discussed here encompass ecological and climatic transitions in Pliocene to Early (possibly Middle) Pleistocene times and thus represent significant episodes of the late Caenozoic marine history of Sicily.

GEOLOGIC AND STRATIGRAPHIC SETTING

The studied localities of Altavilla and Sferracavallo are situated near Palermo in north-western Sicily (Figs 1-3), in the easternmost sector of the Maghrebian foldthrust belt, resulting from the deformation of different palaeogeographic domains. As a part of the Alpine collisional belt developed between the African and European plates, Sicily is characterized by a complex structural geology, especially in its northern part. Main thrust tectonics in Sicily are the late Oligocene, with deformation of platform and pelagic sediments and formation of carbonate and terrigenous chains in the north-western part (Nigro & Renda 1999, Arisco et al. 2006 with references, see Fig. 1D). Compressional and extensional deformations mainly occurred during late Neogene-Quaternary time along the northern Sicilian coast, forming structural highs and basins (Catalano et al. 2000; Giunta et al. 2009; Catalano et al. 2013).

The Altavilla succession crops out close to the Altavilla Milicia village, about 20 km SE of Palermo (Fig. 1A, B and Fig. 2). This is well-known for its richly-fossiliferous deposits and high-diversity shelly assemblages occurring along the right flank of the Milicia creek (Altavilla s.s. succession in Moroni & Paonita 1964; unit ALT in Dominici et al. 2020) [included in the "Marly-Arenaceous Formation of Belice", BLC of Catalano et al. 2013]. High-frequency eustatic variations drove the formation of the Altavilla succession in shoreface-to-offshore transition and delta-front environments (Dell'Angelo et al. 2012; Dominici et al. 2020). Within the Altavilla sandstones, cyclicity is highlighted by the alternation of shelly or cemented strata with thicker, uncemented ones, possibly produced by the alternation of dry and wet conditions under climatic forcing (Dominici et al. 2020). Though trace fossils are very abundant, particularly on mollusc shells, where bioerosion structures produced by polychaetes and entobians are locally very common, ichnological studies have only recently been undertaken (Dávid et al. 2017; Dominici et al. 2017, 2020).

Samples collected at Sferracavallo, a few kilometres west of Palermo (Fig. 1), belong to the calcarenites of the Marsala Synthem of Calabrian to early Chibanian age (Agate et al. 2017 with references).

PALAEOENVIRONMENTS

The sample from site S1 was collected from the lower bed of a triplet of yellowish, cemented sandstone beds attributable to the Gelasian (Dominici et al. 2020). These cemented beds alternate with uncemented sandy beds with scattered small pebbles

Fig. 1 - The study area) A General location of the study sites in north-western Sicily, Italy. B) Location of the sites S2 and S3 near Sferracavallo, Palermo. C) Location of the sites S1 and S4 near Altavilla Milicia, Palermo. D) Schematic geo-structural map of part of north-western Sicily (from Arisco et al. 2006, modified).
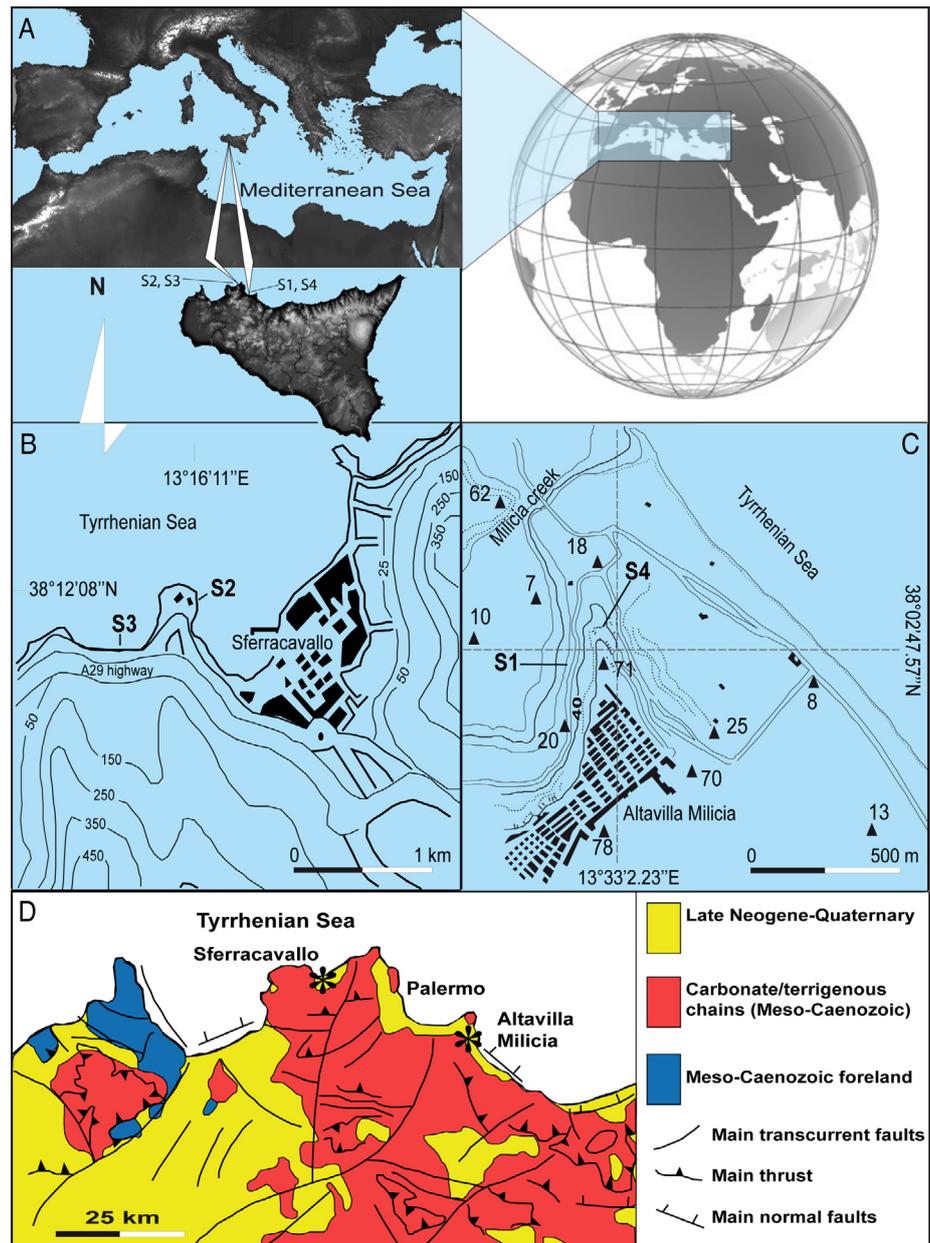
(Fig. 2C, D). The bed containing the studied sample formed in a shoreface delta-front environment under conditions of sediment starvation and winnowing (Dominici et al. 2020). This bed overlies an uncemented yellowish bed with a *Corbula-Pelecyora* bivalve association, about 2 m-thick. The *Corbula-Pelecyora* bed overlies a grey bed with *Lucinoma borealis* (Linnaeus, 1767) in life position. Cemented beds are dominated by epifauna (brachiopods, balanids, ostreid and pectinid bivalves, regular echinoids and encrusting bryozoans), usually preserved as casts. Sample from site S4 was collected where bioerosional traces are most intense and diverse (Dávid et al. 2017), in coincidence with an ostreid-rich sandy-pebbly bed with a low-diversity mollusc assemblage (Fig. 1C and Fig. 2A, B, D). This bed presumably formed at a delta-front environment periodically swept by high-density currents, at a shallower water paleodepth with respect to the preceding sample (Dominici et al. 2020). Sample from site S1 consists of a natural cast of several camerated branches of *Entobia* (Fig. 4C-F) found in association with a natural cast of the polychaete boring *Caulostrepsis taeniola* Clarke, 1908 (Fig. 4D). This association was found on a cemented portion of sediment, incorporating an incomplete cluster of balanids with different orientations. The largest balanid in the cluster is very incomplete, showing the undulating margin that separates the crown from the basal plate (cf. Radwańska & Radwański
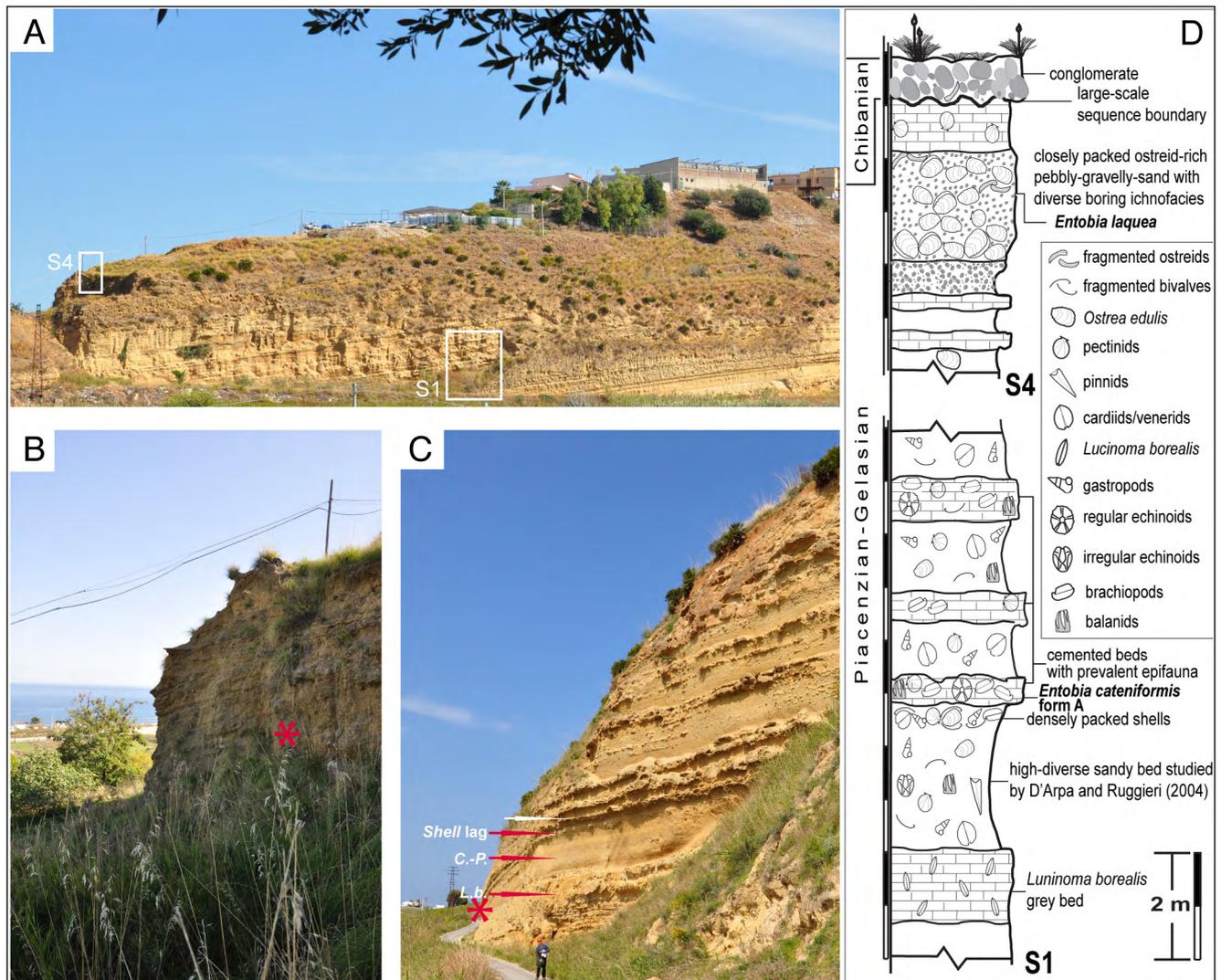
Fig. 2 - Sites S1 and S4 at the Piacenzian-Gelasian Altavilla Milicia section, Palermo, north-western Sicily. A) Panoramic view of the northern part of the Altavilla Milicia succession showing position of S1 and S4 (white rectangles). B) Detail of the site S4 with location of the finding place of *Entobia laquea* natural cast (red asterisk). C) The site S1 showing location of *Entobia cateniformis* form A (red asterisk) and the *Corbula-Pelecyora* (*C.-P.* and red arrow) and *Lucinoma* (*L.b.* and red arrow) beds. D) Simplified log of sites S1 and S4 with the main mollusc assemblages and the *Entobia* findings.

2008, pl. 9, figs 2, 4). This balanid, showing a thickness of about 1mm, bears an inner ribbed sculpture, which, according to Relini (1980), is typical of the genera *Balanus* or *Concavus*. The *Entobia* branches are in contact with the inner part of the basal plate and the crown of the larger balanid specimen, and overlap small balanid basal plates, mostly in the form of traces (Fig. 4C). Another natural cast of *Entobia* was found on an *Ostrea edulis* (Linnaeus, 1758) shell from S4 (Fig. 5B).

Samples from sites S2 and S3 (Fig. 4A, B; Fig. 5A, C-F; Figs 6-8) were collected from decametric to metric, *in situ* blocks of calcarenite-calcilutite. Most samples are from the locality known as Baia del Corallo (site S2: Fig. 1A, B and Fig. 3A, C, E,

F) and were collected between a few centimetres to 5 m a.s.l. A few samples are from the nearby bay known as La Cala (site S3: Fig. 1A; also see Figs 3B, D), where large blocks were investigated at 8-12 m a.s.l. At site S2 blocks were used for filling coastal depressions and building a concrete platform. At site S3 blocks were just dumped on the coastal plain. The blocks are ochre, occasionally whitish, discretely to strongly cemented and contain a rich faunal assemblage consisting of abundant, often densely-packed (Figs 3D, F) molluscs (mainly bivalves), remains of encrusting and erect bryozoans, rare polychaetes, among which is *Ditrupa,* rarely concentrated in pockets by bottom current flow (Fig. 3E), and some encrusting species (Fig.
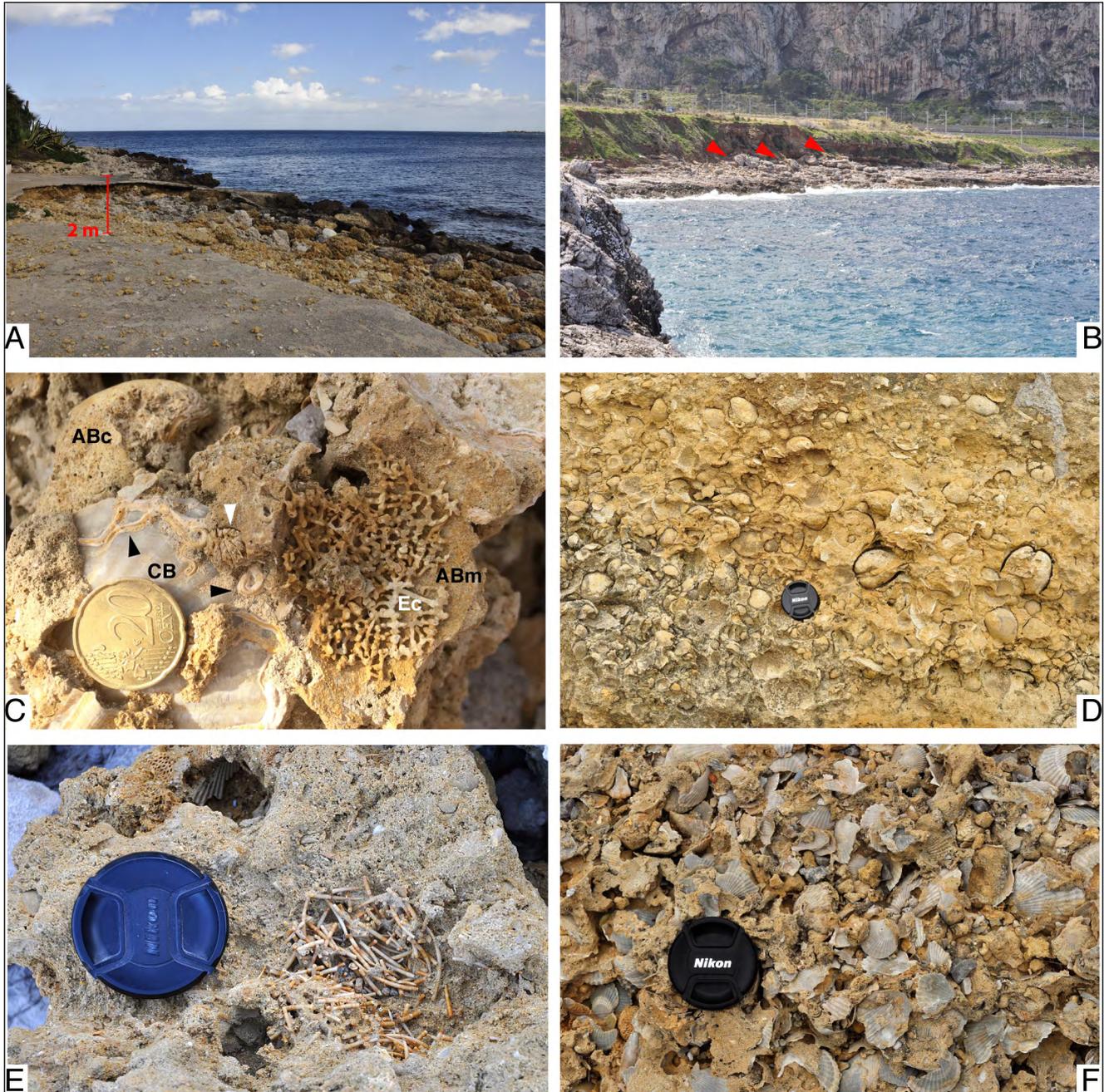
Fig. 3 - Sites S2 and S3 along the north-western coast of Sicily near the village of Sferracavallo, Palermo. A) Panoramic view of the site S2 with Pleistocene, prevalently yellow, calcarenite-calcilutite blocks, partially covered by a concrete sheet, with *Entobia* casts. B) Panoramic view of the site S3 showing the Pleistocene calcarenite-calcilutite blocks (some of them indicated by arrows). C) Typical association from the calcarenite of the Marsala Synthem at site S1 showing preserved bivalve calcite shell (CB) with encrusting polychaete (black arrows), moulds (ABm) and casts (ABc) of veneroid bivalves, casts of a solitary coral (white arrow) and of a well-developed entobian (Ec). D) Closely packed complete bivalves preserved as casts from a calcarenite block with entobians at S3 site. E) *Ditrupa* tubes densely packed by bottom current at site S2. F) Shell lag with the pectinid *Aequipecten opercularis* (Linnaeus, 1758) from site S2. Diameter of the 20 euro cents coin in C is 22.25 mm; diameter of the camera caps is 7 cm in E and 6.5 cm in D and F.

3C), echinoids, solitary corals and worn fragments of rhodoliths. With the exception of pectinids and rare ostreids (mainly *Ostrea edulis* Linnaeus, 1758), which have calcite shells, molluscs are preserved as moulds or casts of large veneriids (possibly *Callista* sp. and *Arctica islandica* (Linnaeus, 1767)), cardiids (*Cardium* sp. and *Laevicardium* sp.), thraciids (*Thracia convexa* (W. Wood, 1815) and *T. pubescens* (Pulteney, 1799)) and small lucinids (possibly *Loripes orbiculatus* Poli, 1795). Bivalves are articulated, but not in life position (Fig. 3D). The pectinids *Aequipecten opercularis* (Linnaeus, 1758) (Fig. 3F), *Pecten jacobaeus*

Ichnospecies	Apertures	Apertural canals	Chambers	Intercameral canals	Apophyses	Growth phase(s)	Tiering
Entobia cateniformis Bromley and D'Alessandro, 1984*	Subcircular, irregularly spaced, 0.5-1.0 mm in diameter	Well developed	Cylindrical, elongated	Reduced	Numerous, slender (A) thicker and less (C)	A, B, C well developed, D reduced	Poorly developed in C
Entobia cateniformis form A Bromley and D'Alessandro, 1984*	Circular, regularly spaced, 0.15-0.2 mm in diameter	Short, thick, 1.5 mm long	Elongated, flattened, rounded	Short or missing	Short, thick	A-C	One
Entobia geometrica Bromley and D'Alessandro, 1984*	Two different sizes. Large: 0.7-3.8 mm. Small: 0.3-1.5 mm.	Very short	Oval, subspherical in B rounded, polygonal in C and D	Numerous, short	Long and numerous	B-D	One-two
Entobia gigantea Bromley and D'Alessandro, 1989	Owing to the special structure of the boring it can be hardly observed	-	Irregular, amoeboid	-	Numerous, long, much-branched, cylindrical or blade-shaped	D, E	
Entobia laquea Bromley and D'Alessandro, 1984*	Circular, numerous, irregularly spaced, 0.5-0.7 mm.	Very short	Oval, subtriangular, subquadrate		Long, commonly forked but scarce	B, C	Several
Entobia magna Bromley and D'Alessandro, 1989	Rounded, numerous, diameter of generally 1-2 mm, 3 mm in D	Short	Large, flattened, interlocking, rounded or irregular	Numerous, slender	Abundant, thin, unbranched	A-D	Normally one
Entobia ?megastoma (Fischer, 1868)*	Circular or suboval, numerous, irregularly spaced, 0.6-1.7 mm in diameter	Subcylindrical	Non-camerate	-	Short, rare	A-D	-
Entobia ovula Bromley and D'Alessandro, 1984*	Regularly spaced, numerous, 0.5-0.8 mm	Short, tapering outward or weakly inflated, barrel-like	Globose, ovoid, greatly crowded, 0.5-0.8 mm in diameter	Short, reduced to a constriction	Slender, few	A-C	One or two (poorly developed in growth phase C)
Entobia ?paradoxa (Fischer, 1868)*	Circular, uncrowded, 0.6-1.2 mm in diameter	Very short, 0.5 mm (in C)	Amoeboid, irregular, triangular, polygonal, star-shaped	-	Slender, some bifurcated	A-E	One or two well-developed
Entobia parva Bromley and D'Alessandro, 1989	Circural, oval, irregularly nestled 2-4 mm	Extremely short	Minute, forming patches, boxwork of inflated chambers (in D)	well-developed and enlarged in D	-	A-D	Several
Entobia retiformis (Stephenson, 1952)	Circular, small, 0.3-0.6 mm in diameter	Long (for the upper tier only)	The irregularly rounded chambers form rings along the intercameral canals 0.9-2.4 mm	Well-developed	Sparse	A-D	Two

Tab. 1 - Synoptical framework for comparison showing main features of selected ichnospecies of *Entobia* Bronn, 1837, among which those studied from the late Caenozoic of Sicily (indicated by asterisks).

(Linnaeus, 1758), *Talochlamys multistriata* (Poli, 1795) and *Pseudoamussium clavatum* (Poli, 1795) are common to abundant. The gastropod assemblage is characterised by moulds of *Turritella* sp. (probably *Turritella turbona* Monterosato, 1877) and casts of undetermined taxa. All these assemblages suggest that deposits at S2 and S3 sites formed in foreshore to shoreface environments. Bivalves are in general closely-packed, some of them articulated, and may form shell lags (Fig. 3D, F). Bioturbation structures also occur. A facies similar to that found in blocks at Sferacavallo was observed in the small bay at Torre Pozzillo, about 14 km west from S2, where calcarenites-calcilutites unconformably cover Mesozoic limestone. At S2 and S3 sites we found several natural cast of *Entobia* ispp. on bivalve casts and moulds.

MATERIAL AND METHOD

The ichnotaxa were determined on the basis of their morphological features, mainly following Bromley & D'Alessandro (1984). Measuring and counting data of the *Entobia* ichnospecies found have been carried out using InkScape 1.1 graphical software. A synoptical view of the main diagnostic characters of selected *Entobia* ispp. described here is shown in Table 1. We avoided collecting some samples at the Sferracavallo sites not to hamper the preservation of fossils. We instead based the taxonomic study at this site also on *in situ* observations and on pictures. All the collected material is housed at the Museo di Storia Naturale, Università di Firenze, Italy, with the exception of specimen TBE 153.2016 from site S4, housed at the A. Dávid collection, Department of Mineralogy and Geology, Debrecen University, Hungary.

Fig. 4 - *Entobia cateniformis* (IGF 104731, A-B) and *Entobia cateniformis* form A (IGF 102797, C-F) respectively from the Sferracavallo S2 (Calabrian to early Chibanian) and Altavilla Milicia (Piacenzian) S1 sites in north-western Sicily. A - *Entobia cateniformis* showing growth phase C-D. B - Close-up of sample as in A. C) *E. cateniformis* form A, showing growth phase A. C - Inner part of the large balanid showing the branched geometry of *E. cateniformis* form A. Note traces of small balanids (white outlines) covered by *Entobia* (red arrows). D - Close-up of specimen as in C (black rectangle) showing the contact area between *Entobia* and *Caulostrepsis* natural casts (white circles). E - *Entobia cateniformis* form A, showing elongated and flattened, rounded chambers with the circular chamberward terminals of the apertures (indicated by the arrows). F - *Entobia cateniformis* form A, showing row of chambers (indicated by the arrows). Arrows indicate short apertural canals. Scale bars: 1 cm in Fig. C; 0.5 cm in A, B, D; 0.1 cm in Figs E, F.
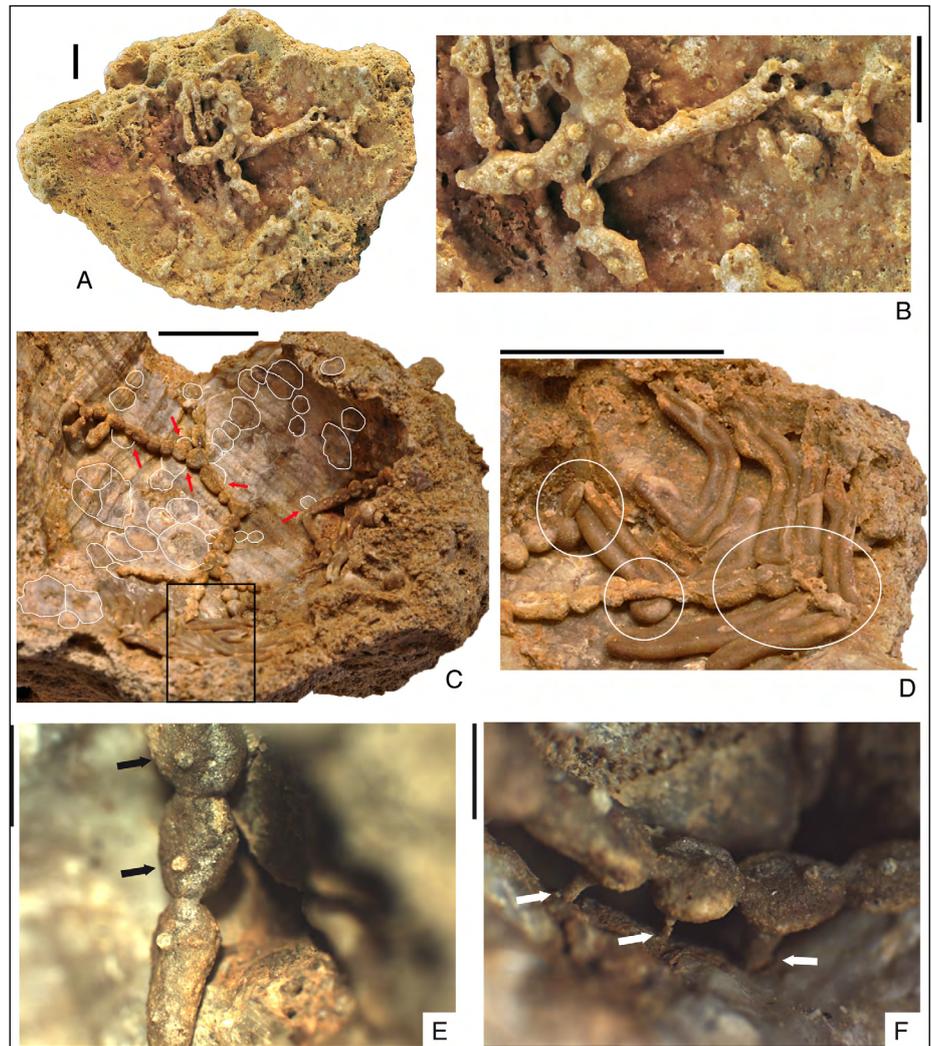
SYSTEMATIC ICHNOLOGY

Ichnogenus *Entobia* Bronn, 1837

Type ichnospecies: *Entobia cretacea* Portlock, 1843 by subsequent designation of Häntzschel (1962).

Entobia cateniformis Bromley & D'Alessandro, 1984

Fig. 4A, B

1984 *Entobia cateniformis* - Bromley & D'Alessandro, p. 238, pl. 16, figs. 1, 3-5; pl. 17, fig. 3; pl. 27, fig. 3.

Material: One sample (IGF 104731) from site S2 showing growth phases C-D. Natural cast on a probable veneriid bivalve cast.

Diagnosis: "Entobian developed as an open camerate system, comprising long rows of cylindrical chambers forming an irregular maze through branching and anastomosis. Many chambers elongated, commonly T-, L-, or cross-shaped where rows intersect. Elsewhere, no fusion of chambers. Intercameral canals reduced to constrictions. Apertures small, irregularly distributed; apertural canals well developed. Ontogenetic phases A, B and C well developed, D reduced" (Bromley & D'Alessandro 1984).

Description. This boring has a stenomorphic appearance due to the thin bivalve shell in which the bioerosion structure developed. The cylindrical chambers are variable in length. Twelve chambers have been measured. The results are the following: range 2.23-7.31 mm; average 3.39 mm; median: 2.8 mm; standard deviation 1.44 mm. Going to the main anastomosis the chambers are getting shorter, even spherical or bulbous.

Remarks. *E. cateniformis* is produced by the clionaid sponge *Cliona vermifera* Hancock, 1849 (Bromley & D'Alessandro 1984).

Distribution. Pleydell & Jones (1988) found this ichnospecies in the Miocene-Oligocene of the Grand Cayman Island. Recently reported from the Early Eocene (Gurav & Kulkarni 2018) and Miocene (Burdigalian) (Kulkarni et al. 2007) of western India, the Miocene of Ukraine (Radwański et al 2011) and north-eastern Spain (Belaústegui et al. 2018), the Pliocene of south-eastern Spain (as *E.* cf.
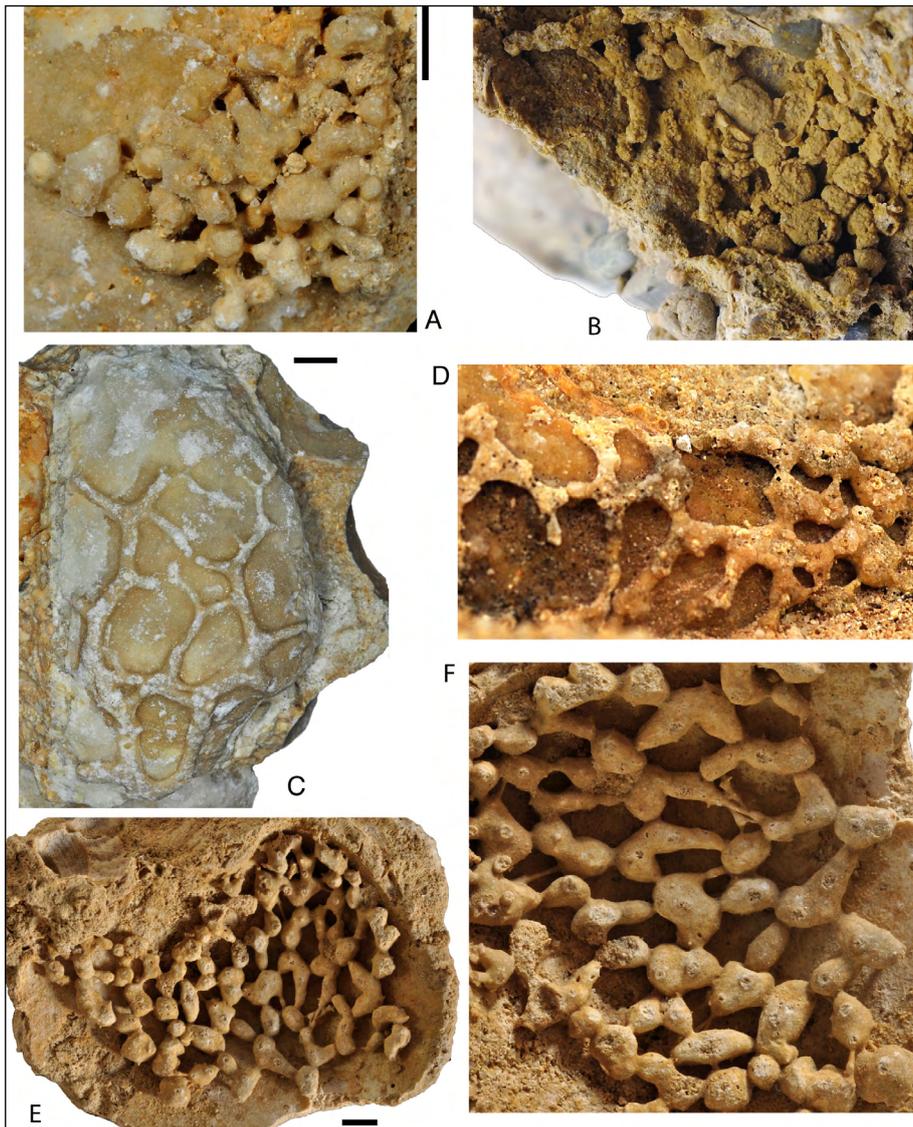
Fig. 5 - *Entobia geometrica* (A, B) and *E. laquea* (C-F) from the Gelasian of Altavilla Milicia (site S4) and the Calabrian to early Chibanian of Sferracavallo (sites S2 and S3), northwestern Sicily. A) *Entobia geometrica* (IGF 104732), site S2, showing growth phase C-D. B) *Entobia geometrica* (TBE 153.2016), site S4, showing growth phase C-D. C) *Entobia laquea* (IGF 104735), site S2, showing growth phase A. D) *Entobia laquea* (not collected specimen), site S3, showing growth phase B-C. E) *Entobia laquea* (IGF 104734), site S2, showing growth phase C. F) Close-up of the same specimen as in E. Scale bars: 0.5 cm.

cateniformis, see Łaska et al. 2021), and the Gelasian of Sicily (Dávid et al. 2017). Originally described from the Early Pleistocene (presumably Gelasian to Calabrian) of South Italy (Bromley & D'Alessandro 1984). The studied material is from the Calabrian to early Chibanian Marsala Synthem at Sferracavallo (Palermo, north-western Sicily).

Entobia cateniformis Bromley & D'Alessandro, 1984 form A
Fig. 4C-F

Material: One sample (IGF 102797) from site S1, natural cast of growth phases B-C on a large incomplete barnacle test.

Description. Apertures are not preserved, but their position is indicated by small (0.15-0.2 mm in diameter) circles that are distributed in regular rows (Fig. 4E). These circles represent terminations of the apertural canals toward the chamber. The number of circles depends on the length and form of the chamber. The elongated chambers show two circles at both ends; rounded. Flattened chambers displays only one circle in their central to peripheral part. These small circles represent terminations of the apertural canals toward the chamber. The length of the apertural canals do not exceed 1.5 mm.

In phase B rounded, flattened chambers, which are ordered in rows and branched at acute angles are present. The exploratory threads are absent, only short and slender apophyses occur rarely (Fig. 4F).

Phase C appears with characteristic elongated, cylindrical chambers that are narrower than those in the phase B. They are two or three times longer than the diameter of the flattened chambers
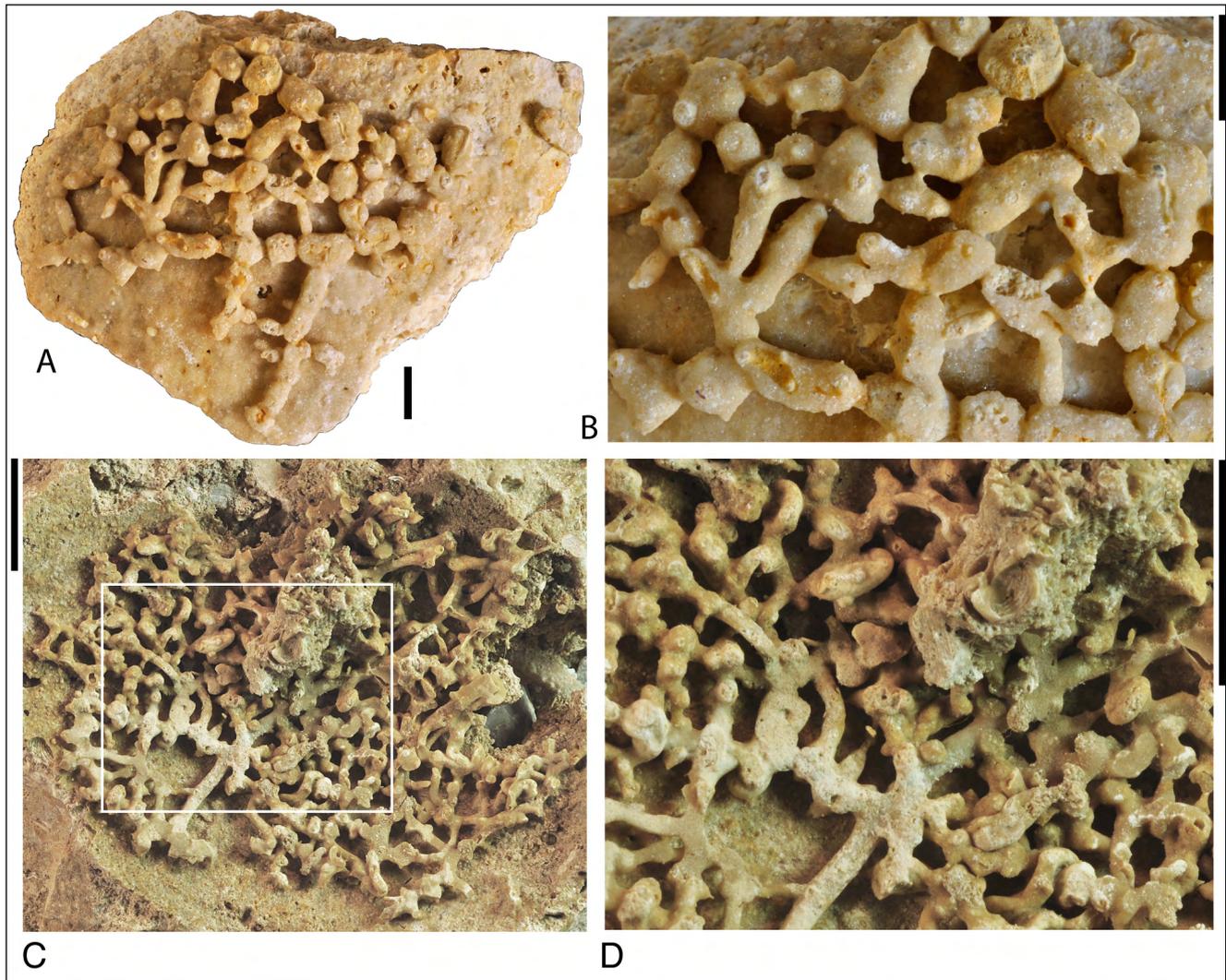
Fig. 6 - *Entobia laquea* from the Calabrian to early Chibanian S2 site, Sferracavallo, north-western Sicily. A-B) Sample IGF 104736 showing growth phase B-C (A) and close-up (**B**). C-D) Sample (not collected) on the inner side of a large mollusc valve preserved as a mould showing growth phase B-C (C) and close-up of the white rectangle in C (D). Scale bars: 0.5 cm in A and B; 1 cm in C and D.

of phase B. Remains of apertural canals occur also at the peripheral parts of the chambers. The chambers form long rows, which bend at right angles in some cases (Fig. 4C). The intercameral canals are short and thick (Fig. 4F). Exploratory threads do not occur, but the remains of the tiny apophyses increase in number compared with the previous growth phase.

Remarks. The studied clionaid boring from S1 is very shallow. A single tier of chambers has been developed just below the surface as a result of the thin substrate. The sponge boring overarches *Caulostrepsis taeniola* at a few places (Fig. 4D), but there are no significant changes regarding the morphology or the shape of the bioerosion structure.

The presented boring shows similarities with *Entobia cateniformis* Bromley and D'Alessandro, 1984*,* having long rows of cylindrical chambers, and showing a course parallel to the surface. However, it shows two distinct forms of chambers in the growth phases B and C, which differ from the typical variants of *E. cateniformis*.

Distribution: Known only from the study site S1, Pliocene (Piacenzian) of Altavilla Milicia, Palermo, north-western Sicily.

Entobia geometrica Bromley & D'Alessandro, 1984
Fig. 5A, B

1984 *Entobia geometrica* - Bromley & D'Alessandro, p. 241, pl. 18, fig. 1; pl. 19, fig. 1; pl. 20, fig. 1; pl. 21, figs. 1, 4, 5; pl. 22, figs. 1, 2, 5.
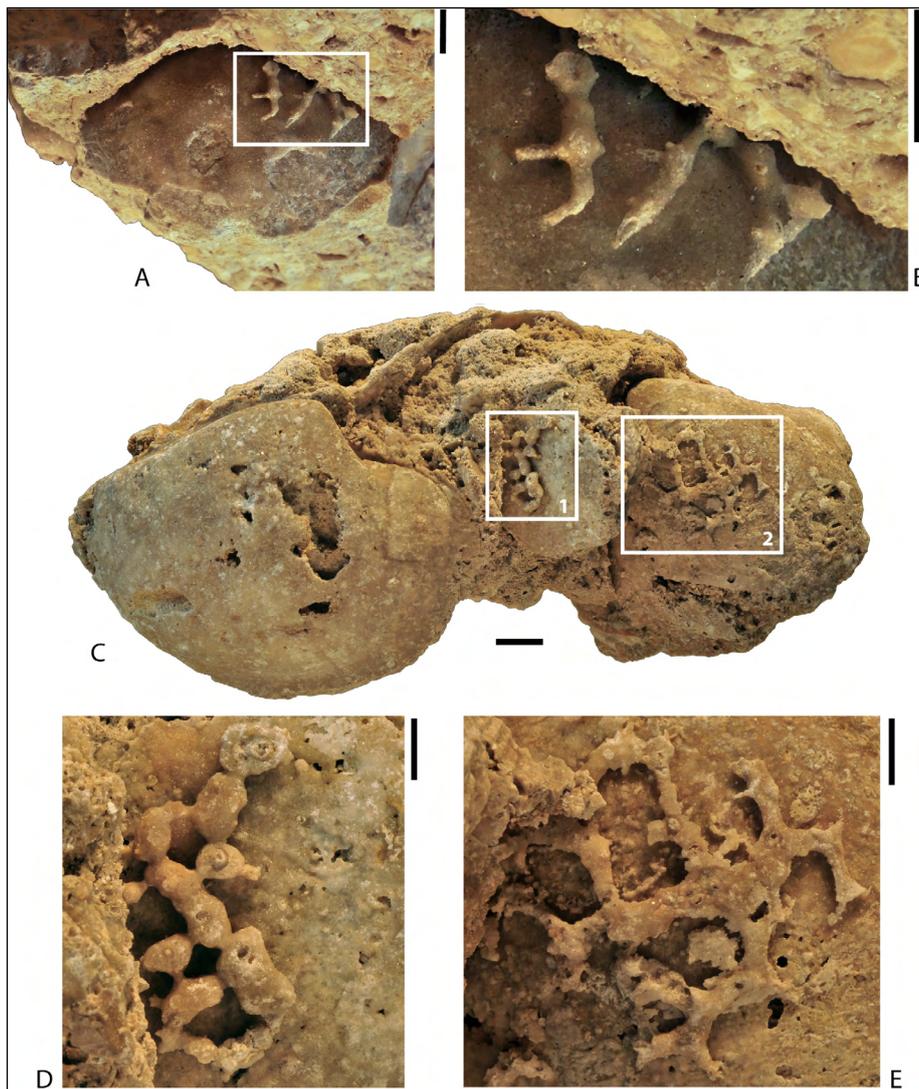
Fig. 7 - *Entobia laquea* and *E.* ?*megastoma* from the Calabrian to early Chibanian site S2, Sferracavallo, north-western Sicily A-B) *Entobia laquea*, (IGF 104737), showing growth phase C (A), and close-up of the same sample (B). C) Calcarenite block (IGF 104733) with casts of large bivalves, presumably *Arctica islandica* (Linnaeus, 1767), and natural casts of *Entobia laquea* (rectangle 1) and *E.* ?*megastoma* (rectangle 2). D) Close-up of rectangle 1 as in C showing *Entobia laquea* growth phase B-C. E) Close-up of rectangle 2 as in C showing *Entobia* ?*megastoma* growth phase C-D. Scale bars: 0.5 cm in A, C, D, E; 1 cm in B.

Material: One sample (IGF 104732) from site S2, natural cast of growth phases C-D on an internal mould of a bivalve, possibly a veneriid (Fig. 5A). One sample (TBE 153.2016) from site S4, a natural cast of growth phases C-D found on an *Ostrea* valve (Fig. 5B).

Diagnosis: "Camerate entobian. Apertures of two markedly different sizes; the larger generally unfused, variable in diameter; the smaller spread among the larger ones. Apertural canals very short. Chambers wide, generally polygonal in section in mature growth-phases, sepa- rated by thin walls perforated by numerous short intercameral canals that may be fused together. In more juvenile phases, the chambers are oval to subspherical, always joined by a distinct intercameral canal. Chambers disposed in weakly developed rows tending to form a subretangular network. The dominant growth phase is D; B and C are usually much reduced. The system is developed parallel to the external substrate surface, in usually only one or two tiers" (Bromley & D'Alessandro 1984).

Description. In the specimen from site S2, the development of the boring is nearly idiomorphic (Fig. 5A). Chambers are subsperical but interconnected by fewer intercameral canals situated in two tiers more or less parallel to the substrate. While in the case of the specimen from site S4, its appear-

ance is stenomorphic. It is shown by the flattened chambers and low number of intercameral canals.

Remarks. *Entobia geometrica* is produced by *Cliona celata* Grant, 1826, which lives on intertidal and subtidal bottoms (Bromley & D'Alessandro 1984; Bromley & Asgaard 1993a). Bromley & D'Alessandro (1990) stated that *E. geometrica* is relatively abundant in infralittoral Plio-Pleistocene in the Mediterranean region.

Distribution. Originally described from the late Miocene (Tortonian), Pliocene and Early Pleistocene (presumably Gelasian to Calabrian) of South Italy (Bromley & D'Alessandro 1984). Pleydell & Jones (1988) reported it from the Miocene-Oligocene of the Grand Cayman Island. Recently found in the Early Eocene of western India (Gurav & Kulkarni 2018), the Miocene of Ukraine (Radwański et al. 2011) and north-eastern Spain (Belaústegui et al. 2018), the Pliocene of south-eastern Spain (as *E.*

Fig. 8 - *Entobia ovula* and *E.* ?*paradoxa* from the Calabrian to early Chibanian site S2, Sferracavallo, north-western Sicily. A-B) *Entobia ovula* (IGF 104738), showing growth phase B-C (A), and close-up (B). C-D) *Entobia* ?*paradoxa* (IGF 104739), showing growth phase E (C), and close-up (D). E) *Entobia* ?*paradoxa* (IGF 104740) showing growth phase B-C. Scale bars: 0.5 cm in A, B, C, D; 1 cm in E.
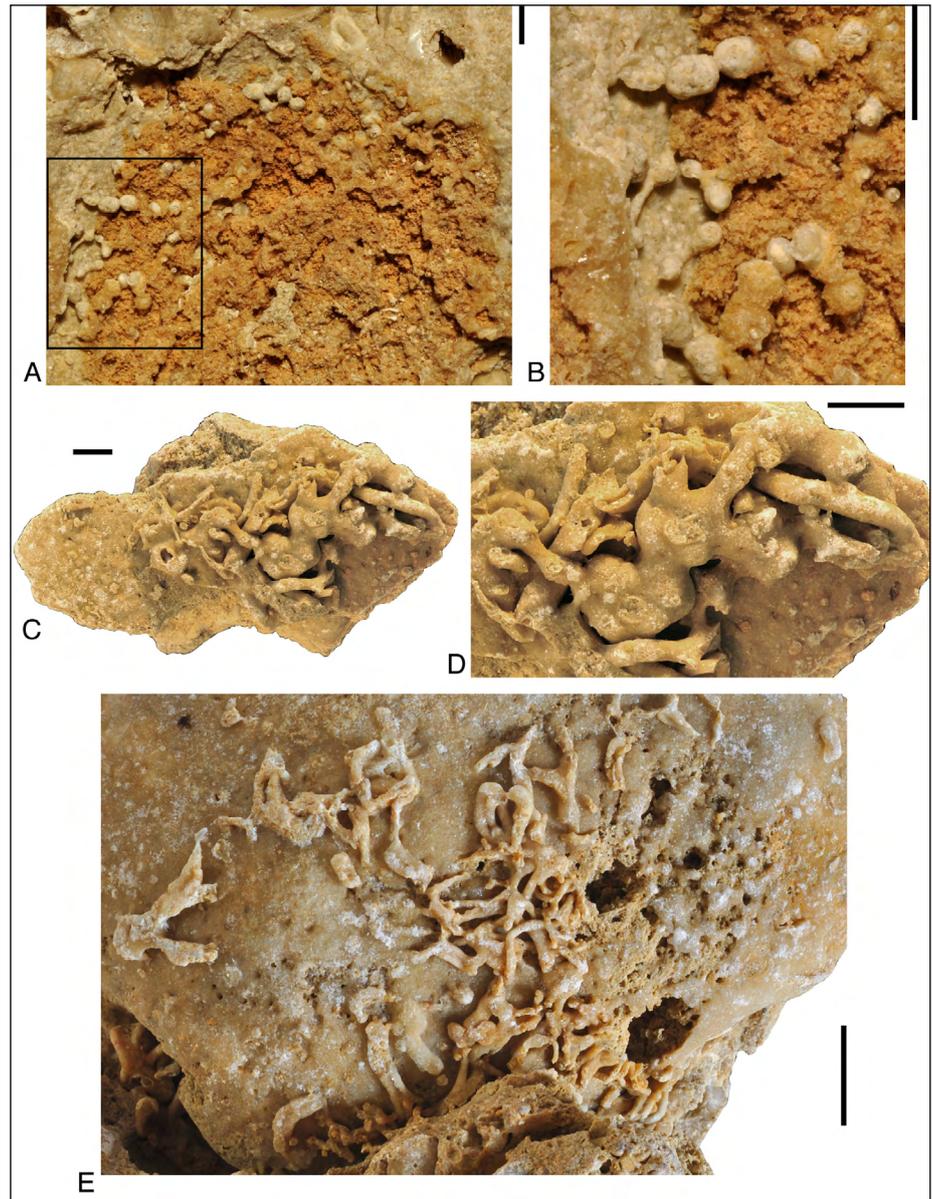
cf. *geometrica,* see Łaska et al. 2021), and the Gelasian of Sicily (Dávid et al. 2017). The studied material is from the Calabrian to early Chibanian Marsala Synthem at Sferracavallo and from the Gelasian of Altavilla Milicia (Palermo, north-western Sicily).

Entobia laquea Bromley & D'Alessandro, 1984

Fig. 5C-F; Fig. 6A-D; Fig. 7A-C, D

1984 *Entobia laquea* - Bromley & D'Alessandro, p. 244, pl. 17, fig. 2; pl. 19, fig. 2; pl. 23, fig. 1.

Material: Eight specimens from two sites. One, not collected, is from site S3 (Fig. 5D), five specimens (IGF 104733, IGF 104734, IGF 104735, IGF 104736, IGF 104737) are from site S2. Further two specimens observed in the field (one of them in Fig. 6C, D) are from the same site. All of them are on internal moulds of bivalves.

Diagnosis: "A camerate entobian composed in mature stages of networks of small chambers arranged in several tiers subparallel to the substrate surface. The chambers, variable in shape, taper abruptly near the constrictions that separate them from the neighbours. They are organized in short, more or less arcuate chains that encircle small spaces in a way that resembles lace. The apertures, circular in shape, rarely fused, are small, numerous and distributed irregularly. Phase A well represented by branched exploratory threads that anastomose early to produce a slender network. Furthermore, phase A is usually present at the periphery, even in mature specimens. Phase B is greatly reduced or absent, the enclosed meshes passing almost directly into phase C. The most characteristic growth of the ichnospecies is C" (Bromley & D'Alessandro 1984).

Description. Chambers are very variable, showing subtriangular, irregularly oval or subglobose forms (Fig. 5D-F). They are well-developed and very similar in the growth phases B-C to C (Figs 6A, B and 7A, B). The exploratory threads are oc-

casional and restricted only to the marginal part of the boring (Fig. 6C). The growth phase A shows an irregular network of branched exploratory threads (Fig. 5C).

Remarks. Pursuant to Bromley & D'Alessandro (1984), _Entobia laquea_ is very similar to borings produced by _Cliona viridis_ (Schmidt, 1862), which lives in symbiosis with green algae, mostly in the shallow sea. Furthermore, Bromley & Asgaard (1993a) stated _Pione vastifica_ (Hancock, 1849) as the tracemaker of _E. laquea_. _P. vastifica_ is widely distributed from the lower intertidal to shallow subtidal environments. Bromley & D'Alessandro (1990) pointed out that _E. laquea_ is relatively abundant in the Mediterranean bathyal Pliocene.

Distribution. First described from several late Miocene (Tortonian), Pliocene and Early Pleistocene (presumably Gelasian to Calabrian) localities of South Italy (Bromley & D'Alessandro 1984). Pleydell & Jones (1988) recorded it from the Miocene-Oligocene of the Grand Cayman Island. Subsequently reported from the Early Eocene (Gurav & Kulkarni 2018) and Miocene (Burdigalian) (Kulkarni et al. 2007) of western India, the middle Miocene of Ukraine (Radwański et al. 2011), the Pliocene of south-eastern Spain (Łaska et al. 2021), as _E._ cf. _laquea_, and the Gelasian of Sicily (Dávid et al. 2017). The studied material is from the Calabrian to early Chibanian Marsala Synthem at Sferracavallo (Palermo, north-western Sicily).

Entobia ?megastoma (Fischer, 1868)
Fig. 7C, E

?1868. _Cliona megastoma_ - Fischer, p. 165, pl. 24, figs. 2, 2a;
?1984. _Entobia megastoma_ Fischer - Bromley & D'Alessandro, p. 250, pl. 23, fig. 3; pl. 24, figs. 2, 3; pl. 26, fig. 1; pl. 27, fig. 2.

Material: One sample (IGF 104733) from site S2, natural cast of growth phases C and D on a bivalve internal mould, possibly of _Arctica islandica_.

Description. Non-camerate entobian. The galleries are flattened, bifurcated and fused at nodal points, so they forms an irregular boxwork system. Apertural canals are absent. Occurrence of apophyses are not characteristic. The width of the galleries shows great differences. On the basis of nine measurements the values are the following: range 1.76-4.07 mm; average 2.44 mm; median 2.28 mm.

Remarks. The specimen is stenomorphic

due to the substrate in which it is developed; thereby hindering undoubted specific determination.

Distribution. Originally described from the Eocene of northern France (Fischer 1868). Pleydell & Jones (1988) reported this ichnospecies from the Miocene-Oligocene of the Grand Cayman Island; Perry (1966) from the late Miocene of Mallorca; Bromley & D'Alessandro (1984) from the Miocene (Tortonian), Pliocene and Early Pleistocene of South Italy. Recently reported from the middle Eocene to middle Miocene of Jamaica (Blisset & Pickerill 2004) and from the middle Miocene of Egypt (Abdel-Fattah & Assal 2016). The studied material was collected from the Calabrian to early Chibanian Marsala Synthem at Sferracavallo (Palermo, north-western Sicily).

Entobia ovula Bromley & D'Alessandro, 1984
Fig. 8A, B

1984 _Entobia ovula_ - Bromley & D'Alessandro, p. 254, pl. 17, figs. 1, 4; pl. 18, fig. 2; pl. 21, fig. 3; pl. 23, fig. 2; pl. 26, fig. 3; pl. 27, fig. 1; pl. 28, fig. 4; pl. 29, fig. 3.

Material: One sample (IGF 104738) from site S2, natural cast of growth phases B-C on a bivalve internal mould.

Diagnosis: "A camerate entobian composed in the mature stage of small chambers of globose to ovoid shape, greatly crowed, arranged in a boxwork. The chambers are separated from neighbours by a very short intercameral canal, usually reduced to a constriction. In phase C, the chambers are arranged in straight strings, forked at variable angles and anastomosed, giving rise to network in one or two, poorly distinguishable tiers. A and B phases are reduced. Apertural canals distinct, tapering distally, or slightly inflated as a barrel. The openings are relatively small, numerous, rather regularly disposed, rarely fused" (Bromley & D'Alessandro 1984).

Description. Camerate entobian encrusted in a large part by thin ferruginous material. Exploratory threads are not visible. The chambers are ovoid and globose in shape, arranged in straight strings. The chambers are separated by constrictions (Fig. 8B) and appear in two tiers. Most of the bioerosion structure is encrusted by thin ferruginous material.

Remarks. _Entobia ovula_ is produced by _Pione vastifica_ Hancock, 1849 and _Cliona glomerata_ Michelin, 1846 (Bromley & D'Alessandro 1984) or _Cliona schmidti_ (Ridley, 1881) and _C. vermifera_ Hancock, 1867 (Bromley & Asgaard (1993a). These sponges occur from the intertidal to shallow subtidal marine environments, while _E. ovula_ is characteristic to the infralittoral Plio-Pleistocene of the Mediterranean region (Bromley & D'Alessandro 1990).
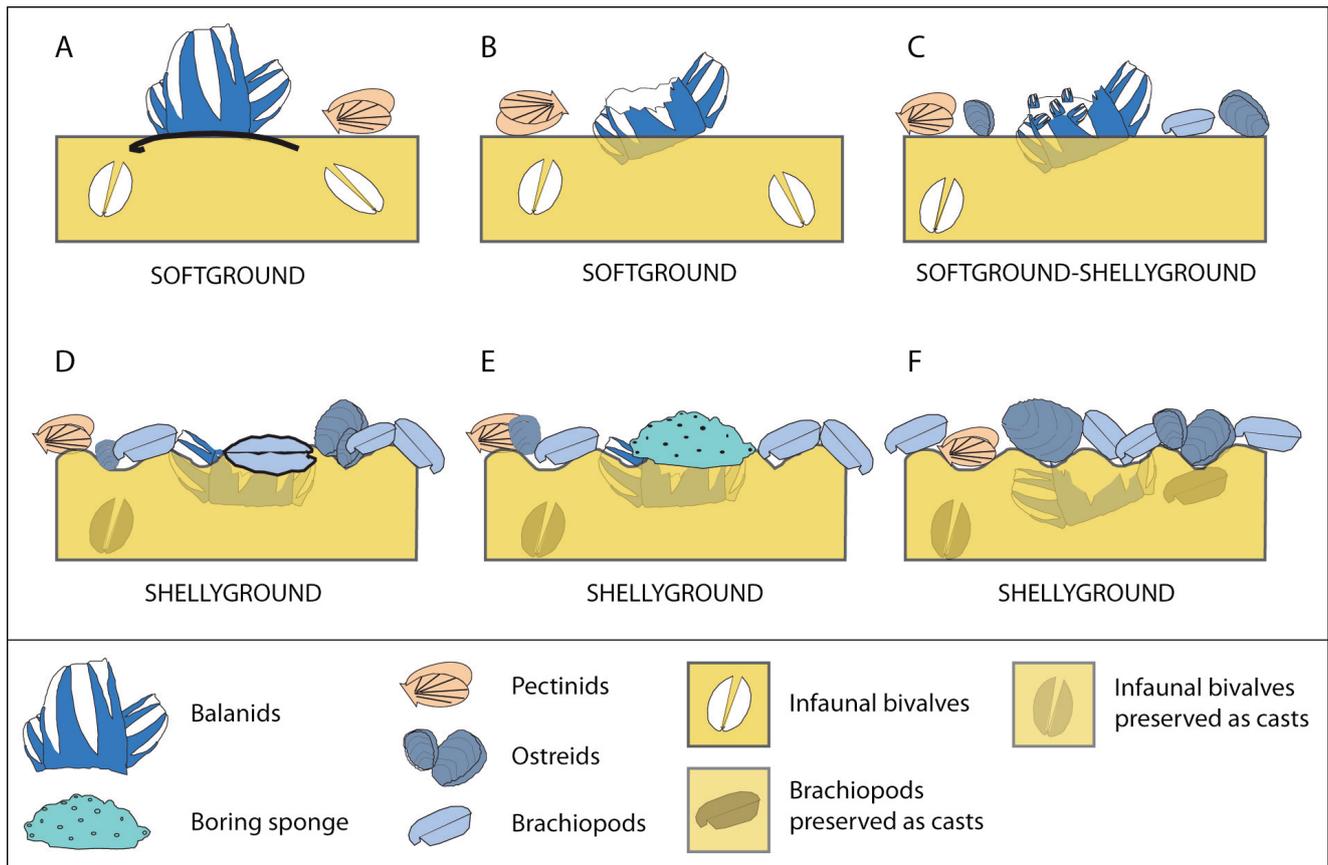
Fig. 9 - Simplified taphonomic pathway proposed for the formation of the *Entobia cateniformis* form A and *Caulostrepsis taeniola* Clarke, 1908 casts found on the inner part of a large balanid collected from a cemented bed at the Piacenzian of Altavilla Milicia. A) A balanid cluster formed on a stable large shell fragment on a soft ground. B) Substrate erosion and possible resedimentation, with partial burial, of the large balanid. C) Colonization of small barnacles in a low sedimentation regime, increase of epifauna and transition to a shelly ground. D) Erosion/dissolution with disappearance of small barnacles, encrusting organism on the large balanid, formation of a shelly ground and casts of infaunal shells. E) Colonization by borers (mainly sponges and polychaetes). F) After the death of borers, their traces became infilled by fine sediments whose lithification produced casts; subsequent dissolution of the bored shell.

Distribution. First described by Bromley & D'Alessandro (1984) from the Miocene (Tortonian), Pliocene and Early Pleistocene of South Italy. Pleydell & Jones (1988) reported it from the Miocene-Oligocene of the Grand Cayman Island. Recently reported from the Early Eocene of western India (Gurav & Kulkarni 2018) and the middle Miocene of Egypt (El-Hedeny & El-Sabbagh 2018, Abdel-Fattah & Assal 2016). Dávid et al. (2017) found it in the Gelasian of Sicily. The studied material is from the Calabrian to early Chibanian Marsala Synthem at Sferracavallo (Palermo, north-western Sicily).

Entobia ?paradoxa (Fischer, 1868)
Fig. 8C-E

? 1868 *Cliona paradoxa* - Fischer, p. 169, pl. 25, fig. 8.
? 1990 *Entobia* cf. *paradoxa* (Fischer, 1868) - Bromley & D'Alessandro, p. 259, pl. 20, fig. 2, pl. 26, fig. 4, pl. 28, fig. 3; pl. 29, figs. 1, 4, text-fig. 12.

Material: Two samples (IGF 104739, IGF 104740) from site S2. Natural casts showing the growth phases C-D and B-C on incomplete bivalve internal moulds.

Description. Camerate entobian forming a network of chambers that are mostly elongated, amoeboid or polygonal shaped. These are arranged parallel to the substrate surface in two weakly developed tiers. Gradual tapering of the chambers before interconnections is clearly visible. Two growth phases can be observed, C-D (Fig. 8C, D) and B-C (Fig. 8E). The shape of chambers is dominantly elongated. Amoeboid forms also occur in the case of the growth phase B-C, while the growth phase C-D appears in massive amoeboid and semi-globose chambers fused by thickened galleries.

Remarks. The examined specimens are moderately well-preserved. The diagnostic features, such as the size of apertures, length of ap-

Ichnotaxa	Ethological category	Producer organisms
Entobia cateniformis	Domichnia	*Cliona vermifera*
Entobia cateniformis form A	Domichnia	*Cliona vermifera*
Entobia geometrica	Domichnia	*Cliona celata*
Entobia laquea	Domichnia	*Cliona viridis* *Pione vastifica* *Spiroxya heteroclita*
Entobia ?megastoma	Domichnia	*Cliona celata*
Entobia ovula	Domichnia	*Pione vastifica* *Cliona glomerata* *Cliona schmidtii* *Cliona vermifera*
Entobia ?paradoxa	Domichnia	*Cliona celata*

Tab. 2 - Ethology and producer organisms of the identified entobian ichnotaxa in the late Caenozoic of Altavilla Milicia and Sferracavallo, northwestern Sicily.

ertural canals, or the depth of penetration into the substrate cannot be observed. However, following Bromley & D'Alessandro 1990, it is possible to tentatively ascribe these specimens to *Entobia paradoxa*. According to Bromley & Asgaard (1993a), this entobian is produced by *Cliona celata*. *Entobia paradoxa* is relatively abundant in the Mediterranean bathyal Pliocene (Bromley & D'Alessandro 1990).

Distribution. Fischer (1868) described this ichnospecies from the French Turonian. Pleydell & Jones (1988) reported it from the Miocene-Oligocene of the Grand Cayman Island; Bromley & D'Alessandro (1984) from the Miocene (Tortonian), Pliocene and Early Pleistocene of South Italy. More recent reports concern the middle Miocene of Ukraine (Radwański et al. 2011) and the Eocene of western India (Gurav & Kulkarni 2018). The studied material was found in the Calabrian to early Chibanian Marsala Synthem at Sferracavallo (Palermo, north-western Sicily).

DISCUSSION

The boring *Entobia* belongs to the ethological class domichnion and is produced by borers needing rather stable and relatively thick carbonate marine substrates. They are therefore widespread in Recent and fossil rocky shores (De Groot 1977; Gibert et al. 1998; Rosell & Uriz 2002; Anthony 2008; Bromley et al. 2009; Santos et al. 2010), though shells and other skeletal elements may be appropriate substrates even in deeper (palaeo)environments with soft sediments (Old 1941; Loren-

zo & Verde 2004; Lescinsky et al. 2002; Ledesma-Vázquez et al. 2006; Santos & Mayoral 2008). This is the case with the quite diverse *Entobia* association revealed by our study on Pliocene-Pleistocene sediments from Sicily. This ichnoassemblage consists of seven ichnotaxa produced by boring sponges of the genera *Cliona* Grant, 1826, *Pione* Gray, 1867 and *Spiroxya* Topsent, 1896 (Table 2). The producer sponges lived on "benthic islands" (*sensu* Taylor & Wilson 2003) deposited in the shoreface-offshore transition. At sites S2 and S3, these benthic islands were mainly represented by veneroid taxa with aragonite shells. Presumably the same kind of substrates was bored at sites S1 and S4.

The general good preservation of the studied *Entobia* ispp., showing many relevant morphological details, is likely due to the fine-grained nature of the sediment, where the host shells/substrates deposited and were buried. With the exception of the sample found on an ostreid shell at site S4, the recovered entobians show idiomorphic boring systems, indicating that nature and structure of the substrate represented suitable ecological conditions for boring sponges. Also, the quality of the surrounding environments (such as hydrodynamism, degree of illumination, rate of sedimentation) was good enough to ensure a good development of the boring sponges (see Bromley & D'Alessandro 1984).

A taphonomical process similar to those proposed by Gurav & Kulkarni (2018) and Łaska et al. (2021) should be invoked to explain the formation of the *Entobia* natural casts studied, particularly those found on moulds and casts of

aragonitic veneroid bivalves. Aragonitic shells were bored by endolithic sponges and then buried; soft, fine sediment surrounding the shells filled the borings; sediments around the shell and filling the boring were cemented by calcite precipitation; aragonite shell underwent dissolution. A more complex process was possibly responsible of the formation of *Entobia cateniformis* form A found at site S1, which is associated with a shelly ground formed by epifaunal bivalves. At this site, the *Entobia* cast was found associated with other ichnofossils on an incomplete balanid test, whose modest thickness could not have allowed the sponge to proliferate. This natural cast and the associated *Caulostrepsis taeniola* cast very likely formed inside a sufficiently-thick hard carbonate substratum, other than the barnacle test. A possible explanation of the formation of these casts likely involved several taphonomic stages here listed in chronological order (see Fig. 9):

- the *Entobia*-bearing large balanid underwent partial dissolution/erosion which strongly reduced the thickness of its test;
- after its breaking and the partial dissolution of its inner part, the large balanid test was colonized by small balanids, as testified by several imprints of small basal plates;
- the small balanids were eroded or dissolved;
- a calcified organism, possibly an encrusting bivalve, attached to the inner part of the fragmented large balanid and successively was bored by a sponge and the polychaete producing *Caulostrepsis taeniola*;
- after the death of the sponge and the polychaete, the sediment filled the bored bivalve shell and consolidated thus producing natural casts of *Entobia* and *Caulostrepsis*;
- the calcified organism attached to the large balanid was dissolved, possibly due to its aragonitic composition, or simply underwent detachment/erosion.

The above taphonomical evidences imply conditions of low sedimentation rate, where bioerosion, fragmentation and dissolution of aragonite are common (Taylor & Wilson 2003; Palmer & Wilson 2004). This taphonomical setting involved chemical conditions favorable to the preservation of calcite shells, similarly to what has been described for older, early Caenozoic, entobians from India (Gurav & Kulkarni, 2018), and is consistent with the morphological observation of the *Entobia*-bearing deposits. In fact, these deposits particularly at site S1, bounded by irregular surfaces, appear as condensed hard deposits, consisting of shelly beds bearing encrusting and other boring organisms (Fig. 3D, F for sites S2 and S3).

It is noteworthy that at site S1 *Entobia cateniformis* form A occurs in contact with the boring traces of *Caulostrepsis taeniola* with no significant modification of their respective morphostructures, which clearly maintained their idiomorphic shape. The microscopic analysis performed on these bioerosion structures revealed that the infilling shows the same granulometry and colour in these both borings. All these observations allow suggesting a *syn-vivo* contact between the two boring species.

Conclusion

This is the first report from Sicily of fossil ichnospecies originated by boring sponges and preserved as natural casts. The studied assemblage consists of the following ichnotaxa: *Entobia cateniformis*, *E. cateniformis* form A, *E. geometrica*, *E. laquea*, *E. ?megastoma*, *E. ovula*, *E. ?paradoxa* and the polychaete boring trace *Caulostrepsis taeniola.* In general, all these ichnospecies are represented by well-preserved natural casts that formed after a complex taphonomic pathway comprising events of bioencrustation, differential dissolution and slow filling of long and sinuous cavities with very fine-grained sediment, which all imply conditions of low sedimentation rate and selective preservation of molluscan shells within the late Caenozoic Marly-Arenaceous Formation of Belice and the Marsala Synthem. The sponges that produced the studied entobians mostly bored infaunal veneroid bivalves, which represented suitable substrates for the formation of well-diversified *Entobia* assemblages.

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