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New trace fossils produced by etching molluscs from the Upper Neogene of the southwestern Iberian Peninsula

ANA SANTOS[1], EDUARDO MAYORAL[2] & FERNANDO MUÑIZ[3]

[1]*Centro de Investigação Marinha e Ambiental, Faculdade Ciências do Mar e do Ambiente, Universidade do Algarve, Campus de Gambelas, 8000-117 Faro, Portugal. E-mail: aasantos@ualg.pt*
[2]*Departamento de Geodinámica y Paleontología, Facultad de Ciencias Experimentales, Universidad de Huelva, Campus del Carmen, Avda. de las Fuerzas Armadas s/n, 21071 Huelva, Spain. E-mail: mayoral@uhu.es*
[3]*Grupo de Investigación Tectónica y Paleontología, Spain. E-mail: gyrolithes@yahoo.es*

ABSTRACT:

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New trace fossils produced by etching molluscs, mainly gastropods (*Crepidula*) and bivalves (Ostreacea), from the southwestern part of the Iberian Peninsula (southeast of Portugal and southwestern of Spain) are described. These trace fossils are here described as *Lacrimichnus* ichnogen. nov. due to the tear-shape of the scars. Two new ichnospecies are established: *L. cacelensis* ichnosp. nov. and *L. bonarensis* ichnosp. nov. Both ichnospecies are of Late Miocene (Late Tortonian) - Holocene age.

Key words: Etching molluscs, Trace fossils, *Lacrimichnus* ichnogen. nov., *L. cacelensis* ichnosp. nov., *L. bonarensis* ichnosp. nov., Upper Neogene, Portugal, Spain.

INTRODUCTION

A variety of molluscs live etching to a substrate. This is particularly true in bivalves, which attach to their substrate with a byssus (e.g. *Pectinidae*, *Mytilidae*), a muscle (e.g. *Anomiidae*) or, simply, some type of binder (e.g. *Gryphaeidae*, *Ostreidae*). The fossil record contains only references to attachment scars produced by anomiids. The other bivalves have not been systematically documented in palaeoichnological terms. Among gastropods attaching habit is not so common. There are, however, numerous representatives of the family *Vermetidae* (genus *Lemintina* RISSO, 1826; *Petaloconchus* LEA, 1843), *Hipponicidae* (*Hipponix* DEFRANCE, 1819), *Capulidae* (*Capulus* MONTFORT, 1810) and *Calyptraeidae* (*Crepidul,* LAMARCK, 1799; *Calyptrea* LAMARCK, 1799).

As a rule, living habits results in the presence of many trace fossils of the cubichnia and domichnia types that reflect most of the morphological features of the tracemakers quite accurately. Palaeoichnologically, only two types of structure have been studied in this respect. One is that of anomiid bivalves, compiled under the ichnotaxon *Centrichnus* BROMLEY & MARTINELL, 1991, and those corresponding to attached vermetid gastropods, which have been grouped in the ichnotaxon *Renichnus* MAYORAL, 1987. Several others including those produced by some hipponicid gastropods have been briefly described (CERNOHORSKY 1968; RADWAŃSKI 1977), but never dealt with systematically as trace fossils. The present paper provides their formal description and their high palaeoecological value is emphasized.

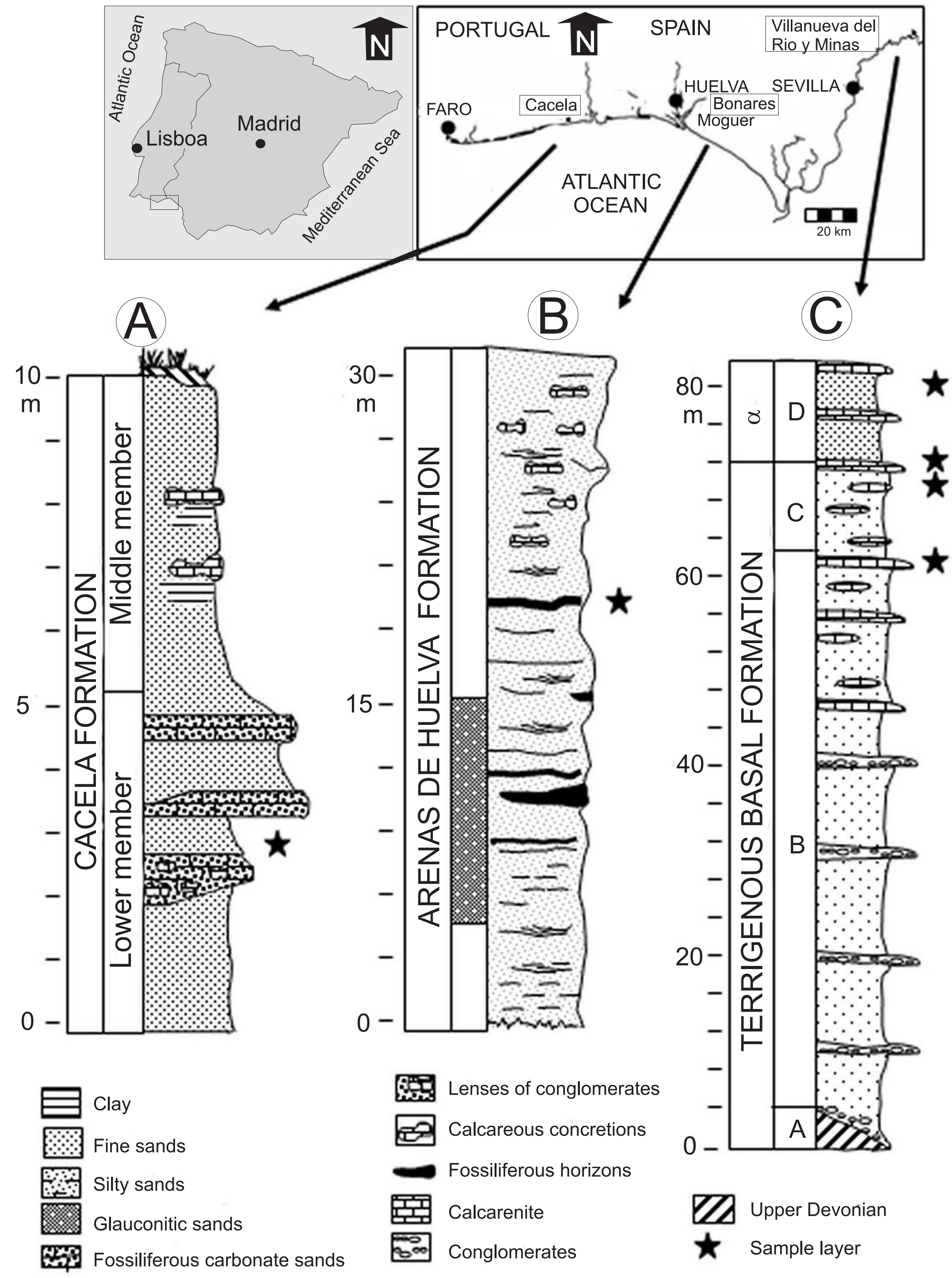

Fig. 1. Geographical location of the studied areas with the synthetic stratigraphical series; A – Upper Miocene, Cacela (Portugal) (CACHÃO 1995); B – Lower Pliocene, Bonares (Huelva, Spain) (MAYORAL 1986); C – Upper Miocene, Villanueva del Río y Minas (Seville, Spain) (SANTOS, MAYORAL, & MUÑIZ 2002)

GEOGRAPHIC AND GEOLOGICAL SETTING

The studied material comes from various sites in the southwestern part of the Iberian Peninsula. The oldest specimens, from the Late Miocene, come from southeastern Portugal, from the vicinity of Cacela Velha (Text-fig. 1A), located in the Ría Formosa Natural Park, as well as from various outcrops in Villanueva del Río y Minas, in the Seville Province, Spain (Text-fig. 1C). The other specimens, from the Lower Pliocene, were obtained from Bonares, in the Huelva Province, in the southwestern sector of the Guadalquivir Basin, Spain (Text-fig. 1B).

The Portuguese section lies within the lower part of the Cacela Formation, represented by the sediments of a shallow infralitoral environment. Two of the three members that characterize the formation are here represented (*sensu* CACHÃO & *al*. 1998) (Text-fig. 1A). The lower member consists of 5-6 m of fossiliferous conglomerate and silt from Ribeira de Cacela, and the middle member, 5-13 m thick, consists of silt and lutites, forming a sequence of orange-yellow silt with 50 cm thick, grey coloured, more pelitic intercalations.

The site possesses particularly rich and diversified fossil fauna, particularly molluscs as documented by SANTOS (2000) and ichnofossils (bioturbation and bioerosion structures) (CACHÃO & *al.* 2000; SANTOS & *al.* 2001a, b), which are generally very well preserved in taphonomic terms.

Based on calcareous nannoplankton (CACHÃO 1995) the lower member spans an interval between the first appearance level of *Discoaster berggrenni* and *D. quinqueramus* and the last appearance level of *Minylita convalis*, indicating its Late Tortonian age (Late Miocene). These results are consistent with dating based on planktonic foraminifers (LEGOINHA 2001). In geochronological terms it corresponds to the time interval between 8.2 and 7.5 my.

The Spanish sites, of Late Tortonian age, correspond to the Basal Terrigenous Unit (SIERRO & *al.* 1990) represented by the bioclastic facies typical of the northwestern end of the Guadalquivir Basin in the province of Seville. Essentially, it consists of alternate layers of medium- and coarse- to very coarse-grained sand and conglomerate in the lower portion, and fine-grained sand, with some intercalations of coarse-grained sand, in the upper part (Text-fig. 1C). These deposits, 20-50 m thick, represent a shallow marine environment of prograding delta system (BORREGO & PENDÓN 1988).

The Lower Pliocene source sites belong to the Arenas de Huelva Formation (Text-fig. 1B) consisting of yellowish-brown fine sand, silty in its lower interval, with the glauconitic horizon at the bottom. Abundant bioturbation structures occur throughout the succession. The succession contains a large number of macrofossils, particularly of molluscs (bivalves, gastropods, scaphopods), what is typical of a shallow infralitoral marine environment. They are quite diversified, well preserved, and contain abundant bioerosive structures. Also common is microfauna, particularly benthonic (GONZÁLEZ-REGALADO 1986; GONZÁLEZ-REGALADO & CIVIS 1987; GONZÁLEZ-REGALADO & RUIZ MUÑOZ 1991).

The Arenas de Huelva Formation is 10-30 m thick (CIVIS & *al.* 1987), and is dated for the Tabianian (upper part of the *Globorotalia margaritae* Zone and lower part of the *G. puncticulata* Zone; see SIERRO 1985; CIVIS & *al.* 1987; GONZÁLEZ-REGALADO 1986).

MATERIALS

The bioerosive structures from the Late Miocene were found both on epifaunal bivalves (*Gigantopecten tournali*, DE SERRES *in* ROGER 1939) from the lower member of the Cacela Formation and on clypeasteroid echinoids (*Clypeaster cermenatii*, *Clypeaster portentosus* and *Clypeaster* sp.) from the top of the Basal Terrigenous Unit. The Lower Pliocene specimens occur mostly on the gastropod *Xenophora infundibulum* (BROCHI 1814), coming from the Arenas de Huelva Formation.

Some of these structures are also observed in the Recent (Holocene) shells of the Cabo Verde Island and on Spanish North Atlantic coast.

An overall 23 bioerosive structures from the Miocene and 17 from the Pliocene were examined and measured. Twenty of the Miocene specimens are housed in the collections of the University of Algarve (Portugal) and the rest of the collection is stored in the Geological Museum of the University of Seville (Spain) (MGUS). The acronym RC (Ribeira de Cacela) is a temporary museum reference pending definitive cataloguing.

SYSTEMATIC PALEOICHNOLOGY

Lacrimichnus nov. ichnogen.
(Pl. 1, Figs 1-5; Pl. 2, Figs 1-4, 7-8)

1968. Etching marks produced by slipper-shaped gastropods; W.O. CERNOHORSKY, pl. 41, figs 3-4.

1977. Etching marks produced by the gastropod *Hipponix conicus* (SHUMACHER); A. RADWAŃSKI, p. 242, pl. 7, figs b2, 2-4.

TYPE ICHNOSPECIES: *Lacrimichnus cacelensis* SANTOS, MAYORAL & MUÑIZ (this paper).

DIAGNOSIS: Surface marks with oval to slightly ellipsoidal margin terminating on sharp end, with overall teardrop-shape. The margin clearly distinguished by colour of surrounding substrate, which is usually more heavily weathered or eroded, or by fairly deep, wide boring. Marks are smooth or exhibit light ornamentation consisting of discrete, shallow series of eccentric borings on interior.

ETYMOLOGY: From the Latin *lacrima* (teardrop) and the Greek *ichnos* (trace), after the teardrop-shaped marks.

OCCURRENCE: Upper Tortonian (Upper Miocene) – Holocene.

Lacrimichnus cacelensis ichnosp. nov.
(Pl. 1, Figs. 1-5)

DIAGNOSIS: Oval, very elongate to ellipsoidal margin, round on one end and very sharp on other; overall mark of clearly teardrop shape. Margin defined by relatively deep boring and encloses slightly depressed inner zone that can either be smooth or with light ornamentation consisting of eccentric lines.

HOLOTYPE: RC/M1/1.

PARATYPES: RC/M1/2 to RC/M1/6.

TYPE LOCATION: Cacela Velha (Portugal).

TYPE HORIZON: Cacela Formation.

OCCURRENCE: Upper Tortonian (Upper Miocene) - Holocene.

ETYMOLOGY: From Cacela, the source locality of the holotype.

DESCRIPTION: The trace with oval to ellipsoidal, markedly elongate margin, with the two well-defined terminations; one round (rear edge) and the other ending in a variably sharp apex (front edge). Such an apex is related to a roughly triangular zone bounded by a small platform that is usually slightly more depressed than the remaining part of the trace fossil. The margin consists of a well-defined furrow that is 0.1 mm deep on average and 0.23-0.38 mm thick.

If the mark occurs on an ornamented substrate, with ribs or growth lines, the lines exhibit little or no relief. The interior of the marks can be smooth or ornamented. Ornament is always delicate, and consist of small, very shallow, curved furrows and crests, arranged in a concentric pattern and converging on the lateral edge of the mark. The marks are 24.6-43.5 mm long and 15.9-27.8 mm wide.

Usually, the marks occur either in an isolated, oriented way (Pl. 1, Figs 1-3), in small groups or in juxtaposition. It is possible to see two or more individuals superimposed along more or less aligned pathways (Pl. 1, Figs 4-5).

REMARKS: The marks of *Lacrimichnus cacelensis* are very similar to some oval marks seen on the bivalve *Chesapecten madisonius* LISTER 1687, from the Pliocene Yorktown Formation (Virginia), the earliest fossil reported and illustrated from North America (LISTER 1687). Although they have not been described formally, they have been interpreted as attachment scars from balanid cirripeds (specifically, *Balanus concavus* BRONN 1831), which are frequently found on *Chesapecten* shells from the Yorktown Formation (GRIFFING 1996). Despite this apparent connection, the external features of the marks as seen on the original plate strongly suggest their affinity to *Lacrimichnus*.

Very close to *Lacrimichnus cacelensis* are attachment scars left by the gastropod *Hipponix conicus* (SCHUMACHER, 1817), reported originally by CERNOHORSKY (1968) and illustrated and commented subsequently by RADWAŃSKI (1977). Such marks are elliptically shaped and are of similar size. Their margin consists of a crenulate, highly irregular furrow that is well defined on the rear edge but badly defined, or absent, from the front edge. The ornamentation in the inner zone consists of thin radial lines that reproduce the radial ribs of the gastropod shell. However, no concentric lines are observed. The deepest zones of these marks lie on the lateral edges and at the centre, which is typical of *Lacrimichnus* (the furrows are not so deep as in some *L. cacelensis*). Additionally, the front edge, which should correspond to the oldest apical portion of the shell, exhibits a relatively deep depression (RADWAŃSKI 1977) reminding somewhat the roughly triangular, depressed zone observed on the front edge of *Lacrimichnus*. All these features are consistent with the general diagnosis of *Lacrimichnus* ichnogen. nov., even though they do not correspond to any of the ichnospecies here described. Further material is needed to make their final ichnotaxonomic determination.

Lacrimichnus cacelensis is also somewhat similar to the Holocene ichnospecies *Centrichnus eccentricus*

BROMLEY & MARTINELL 1991. Both traces are very similar in the external appearance. They differ, however, in their inner structure and dimensions (10 mm for *C. eccentricus*). *Centrichnus eccentricus* is a trace with a compact, drop or teardrop-shaped margin that encloses more or less grouped series of very well defined arched, concave furrows leading to a sharp end. Moreover, the marginal furrow in *C. eccentricus* is less well defined than in *Lacrimichnus cacelensis*. Finally, it lacks the subtriangular zone or platform on the sharp end.

Lacrimichnus bonarensis. nov. ichnosp.
(Pl. 2, Figs 1-4, 7-8)

DIAGNOSIS: Subcircular to suboval margin, consisting of extremely shallow furrow. Bands or rings usually not observed. Inside smooth with no ornament. One end slightly sharp, other completely rounded.

HOLOTYPE: MGUS-2200.

PARATYPES: MGUS-2201–2208, MGUS-2021, MGUS-2057-2058.

TYPE LOCATION: Bonares (Huelva, Spain).

TYPE HORIZON: Arenas de Huelva Formation.

OCCURRENCE: Upper Tortonian (Late Miocene) - Holocene.

ETYMOLOGY: From Bonares, the place where the holotype was found.

DESCRIPTION: The margin is subcircular to suboval (Pl. 2, Figs 8-9), 4 × 3 to 27 × 28 mm in diameter, to markedly elongate (Pl. 2, Figs 1-4, 7), 21 × 32 to 15 × 24 mm in diameter. The zone within the margin is slightly depressed (0.1 mm deep) and always differs in colour from the substrate, which is usually less well preserved. A very shallow furrow, 0.19 mm wide on average, is bound this zone. The subtriangular platform on the slightly sharper end is less well defined than in *Lacrimichnus cacelensis* (Pl. 2, Fig. 8), in fact, it can rarely be identified.

DISCUSSION

Because some remains of the fossilized bodies of the tracemakers were found directly or very closely related to the corresponding traces, there is little doubt about the origin of *Lacrimichnus*. From the examination of the Holocene material it is clear that the traces result from the attachment of several specimens of *Crepidula* LAMARCK 1979 to various bivalve or gastropod shells (Pl. 2, Figs 6-7). The fossil specimens of *Lacrimichnus* also reflects clearly morphological features of *Crepidula* (Pl. 1, Figs 1-5). This gastropod exhibits an attaching habit (Pl. 1, Fig. 6). The younger male specimens attach themselves to the others with thicker shells (females) to form juxtaposed, chained groups lying one on top of the others. This pattern is convincingly recorded also in the fossil material, which very often exhibits several superimposed *Lacrimichnus* traces along the same pathway on the substrate (Pl. 1, Figs 2, 4-5). This allows the reconstruction of the attachment sequence for these individuals, which in the Miocene *Gigantopecten* specimens studied herein originated from the ventral edge to the umbus. *Lacrimichnus bonarensis*, which occurs usually at the opening edge of the gastropod *Xenophora*, contains frequently one or more *Crepidula* specimens on the inside by effect of their detachment from their initial position. In other cases, they fossilized *in situ*, alongside ostraceans (Pl. 2, Figs 5, 9), which are also responsible for this structure. Thus, when *L. bonarensis* lies on shells of clypeasteroid sea-urchins from the Miocene, it is usually attached to the valves of the ostracean (SANTOS & *al.* 2002), on the alimentary canals of the oral side of the test (Pl. 2, Fig. 9).

The material from the Lower Pliocene in Bonares was found to contain species of both *Crepidula gibbosa* DEFRANCE 1818 and *Crepidula unguiformis* LAMARCK 1822. Most probably, the attachment scars left by *Hipponix cornucopiae* (LAMARCK 1802), a typical gastropod of the Middle Eocene in Western Europe, are similar to those of *Lacrimichnus cacelensis* as their boundaries are similar to those of the *Crepidula* species, assumed to be the tracemakers for this ichnotaxon. Likewise, the attachment scars left by the gastropods *Capulus* and *Calyptrea* could also, in principle, be included in this ichnospecies. However, there are hitherto no records in support of this assignation. In this respect, the potential attachment scars of *Crepidula lucenica* LANDAU 1984, which was relatively common during the Lower Pliocene in Huelva, would be very similar to those produced by *Hipponix conicus*, as their margin and ornamentation are very similar (crenulate in both cases). If so, they should be included in the other new ichnospecies identified. Before such an assignation can be made, however, the new specimens should be found and their characteristics compared with the few contemporary specimens available.

The morphology of *Lacrimichnus cacelensis* is consistent with the growth pattern of its tracemaker. In fact, *Crepidula* binds to the substrate by its mantle. In this way, the furrow bounding the traces is the result of the interaction between the shell ridges, as it grows, and the surface of the substrate on which it rests. This attachment mechanism differs from that used by verrucids (the tracemakers for *Centrichnus eccentricus*), which bind to the substrate by a chitin membrane (RADWAŃSKI 1977) and produce a different scar record.

This new bioerosive structure possesses a substantial paleoecological value as it can be used to determine and quantify the presence of populations of the gastropods and/or bivalves considered. These groups could be missed or undervalued as their shells are often very fragile, particularly those of gastropods, and easily destroyed before they can fossilize. As a result, they are easily detached from their supporting substrates, so their attachment scars constitute one of the few reliable evidences of their existence. Additionally, by identifying and examining the traces, one can reconstruct the relationship between the epizooarian organism and the host substrate (BOEKSCHOTEN 1967).

In the specimen recorded on *Gigantopecten tournali* from the Upper Miocene in Cacela (*Lacrimichnus cacelensis*), the producer attaches to the very specific places of the shell, such as the inter-rib spaces of the ventral ridge of the valve, pointing in its direction. In *Xenophora infundibulum* from the Lower Pliocene in Bonares, *L. bonarensis* occurs on the outer ridge of the peristome, also pointing at the edge. In the former case, the organism attached while the host was alive, *Crepidula* would occupy the most favourable positions with respect to the water flows produced by the opening of the pectinid valves. In the latter, the attachment was clearly *post-mortem* and the host substrate was used as a permanent dwelling providing shelter and facilitating nutrient capture, as *Crepidula* is an active filtering organism. This also applies to the ostraceans found on the alimentary canals of sea-urchins.

CONCLUSIONS

The material studied herein, represented primarily by echinoids, epifaunal bivalves and gastropods from marine sediments of the Upper Neogene in the Iberian Peninsula, specifically from the Upper Miocene (Cacela, SE Portugal, and Villanueva del Río y Minas, SW Spain) and Lower Pliocene (Bonares, SW Spain), provides new information on bioerosive structures. A new attachment scar was identified as produced by gastropods and bivalves including, at least, *Crepidula* LAMARCK 1799, which has been documented to occur since the Late Miocene, and *Hipponix* DEFRANCE 1819, known so far exclusively from the Holocene.

The new bioerosive structures studied are described herein as a new ichnotaxon, *Lacrimichnus* ichnogen. nov., named after its overall appearance. Two different ichnospecies have been defined:

(*a*) *Lacrimichnus cacelensis* ichnosp. nov., which exhibits surface marks with an oval, very elongate or ellipsoidal margin, with one end rounded and the other very sharp. The margin is defined by a relatively deep furrow, which encloses a slightly depressed inner zone that can either be smooth or finely ornamented with eccentric lines.

(*b*) *Lacrimichnus bonarensis* ichnosp. nov. possesses a subrounded to suboval margin that differs in colour from the surrounding substrate. Although a very shallow furrow defines its margin, it normally exhibits no bands or rings, and no ornamentation on the inside.

The former ichnospecies is related to the attachment of at least calyptracean gastropods and ostracean bivalves also produce the latter.

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PLATES 1 – 2

PLATE 1

1 – External view of the right valve of *Gigantopecten tournali* DE SERRES with ostreids and etching traces *Lacrimichnus cacelensis* ichnosp. nov. on the left ventral margin; holotype RC/M1/1.

2-3 – Close-up of *Lacrimichnus cacelensis* ichnosp. nov.

4 – A composed trace of *Lacrimichnus cacelensis* ichnosp. nov.; arrows show the successive situation of the apical point of the producers. Holotype RC/M1/1.

5 – The same trace fossil in plan view; letters point to the progressive settling of the different superimposed producers.

6 – Lateral view of recent *Crepidula fornicata* (LINNÉ) on *Ostrea edulis* LINNÉ from Rias Baixas (Galicia, Spain); arrow shows the etching point of the gastropod.

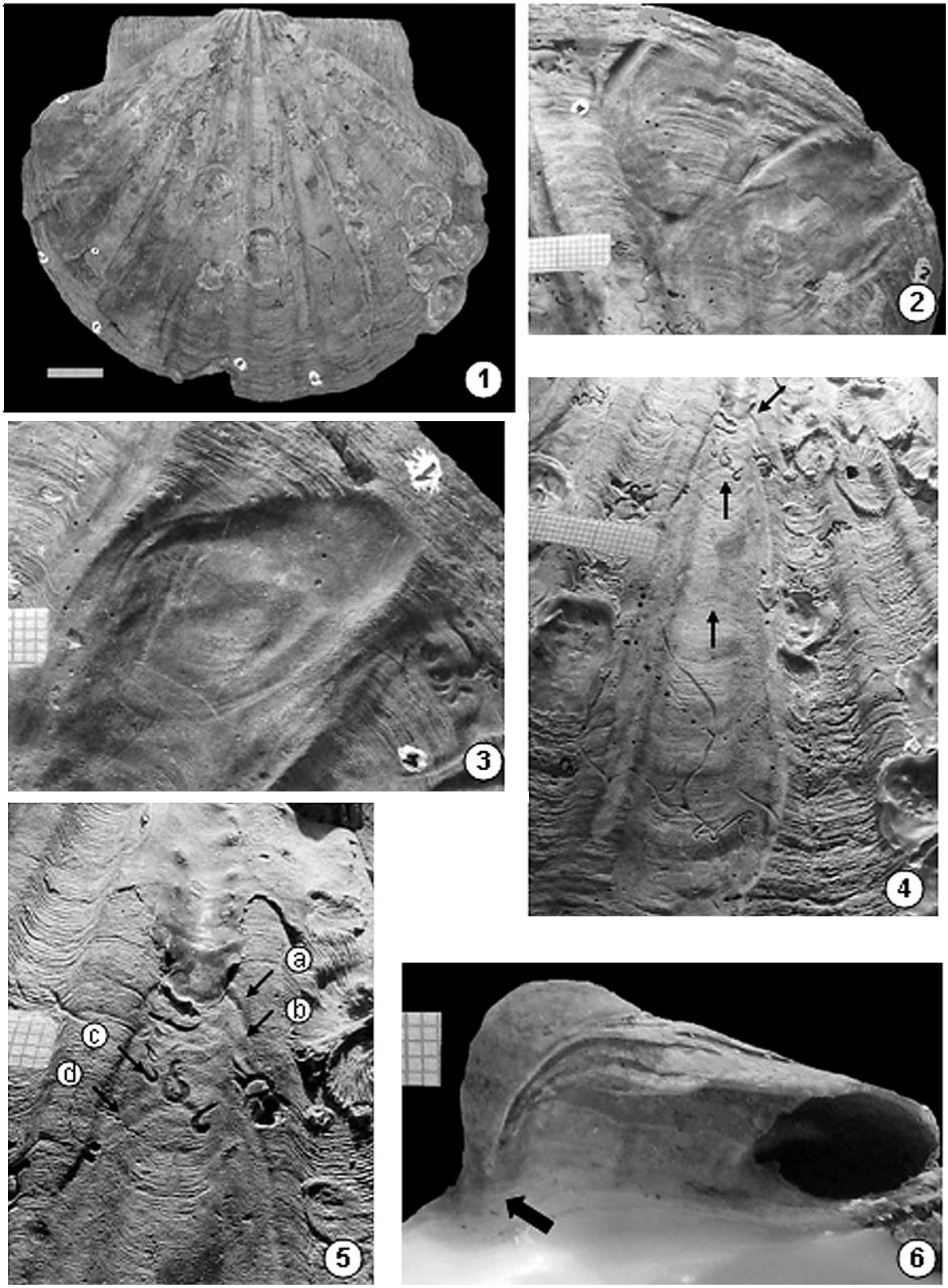
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PLATE 2

1-4 – *Lacrimichnus bonarensis* ichnosp. nov. on *Xenophora infundibulum* BROCCHI. Arrows show the outline of the trace fossils; 2-4 – Details of figures 1 and 3 respectively; 1 – Holotype MGUS-2200; 3 – Paratype MGUS-2202.

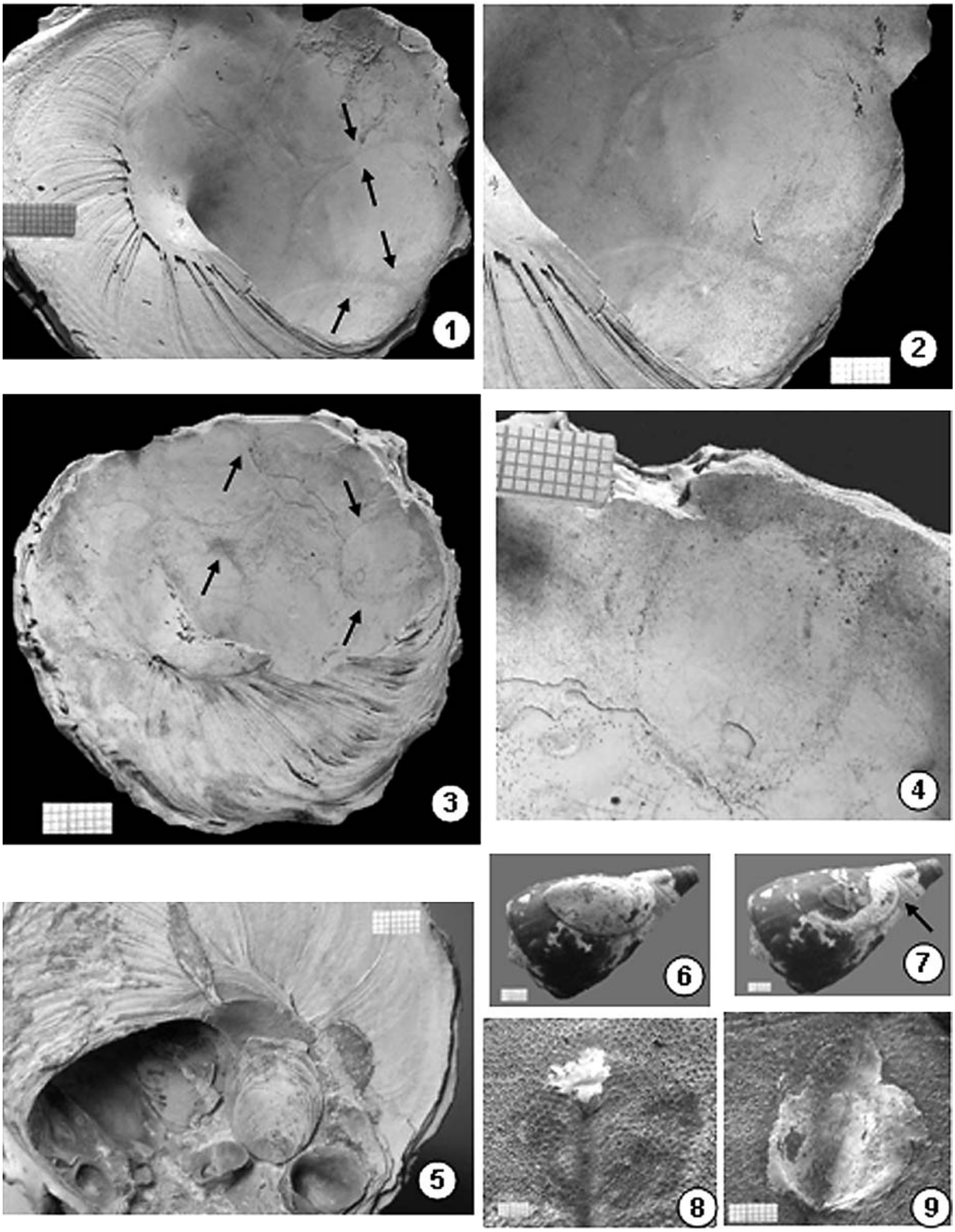
5 – Trace makers of *Lacrimichnus bonarensis* ichnosp. nov.; bivalves (Ostreacea) and gastropods (*Crepidula unguiformis* LAMARCK). Paratype MGUS-2208.

6 – Recent *Crepidula porcelana* LAMARCK on the gastropod *Conus luquei* RULAN & TROVÃO from the Cabo Verde Island.

7 – *Lacrimichnus cacelensis* ichnosp. nov. produced by the etching of the former *Crepidula*; arrow point to the outline of the trace.

8 – *Lacrimichnus bonarensis*. ichnosp. nov. on the oral side of *Clypeaster portentosus* DESMOULINS; paratype MGUS-2057.

9 – Bivalve (Ostreacea) producer of *Lacrimichnus bonarensis* ichnosp. nov. on the alimentary canals of *Clypeaster* sp.; paratype MGUS-2058.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