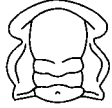


Lower Cretaceous (Albian) shell-armoured and associated echinoid trace fossils from the S acaras Formation, Serra Gelada area, southeast Spain

PAOLO MONACO, ALICE GIANNETTI, JES US E. CARACUEL AND ALFONSO Y EBENES

LETHAIA



Monaco, P., Giannetti, A., Caracuel, J.E. & Yebenes, A. 2005 00 00: Lower Cretaceous (Albian) shell-armoured and associated echinoid trace fossils from the S acaras Formation, Serra Gelada area, southeast Spain. *Lethaia*, Vol. 38, pp. 1–13. Oslo. ISSN 0024-1164.

The S acaras Formation (Albian, Lower Cretaceous) of the Serra Gelada succession (Prebetic of Alicante), southeast Spain comprises carbonate-rich, upwards thickening parasequences in which many types of trace fossils have been identified. The present study focuses on two types of tubular trace fossil characterized by features of their external coating. The first type is represented by a shell-covered, structured trace fossil, up to 4 cm in diameter and 40 cm in length, built horizontally, from rectilinear (type 1) to gently curved (type 2), which envelopes an unstructured pipe of grey silty sediment. The coating is characterized by imbricated, flat particles, mainly orbitolinid foraminifers and other planar bioclasts, forming thin concentric layers; in cross section the bioclasts produce a typical plumed structure. This trace fossil represents a new ichnogenus and ichnospecies, here named *Ereipichnus geladensis*. Particle arrangement of the external coating is similar to that of terebelloid tubes, but *Ereipichnus* is a horizontal trace fossil, whereas structured worm tubes are vertical. The second type is a grain-coated trace fossil, tubular in shape, with a simple internal structure. The coating is often reddish with respect to the neighbouring dark grey sediment and shows a slightly coarser-grained texture, which envelopes the internal muddy pipe. This type, which yielded echinoids, was produced by irregular or heart-shaped sea-urchins (spatangioids) and is attributed to *Scolicia* or *Cardioichnus*. Facies analysis of the Serra Gelada succession with *Ereipichnus* and *Scolicia* or *Cardioichnus* locally shows other types of branched trace fossils (primarily represented by different forms of *Thalassinoides*) and bioturbation is developed in tiers, increasing upwards in abundance and diversity. □ *Cardioichnus*, *Ereipichnus*, *Ichnology*, *Imbricated trace fossils*, *Lower Cretaceous*, *Prebetic*, *Scolicia*, *Spain*.

Paolo Monaco [pmonaco@unipg.it], & Alice Giannetti, Dipartimento di Scienze della Terra, piazza dell'Universit  I-06100 Perugia, Italy; Jes us E. Caracuel [jesus.caracuel@ua.es], and Alfonso Y ebenes Departamento Ciencias de la Tierra y del Medio Ambiente, Fac. Ciencias, Univ. Alicante, Apdo. 99 San Vicente del Raspeig, E-03080 Alicante, Spain; 27th March 2004, revised 31st July 2005.

The structure of grain-coated trace fossils is well established in the ichnologic literature but a tidy arrangement of gravel-oriented particles is rarely observed and only few examples of unbranched, coarse-grained trace fossils preserved as full relief structures have been described (Seilacher 1964; Roniewicz 1970; Bromley 1996; de Gibert 2003). Many marine organisms are able to pick up sand-sized particles from the substrate in order to construct and reinforce their burrows, but far fewer taxa stack tabular shells or flat skeletal grains to produce imbricated structures (Fager 1964; Hallam 1970; Bromley 1996; de Gibert 2003).

In shallow-water marine settings, several families of annelid worms build frameworks to produce shell-armoured vertical tubes (tube-building polychaetes, terebelloid tubes). Among worms only three families

(Onuphidae, Oweniidae and Terebellidae) contain species that actively pick up shells and heavy particles above the sediment surface (Fager 1964; Bromley 1996; de Gibert 2003). The construction of coated tubes (e.g. the tube-building polychaete *Lanice* in intertidal sands; Carey 1987) may help to stabilize the substrate in sandy sea-floor against water movement caused by wave surges, rip currents or spring tides (Fager 1964). Myers (1972) described a similar reinforcement of the upper portion of a vertical tunnel produced by the terebelloid worm *Diopatra cuprea*. In this case only the upper portion of tube (tube cap 2–5 cm long), which is built at or above the sediment surface, shows the characteristic camouflage-reinforcement comprising flat shells and rock fragments or algae (see also the trace fossil *Lepidenteron* of terebelloid worms, Suhr 1988). It is noteworthy that

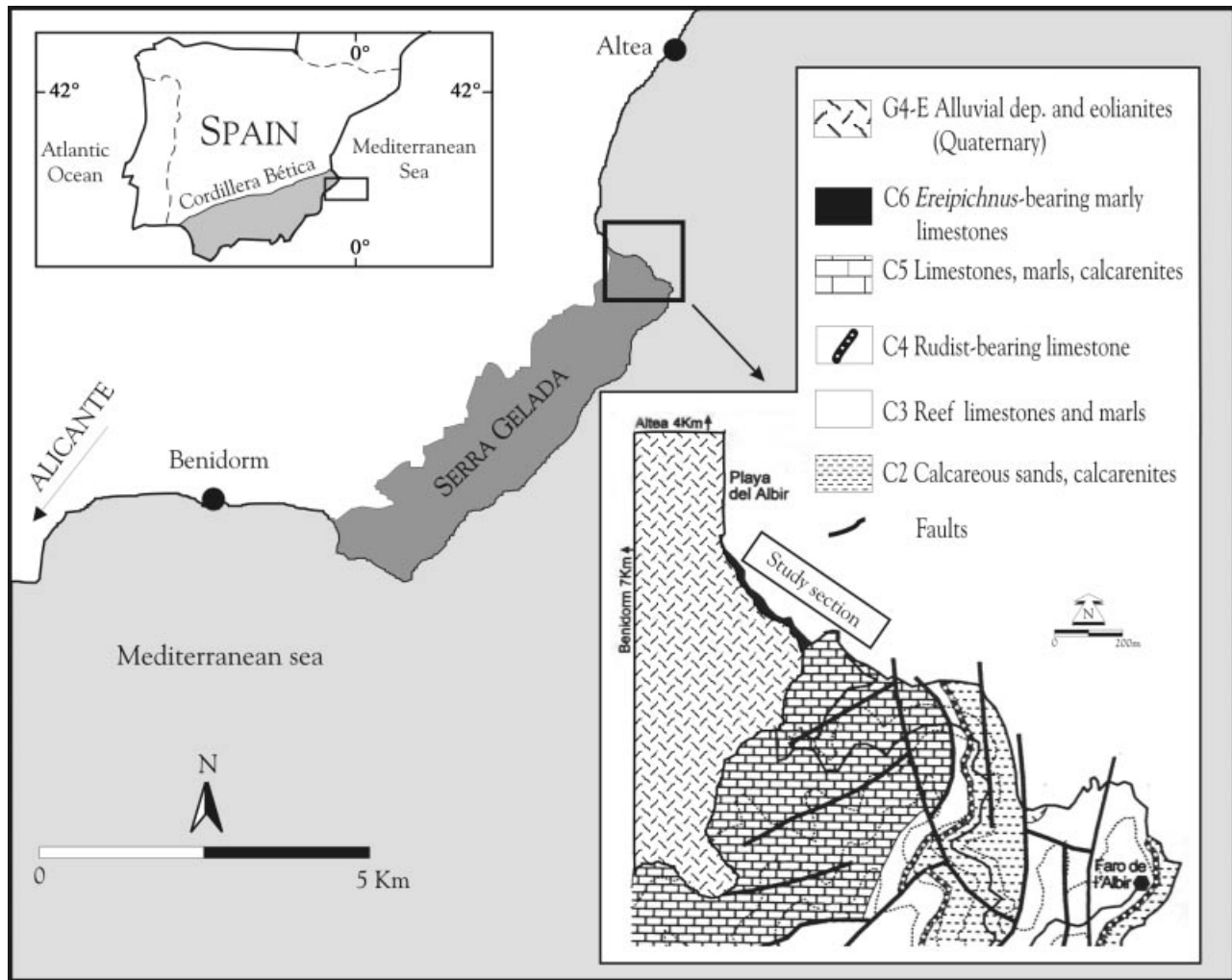


Fig. 1. The study area and position of the Serra Gelada section, Alicante area, southeast Spain. Units C2–C6 and G4–E are lithological subdivisions: C5–C6 are referred to the Lower Cretaceous Sácaras Formation (Fig. 2; after Yébenes 2004).

individuals of some polychaetes such as *Owenia fusiformis* and *Lanice conchilega* are not randomly distributed, but lump their burrows together during conditions of strong ripple currents or tides. The period of rapid growth in *Owenia* coincides with the time (spring) of phytoplankton bloom (Fager 1964; Carey 1987). Therefore, dense populations of shell-armoured tubes may reflect a peak in the worm-population density formed under unidirectional currents.

A count of dark and light particles on each tube indicates that *Owenia* worms must have handled about 25,000 sand or shell grains per centimetre of each tube (Fager 1964). The size of grains may change in relation to the size of the burrowing organism (in the case of juvenile *Owenia*, vertical tubes reach lengths of 15 cm and heavy mineral grains reach in size up to 80 μ) but the particles are attached in a manner, so that the resulting tube is imbricated upwards. Even fishes can create vertical tunnels, which are coated

by coarse-grained particles. In particular taxa of Opisthognatidae use the mouth and select shells or coarse-grained particles to reinforce the walls of their deep vertical tunnels (von Frisch 1975).

In the geological record, examples of shell-armoured and well-structured coated trace fossils are rarely encountered. Two types are described from the Middle Jurassic of Oxfordshire (England) and referred respectively to *Diopatrighnus roederensis* and *Diopatrighnus odlingi*, indicating their close resemblance to *Diopatra* tube caps (Kern 1978; de Gibert 2003). An additional type has now been observed in the Lower Cretaceous (Albian) succession from the Serra Gelada section (Prebetic of Alicante), Spain (Fig. 1) and is here erected as a new ichnogenus and ichnospecies *Ereipichnus geladensis* (see Appendix). The trace fossil is horizontal and tubular in shape. The cross section reveals a coating made up by a concentric, coarsening-outward pattern composed of

skeletal fragments, which are imbricated and arranged in several thin layers. An unsolved problem concerns the identity of organisms that could build such a type of horizontal tube because all previously known grain-coated structured tubes are vertical and do not develop on the horizontal bedding plane (de Gibert 2003).

This paper presents the first ichnological analysis from the Serra Gelada section. The ichnoassemblage recorded in the Serra Gelada area is composed of *Ereipichnus geladensis* and non-imbricated, grain-coated trace fossils, which are produced by irregular (heart-shaped) sea-urchins (spatangoids) and are referred to the ichnogenera *Scolicia* and *Cardioichnus*. Different types of *Thalassinoides* – typical *Ophiomorpha* – are also present, but only in the coarse-grained calcarenitic beds.

Study area: geological and stratigraphical setting

The trace fossils described here were analyzed in a well-exposed section cropping out in the Serra Gelada area (Figs 1, 2; Yébenes 1996, 2004). The Serra Gelada area is located northeast of Alicante and between the bays of Benidorm and Altea (Fig. 1). The area belongs to the northeastern part of the Internal Prebetic Domain (also named Prebetic of Alicante), corresponding to the (para-) autochthonous sector of the External Zone of the Cordillera Bética (de Ruig 1992).

Upper Jurassic–Lower Cretaceous sedimentary rocks are well exposed in the Serra Gelada area and the succession is up to 800 m thick. The succession is subdivided into seven lithostratigraphic units (Yébenes 2004) of which the uppermost part yielded the trace fossils of this study and is assigned to the Sácaras Formation (Lower Cretaceous, Fig. 2). The formation consists of mainly marls, calcarenites and irregularly bedded limestones, about 200 m thick (units C5 and C6 of Yébenes 2004; Fig. 1). According to biostratigraphic analysis this portion is referred to Lower – Middle Albian (Granier 1987; Castro 1998).

Four different litho-facies can be distinguished:

1. Arenaceous and calcareous grey marlstones. Bioclasts are abundant, consisting of thin-shelled bivalves, planktonic foraminifers and Orbitolinidae; echinoids are frequent mainly in the lower part of the unit.
2. Alternating calcareous marls and bioturbated nodular marly limestones, composed of bioclastic wackestones and packstones. Echinoids, bivalves, rare ammonites and belemnites are the most frequent but fragmentary bioclasts also occur.

3. Nodular and bioturbated bioclastic limestones (packstones). Bioclasts are abundant and diverse including bivalves, crinoids, gastropods, bryozoans, echinoids, and rodophytes.
4. Bioclastic rudstones and grainstones with some ooids, forming plano-convex, cross-stratified calcarenitic beds, more or less bioturbated. Fragmentary and occasionally oriented bioclasts include bivalves, crinoids, gastropods, bryozoans, algae, benthic foraminiferans and rare echinoids.

These lithofacies are organized in upwards coarsening-, thickening- and carbonate-rich parasequences, in which bioturbation increases in abundance and diversity from facies 1 to 3.

Methods

The Lower Cretaceous (Albian) trace fossils from the Serra Gelada area have been studied in terms of their preservation (full or hemirelief) and three-dimensional development in marly and calcareous beds. Three-dimensional orientation of tubes and their relationship to the bedding have been analyzed along with the degree of flattening due to compaction. Measurements of the orientations are plotted as rose-diagrams on Fig. 2, which gives clear evidence of the uni-directional orientation of the trace fossils and also shows the stratigraphic distribution of ichnoassemblages. The external shape and framework have been considered and ichnofabric has been analyzed in the field including also observations from large fallen blocks along the coastal cliff. Trace fossils have been studied in transverse and longitudinal sections to document the structure of the external tube and internal pipe (Fig. 3). Skeletal grain arrangement has been observed in thin sections. In cases where echinoids have been found preserved within the trace fossils, grain distribution and colour in the external and the internal part of the trace fossil have been defined.

Grain-coated trace fossils

Based on the structure and shape of trace fossils it is possible to distinguish between two grain-coated types, whose morphological affinities are discussed: (1) imbricated shell-armoured (structured), and (2) grain-coated (unstructured).

(1) The shell-armoured trace fossils (structured)

Description of specimens in the type area. – Shell-armoured (structured) trace fossils appear in

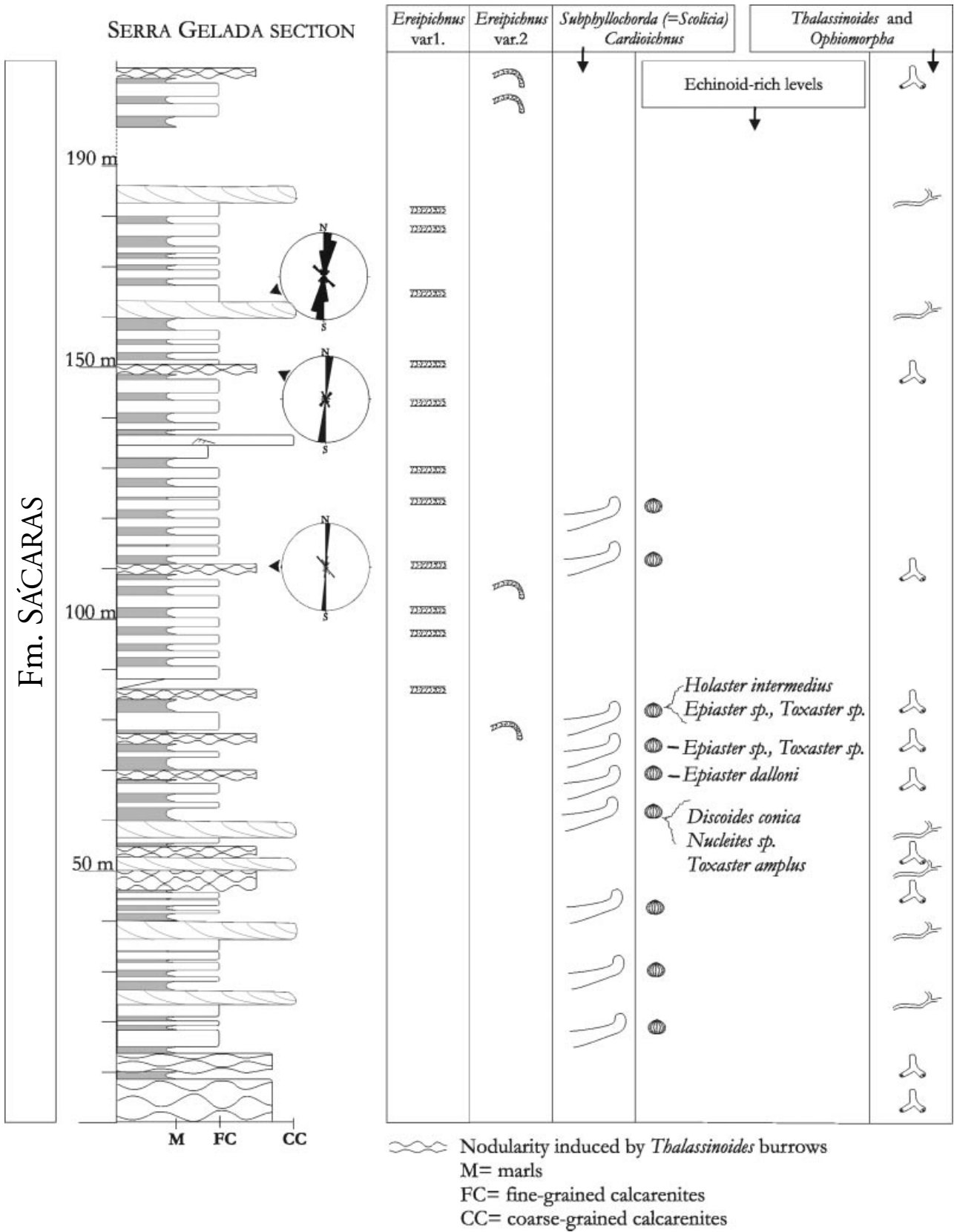


Fig. 2. Detailed log of the SÁCARAS Formation, which is the upper part of the Serra Gelada succession, Alicante area, southeast Spain. Horizons with shell-armoured trace fossils and echinoid-rich levels are shown. The orientation of shell-armoured trace fossils is indicated by the rose diagrams.

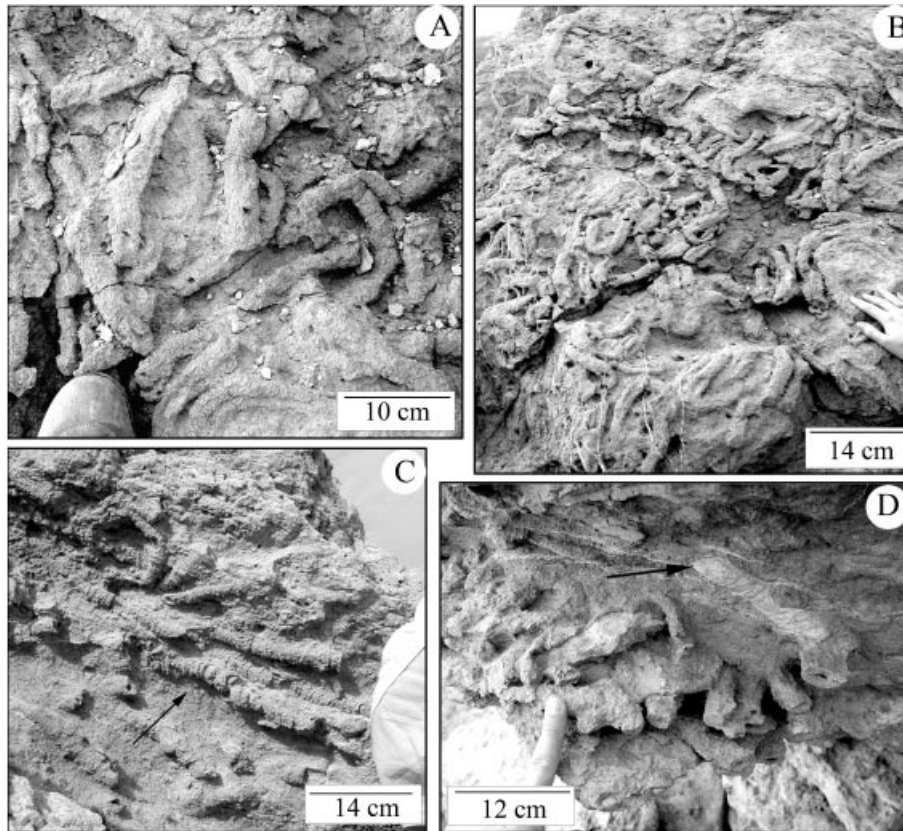


Fig. 3. General view of shell-armoured trace fossils *Ereipichnus geladensis* (Albian, Lower Cretaceous), Serra Gelada section, Alicante area, southeast Spain. □A–B. Slightly meandering, horizontal tubes (10 to 40 cm in length) of *Ereipichnus geladensis* (type 2). □C–D. Rectilinear tubes of *Ereipichnus geladensis* (type 1) packed on superimposed layers showing subcircular or slightly elliptical (ovoid) cross-sections. Meniscate structures and internal muddy pipe are seldom preserved (see arrow in C and D, respectively).

horizontal full relief, well cemented and tubular in shape, between 10 and 40 cm in length, and sub-circular or slightly elliptical (ovoid) in cross-section (Fig. 3A–D). Diameters range from 2 to 4 cm, most frequently 2.5 cm. The degree of eccentricity of the transverse section (calculated as horizontal vs. vertical diameter) ranges from 1 (circular) to 4 (elliptic). Frequently, trace fossils are more flattened in the marly beds, showing a planar base and a convex top (Fig. 4A). Most (95%) of the trace fossils are horizontally distributed and parallel to bedding, rarely (5%) gently inclined forming a 20–30° angle with respect to the stratification (Fig. 3C). In the stratification plane, they range from rectilinear (type 1) to slightly meandering or gently curved (type 2), changing their direction of locomotion at most 35°. In some beds they form sinuous mazes (Fig. 3A–B) developed horizontally and distributed on superimposed layers, more or less strictly packed according to lithology and trace fossil abundance (Fig. 3C–D).

Imbrication of grains is the most important feature of these trace fossils (Fig. 4D–F). It is shown by the distribution of tabular-shaped skeletal particles,

mainly orbitolinids and well-sorted, flat fragments of bivalve and gastropod shells, along with other, more or less platy, carbonate and siliciclastic grains. A transverse section of the lined trace fossil (Fig. 4B) reveals a concentric, coarsening-centrifugal pattern of skeletal fragments. Grains of the shell-armoured tube change in size from fine-grained sand (0.03 to 0.1 mm), in the inner part close to the internal rod, to very coarse-grained sand (0.5 to 1.5 mm), in the outer portion of trace fossil (Fig. 4D–F). Grains are aligned defining curved, conical laminae, which are concentrically placed around the axis with progressively increasing angles from 10–15° (close to the internal rod) to 80–90° (close to the outer part) (Fig. 4D–F). Imbrication of grains is clearly visible in the internal lumen floor where flat particles are tangentially disposed (as a tiled floor). Close to the internal channel, particles are concentrically stacked (Fig. 4E–F); this particular disposition of grains forms, in longitudinal section, a characteristic plumed structure (Caracuel *et al.* 2002).

Locally, the coarse-grained framework shows convex structures, similar in shape to meniscate

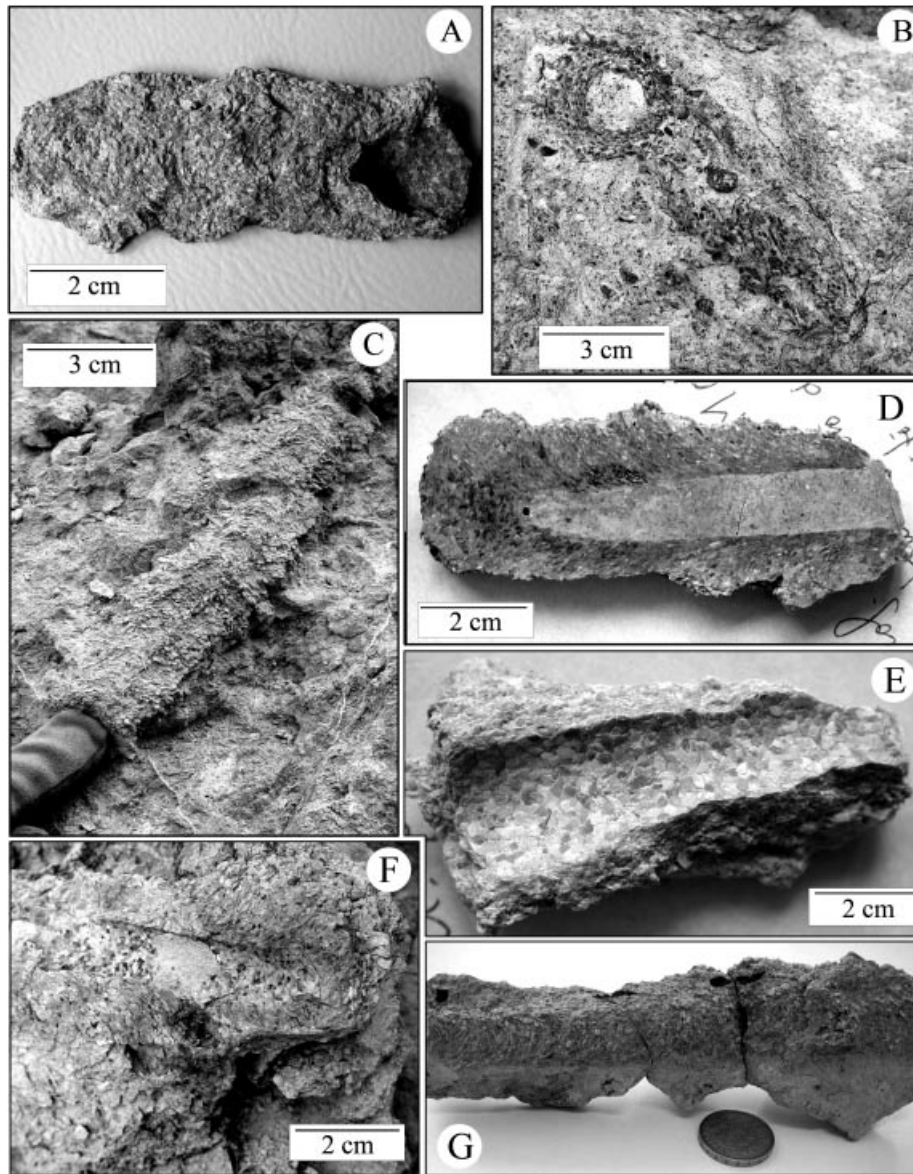


Fig. 4. Coating structures of shell-armoured trace fossil *Ereipichnus geladensis* (Albian, Lower Cretaceous), Serra Gelada section, Alicante area, southeast Spain. □A. Full relief showing a coarse-grained coating without the internal pipe (not preserved). □B. Transverse section of the lined burrow with coarsening-centrifugal distribution of skeletal fragments (from fine- to coarse-grained sand) coating the internal muddy pipe. □C. Meniscate structure aligned along the central axis of the burrow which is emphasized by weathering. □D–F. Imbrication is shown by distribution of tabular-shaped skeletal particles (mainly orbitolinids, well-sorted flat fragments of bivalve and gastropod shells, carbonate and siliciclastic grains). Grains are aligned defining curved laminae, which are concentrically arranged around the axis with progressively increasing angles from the internal rod towards the outer part, forming a characteristic 'plumed structure'. Note the internal (unstructured) muddy pipe arrowed in the holotype of Fig. 4D (EGSG T109). Paratypes (EGSG T110–T111–T112) are illustrated in Fig. 4A, C, F & G.

fill preserved in convex hyporelief, as indicated by Keighley & Pickerill (1994, pl. 1, fig. 6). Menisci converge at the margins of a depressed U-shaped region aligned parallel to the central axis, while the coarsest grains are distributed laterally (Fig. 4C–G).

The spreiten, marking the direction of locomotion of the burrower, are generally clearly visible in the outer bioclastic part, indicating that most burrowers had the same direction of locomotion. Crossing trace fossils appear closely and tightly entwined and

never cut each other, probably because of the early cementation induced by biogenic mucus.

Morphological affinities. – Lined, cylindrical and horizontal tubes of the Serra Gelada area show morphological affinities with several trace fossils, but reveal also many differences, considering both the internal imbricated structure of the shell-armoured tube and external shape. First of all, the framework (particle organization and related imbrication) suggests close

331 affinities with the ichnospecies *Diopatrachus*
 332 *roederensis* Kern (1978) and *Diopatrachus odlingi*
 333 de Gibert (2003), both known from their holotypes
 334 only. In cross-section, the concentric distribution
 335 of particles is closely similar to the shell-lined tube
 336 *Diopatrachus odlingi* described by de Gibert (2003).
 337 Longitudinally, instead, the shape and peculiar
 338 framework of the skeletal fragments differs from
 339 the holotype of *Diopatrachus odlingi* de Gibert (2003)
 340 which does not show the characteristic imbricated
 341 structure (see Kern 1978, fig. 2; de Gibert 2003, fig. 4).

342 Moreover, our shell-armoured tube coats an
 343 inner, unstructured pipe made of silty sediment
 344 which is lacking in *Diopatrachus roederensis* and,
 345 probably, also in *D. odlingi*. Kern (1978) interpreted
 346 *Diopatrachus roederensis* as the tube cap of a *Diopatra*
 347 species, i.e. an onuphid worm building shell-
 348 armoured vertical burrows (Myers 1970, 1972).
 349 Attached particles are imbricated upwards also in
 350 other extant tube-building polychaetes such as *Owenia*
 351 (Fager 1964). The chimney-building worm *Diopatra*
 352 may form an inverted J-bent burrow sticking out from
 353 1 to 6 cm above the sediment surface whose tube
 354 termination is bent over so that the tube mouth
 355 faces the sea-floor obliquely (Bromley 1996). In this
 356 position, the tube cap is oriented normal to the main
 357 direction of current flow (Myers 1970). De Gibert
 358 (2003) suggested a similar organism for terebelloid
 359 worm tubes recovered from the Middle Jurassic White
 360 Limestones of Oxfordshire, although the horizontal
 361 development of tubes is unsuitable for tube-building
 362 polychaetes (Fager 1964; Myers 1972). De Gibert
 363 (2003) interpreted horizontal *Diopatra* tubes to be the
 364 result of reworking by storm activity. According to
 365 Myers (1970), the tube cap of *Diopatra* might be
 366 horizontally oriented only if compressed during
 367 sediment compaction after final burial (see type I
 368 of Myers 1970, fig.1b). Therefore, the ichnogenus
 369 *Diopatrachus* should be employed exclusively for
 370 vertical burrows and thus is not appropriate for
 371 the horizontally structured tubes from the Serra
 372 Gelada area.

373 The horizontal tube-like trace fossil *Lepidenteron*,
 374 which may be referred to the activity of terebelloid
 375 worms, has been redescribed by Suhr (1988) and
 376 this author indicated four ichnospecies based on
 377 the construction material of the tube (fish remains,
 378 needles of coniferes, mucous particles and a lot of
 379 various grains) which the worm had used. The
 380 thickness and length (up to 35 mm and
 381 20 cm, respectively) and horizontal development of
 382 *Lepidenteron variabilis* (Suhr 1988, fig. 3) are
 383 consistent with the Spanish trace fossils, but organization
 384 of the various grains are very poorly imbricated in
 385 *Lepidenteron* and suggests that affinity with the Serra

Gelada trace fossils is unlikely. In addition, information concerning the arrangement of grains in the holotype of *Lepidenteron* is lacking.

Imbrication, involving tests of large foraminiferans, is also present in tube-like trace fossils illustrated by Roniewicz (1970, fig. 9) and defined as *Nummipera eocenica* by Holder (1989, figs. 2–9). The latter author described a new ichnogenus and ichnospecies from the Eocene as a vertical tube-like trace fossil build of flat tests of large foraminifers (nummulitids). Some characteristics concern only the organization of skeletal particles: they are imbricated and all grains are of the same size (e.g. discocyclinids) but do not show the typical concentric, coarsening-centrifugal pattern, which is typical for the Serra Gelada trace fossils. Moreover, the internal rod is not present in *Nummipera eocenica* and the internal part is not a tubular muddy pipe that changes in size (Holder 1989, fig. 2).

The external shape, as discussed by Caracuel *et al.* (2002), also reveals some morphologic affinities to *Imbrichnus wattonensis*, which is described from the Forest Marble (Bathonian) in Dorset, England (Hallam 1970, pl. 2b, c, text-fig. 2). Caracuel *et al.* (2002) emphasized the similarities with *Imbrichnus wattonensis* with respect to the external morphology, which is meandering in shape and aligned more or less parallel to the bedding (positive hyporelief). Probably, the meandering represents bivalve locomotion, included in *Protovirgularia* by Seilacher & Seilacher (1994). The Dorset trace fossil shows a sediment-filling feature with a characteristic imbrication (as indicated by the name) consisting of successive pads of sandstone 1 to 3 mm thick. However, many differences exist in the imbrication style of the pads in *Imbrichnus*, which seems to be a superficial (external) structure (Hallam 1970). Imbrication of *I. wattonensis* develops as V-shaped folds only in the horizontal plane (folds inclined at 60° or less compared to the axis), not affecting the whole coating as observed in the Serra Gelada material. Moreover, the internal muddy pipe of the latter is lacking in the traces from the Forest Marble and the grains do not reach the coarse sand or pebble size observed in the specimens from Spain. Thus, the grain arrangement and the framework of the coated tubes are totally different in these two cases.

Grain alignment in the external coating shows some analogies to the arcuate meniscate fill preserved in convex hyporelief of *Taenidium barretti* (Bradshaw), which is illustrated and discussed by Keighley & Pickerill (1994). Nevertheless, menisci are each shaped like a crescent moon in *Taenidium barretti* and are clearly developed in the entire burrow; they converge at the margins of the structure forming cusps and

giving the general appearance of a crescentic meniscate segment (Keighley & Pickerill 1994). In the Serra Gelada material, menisci are seldom preserved (Fig. 3C, see arrow) and the convergence is not clearly visible at the margins, probably due to the nature of the coarse-grained material. Locally, menisci are concentrated in a couple of internal bands aligned mainly along the central axis of the burrow and are more easily visible because of weathering (Fig. 4C–G). For a detailed description of *Taenidium* and its affinities with other ichnogenera such as *Beaconites* and *Ancorichnus* we refer to Keighley & Pickerill (1994).

The shell-armoured burrows of the Serra Gelada section show an inner, unstructured horizontal pipe represented by fine-grained, peloidal grey silty mud (Fig. 4D). This silty pipe differs from the internal rod, which is named *Bichordites* (Plaziat & Mahmoudi 1988), since no cordate or lozenged-shaped section is revealed in cross-section, as reported by these authors. The meniscate pattern of *Bichordites* is not present in the Serra Gelada trace fossils, where the pipe is completely unstructured and their external surface retraces the smooth lining made by the coarse-grained material. Therefore, it is possible that the internal pipe represents an infill of faecal products by the same organism, which produced the shell-armoured coating tube.

(2) Non-imbricated, grain-coated trace fossils (unstructured)

Description. – These horizontal burrows consist of an inner muddy pipe, which is coated by a coarse-grained tube. The tube – and in contrast to the shell-armoured trace fossils described above – is without any well-defined framework of particles, where the coarse-grained grains are casually distributed and not imbricated. A transverse section of the burrows reveals a peculiar structure in the internal muddy pipe, which shows two lateral lobes and a central V-shaped region (Fig. 5D). The internal pipe changes in size, reaching up to 4–5 cm in diameter, in one and the same burrow (Fig. 5F). Concerning the preservation of the coating, the lower half of the burrow is preferentially lithified in contrast to the upper half where it is lacking (Fig. 5B–F). Coating is often reddish and shows a slightly coarser-grained texture in respect to the neighbouring dark grey and finer sediment, enveloping a pipe, which resembles a monk's cowl (Fig. 5A). The unstructured coating tube generally consists of small bioclasts or detrital sandy grains mixed with finer sediment, probably cemented during early diagenesis. The boundary between the coating and the pipe is sharp and clearly visible in cross-section (Fig. 5C). In some samples echinoid tests

(spatangoids) are preserved within their burrows or concentrated at the end of trace fossils (Fig. 5B–C, arrow). Echinoid tests are very abundant in the lower – middle parts of the section (Fig. 2, *Holaster intermedius*, *Epiaster* sp., *Epiaster dalloni*, *Toxaster* sp., *Toxaster amplius*, *Discoides conica*, *Nucleites* sp.) where well-preserved tests are scattered or concentrated (Fig. 5E). In any case the distribution of echinoids coincides with the abundance of grain-coated trace fossils and indicates that spatangoid echinoids perished very close to their burrows (Fig. 5A, B–C).

Locally, convex resting impressions, ovoid in outline, are preserved at the end of the slightly meandering echinoid burrows (*Cardioichnus*, see Fig. 6A, B).

Morphological affinities. – A close relationship exists between the grain-coated trace fossils of the Serra Gelada area and the horizontal ones formed mainly by spatangoids (see Fig. 2). For irregular echinoids of the order Spatangoida, burrowing is considered the rule (Bromley & Asgaard 1975; Smith & Crimes 1983; Uchman 1995; 1998; Kanazawa 1995; Lebrun 2000). The excavation activity of lateroventral spines of the echinoid results in forward movement and redeposition of grains in sandy sediment, while it does not work well in muddy sediments, which are too soft and cohesive for excavation and transport (Kanazawa 1995). Grain alignment does not generally show sorting or imbrication, but flat grains are concentrically disposed around the axis of the trace, as observed in *Echinocardium cordatum* (Kanazawa 1995) and in the Serra Gelada trace fossils (Fig. 5C, white arrow). As far as lithification of *Echinocardium cordatum* traces is concerned, Bromley & Asgaard (1975) noted that the lower halves of burrows are preferentially lithified in contrast to the upper ones due to mucus secreted at the ambitus (Péquignat 1970; Kanazawa 1995). Thus, the grain-coated trace fossils from Serra Gelada can be attributed to spatangoid activities since only the lower halves of their burrows are preserved (Fig. 5B, D–F).

The external shape and cross-section of *Subphyllochorda* and *Cardioichnus* [illustrated by Smith & Crimes (1983, figs. 3–5, 7)] and *Scolicia* (i.e. Uchman 1998, fig. 60) show close analogies to the Serra Gelada non-imbricated, grain-coated trace fossils. *Subphyllochorda* consists of meandering ridges usually bilaterally symmetrical and convex in shape (Smith & Crimes 1983). As reported by those authors, the trace in cross-section is ovoid in outline and concentric lamination can be observed in polished or etched sections (Smith & Crimes 1983; Uchman 1998, fig. 60). Although Smith & Crimes (1983) described two separate ichnogenera (*Subphyllochorda*

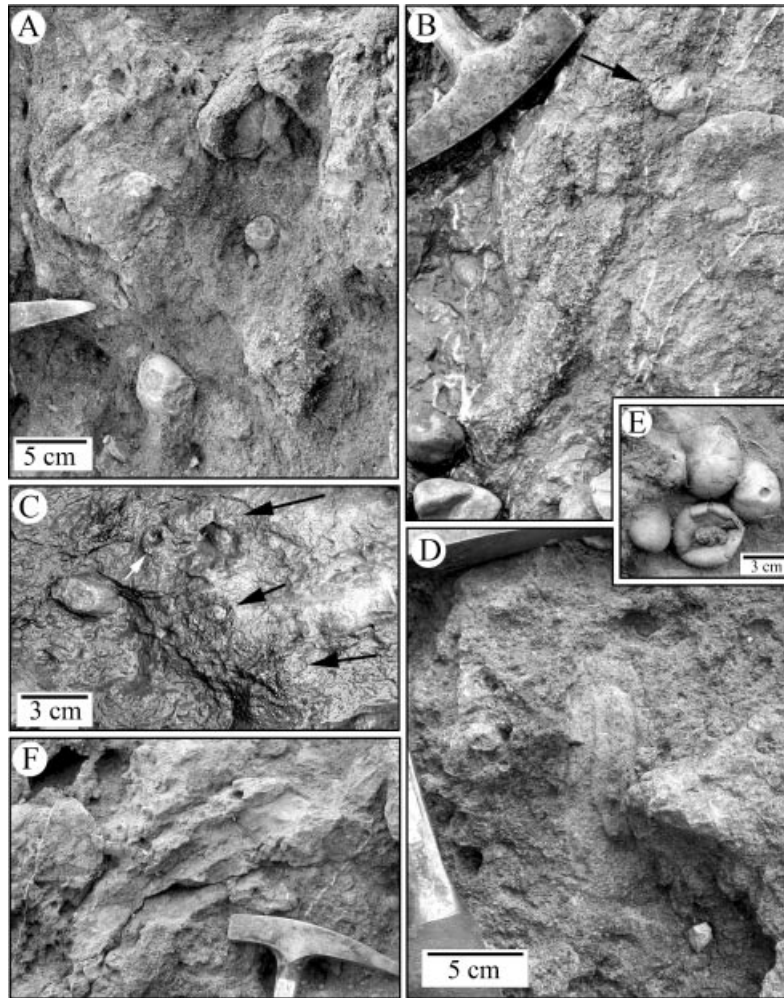


Fig. 5. Grain-coated trace fossils (non-imbricated) referred to the ichnogenera *Scolicia* and *Cardioichnus*, and echinoid-rich levels, Serra Gelada section (Albian, Lower Cretaceous), Alicante area, southeast Spain. □A. Unstructured, coarse-grained burrow, which envelops a muddy sediment. □B. Lower halves of burrows are preferentially lithified in contrast to the upper ones that are destroyed (see also Fig. 5D–F). Echinoid tests (spatangoids) are seldom preserved within their burrows (see arrow). □C. The boundary between coating and pipe is sharp and clearly visible in transverse sections. □D–F. The internal muddy pipe shows two lateral lobes and a central V-shaped region; the changes in size in a same burrow reach up to 4–5 cm in diameter. □E. Echinoid-rich level in which, compaction and collapse of echinoid tests are characteristic biostratigraphic features. Hammer head for scale in Fig. 5A, B, D & F.

and *Scolicia*), Uchman (1995, 1998) included *Subphyllochorda* and other similar taxa, such as *Taphrhelminthopsis*, *Laminites* and *Taphrhelminthoida* within *Scolicia* as taphonomic variants of the same ichnogenus produced by heart-shaped sea-urchins. Uchman (1995, 1998) pointed out that *Subphyllochorda*-like specimens, which do not show peculiar features (such as clear division of the main ridge), cannot properly be distinguished as different ichnogenera. Thus Uchman (1998) proposed to polish the *Subphyllochorda*-like specimens at the lowermost part in order to expose the structure of medial lobe for a proper identification. *Scolicia* is a bilobate or trilobate back-filled echinoid trace fossil (usually meandering) with two parallel sediment strings, which represent the drainage canals of spatangoid echinoids

(Kanazawa 1995). Well-defined laminae (2–4 mm) of the lateral mantle are arranged in two alternating series along a central zone, which is also laminated (floor according to Smith & Crimes 1983). *Scolicia* is commonly developed in medium to fine-grained sandstone beds, few centimetres below the top of turbidite-hemipelagite bed and preserved in full reliefs (Uchman 1995, 1998).

In the Serra Gelada material the echinoid burrowing activity is concentrated close to the sand/mud interface without producing double sanitary tubes (2–5 mm in diameter, ovoid in cross-section and cohesive; see Smith & Crimes 1983). This double sanitary tube is seldom visible in the Serra Gelada trace fossils. Only two cases have been recognized in the Serra Gelada section. The paucity of two parallel

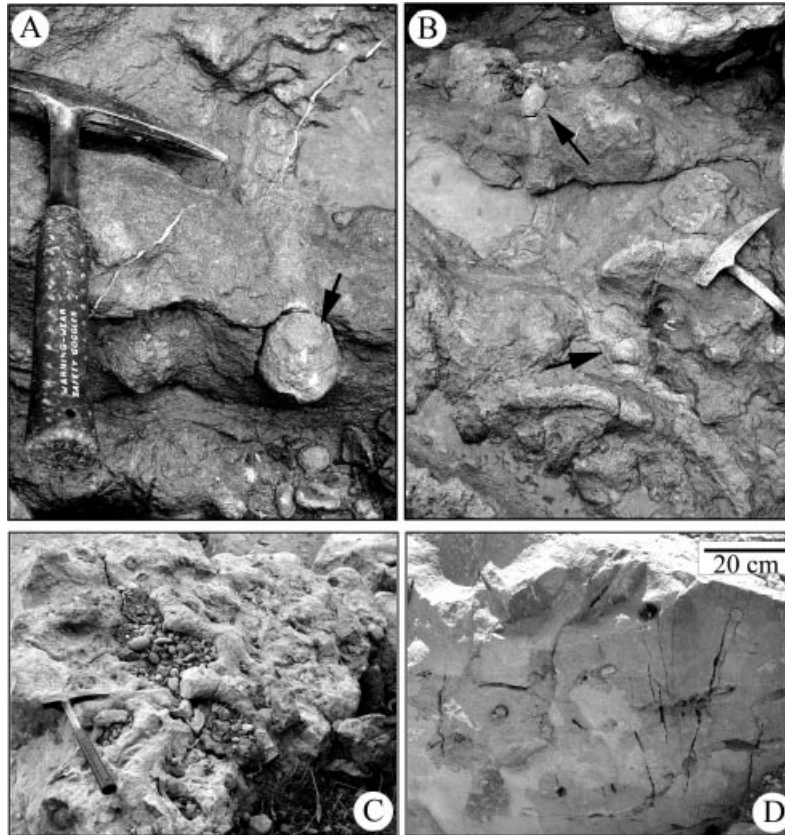


Fig. 6. Grain-coated trace fossils (non-imbricated) attributable to heart urchins (*Cardioichnus* isp.), (Albian, Lower Cretaceous), Serra Gelada section, Alicante area, southeast Spain. □A–B. Convex resting impressions, ovoid in outline, preserved at the end of the slightly meandering echinoid burrow (*Cardioichnus* isp., see arrows). Hammer for scale. □C. Horizontal mazes of Y-shaped *Thalassinoides* isp.; the lower surface of bed is upside down. Hammer for scale. □D. Top of a coarse-grained calcarenite bed with a trace fossil assemblage of *Ophiomorpha* isp. From the lower part of the Serra Gelada section.

strings of fine sediment produced by the heart urchin may be explained, firstly, by the poor preservation of the lower halves of the burrows, and secondly, by the development of diagenetic features affecting the coarse grain size of involved sandy/pebbly particles.

Cardioichnus is a convex resting impression, ovoid in shape and also bilaterally symmetrical, showing two wide lateral lobes, anteriorly linked and with a depressed V-shaped region towards its posterior part. In the description by Smith & Crimes (1983), *Cardioichnus* and *Subphyllochora* are frequently associated in continuity, the first one generated when the echinoid temporarily stops and slightly changes its vertical locomotion for temporary refuge, forming the characteristic *Cardioichnus* convex shape (Smith & Crimes 1983, fig. 9). This relationship between *Cardioichnus* and *Subphyllochora*-like specimens is recognized in echinoid-rich levels in the Serra Gelada specimens (Fig. 6A–B, arrow). The holotype of *Cardioichnus planus* (Smith & Crimes 1983, fig. 7c) is similar to the grain-coated

trace fossils collected from the Serra Gelada section (Figs 5–6).

Discussion and conclusions

Two varieties of *Ereipichnus geladensis* may be distinguished: type 1 is rectilinear in shape and unidirectional (most of the burrows are N–S oriented both for each bed and along the whole section), and type 2 is curved and slightly meandering in the horizontal plane (Fig. 3C, D and A, B, respectively). Both varieties are segregated at different stratigraphic intervals: type 1 is present in the middle part of the Serra Gelada section, while type 2 has been found at the top of the section. Their abundance is controlled by lithology. Rectilinear, tightly packed tubes of *Ereipichnus geladensis* type 1 dominate in fine-grained, marly beds where the density of jutting tubes is high, reaching in some beds 400 specimens/m². These jutting burrows are similar to terebelloid tubes cited for the Serra Gelada area by Moseley (1990).

A comparable high density has been recognized for some tube-building marine polychaetes, such as *Owenia*, which are estimated to include more than 500 worms per square metre. This dense population seems to coincide with the presence of *rip* currents in the surf zone (Fager 1964). The presence of uni-directionally and relatively strong currents would explain the high density of uni-directional jutting tubes of *Ereipichnus geladensis* type 1, although, in the case of Serra Gelada section, the burrowing organisms are unknown (worms?).

Sinuously arranged specimens of *Ereipichnus geladensis* type 2 are densely packed in coarse-grained calcarenitic beds and developed in different stacked layers, reaching burrow densities on a horizontal plane of 80–100 specimens/m². Both varieties are frequently associated with different forms of *Thalassinoides* (Fig. 6C). In some levels a close relationship exists between shell-armoured *Ereipichnus* and muddy, Y-shaped *Thalassinoides* trace fossils and horizontal mazes of giant *Thalassinoides* are always distributed deeper than *Ereipichnus*, which tends to occupy shallower tiers. In other marly levels of the middle part of the Serra Gelada section, some shallower tiers are dominated by a *Cardioichnus* ichnoassemblage and occasionally specimens of *Ereipichnus geladensis* occur (Fig. 2).

The second type of trace fossil comprises unstructured, grain-coated traces which are attributable to *Scolicia* and *Cardioichnus*. These traces fossils were produced by heart urchins (spatangoids) whose tests are well preserved at some levels in the Serra Gelada section. The attribution of these burrows to echinoid activity is confirmed by the recognition of spatangoid body fossils inside the end of burrow path. Moreover, as usual for echinoid burrows, only the lower halves of burrows are lithified. The major concentration of *Scolicia* and *Cardioichnus* seems to coincide with the highest concentration of whole echinoid tests, which can reach a density of population of about 3 specimens/m².

The Serra Gelada section is important from the ichnological point of view, because it contains rich, diverse and unique trace fossil associations. Apparently, a close relationship between diversity and abundance of burrows and parasequences exists, which is also observed in the Lower Jurassic succession of the Trento Platform, northern Italy (Monaco & Garassino 2001; Monaco & Giannetti 2002).

Acknowledgements. – The authors are grateful to the reviewers, Prof. A. Uchman (University of Kraków), Dr J.W. Jagt (Museum of Maastricht) and to A. Baldanza for helpful suggestions, which improved the final version. Many thanks to Joaquín López (Caudete, Spain) for a classification of echinoid tests of Serra Gelada. This work was financially supported by the Biosedimentary

Laboratory of Perugia University, Italy and the research Project GV04B-629 (Generalitat Valenciana, Spain).

References

- Bromley, R.G. 1996: *Trace Fossils. Biology, Taphonomy and Applications*. 361 pp. Chapman & Hall, London.
- Bromley, R.G. & Asgaard, U. 1975: Sediment structures produced by a spatangoid echinoid: a problem of preservation. *Bulletin of the Geological Society of Denmark* 24, 261–281.
- Caracuel, J.E., Monaco, P., Yébenes, A. & Giannetti, A. 2002: Trazas afines a *Imbrichnus wattonensis* Hallam de edad Albiense en el Prebético de Alicante (Serra Gelada). *Geogaceta* 31, 171–174.
- Carey, D.A. 1987: Sedimentological effects and palaeoecological implications of the tube-building polychaete *Janice conchilega* Pallas. *Sedimentology* 34, 49–66.
- Castro, J.M. 1998: Las Plataformas del Valanginiense Superior – Albiense Superior en el Prebético de Alicante. 464 pp. Unpublished Doctoral thesis, Universidad de Granada, Spain.
- de Gibert, J.M. 2003: *Diopatrachus odlingi* n. isp. (annelid tube) and associated ichnofabrics in the White Limestone (M. Jurassic) of Oxfordshire: sedimentological and palaeoecological significance. *Proceedings of the Geologists' Association* 107, 189–198.
- de Ruig, M. 1992: Tectono-sedimentary evolution of the Prebetic Fold Belt of Alicante (SE Spain). 208 pp. Unpublished Doctoral thesis, Vrije Universiteit Amsterdam, The Netherlands.
- Fager, E.W. 1964: Marine sediments: effects of a tube-building Polychaete. *Science* 143, 356–359.
- Granier, B. 1987: Le Crétacé inférieur de la Costa Blanca entre Busot et Altea (Alicante, Espagne): biostratigraphie, sédimentologie, evolution tectono-sédimentaire. 281 pp. Unpublished Thèse Doctorat d'Etat, Université de Paris VI, France.
- Hallam, A. 1970: *Gyrochorte* and other trace fossils in the Forest Marble (Bathonian) of Dorset, England. In Crimes, T.P. & Harper, J.C. (eds): *Trace Fossils, Geological Journal, Special Issue* 3, 189–200. Seel House Press, Liverpool.
- Holder, H. 1989: Spuren auf der Spur. Palichnologische und verwandte Notizen über *Teredolites*, *Entobia*, *Nummipera* nov. gen. und einiges andere. *Münster. Forsch. Geol. Paläont.* 69, 13–30. AQ1
- Kanazawa, K. 1995: How spatangoids produce their traces: relationship between burrowing mechanism and trace structure. *Lethaia* 28, 211–219.
- Keighley, D.G. & Pickerill, R.K. 1994: The ichnogenus *Beaconites* and its distinction from *Ancorichnus* and *Taenidium*. *Palaeontology* 37, 305–337.
- Kern, J.P. 1978: Palaeoenvironment of new trace fossils from the Eocene Mission Valley Formation, California. *Journal of Paleontology* 52, 186–194.
- Lebrun, P. 2000: Oursins 2: une histoire naturelle des échinides. *Minéraux & Fossiles, éd. CEDIM Hors-série* 10, 117–224.
- Monaco, P. & Giannetti, A. 2002: Three-dimensional burrow systems and taphofacies in shallowing-upward parasequences, lower Jurassic carbonate platform (Calcarei Grigi, Southern Alps, Italy). *Facies* 47, 57–82.
- Monaco, P. & Garassino, A. 2001: Burrows and body fossil of decapod crustaceans in the Calcarei Grigi, Lower Jurassic, Trento platform (Italy). *Geobios* 34, 291–301.
- Moseley, F. 1990: *A Geological Field Guide to the Costa Blanca, Spain*. 79 pp. The Geologists' Association, London.
- Myers, A.C. 1970: Some palaeoichnological observations on the tube of *Diopatra cuprea* (Bosc): Polychaeta, Onuphidae. In Crimes, T.P. & Harper, J.C. (eds): *Trace Fossils. Geological Journal, Special Issue* 3, 331–334. Seel House Press, Liverpool.
- Myers, A.C. 1972: Tube-worm-sediment relationships of *Diopatra cuprea* (Polychaeta: Onuphidae). *Marine Biology* 17, 350–356.
- Péquignat, C.E. 1970: Biologie des *Echinocardium cordatum* (Pennant) de la Baie de la Seine. *Forma et Functio* 2, 121–168.
- Plaziat, J.C. & Mahmoudi, M. 1988: Trace fossils attributed to burrowing echinoids: a revision including new ichnogenus and ichnospecies. *Geobios* 21, 209–233.

- Roniewicz, P. 1970: Borings and burrows in the Eocene littoral deposits of the Tatra Mountains, Poland. In Crimes, T.P. & Harper, J.C. (eds): *Trace Fossils, Geological Journal, Special Issue* 3, 439–446. Seel House Press, Liverpool.
- Seilacher, A. 1964: Sedimentological classification and nomenclature of trace fossils. *Sedimentology* 3, 253–256.
- Seilacher, A. & Seilacher, E. 1994: Bivalvian trace fossils: a lesson from actuopaleontology. *Courier Forschung Senckenberg* 169, 5–15.
- Smith, A.B. & Crimes, T.P. 1983: Trace fossils formed by heart urchins – a study of *Scolicia* and related traces. *Lethaia* 16, 79–92.
- Suhr, P. 1988: Taxonomie und Ichnologie fossiler Wohnröhren terebelloider Würmer. *Freiberger Forschungshefte C419*, 81–87.
- Uchman, A. 1995: Taxonomy and paleoecology of flysch trace fossils: the Marnoso-arenacea Formation and associated facies (Miocene, Northern Apennines, Italy). *Beringeria* 15, 1–115.
- Uchman, A. 1998: Taxonomy and ethology of flysch trace fossils: a revision of the Marian Książkiewicz collection and studies of complementary material. *Annales Societatis Geologorum Poloniae* 68, 105–218.
- von Frisch, K. 1975: *L'Architettura degli Animali*. 320 pp. Mondadori, Verona.
- Yébenes, A. 1996: Estratigrafía y estructura de la Serra Gelada. *Cuadernos de Geografía de la Universidad de Valencia* 60, 201–222.
- Yébenes, A. 2004: Serra Gelada. In Alfaro, P., Andreu, J.M., Estévez, A., Trent-Manclús, J.E. & Yébenes, A. (eds): *Geología de Alicante*, 225–244. Compobell S.L. Press, Alicante.

Appendix

Taxonomy

Ichnogenus *Ereipichnus* n. ichnogen.

Type ichnospecies. – *Ereipichnus geladensis* n. ichnosp.

Derivation of name. – *Ereipia* (Greek) = debris; *ichnos* (Greek) = trace; *geladensis* (Latin) = from the Serra Gelada area.

Type locality. – Type specimens were taken from marls, calcarenites and nodular limestones (units C5 and C6 of Yébenes 2004) in the Lower–Middle Albian of the Sácaras Formation, Serra Gelada (Prebetic of Alicante), Spain.

Repository. – Type material has been placed in the ichnological collection of the Department of Earth Sciences (Geology), Universities of Perugia (Italy) and Alicante (Spain), specimen numbers: holotype EGSG T109; paratypes EGSG T110, T111 & T112.

Diagnosis. – Unbranched, shell-armoured, tubular trace fossil. Tubes are distributed parallel to bedding and the plane of stratification they range from rectilinear to slightly meandering or gently curved. Type specimens differ from all known shell-armoured trace fossils (i.e. shell-lined ichnogenus *Diopatrachus*). The coating of the tube is characterized by imbrication of tabular-shaped, skeletal particles and in transverse section is a concentric, coarsening-centrifugal distribution of skeletal fragments; the inner pipe, when preserved, consists of unstructured muddy infill.

Ereipichnus geladensis n. ichnosp.

Figs 3–4

Types. – Holotype, EGSG T109 (Fig. 4D); paratypes EGSG T110, T111 & T112 (Fig. 4A–C, F–G).

Diagnosis. – Shell-armoured trace fossil characterized by imbrication of tabular-shaped skeletal particles: they are orbitolind foraminiferans, well-sorted, flat fragments of bivalve and gastropod shells, and carbonate or siliciclastic grains. A transverse section reveals a concentric, coarsening-centrifugal pattern of skeletal fragments. The inner pipe, if preserved, is constituted of unstructured muddy infill.

Type locality. – Lower–Middle Albian of the Sácaras Formation, Serra Gelada (Prebetic of Alicante), Spain.

Discussion. – Concentric distribution of particles slightly similar to the shell-lined tube *Diopatrachus odlingi*. Features of *Ereipichnus geladensis* are: the horizontal path of the trace, the peculiar imbricated arrangement of skeletal grains in the coating, the cylindrical muddy pipe. Two types may be distinguished: type 1 is rectilinear in shape, 15–20 cm in length and 4–6 cm in diameter, uni-directional in fine-grained marly beds with high density of jutting tubes (400 specimens/m²); type 2 is curved and slightly winding in the horizontal plane, 20–40 cm in length and 4–6 cm in diameter. Sinuously arranged specimens are densely packed in coarse-grained calcarenitic beds and develop in different stacked layers parallel to bedding (burrow densities on a horizontal plane of 80–100 specimens/m²).

Lethaia

AUTHOR QUERY SHEET

661
662
663
664
665 Author(s): P. Monaco et al.

666 Article title: Lower Cretaceous (Albian) shell-armoured and associated echinoid trace fossils from the Sácaras Formation,
667 Serra Gelada area, southeast Spain

668 Article no: SLET 235
669

670 Dear Author,
671

672 Some questions have arisen during the preparation of your manuscript for typesetting. Please consider each of the
673 following points below and make any corrections required in the proofs.
674

675 Please do not give answers to the questions on *this* sheet. All corrections should be made directly in the printed proofs.
676

677 AQ1: Full journal title for Holder 1989 in refs?
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715