A double-helix trace fossil and associated ichnofabrics from the Miocene of Mallorca, Balearic Islands, Spain

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The Miocene succession in Mallorca, the largest island of the Balearic archipelago in the western Mediterranean, is constituted by two broad groups of lithostratigraphic units related with Middle Miocene (Alpine) tectonics. Upper Miocene units are post-tectonic, and they unconformably overlie deformed Mesozoic, Paleogene, and Lower to Middle Miocene deformed rocks. The lowermost upper Miocene unit, known as the *Heterostegina* Calcisiltites (Lower Tortonian), was defined from borehole data in southwestern Mallorca, and it underlies a well known and beautifully exposed Reef Complex Unit, which has been the object of numerous publications (e.g., Pomar, 2001). Outcrops of the *Heterostegina* Calcisiltite Unit are limited to coastal exposures in the western side of the Palma bay. In this sector, it is constituted mostly by calcisiltites and fine-grained calcarenites, with increasingly abundant conglomeratic intercalations closer to the reliefs of the Sierra de Tramuntana. Not much attention has been devoted to this unit, which is commonly interpreted as deposited in an open carbonate platform with localized terrigenous coastal fans draining from the highlands (Pomar *et al*., 1990). Examination of the outcrops at a series of coves (from SW to NE: Cala Portals Vells, El Mago and Cala Xada) revealed that these deposits are strongly bioturbated. In these beds we observed abundant unusual helicoidal trace fossils similar to the ichnogenus *Lapispira*, previously known only from the Jurassic (Lanes *et al.*, 2007).

The stratigraphy of the studied localities is constituted by a succession of 2-to-6-m-thick calcisiltite to fine-grained calcarenite sequences. Body fossils are common, particularly small scaphopods (*Cadulus*), pectinid bivalves (*Amusium*) and large spatangoid echinoids (*Schizaster*), which occur together with some clypeasteroid echinoids (*Clypeaster marginatus*), branching bryozoans and vertebrate bones (probably cetacean). *Amusium* is most frequent in siltier facies and *Schizaster* in sandier deposits. The first occurs generally with both valves articulated and complete despite being fragile and thin-shelled, while spatangoids occur either complete or locally crushed by compaction. Those taphonomic attributes are indicative of the autochntonous nature of the fossils and the low-energy conditions of the depositional setting.

Bioturbation is very intense (ii 4-5 *sensu* Droser & Bottjer, 1986) and two distinct ichnofabrics maybe distinguished, which replace one another in the best developed and exposed sequences. They consist of a lower *Cylindrichnus* ichnofabric in the calcisiltitic facies and an upper *Lapispira* ichnofabric in the fine-grained calcarenites. In the first, bow-shaped, concentrically laminated *Cylindrichnus concentricus* is the dominant ichnotaxon. The burrows of *Amphitrite ornate* as described by Aller and Yingst (1978) are a good modern analogue for this trace fossil and they allow us to interpret it as produced by a superficial detritus feeding terebellid polychaete (Belaústegui & Gibert, 2009). Other trace fossils include only *Teichichnus* isp., possible *Palaeophycus* and rare, small and isolated *Lapispira*. Meanwhile, the overlying calcarenitic facies exhibit very dense occurrences of crustacean burrows. These are complex branching burrow systems, which may bear a distinct pelleted lining (*Ophiomorpha nodosa*), a thin simple lining or be

unlined (*Thalassinoides suevicus*). These kinds of structures are most typically produced by thalassinidean shrimps. Galleries often display retrusive spreiten and in some occasions the final tunnel infill is meniscated. Associated with these burrows are abundant, complex spiral burrows. No complete 3-D specimens were recovered. Vertical cross-sections show a certain morphological variation. Some double-helix specimens display a morphology identical to what has been described in the Jurassic as *Lapispira bispiralis*, but other specimens apparently are more irregular. These burrows bear a thin muddy lining, which can be seen as composed by small pellets in some specimens. The nature of the lining and the helicoidal morphology point to a crustacean tracemaker for these *Lapispira* burrows. They might be connected to *Ophiomorpha* and *Thalassinoides* but no clear evidence of that was observed. Very rare occurrences of a stellate burrow, probably *Dactyloidites peniculus*, complete the assemblage. Background sediment is structureless and apparently thoroughly bioturbated. Although no echinoid traces have been recognized, the abundance of autochthonous spatangoids suggests that those may have been responsible for at least part of the shallow-tier bioturbation. This succession from a terebellid-produced to a thalassinidean-produced ichnofabric is known and has been described from other Miocene deposits in the western Mediterranean (Belaústegui & Gibert 2009, 2011). Such "worm-to-shrimp" ichnofabric sequences record progradation and shallowing in a dominantly carbonate middle-to-outer platform under low-energy conditions.

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