

PROXIMAL-DISTAL VARIATIONS OF TRACE FOSSIL ASSEMBLAGES IN A PLIOCENE RIA, BAIX LLOBREGAT, NORTHEASTERN SPAIN

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Abstract: The Baix Llobregat Basin, Northeast Spain, was a small shallow, elongated ria during the Pliocene. Four trace fossil assemblages named after their most common ichnogenera have been recognized in the Sandy clay unit. The *Ophiomorpha* assemblage corresponds to the *Skolithos* Ichnofacies, the *Phycosiphon-Skolithos* assemblage is a mixture of *Skolithos* and *Cruziana* Ichnofacies, while the *Phycosiphon-Sinusichnus* and the *Scalarituba-Scolicia* assemblages belong to the *Cruziana* Ichnofacies. These assemblages substitute each other from the proximal to the distal parts of the basin, showing a progressive change from *Skolithos* to *Cruziana* Ichnofacies. That rapid geographic change, unusual in such a small basin, indicates the existence of a very strong longitudinal gradient in the palaeoenvironments, mostly due to a decrease in bottom energy and an increase of water salinity from brackish to fully marine.

Key words: Pliocene, NE Spain, ria, paleoichnology, salinity.

Resumen: Los sedimentos pliocenos del Baix Llobregat, en las cercanías de Barcelona, se depositaron en una pequeña ría flanqueada por los relieves de la Cordillera Litoral. En la Unidad de arenas y arcillas, que representa el techo de la secuencia pliocena, se han reconocido cuatro asociaciones de trazas fósiles designadas a partir de los icnogéneros más comunes. La asociación de *Ophiomorpha* corresponde a la Icnofacies de *Skolithos*, la asociación de *Phycosiphon-Skolithos* es una mezcla de las Icnofacies de *Skolithos* y *Cruziana*, mientras que las asociaciones de *Phycosiphon-Sinusichnus* y *Scalarituba-Scolicia* pertenecen a la Icnofacies de *Cruziana*. Estas cuatro asociaciones se suceden a lo largo de la cuenca mostrando un progresivo cambio desde Icnofacies de *Skolithos* en la zona más proximal a Icnofacies de *Cruziana* en la zona más distal. La variación en las asociaciones icnológicas es rápida en una cuenca relativamente pequeña indicando la existencia de un marcado gradiente longitudinal en los paleoambientes, relacionado principalmente con una disminución de las condiciones energéticas del fondo y a un incremento de la salinidad de la masa de agua, desde salobre hasta marina normal.

Palabras clave: Plioceno, NE España, ria, paleoicnología, salinidad.

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Trace fossil assemblages in marginal marine settings are difficult to exemplify due to their usually fluctuating and unpredictable environmental conditions. Salinity, bottom turbulence, substrate character and sedimentation rates are highly variable and they affect in a determinant way the inhabiting organisms. Ekdale *et al.* (1984) characterized the ichnofaunas of such settings as a mixture of *Skolithos* and *Cruziana* ichnofacies exhibiting low ichnotaxonomic diversity and constituted by trophic generalists typically found in open marine settings. The Lower Pliocene deposits of the Baix Llobregat Basin were deposited in a small, shallow, elongated ria that was located near Barcelona in northeastern Spain. The trace fossil assemblages exhibit an unusual variation that reflects proximal-distal palaeoenvironmental variations and contributes to a better knowledge of the trace fossil characteristic of marginal marine settings.

Geological setting

The Baix Llobregat Basin includes several outcrops located along the Llobregat River, near Barcelona (Fig. 1A). The basin has an elongate morphology, and its northwest-southeast orientation coincides with the underlying Llobregat fault, which belongs to a system of faults that transversally cut the structural unit known as the Catalan Coastal Range (Anadón *et al.*, 1979). During the Messinian (Upper Miocene) a very significant sea-level drop affected the Mediterranean, and the Llobregat fault acted as a weakness zone that was excavated as a fluvial valley. During the Zanclean (Lower Pliocene) a transgression flooded the valley, giving rise to the deposition of marginal marine sediments in the Baix Llobregat Basin (Gibert and Martinell, 1993). The basin was narrow (no more than five kilometres in its distal part) and short (less than 15 kilometres long) and it connected to the south with the open Mediterranean Sea (Fig. 1B).

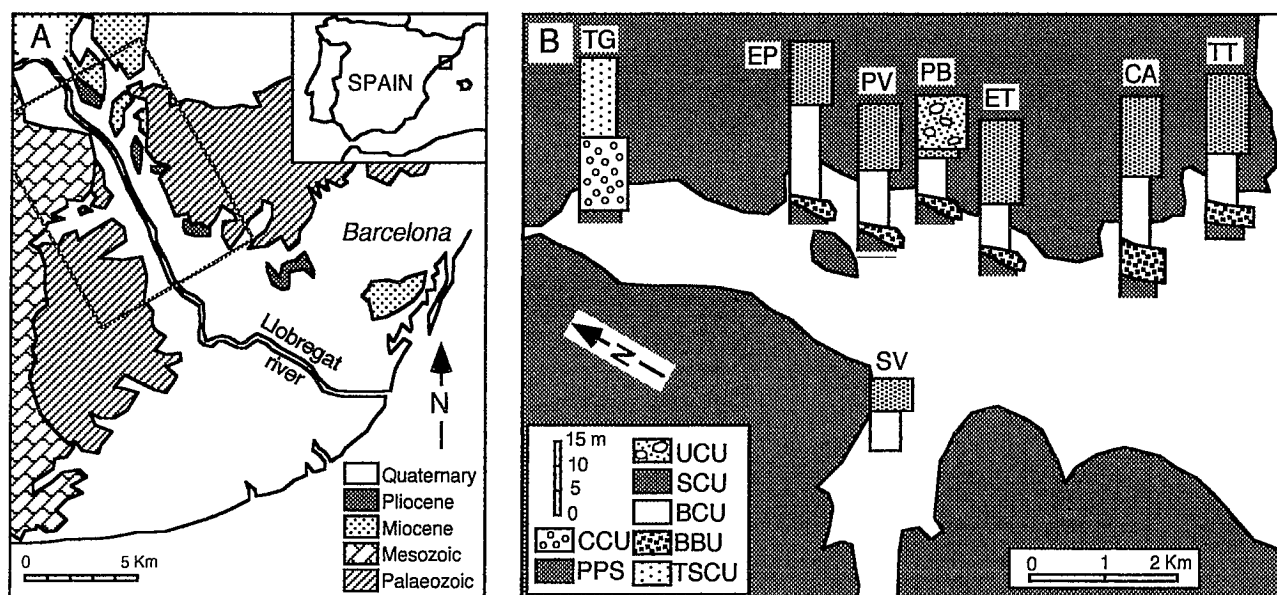


Figure 1.- A) Geographic and geological setting of the Baix Llobregat Basin. The empty rectangle corresponds to the area shown in figure 1b. B) Palaeogeography of the Baix Llobregat during the Pliocene with the position of the different outcrops (TG=Turó de la Gataxarella, EP=El Papiol, PV=Pic d'en Valls, SV=San Vicenç dels Horts, PB=Plaça de les Bruixes, ET=El Tarc, CA=Can Albareda, TT=Torrent del Terme) and synthetic stratigraphic sections showing the distribution of the main lithological units (PPS=pre-Pliocene substrate, CCU=Castellbisbal conglomeratic unit, TSCU=Transitional sandy clay unit, BBU=Basal breccia unit, BCU=Blue clay unit, SCU=Sandy clay unit, UCU=Upper conglomeratic unit).

The outcrops are relatively small and isolated, and most are in very bad condition due to their proximity to the metropolitan area of Barcelona. However, they are present all along the palaeoria (Fig. 1B). From the proximal to the distal part, they are Turó de la Gataxarella (TG), El Papiol (EP), Pic d'en Valls (PV), San Vicenç dels Horts (SV), Plaça de les Bruixes (PB), El Tarc (ET), Can Albareda (CA) and Torrent del Terme (TT).

Stratigraphy

Pliocene deposits in the Baix Llobregat Basin record a single transgressive-regressive sequence. Several informal lithostratigraphic units were defined by Clauzon *et al.* (1987), and they are followed here with minor modifications (Fig. 1b):

- Castellbisbal conglomeratic unit (CCU). This is the only Pliocene continental unit present in the Baix Llobregat Basin. It is restricted to the most proximal outcrop (Turó de la Gataxarella), and it consists of fluvial conglomeratic deposits.

- Transitional sandy clay unit (TSCU). This unit corresponds to shallow, brackish-water deposits, as indicated by the molluscs and microfossils (Gillet, 1959). It overlies the Castellbisbal unit in Turó de la Gataxarella.

- Basal breccia unit (BBU). This unit is present in all the outcrops except in Turó de la Gataxarella. It is constituted by sands and breccias directly overlying the pre-Pliocene paleorelief and corresponding to rocky shore and fan delta deposits.

- Blue clay unit (BCU). This is the most extensive unit in the basin, present in all outcrops except in Turó de la Gataxarella. It consists of blue-gray clays, locally

siltier, including a rich shallow-marine mollusc fauna (Martinell *et al.*, 1984).

- Sandy clay unit (SCU). It is constituted by an alternation of yellow silty clays and sandstones. It overlies the blue clays and has their same geographic distribution. These deposits correspond to a shallower and more marginal area with coarser terrigenous input than the blue clays.

- Upper conglomeratic unit (UCU). These conglomerates occur only in Plaça de les Bruixes, where they overlie the blue clays and a thin sandy clay unit. They are interpreted as fan delta deposits.

Trace fossils

Trace fossils have been found in three different stratigraphic positions within the basin (Gibert and Martinell, 1992).

The basal rocky shore, including the palaeocliff and the associated deposits, exhibits abundant bioerosion trace fossils, including *Gastrochaenolites*, *Entobia*, and less abundant *Maeandropolydora*, *Caulostrepsis*, and *Trypanites* (Martinell and Domènech, 1995; Gibert *et al.*, 1998). The assemblage is typical of the *Entobia* ichnofacies, as defined by Bromley and Asgaard (1993), for littoral rocky shores.

The blue clays show a homogenized fabric without evidence of primary laminae. However, distinct trace fossils are very scarce. Poorly preserved worm-like burrows, small spiral burrows, small branching burrows and possible *Scolicia* have been recognized. Small mammal tracks are present in Plaça de les Bruixes and thus demonstrate the locally very shallow

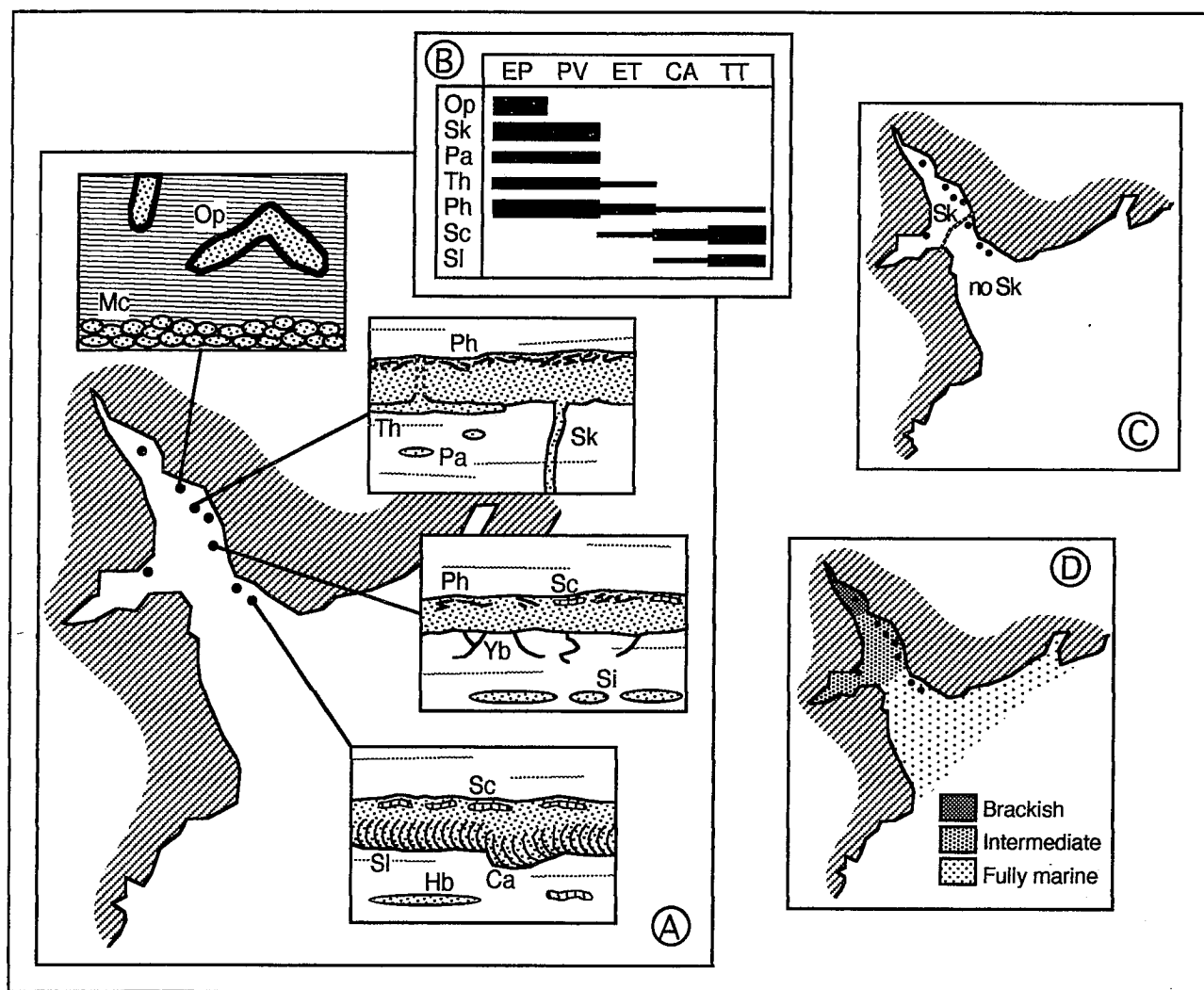


Figure 2.- A) Distribution of the trace fossil assemblages (from the top to the bottom): *Ophiomorpha* assemblage, *Phycosiphon-Skolithos* assemblage, *Phycosiphon-Sinusichnus* assemblage, and *Scalarituba-Scolicia* assemblage. The dots indicate the position of the outcrops named in figure 1b. Op=*Ophiomorpha*, Mc=*Macaronichnus*, Ph=*Phycosiphon*, Th=*Thalassinoides*, Pa=*Palaeophycus*, Sk=*Skolithos*, Sc=*Scalarituba*, Yb=small spiral, Y, and J-shaped burrows, Si=*Sinusichnus*, Sl=*Scolicia*, Ca=*Cardioichnus*, Hb=unnamed horizontal burrows. B) Distribution and relative abundance of the main ichnogenera in different outcrops from the proximal (left) to the distal areas (right). C) Division of the basin in a proximal area with abundant *Skolithos* and a distal area where this ichnotaxon is absent. D) Salinity zonation proposed for the Baix Llobregat during the Pliocene.

character of the deposits of this unit (Martinell and Marquina, 1984).

The sandy clay unit host most of the bioturbation structures in the Baix Llobregat. We found *Cardioichnus planus* Smith and Crimes, 1983, *Macaronichnus* isp., *Ophiomorpha nodosa* Lundgren, 1891, *Palaeophycus* isp., *Phycosiphon incertum* Fischer-Ooster, 1858, *Planolites montanus* Richter, 1937, *Scalarituba* (= *Neonereites*) *biserialis* (Seilacher, 1960), *Scalarituba missouriensis* Weller, 1899, *Scolicia* isp., *Sinusichnus sinuosus* Gibert, 1996, *Skolithos linearis* Halde-man, 1840, *Thalassinoides suevicus* (Rieth, 1932), and two other unnamed trace fossils. The whole assemblage indicates shallow water conditions for these deposits. Four different assemblages are identified in different outcrops (Fig. 2a). The detailed analysis of them is the object of this paper.

Trace fossil assemblages

Ophiomorpha assemblage

This assemblage (Fig. 2A) is associated with sandy channel deposits only present in El Papiol, the most proximal outcrop of the Sandy clay unit. The channels have erosional soles and exhibit small lateral continuity. The filling is sandy, multi-episodic, with low-angle cross lamination. *Ophiomorpha nodosa* is the most abundant trace fossil, and it occurs as sparse tunnels and shafts within the laminated background. Some levels with *Macaronichnus* isp. and a few *Skolithos linearis* have been observed. The bioturbation never exceeds indices over 2 (following Taylor and Goldring, 1993). The sand bodies are interpreted as distributary channels located in the innermost part of the ria. In this

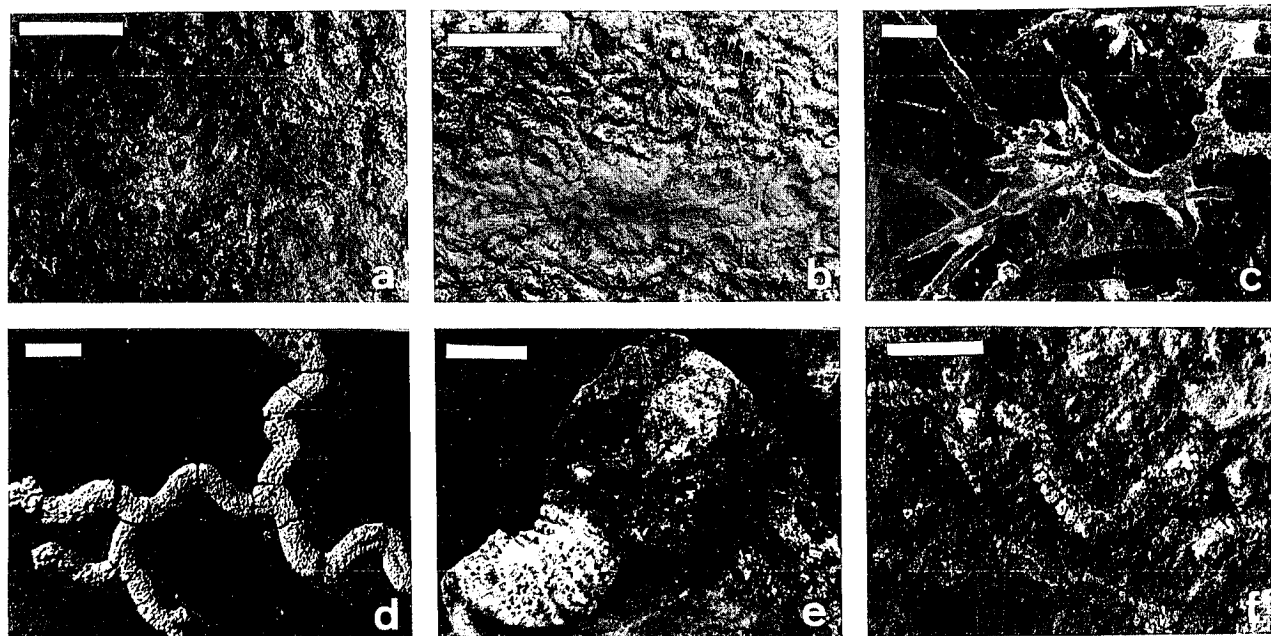


Figure 3.— Trace fossils from the Pliocene of the Baix Llobregat. A) *Phycosiphon incertum* (scale bar=1cm). B) *Planolites montanus* (scale bar=2cm). C) *Thalassinoides suevicus* (scale bar= 5cm). D) *Sinusichnus sinuosus* (scale bar= 10cm). E) *Scolicia* isp. (left) and *Cardioichnus planus* (right) (scale bar= 2cm). F) *Scalarituba biserialis* (scale bar= 2cm).

setting the high energy and frequent turbulence inhibited the biogenic activity that was reduced to a few ichnotaxa typical of shifting substrates in energetic environments. The ichnofabric of these sandstones is comparable to ichnofabric 3 (*Macaronichnus-Ophiomorpha* ichnofabric with primary lamination) described by Pollard *et al.* (1993).

Phycosiphon-Skolithos assemblage

This assemblage (Fig. 2A) occurs in El Papiol, Pic d'en Valls, and San Vicenç dels Horts. All three outcrops are located in the northern part of the basin. The deposits that host this assemblage consist of alternating silty clay and sandstone. The sandstone beds are between a few millimetres to 20 centimetres thick, with planar sole, small lateral continuity and low angle cross-lamination and current ripples. These deposits were sedimented by sporadic, laminar, non-channelized flows, in contrast with those hosting the *Ophiomorpha* assemblage. Trace fossils are common and include *Skolithos linearis*, *Palaeophycus* isp., *Phycosiphon incertum* (Fig. 3a), *Planolites montanus* (Fig. 3b), and *Thalassinoides suevicus* (Fig. 3c). *Skolithos* and *Palaeophycus* occur in the clays, and they are filled with sand. *Skolithos* may be very abundant, up to 7 traces per square meter, and they usually exhibit a diagenetic halo in the form of a thick limonitic lining or a hardened aureola, which originally caused them to be mistakenly attributed to *Ophiomorpha* and *Rosselia*, respectively (Gibert and Martinell 1993, 1995). In the sandstone beds irregular *Thalassinoides* are common on the soles, while the tops are covered by *Phycosiphon* and less frequently by *Planolites*. Both ichnotaxa resulted from the work of opportunistic deposit-feeders

that colonized the bottom after sand depositional events.

Phycosiphon-Sinusichnus assemblage

This assemblage (Fig. 2A) is restricted to a single outcrop, El Tarc, which is located in the middle part of the ria. It occurs in facies essentially identical to those described above for the *Phycosiphon-Skolithos* assemblage. However, the trace fossil content is different. The clays host extensive *Sinusichnus sinuosus* networks (attributed to deposit-feeding crustaceans by Gibert, 1996) (Fig. 3d) and thin (1-2 millimetres in diameter) unnamed vertical burrows with variable morphology (J-shaped, Y-shaped and spiral). As *Skolithos* in the previous assemblage, they exhibit a thick diagenetic lining. *Thalassinoides suevicus* occurs on the soles of the sandstone beds, while crowded occurrences of *Phycosiphon incertum* with some *Scalarituba missouriensis* covered their tops.

Scalarituba-Scolicia assemblage

This assemblage (Fig. 2A) is present in the two distal outcrops (Can Albareda and Torrent del Terme) in the same kind of facies than the two previous assemblages. Some horizontal dwelling burrows and occasional *Scalarituba missouriensis* are the only distinct trace fossils in the clays. *Scolicia* isp. and *Cardioichnus planus* (Fig. 3e), representing crawling and resting traces, respectively, of irregular echinoids, are frequent on the soles of the sandstones. The tops are usually covered by very abundant *Scalarituba missouriensis* and less common *Scalarituba biserialis* (Fig. 3f) and *Phycosiphon incertum*. *Chondrites* and simple rectilinear trails occur less commonly.

Discussion

Despite the small dimensions of the Baix Llobregat basin, the trace fossil assemblages of the Sandy clay unit are very variable from one outcrop to the other. The ichnological associations exhibit longitudinal changes along the axis of the ria, and they indicate a very strong proximal-distal palaeoenvironmental gradient (Fig. 2A). The more proximal assemblage, the *Ophiomorpha* assemblage, corresponds to the *Skolithos* Ichnofacies; the *Phycosiphon-Skolithos* assemblage, the next one to the south, is a mixture of the *Skolithos* and *Cruziana* Ichnofacies; while the *Phycosiphon-Sinusichnus* and the *Scalarituba-Scolicia* assemblages, located in the middle and outer part of the ria, respectively, are typical of the *Cruziana* Ichnofacies. *Skolithos*, which is common in the two more proximal assemblages, is absent in the other two (Fig. 2C). This ichnofacies variation indicates a gradient from higher energy and more turbulent conditions in the northern half of the basin to much quieter, more predictable environments in the distal parts.

Considering individual ichnotaxa, we observe that some trace fossils are progressively less abundant in the outer part of the basin, while others show the opposite tendency (Fig. 2B). In the particular case of *Phycosiphon* and *Scalarituba*, considering that both occupy the same ecological niche (opportunistic post-event deposit-feeders), it seems that there is a progressive substitution of *Phycosiphon* by *Scalarituba* when moving into the distal areas. Especially remarkable is the presence of echinoid burrows (*Cardioichnus* and *Scolicia*) only in the distal outcrops. Echinoids are stenohaline animals that live only in conditions of fully marine salinity. This fact reveals an important salinity gradient within the basin from the brackish conditions of the innermost outcrop (Turó de la Gatzarella, as indicated by the body fossil assemblages, Gillet, 1959) to the fully marine conditions in the area close to the open sea (Can Albareda and Torrent del Terme) with a middle area reflecting intermediate and/or highly variable salinities (Fig. 2D).

Conclusions

The distribution of the trace fossils and trace fossil assemblages along the Lower Pliocene Baix Llobregat palaeoria allow us to demonstrate a strong palaeoenvironmental gradient from the proximal to distal parts that had a very strong influence over the benthic palaeocommunities. Although the body fossils of the basin are well known (especially the molluscs), this gradient had not been observed before. The assemblages exhibit a transition from *Skolithos* Ichnofacies in the most proximal areas to the *Cruziana* Ichnofacies in the areas close to the open sea, which indicates the highest degree of instability and bottom turbulence in the innermost parts. On the other hand, trace fossils of typi-

cally stenohaline animals, such as echinoderms, are only present in the most distal outcrops. This suggests a very important influence of the salinity of the water body on the trace fossil distribution. Changes in the Baix Llobregat ichnofauna are remarkable in such a small basin, and they provide a very interesting example of the use of trace fossils in establishing palaeogeographic variations of palaeoenvironmental conditions in marginal marine settings.

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