ICHNOFABRICS OF THE PLIOCENE MARGINAL MARINE BASINS OF THE NORTHWESTERN MEDITERRANEAN

J. M. de Gibert [1] y J. Martinell [2]

[1]*Department of Geology and Geophysics, University of Utah, 135 South 1460 East Room 719, Salt Lake City, Utah 84112-0111, U.S.A.*
[2]*Departament d'Estratigrafia i Paleontologia, Facultat de Geologia, Universitat de Barcelona, 08028 Barcelona, Spain*

Abstract: The ichnological study of seven coastal Pliocene basins in the northwestern margin of the Mediterranean has revealed the existence of nineteen ichnofabrics. Bioerosion ichnofabrics are dominated by the ichnogenera *Gastrochaenolites* and *Entobia* and are restricted to palaeocliffs and gravel deposits in littoral settings. Bioturbation ichnofabrics display a greater variation, but most of them are dominated by simple feeding traces (such as *Phycosiphon*, *Scalarituba*, *Teichichnus* or *Thalassinoides*) and dwelling burrows (such as *Skolithos* or *Palaeophycus*). The dominance of structures produced by low-specialized organisms is consistent with a marginal marine, unstable setting. The particular features (trace fossil assemblage, degree of bioturbation, tiering) of each ichnofabric allow the characterization and comparisons of local palaeoenvironmental conditions (salinity, depth, hydrodynamic energy, etc.) among the different basins. The ichnofabric study confirms the deeper character of the Var basin, which had been suggested by other authors based on other palaeontologic and sedimentologic data.

Key words: Pliocene, northwestern Mediterranean, ichnofabrics, ichnology

Resumen: El estudio icnológico de siete cuencas costeras pliocenas en el margen noroccidental del Mediterráneo en Cataluña y el sureste de Francia ha revelado la existencia de diecinueve icnofábricas bien diferenciadas que incluyen tanto estructuras de bioerosión como de bioturbación. Las icnofábricas en substrato duro incluyen diversos tipos de perforaciones, siendo los icnogéneros *Gastrochaenolites* y *Entobia* los dominantes. Estas se hallan restringidas a paleoacantilados y depósitos de gravas en condiciones litorales. Las icnofábricas en substrato blando son más variadas aunque la mayoría presentan un dominio de estructuras de alimentación simples (tales como *Phycosiphon*, *Scalarituba*, *Teichichnus* o *Thalassinoides*) y madrigueras de habitación (tales como *Skolithos* o *Palaeophycus*). El dominio de pistas producidas por organismos poco especializados es propio de ambientes marginales marinos en que las variables e inestables condiciones paleoambientales no permiten el establecimiento de comunidades de equilibrio. Las características propias de cada icnofábrica (asociación icnológica, intensidad de bioturbación, estratificación ecológica) permiten la interpretación de las condiciones paleoambientales locales (salinidad, profundidad, energía hidrodinámica, etc.) en que fueron producidas y la comparación entre los contenidos icnológicos de las diferentes cuencas. El estudio de las icnofábricas ha puesto de manifiesto el carácter más profundo de la cuenca de Var, hecho que ya había sido sugerido por otros autores a partir de otros datos paleontológicos y sedimentológicos.

Palabras clave: Plioceno, Mediterráneo noroccidental, icnofábricas, icnología

Gibert, J.M. de y Martinell, J. (1998): Ichnofabrics of the Pliocene marginal marine basins of the northwestern Mediterranean. *Rev. Soc. Geol.España*, 11(1-2): 43-56

Marginal marine settings are areas with fluctuating and unpredictible environmental parameters. Changes in salinity, hydrodynamic energy, substrate, sedimentation rate, bottom oxygenation or depth can be very important and they affect in a determinant way the inhabiting organisms. Partly enclosed environments, such as bays, rias or estuaries, are particularly unpredictible. These environments are difficult to characterize from an ichnological point of view. They were not taken into account in the classical ichnofacies model proposed by Seilacher (1964). Ekdale *et al.* (1984) and Pemberton and Wightman (1992) typified the trace fossil assemblage of these settings as a mixture of the Skolithos and the Cruziana ichnofacies that displays a low ichnotaxonomic diversity of ichnotaxa constructed by trophic generalists typically found in marine

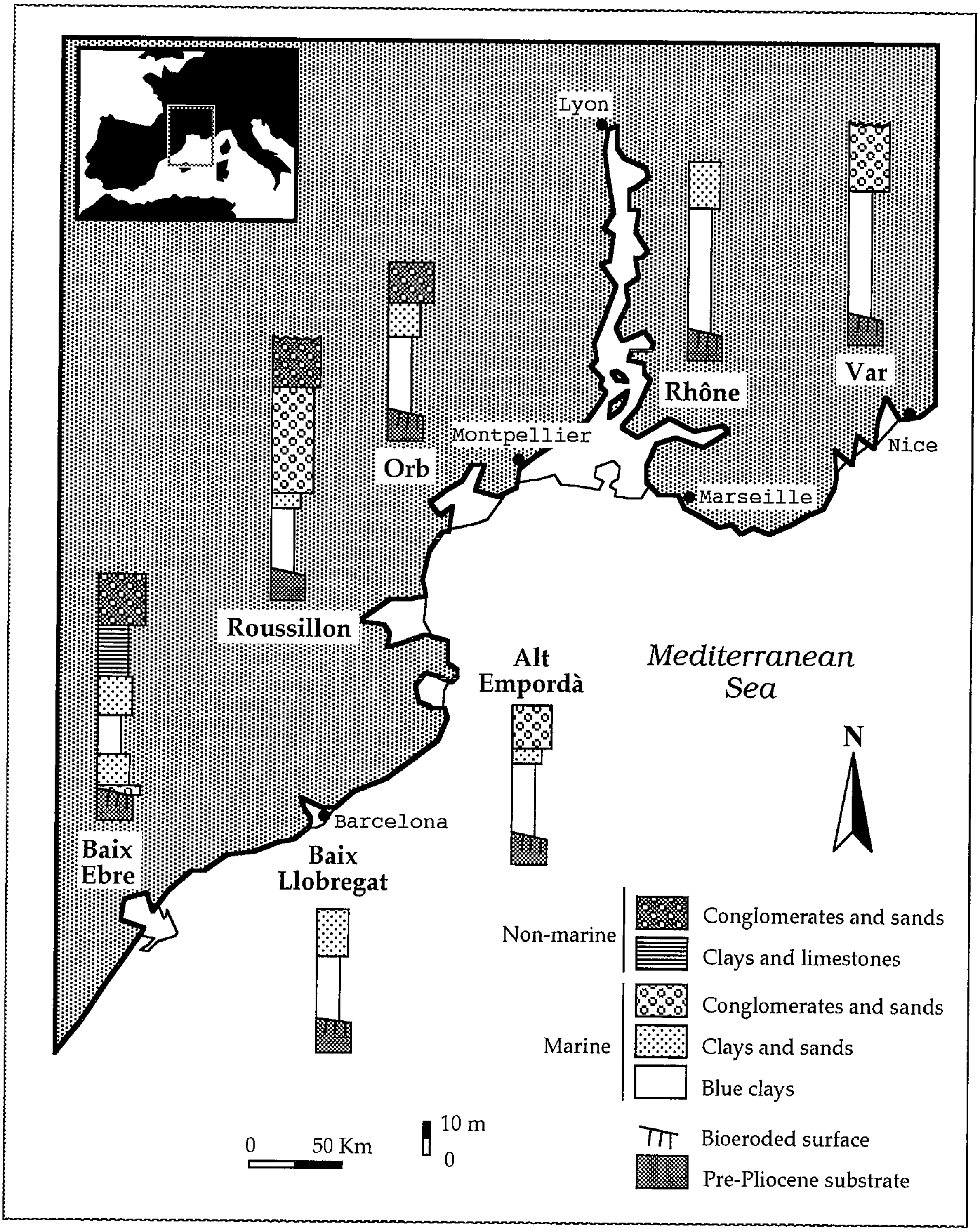


Figure 1.- Palaeogeographic map of the northwestern Mediterranean during the Pliocene and synthetic stratigraphic sections of the studied basins. The thicker line indicates the Pliocene shoreline and the thinner line the recent coastline.

environments. In the NW Mediterranean, several Pliocene rias (sea-flooded river valleys) offer the possibility to study trace fossil assemblages in coastal palaeoenvironments ranging from very shallow and brackish to deeper fully marine offshore settings (Gibert, 1995). Previous works have dealt on more local or particular aspects of the ichnology of these basins (Gibert, 1996; Gibert and Martinell, 1992, 1993, 1995a, b, 1996, 1988; Martinell and Domènech, 1986, 1995; Martinell *et al.*, 1995), but in this paper we try to offer an integrated approach to the ichnofabrics of these settings and their significance.

Geological setting

The palaeogeographic and palaeophysiographic features of the studied Pliocene marginal basins were strongly controlled by the «Messinian crises», a late Miocene event which affected the Mediterranean (Hsü *et al.*, 1973; Busson, 1990). During the latest Messinian (Late Miocene), the Mediterranean basin was isolated from the Atlantic Ocean resulting in a very important sea-level fall, estimated between 1500 and 2000 m (Ryan, 1976; Clauzon, 1982). As a consequence, deep fluvial valleys were excavated in the margin of the Mediterranean (Ryan and Cita, 1978; Clauzon, 1978, 1979, 1982). Later, in the earliest Zanclean (Early Pliocene) a transgression restablished the connection with the ocean producing flooding of the Messinian fluvial valleys and giving rise to several marginal marine basins (bays and rias) along the Mediterranean coast. In the NW area, seven main basins have been recorded: the Baix Ebre, Baix Llobregat and Alt Empordà basins in Catalonia (NE Spain) and the Roussillon, Orb, Rhône and Var basins in SE France (Fig. 1).

The sedimentary filling

The marine sedimentation of all these basins occurred exclusively during the Zanclean (Martinell, 1988; Clauzon *et al.*, 1990), except in the case of the Var basin where sedimentation went on until the Upper Pliocene (Irr, 1984; Clauzon *et al.* 1990). Detailled stratigraphic studies can be found in several papers: Gibert (1995) for all the basins; Arasa (1990) and Gibert and Martinell (1996) for the Baix Ebre; Clauzon *et al.* (1987b) and Gibert and Martinell (1993) for the Baix Llobregat; Agustí *et al.* (1990), Fleta and Escuer (1991) and Fleta *et al.* (1991) for the Alt Empordà; Martinell *et al.* (1984) and Martinell (1988) for all the Catalan basins; Clauzon *et al.* (1987a,b, 1989) for the Roussillon; Ambert (1989) for the Orb; Ballesio (1972) for the Rhône; Irr (1984) and Gibert and Martinell (1988) for the Var; and Clauzon *et al.* (1990) for all the French basins. The stratigraphic sequences in all basins record a transgressive-regressive terrigenous cycle. Despite the peculiarities of each basin, their sedimentary filling can be divided in four parts from bottom to top: the coarse transgressive deposits, the blue clays, the coarse marine regressive deposits and the non-marine deposits. Synthetic stratigraphic sections of each one of the basins are given in figure 1.

The coarse transgressive deposits

The Pliocene transgression was rapid and flooded very abrupt and irregular rocky palaeoreliefs. For this reason the transgressive units are commonly poorly developed. In most of the basins, the only evidence for the transgression is an extensive bioeroded and encrusted surface developed over the pre-Pliocene rocky substrate and sometimes associated with a thin transgressive lag. These rocky shores are known from all the basins except from the Roussillon (Martinell and Domènech, 1995; Martinell *et al.*, 1995). In the Baix Ebre and the Rhône basins more important transgressive units are represented by beach and shallow bay deposits in the former (Gibert and Martinell, 1996) and brackish estuarine deposits in the latter one (Ballesio, 1972).

The blue clays

The blue clays constitute the most characteristic and widespread sedimentary unit of the Mediterranean Pliocene. They are well represented in all of the studied basins and are commonly hundreds of meters thick in distal areas of the basins as known from different drillings (Clauzon *et al.*, 1990). The blue clays were deposited in the central and deeper areas of each basin and their widest extension corresponds to the Zanclean maximum flooding. Hence, this unit is probably partly transgressive and partly regressive.

The blue clays almost always (except in the Orb basin) bear a rich fossil assemblage (molluscs, echinoids, foraminifera, fishes, ostracods, etc.). They are well known since last century for their malacological content (e.g. Martinell *et al.*, 1984). In general, it is a very homogeneous unit constituted exclusively by grey-blue clays although in some basins (Roussillon), or areas within a basin, the unit can be more sandy.

The blue clays record the sedimentation by suspension fall-out in a quiet palaeoenvironment with depth variable from very shallow (Orb) to shallow (Baix Ebre, Baix Llobregat, Alt Empordà, Roussillon, Rhône) to relatively deep (Var). The terms shallow and deep are used herein as they are used in Gili and Martinell (1993) for the same basins; shallow for depths lower than 50 m and deep for depths greater than 100 m.

The marine regressive units

The blue clays in all the basins are overlain by coarser terrigenous marine units which correspond to regressive sedimentary systems built up in more proximal areas. These marine regressive units exhibit important differences between basins because they are strongly conditioned by the particular palaeogeography, palaeophysiography and geology of each area. Those basins located close to high mountain ranges (the Pyrenees and the Alps) developed conglomeratic or sandy-conglomeratic sedimentary systems, while the sedimentation in other basins located in regions with lower reliefs was mainly sandy or clayey-sandy. Considering this, the marine regressive units can be classified in two groups: sandy units and conglomeratic units.

The sandy units: This group includes the marine regressive units of the Baix Ebre, Baix Llobregat, Orb and Rhône basins. In the Baix Ebre and Baix Llobregat they are constituted by yellow clays with frequent intercalations of thin sand beds from turbiditic flows or storms. In the most proximal areas the sands can form thicker beds which correspond to sand bars in the Baix Ebre and to distributary channels in the Baix Llobregat.

The Rhône basin is the largest of all the studied basins and includes several sub-basins with their own peculiarities (Ballesio, 1972). In the area we have studied in more detail (the Pichegu outcrop near Nimes), the blue clays are overlain by a well-developed sandy unit interpreted as a delta front and including a thick muddy intercalation interpreted as interdistributary bay deposits.

The conglomeratic units: The Var, Roussillon and Alt Empordà basins exhibit conglomeratic or sandy conglomeratic deposits on top of the marine sequence. These deposits have been studied in the Var basin by Irr (1984) who classified the sedimentary system as a medium-deep depositional fan. In the Roussillon, Clauzon (1990) considered the marine sandy-conglomeratic units as the submarine part of a Gilbert delta. The sandy-conglomeratic sediments of the Alt Empordà correspond to deltaic and locally fan-deltaic deposits.

The continental units

The continental deposits culminate the Pliocene sequence in the Baix Ebre, Roussillon, Orb and Rhône basins and grade laterally into the marine units in the Alt Empordà. They are dominated by fluvial deposits except in the Baix Ebre where lacustrine and palustrine sedimentation was the most important.

Trace fossils, trace fossil assemblages and ichnofabrics

Despite a few trace fossils that are common in several basins, most of the trace fossil assemblages are restricted to one basin or even to a single outcrop. This high variability is a consequence of the unpredictibility of marginal marine environments. Nineteen ichnofabrics (Fig. 2) are described from their trace fossil constituents, tiering, degree of bioturbation and relation with sedimentary structures. They are named after the most significant ichnotaxon or ichnotaxa. In order to offer a clear description we are going to group them in three groups: those related with the rocky shores of the transgressive surface, those corresponding to the central basin deposits (blue clays) and those of the more proximal units, including both transgressive and regressive units.

Trace fossils on rocky shores

The base of the Pliocene sequence in most of the basins is recorded by the presence of borings and encrusting shells over the pre-Pliocene susbtrate. This surface corresponds to the Lower Zanclean transgressive surface. The ichnofossil assemblage is very recurrent and gives place to a typical ichnofabric.

Ichnofabric one: *Gastrochaenolites* in rocky substrate

Description: This ichnofabric is developed on pre-Pliocene rocky substrates, preferentially those which are carbonatic. It is known on Messinian tuffs (Orb), Miocene carbonate conglomerates (Baix Ebre), Mesozoic and Tertiary limestones (Baix Llobregat, Alt Empordà, Rhône, Var), and Palaeozoic carbonatic slates (Baix Llobregat). The trace fossil assemblage consists of bioerosion structures of which the dominant ichnotaxa are the bivalve ichnospecies *Gastrochaenolites torpedo* and *Gastrochaenolites lapidicus* and the sponge boring *Entobia*. Other trace fossils commonly present are the annelid borings *Maeandropolydora*, *Caulostrepsis* and *Trypanites* (Martinell and Domènech, 1995; Martinell *et al.*, 1995). Echinoid bowl-shaped pits, corresponding to the ichnogenus *Circolites*, erected by Mikulás (1992), are present only in the Alt Empordà basin (Martinell and Domènech, 1986). *Gastrochaenolites* is the most typical ichnotaxa because of its abundance and also because it is the trace fossil with the highest preservation potential because it occupies the deepest tier. Associated with this trace fossil assemblage, encrusting shells (oysters, the pectinid *Hynnites ercolanianus*, barnacles) are very common and they often host a rich boring assemblage (*Entobia*, *Maeandropolydora*, *Caulostrepsis*, *Trypanites*, *Iramena*).

Occurrence: This ichnofabric occurs in several outcrops in the Baix Ebre, Baix Llobregat, Alt Empordà, Orb, Rhône and Var basins. The only major variation between the occurrences in different basins is the presence of *Circolites* in the Alt Empordà, absent in the other basins. This ichnofabric does not occcur in the Roussillon basin due to the non-carbonatic nature of the pre-Pliocene substrate.

Palaeoenvironmental significance and discussion: Both the trace fossil and the body fossil assemblages indicate the littoral character of the rocky shores in the NW Mediterranean Pliocene basins. The *Gastrochaenolites-Entobia* assemblage has been recorded from shallow marine rocky shores by different authors (e.g. Bromley and Asgaard, 1993; Silva *et al.*, 1995; Gibert *et al.*, 1996) and it has been suggested as a recurrent ichnocenosis for littoral rocky settings in the Neogene and Quaternary (Martinell and Domènech *1995*). MacEachern and Pemberton (1994a) in their study of the ichnology in a Cretaceous incised-valley system, record an association typical of the Glossifungites ichnofacies in the same stratigraphic position as the present gastrochaenolites ichnofabric. Both assemblages are comparable as they record an initial transgression over a previous palaeorelief, but the Cretaceous example occurs on a firmground, whereas the Pliocene example occurs on a rockground.

Ichnofabrics of the blue clays

The blue clays correspond to fine-grained sediments deposited in the central areas of each basin. Four distinctive ichnofabrics have been recognized.

Ichnofabric 2: *Phycosiphon*

Description: The host sediments are dark grey slightly sandy clays. Primary lamination is almost totally obscured by bioturbation (Bioturbation Index 4-5, sensu Taylor and Goldring, 1993). *Phycosiphon incertum* is the only abundant trace fossil and constitutes the major part of the ichnofabric. Other trace fossils only include very rare *Palaeophycus*.

Occurrences: In the Cessenon outcrop (Orb basin).

Palaeoenvironmental significance and discussion: This ichnofabric is interpreted as being produced in a very shallow, restricted and probably brackish environment. The palaeogeographic position of the outcrop corresponds to a proximal situation where the Pliocene ria was only a few tens of meters wide. In this setting a lot of organic matter could have accumulated but only a few deposit-feeders (the *Phycosiphon* producers) could inhabit the area because of its restricted conditions. This interpretation is consistent with the poor body fossil content, represented by ostracods and foraminifera indicative of restricted environments. A similar assemblage was described by Ekdale and Lewis (1991) as *Anconichnus horizontalis* ichnofacies (*A. horizontalis* is considered synonymous of *P. incertum* following Wetzel and Bromley, 1994) from the Pleistocene of New Zealand and interpreted in a very similar way.

Ichnofabric 3: Shell-filled *Thalassinoides*

Description: This ichnofabric occurs in blue clays rich in shelly fossils, mainly molluscs. The only distinct trace fossil is *Thalassinoides*. It exhibits a fill consisting of shells which belong to the same species that those of the host sediment but in higher concentrations. The burrow boundaries are not sharp and *Thalassinoides* can be recognized only because of the contrast between the fill and the host sediment. *Thalassinoides* systems usually are sparse but locally can be very abundant. The background is structureless; there is not any evidence of primary lamination or other trace fossils other than very rare small worm-like burrows (*Planolites*?). This absence of lamination is suggested to be the product of the activity of shallow burrowers in a soupy substrate. Most of the molluscs in the clays hosting this ichnofabric are shallow infaunal organisms and must have destroyed all evidence of lamination.

Occurrence: In Sant Onofre (Baix Ebre) and Siurana (Alt Empordà). In the Baix Llobregat and Rhône basins the blue clays show a very similar homogenous ichnofabric but without *Thalassinoides* or any other distinct trace fossil.

Palaeoenvironmental significance and discussion: This ichnofabric must have been produced in a quiet, shallow marine environment, as indicated by the faunal assemblage, where a high rate of sedimentation, the soupyness of the substrate and/or other stressed conditions inhibited the establishment of a complex endobenthic community. The tiering profile was very simple with only two main tiers: the shallow infaunal or semiinfaunal organisms which destroyed the lamination, and the deeper producers of *Thalassinoides* which gave place to the only distinct trace fossils. The preservation of *Thalassinoides* is due to the accumulation of shells inside the burrow after bottom turbulences or weak storms.

Ichnofabric 4: *Planolites-Teichichnus-Thalassinoides*

Description: This ichnofabric occurs in sandy blue clays containing abundant shelly fossils. The degree of bioturbation is high (B.I. 4-5) and primary lamination is almost absent. The main constituents of the trace fossil assemblage are *Planolites montanus*, *Thalassinoides*, and *Teichichnus rectus*; echinoid burrows atributable to *Scolicia* are common, and *Skolithos* is very scarce. Other trace fossils that can be identified are borings on wood fragments that can be atributed to the bivalve ichnogenus *Teredolites*. From the crosscutting relationships between different ichnotaxa a tiering profile can be deduced consisting of shallow tier *Planolites*, medium tier *Scolicia* and *Teichichnus*, and deep tier *Thalassinoides*. *Planolites* can also occur in deeper tiers when it bioturbates *Thalassinoides* fills. Rarely, centimeter-thick sand beds can occur hosting *Ophiomorpha* burrows.

Occurrence: In the Valmagna valley in the Roussillon basin.

Palaeoenvironmental significance and discussion: The trace fossil assemblage suggests a shallow, fully marine setting with dominant quiet sedimentation of clays and sporadic sand inputs. The higher complexity of the endobenthic community in comparison with the previously described ichnofabrics for the blue clays suggests a slightly deeper environment, but it should be considered that the presence of sands could have favoured preservation of distinct trace fossils. A similar assemblage is described by Howard and Frey (1984) from the Cretaceous of Utah from upper offshore deposits.

Ichnofabric 5: *Diplocraterion*-spreite burrow-*Phycosiphon*

Description: The host sediments are blue clays. The lamination is mostly destroyed by biogenic activity (B.I. 4-5). The ichnofabric is dominated by hardly identificable spreite burrows (including *Teichichnus* and probably *Asterosoma*, *Rhizocorallium* and *Zoophycus*) in a background containing abundant *Phycosiphon incertum* and less common *Scalarituba missouriensis*. Long *Diplocraterion* are also common and exhibit a distinct strong ferrugination. Other trace fossils, such as *Chondrites*, *Thalassinoides* and *Palaeophycus* are scarce. From the cross-cutting relationships and the

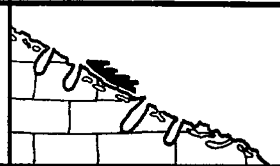
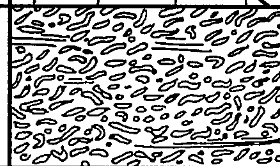
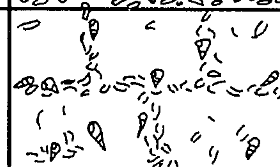
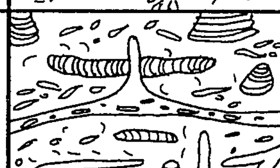
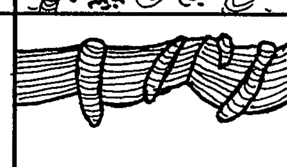
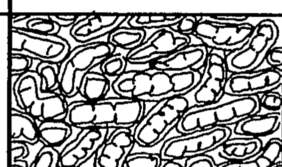
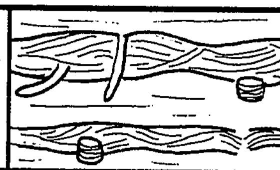
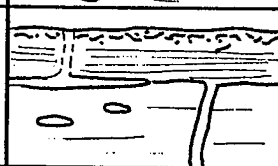
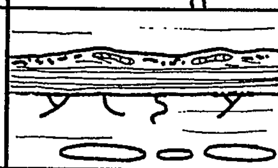
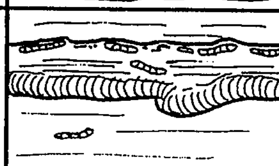
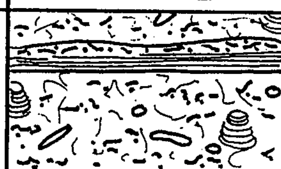
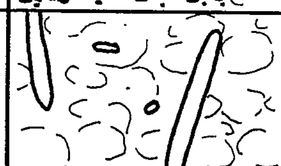
ICHNOFABRIC	DRAWING	TRACE FOSSILS	B.I.	BASINS
Ichnofabric 1: *Gastrochaenolites* in rocky shores		*Gastrochaenolites torpedo, G. lapidicus, Entobia, Maeandropolydora, Caulostrepsis, Trypanites*	-	BE BL AE O RH V
Ichnofabric 2: *Phycosiphon*		*Phycosiphon incertum, Palaeophycus*	4-5	O
Ichnofabric 3: Shell-filled *Thalassinoides*		*Thalassinoides, Planolites*?	6	BE AE
Ichnofabric 4: *Planolites-Teichichnus-Thalassinoides*		*Planolites montanus, Thalassinoides, Teichichnus rectus, Scolicia, Skolithos, Teredolites*	4-5	RO
Ichnofabric 5: *Diplocraterion*-spreite burrow-*Phycosiphon*		*Phycosiphon incertum, Scalarituba missouriensis, Teichichnus, Asterosoma, Rhizocorallium, Diplocraterion, Chondrites, Zoophycus, Thalassinoides, Palaeophycus*	4-5	V
Ichnofabric 6: *Teichichnus*		*Teichichnus rectus*	5-6	BE
Ichnofabric 7: *Scalarituba*		*Scalarituba missouriensis*	5-6	RH
Ichnofabric 8: J-burrow		J-burrows, escape structures. single trails, bilobate trails	2	BE
Ichnofabric 9: *Sinusichnus*		*Sinusichnus sinuosus, Gyrochorte, Teichichnus rectus, Scalarituba missouriensis, Scolicia*	2	BL

Figure 2.- Table showing the nineteen ichnofabrics described in the text, their trace fossil constituents, degree of bioturbation (Bioturbation Index, B.I., of Taylor and Goldring, 1993) and their palaeogeographic distribution (BE=Baix Ebre, BL=Baix Llobregat, AE=Alt Empordà, RO=Roussillon, O=Orb, RH=Rhône, V=Var).

study of some frozen profiles (below thin silty event beds) the tiering profile has been reconstructed (Gibert and Martinell, 1998). The shallow tier was occupied by *Phycosiphon* and *Scalarituba*, the medium tier by the spreite burrows and the deep tier by *Diplocraterion*. The burrow boundaries, except in the case of *Diplocraterion*, are irregular and diffuse and traces are sometimes deformed indicating a rather soft substrate.

Ichnofabric 10: *Teichichnus*-Fugichnion		*Teichichnus rectus*, escape structures, J-burrows	2	BE
Ichnofabric 11: *Phycosiphon-Skolithos*		*Phycosiphon incertum, Skolithos linearis, Thalassinoides suevicus, Palaeophycus, Planolites montanus*	2	BL
Ichnofabric 12: *Phycosiphon-Sinusichnus*		*Sinusichnus sinuosus*, tiny vertical burrows, *Scalarituba missouriensis, Phycosiphon incertum, Thalassinoides suevicus*	2	BL
Ichnofabric 13: *Scalarituba-Scolicia*		*Scalarituba missouriensis, S. biserialis, Phycosiphon incertum, Scolicia, Cardioichnus planus*	2	BL
Ichnofabric 14: *Phycosiphon-Palaeophycus*		*Phycosiphon incertum,Palaeophycus, Teichichnus rectus,Scalarituba missouriensis,Diplocraterion,Thalassinoides, Skolithos linearis,Chondrites,Scolicia, Sinusichnus sinuosus*	4-5	V
Ichnofabric 15: *Skolithos*-mottling		*Skolithos linearis, Palaeophycus*	4-5	BE
Ichnofabric 16: *Skolithos*-primary lamination		*Skolithos linearis*, escape structures	1-2	BE
Ichnofabric 17: *Ophiomorpha*		*Ophiomorpha nodosa, Macarronichnus, Skolithos linearis*	1-2	BL
Ichnofabric 18: *Phycosiphon*-primary lamination		*Phycosiphon incertum, Scolicia, Palaeophycus*	1	V
Ichnofabric 19: *Gastrochaenolites* in gravels		*Gastrochaenolites torpedo, G. lapidicus, Entobia, Maeandropolydora, Caulostrepsis, Trypanites*	-	BE BL AE RH

Occurrence: In Saint Isidore (Var basin).

Palaeoenvironmental significance and discussion: This ichnofabric is interpreted as having formed in an offshore fully marine setting deeper than the previous ichnofabrics as indicated by the higher diversity, presence of more deposit-feeding specialists and the higher complexity of the tiering. Other authors have pointed out the deep character of the Var Basin

(Irr, 1984; Nolf and Cappeta, 1988; Gili and Martinell, 1993). The presence of long Diplocraterion is rather anomalous in this setting but it can be explained as the response of a peculiar organism to very sporadic erosive processs related with slides of the fan front that can be observed in the field as scours with conglomeratic filling. A similar ichnofabric is described and figured by Martin and Pollard (1996) from the offshore transition zone in the Jurassic of the North Sea. These authors also remark the local presence of long *Diplocraterion habichi* interpreted as related with firmground omission surfaces.

Ichnofabric in the proximal units

The coarser proximal deposits include very variated facies associations related with the peculiarities of each of the basins. These facies associations include dominantly clayey deposits, sand-clay intercalations, sandy deposits and conglomeratic deposits. Consequently, the ichnofabrics are more varied than in the rather homogeneous blue clays. Thirteen ichnofabrics are going to be described from these units.

Ichnofabric 6: *Teichichnus*

Description: This ichnofabric is restricted to thin beds (about 20 cm) which are fully bioturbated (B.I. 5-6) by crowded *Teichichnus rectus*. These beds are associated with clays that contain a poorly diverse microfauna constituted by agglutinated foraminifera and a few *Ammonia*.

Occurrences: Sant Onofre (Baix Ebre), in the uppermost part of the marine sequence (Gibert and Martinell, 1996).

Palaeoenvironmental significance and discussion: This ichnofabric is interpreted as being produced by the work of an opportunistic deposit-feeding species in a very shallow, restricted, organic rich, and probably brackish environment. This is consistent with its stratigraphic position (near the transition to fully continental facies) and with the foraminifer assemblage. Low diversity *Teichichnus* ichnofabrics have been described by Beynon and Pemberton (1992) from brackish settings in the Lower Cretaceous of Alberta (Canada).

Ichnofabric 7: *Scalarituba*

Description: This ichnofabric is restricted to a few-centimeter thick beds. The beds are thoroughly bioturbated (B.I. 5-6) carbonate mudstones which contain the trace fossil *Scalarituba missouriensis*. These levels are associated with sandy clays containing *Psilonichnus tubiformis*.

Occurrences: Pichegu (Rhône).

Palaeoenvironmental significance and discussion: The sedimentary setting for this ichnofabric corresponds to an interdistributary bay of a delta. Conditions had to be restricted, organic rich, and probably low salinity, favouring the opportunistic occurrence of deposit-feeders that produced *Scalarituba*. The presence of *Psilonichnus* is consistent with a very shallow setting (Frey and Pemberton, 1987). Bjerstedt (1988) described an assemblage of *Planolites* and *Scalarituba* in the Lower Carboniferous of U.S.A. from a similar environment.

Ichnofabric 8: J-burrow

Description: This ichnofabric occurs within interbedded clays and sandstones. Both facies are horizontally laminated, and the sandstone layers are usually a few millimeter or centimeter thick and grouped in packets of up to a few decimeters. The ichnological assemblage is poorly diverse and the degree of bioturbation is low (B.I. 2). The only abundant structures are J-shaped, more rarely U-shaped, dwelling burrows that occasionally exhibit equilibrium spreiten related to the continuous depositional agradation. These burrows can be very abundant locally. The assemblage also contains common escape structures and scarce, single and bilobated, epigenic trails. The clays include a poor and poorly preserved microfossil assemblage (mainly foraminifers and ostracods), but no macrofossils.

Occurrences: Sant Onofre (Baix Ebre) in the Lower sandy clay subunit (Gibert and Martinell, 1996).

Palaeoenvironmental significance and discussion: This ichnofabric is interpreted as having formed in a bay environment with discontinuous input of sands. The low degree of bioturbation and ichnological diversity indicate rather restricted conditions. The presence of a single endogenic ichnotaxon probably points out oxygen-depleted conditions in the sediment.

Ichnofabric 9: *Sinusichnus*

Description: This ichnofabric is hosted by sandstone beds that are horizontally laminated at the bottom and rippled at the top and are intercalated with horizontally laminated clays. These facies show a low degree of bioturbation (B.I. 2). *Sinusichnus sinuosus* (a crustacean burrow network described by Gibert, 1996) is the most abundant ichnotaxon of this assemblage and occurs with *Gyrochorte*, *Teichichnus rectus*, and more rarely *Scalarituba missouriensis* and *Scolicia*.

Occurrences: Sant Onofre (Baix Ebre) in the Upper sandy clay subunit (Gibert and Martinell, 1996).

Palaeoenvironmental significance and discussion: This ichnofabric is more diverse than the litologically similar ichnofabric 8. This indicates a less restricted environment although the conditions did not allow for a high degree of bioturbation. The setting where this assemblage was developed corresponds to a marginal bay with frequent coarse sediment input and at least occassionally fully marine conditions as indicated by the presence of the echinoid trace *Scolicia*.

Ichnofabric 10: *Teichichnus*-Fugichnion

Description: This ichnofabric occurs in hummocky laminated sandstone beds. The degree of bioturbation is low and the assemblage consists of *Teichichnus rectus*, escape structures, and some J-burrows.

Occurrences: Sant Onofre (Baix Ebre) in the Upper sandy clay subunit (Gibert and Martinell, 1996).

Palaeoenvironmental significance and discussion: This ichnofabric corresponds to a post-event trace fossil assemblage associated to shallow tempestites in a more energetic area of the bay than the *Sinusichnus* ichnofabric which occurs in the same stratigraphic unit.

Ichnofabric 11: *Phycosiphon-Skolithos*

Description: The sedimentary facies hosting this ichnofabric is constituted by horizontally laminated clays with alternating massive or planar laminated sandstone beds (usually not thicker than 10 cm). These facies do not exhibit a high degree of bioturbation (B.I. 2). Five trace fossils have been recognized: *Phycosiphon incertum, Skolithos linearis, Thalassinoides suevicus, Palaeophycus* isp., and *Planolites montanus*. These can be separated into two different trace fossil suites in relation with the sedimentation of the sandstone beds. The pre-depositional suite is constituted by *Skolithos* and *Palaeophycus*. The post-depositional suite consists of *Thalassinoides* at the bottom of the sand beds, and *Phycosiphon* and *Planolites* (the latter being much more rare), occurring in high densities at the top of the sandstone beds.

Occurrences: El Papiol and Pic d'en Valls (Baix Llobregat).

Palaeoenvironmental significance and discussion: This ichnofabric correspond to a bay setting probably under stressed conditions (high rate of sedimentation, poor oxygenation, variable salinity) as indicated by the poor diversity of the assemblage, the low degree of bioturbation and the abundance of *Skolithos*. Periodically, sand beds were deposited by turbiditic or storm currents and were colonized by opportunistic organisms producing total bioturbation on the top of the beds (*Phycosiphon* and *Planolites*), and by crustaceans giving rise to *Thalassinoides*.

Ichnofabric 12: *Phycosiphon-Sinusichnus*

Description: This ichnofabric is contained in a sandy clayey lithofacies, essentially identical to those of the previous ichnofabric and with a very similar degree of bioturbation (B.I. 2). Again it is possible to differentiate pre-depositional and post-depositional suites. The first consists of abundant tiny (1 mm diameter) vertical burrows with different shapes (straight, slightly spiral, J-shaped, Y-shaped) and *Sinusichnus sinuosus*; both are greatly enhanced by the presence of a thick limonitic crust. The post-depositional suite is constituted by *Scalarituba missouriensis* and very abundant *Phycosiphon incertum* on the top of the sandstone beds and *Thalassinoides suevicus* on the bottom.

Occurrences: El Tarc (Baix Llobregat).

Palaeoenvironmental significance and discussion: The interpretation of this ichnofabric is very similar to that of ichnofabric 11, the major difference is the absence of *Skolithos*, which probably indicates less stressed conditions and is consistent with the slightly more distal position of the outcrop where it is found.

Ichnofabric 13: *Scalarituba-Scolicia*

Description: This ichnofabric, as in ichnofabrics 11 and 12, occurs in a sandy clay facies. In this case the post-depositional suite consists of unnamed horizontal burrows and *Scalarituba*. The post-depositional suite is formed by *Scalarituba missouriensis*, *Scalarituba biserialis* and *Phycosiphon* incertum at the top of the sandstone beds (the first being much more abundant), and the echinoid traces *Scolicia* isp. and *Cardioichnus* planus at the bottom.

Occurrences: Torrent del Terme and Can Albareda (Baix Llobregat).

Palaeoenvironmental significance and discussion: The presence of echinoid traces indicates at least temporary fully marine conditions for this ichnofabric, which is consistent with its palaeogeographic position at the outer end (more distal than those of ichnofabrics 11 and 12) of the Baix Llobregat ria (Gibert and Martinell, 1993).

Ichnofabric 14: *Phycosiphon-Palaeophycus*

Description: This ichnofabric occurs in a facies association consisting of highly bioturbated silts and fine sandstone intercalations (from a few mm to 20 cm thick) exhibiting horizontal or low-angle parallel lamination. *Phycosiphon incertum* is the dominant ichnotaxa. *Palaeophycus* isp., *Teichichnus rectus* and *Scalarituba missouriensis* are also important constituents. Other trace fossils including *Chondrites* isp., *Skolithos linearis*, *Thalassinoides* isp., *Sinusichnus sinuosus*, *Diplocraterion* isp., and *Scolicia* isp. are less common. The silts hosting this trace fossil assemblage are fully bioturbated (B.I. 4-5); only the thicker sandstone beds, corresponding to event deposition, preserve the primary lamination and exhibit very few trace fossils, mainly *Phycosiphon* and *Scalarituba*, at the top of the beds.

Occurrences: Saint Isidore (Var).

Palaeoenvironmental significance and discussion: The high diversity, degree of bioturbation, and the presence of echinoid traces (*Scolicia*) suggest an open marine setting for this ichnofabric, but the small size of most of the traces, the absence of structures resulting from complex behaviour and the great dominance of very simple structures probably produced by opportunistic organisms points out a stressed, unstable environment. This situation is consistent with the sedimentological evidence for the hosting facies. They were deposited in a relatively deep offshore environment but in a slope area where sedimentation took place from distal turbidite currents which did not allow the settling of a more complex benthic community (Gibert and Martinell, 1998). Similar ichnofabrics have been described by Goldring *et al.* (1991) and Martin and Pollard (1996) from the offshore transition zone in the Jurassic of the North Sea.

Ichnofabric 15: *Skolithos*-mottling

Description: This is an almost monospecific ichnofabric related to thick sandy deposits. *Skolithos linearis* is the only common trace fossil and occurs in a structureless background. The degree of bioturbation is high (B.I. 4-5), but the only distinct trace fossils are *Skolithos* and very scarce *Palaeophycus*. The rest of the ichnofabric consists of a very poorly preserved indistinct mottling. The mottling resulted from the activity of shallow-tier burrowers capable of destroying the physically-generated lamination but without forming distinct biogenic structures because of their burrowing mechanism and/or the soupy character of the sediment in shallow tiers.

Occurrences: In Sant Onofre (Baix Ebre) in the Basal detritic marine unit (Gibert and Martinell, 1996) and in the Upper sandy unit of Alt Empordà.

Palaeoenvironmental significance and discussion: The presence of *Skolithos* in a mottled sandy background suggests deposition in a moderate energy or only temporary turbulent setting. This picture is consistent with a shoreface palaeoenvironment as interpreted for this unit (Gibert and Martinell, 1996).

Ichnofabric 16: *Skolithos*-primary lamination

Description: This ichnofabric occurs in a cross-bedded sand bar where *Skolithos linearis* is the only common trace fossil. The background is made up of sedimentary lamination, and the Bioturbation Index is very low (1-2). Some escape structures occur with *Skolithos linearis*.

Occurrences: In the Upper sandy clay subunit, Sant Onofre (Baix Ebre).

Palaeoenvironmental significance and discussion: The presence of *Skolithos linearis* in a sandy unit and the preservation of cross-beding and lamination is indicative of a higher and continuous depositional energy. The preservation of lamination indicates the absence of an active shallow infaunal tier or the elimination of its fossil record by erosion. The second case is less probable because erosive boundaries have not been recognized. This highly energetic setting is consistent with a prograding bar, as is interpreted (Gibert and Martinell, 1996).

Ichnofabric 17: *Ophiomorpha*

Description: This ichnofabric occurs in cross-laminated and horizontally laminated sands. The sedimentary features are dominant in the ichnofabric (B.I. 1-2). *Ophiomorpha nodosa* occurs sparsely as simple burrow systems dominated by shafts. Locally, *Macaronichnus* appears in highly bioturbated thin levels. No other traces, except a few *Skolithos linearis*, are present.

Occurrences: El Papiol (Baix Llobregat).

Palaeoenvironmental significance and discussion: The sands hosting this ichnofabric are interpreted as distributary channels in the proximal part of the Baix Llobregat ria. The high energy of the setting produced the dominance of primary structures over the biogenic structures. *Macaronichnus* is the trace of a deposit-feeder which commonly exhibit great affinity for high energy settings (MacEachern and Pemberton, 1994b). Similar ichnofabrics with *Ophiomorpha* and *Macaronichnus* are described by Pollard *et al.* (1993) in sandy shallow marine palaeoenvironments.

Ichnofabric 18: *Phycosiphon*-primary lamination

Description: This ichnofabric occurs in a laminated sandy channel fill associated to conglomeratic forebeds. It is dominated by primary lamination but a few trace fossils are present (B.I. 1). They are mainly *Phycosiphon* and very scarce *Scolicia* and *Palaeophycus*.

Occurrences: Saint Isidore (Var).

Palaeoenvironmental significance and discussion: The sandy channel facies where this ichnofabric occurs corresponds to a high energy setting with rapid deposition which allowed for very little bioturbation by opportunistic organisms such as the Phycosiphon producer (Gibert and Martinell, 1998).

Ichnofabric 19: *Gastrochaenolites* on gravels

Description: This ichnofabric is constituted by borings in pebbles within gravelly facies. The boring assemblage is very similar to those of ichnofabric 1: *Gastrochaenolites lapidicus*, *Gastrochaenolites torpedo*, *Entobia*, *Maeandropolydora*, *Caulostrepsis* and *Trypanites*. The pebbles are usually bored all around and often host encrusting shells, mainly oysters, barnacles and serpulids.

Occurrences: Sant Onofre (Baix Ebre), Sant Vicenç dels Horts, El Tarc and Can Albareda (Baix Llobregat), and Ciurana and Els Olivets (Alt Empordà).

Palaeoenvironmental significance and discussion: This boring assemblage corresponds to shallow, energetic, littoral conditions. The fact that the pebbles have borings on all sides indicates that they had a relatively long time of residence in the surface. The deposits making up this ichnofabric correspond to gravel beaches, transgressive lags, and marine reworking of previously existent gravel deposits.

Discussion

Bioerosion ichnofabrics

The bioerosion ichnotaxa exhibit a wider distribution pattern in the studied area than do the bioturbation traces. They occur in a very recurrent assemblage dominated by *Gastrochaenolites* and *Entobia* which gives rise to two different ichnofabrics (Ichnofabrics 1 and 19) depending on the kind of substrate where they are hosted (rocky palaeorelief or gravels). This highly recurrent assemblage is mainly substrate-controlled; borings can only develop in hardgrounds, and in the studied basins this kind of substrate only occurs in the base of the sequence where rocky shores were developed (ichnofabric 1) and in conglomeratic deposits (ichnofabric 19). Both situations correspond to littoral, energetic conditions and therefore the trace fossil assemblage is the same. Ichnofabric 1 has a remarkable stratigraphic significance because it records the Zanclean transgressive surface and the beginning of the Pliocene sequence. On the other hand, ichnofabric 19 can only be produced in those gravel settings (mainly gravel beaches or transgressive lags) which display a long time of residence of the pebbles at the sediment-water interface; other marine conglomeratic deposits corresponding to fan deltas or forebeds with higher rates of sedimentation are typically devoid of borings.

Bioturbation ichnofabrics

Most of the bioturbation traces mentioned herein occur in several basins or ichnofabrics. *Phycosiphon incertum* is the most significant trace, occurring in seven ichnofabrics and being the primary constituent of most of them. Other important ichnofabric constituents are *Scalarituba missouriensis*, *Teichichnus rectus*, *Thalassinoides*, *Skolithos linearis*, *Palaeophycus* and *Scolicia*. Most of the traces are simple feeding structures (Fodinichnia and Pascichnia) or dwelling burrows (Domichnia). The dominance of structures produced by low-specialized deposit-feeders is consistent with a marginal marine environment with high organic production and sedimentation but under stressed and changeable conditions (salinity, sedimentation rate, oxygenation) avoiding the settling of more specialized organisms. Some of the most common traces (*Phycosiphon*, *Scalarituba*, *Teichichnus*) exhibit opportunistic occurrences indicating that they were produced by highly tolerant organisms.

Despite most of the traces being widely distributed, ichnofabrics (considering trace fossil assemblage, degree of bioturbation and tiering) are usually restricted to a single basin and even to a single outcrop. They show great variability from monospecific to diverse

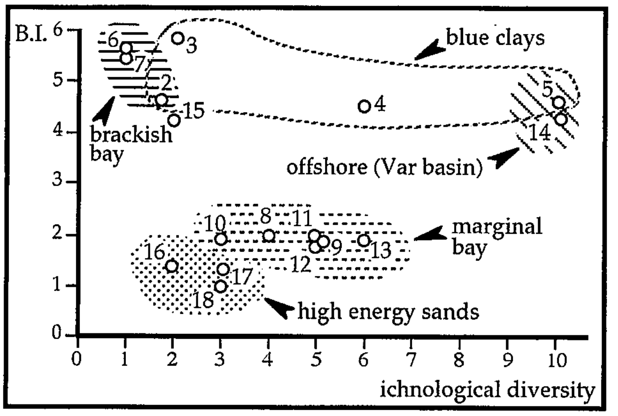


Figure 3.- Ichnological diversity (number of ichnospecies) versus Bioturbation Index (B.I., Taylor and Goldring, 1993) diagram showing the seventeen bioturbation ichnofabrics described and thegroupings discussed in the text.

assemblages and from low to high bioturbation. The bioturbation ichnofabrics have been plotted in a diversity vs. bioturbation index diagram to show this variability (Fig. 3). Some similarities and differences between ichnofabrics can be easily observable from this diagram:

Those ichnofabrics interpreted as having formed in very shallow, brackish and marginal clay environments (ichnofabric 2, 6 and 7) are monospecific and show complete bioturbation. In these settings sediment was organic-rich, but the restricted conditions only allow for colonization by highly tolerant deposit-feeders which completely destroyed the primary fabric.

The blue clays, corresponding to the central area of the basins, are always fully bioturbated (ichnofabrics 2, 3, 4 and 5), but the diversity and complexity of the tiering increase with increasing salinity and depth. Ichnofabric 2 (Orb), which is interpreted as having formed in a brackish setting, is monospecific and includes only a very shallow tier constituted by *Phycosiphon*; ichnofabric 3, corresponding to low salinity (Baix Ebre) or very shallow (Alt Empordà) environments, exhibits a two-tier profile consisting of a shallow tier where shallow infaunal organisms homogeneized the sediment and a deeper one constituted by *Thalassinoides*; ichnofabric 4 (Roussillon), considered fully marine and deeper, hosts a multi-tiered and more diverse trace fossil assemblage with a shallow tier with *Planolites*, a medium tier with *Scolicia* and *Teichichnus* and a deeper tier with *Thalassinoides* and *Skolithos*; finally, ichnofabric 5 (Var), which was formed in relatively deep conditions (100 m or more), has the most diverse assemblage with a more complex tiering profile and includes spreiten feeding burrows almost absent in the preceeding blue clays ichnofabrics.

Sandy clay ichnofabrics from the Baix Ebre and Baix Llobregat produced in marginal bay environments (ichnofabrics 8, 9, 10, 11, 12, 13) are very similar despite the variation in their trace fossil assemblages.

All are moderately diverse and poorly bioturbated. Ichnofabric 13, which is the only one produced in fully marine conditions, exhibits the highest diversity. The similarities between these ichnofabrics remark the similarity between the sedimentary systems in the Baix Ebre and Baix Llobregat basins, both of which correspond to clay dominated bays. Ichnofabric 14, which is contained in a similar lithofacies association (sandy silts), is much more diverse and is fully bioturbated indicating that it was produced in a much deeper setting.

Ichnofabrics 5 and 14, which have been defined in the Var Basin, show a much higher diversity, greater degree of bioturbation and a more complex tiering profile than the other described ichnofabrics. This fact points out the deeper character of this basin, which despite being a ria or estuary from a palaeogeographic point of view is filled by offshore fully marine sediments hosting ichnofabrics comparable to those of open marine settings (Gibert and Martinell, 1998).

Finally, those ichnofabrics produced in sandy lithofacies (ichnofabrics 15, 16, 17 and 18) display a low diversity and a dominance of sedimentary structures over biogenic structures (except ichnofabric 15). Their trace fossil assemblage is dominated by dwelling burrows in facies that correspond to nearshore settings (ichnofabrics 15, 16, 17) or by deposit-feeders in facies produced in a deeper setting (ichnofabric 17).

A general ichnological model

Despite that all the basins are contemporaneous, geographically close and result of the same geological history, it is difficult to establish an ichnological, or even a stratigraphical, synthetic model for the seven basins due to their palaeogeographic, palaeophysiographic and geologic peculiarities. However some common features can be pointed out.

The beginning of the Pliocene sequence is recorded by a very extensive bioerosion surface with *Gastrochaenolites* and *Entobia*, corresponding to ichnofabric 1. This discontinuity is the most recurrent ichnologic and stratigraphic feature of the basins, being absent only in the Roussillon. Transgressive deposits overlaying that flooding surface are usually absent or restricted to thin transgressive lag deposits which contain the same ichnotaxa as the basal surface (ichnofabric 19). Only in the Rhône and the Baix Ebre basins are known thicker transgressive deposits, including in the Baix Ebre littoral and restricted bay ichnofabrics (ichnofabrics 19, 15 and 8). The blue clays are present in all basins overlying the transgressive deposits or the transgressive bored surface. They are always fully bioturbated, but their salinities and depths are variable from brackish and very shallow (Orb) to fully marine offshore conditions (Var), as indicated by the increasing tiering complexity and diversity of the ichnofabrics (ichnofabrics 2, 3, 4 and 5) and also, by the body fossil assemblages. The coarser deposits overlying the blue clays constitute a mosaic of different sedimentary facies and ichnofabrics including relatively deep fully bioturbated turbiditic deposits (ichnofabric 14), marginal bay sediments hosting a moderately diverse trace fossil assemblage (ichnofabrics 9, 10, 11, 12 and 13), low bioturbated high-energy sands (ichnofabrics 16, 17 and 18), bored (ichnofabric 19) or unbored conglomerates and brackish monospecific ichnofabrics (ichnofabrics 6 and 7).

Conclusions

Trace fossil assemblages and ichnofabrics in marginal marine environments are difficult to typify. These settings display many temporal and geographical variations in palaeoecological parameters (salinity, oxygenation, light, depth) and sedimentological features (sedimentation rate, grain size, substrate consistency) and hence, benthic communities are also very variable. The Pliocene coastal basins of the NW Mediterranean margin offer the possibility to study a great range of trace fossil assemblages. Despite the same origin, age and geological history of the basins, most of the nineteen ichnofabrics described in this paper are restricted to one basin or even one outcrop.

Only the bioerosion structures occur in a single very recurrent trace fossil assemblage (dominated by *Gastrochaenolites*) which is present in most of the basins and gives rise to two different ichnofabrics. The great recurrency and wide geographic distribution of this assemblage is due to the fact it is a substrate-controlled assemblage which was developed in hard substrates (rocky shores or gravels) that mostly occur in high energy littoral settings.

The seventeen bioturbation ichnofabrics are very variable ranging from monospecific to diverse assemblages and from low to high bioturbation. The trace fossil constitutents are mainly simple feeding burrows (*Phycosiphon*, *Scalarituba*, *Teichichnus*, *Thalassinoides*) and secondary dwelling burrows (*Skolithos*, *Palaeophycus*). The local character of the ichnofabric and the dominance of simple deposit-feeders are the main features characterizing these marginal marine basins. The basins were organic rich settings able to host a deposit-feeder-dominated benthic community, but their coastal position determined very variable temporal and spatial conditions which avoided the installation of an equilibrium community and kept the assemblages very local.

Some remarkable points are revealed from the ichnofabric approach to the bioturbation assemblages: a) very shallow, restricted, low salinity settings are characterized by highly bioturbated monospecific ichnofabrics constituted by simple feeding traces, b) the central areas of the basin where deposition was fine-grained (blue clays) display fully bioturbated ichnofabrics but complexity of tiering and diversity increases with deeper and more marine conditions, c) marginal areas of clayey-dominated bays (Baix Ebre and Baix Llobregat) host low bioturbated, low-to-moderately diverse ichnofabrics, d) high-energy sandy facies exhibit poorly bioturbated and low diversity ichnofabrics and e) ichnofabrics of the Var basin are much more diverse and bioturbated pointing out that despite being a marginal marine basin from a palaeogeographic point of view its ichnofabrics are closer to open marine than marginal marine settings.

This work was supported by the Research Project PB94-0946 o the DGICYT (Spanish Government and by the integrated Spanish-Portuguese research projects HP95-46 and HP96-60. We thank Peter Steen (University of Utah) for reading and correcting the original manuscript, and Luis Buatois (University of Kansas) and Eduardo Mayoral (Universidad de Huelva) for their comments and suggestions.

References

Agustí, J., Domènech, R., Julià, R., and Martinell, J. (1990): Evolution of the Neogene Basin of Empordà (NE Spain). *Paleontologia i Evolució, Mem. Esp.* 2: 251-268.

Ambert, P. (1989): Les formations à blocs messiniennes du piémont du Languedoc Central. Implications tectoniques et corrélations régionales. *C. R. Acad. Sci. Paris,* sér. II, 309: 2077-2084.

Arasa, A. (1990): El Terciario del Baix Ebre: aportaciones estratigráficas y sedimentológicas. *Acta Geol Hisp,* 25: 271-288.

Ballesio, R. (1972): Étude stratigraphique du Pliocène rhodanien. *Doc. Lab. Géol. Fac. Sc. Lyon,* 53: 333 p.

Beynon, B.M., and Pemberton, S.G. (1992): Ichnological signature of a brackish water deposit: an example from the Lower Cretaceous Grand Rapids Formation, Cold Lake Oil Sands Area, Alberta: En *Applications of ichnology to petroleum exploration* (Pemberton, S.G., Ed.), S.E.P.M. Core Workshop, 17: 199-221.

Bjerstedt, T.W. (1988): Trace fossils from the Early Mississippian Price delta, Southeast West Virginia. *J. Paleont.,* 62: 506-519.

Bromley, R.G, and Asgaard, U. (1993): Endolithic community replacement on a Pliocene rocky coast. *Ichnos,* 1: 43-49.

Busson, G. (1990): Le Messinien de la Méditerranée... vingt ans après. Géologie de la France, 3-4: 5-58.

Clauzon, G. (1978): The Messinian Var Canyon (Provence, Southern France) - Paleogeographic implications. *Marine Geology,* 27: 231-246.

Clauzon, G. (1979): Le canyon messinien de la Durance (Provence, France): une preuve paléogéographique du bassin profond de dessication. *Palaeogeogr., Palaeoclimatol., Palaeoecol.,* 29: 15-40.

Clauzon, G. (1982): Le canyon messinien du Rhône: une preuve décisive du «dessicated deep-basin model» (Hsü, Cita & Ryan, 1973). *Bull Soc. géol. France,* sér 7, 24: 597-610.

Clauzon, G. (1990): Restitution de lÍevolution geodynamique neogene du bassin du Roussillon et de lÍUnité adjacente des Corbieres dÍaprès les donées ecostratigraphiques et paleogeographiques. *Paléobiol. cont.,* 17: 125-155.

Clauzon, G., Aguilar J.P. and Michaux, J. (1987a): Le bassin pliocène du Roussillon (Pirénées-Orientales, France): exemple dÍévolution géodynamique dÍune ria consécutive a la crise de salinité messinienne. *C. R. Acad. Sc. París,* sér. 2, 304: 585-590.

Clauzon, G., Martinell, J., Aguilar, J.P., and Suc, J.P. (1987b): *Livret-guide des excursions (Roussillon, Penedès et Baix Llobregat).* Regional Committee on Mediterranean Neogene Stratigraphy, Working Group on Ecostratigraphy, Interim Colloquium (Montpellier-Barcelone): 77 p.

Clauzon, G., Aguilar, J.P. and Michaux J. (1989): Relation temps-sédimentation dans le Néogène méditerranéen franìais. *Bull. Soc..géol. France,* sér. 1, 5: 361-371.

Clauzon, G., Suc, J.P., Aguilar, J.P., Ambert, P., Cappeta, H., Cravatte, J., Drivaliari, A., Domènech, R., Dubar, M., Leroy, S., Martinell, J., Michaux, J., Roiron, P., Rubino, J.L., Savoye, B., and Vernet, J.L. (1990): Pliocene geodynamic and climatic evolution in the French Mediterranean Region. *Paleontologia i Evolució, Mem. Esp.* 2: 131-186.

Ekdale, A.A., Bromley, R.G. and Pemberton S.G. (1984) *Ichnology. The use of trace fossils in sedimentology and stratigraphy.* S.E.P.M. Short Course 15: 317.

Ekdale, A.A. and Lewis, D.W. (1991): Trace fossils and paleoenvironmental control of ichnofacies in a late Quaternary gravel and loess fan delta complex, New Zealand. *Palaeogeogr., Palaeoclim., Palaeoecol.* 81: 253-279.

Fleta, J. and Escuer, J. (1991): Sistemas sedimentarios de la cuenca neógena del Alt Empordà y su relación con la tectónica y el vulcanismo. *I Congreso del Grupo Español del Terciario, Libro-Guía Excursión* nº 7: 128.

Fleta, J., Arasa, A. and Escuer, J. (1991): El Neógeno del Empordà y Baix Ebre (Catalunya): estudio comparativo. *Acta Geol. Hisp.,* 26: 159-172.

Frey, R.W. and Pemberton, S.G. (1987): The *Psilonichnus* ichnocoenose, and its relationship to adjacent marine and nonmarine ichnocoenoses along the Georgia Coast. , 35: 333-357.

Gibert, J.M. de (1995): *Icnologia de les conques marines pliocenes del marge nord-occidental de la Mediterrània.* Ph.D. Thesis, Universitat de Barcelona, unpublished: 264.

Gibert, J.M. de (1996): A new decapod burrow system from the NW Mediterranean Pliocene. *Rev. Esp. Paleont.,* 11: 251-254.

Gibert, J.M. de, and Martinell, J. (1992): Principales estructuras biogénicas en el Plioceno marino de la Cuenca del Baix Llobregat (Catalunya). *Geogaceta,* 12: 104-105

Gibert, J.M. de, and Martinell, (1993): Controles paleoambientales sobre la distribución de las paleoicnocenosis en el estuario plioceno del Baix Llobregat (Barcelona, Catalunya). *Rev. Esp. Paleont.,* 8: 140-146.

Gibert, J.M. de, and Martinell, J.. (1995a): Sedimentary substrate and trace fossil assemblages in marine Pliocene deposits in Northeast Spain. *Geobios, Mem. Sp.,* 18: 197-206.

Gibert, J.M. de, and Martinell, J.. (1995b): Bioturbation in the Lower Pliocene sediments of the North-Western Mediterranean area. *Romanian Journal of Stratigraphy,* 76 (suppl. 7): 193-194.

Gibert, J.M. de, and Martinell, J. (1996): Trace fossil assemblages and their palaeoenvironmental significance in the Pliocene marginal marine deposits of the Baix Ebre (Catalonia, NE Spain). *Géologie Méditerranénne,* 23: 211-225.

Gibert, J.M. de, and Martinell,J. (1998): Ichnofabric analysis of the Pliocene marine sediments of the Var Basin (Nice, SE France). *Géobios,* 31: 271-281.

Gibert, J.M. de, and Martinell, J.. and Domènech, R. (1996): El Mioceno marino entre las playas de L'Arrabassada y El Miracle (Tarragona): aspectos paleontológicos e implicaciones sedimentológicas. *Acta Geol Hisp,* 29 (1994): 133-148.

Gili, c. and Martinell, J. (1993): The distribution on Pliocene Nasariidae (Mollusca, Gastropoda) from the Western Mediterranean: Palaeoecological and historical considerations. *Contr. Tert. Quatern. Geol.*, 30: 29-39.

Goldring, R., Pollard, J.E. and Taylor, A.M. (1991): *Anconichnus horizontalis*: a pervasive ichnofabric-forming trace fossil in post-paleozoic offshore siliciclastic facies. *Palaios*, 6: 250-263.

Howard, J.D. and Frey, R.W. (1984): Characteristic trace fossils in nearshore to foreshore sequences, Upper Cretaceous of East-Central Utah. *Canadian Jour. Earth Sc.*, 21: 200-219.

Hsü, K.J., Cita, M.B. and Ryan, W.B.F. (1973) Late Miocene dessication of the Mediterranean. *Nature*, 242: 240-244.

Irr, F. (1984): *Paléoenvironnements et évolution géodynamique néogenes et quaternaires de la bordure nord du bassin méditerranén occidental.* Travaux du C.R.M. Jean Cuviller, 6: 464 pp.

Martin, M.A. and Pollard, J.E. (1996): The role of trace fossil (ichnofabric) analysis in the development of depositional models for the Upper Jurassic Fulmar Formation of the Kittiwake Field (Quadrant 21 UKCS). En: *Geology of the Humber Group: Central Graben and Moray Firth, UKCS* (Hurst, A. *et al.*, Eds.), Geological Society Special Publication No. 114: 163-183.

Maceachern, J.A. and Pemberton, S.G. (1994a): Ichnological aspects of incised-valley fill systems from the Viking Formation of the Western Canada Sedimentary Basin, Alberta, Canada. En: Incised valley systems: origin and sedimentary sequences *S.E.P.M. Sp. Pub.*, 51: 129-156.

Maceachern, J.A. and Pemberton, S.G. (1994b): Ichnological aspects of Cretaceous shoreface succesions and shoreface variability in the Western Interior Seaway of North America: En: *Applications of ichnology to petroleum exploration* (Pemberton, S.G. Ed.), S.E.P.M. Core Workshop, 17: 57-84.

Martinell, J. (1988): An overview of the marine Pliocene of NE Spain. *Géologie Méditerranéene*, 15: 227-233.

Martinell, J. and Domènech, R. (1986): Actividad bioerosiva en el plioceno marino del Empordà (Catalunya). *Paleontologia i Evolució*, 20: 247-251

Martinell, J. and Domènech, R. (1995): Bioerosive structures on the Pliocene rocky shores of Catalonia (Spain). *Rev. Esp. Paleont.*, 10: 37-44.

Martinell, J., Domènech, R.. and Marquina, M.J. (1984): Molluscan assemblages in the North-East marine Spanish Pliocene. Ann. Geol. Pays Hellen. 32: 35-56.

Martinell, J. and Domènech, R. and Gibert, J.M. de (1995): Bioerosion in Lower Pliocene rocky shores of the Northwestern Mediterranean area. *Romanian Journal of Stratigraphy*, 76 (suppl. 7): 199-200.

Mikulás, R. (1992): Early Cretaceous borings from Stramberk (Czechoslovakia). Casiopis pro mineralogii a geologii, 37: 297-323.

Nolf, D. and Cappetta, H. (1988): Otolithes de poissons pliocènes du Sud-Est de la France. *Bull. Inst. royal Sci. nat. Belgique*, 58: 209-271.

Pemberton, S.G. and Wightman, D.M. (1992). Ichnological characteristics of brackish water deposits. En: *Applications of ichnology to petroleum exploration* (Pemberton, S.G., Ed.), S.E.P.M. Core Workshop, 17: 141-168

Pollard, J.E., Goldring, R. and Buck, S.G. (1993): Ichnofabrics containing *Ophiomorpha*: significance in shallow-water facies interpretation. *Jour. Geol. Soc., London*, 150: 149-164.

Ryan, W.B.F. (1976): Quantitative evolution of the depth of the Western Mediterranean before, during and after the Late Miocene salinity crisis. *Sedimentology*. 23: 791-813.

Ryan, W.B.F. and Cita, M.B. (1978): The nature and distribution of Messinian erosional surfaces - indicators of a several kilometers deep Mediterranean in the Miocene. *Marine Geology*, 27: 193-230.

Seilacher, A. (1964): Biogenic sedimentary structures. En: *Approaches to paleoecology* (Imbrie, J. and Newell, N., Eds.), Wiley, New York: 296-316.

Silva, C.M. da, Cachao, M., Martinell, J. and Domènech, R. (1995): Estruturas bioerosivas como indicadores de paleolitorais rochosos. O exemplo do Miocénico da Foz da Fonte (Sesimbra, Portugal). Dados preliminares. *Universidade do Porto-Facultade de ciências. Museu e Laboratório Mineralógico e Geológico Mem.*, 4:133-137.

Taylor, A. and Goldring, R. (1993): Description and analysis of bioturbation and ichnofabric. *Jour. Geol. Soc., London*, 150: 141-148.

Wetzel, A. and Bromley, R.G. (1994): *Phycosiphon incertum* revisited: *Anconichnus horizontalis* is its junior subjective synonim. *J. Paleont.*, 68: 1396-1402.

Manuscrito recibido el 7 de Setiembre de 1997
Aceptado el manuscrito revisado el 16 de Marzo de 1998