

The significance of a densely bored surface at the top of the Camacho Formation (Late Miocene) of Uruguay

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Abstract. The presence of a bivalve boring assemblage is reported from the uppermost part of the Camacho Formation (Late Miocene), at Barrancas de San Juan (Colonia Department, Uruguay). The trace fossil assemblage, composed of several ichnospecies of *Gastrochaenolites* and showing a high density, allowed to infer that this stratum suffered a certain degree of consolidation before colonization by the borers, and is interpreted as a hardground developed by dewatering of the seafloor. The great abundance of specimens of this ichnogenus also helped to interpret this surface as an omission surface, suggesting a period of diminished deposition or non deposition, at least in ecological time scale. Subsequently, at least one erosive event is recorded by the truncation of the ichnofossils. The bivalve boring assemblage indicates the development of a hardground under extremely shallow water conditions very close to the shore line and, therefore, the presence of a rocky shore landscape. The trace fossil assemblage, together with other evidence from body fossils and sedimentary facies, suggests a general shallowing trend in the Camacho Formation.

Resumen. EL SIGNIFICADO DE UNA SUPERFICIE DENSAMENTE PERFORADA EN EL TOPE DE LA FORMACIÓN CAMACHO (MIOCENO TARDÍO) DE URUGUAY. Se reporta la existencia de una asociación de perforaciones de bivalvos en el tope de la Formación Camacho (Mioceno Tardío), en la localidad de Barrancas de San Juan (Departamento de Colonia, Uruguay). La asociación compuesta por varias icnoespecies de *Gastrochaenolites*, muestra una alta densidad por unidad de área, permitiendo establecer que el estrato portador de las perforaciones sufrió un cierto grado de consolidación previo a la colonización por parte de los bivalvos, y es interpretado como un *hardground* producto de la deshidratación del sustrato. La presencia de abundantes *Gastrochaenolites* permitió además reconocer que el nivel perforado por los bivalvos representa una superficie de omisión, lo que significa un período de no depositación o escasa depositación, al menos en tiempo ecológico. Posteriormente se registra uno o más eventos erosivos evidenciados por el truncamiento de los icnofósiles. Esta asociación de perforaciones de bivalvos, que se extiende unos once kilómetros en la horizontal, es indicadora de *hardgrounds* desarrollados en ambientes de escasa profundidad muy cercanos a la línea de costa y por ende un paisaje de paleorupicosta. Los icnofósiles en cuestión junto a otras evidencias paleontológicas y sedimentológicas sugieren una tendencia general de somerización en toda la sección de la Formación Camacho.

Key words. Hardground. Bioerosion. Bivalve borings. *Gastrochaenolites*. Paleoecology. Miocene. Uruguay.

Palabras clave. Hardground. Bioerosión. Perforaciones de bivalvos. *Gastrochaenolites*. Paleoecología. Mioceno. Uruguay.

Introduction

The Camacho Formation represents a transgressive event - known in the old literature (Teisseire, 1928; Roselli, 1939; Serra, 1943) as "Transgresión Entrerriana" - well documented from the Miocene outcrops of Uruguay and also recorded in parts of eastern Argentina and southern Brazil. The Camacho Formation mainly crops out in the southern coastal region of Uruguay at Colonia and San José Departments, and can be found in the subsurface along the Uruguayan coast in Chuy well N° 364, lo-

cated in the western region of the Pelotas Basin, close to the Uruguay-Brazil border (de Medina, 1962; Figueiras and Broggi, 1971, 1973; Sprechmann, 1978).

Typical lithologies of the Camacho Formation are fine-to coarse-grained sandstone, mudstone, packstone and siltstone, with some thin beds of claystone. Caorsi and Goñi (1958) coined the name "Camacho Sandstone"; the Formation rank was given by Goso and Bossi (1966) subsequently.

This unit is well known by its rich and abundant fossiliferous content which includes marine microfossils, invertebrates and invertebrate trace fossils, as well as marine and terrestrial vertebrates. On the other hand, despite the abundance and diversity of invertebrate trace fossils in this unit, they were sel-

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Anchorena Ranch, Colonia Department) (figure 1) begins with a section composed mainly of mudstone, packstone, and sandstone; locally interbedded with siltstone. This section is approximately four meters

Figure 1. Map showing the location of the outcrops with the *Gastrochaenolites* ispp. assemblage. From north to south: Cañada La Negra, Barrancas de San Pedro, North of Arroyo El Caño mouth. Single arrows point to local occurrences, dotted line marks continuous occurrences / *Mapa con la ubicación de las localidades que presentan la asociación de Gastrochaenolites ispp. De norte a sur: Cañada La Negra, Barrancas de San Pedro, Norte de Arroyo El Caño. Las flechas indican presencias puntuales, la línea punteada indica presencia continua.*

dom reported in the literature (Martínez, 1994; Sprechmann *et al.*, 1994, 1998; Verde and Piñeiro, 1994; Verde, 2000, 2002). Among these few references about ichnofossils in the Camacho Formation, soft substrate trace fossils (burrows) are the most frequently reported, and are known to occur at several levels of the unit; on the contrary hard substrate traces (borings) were thought to be confined only to the oyster banks located in Colonia and San José Department (Sprechmann *et al.*, 1998).

The purpose of this contribution is to document the presence of a hardground situated on the top of the Camacho Formation that was formerly regarded as belonging to soft substrate facies. This hardground occurs in three localities (figure 1); it was revealed by its ichnofossils, and is interpreted here as an omission surface.

The trace fossil assemblage

The stratigraphic log of the Camacho Formation at Barrancas de San Juan (Presidential Park,

Figure 2. Stratigraphic section of the Camacho Fm. in the studied area. The arrow indicates the level with the *Gastrochaenolites* assemblage. / *Sección estratigráfica de la Fm. Camacho en el área estudiada. La flecha señala el nivel con la asociación de Gastrochaenolites.*

thick, and is capped in some places by a very friable fine-grained sandstone. At other localities - e.g. Cañada La Negra - the friable fine-grained sandstone is lacking, and the section mentioned above is capped by a coarse-grained sandstone that is also present at other outcrops of the Camacho Formation (Martínez, 1994; Verde and Perea, 1992) (figure 2).

The hardground trace fossil assemblage was found in the mudstone under the coarse sand, in the uppermost part of the Camacho Formation. This mudstone was treated with HCl (10%) to test its carbonate content, and did not react at all. The borings cross cut occasional clay intraclasts, and are filled with the coarse sand. Thus, the kind of preservation of the traces is of the bed-junction type.

The trace fossil assemblage at Cañada La Negra is impressive, as this planar surface is almost completely bored by the bivalves (figure 3). All the borings were referred to *Gastrochaenolites* Leymerie, 1842, and five ichnospecies were recorded: *G. lapidicus*, *G. ornatus*, *G. torpedo*, *G. turbinatus*, and *G. isp.* (probably a new form). The bored surface is areally extensive and can be traced horizontally for at least several hundred meters in this locality.

In addition to the morphologic diversity of borings, a wide range of size was recorded, being 3 mm to 40 mm approximately in maximum diameter and up to 80 mm long in many complete specimens (figure 4). Several specimens bear well-preserved concentric bioglyphs in their bases (*G. ornatus*), that

Figure 3. Hardground with *Gastrochaenolites* spp. at Cañada La Negra. **A:** Top of the Camacho Formation (the arrow points the omission surface), the hammer on the right is 28 cm. **B:** Plain view of the surface with crowded *Gastrochaenolites* lens cap is 5,5 cm in diameter. **C:** Vertical section of the level with borings, the brush is 20 cm long./ Hardground con *Gastrochaenolites* spp. en Cañada La Negra. **A:** Tope de la Formación Camacho (la flecha señala la superficie de omisión), el martillo de la derecha mide 28 cm. de longitud. **B:** Vista en planta de la superficie con numerosos *Gastrochenolites*, el cubre lente mide 5,5 cm. de diámetro. **C:** Corte vertical del nivel con perforaciones, el pincel mide 20 cm de longitud.

Figure 4. Complete specimen of *Gastrochaenolites lapidicus* (artificial paraffin cast). Scale bar is 1 cm / *Ejemplar completo de Gastrochaenolites lapidicus (molde artificial de parafina). La escala representa 1 cm.*

match well the morphology of some recent pholadid bivalve borings, which were made by mechanical means. Truncation of the neck region of the borings is common, and in some points, only the basal part of *Gastrochaenolites* is preserved; this fact allowed to infer the amount of erosion subsequent to the period of boring. No shells have been found inside the borings, even in the complete ones.

At another locality, north of Arroyo El Caño mouth (Colonia Department), 11.5 km southeast from Barrancas de San Juan, a well preserved similar assemblage of *Gastrochaenolites* spp. was found at the top of the Camacho Formation, although it was not possible to trace laterally due to the vegetation cover and landslides in the cliff. A third locality was studied, Barrancas de San Pedro, located between Barrancas de San Juan and Arroyo El Caño mouth, 7.5 km southeast from Barrancas de San Juan. In this outcrop some *Gastrochaenolites* were found at the top of the Camacho Formation, but the remains are scarce and poorly preserved, perhaps due to the coarse-grained sediments of the overlying materials (a conglomerate with coarse-grained sandy matrix). Nevertheless, the bored surfaces at north of Arroyo El Caño mouth and Barrancas de San Pedro can be correlated with those present at Cañada La Negra.

The lack of *Entobia* in this hardground is noteworthy, taking into account that sponge borings are very

common in other hard substrates of the Camacho Formation (e.g. oyster banks, Sprechmann *et al.*, 1998; Verde, 2002) and that they are also abundant in many Cenozoic hardgrounds worldwide (Bromley, 1994). The absence of sponge borings in this hardground is discussed below.

Discussion and conclusions

The stratigraphic position and mode of preservation of the trace fossil association of *G. lapidicus*, *G. ornatus*, *G. torpedo*, *G. turbinatus* and *G. isp.* in a distinct horizon showing a high density indicates the development of an omission surface and a hardground at the top of the Camacho Formation. The absence of *Entobia* can be explained by the virtual lack of carbonate in this level, the high siliciclastic content of the rock, and the fact that boring sponges can only colonize calcareous substrate. Thus, the origin of this hardground can be interpreted as a consequence of seafloor dewatering, rather than cementation, taking into account the lack of carbonate in the rock. This boring assemblage can be identified as an "omission suite" of Bromley (1975) due to its bed-junction kind of preservation. From an ecological point of view, this assemblage can be assigned to the IG-V ichnogenus for hard substrates (Bromley and Asgaard, 1993), which is composed of medium to deep tier domiciles of suspension-feeding bivalves.

Both the analysis of this trace fossil assemblage and its kind of preservation lead to an understanding of the environmental conditions and processes leading to its formation. Such processes are depicted in figure 5 and described herein as follows. First, following the deposition of the sediments recorded by the trace fossil bearing strata, the substrate suffered some degree of consolidation by dewatering, before the establishment of the boring bivalve community on this surface. The lithification event may have taken place underwater (Garrison *et al.*, 1969) or under sporadic events of subaerial exposure, due to the paleobathymetric condition of these deposits (interpreted as very shallow), although no evidence of exhumation was found. Then a considerable lapse of time - at least in ecological scale - had to occur without either significant erosion or copious sedimentation to allow the trace makers to establish themselves and reach their adult size. It is noteworthy that endolithic communities, composed mainly of suspension-feeding organisms, are sensitive to silting and small quantities of sediment can kill them (Bromley, 1994). Subsequently, at least one erosive event took place locally, which removed approximately the uppermost 6-7 cm of the bioeroded surface; this was estimated by taking into account the maximum length of complete specimens in nonerod-

Figure 5. Scheme of the processes involved in the formation of the hardground, the omission surface and the bivalve boring assemblage./ *Representación esquemática de los procesos involucrados en la formación del hardground, la superficie de omisión y la asociación de perforaciones de bivalvos.*

ed areas (see the difference between horizontal arrows in figure 5). This erosive episode can be recognized from abundant truncated borings. This event is not thought to be contemporaneous with the colonization of the bivalves as the borings infill - coarse-grained sand - can be easily distinguished from the

matrix bored by the molluscs. After or even during the erosive event, the borings were filled by a coarse-grained beach sand.

The dense *Gastrochaenolites* association found on this surface can be compared with other examples interpreted as indicative of extremely shallow water

conditions, with high energy and very close to the shoreline (Lewy, 1985; Bromley, 1994; Mikuláš and Pek, 1995; Domènech *et al.*, 2001).

An overall shallowing upward trend can be recognized for the Camacho Formation on the basis of several lines of evidence. From the base upwards, and along a large part of the section, subtidal trace fossil assemblages (mainly *Ophiomorpha* and *Thalassinoides*) are found, as well as abundant distal tempestites. At the top, oyster banks typical of the intertidal zone are recorded. In addition, at some localities the Camacho Formation is capped by a sandstone deposited in coastal dune fields (Martínez, 1994). The *Gastrochaenolites* association analyzed here is consistent with this general shallowing trend seen in the Camacho Formation. The fact that the bored surface is not a local phenomenon, but can be traced horizontally along several hundred meters - at Cañada La Negra -, and at least 11,5 km - taking into account the correlation proposed for three localities studied - (figure 1), strengthens the conclusions reached here.

From a paleogeographic point of view, the ichnological assemblage analyzed is important, since it records the development of an ancient rocky shore or paleorupicost (Johnson, 1988) composed of consolidated mudstones - that can be compared with other examples, *e.g.* Domènech *et al.*, 2001, for the Miocene of Spain - during the latest regressive phase of the "Entrerriense" Sea that deposited the Camacho Formation. This rocky shore landscape probably had an extension of at least 11,5 km, as documented by the three outcrops examined in this work.

This study highlights the importance of trace fossils and shows that more attention must be focused on the ichnology of this unit in order to recognize the presence of hardgrounds in strata formerly thought to encompass exclusively soft substrates, and to understand the processes that formed them. It is also noticeable the value of trace fossils in the Camacho Formation as indicators of a certain kind of ancient landscape that was unknown for this unit.

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