

Bioerosion on marine molluscs of MIS 5e in Faro Segunda Barranca, South of Buenos Aires Province, Argentina

Melisa P. CHARÓ¹, José L. CAVALLOTTO², Guillermo ACENÓLAZA¹ y Gisela D. CHARÓ³

Resumen: *BIOEROSIÓN EN MOLUSCOS MARINOS DE MIS 5E EN FARO SEGUNDA BARRANCA, SUR DE LA PROVINCIA DE BUENOS AIRES, ARGENTINA.* Faro Segunda Barranca se encuentra en el sur de la Provincia de Buenos Aires (40°46'S/62°16'O), donde se identifican depósitos marinos del Pleistoceno Superior (108.000-102.000 años A. P., correlacionados con MIS 5e) y playas actuales. Se analizaron en total 158 valvas de moluscos y se identificaron nueve icnogéneros y cuatro icnoespecies en dos sitios. En los depósitos del Pleistoceno Superior (Sitio 1) se detectaron siete icnogéneros, mientras que en la playa actual (Sitio 2) se registraron nueve icnoespecies y otros cuatro morfotipos de microbioerosión. En ambos sitios se identificaron *Iramena*, *Maeandropolydora*, *Entobia*, *Caulostrepsis* y *Pinaceocladichnus* (Domichnia), *Finichnia* (Fixichnia) y *Oichnus* (Praedicnia); *Trypanites* y *Gastrochaenolites* (Domichnia) están presentes solo en el Sitio 2. En el Sitio 1 los icnogéneros más abundantes son *Iramena* y *Pinaceocladichnus*, los cuales sugieren un ambiente de baja sedimentación, corrientes de aguas moderadas y disponibilidad de partículas de suspensión. Mientras que en la playa actual domina *Maeandropolydora* que indica un ambiente sublitoral y sedimentos arenosos y la presencia de *Trypanites* y *Gastrochaenolites* indica sustratos duros y ambientes litorales. Los icnogéneros identificados sugieren cambios en los factores ambientales entre el Pleistoceno Superior y la playa actual en el área de estudio.

Abstract: Faro Segunda Barranca is located in the south of Buenos Aires Province (40°46'S/62°16'W), where Late Pleistocene marine deposits (108 – 102 Ka correlated with MIS 5e) have been identified, as well as the modern beach. In a sample of 158 mollusc shells, nine ichnogenera and four ichnospecies were found in two sites. Seven ichnogenera were found in the Late Pleistocene (Site 1), while nine ichnogenera and four microbioerosion morphotypes were found in the modern beach (Site 2). Both sites yielded *Iramena*, *Maeandropolydora*, *Entobia*, *Caulostrepsis* and *Pinaceocladichnus* (Domichnia), *Finichnia* (Fixichnia) and *Oichnus* (Praedicnia); *Trypanites* and *Gastrochaenolites* (Domichnia) were present only in Site 2. The most abundant Late Pleistocene ichnogenera are *Iramena* and *Pinaceocladichnus*, suggesting an environment of low sedimentation, with moderate water current and availability of suspension particles. Whereas in the modern beach, *Maeandropolydora* is dominant, suggesting a sublitoral environment and sandy bottom; the record of *Trypanites* and *Gastrochaenolites* indicates hard substrate and shallow environment. The identified ichnogenera suggest changes in the environmental features between the MIS 5e and the modern beach at Faro Segunda Barranca.

Palabras clave: Bioerosión. Moluscos marinos. Pleistoceno. Argentina.

Key words: Bioerosion. Marine molluscs. Pleistocene. Argentina.

¹ Instituto Superior de Correlación Geológica (INSUGEO /CONICET-UNT) Miguel Lillo 205, 4000 Tucumán, Argentina, e-mail: charomelisa@gmail.com, e-mail: gfacenolaza@gmail.com

² Servicio de Hidrografía Naval, Av. Montes de Oca 2124, C1270ABW Buenos Aires, Argentina, e-mail: jlcavallotto@gmail.com.

³ Laboratorio de Fluidodinámica, Departamento de Ingeniería Mecánica, Facultad de Ingeniería, Universidad de Buenos Aires, Paseo Colón 850, C1063ACV, Ciudad Autónoma de Buenos Aires, Argentina, e-mail: charogiselad@gmail.com

Introduction

Trace fossils are a key source of information about ecological interactions and animal behavior in the past (Bengtson and Rasmussen, 2009).

The subjects of paleoichnology are trace fossils (also called ichnofossils), which are fossilized structures produced in substrates ranging from unlithified sediment to sedimentary rock or organic matter (including shell, bone, wood and peat) by the activity of organisms (Knaust, 2017).

Most groups of trace fossils are generally considered of little use as stratigraphic indicators, because they provide information on the behavior of the trace-maker rather than of its biological identity, and because most ichnotaxa are stratigraphically long-ranging (Bromley, 2004).

Trace fossils include bioturbation structures (e.g., burrows, trails, footprints), and evidence of biodeposition (e.g., coprolites, fecal pellets), biostratification (e.g., microbial mats) and bioerosion. There is a “grey zone” of dubious structures, however, that some workers include as trace fossils and others do not (e.g. traces: coprolites, spider webs, all kinds of nests, etc. and no traces: eggs, pearls, etc.) (Bertling *et al.*, 2006).

The term ‘bioerosion’ (Neumann, 1966) itself has been reinterpreted, expanded, and/or redefined by multiple authors over the last half century (Davidson *et al.*, 2018). Bioerosion is a mechanism of taphonomic alteration caused by mechanical and/or chemical biological activity of a large number of organisms that may bore, penetrate, gnaw, graze or etch surfaces on persistent firm/hard substrata including rock, shell, bone, dead wood, peaty or compacted mud banks and cliff faces, and human-made substrata (metal, concrete, plastics, etc.) (Taylor and Wilson, 2003; Davidson *et al.*, 2018).

The bioerosion process is particularly common in the marine environment and occurs similarly on rocky bottoms, such as carbonate structures of biotic origin (eg. corals, mollusk

shells, brachiopods), and skeletons of marine vertebrates (eg, whale bones). Among the organisms that produce bioerosion structures are the microborers that belong to one of the two major groups of energy generation: photoautotrophs (bacteria, cyanobacteria and algae) and heterotrophs (foraminifera, sponges, bryozoans); macroborers (polychaetes, sponges, bivalves) and browsers (echinoderms, gastropods and crustaceans) (Molinu, 2015).

Hard substrate trace fossils are classically divided into macroborings versus microborings, for the study of which a hand lens or a scanning electron microscope is used, respectively (Bromley, 2004). Taylor *et al.* (1999) proposed an intermediate category named “mesoboring” for which the optical microscope is used.

Macroborings are defined as any boring that can be detected with the naked eye, about 1 mm diameter (Wilson, 2007). Marine macroborings are very common and most valuable for paleoecological analyses. Most described macroborings are found in marine deposits even if some of the substrate, such as wood, bones, and even coprolites (Tapanila *et al.*, 2004) originated on dry land. They are thus important contributors to what we know about the ecological driving forces of evolution among marine organisms (Wilson, 2007). Whereas microbioerosion features are less than one millimeter in size with tunnel diameters commonly less than a hundred microns (Wisshak, 2012). Microborers are most common and diversified in marine environments, but are also known on fresh water and air-exposed rocks (Golubic and Schneider, 2003). Microborings are abundant in the fossil record related to calcareous substrates such as coral skeletons, mollusc and brachiopod shells, limestones and ooids (Glaub and Vogel, 2004). The well fossilized microborings of euendoliths are used as proxies in paleoecological and paleobathymetrical studies (Tribollet *et al.*, 2010). This bioerosion is a useful tool in paleoenvironmental interpretation because of its abundance and trace morphology; as well, regarding the evolutionary rates, microboring groups are very conservative through the geolo-

gic time. Diversity, distribution and abundance of microborings depend on the substrate and environmental conditions (Vogel *et al.*, 2000).

“Shells” as understood here include any mineralized invertebrate (eg. echinoderm, some bryozoans and cephalopods). External shells can be encrusted or bored while the host animal is still alive (Taylor and Wilson, 2003). Shell borings are useful for paleoecologic and taphonomic reconstructions (Warne, 1975).

Bored shells are very common in the Cenozoic, being the main boring agent clionid sponges, bivalves, polychaetes, phoronids, ctenostome cryozoans and acrothoracican barnacles (Taylor and Wilson, 2003). Bioerosion traces have been studied in Miocene deposits worldwide (eg. Árpád, 2001, 2010; Farinati and Zavala, 2002; Verde, 2002; El-Hedeny, 2007; Santos and Mayoral, 2008; Santos *et al.*, 2010; Domènech *et al.*, 2014; Pineda-Salgado *et al.*, 2015), Pliocene (eg. Mayoral, 1987, 1988ab, 1991; Gibert and Martinell, 1992; Martinell and Domènech, 1986, 1995; Gibert and Martinell, 1996; Gibert *et al.*, 2007; Molinu *et al.*, 2015), as well as in Pleistocene ones (eg. Bromley and D’Alessandro, 1983, Bromley, 1999; Ruggiero and Annunziata, 2002; Lorenzo and Verde, 2004; Wisshak and Neumann, 2018).

Bioerosion traces of the Argentine Quaternary have been studied mainly in Holocene ridges and modern beaches on marine molluscs (bivalves, gastropods and barnacles) and lithics (e.g. Farinati and Aliotta, 1995; Farinati and Zavala, 1995; Pastorino and Ivanov, 1996; Farinati *et al.*, 2006; Arregui *et al.*, 2009; Cardenas and Gordillo, 2009; Aguirre *et al.*, 2011; Charó *et al.*, 2012; Gordillo and Archubi, 2012; Gordillo, 2013; Spagnuolo *et al.*, 2013; Richiano *et al.*, 2014; 2015; Charó *et al.*, 2015c,d, 2017a, b). However, studies of Late Pleistocene deposits are scarce (e.g. Richiano *et al.*, 2015; Charó *et al.*, 2015a,b).

The main goal of this paper is to describe the bioerosion traces on bivalve and gastropod shells found in Late Pleistocene deposits of Faro Segunda Barranca, south of the Buenos

Aires Province, as well as to interpret the environmental features and their paleoecological significance.

Geological setting

During the transgressions of the Quaternary, large extensions of the littoral of the Province of Buenos Aires and along the Patagonian coast were affected by processes of accumulation and erosion generated by the different oscillations of the sea level (Isla *et al.*, 2000). These marine deposits have been intensely studied from a geomorphologic, stratigraphic and geochronologic stand points (eg. Angulo *et al.*, 1981; Trebino, 1987; Rutter *et al.*, 1989, 1990; Weiler, 1988, 1993, 2000; Schnack *et al.*, 2005; Fucks *et al.*, 2012a, b), as well as their paleontologic content (Pastorino, 2000; Charó *et al.*, 2013a, b, 2014; Charó, 2014).

The Pleistocene marine deposits along the Buenos Aires coastline are restricted and discontinuous, interbedded or lying over Pampean sediments, and represented by different facies (Schnack *et al.*, 2005). The highest levels reached by these deposits are between 6–8 m, mostly distributed on the northeast and south of Buenos Aires (eg. Codignotto and Aguirre, 1993; Isla *et al.*, 2000; Weiler, 2000; Fucks *et al.*, 2012; Charó, 2014), and are assigned to the Puente de Pascua Formation (Fidalgo *et al.*, 1973; Fucks *et al.*, 2006, 2010) correlated to MIS 5e (Table 1). In some localities this transgression is represented as a highly cemented coquina (Schnack *et al.*, 2005).

Study area

Faro Segunda Barranca, is near 20 km south of Bahía San Blas (40°33'S/62°14'W) between Segunda Barranca and Punta Rasa, south of Buenos Aires Province (Figure 1).

Site 1. Late Pleistocene marine deposits are represented by littoral ridges 8-10 m high along the south of Buenos Aires Province. They are composed of clasts that correspond to a trans-

Buenos Aires Province	Localities	Coordinates (Lat-long)	Ages (14C, ESR)	Altitude (m.a.m.s.l.)	authors
North	northeast area	35°55'S/57°43'W	>40ka corresponded with MIS 5e=Puerto de Pascua Formation (Fucks et al 2010)	8	Fucks <i>et al.</i> , 2005
	Claromecó	38°51'S/60°05'W	93.5 ± 3.5ka (U/Th)		Isla <i>et al.</i> , 2010
North	Río Colorado área	39°47'/39°52' S	Corresponded with MIS 5e	6 - 10	Charó <i>et al.</i> , 2015
	Bahía Anegada área	39°49'/40°26' S	43Ka, 38.8 Ka and 31 Ka	8-10	Gonzalez y Weiler, 1983 Weiler, 1993,2000
	Bahía San Blas área	40°26' S/62°25' W	38.8 Ka	7	Weiler, 2000, Charó,2014
	Balneario Los Pocitos	40°26' S/62°25' W	28.4 y 29.1 Ka		
	West of Isla Jabali	40°35' S/62°17' W	30.7 Ka		
	Salina El Inglés	40°40' S/62°30' W	72.7 - 94.5 Ka	2	Rutter <i>et al.</i> , 1990

Table 1. Ages of marine deposits of Late Pleistocene (MIS5e) in Buenos Aires Province. / **Tabla 1.** Edades de depósitos marinos del Pleistoceno Tardío (MIS 5e).

gressive event of MIS 5e. One of these deposits was dated in 108-102 Ka at about 10 m above sea level (Rutter *et al.*, 1989, 1990) (Site 1), and is divided in two layers. Only the upper layer was studied, which is composed of clast-supported gravel, with sand and sandy conglomerate level on the surface. The overall color is grey, with

clearly defined parallel to low-angle cross bedding, showing a slight southern inclination and partial clustering in some strata (Figure 2 A and B).

Site 2. Modern beaches of this area are wide and sandy with clasts and remains of marine mollusc shells (Figure 2 C).

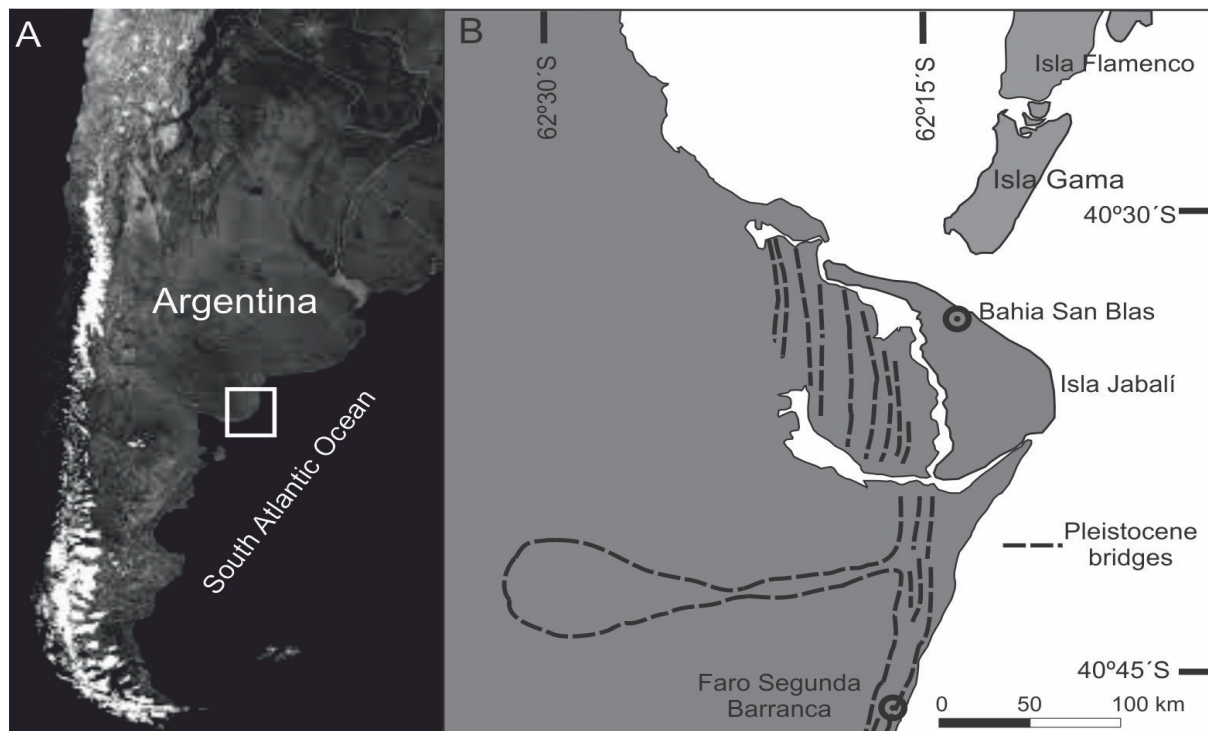


Figure 1. A) Study area. **B)** Description of Pleistocene deposits in the south of Buenos Aires Province (Charó *et al.*, 2013). / **Figura 1. A)** Área de estudio. **B)** Descripción de los depósitos marinos pleistocenos del sur de la Provincia de Buenos Aires (Charó *et al.*, 2013).

Materials and Methods

Two sites were studied. Site 1 was studied on samples 1dm³ volume. Site 2 was studied on three samples collected on a 1m x 1m quadrant on transects perpendicular to the coast line.

Once the valves were separated from the sediment with sieves, the proportion of valves with bioerosion was quantified (Charó, 2014).

The study of trace fossils was made following the different ethologic classes of Seilacher (1953) modified by Bromley (1981, 1994, 1996) and specific papers on ichnotaxonomy (eg. Mayoral, 1988a, b; Blissett and Pickerill, 2007; Taylor *et al.*, 2013). Bioerosion traces were observed by naked eye and images were digitalized through a scanner (HP Scanjet 300), following the technique used by Bromley and Richter (1999). Externally, microborings were studied using incident light on the surface, and the observation of microscopic marks was made through a stereoscope microscope model SMZ 800 with a program NIS - Elements (INSUGEO-UNT, Horco Molle, Tucumán). While the internal analysis will be studied in future investigations. Images were processed with Corel – Draw 13 and Adobe Photoshop.

All graphics were created through the package PGFPlots (Feuersänger, 2010) of LaTeX program and MATLAB 16. For the analysis of the bioerosion marks on valves, bivalves and gastropods were divided into different sections. The surface of bivalves was divided into four sections (umbonal, central, muscular and posterior areas), and gastropods were divided into two sections: whorls and last whorl, except for the genera *Crepidula* and *Bostrycapulus*.

Results

Among the collected material (158 valves) a total of 7 species of bivalves and 11 gastropods were recognized, 11 of them are bioeroded (7 gastropods and 4 bivalves).

Bivalves and gastropods

In MIS 5e deposits, eight species were found (three gastropods and five bivalves) fossil remains include the gastropods *Tegula patagonica*, *Bostrycapulus odites*, *Crepidula* sp., and the bivalves *Pitar rostratus*, *Mytilus edulis*, *Brachidontes rodriguezii*, *Aequipecten tehuelchus*, *Ostreola equestris* and *Ostrea puelchana*. Whereas in modern beaches, 15 species were found (10 gastropods and

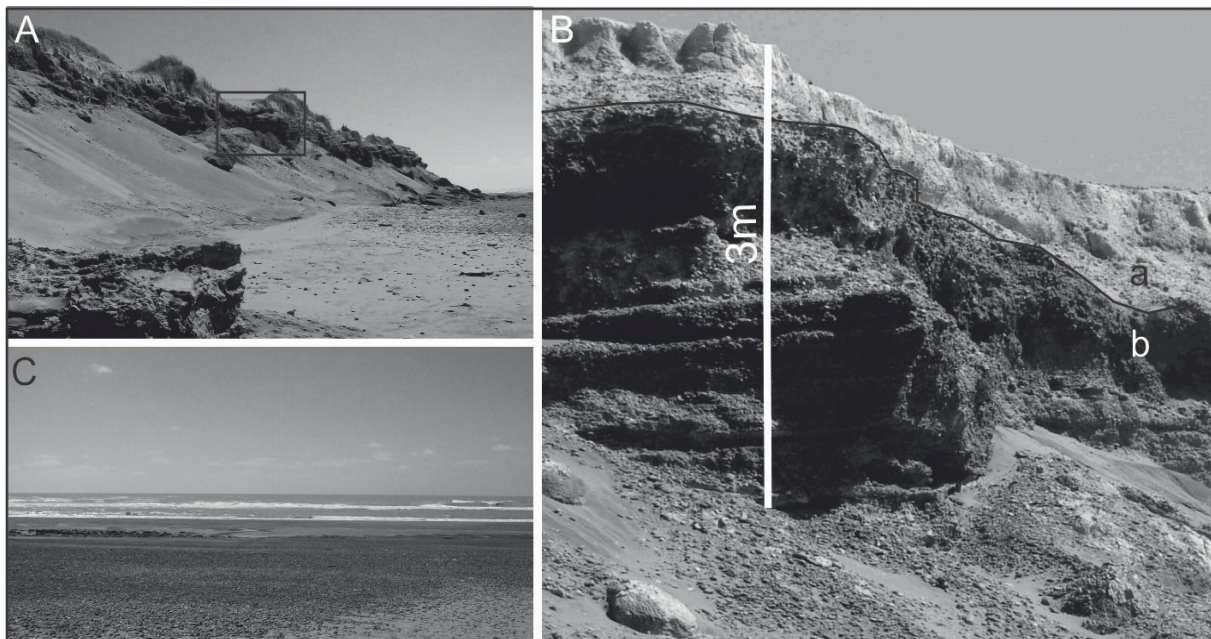


Figure 2. A and B) Late Pleistocene marine deposit (MIS 5e) a) sandy conglomerate level and b) clast-supported gravel with sand. C) Modern beach at FSB. / **Figura 2. A y B)** Depósito marino del Pleistoceno Tardío (MIS 5e), a) nivel de conglomerado arenoso y b) grava clasto-sostén con arena. C) Playa actual en FSB.

five bivalves), being the most abundant the gastropods *O. equestris*, *T. patagonicus*, *B. odites* and *T. argentina* (Table 2).

Paleoecology

The benthic community of molluscs found in MIS 5e deposits is characterized by the dominance of euryhaline, epifaunal, rocky substrate species, mostly filtering and herbivores. Whereas the living communities are mostly euryhaline, with lesser proportion of polyhaline-euhaline and increasing species of rocky substrate, being mostly carnivores with a low proportion of filtering species (Table 3, Figure 3).

Marine bioerosion

Bioerosion traces are represented by nine ichnogenera (*Iramena*, *Maeandropolydora*, *Entobia*, *Caulostrepsis*, *Pinaceocladichnus*, *Trypanites* and *Gastrochaenolites* (Domichnia), *Finichnia* (Fixichnia) and *Oichnus* (Praedicinia) (Figure 4), and four ichnospecies (*O. simplex*, *M. sulcans*, *P. onubensis* and *C. taeniola*) (Figure 5), as well as four micro-bioerosion morphotypes (Figure 6).

Macrobioerosion

Finichnia (Taylor *et al.*, 2013) are groups of elliptic or pear-shaped pits wider than deep, ranging from the Cretaceous to Recent (Mangano and Buatois, 2016). This ichnogenus is dominant in Site 2. It covers the umbonal and central areas of bivalves, and the whorls area of gastropods. It was found on *T. patagonica* and *B. odites* of both sites (Figure 5A, B).

Caulostrepsis Clarke, 1908 is a boring of a single entrance, U-shaped, on the surface of the valve. The branches may be connected through a lamella, or merging the margins producing an oval or flat “pocket” (Verde, 2002). It has been attributed to the activity of spionid polychaetes and is known since the Devonian (Taylor and Wilson, 2003). This ichnogenus was found in the umbonal area of *P. rostratus* in Site 1 and *O. puelchana* in Site 2. The ichnospecies *Caulostrepsis taeniola* Clarke, 1908 is a subdivided U-shaped gallery, with the internal margins connected by a sheath; it was identified on the umbonal area of *O. puelchana* of Site 2 (Figure 5C, E).

Maeandropolydora Voigt, 1965 is abundant in Site 2 and covers the umbonal, muscular

Acronym	Bivalvia	Site 1	Site 2
Br	<i>Brachidontes (B.) rodriguezi</i> (d'Orbigny, 1846)		X
Me	<i>Mytilus edulis platensis</i> d'Orbigny, 1846	X	
Oe	<i>Ostreola equestris</i> (Say, 1834)	X	X
Op	<i>Ostrea puelchana</i> d'Orbigny 1841	X	
Cg	<i>Crassostrea gigas</i> (Thunberg, 1793)		X
At	<i>Aequipecten tehuelchus</i> (d'Orbigny, 1842)	X	X
Pr	<i>Pitar (P.) rostratus</i> (Philippi, 1844)	X	X
Gastropods			
Dp	<i>Diodora (D.) patagonica</i> (d'Orbigny, 1841)		X
Tep	<i>Tegula (A.) patagonica</i> (d'Orbigny, 1835)	X	X
Bo	<i>Bostrycapulus odites</i> (Collin, 2005)	X	X
Ca	<i>Crepidula argentina</i> Simone, Pastorino & Penchaszadeh, 2000	X	
Ha	<i>Heleobia australis</i> (d'Orbigny, 1835)		X
Tp	<i>Trophon patagonicus</i> (d'Orbigny, 1839)		X
Zd	<i>Zidona dufresnei</i> (Donovan, 1823)		X
Bm	<i>Buccinanops monilifer</i> (Kiener, 1834)		X

Table 2. Bivalvia and gastropods found in Faro Segunda Barranca, south of Buenos Aires Province/ **Tabla 2.** Bivalvos y gasterópodos encontrados en Faro Segunda Barranca, sur de Buenos Aires.

Bivalvia	Salinity	Life habit	Depth	Substrate	Trophic type	Distribution area
<i>Brachidontes (B.) rodriguezii</i> (d'Orbigny, 1846)	P-E	Ep	0 - 25	R	F	34°S - 42°S
<i>Mytilus edulis platensis</i> d'Orbigny, 1846	P-E	Ep	0 - 50	R	F	68°N - 55.5°S
<i>Ostreola equestris</i> (Say, 1834)	P-E	Ce	0 - 80	R	C	37°N - 42°S
<i>Ostrea puelchana</i> d'Orbigny 1841	P-E	Ce	0 - 70	R	C	22°S - 42°S
<i>Crassostrea gigas</i> (Thunberg, 1793)	E	Ce	0 - 40	R	F	Cosmopolitan
<i>Aequipecten tehuelchus</i> (d'Orbigny, 1842)	E	Ep	10 - 120	M	F	21°S - 53°S
<i>Pitar (P.) rostratus</i> (Philippi, 1844)	E	I	10 - 100	S	F	22°S - 38.7°S
Gastropods						
<i>Diodora (D.) patagonica</i> (d'Orbigny, 1841)	E	Ep	0 - 15	R	He	11°N - 45°S
<i>Tegula (A.) patagonica</i> (d'Orbigny, 1835)	E	Ep	0 - 57	R	He	23°S - 54°S
<i>Bostrycapulus odites</i> (Collin, 2005)	E	Ep	0 - 46	R	F	25°S - 45.8°S
<i>Crepidula argentina</i> Simone, Pastorino & Penchaszadeh, 2000	E	Ep	30 - 50	R	F	38°S - 41.03°S
<i>Heleobia australis</i> (d'Orbigny, 1835)	O, P, M	Ep	0 - 60	M	He	24°S - 41°S
<i>Trophon patagonicus</i> (d'Orbigny, 1839)	E	Ep	0 - 50	R	C	32°S-40°S
<i>Zidona dufresnei</i> (Donovan, 1823)	E	Ep	10 - 90	S	C	23°S - 42°S
<i>Buccinanops monilifer</i> (Kiener, 1834)	E	Ep	0 - 50	S	C	35°N - 42°S
<i>Buccinanops globulosus</i> (Kiener, 1834)	E	Ep	0 - 6	S	C	35°S - 46°S
<i>Olivancillaria carcellesi</i> Klappenbach, 1965	E	Ep	0 - 22	S	C	23°S - 42.5°S
<i>Parvanachis isabellei</i> (d'Orbigny, 1839)	E	Ec	10 - 65	S	C	30°S - 54°S

Table 3. Paleoecology and distribution of bivalvia and gastropods. Ep= epifaunal; I=infaunal; Ce= cemented; Ec=ectoparasite; R=hard;S=soft; M=mixed; C=carnivorous; He=herbivore; F= suspension feeder; O=Oligohaline (3-8‰); M=mesohaline (8-18‰); P=polyhaline (18-30‰); E=euhaline (30-35 ‰)./ **Tabla 3.** Paleoecología y distribución de bivalvos y gasterópodos. E= epifaunal; I=infaunal; Ce=cementado; Ec=ectoparásito; R=rocoso; S=arenoso; C=carnívoro; He=herbívoro; F=filtradores suspensívoros; O=oligohalino; M=mesohalino; P=polihalino; E=euhalino..

and central areas of bivalves. This ichnogenus is dominant in *Crepidula* sp. and *O. equestris* of Site 1 and *B. odites*, *O. equestris* and *O. puelchana* of Site 2. The ichnoespecies *Maeandropolydora sulcans* (Bromley and D'Alessandro, 1983) was identified in Site 2. It is represented by cylindrical borings, uniform in diameter, with irregular sinuous, plano-spiral and/or helicoidal shape (Taylor and Wilson, 2003). It is known since the Cretaceous (Taylor and Wilson, 2003), occurring in both shallow- and deep-marine settings (Mangano and Buatois, 2016) (Figure 5D).

Iramena Boekschoten, 1970 is a boring

system consisting in long primary tunnels little bifurcated, in irregular pattern with primary apertures, rounded to kidney-shaped, opening into a main cavity (Mayoral, 1988a). This ichnogenus covers the entire external surface of the valve of bivalves and the whorls and last whorl areas of gastropods. It is abundant in *B. odites*, *Crepidula* sp., *P. rostratus*, *B. rodriguezii* and *T. patagonica* of Site 1, and in *B. odites*, *D. moniliferum*, *B. globulosus* and *Crepidula* sp. of Site 2 (Figure 5F).

Oichnus Bromley, 1981 are circular, subcircular or oval borings perpendicular to the subs-

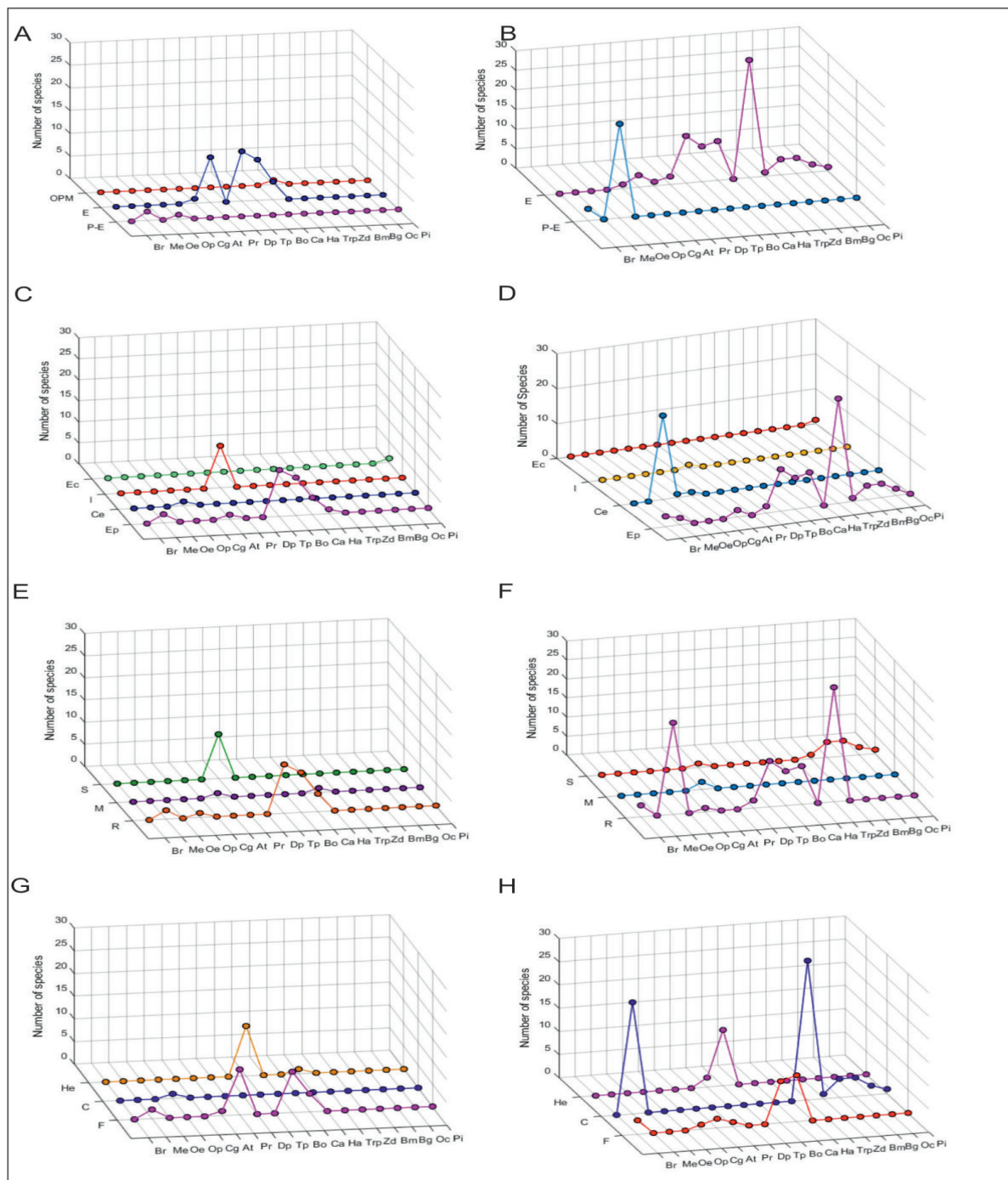


Figure 3. Paleoecological requirements of bivalves and gastropods in Late Pleistocene **A)** Salinity; **C)** Life habit; **E)** Substrates; **G)** Trophic type and modern beaches **B)** Salinity; **D)** Life habit; **F)** Substrates and **H)** Trophic type. / **Figura 3.** Requerimientos paleoecológicos de bivalvos y gasterópodos en el Pleistoceno Tardío **A)** Salinidad; **C)** Modo de vida; **E)** Sustratos; **G)** Tipos tróficos, y playas actuales: **B)** Salinidad **D)** Modo de vida **F)** Sustratos y **H)** Tipos tróficos.

trate that can or cannot perforate the surface. It is mostly generated during predation by gastropods and octopods (Wisshak *et al.*, 2015). This ichnogenus is known from the Ediacaran to Recent (Taylor and Wilson, 2003) occurring in both shallow- and deep-marine settings (Man-

gano and Buatois, 2016) (Figure 5G).

The ichnospecies *Oichnus simplex* Bromley, 1981 is characterized by a cylindrical or sub-cylindrical aperture, perpendicular to the surface of the substrate. It was identified in both sites, on bivalves mostly on the umbonal, central

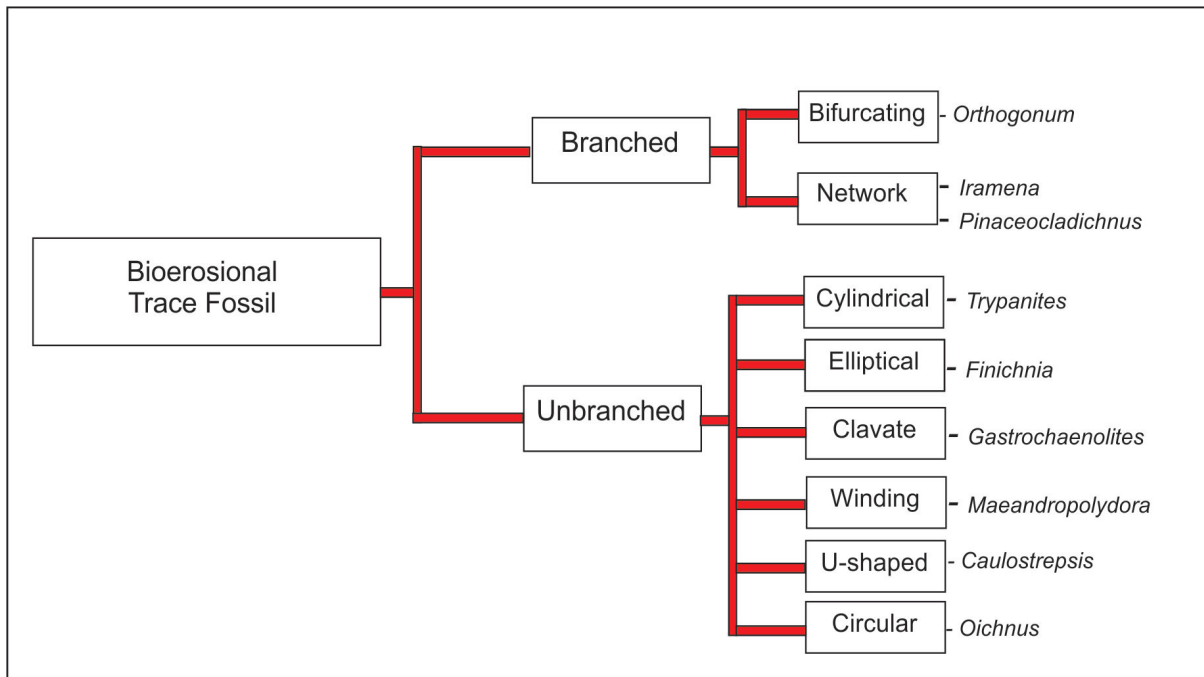


Figure 4. Morphological classification of bioerosional trace fossils (Knaust and Bromley, 2012). / **Figura 4.** Clasificación morfológica de trazas fósiles de bioerosión (Knaust and Bromley, 2012).

and muscular areas, and on gastropods, on the last whorl area. It was found on *C. argentina* of Site 1 and on *B. globulosus*, *T. patagonica*, *O. carcellési*, *O. equestris* and *O. puelchana* of Site 2.

Trypanites Mägdefrau, 1932 and *Gastrochaenolites* Kelly and Bromley, 1984 were found only in Site 2. *Trypanites* are simple borings, elongated or cylindrical, generally circular in cross-section. This ichnogenus covers the umbonal and central areas of the internal valve of *O. equestris* of Site 2 (Figure 5H). *Gastrochaenolites* is a club-shaped boring with the apertural region narrower than the main chamber that may be circular, oval or dumb-bell. In this case, the apertural region is circular with the widest part near the base and perpendicular to the substrate surface. This ichnogenus was found in the umbonal, muscular and central areas of the external valve of *O. equestris* of Site 2 (Figure 5J).

Pinaceocladichnus Mayoral, 1988b is a boring pattern formed by a regular network of fine tunnels, slightly curved and laterally opposite. The ichnospecies *Pinaceocladichnus onubensis* (Mayoral, 1988b) is a pattern of straight to slightly arched main tunnels with verticillate and also random bifurcations. It has elongate cavi-

ties with apertures near the bifurcation of the tunnels. This bioerosion mark was identified in both sites covering the umbonal, central and posterior areas of bivalves. It was found on *B. odites* and *P. rostratus* of Site 1 and on *O. equestris* of Site 2 (Figure 5I).

Entobia Bronn, 1838 are cylindrical galleries parallel to the surface, composed by interconnected chambers, with network-shaped borings on the surface of the valve (Árpád, 2010). This ichnogenus covers mainly the umbonal area of bivalves and the whorls area of gastropods. It was recorded on *O. equestris* and *P. rostratus* of Site 1 and *T. patagonica* of Site 2 (Figure 5K).

Microbioerosion

Microborings made by tallophytas were found in low frequency in Site 2. Four morphotypes were identified. Morphotype 1 is a series of cylindrical conducts very uniform in diameter with a bifurcated pattern in almost orthogonal angles that can bifurcate again in the same way or more frequently as Y-shape. It was found in the inner valve of *O. equestris* (Figure 6A). It is recognized by Mayoral (1988a) as morphotype C.

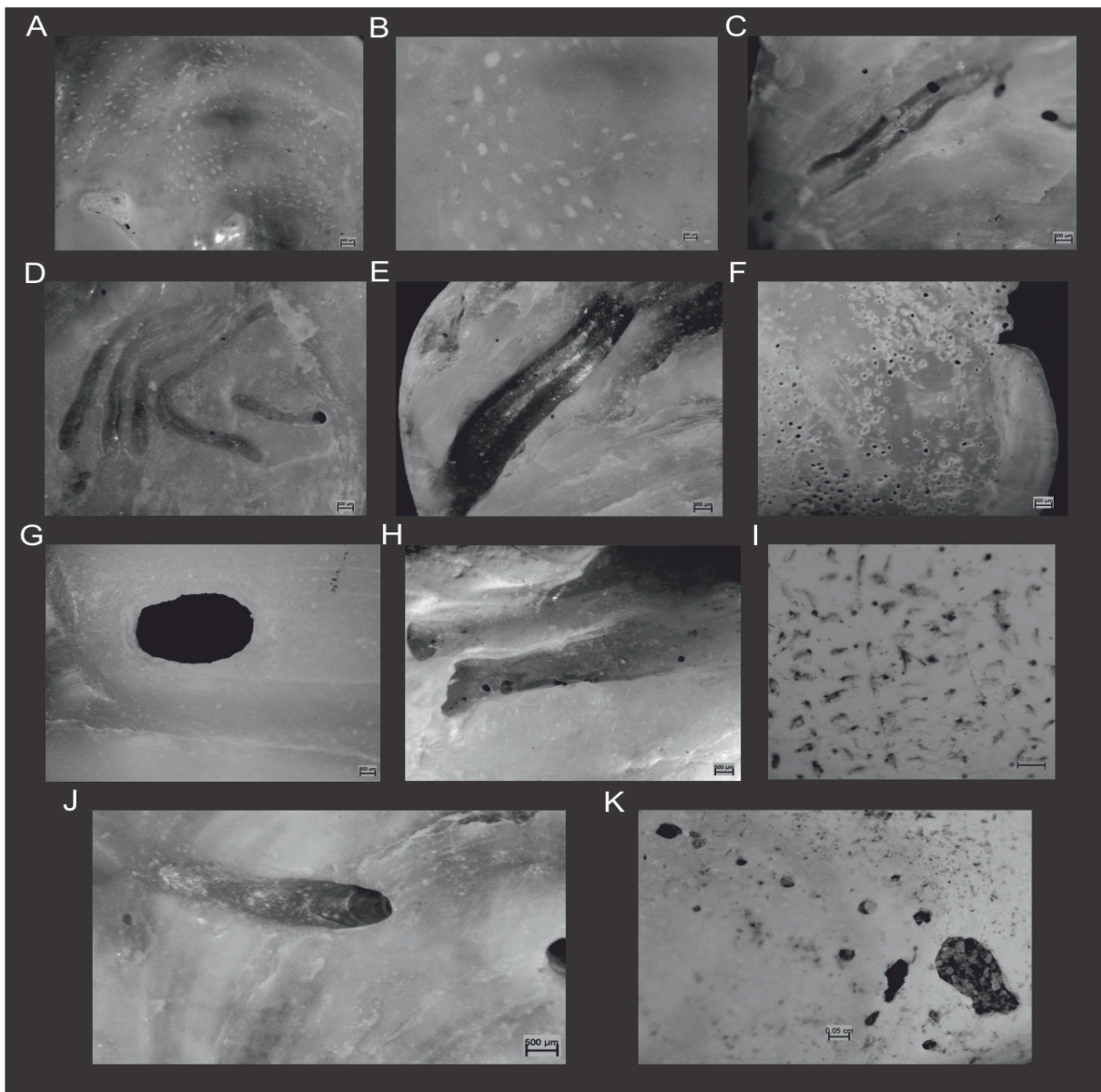


Figure 5. Ichnogenera of FSB sites. **A)** *Finichnus* on *B. odites* (PIL, Site 2, modern); **B)** details of **A**; **C)** *Caulostrepsis taeniola* on *O. equestris* (PIL, Site 2, modern); **D)** *Maeandropolydora sulcans* on *O. equestris* (PIL, Site 2, modern); **E)** *Caulostrepsis taeniola* on *O. puelchana* (PIL, Site 2, modern); **F)** *Iramena* on *B. odites* (PIL, Site 2, modern); **G)** *Oichnus* on *O. carcellesi* (PIL, Site 2, modern); **H)** *Trypanites* on *Ostrea* sp. (PIL, Site 2, modern); **I)** *Pinacocladichnus* on *P. rostratus* (PIL, Site 2, modern); **J)** *Gastrochaenolites* on *O. equestris* (PIL, Site 2, modern) and **K)** *Entobia* on *P. rostratus* (PIL, Site 1, Pleistocene). / **Figura 5.** Ichnogéneros en los sitios de FSB. **A)** *Finichnus* en *B. odites* (PIL, Sitio 2, actual); **B)** detalles de **A**; **C)** *Caulostrepsis taeniola* en *O. equestris* (PIL, Sitio 2, actual); **D)** *Maeandropolydora sulcans* en *O. equestris* (PIL, Sitio 2, actual); **E)** *Caulostrepsis taeniola* en *O. puelchana* (PIL, Sitio 2, actual); **F)** *Iramena* en *B. odites* (PIL, Sitio 2, actual); **G)** *Oichnus* en *O. carcellesi* (PIL, Sitio 2, actual); **H)** *Trypanites* en *Ostrea* sp. (PIL, Sitio 2, actual); **I)** *Pinacocladichnus* en *P. rostratus* (PIL, Sitio 2, actual); **J)** *Gastrochaenolites* en *O. equestris* (PIL, Sitio 2, actual) y **K)** *Entobia* en *P. rostratus* (PIL, Sitio 1, Pleistoceno).

Morphotype 2 consists of a series of sub-circular subcavities which are part of the main filament; they bifurcate in secondary filaments in almost orthogonal angles that in turn bifurcate in shorter filaments at lower angles (Mayoral, 1988a) (Figura 6B). It was found in the inner valve of *O. equestris*. It is recognized by Mayoral

(1988a) as morphotype B1. This is the first record in Argentine modern beaches.

Morphotype 3 is composed by four curved furrows similar in length and opposite; each furrow is almost 1500- 2000 μm long (Figura 6C). This microbioerosion is abundant on epifaunal elements, and was found on *O. equestris* in Site 2. It is recogni-

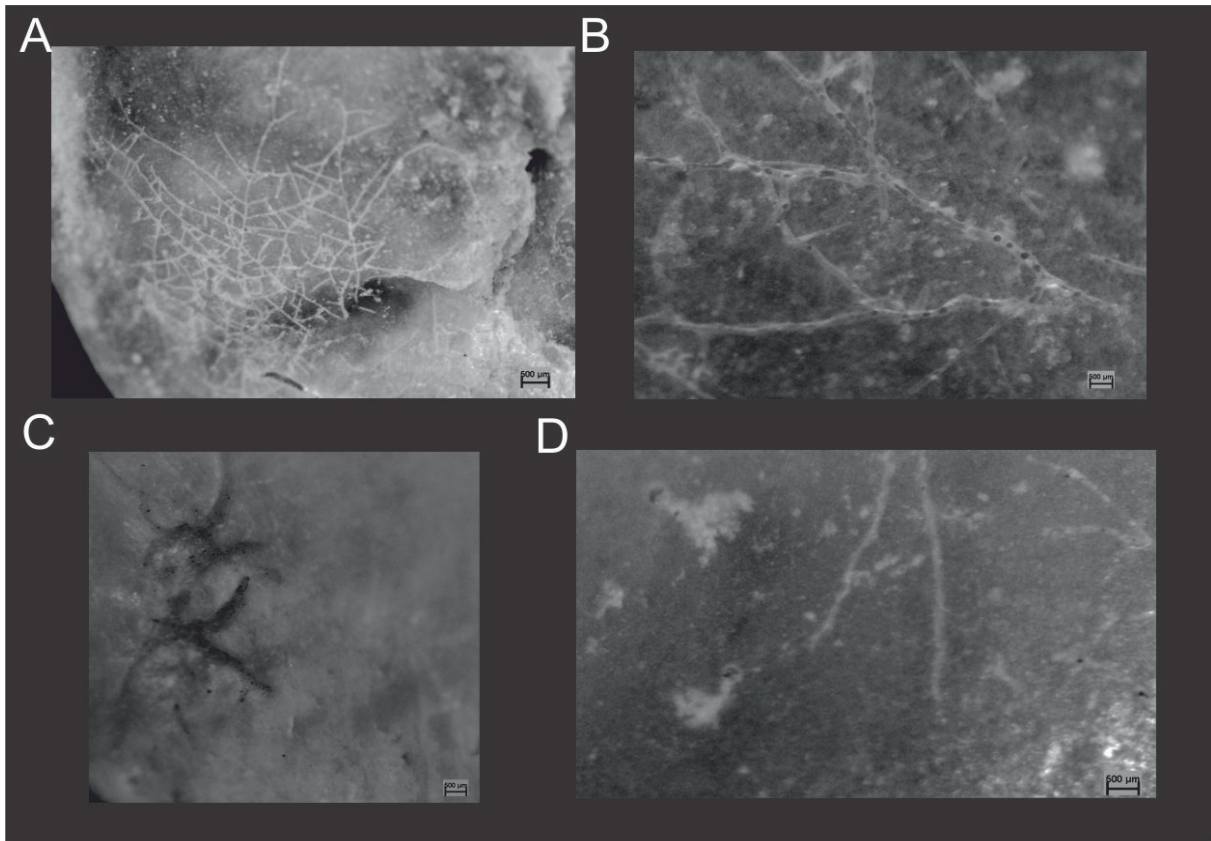


Figure 6. Microbioerosion in internal valves of Site 2 of FSB. A) Morphotype 1 on *O. equestris* (PIL: 15.210); B) Morphotype 2 on *O. equestris* (PIL: 15.770); C) Morphotype 3 on *O. equestris* (PIL: 15.771) and D) Morphotype 4 on *B. odites* (PIL: 15.772). / **Figura 6.** Microbioerosion en valvas internas del Sitio 2 de FSB. A) Morfotipo 1 en *O. equestris* (PIL: 15.210); B) Morfotipo 2 en *O. equestris* (PIL: 15.770); C) Morfotipo 3 en *O. equestris* (PIL: 15.771) and D) Morfotipo 4 en *B. odites* (PIL: 15.772).

zed by Mayoral (1988a) as morphotype B4. This is the first record in Argentine modern beaches.

Morphotype 4 is an arborescent model of reduced extension that originates from a sub-circular opening located on the surface of the shells. It consists of a series of more or less radial furrows and a rounded central cavity not quite defined, dichotomically bifurcated and Y-shaped (Figura 6D). It is recognized as morphotype B in Mayoral (1988a); the most eroded ones are similar to morphotypes B3 or B2.

Ichnogenera vs. Abundance

The dominant ichnogenera of Site 1 are *Iramena*, *Pinaceocladichnus* and *Entobia* with a low proportion of *Oichnus* and *Caulostrepsis*, whereas the most abundant of Site 2 are *Maeandropolydora*, *Iramena* and *Oichnus* with less representation of *Finichnia*, *Trypanites* and *Pinaceocladichnus* (Figura 7A).

Traces are located according to the behavior of the organism. Dwelling traces (*Domichnia*): for

Maeandropolydora and *Caulostrepsis* there is not a particular area, they are produced by locomotion. *Entobia* is more frequent on the last whorl of gastropods and the central and umbonal area of bivalves. *Pinaceocladichnus* and *Iramena* found the umbonal area, being *Iramena* dominant on all the shell. Predation traces (*Praedichnia*): *Oichnus* affects mainly the muscular area of bivalves and the last whorl of gastropods (Figura 7B).

Seven bioeroded species were identified in Site 1: the gastropods *Tegula patagonica*, *Bostrycapulus odites*, *Crepidula argentina* and *Olivancillaria carcellesi* and the bivalves *Brachidontes rodriguezii*, *Ostreola equestris* and *Pitar rostratus*. Of a total of 52 valves, 30.76 % showed bioerosion marks of *Iramena*, *Pinaceocladichnus*, *Entobia*, *Finichnus*, *Maeandropolydora*, *Caulostrepsis* and *Oichnus* (Figura 7C).

Eight bioeroded species were recorded in Site 2: the gastropods *Tegula patagonica*, *Bostrycapulus odites*, *Zidona dufresnei*, *Trophon patagonicus*, *Dorsanum moniliferum*, *Olivancillaria carcellesi*, *Buccinanops globulosus* and the bivalve *Ostreola equestris*. Of a

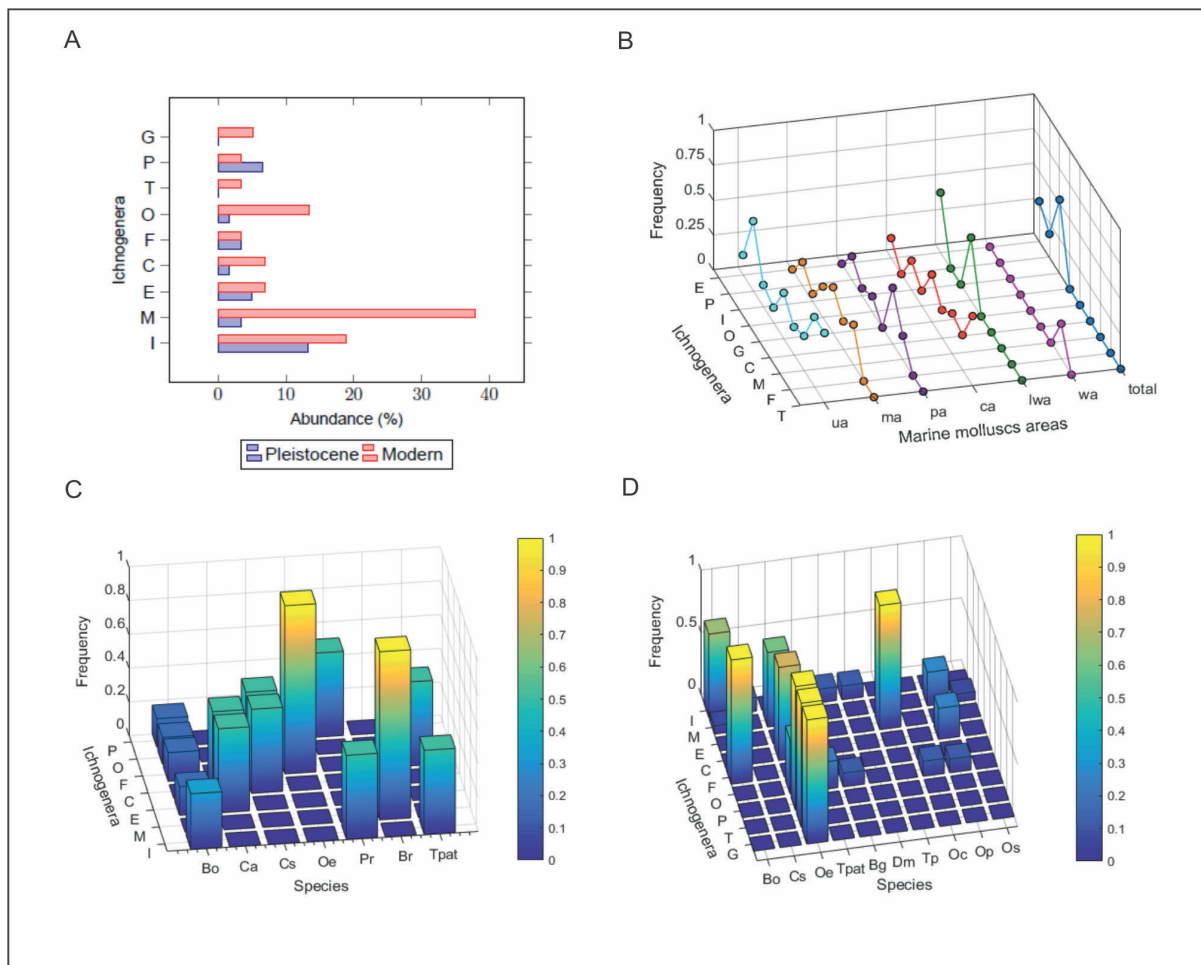


Figure 7. A) Abundance of ichnogenera in Late Pleistocene and modern beaches; **B)** Bioerosion traces found in the different areas of bivalves and gastropods. Total: total area; ua: umbonal area; ca: central area; ma: muscular area; pa: posterior area; wa: whorls area; lwa: last whorl area; **C)** Proportion of ichnogenera present in the Late Pleistocene and **D)** Proportion of ichnogenera present in the Modern beach. I: *Iramena*, M: *Maeandropolydora*, E: *Entobia*, C: *Caulostrepsis*, F: *Finichnus*, O: *Oichnus*, T: *Trypanites*, P: *Pinaceocladichnus* and G: *Gastrochaenolites*. / **Figura 7. A)** Abundancia de icnogéneros en el Pleistoceno Tardío y playas actuales; **B)** Trazas de bioerosión encontradas en las diferentes áreas de valvas de bivalvos y gasterópodos. Total: área total; ua: área umbonal; ca: área central, ma: área muscular; pa: área posterior; wa: área de espira; lwa: área de la última vuelta; **C)** Proporción de icnogéneros presentes en el Pleistoceno Tardío y **D)** Proporción de icnogéneros presentes en las playas actuales. I: *Iramena*, M: *Maeandropolydora*, E: *Entobia*, C: *Caulostrepsis*, F: *Finichnus*, O: *Oichnus*, T: *Trypanites*, P: *Pinaceocladichnus* and G: *Gastrochaenolites*.

total of 106 valves, 44.33 % showed bioerosion marks of *Maeandropolydora*, *Iramena*, *Oichnus*, *Entobia*, *Caulostrepsis*, *Gastrochaenolites*, *Finichnus*, *Trypanites* and *Pinaceocladichnus* (Figura 7D).

Discussion

Ichnogenera were more abundant in Site 2 than in Site 1 of Faro Segunda Barranca. In Site 1 *Iramena* and *Pinaceocladichnus* were dominant, suggesting quiet waters of low sedimentation, moderate water currents and sandy bottom. Both ichnogenera indicate a benthic communi-

ty composed of ctenostomata bryozoans. Their increasing record in the Pleistocene deposit suggests larger availability of phyto and zooplankton in the environment and high oxygenation of water. The dominance of both ichnogenera indicates intermediate stability in the marine environment. In Site 2, instead, the abundance of *Maeandropolydora* suggests the existence of polychaete annelids, mostly *Spionidae* and indicates sandy bottom at the sediment-water interface. The occurrence of *Oichnus* does not indicate any particular environment but suggests the existence of muricaceans, such as *T. patagonicus*

which is abundant in this site. The presence of *Gastrochaenolites* produced by bivalves of the Family *Mytilidae* and *Trypanites* made by sipunculid annelids (Neumann *et al.*, 2008), indicates hard substrate and a shallow coastal marine environment. The presence of *G. torpedo* in modern beaches suggests a shallow marine environment than that of the Late Pleistocene.

Macrobioerosion on marine molluscs in the Late Pleistocene of South America

Richiano *et al.* (2014) studied bioerosion markers in bivalves and gastropods in Quaternary deposits along the Atlantic Argentine coast from Río de la Plata to Patagonia, southern Santa Cruz Province. These authors recognized five ichnogenera (*Maeandropolydora*, *Finichnus*, *Entobia*, *Caulostrepsis* and *Oichnus*) for the Late Pleistocene of Patagonia. While in this paper, seven ichnogenera and two ichnospecies (*O. simplex* and *P. onubensis*) were recognized suggesting that the south of Buenos Aires is richer in bioerosion on mollusc shells than Patagonia. From the ethological point of view, the dominant ichnofacies was Domichnia, the same as in both sites of Faro Segunda Barranca.

Charó *et al.* (2015b) studied two littoral ridges of the north Patagonian coast, San Antonio Oeste (SAO) (40°42'S/ 64°57'W) and La Rinconada (LR) (40°48'S/ 65°4'W) sites. Both deposits are Late Pleistocene in age (120 Ka, MIS 5e). In SAO the authors reported 33 % of bioerosion markers with three ichnogenera: *Entobia*, *Maeandropolydora* and low proportion of *Oichnus*. While for LR, they reported 10.3 % of bioerosion markers (*Entobia*, *Iramena*, *Pinaceocladichnus* and low proportion of *Meandropolydora*) in all the valves. All these ichnogenera were present in Site 1 of Faro Segunda Barranca. The abundance of *Entobia* in both sites (SAO and LR) of north Patagonia indicates stable substrate; on the contrary, *Entobia* was found in low proportion in both sites of Faro Segunda Barranca. Although with different abundance of gastropod and bivalve species because of the

geographic location of the sites, the record of *Iramena* and *Pinaceocladichnus* in LR is similar to that of Site 1 of Faro Segunda Barranca.

Richiano *et al.* (2015) studied the bioerosion on marine mollusc in the Middle Pleistocene (MIS 11) of Bahía Camarones, Chubut Province (44°50'S/65°40'W). They studied 536 valves of molluscs and found 8 ichnogenera: *Entobia*, *Maeandropolydora*, *Iramena*, *Caulostrepsis*, *Pinaceocladichnus*, *Finichnus*, *Podichnus* and *Oichnus*. All of them are represented in the study area except for *Podichnus*. The most abundant was *Iramena*, similar to Site 1 of Faro Segunda Barranca (Table 4).

Microbioerosion in the south of Buenos Aires Province.

Microbioerosion is an important issue in the study of marine communities but it has not been studied as comprehensively as macrobioerosion in the marine Quaternary of Argentina.

In the microbioerosion analysis four morphotypes were found on mollusc shells of the modern beaches. Morphotype 1, recognized as *Orthogonum lineare* Glaub, 1994 is produced by an unknown heterotroph. It has been recorded from the Ordovician to the Recent (Wisshak, 2012). This ichnospecies is found in Lower Pliocene and Pleistocene sediments of the NW Mediterranean (Molinu *et al.*, 2015) and Arenas de Huelva Formation (Inferior Pliocene) (Mayoral, 1988a) in Spain. Its paleobathymetric significance is under debate (Heindel *et al.*, 2009); whereas other authors stated that this morphotype is used to recognize the aphotic zone (Glaub, 2004; Wissack, 2012)

Morphotypes 2-4, display an arborescent model which is typically produced by algae, but no taxonomic assignment is concluded. Morphotype 2 is observed as macroborings with an arborescent model in surface. Its very common on *Ostreidae* in the Pliocene Arena de Huelva Formation, Bajo Guadalquivir Basin, Spain (Mayoral, 1988a). This microbioerosion morphotype was found in the inner valve of *Amiantis purpurata* from the Holocene of Jabalí Island (40°34'S/ 62°13'W) (Charó *et al.*, 2017).

Ichnogenera	Southern Brazil Chui Creek Formation (230 ky) (Lopes et al., 2013)	Uruguay Villa Soriano Formation (Pl-Hol) (Lorenzo and Verde, 2004)	South of Buenos Aires Province (this paper)	North of Rio Negro Province (Charó <i>et al.</i> 2015) MIS5e SAO LR	North patagonia (Richiano et al., 2015)	South of Patagonia (Richiano et al., 2015)
<i>Entobia</i>	X	X	X	X X		
<i>Maeandropolydora</i>			X	X X		X
<i>Oichnus</i>		X	X	X	X	X
<i>Caulostrepsis</i>	X	X	X			X
<i>Finichnus</i>			X		X	X
<i>Iramena</i>			X	X		
<i>Pinaceocladichnus</i>			X			X
<i>Pennatichnus</i>	X					X
<i>Gastrochaenolites</i>	X		X			
<i>Trypanites</i>			X			

Table 4. Ichnogenera presents in Pleistocene marine deposits in South of America. / **Tabla 4.** Icnogéneros presentes en los depósitos marinos Pleistoceno en el Sur de América.

Morphotype 3 is an irregular arborescent microboring. It was found in Arenas de Huelva Formation (lower Pliocene) in Spain (Mayoral, 1988a). This morphotype is similar to *Clionolithes* but quite smaller. Morphotype 4 is found on the inner valve of *Bostrycapulus odites* in the Holocene of Villalonga Canal (40°01'S/ 62°19'W), south of Buenos Aires. Morphotypes 3 and 4 are dominant, suggesting low energy waters, and are found on shells of infaunal organisms.

Charó *et al.* (2017a) studied for the first time microbioerosion on bivalves and gastropods shells in Holocene marine deposits of the Buenos Aires Province. In this study, the authors described the microbioerosion morphotypes observed through optical microscope on internal valves of *Crepidula* and *Plicatula gibbosa* from the Holocene deposit of Villa 7 de Marzo (40°48'S/62°59'W) and the inner valve of *B. odites* in the Holocene of Villalonga Canal (40°01'S/62°19'W). Among the microbioerosion morphotypes preliminary described only

two were found in the study area (Morphotype 1 and Morphotype 4).

Conclusions

The dominant ichnofacies in both sites of FSB is Domichnia with the presence of Fixichnia and Praedichnia. The following ichnogenera were identified in both sites: *Iramena*, *Maeandropolydora*, *Entobia*, *Caulostrepsis*, *Pinaceocladichnus*, *Finichnia*, *Oichnus*, *Trypanites* and *Gastrochaenolites*, as well as four ichnospecies: *O. simplex*, *M. sulcans*, *P. onubensis* and *C. taeniola*. *Iramena* and *Pinaceocladichnus* were the most abundant ichnogenera in Site 1, whereas *Maeandropolydora*, *Iramena* and *Oichnus* were the most abundant in Site 2. Among microbioerosion traces, four morphotypes were found, produced by endolithic microorganisms (eg. heterotrophs and algae) in modern shells. The study of this kind of trace will enlarge the knowledge of past environmental factors and will also be useful in paleobathymetric and paleotemperature issues.

All the ichnogenera suggested a marine benthic community composed of ctenostomate bryozoans, polychaete annelids, carnivorous gastropods, bivalves, clionaid sponges, sipunculids annelids and algae. The Late Pleistocene was characterized by low sedimentation, high oxygenation of water, and moderate stability in the marine environment, sublittoral and sandy bottom. The modern beach instead, is characterized by sandy bottom at the sediment-water interface suggested by the dominance of *Meandropolydora* and hard bottom and low sedimentation rate suggested by *Gastrochaenolites* and *Trypanites*, and the dominance of morphotype 3 and 4 suggesting low energy waters.

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