

PREDATION ON NEOGENE OSTRACODS OF SOUTHWESTERN SPAIN

FRANCISCO RUIZ ¹, MANUEL ABAD ¹, MARÍA LUZ GONZÁLEZ-REGALADO ¹, JORGE CIVIS ², JOSÉ ÁNGEL GONZÁLEZ-DELGADO ², EDITH XIO MARA GARCÍA ³ & ANTONIO TOSCANO ¹

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Abstract. This paper analyzes the evidence for predation on ostracods observed in Neogene sediments of southwestern Spain. Eighty bored valves were extracted from the analysis of more than 2000 specimens collected in shallow marine to upper bathyal palaeoenvironments. Bored specimens are more abundant in Neogene shallow marine areas, although very high percentages can be obtained in deeper sediments with very low ostracod densities. Two main types of boreholes can be distinguished, being concentrated mainly in the central areas of the valves, and drilled mainly by the gastropods: a) *Oichnus paraboloides* Bromley, with more of 70% of the total boreholes; and b) *Oichnus simplex* Bromley. Borehole diameter shows a positive but no significant correlation with the dimensions of the predated valves. Ornamentation seems to be secondary in the predatory selection.

Riassunto. In questo articolo vengono analizzate le evidenze di predazione su ostracodi in sedimenti neogenici del sudovest della Spagna. Analizzando oltre 2000 esemplari di ostracodi provenienti da sedimenti depositi in ambienti da infralitorale a batiale superiore, sono state individuate 80 valve con perforazioni. Gli esemplari perforati provengono in maggioranza da sedimenti marini neogenici di bassa profondità, sebbene percentuali elevate sono state ottenute in sedimenti più profondi, dove la densità di ostracodi è però molto bassa. Vi sono due tipi principali di perforazioni dovute soprattutto all'attività di gasteropodi: Esse sono concentrate nell'area centrale delle valve e vengono riferite a *Oichnus paraboloides* Bromley, con più del 70% del totale dei fori e a *Oichnus simplex* Bromley. Il diametro delle perforazioni indica una correlazione positiva, ma non particolarmente accentuata, con la dimensione delle valve predate. Il tipo di ornamentazione sembra invece avere un'importanza secondaria nella selezione per la predazione.

Introduction

Ostracods are microcrustaceans that are predated upon by different aquatic organisms; they constitute a

minor component in the diet of bivalves, scaphopods, amphibians, fish and annelids (Glover et al. 2003; Fidalgo et al. 2006; Leal 2008; Vaske Junior et al. 2008). In some cases, this predatory pressure can be detected by the presence of drill holes on the ostracod valves (Reyment 1966; Reyment et al. 1987) or the abundance of ostracod carapaces and eggs in faeces (Green et al. 2008). In addition, ostracod eggs are also a food source (Spencer & Blaustein 2001). In some cases, this predatory activity may be due to changes in environment (Elewa 2007).

This paper analyze the predation evidences observed on Neogene ostracod populations of southwestern Spain. Boreholes were measured and mapped using Pope diagrams in the ostracod carapace, and results from different environments were compared.

Study area

In the western sector of the Guadalquivir basin (Fig. 1a), four Neogene formations are defined, lying unconformably on a Palaeozoic-Mesozoic substrate (Fig. 1b):

a) *Niebla Calcarenite Formation* (Civis et al. 1987). This Tortonian unit has a variable thickness (0-25 m) and consists of fluvial conglomerates, littoral sands and beach sandy calcarenites.

b) *Gibraleón Clay Formation* (Civis et al. 1987). This Tortonian-Messinian formation comprises a very monotonous lithofacies consisting of gray-blue marls

1 Corresponding author. Departamento de Geodinámica y Paleontología, Univ. de Huelva, Avda. Tres de marzo, s/n., 21071-Huelva, Spain. E-mail: ruizmu@uhu.es

2 Departamento de Geología, Univ. de Salamanca, 37008-Salamanca, Spain.

3 Departamento de Botánica y Zoología, Centro Universitario de Ciencias Biológicas y Agropecuarias, Universidad de Guadalajara, 45110-Jalisco, Mexico.

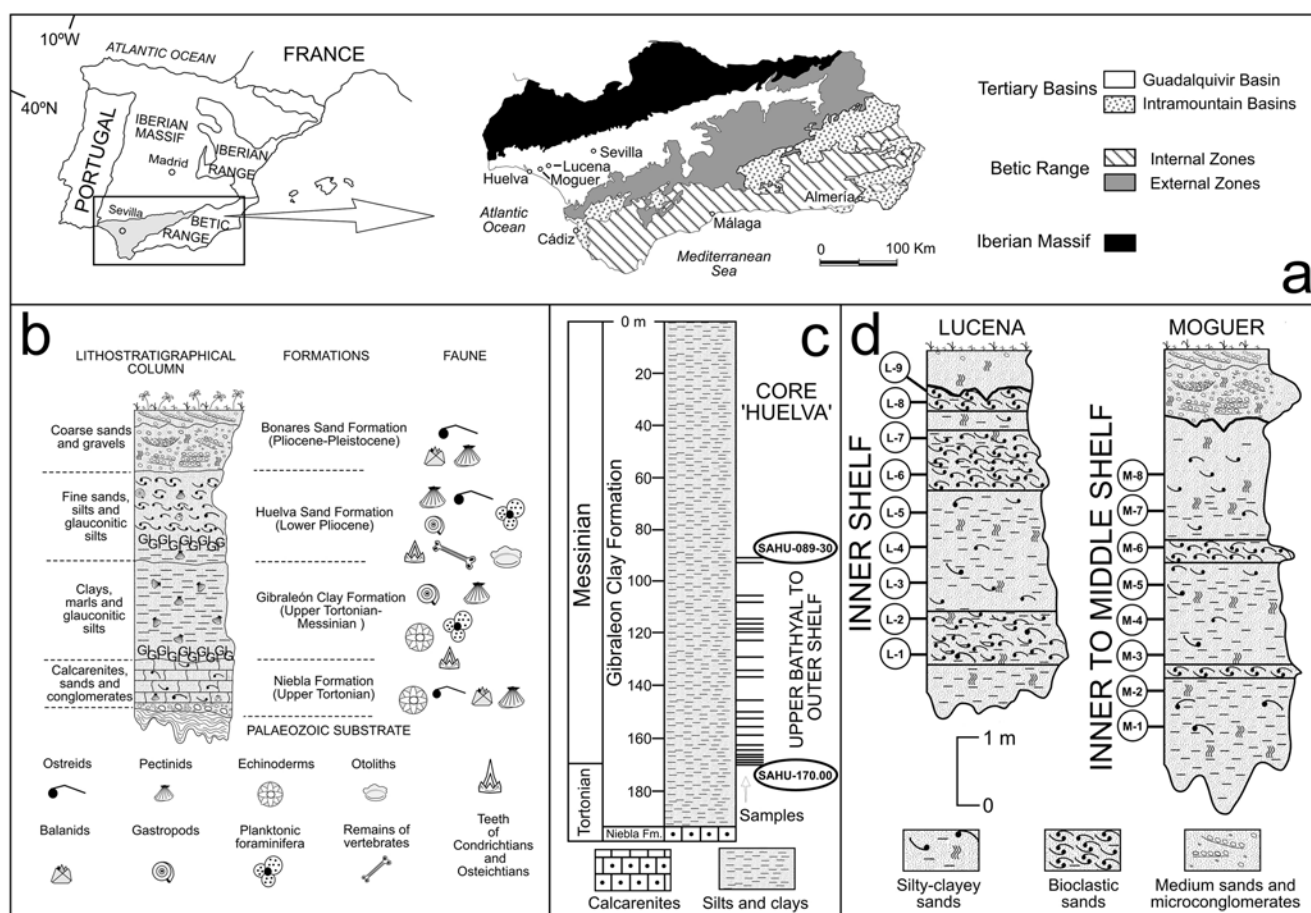


Fig. 1 - a: geological map of southwestern Spain, with location of sections and core; b: regional lithostratigraphical column of the Guadalquivir Basin; c: lithological features and sampling of core 'Huelva'; d: lithological features and sampling of Lucena and Moguer sections.

and clays, only interrupted by the presence of a condensed, silty glauconitic layer near the base. In Huelva city, thickness of this formation surpasses 190 m in a continuous core collected by the Geological Institute of Spain (Fig. 1c). These fine sediments were deposited in outer shelf to upper bathyal palaeoenvironments (Siero & Civis 1987; González-Regalado & Ruiz 1990).

c) *Huelva Sand Formation* (Civis et al. 1987). The overlying deposits are composed of Pliocene silty sands enclosing a glauconitic layer near the base, which presents a rich fauna of selachians (Ruiz et al. 1998a). In the upper part, this formation consists of several lenticular, sometimes lumachellic layers of mollusc shells interbedded with massive, bioturbated levels.

Two sections of this Formation are located in Lucena and Moguer (Fig. 1d). Both sections are constituted by smectitic silty-clayey sands, with a disperse macrofauna disposed in several lenticular patches of variable thickness (5–20 cm) and limited lateral continuity. Some fossil-bearing, shell-supported sandy-pelitic sediments are interbedded, disposed in subhorizontal layers (10–120 cm thickness) with an erosional base. Both macrofaunal and microfaunal assemblages indicate the presence of a palaeobiocoenosis that lived in shallow

infralittoral (Lucena) to circalittoral (Moguer) palaeoenvironments, subjected to periodic storms (Andrés 1982; González Delgado 1983; González Delgado et al. 1995).

d) *Bonares Sand Formation* (Mayoral & Pendón 1986). The lowermost sediments of this formation are formed by coarse-grained sands with some mollusc-rich beds and abundant bioturbation. Near the top, this facies is replaced by fluvial conglomerates. Age of this Formation is probably Upper Pliocene-Pleistocene (Torcal et al. 1990).

Methodology

Sampling

Core 'Huelva' (Gibralfón Clay Formation). Twenty-five samples (15 g) were extracted from the lower part of a long core (Fig. 1c: 197 m depth) collected by the Spanish Institute of Geology in Huelva (SW Spain).

Lucena and Moguer sections (Huelva Sand Formation). Seventeen samples (250 g wet sediment) were collected each 0.5 m from the Lucena and Moguer sections (Fig. 1d) in order to compare them with Holocene and modern samples. The ostracod distribution of these sections was studied by Ruiz & González-Regalado (1990, 1993).

Methods

All samples were washed through a 63- μ m sieve and then dried in an oven at 70°C. If possible, a minimum of 150 individuals were picked from each sample, with a later recalculation to yield the total number of ostracods in the whole sample and the number of individuals

per 10 g of dry weight sediment. If the number of specimens is lower than 150, the total ostracod fauna was picked. In addition, the palaeontological record of possible predators was tested.

In a second step, valves or carapaces with predation evidences were separated and drawn (Fig. 2), although broken or abraded valves were rejected. Ontogenetic stage of each bored shell was determined from data obtained by Aranki (1987), Ruiz et al. (1996), Ruiz et al. (1998b) and numerous short papers of the Stereo Atlas of Ostracod Shells. Location of drill holes was classified as anterior, central, posterior, dorsal and ventral.

In addition, the external diameter (for circular holes) or the longest axis (for elongated holes) of the borings were measured and compared with length and height of valves that include them. The Pearson linear correlation coefficient (if $n > 10$) was used for this purpose (Fig. 3). Finally, the percentage of bored individuals was obtained in each sample.

Results and discussion

Hole frequency

Frequent predated valves (80 in total) were collected in all samples obtained in the Lucena section, with important percentages of the total ostracod populations (3.9%-17.3%; mean 6.37%). Eighteen species were affected by borings, such as *Aurila convexa*, *Cytherella vulgata*, *Hiltermannicythere* spp. and *Semicytherura sella* (Tab. 1). Similar percentages of bored valves have been observed in Pliocene infralittoral environments of southeastern Spain (Aranki 1987), although these percentages reach up to 35% in Lutetian

shallow marine sediments of India (Bhatia et al. 1989). These higher percentages might be due to different age structure populations, because the Lucena section includes even A-5 moults of some species whereas the fossil record is usually dominated by adults and the last juvenile instars (e.g., Reymont 1966; Reymont et al. 1987).

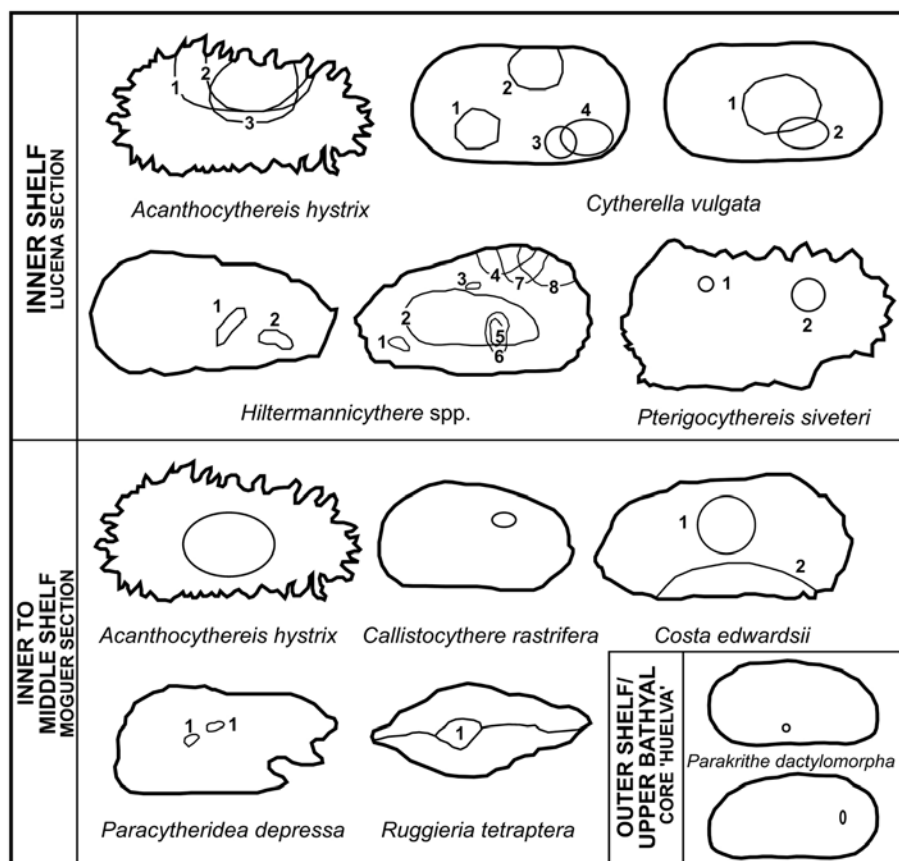
These percentages decrease remarkably in the Moguer section (mean: 0.93%), with little evidence of predation (6 valves; 5 species) in three samples. These valves were extracted in the massive, bioturbated levels of this section (Fig. 1: samples M3, M5 and M7).

Ostracod populations (<1 individual per 10 g) and bioerosion marks were very scarce in all samples collected in core 'Huelva'. Only isolated valves of *Parakrithe dactylomorpha* and *Cytherella vulgata* were affected by these phenomena.

Location and number of drill holes

Pope-diagrams (*sensu* Carriker 1955) indicate a preferential location of the drill holes on the central (>65%) and, to a lesser extent (18%), dorsal areas of the valves, whereas very few predation structures were found near the posterior and ventral margins (Fig. 2). This central concentration has been also observed by Reymont (1963, 1966), although other studies do not detect any preferential area (Aranki 1987).

Fig. 2 - Pope-diagrams showing evidence of predation observed in the different palaeoenvironments. Scale not respected.



Species	SECTION																								
	<i>Acanthocythereis</i> <i>hyper</i>	<i>Aurila</i> <i>convexa</i>	<i>Callistocythereis</i> <i>astrea</i>	<i>Cardiocythereis</i> <i>gr. whitei</i>	<i>Catala</i> <i>edwardsii</i>	<i>Cythereocythereis</i> <i>polonyi</i>	<i>Cytherea</i> <i>virgata</i>	<i>Cytherea</i> <i>sp.</i>	<i>Cythereoides</i> <i>neapolitana</i>	<i>Heteromacropythere</i> <i>sp.</i>	<i>Loxocoina</i> <i>agilis</i>	<i>Neocythereis</i> <i>subtilis</i>	<i>Paracythereis</i> <i>depressa</i>	<i>Paracythereis</i> <i>discolor</i>	<i>Pontocythereis</i> <i>elongata</i>	<i>Pugocythereis</i> <i>slender</i>	<i>Rugocythereis</i> <i>templei</i>	<i>Semicythereis</i> <i>seta</i>	<i>Trochocythereis</i> <i>angulosa</i>	<i>Unocythereis</i> <i>oblonga</i>	<i>Unocythereis</i> <i>sp.</i>	Individuals picked	Individuals per 10 g	% Bored	
LUC-1				1		1	1	1				1				1		1				21	3	8.2	
LUC-2	2						3			6							1		1			73	10	7.1	
LUC-3		1			2		3		1	3								2			1	7	6.4		
LUC-5	1									4									1			233	9	5.2	
LUC-6		2								5								2				136	5	6.6	
LUC-7										1												25	1	12	
LUC-8		1			1		1			3						2		2				52	2	17.3	
LUC-9		2								3	1					1		4				304	12	3.9	
MOGUER SECTION																									
MOG-1																						5	<1		
MOG-2																						14	<1		
MOG-3					1																	18	<1	5.6	
MOG-4																						47	1		
MOG-5	1		1										1									497	10	0.8	
MOG-6																						25	<1		
MOG-7					1																	23	<1	4.3	
MOG-8																						16	<1		
CORE 'HUELVA'																									
SAHU-089.30																							4	<1	
SAHU-092.30																							2	<1	50
SAHU-106.30														1									3	<1	
SAHU-109.30																							16	<1	
SAHU-114.85																							2	<1	
SAHU-116.85																							1	<1	
SAHU-118.90																							4	<1	
SAHU-119.35																							6	<1	
SAHU-122.30																							6	<1	
SAHU-129.30																							5	<1	16.6
SAHU-134.30																							6	<1	
SAHU-136.85																							5	<1	
SAHU-146.80																							5	<1	
SAHU-159.80																							1	<1	
SAHU-163.30																							2	<1	
SAHU-165.80																							3	<1	33.3
SAHU-161.80																							11	<1	
SAHU-163.85								1															7	<1	
SAHU-164.80																							8	<1	
SAHU-167.90																							4	<1	
SAHU-167.70																							4	<1	
SAHU-168.40																							4	<1	
SAHU-169.40																							1	<1	
SAHU-170.80																							1	<1	

Tab. 1 - Evidence of predation observed in the Neogene samples from southwestern Spain, with the number of individuals picked, relative abundance and percentages of bored shells. Individuals were calculated per 10 g of unwashed sediment.

In general, valves were drilled only once, although multiple boreholes are observed in very rare specimens (Fig. 2: e.g. *Paracytheridea depressa*), without a preferential concentration. Reymont et al. (1987) attribute the presence of multiple boreholes in a single valve to the simultaneous attack of two gastropods, whereas Kitchell et al. (1986) suggest that several predatory molluscs were working as a team. In addition, some carapaces have a hole that includes the dorsal areas of both valves (Fig. 2: e.g., *Ruggieria tetraptera*).

Types of drill holes

Two main types of drill holes have been distinguished:

a) Parabolic, elliptical or wide conical holes, with an external diameter of the borehole larger (50–500 μm) than the internal opening (Pl. 1a–b). In the external side, it is frequent the presence of a peripheral area with scratches or even deep incisions. These borings are assigned to *Oichnus paraboloides* Bromley and attributed to predatory activity by naticid gastropods (Reymont 1966; Jonkers 2000) or other groups of gastropods (e.g. Cassidae, Tonnidae; Mayoral 1986). They are the dominant predatory structures (> 70%).

b) Cylindrical holes, with external and internal openings of about the same size (Pl. 1c: 25–125 μm in most cases). These holes are classified as *Oichnus simplex* Bromley and attributed to the predatory strategy of

muricid or euliminid gastropods (Carriker 1955; Reymont 1963; Donovan & Pickerill 2004) and small turbellarians (Maddocks 1988).

Specimen size vs drill hole diameter

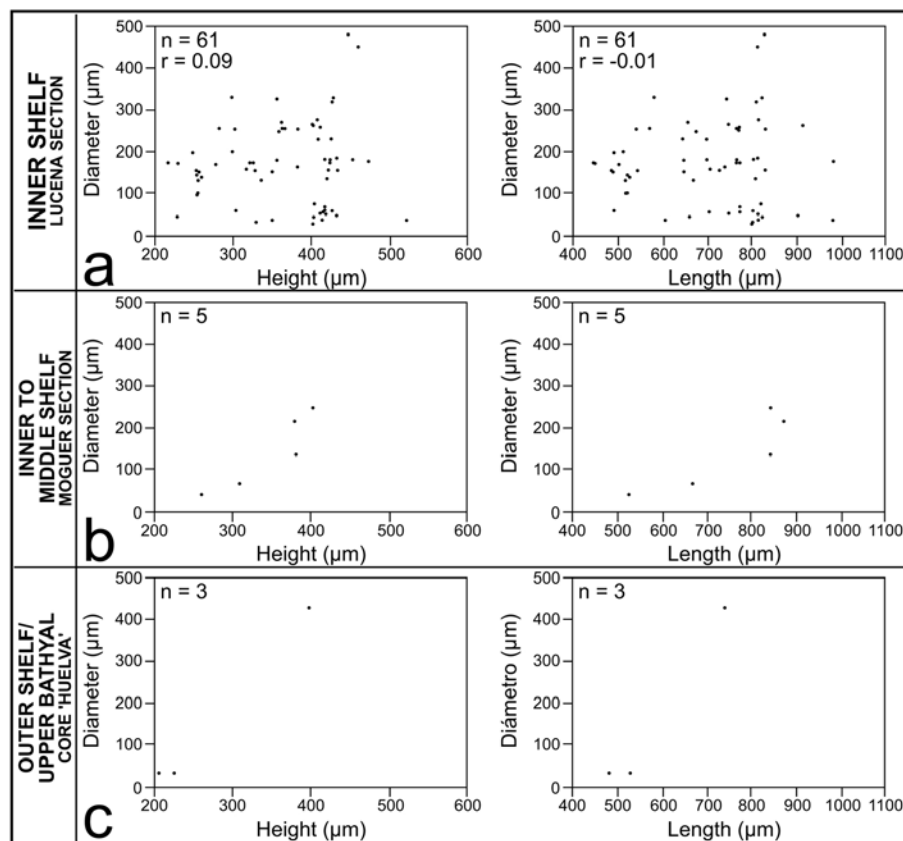
In Lucena section, the analysis of the specimen size vs drill hole diagrams (Fig. 3a) shows a positive but no significant positive correlation between the carapace dimensions and the maximum external diameter of the boreholes when sample size is large ($n > 30$). Similar results have been found in Recent and Neogene ostracod populations of Western Niger Delta and southern Spain (Reymont 1966; Aranki 1987) and Permian brachiopods of west Texas (Hoffmeister 2002).

In Moguer section (Fig. 3b) and core 'Huelva' (Fig. 3c), the number of holes is insufficient to draw conclusions, but the previous positive correlation is also present.

Predation and ostracod ontogeny

In Lucena section (inner shelf), only adults to (A-2) instars present predation evidences (Fig. 4). In the middle shelf to upper bathyal (palaeo)environments, predation was concentrated on adults and (A-1) instars, although isolated (A-3) instars are also bored. These results coincide with those observed in other investigations, with a selective predation of adults and the last juvenile instars (Reymont et al. 1963, 1966).

Fig. 3 - Height vs diameter and length vs diameter diagrams of predation evidences, with inclusion of the Pearson's correlation coefficient (if $n > 10$).



		Adults	A-1	A-2
INNER SHELF LUCENA SECTION	<i>Aurila convexa</i>			
	<i>Cytherella vulgata</i>			
	<i>Hiltermannicythere</i> spp.			
	<i>Semicytherura sella</i>			
INNER TO MIDDLE SHELF MOGUER SECTION	<i>Acanthocythereis hystrix</i>			
	<i>Callistocythere rastrifera</i>			
	<i>Costa edwardsii</i>			
	<i>Ruggieria tetraptera</i>			
OUTER SHELF TO UPPER BATHYAL CORE HUELVA	<i>Cytherella vulgata</i>			
	<i>Parakrithe dactylomorpha</i>			

Fig. 4 - Ontogenetic stages of the most abundant species with evidence of predation.

Predation and ostracod ornamentation

A total of 21 ostracod species show predation evidences. This group includes different architectural patterns, such as smooth/punctuated (*Cytherella vulgata*), spinose (*Carinocythereis* gr. *C. whitei*, *Acanthocythereis hystrix*), ribbed (*Costa* spp., *Ruggieria*) or reticulated (*Urocythereis oblonga*) species. A dominance of bored forms with very different ornamentations has been described in recent shallow marine areas of India (Honappa & Venkatachalapathy 1978). This result contrasts with the predatory selection of smooth species observed by Reyment et al. (1987) on Late Cretaceous and Early Palaeocene ostracods of Israel and Nigeria.

Predation and (palaeo-)environment

According to our previous data (see Tab. 1), ostracods are preferentially predated in infralittoral palaeoenvironments of southwestern Spain (e.g. Lucena) in comparison with deeper marine areas (e.g., Moguer and Huelva). Important percentages of bored valves

(mean: 5,85%) have been also observed on ostracod populations collected in Pliocene shallow marine areas of southern Spain (Aranki 1987). These percentages are very high in relation to those observed in some Holocene lagoons of southwestern Spain (0,15%; Ruiz et al. in press).

Predation and predators

The important percentages of bored valves observed in Lucena section may be due to the presence of numerous predators in this infralittoral area. In this section, gastropods are abundant, including naticids (e.g. *Naticarius tigrinus*, *Neverita josephina*, *Lunatia macilenta*) and muricids (e.g. *Trunculariopsis truncula conglobata*, *Bolinus brandaris torularius*, *Ocenebrina scalaris*). In Moguer section, these groups are scarcer, whereas any gastropod was observed in Huelva core.

Conclusions

The analysis of ostracod populations collected in Tortonian to Pliocene sediments from southwestern Spain permits to delimitate the predatory activity of different groups (mainly gastropods) on these microcrustaceans. Bored valves are frequent in shallow marine palaeoenvironments, although higher percentages are obtained in deeper areas with scarce ostracod populations. These differences may be due to the higher proportions of gastropods present in the Pliocene infralittoral areas.

Parabolic boreholes (*Oichnus paraboloides* Bromley) are dominant (>70%) over cylindrical boreholes (*Oichnus simplex* Bromley). There is a positive correlation between the borehole diameter and the size of the predated valves. This correlation is not statistically significant in most environments.

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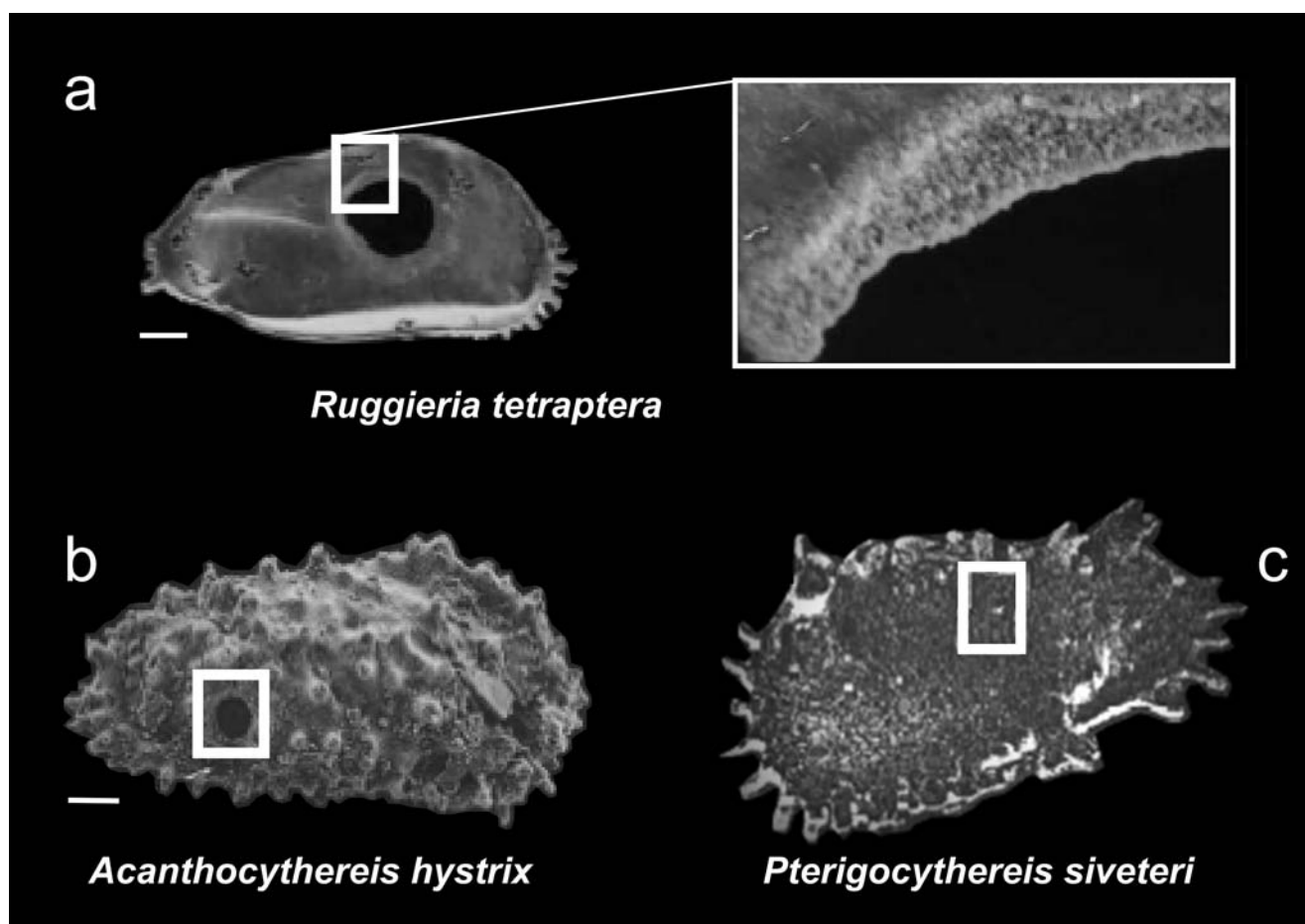


PLATE 1

a-b: *Oichnus paraboloides* Bromley; c: *Oichnus simplex* Bromley. Scale: 100 μ m.

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