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BRACKISH MARSH BENTHIC MICROFAUNA AND PALEOENVIRONMENTAL CHANGES DURING THE LAST 6.000 YEARS ON THE COASTAL PLAIN OF MARATHON (SE GREECE)

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Key words: benthic foraminifers, ostracodes, microfaunal biotopes, marsh paleoenvironments, Holocene, Marathon plain.

Abstract. The present study, based mainly on the analysis of foraminifers and ostracodes, provides evidence of paleoenvironmental changes on the coastal plain of Marathon (E. Greece) during the last 6.000 yrs.

Three sedimentary units –lagoonal formations - were recognized and identified as A, B and C. They range in time between before 5500BP - 3500BP, 3500BP-2500BP and 2500BP- recent, respectively. The study of the brackish marsh microfauna of the Marathon plain Holocene sediments reveals the presence, during the last 5500 yrs, of three distinct biofacies in the sedimentary units already established. Alternating mesohaline – oligohaline (MO), oligohaline – fresh water (OFW) and mesohaline – oligohaline to oligohaline – fresh water (MO-OFW) biofacies in the framework of the sedimentary units indicate a general trend landward along the plain suggesting a slowing of sea-level rise probably correlated with a relevant tectonic uplift.

One prominent feature of this study is the clarification of the ecological preference of the species *Trichohyalus aguayoi* (Bermudez, 1935), which is dominant in oligohaline conditions under an influence of fresh water input (salinity less than 15 ‰).

Riassunto. Questo studio è basato soprattutto sull'analisi di foraminiferi ed ostracodi e consente di valutare le variazioni ambientali durante gli ultimi 6.000 anni nella pianura costiera di Maratona (Grecia). Sono state distinte tre unità sedimentarie di ambiente lagunare, definite A, B, e C, che si distribuiscono in tempo tra 5500BP - 3500BP, 3500BP-2500BP and 2500BP-Attuale, rispettivamente.

Lo studio della microfauna della palude salmastra nei sedimenti olocenici di Maratona rivela la presenza di tre biofacies all'interno delle tre unità sedimentarie precedetentemente stabilite. L'alternanza di biofacies mesohaline – oligohaline (MO), oligohaline – acqua dolce (OFW) e da mesohaline – oligohaline a oligohaline – acqua dolce (MO-OFW), nel contesto delle tre unità sedimentarie, indica la tendenza verso l'incremento dell'area emersa della piana, ottenuta mediante un rallentamento dell'innalzamento del livello del mare collegato con un significativo sollevamento strutturale. Un aspetto importante di questo studio è l'individuazione delle preferenze ecologiche del foraminifero *Trichohyalus aguayoi* (Bermudez, 1935), che domina nelle condizioni oligohaline sotto l'influenza di apporti di acqua dolce (salinità inferiore al 15 ‰).

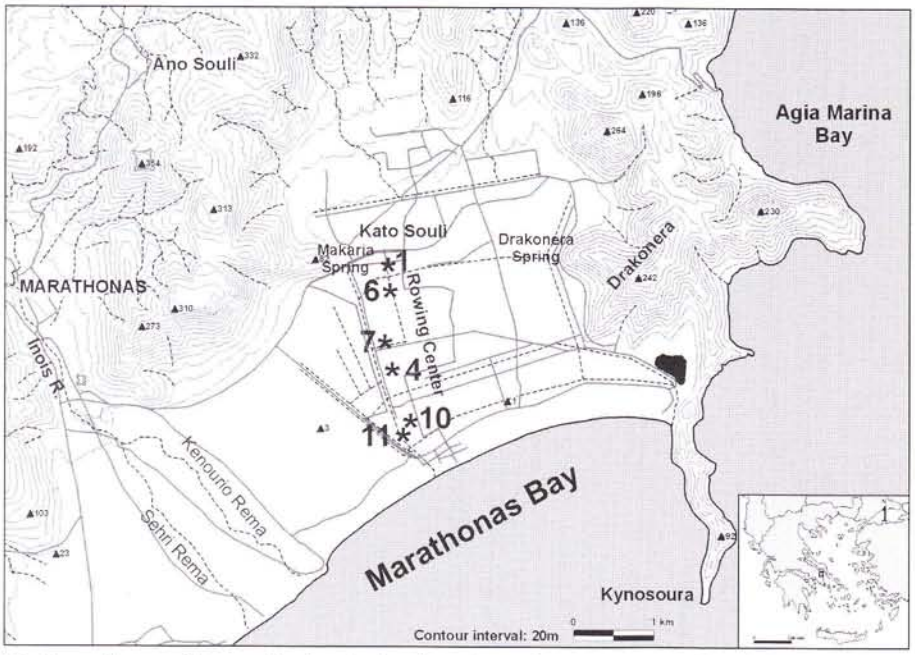

Fig. 1 - Topographic map showing the location of trenches (1,4,10,11) and boreholes (6,7).

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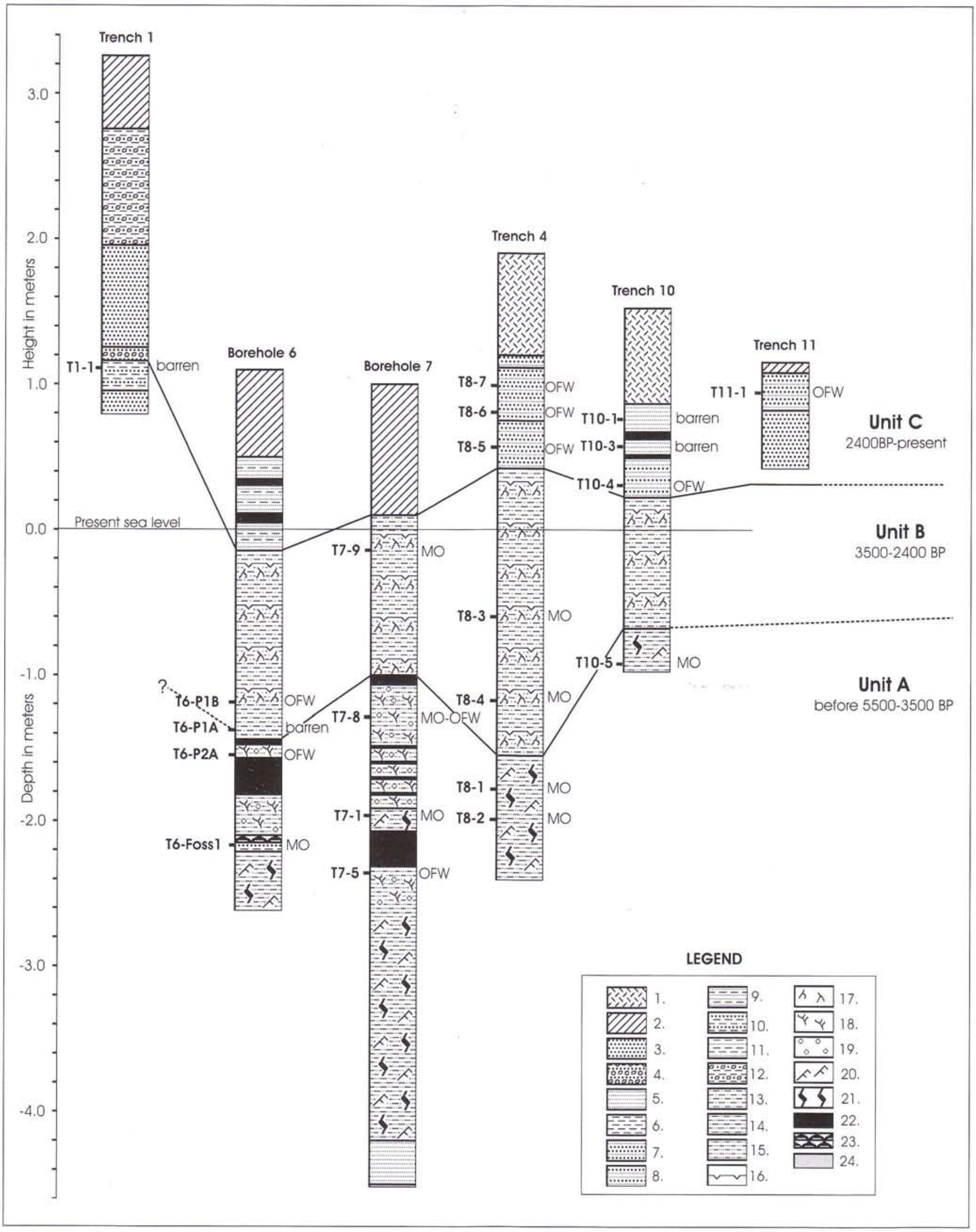

Fig. 2 - Stratigraphic correlation of the boreholes and trenches studied, location of the samples analyzed and position of sedimentary units and biofacies (MO=mesohaline-oligohaline, OFW=oligohaline-fresh water, MO-OWF=mesohaline-oligohaline to oligohaline-fresh water).

Legend: 1. Artificial fill, 2. Topsoil, 3. Sand, 4. Sand with gravels and pebbles, 5. Silt, 6. Clay, 7. Silty sand, 8. Sandy silt, 9. Clayey silt, 10. Sandy clay, 11. Silty clay, 12. Sandy clay with sub-rounded gravels, 13. Palustrine mud, 14. Lagoonal mud, 15. Peloidal algal mud, 16. Mudcracks, 17. Rootlets, 18. Charophytes, 19. Pellets, 20. Gastropods, Bivalves, 21. Bioturbation, 22. Peat, 23. Algal peat, 24. Hard horizon. Peat ages are calibrated (in yr. B.P.).

Sample	Absolute Altitute (m)	Depth (m)	Sediment description	Color (Munsell scale)	Biofacies	Units (Pavlopoulos et al. in press)
TRENCH 1						
T1-1	1.30	2.10	Sandy clay containing ceramic fragments and gastropods.	pale yellow (5Y V8/C2)	barren	B
BOREHOLE 6						
T6-P1B	-1.29	2.38	Palustrine mud containing charophytes and gastropods.	olive brown (2.5 Y V4/C2)	OFW	B
T6-P1A	-1.4	2.42	silty peat containing terrestrial gastropods, charophytes and foraminiferal fragments.	dark gray (2.5 Y/1)	barren	B
T6-P2A	-1.53	2.62	Pelleted mud containing molluscs.	olive brown (2.5 Y V4/C3)	OFW	A
T6-FOSS1	-2.20	3.20	Sandy clay containing charophytes, gastropods and bivalves.	gray (5Y V5/C1)	MO	A
BOREHOLE 7						
T7-9	-0.25	1.21	Palustrine mud including yellowish reduction spots.	olive (5Y V5/C3)	MO	B
T7-8	-1.33	2.32	Pelleted algal mud.	pale brown (10YR V6/C3)	MO-OFW	A
T7-1	-2.00	3.00	Lagoonal mud containing charophytes, gastropods and bivalves.	pale olive (5Y V6/C2)	MO	A
T7-5	-2.33	335	Pelleted algal mud containing charophytes and gastropods.	light gray (10YR V7/C1)	OFW	A
TRENCH 4						
T8-7	1.15	0.75	Silty sand containing charophytes and gastropods.	light gray (5Y V7/C2)	OFW	C
T8-6	0.95	0.95	Silty sand.	gray (5Y V5/C1)	OFW	C
T8-5	0.55	1.35	Silty sand.	light gray (5Y V7/C2)	OFW	C
T8-3	-0.62	2.55	Palustrine mud including reduction spots.	light brown (7.5YR V6/C4)	MO	B
T8-4	-1.25	3.15	Palustrine mud including reduction spots.	light brown (7.5YR V6/C4)	MO	B
T8-1	-1.80	3.70	Lagoonal mud containing charophytes, gastropods and bivalves.	grayish brown (2.5 Y V5/C2)	MO	A
T8-2	-2.02	3.92	Lagoonal mud containing gastropods.	light gray (5Y V7/C1)	MO	A
TRENCH 10						
T10-1	0.70	0.70	Clayey silt.	light gray (5Y V7/C2)	barren	C
T10-3	0.50	0.95	Clayey silt.	gray (5Y V5/C1)	barren	C
T10-4	0.20	1.20	Sandy silt.	light gray (5Y V7/C2)	OFW	C
T10-5	-1.00	2.30	Lagoonal mud.	grayish brown (2.5 Y V5/C2)	MO	A
TRENCH 11						
T11-1	1.85	0.20	Silty sand.	dark gray (5YR V4/C1)	OFW	C

Tab. 1 - Description of the samples studied and their relation with sedimentary units and biofacies.

Introduction

The elongated, NE-SW oriented, Marathon plain is located in East Attica, E. Greece (Fig.1). The broader area surrounding the Marathon plain consists of the "NE Attica" geotectonic unit, representing a "relatively autochthonous" metamorphic sequence (Lozios 1993).

The Quaternary is represented by various types of alluvial deposits formed mainly by the Inois river, which divides the plain into two parts. Pleistocene and Holocene talus cones and screes cover steep valley sides as well as fault zones.

The marsh of Marathon is extended at the eastern side of the plain and separated from the sea by a barrier beach with low sand dunes, morphologically resembling the typical coastal plains of Greece according to Kraft (Kraft et al. 1975, 1977).

Baeteman (1985) conducted a systematic drill hole study of the area and presented detailed information on the stratigraphic sequence of the plain. Pavlopoulos et al. (in press) determined the sequence of depositional environments and the climate and sea level changes recorded in the area since about 6000 years BP, using micromorphological and micropaleontological methods in addition to radiocarbon dating of several horizons, including peat layers. They recognised three sedimentary units, named A, B and C respectively (Fig. 2), on the basis of the features of each sedimentary phase. Sedimentary unit A (before 5500 to 3500 BP) is generally composed of fossiliferous bioturbated lagoonal mud with occasional peloidal charophytic mud, algal peats and macrophytic peats. Unit B (3500-2500 BP) consists of mixed carbonate and siliciclastic palustrine mud and the uppermost sedimentary unit C (2500 BP-Present) represents mostly fluvial deposits.

The Marathon coastal plain is famous for the ancient battle of 490 BC, fought between the Athenians and the Persians. This area was proclaimed a national park by the Greek government after Athens won the competition for the organization of the 2004 Olympic Games. However, a rowing center has been under construction since early 2001. Given the great environmental and archaeological importance of the area, great interest developed for understanding the palaeoenvironmental conditions of this plain in the past.

This paper presents a detailed micropaleontological study of the subsoil of Marathon coastal plain.

Taking into account the benthic foraminiferal and ostracode assemblages (together with sedimentological data; Pavlopoulos et al. in press) the analysis attempts to determine the paleoenvironmental changes during the last 6.000 yrs on the coastal plain of Marathon, based on the study of the brackish marsh benthic microfauna.

Materials and methods

In order to obtain information about the Holocene stratigraphy under the Recent alluvial cover two bore-

	T6 foss-1	T6 P1 B	T6 P2 A	T7-1	T7-5	T7-8	T7-9	T8-1	T8-2	T8-3	T8-4	T8-5	T8-6	T8-7	T10-4	T10-5	T11-1
Ostracodes																	
Cyprideis torosa (Jones)	97%	11.40%	11.5%	77.6%	46.7%	17.4%	64%	82%	89.7%	74.5%	85%	8%	2.7%	12%		88%	69.1%
Cyprinotus salinus (Brady)		1.7%	7%	16.7%	2.2%	29.8%	9%	6%	8.3%	17.4%	12%	2.9%	3.6%	1.6%		3%	1.8%
Cyprinotus sp.	0.50%																
Loxoconcha elliptica Brady	2%			5.7%		2.5%	2%	12%	4.2%		2%					9%	
Candona neglecta Sars		61.7%	78%		11.1%	20.8%	6%			3.2%		12%	25%	24.8%	14.5%		13.8%
Other Candoninae		12%	2.5%		10.7%	4.3%	0.5%					0.5%					6.5%
Limnocythere inopinata (Baird)					16.9%	3.4%	1%										
Limnocythere sp.		0.6%				12.8%						1%		1.6%			0.5%
Ilyocypris bradyi Sars		4.6%				0.8%	16%			0.7%		3.8%	6.8%	4.8%	13.5%		
Ilyocypris gibba (Ramdohr)		8%					1%			4%		72%	61.8%	55.2%	72%		1.4%
Ilyocypris sp.			1%								0.7%						
Darwinula stevensoni (Brady & Robertson)	0.5%				12%	9%	0.5%										6%
Herpetocypris sp.																	0.9%
Benthic Foraminifers																	
Ammonia beccarii (LINNE)	90.4%			90%			96.4%	86%	100%		28.3%					2%	
Haynesina germanica (EHRENBERG)							3.6%			95%						93.5%	
Haynesina depressula (WALKER & JACOB)	3.6%			7%				7.5%		4%	35.2%						
Trichohyalus aguayoi (BERMUDEZ)			100%														
Elphidium granosum D'ORBIGNY	6%			1.7%				6.5%		1%	36.5%					4.5%	
Quinqueloculina sp.				1.3%													

Tab. 2 - Relative percentage abundances of species in at least 300 counts (ostracodes) / 200 counts (benthic foraminifers), in the samples studied.

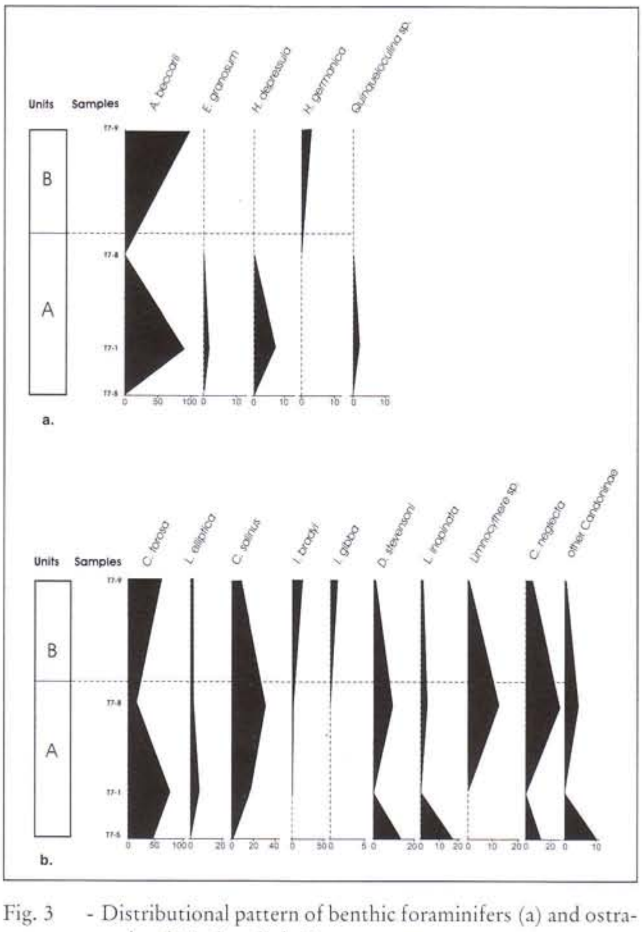

Fig. 3 - Distributional pattern of benthic foraminifers (a) and ostracodes (b) in borehole 7.

holes were drilled -with a portable drilling set- and 4 trenches were excavated (Fig. 1). The description of the sediments in the sequences and their stratigraphic correlation are presented in Table 1 and Fig.2 .

Twenty-one samples of about 50 g each were collected from all the boreholes and trenches (Fig. 2). They were treated with H_2O_2 to remove the organic matter, and then washed through 63, 125, 250, 500 μm sieves and dried in an oven at 50° C. Qualitative analysis was performed on all samples, and seventeen samples presented a foraminiferal and ostracode abundance which was sufficient for the quantitative analysis. A subset of each sample (fraction of 125μm/benthic foraminifers, 250μm/ostracodes) was obtained using an Otto microsplitter until aliquots of at least 200 benthic foraminifers and 300 ostracodes, respectively, remained. A scanning electron microscope analysis (SEM Jeol JSM 5600) was used to assist in the identifications. The taxonomy of benthic foraminifers in this paper is based upon Loeblich & Tappan (1988, 1994) and Bronnimann et al. (1992). Taxonomic references of the ostracodes include mainly Athersuch et al. (1989) and additionally Mazzini et al (1999), Sun et al. (1999).

The relative abundance of the species was treated in a Q-mode hierarchical analysis, performed to study similarities between samples, which is based on Euclidian metric distance and was carried out using Statgraphics Plus 4.0 statistical software.

Benthic foraminifers and ostracode distribution and microfaunal biotopes

The species diversity of benthic foraminifers is very low. Only six species were actually identified in seventeen samples. Concerning the ostracode fauna, twelve taxa were identified and counted (Table 2).

Ammonia beccarii generally follows *Haynesina* spp. frequency pattern (Figs. 3a, 4a, 5a, 6a) except for sample T8-3 where it shows an opposite trend, towards *Haynesina germanica* (Fig. 4a). Additionally, *A. beccarii* shows a negative trend towards *Trichohyalus aguayoi* in sample T6-P2A (Unit A, borehole 6). Concerning the relative frequency patterns of ostracode species, a

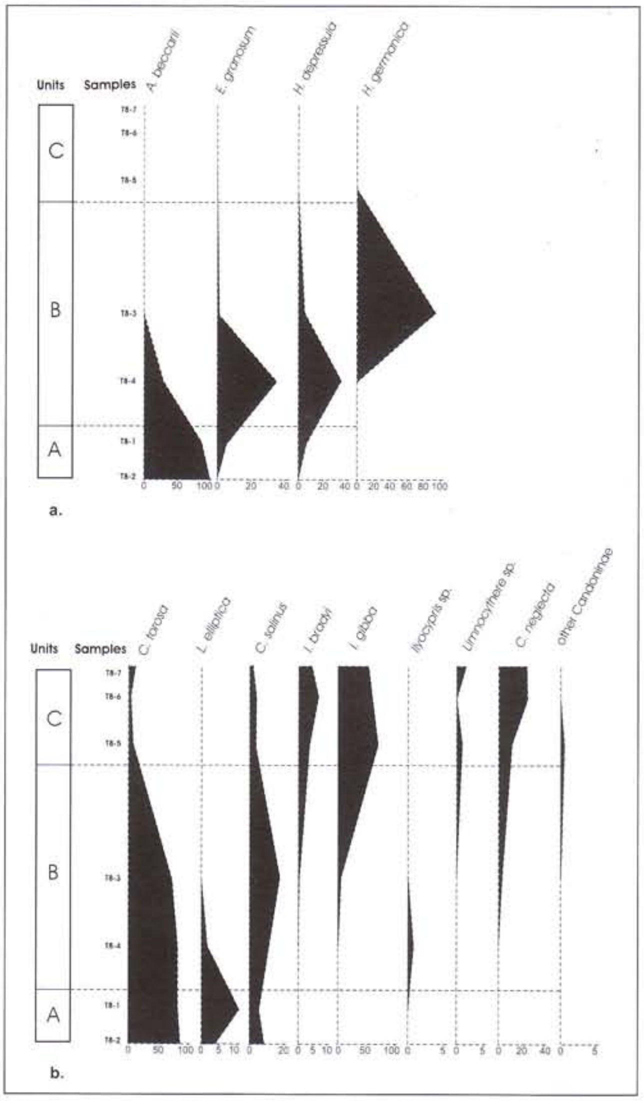

Fig. 4 - Distributional pattern of benthic foraminifers (a) and ostracodes (b) in trench 4.

negative trend emerges in all the units between *Cyprideis torosa* and *Cyprinotus salinus, Darwinula stevensoni, Limnocythere* sp., *Candona neglecta* and *Ilyocypris* spp. (Figs. 3b, 4b, 5b, 6b). The frequency data indicate that several changes in the composition of the benthic microfauna took place in time and space on the coastal plain of Marathon. These changes were confirmed when Q- mode cluster analysis was applied to the data set to define areas of similar environmental conditions. In the resulting dendrograms (Fig. 7) the clusters are regarded as biotopes and are interpreted as representing different ecological conditions.

These biotopes together with the environmental interpretation are:

Cluster I. *Trichohyalus aguayoi, Candona neglecta,* other Candoninae, *Limnocythere inopinata, Darwinula stevensoni, Iliyocypris bradyi, Ilyocypris gibba* assemblage.

Shallow oligohaline - fresh water biofacies *(OFW)*. The first cluster considered (Fig.7) is represented by samples T11-1, T10-4, T8-5, T8-6, T8-7 (belonging to Unit C); T6P1B (belonging to Unit B); and T7-5, T6P2A (belonging to Unit A). They are characterized by the total absence of benthic foraminifers (except for the remarkable monospecific presence of *T. aguayoi,* as a brakish water species (Bronnimann et al. 1992), in sample T6P2A). *C. neglecta, D. stevensoni, L. inopinata, I. bradyi, I. gibba* are indicators of shallow freshwater and oligohaline environments (Athersuch 1979; Grafenstein et al. 2000; Mazzini et al. 1999; Athersuch 1979; Sokac 1978).

This assemblage consisting of dominant freshwater ostracode species, associated with brackish water species (*C. torosa, C. salinus*) indicates the persistence of a restricted temporary communication with the sea (Clavé et al. 2001). It suggests a salinity of less than 15‰ (Neale 1988) and fits well with high-middle marsh environments (Scott et al. 1979), indicating an approximate elevation of 20 cm above the mean paleo-sea level.

Cluster II. *Ammonia beccarii, Haynesina germanica, Haynesina depressula, Cyprideis torosa, Loxoconcha elliptica, Cyprinotus salinus* assemblage.

Shallow mesohaline-oligohaline biofacies *(MO)*. The second cluster considered (Fig.7) is represented by samples T8-1, T8-2, T7-1, T6FOSS1, T10-5 (belonging to Unit A) and T8-4, T8-3 and T7-9 (belonging to Unit B), which are characterized by the high percentages (rising up to 100%) of benthic foraminifers *A. beccarii* or *H. germanica and H. depressula. A. beccarii* –an euryhaline species living in a wide range of different environments (Murray 1991; Alve 1995) - is characteristic of the part of the lagoon which is more affected by marine waters, whereas *Haynesina* is found in the internal portions of the lagoon affected by anthropogenic events (Serandrei Barbero et al. 1997). Both species characterize the lower intertidal environments (Cundy et al. 2000).The ostracode fauna is marked by the dominance of *C. torosa,* rising up to 97%, *L. elliptica* and *C. salinus,* which are typical brackish species (Gliozzi & Mazzini 1998; Mazzini et al. 1999). This assemblage suggests a salinity of more than 15 ‰ (Neale 1988) and fits well with low marsh environments (Scott 1977; Scott et al. 1979; Petrucci et al. 1983), indicating approximately the mean paleo-sea level.

Cluster III. *Cyprideis torosa, Cyprinotus salinus, Candona neglecta, Limnocythere* sp., *Darwinula stevensoni* assemblage.

Shallow mesohaline-oligohaline to oligohaline-fresh-water biofacies (MO-OFW). As shown in Fig. 7, sample T7-8 (belonging to the upper part of Unit A), which is characterized by the absence of benthic foraminifers and the balanced presence of brackish shallow-water and shallow freshwater ostracode species, suggests an intermediate mesohaline-oligohaline to oligohaline-fresh-water lagoonal environment.

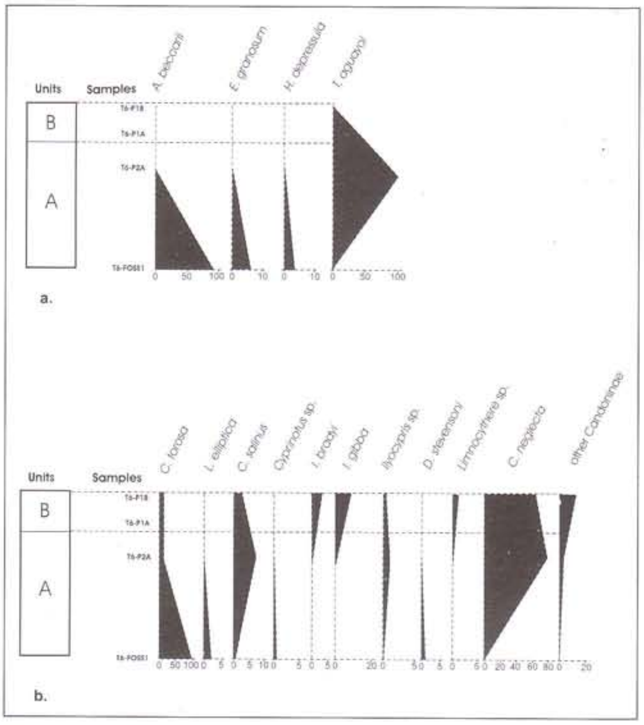

Fig. 5 - Distributional pattern of benthic foraminifers (a) and ostracodes (b) in borehole 6.

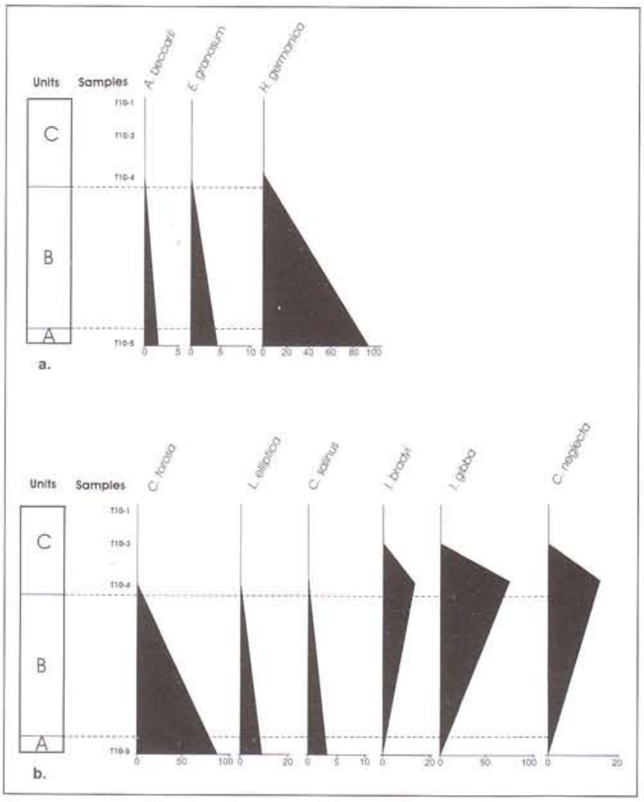

Fig. 6 - Distributional pattern of benthic foraminifers (a) and ostracodes (b) in trench 10.

Paleoenvironmental interpretation and site evolution

The biofacies documented appear in all trenches and boreholes (Table 1, Fig. 2), and therefore they characterize all the three different units.

The MO biofacies (*A. beccarii, Haynesina* spp., *C. torosa, L. elliptica, C. salinus* assemblage) of Unit A (5500-3500 BP) is present in trenches 10, 4 (located in the southern part of the Marathon plain) and in the lower parts of boreholes 7 and 6, indicating a brackish water marsh. The documentation of OFW and MO-OFW biofacies in boreholes 7 and 6, at levels where macrophytic and algal peats and characean oogons intercale with palustrine mud, suggests a brackish water marsh with fresh water inflow, probably associated to several shallowing cycles detected in the inner parts of the plain.

Unit B (3500-2500 BP) has similar characteristics, since the OFW biofacies is present only in borehole 6. Pavlopoulos et al. (in press) suggested frequent exposure of the basin during this time interval, which is definitely confirmed at the northern side of the plain by the terrestrial environment corresponding to substratum 2500BP (documented in sample T1-1 (trench 1) which contains only very few -probably not autocthonous- ostracode valves).

The biofacies distribution is totally different in Unit C (2500-Present). OFW is the only biofacies detected at the southern part of the plain (trenches 11, 10, 4) indicating the dominance of fresh water to oligohaline marsh environments. As Pavlopoulos et al. (in press) suggested, the change from palustrine to alluvial environment happened repeatedly, implying a very shallow and frequently exposed plain without any connection to the sea.

Hence, towards the landward part of the Marathon coastal plain a general trend was documented along the transect A-B (Fig. 8). As shown in Fig. 8 during 5500-2500BP time interval, the southern part of the plain is considered to represent a low marsh environment, whereas the rest of the area was a high-middle marsh. On the contrary the paleoenvironmental conditions changed drastically during the last 2500 yrs, as the high-middle marsh conditions were restricted to the southern part of the plain, while the northern part towards the landward area was probably exposed frequently. This is probably the result of a small apparent tectonic uplift the area underwent during the 5500-1300BP time interval, albeit at slower rates (0.4-0.5mm/

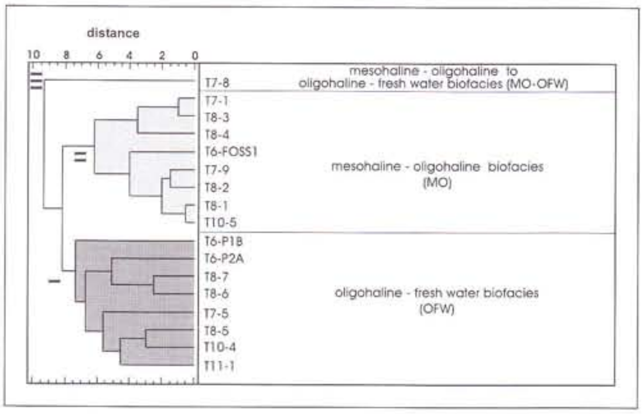

Fig. 7 - Q-mode hierarchical analysis leading to the distinction of three main clusters corresponding to different biofacies.

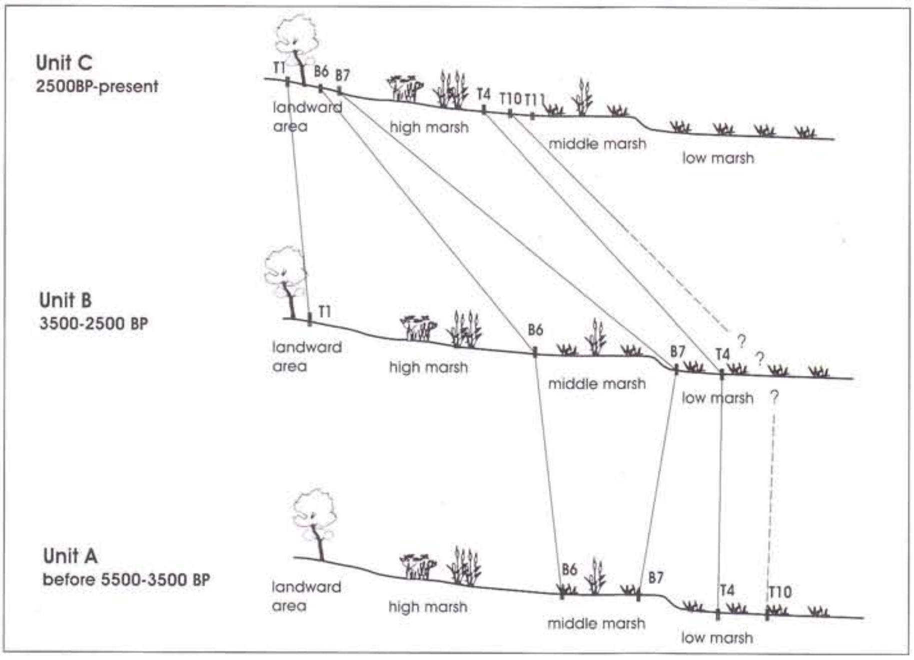

Fig. 8 - Schematic interpretation of paleoenvironmental conditions of the study area, according to the biofacies identified in the sedimentary units A, B, C. (T: trench, B: borehole)

yr; Pavlopoulos et al. in press) than the isostatic rate (0.6-0.7mm/yr, Lambeck 1996), which caused apparent coastal stability from the Classical times onward (Kraft 1972).

Conclusions

The sedimentary sequences of the Middle-Late Holocene of the Marathon plain are represented generally by lagoonal formations related to a slowing of the sea-level rise. The micropaleontological analysis at the Holocene coastal plain of Marathon revealed the absence of agglutinated foraminifers and hence the absence of a salt marsh paleoenvironment (Scott et al. 1979; Cundy et al. 2000). One prominent feature of the present study is the clarification of the ecological preference of the species *Trichohyalus aguayoi* (Bermudez, 1935), (Pl. I, figs 1, 2), which is generally regarded as a brackish species (Bronnimann et al. 1992). Scott et al (1979) documented it under the name *Dicorinopsis aguayoi* in recent coastal marshes of W. Greece. Our results clearly indicate that it dominates in oligohaline conditions (salinity of less than 15 ‰).

Three biofacies were recognized in sedimentary units (Pavlopoulos et al. in press) of the Marathon plain during the last 5500yrs. The alternation of MO, OFW and MO-OFW biofacies in the framework of the sedimentary units indicates a general trend towards the landward area of the plain, suggesting a slowing of sea-level rise probably correlated with a relevant tectonic uplift.

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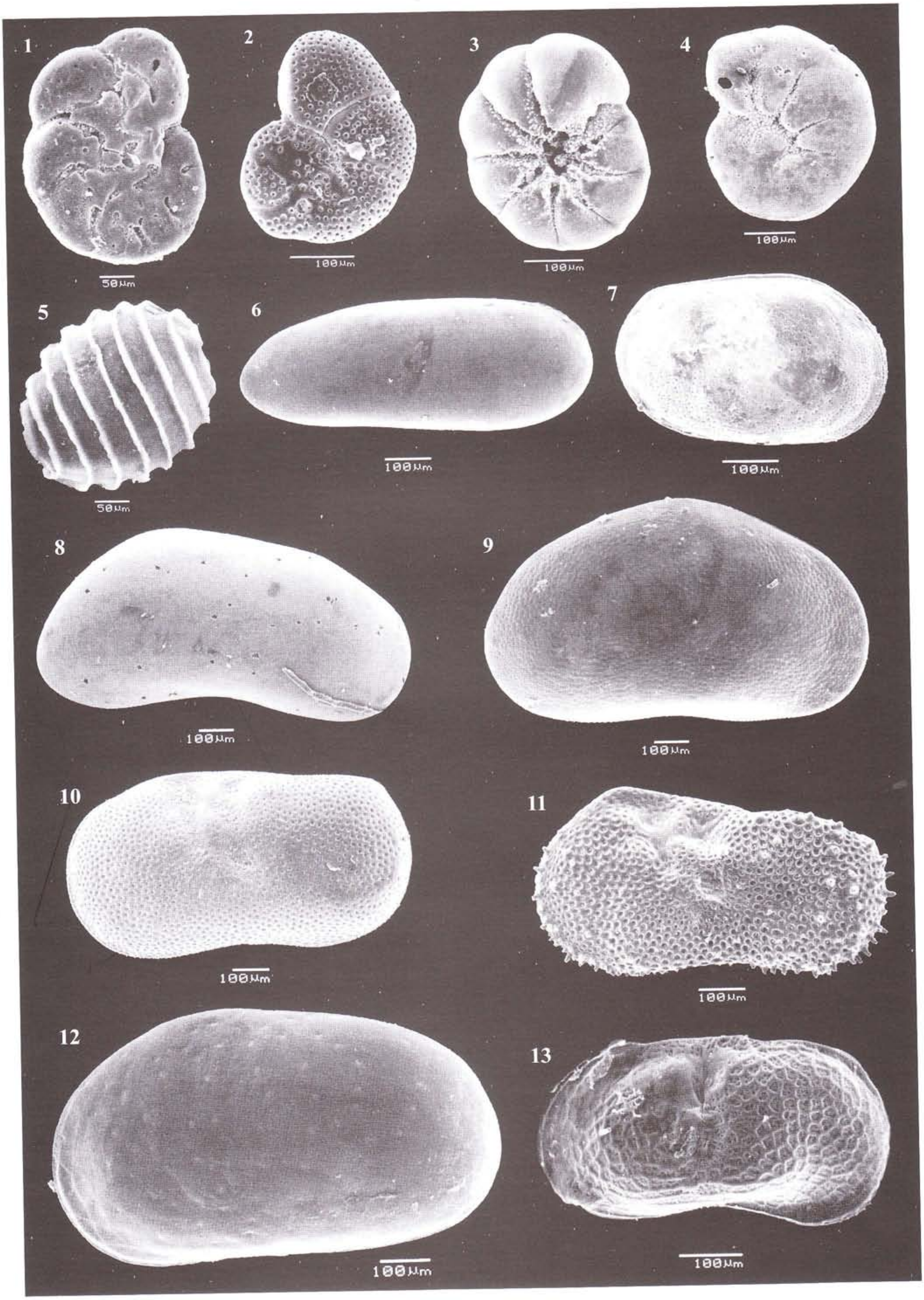
PLATE I

Fig. 1 - *Trichohyalus aguayoi* (Bermudez). Umbilical view, sample T6P2A. Fig. 2 - *Trichohyalus aguayoi* (Bermudez). Dorsal view, sample T6P2A. Fig. 3 - *Ammonia beccarii* (Linne). Umbilical view, sample T6FOSS1. Fig. 4 - *Haynesina depressula* (Walker & Jacob). Side view, sample T6FOSS1. Fig. 5 - *Chara* sp. Sample T10-3. Fig. 6 - *Darwinula stevensoni* (Brady & Robertson), sample T 7-5, left valve, external view. Fig. 7 - *Loxoconcha elliptica* Brady, sample T6 Foss1, right valve, external view. Fig. 8 - *Candona neglecta* Sars, sample T6 P1B, right valve, external view. Fig. 9 - *Cyprinotus salinus* (Brady), sample T 7-5, right valve, external view. Fig. 10 - *Ilyocypris bradyi* Sars, sample T6 P1B, left valve, external view. Fig. 11 - *Ilyocypris gibba* (Ramdohr), sample T6 P1B, left valve, external view. Fig. 12 - *Cyprideis torosa* (Jones), sample T6 Foss1, female, left valve, external view.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