

A re-examination of the Pliensbachian and Toarcian Ostracoda of Zambujal, west-central Portugal

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ABSTRACT – Pliensbachian and Toarcian Ostracoda first described by Exton (*Geological Paper, Carleton University, Ottawa*, 79: 1–104 1979) from the Lusitanian Basin, west-central Portugal have been re-examined. As a result, a greater diversity in the Ostracoda (80 species) is now recognized. Two species are newly described (*Eucytherura zambujalensis* sp. nov., *Ektyphocythere mediodepressa* sp. nov.) from the marls and calcareous shales of the Maria Pares Hill section near the village of Zambujal. Poor preservation precludes a complete taxonomic review of the present material. Five ostracod zones are proposed; *Gammacythere ubiquita*–*Ogmoconchella gruendeli* Zone, *Polycope cerasia*–*Polycope cincinnata* Zone, *Liasina lanceolata*–*Ogmoconcha convexa* Zone, *Bairdiacypris rectangularis*–*Kinkelinella sermoisensis* Zone, and *Cytherella toarcensis*–*Kinkelinella costata* Zone. Although the ostracod assemblages possess strong similarities to those described from Northwest Europe, some of the Zambujal assemblages are dominated by the genus *Polycope*. A marked faunal turnover, in association with the extinction of the Metacopina occurs in the lower Subzone of the *tenuicostatum* Zone of Lower Toarcian age. These faunal events are discussed in relation to changing environmental conditions. *J. Micropalaeontol.* 17(1): 1–14, April 1998

INTRODUCTION

In the light of more recent studies and with a view to detailing major faunal changes during this interval, a review of the Pliensbachian and Toarcian Ostracoda first described by Exton (1979) from the Zambujal section of west-central Portugal has been undertaken by the present authors. Since the earlier work of Exton, over 40 papers have been published on Pliensbachian and Toarcian Ostracoda of northwest Europe. These include Herrig (1969 *et seq.*), Knitter (1983, 1984), Park (1987, 1988), Knitter & Riegraf (1984), Exton & Gradstein (1984), Riegraf (1984, 1985), Dépêche (1985), Bate *et al.* (1984), Donze (1985), Ainsworth (1986 *et seq.*), Ainsworth & Horton (1986), Bodergat & Donze (1988), Boomer & Lord (1988), Boomer (1988 *et seq.*), Lord (1988), Arias & Comas-Rengifo (1992), Arias *et al.* (1992) and Harloff (1993).

The Zambujal section is situated approximately 15 km south-southwest of Coimbra in west-central Portugal, on the flanks of the Maria Pares Hill (48°2'N, 8°28'W) which overlooks the village of Zambujal (Fig. 1). The section extends along the road from Zambujal to Furadouro and covers the stratigraphical interval between the lowest Pliensbachian through to the top of the Toarcian.

SAMPLING

A total of 32 outcrop samples were collected during June 1973 by K. Hooper and W. Cox, from beds which had been numbered and described by Mouterde *et al.* (1964). Additional samples from the lower part of the *tenuicostatum* Zone (*semicelatum* Subzone) at Zambujal, Peniche, and Brenha have also been examined in order to detail the extinction of the metacopid Ostracoda. The ammonite zonation scheme, bed number, approximate thicknesses, and sample numbers are illustrated in Fig. 2. All of the samples excluding sample 117, which comprised a well indurated marl and could not be broken down, comprised marls or calcareous shales. Several preparation methods were tried (boiling, white spirit, hydrogen peroxide), with the latter proving the best method for breaking down the calcareous sediments. A dry weight of 100 g per sample was

found to be the minimum weight needed to gain representative fossil assemblages (Exton, 1979).

GEOLOGY AND GEOLOGICAL SETTING

Portugal's Lower Jurassic sediments outcrop in two main regions; firstly in the Lusitanian Basin which is situated to the west of the Hesperian Massif, between 38°30'N and 41°N, and secondly in an east-west strip on the southern flank of the Algarve Massif. The Lower Jurassic sediments of the Zambujal section are situated close to the present day eastern margin of the Lusitanian Basin, close to the Hesperian Massif (Fig. 1). Throughout the Lusitanian Basin, the Lower Jurassic sediments are dominated by dolomites, limestones and marls, attaining a maximum thickness of over 600 m in the northwest of the region (Figueira da Foz).

The earliest Jurassic sediments in the Lusitanian Basin belong to the Hettangian Dagorda Formation, comprising greyish red marls with dolomites and evaporites (Fig. 3). This formation marks the initial marine transgression upon the terrestrial red lithologies of the Upper Triassic Silves Formation. The overlying Coimbra Formation consists of dolomites and dolomitic limestones and marks the onset of shallow marine conditions throughout the Lusitanian Basin. The upper boundary of this formation is highly diachronous, ranging in age from Upper Sinemurian (*obtusum* Zone) in northwestern outcrops (e.g. Sao Pedro de Muel) close to the basin axis, to Lower Pliensbachian (*jamesoni* Zone) in southeastern outcrops (e.g. Tomar) close to the original basin margin (Mouterde *et al.*, 1971). The interbedded shales, marls and limestones of the overlying informally named Brenha Formation constitute the remainder of the Lower Jurassic succession. The relative proportion of limestones to marl/shale within this formation varies according to the proximity to the paleomargin of the basin. In the vicinity of Tomar, towards the southeastern margin, the marls and shales do not form a significant component of the sediments until the Lower Toarcian. Predominantly argillaceous sedimentation commenced in the Upper Sinemurian towards the basin centre (e.g. Sao Pedro de Muel). A gradual increase in basin

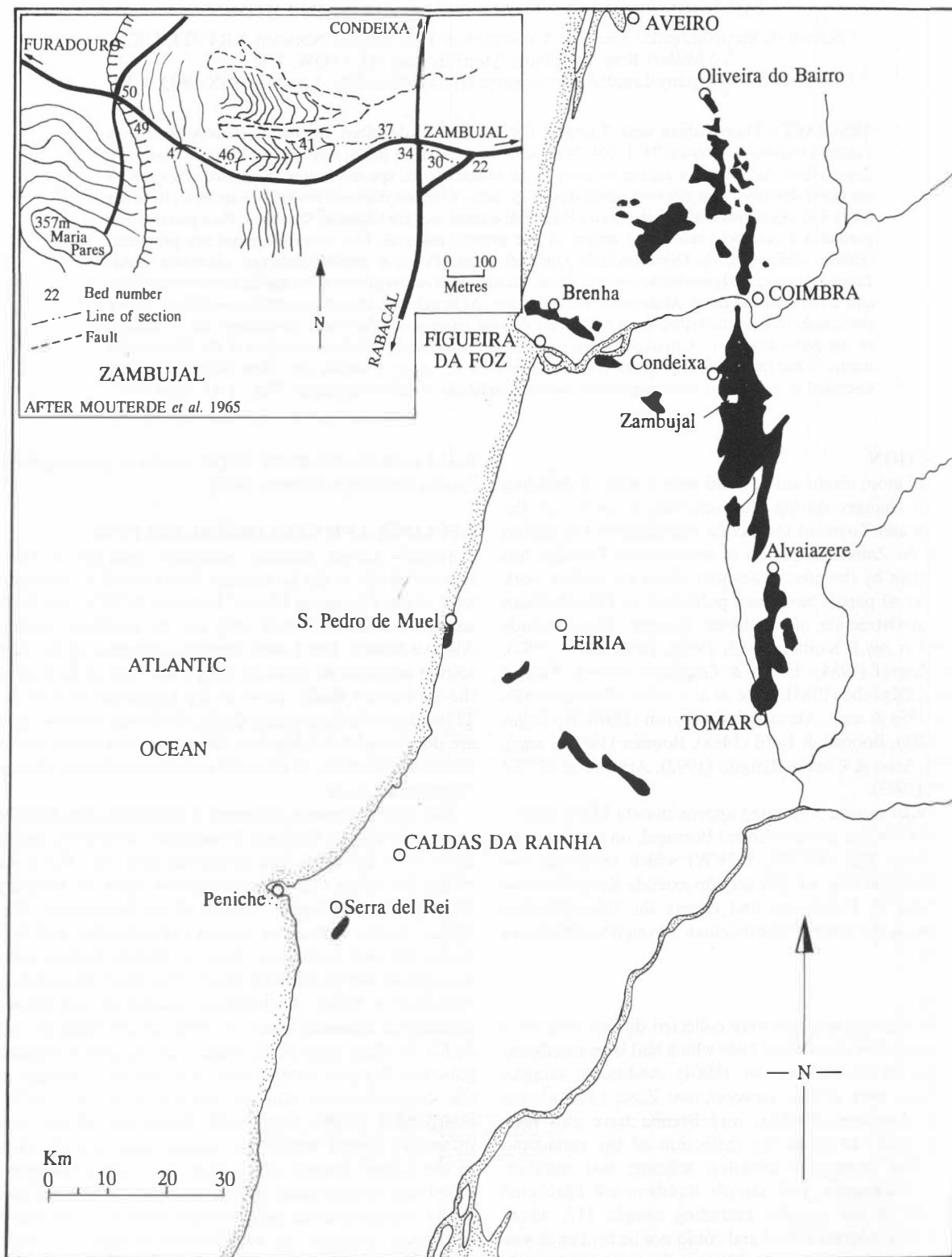


Fig. 1. Location of Lower Jurassic outcrops in west central Portugal.

SYSTEM	SUBSTAGE	AMMONITE ZONES	BED NUMBER	APPROX. THICKNESS (metres)	GENERALISED LITHOLOGY	SAMPLE NUMBERS	LITHOLOGICAL DESCRIPTION			
LOWER JURASSIC	UPPER TOARCIAN	levesquei	50	23		134	Pale grey marl			
						133	Pale grey marl			
	132					Pale grey marl				
	131					Pale grey marl				
	130					Buff marl				
	MIDDLE TOARCIAN	thouarsense	49	5.3		129	Olive green marl			
						128	Grey - green marl			
		bifrons	47	31		127	Pale grey - buff marl			
						126	Pale grey - buff marl			
						125	Pale grey - buff marl			
						124	Pale grey - buff marl			
		falciferum	45	6.0		123	Pale grey - buff marl			
						122	Pale grey - buff marl			
		tenuicostatum	42	10.75		121	Pale grey - buff marl			
						120	Pale grey - buff marl			
	119					Buff marl				
	UPPER PLENSBACHIAN	spinatum	38	12		118	Buff marl			
						37	17.5		117	Grey marl
									116	Grey marl
						margaritatus	36	5		115
35		5		114	Grey calcareous shale					
				113	Dark grey calcareous shale					
112		Buff marl								
111		Dark grey calcareous shale								
110		Dark grey calcareous shale								
LOWER PLENSBACHIAN		davoei	28	7.25		109	Medium grey calcareous shale			
	108					Medium grey calcareous shale				
	ibex	26	10		107	Buff marl				
					106	Pale grey calcareous shale				
jamesoni	24	2 - 3		105	Buff marl.					
				104	Cream - buff marl					
				103	Dark grey - buff marl					

Fig. 2. Stratigraphic summary of the Zambujal section.

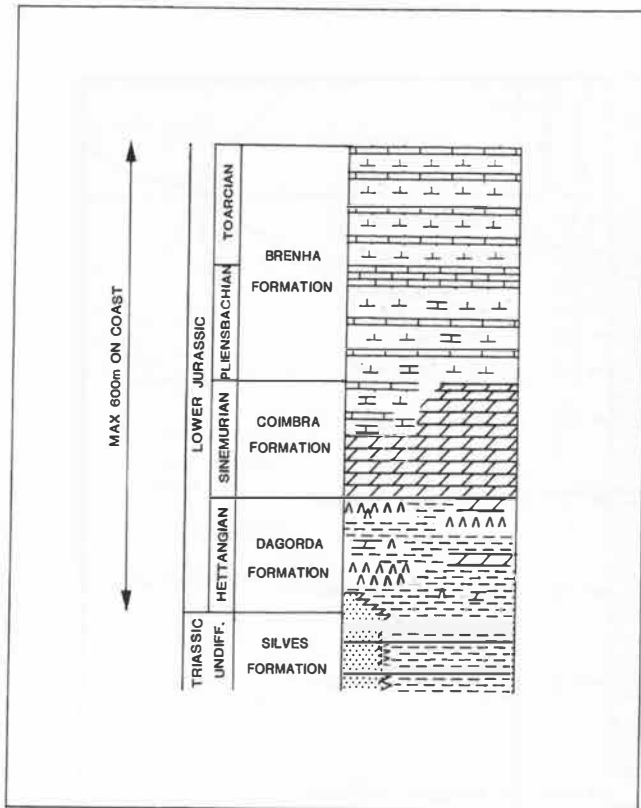


Fig. 3. A generalized lithostratigraphy of the Lusitanian Basin.

water depth occurred throughout the Sinemurian and Lower Pliensbachian, with an apparent maximum water depth occurring in the *margaritatus* Zone of the Upper Pliensbachian. This corresponds to the most widespread episode of argillaceous sedimentation, and also to the common occurrence of bituminous shale beds in the central part of the basin (e.g. Sao Pedro de Muel and Peniche). These 'deep' water shales are abruptly overlain throughout the basin by limestones and indurated marls of the *spinatum* Zone. The position of the Pliensbachian–Toarcian boundary within the Portuguese succession is not well defined. The well indurated limestone and marl sequence containing *spinatum* Zone ammonites forms an easily recognizable lithostratigraphic unit throughout the Lusitanian Basin. A combination of lithostratigraphic and biostratigraphic criteria has apparently been used to place the boundary at the point where these hard lithologies are abruptly overlain by soft blue-grey shales containing abundant specimens of pyritized juvenile dactyloceratid ammonites. However, from the faunal lists provided by Mouterde (1955) for the Peniche coastal exposures, it would appear that a more acceptable boundary position is at the base of Mouterde's Bed 15e, within the limestone–marl unit, corresponding to the first appearance of *Paltarpites paltus* (K. Page, pers. comm., 1994). The underlying beds contain ammonites of the genus *Tauromeniceras* belonging to the *emaciaticeras* Zonule (K. Page, in press) which is believed to be equivalent in age to the upper part of the *spinatum* Zone, *hawskerense* Subzone in northern Europe. The occurrence of soft blue-grey shales with dactyloceratid ammonites immedi-

ately above the hard limestone–marl unit has been found in exposures as far apart as Peniche, Brenha and Zambujal. These assemblages are believed to occur within the lower part of the *semicelatum* Subzone of the *tenuicostatum* Zone. Sample was collected from these beds approximately 50 cm to 1 m above the top of the hard limestone–marl unit. At Zambujal the faunal lists of Mouterde *et al.* (1964) provide no firm indication of the presence of the *paltus* Subzone and it is probable that in the basin margin locations a condensed sequence or a discontinuity occurs between the *spinatum* Zone and the *semicelatum* Subzone of the Lower Toarcian. The Toarcian succession predominantly consists of marls and shales up to the *bifrons* Zone; thereafter the frequency and thickness of interbedded limestones gradually increases.

In the Zambujal region, the Pliensbachian and Toarcian comprises a series of calcareous shales, marls and limestones representing the informally named Brenha Formation. The *jamesoni–ibex* Zones are dominated by interbedded buff to pale grey marls and limestones, with subordinate calcareous shales and claystones. The *davoei* and *margaritatus* Zone sediments become progressively more shaly and darker in colour. A marked lithological change can be seen at the top of the *margaritatus* Zone and into the *spinatum* Zone, with the occurrence of interbedded hard limestones and grey to buff coloured indurated marls. Within the lower part of the *tenuicostatum* Zone, an abrupt change in sedimentation witnesses the reappearance of dominantly pale grey to buff calcareous shales and marls, with subordinate limestone development. The interbedded nature of the shale–marl–limestone lithologies continues through the Toarcian and into the Aalenian, although the proportion of limestone to marl and calcareous shale increases, from the *bifrons* Zone upwards.

OSTRACOD BIOZONATION

Five ostracod zones are defined for the Pliensbachian and Toarcian of Zambujal, Portugal. All five ostracod zones comprise assemblage zones, using the most abundant ostracod taxa, particularly those which possess limited stratigraphical ranges. The proposed zonation is outlined in Fig. 4, in relation to the ammonite biostratigraphy. Accessory species are also included, where they are considered important within the assemblage. A complete ostracod range chart for the Pliensbachian and Toarcian of Zambujal is presented in Fig. 5.

Gammacythere ubiquita–Ogmoconchella gruendeli Ostracod Zone

Definition. Base of the section to the last appearance of *Ogmoconchella gruendeli* Malz, 1971.

Range. Lower Pliensbachian, *jamesoni–ibex* Zones (samples 103–107).

Remarks. Both *Gammacythere ubiquita* Malz & Lord and *Ogmoconchella gruendeli* Malz are extremely common within this Zone. Common accessory species include *Polycope cerasia* Blake, *P. cincinnata* Apostolescu and *Ogmoconcha contractula* Triebel. *Gammacythere ubiquita* Malz & Lord, *Pseudomacropypris subtriangularis* Michelsen and *Monoceratina multistriata* Michelsen, are also limited to this ostracod assemblage zone.

Polycope cerasia–P. cincinnata Ostracod Zone

Definition. Base of zone defined on the last appearance of

STAGE	AMMONITE ZONES	SAMPLE NUMBER		OSTRACOD BIOZONATION
T O A R C I A N	LEVESQUEI	134		C. toarcensis -
		133		
		132		
		131		
		130		
	THOUARSENSE	129		K. costata
	VARIABILIS	128		
	BIFRONS	127		
		126		
		125		
	FALCIFERUM	124		
		123		
TENUICOSTATUM	122			
	121			
	120			
P L I E N S B A C H I A N	SPINATUM	25		L. lanceolata - O. convexa
		119		
		118		
	MARGARITATUS	115		P. cerasia - P. cincinnata
		113		
		112		
		111		
	DAVOEI	110		
		109		
	IBEX	108		
		107		
	JAMESONI	106		G. ubiquita - O. gruendeli
105				
104				
		103		

Fig. 4. Ostracod biozonation scheme of the Zambujal section.

Ogmoconchella gruendeli Malz, with top of the zone marked by the first appearance of *Ogmoconcha convexa* Boomer.

Range. Uppermost Lower–lowermost Upper Pliensbachian, *davoi-margaritatus* Zones (samples 108–115).

Remarks. Throughout this interval, species of *Polycope* dominate the assemblage, reaching a peak abundance of over 90% in sample 111 (lower *margaritatus* Zone) (Fig. 5). The Metacopina are absent from many of the samples within this assemblage zone. *Monoceratina amlingstadtensis* Triebel & Bartenstein, *Monoceratina michelseni* Rieggraf, *Eucytherura zambujalensis* sp.

nov., *Ogmoconcha contractula* Triebel, *Ogmoconchella adenticulata* (Pietrzenuk) and *Paracypris redcarensis* (Blake) have their last occurrences within this zone. *Ektyphocythere quadrata* Boomer & Lord, *Gramannella apostolescui* (Gramann) and *Paradoxostoma pusillum* Michelsen are restricted to this zone.

***Liasina lanceolata-Ogmoconcha convexa* Ostracod Zone**

Definition. Base of zone defined on the common occurrence of *Liasina lanceolata* (Apostolescu), in association with the first appearance of *Ogmoconcha convexa* Boomer. The top of the

STAGE		AMMONITE ZONES	SAMPLE NUMBER																							
T O A R C I A N	LEVESQUEI		134	18																						
			132	13																						
			131	90																						
			130	100																						
	THOUARSENSE		129	65																						
		VARIABLES	128	48																						
	BIFRONS		127	28	1																					
			126	42																						
			125	25																						
			124	7																						
	FALCIFORM		123	35																						
			122																							
	TENUCOSTATUM		121																							
		120																								
Z5				1																						
S P I N A T U M		119	13																							
		118	8	11																						
		116	10	1																						
	MARGARITATUS		113	50																						
			112	80	12																					
			111	55																						
			110	27																						
	DAVOEI		109	25	1																					
			108	13																						
	IBEX		107	40	9	4																				
			106	88	1	3																				
	JAMESONI		105	78	48	5	3	11	1																	
			104	80	10	15																				
		103	1	2	4	3																				

Fig. 5. Ostracod biostratigraphy of the Zambujal section ranked by the first occurrence. Ostracod abundances record the total number of valves per sample (i.e. one carapace = 2). In most cases, abundances above 100 are rounded to the nearest 10. Sample numbers are the same as those used in Exton (1979), except for sample Z5 which is an additional sample.

zone is defined by the first appearance of *Bairdiacypris rectangularis* Ainsworth.

Range. Uppermost Pliensbachian–lowermost Toarcian, *spinatum*–lower *tenuicostatum* Zones (samples 116–119, Z5).

Remarks. Both index taxa are extremely common within this interval. Species which have their last occurrences within the zone include *Polycope cincinnata* Apostolescu, *Liasina lanceolata* (Apostolescu), *L. vestibulifera* Gramann, *Bairdia hahni* Lord & Moorley, *Ogmoconchella aequalis* Herrig and *O. septenaria* (Gründel). *Ogmoconcha convexa* Boomer, *O. inflata* (Ainsworth), *O. sp. A sensu* Boomer, 1992, *Kinkelinella tenuicostata* Martin and *Bairdia carinata undulata* Herrig are restricted to this zone.

The Upper Pliensbachian–lowermost Toarcian ostracod assemblages recorded at Zambujal show strong similarities with those of the Early Toarcian (essentially *tenuicostatum* Zone) of northern Europe (Boomer & Ainsworth, in press). Throughout much of Europe, the Metacopina become extinct within the *tenuicostatum* Zone. However, in the Mochras Borehole, North Wales, their extinction occurs in the lowermost *falciferum* Zone (Boomer, 1991).

***Bairdiacypris rectangularis*–*Kinkelinella sermoisensis* Ostracod Zone**

Definition. Base of zone defined on the first occurrence of *Bairdiacypris rectangularis* Ainsworth and/or *Kinkelinella sermoisensis* (Apostolescu), with the top of the zone defined by the first appearance of *Kinkelinella costata* Knitter, in association with large numbers of *Cytherella toarcensis* Bizon.

Range. Lower Toarcian–lowermost Middle Toarcian, upper *tenuicostatum*–upper *bifrons* Zones (samples 120–126).

Remarks. This assemblage is initially marked by low diversity and low abundance ostracod assemblages (samples 120, 121) (Fig. 5), similar in composition to those described by Ainsworth (1986) and Boomer (1991) from contemporary sequences in the Fastnet Basin and the Mochras Borehole, respectively. These assemblages directly follow the extinction of the Metacopina.

The *Bairdiacypris rectangularis*–*Kinkelinella sermoisensis* Zone contains part of Exton & Gradstein's (1984) *Bairdiacypris* sp. Assemblage Zone. That Zone ranged from mid. *tenuicostatum* to the top of the *variabilis* Zone, and was based on the abundant occurrence of an unnamed species of *Bairdiacypris* sp. recorded by Bate & Coleman. *Ektyphocythere* aff. *E. intrepida* Bate & Coleman, is the only taxon to be stratigraphically restricted to this Zone. Common accessory species include *Bairdiacypris triangularis* Ainsworth and *Polycope* sp.

***Cytherella toarcensis*–*Kinkelinella costata* Ostracod Zone**

Definition. Base of zone defined on the first appearance of *Kinkelinella costata* Knitter, in association with large numbers of *Cytherella toarcensis* Bizon.

Range. Uppermost Middle–Upper Toarcian, uppermost *bifrons*–upper *levesquei* Zones (samples 127–134).

Remarks. From the base of the *thouarsense* Zone (Upper Toarcian) upwards, the assemblages are dominated by the Platycopina, mainly *Cytherella toarcensis* Bizon (Fig. 5). Accessory species within this zone include *Cytheropteron alafastigatum* Fischer, *Monoceratina scrobiculata* Triebel & Bartenstein, *Bairdia ohmertii* Knitter, *Eucytherura transversipli-*

cata (Bate & Coleman), *Praeschuleridea arguta magna* Ainsworth and *P. foveolata* Ainsworth. The occurrence of *Praeschuleridea pseudokinkelinella* Bate & Coleman, in Zambujal (upper *bifrons*–*thouarsense* Zones) is stratigraphically higher than those occurrences in northern Europe, where it ranges from the *falciferum* through to lower *variabilis* Zones.

OSTRACOD BIOSTRATIGRAPHY OF THE ZAMBUIJAL SECTION

Eighty species of Ostracoda have been recognized from the Pliensbachian and Toarcian of Zambujal, Portugal by the present authors (Fig. 5). The marked increase in faunal diversity compared to the earlier study by Exton (1979) reflects the numerous studies undertaken on European Lias sequences since 1979. Many of the taxa from Zambujal have been described throughout northern Europe, albeit with discontinuous or differing stratigraphic ranges, reflecting either the geographical setting and/or facies variation.

Lower Pliensbachian

Thirty ostracod species occur in the Lower Pliensbachian of Zambujal (Fig. 4). Notable occurrences include *Gammacythere ubiquita* Malz & Lord, *Gramannella apostolescui* (Gramann), *Ektyphocythere quadrata* Boomer & Lord, *Monoceratina multi-striata* Michelsen, *Cardobairdia* sp. A *sensu* Ainsworth, *Ogmoconcha contractula* Triebel, *Ogmoconchella adenticulata* (Pietrzenuk), *O. gruendeli* Malz, *Cardobairdia posteroprolata* Ainsworth, C. sp. K (*sensu* Apostolescu), *Polycope cerasia* Blake, *P. cincinnata* Apostolescu, *Bairdia hahni* Lord & Moorley, *B. molesta* Apostolescu, *Bairdiacypris rectangularis* Ainsworth, *Paracypris redcaensis* (Blake), *Liasina lanceolata* (Apostolescu), *Monoceratina michelseni* Riegraf, *M. amlingsstad-tensis* Triebel & Bartenstein, *Eucytherura zambujalensis* sp. nov., *Ogmoconchella aequalis* Herrig, *O. hispinosa* (Gründel) and *O. septenaria* (Gründel). The first nine taxa are stratigraphically restricted to the Lower Pliensbachian. Ten species become locally extinct by the end of the Early Pliensbachian (Fig. 5).

Throughout this interval, the assemblages are generally represented by three groups, the Cladocopina (*Polycope cerasia* Blake, *P. cincinnata* Apostolescu), the Metacopina (*Ogmoconcha contractula* Triebel, *Ogmoconchella gruendeli* Malz) and the cytheracean species (*Gammacythere ubiquita* Malz & Lord, *Eucytherura zambujalensis* sp. nov.).

Upper Pliensbachian

Thirty-one species of Ostracoda occur in the Upper Pliensbachian, of which 14 have their originations. Notable first appearances include *Liasina vestibulifera* Gramann, *Paradoxostoma pusillum* Michelsen, *Kinkelinella tenuicostata* Martin, *Ogmoconcha inflata* (Ainsworth), *O. convexa* Boomer and *O. sp. A sensu* Boomer. Of the 31 taxa occurring in the Upper Pliensbachian, eight are stratigraphically restricted, while 21 species become locally extinct by the end of the Upper Pliensbachian interval (Fig. 5).

In the *margaritatus* Zone (samples 110–115), the ostracod assemblages are dominated by the Cladocopina (*Polycope cerasia* Blake, *P. cincinnata* Apostolescu), in association with *Eucytherura zambujalensis* sp. nov. Both the Metacopina (absent in samples 110–113) and cytheracean components of the

assemblage are less abundant than in the preceding Zone (Fig. 5). A marked faunal change occurs in the *spinatum* Zone (samples 116–119), with the assemblage dominated by the Metacopina (*Ogmoconcha convexa* Boomer, *O. inflata* (Ainsworth)), in association with *Kinkelinella tenuicostata* Martin and *Liasina vestibilifera* Gramann. Three *Ogmoconcha* species occur in the *spinatum* Zone. *Ogmoconcha inflata* (Ainsworth) and possibly *O. sp. A sensu* Boomer can be considered as 'vallate forms' which, although first described from Pliensbachian 'Tethyan' deposits from southern Germany (Malz, 1975), have subsequently been described throughout much of Europe and North Africa (Ainsworth, 1987; Boomer, 1992). The other species of *Ogmoconcha* recorded from the Upper Pliensbachian–lowermost Toarcian of Zambujal, *O. convexa* Boomer, has also been recorded from the *spinatum*–*tenuicostatum* Zones of southern England, the Mochras Borehole, Wales and offshore southwest Ireland (Boomer, 1991, 1992; Ainsworth *et al.*, 1989).

Lower Toarcian

Twenty species of Ostracoda are present in the Lower Toarcian of Zambujal of which 11 taxa have their first appearances. Newly occurring taxa include *Cytherella toarcensis* Bizon, *Pseudomacropyris sp. A sensu* Ainsworth, *Liasina? cylindrica* Ainsworth, *Monoceratina ungulina* Triebel & Bartenstein, *Ektyphocythere cf. E. intrepida* Bate & Coleman, *E. mediodepressa* sp. nov. and *Kinkelinella sermoisensis* (Apostolescu). All the above seven taxa range into the Middle Toarcian (Fig. 5). Eight species become locally extinct by the end of the Lower Toarcian.

A marked change in the ostracod assemblage occurs within the lower part of the *tenuicostatum* Zone (sample Z5), with the extinction of the Metacopina, in association with an abrupt decline in faunal diversity and abundance. During the upper part of the *tenuicostatum* Zone (samples 120, 121), a slight increase in faunal diversity and abundance is noted (Fig. 5). This marked faunal turnover occurs throughout much of onshore and offshore northwest Europe during this time.

A further increase in diversity and abundance occurs within the *falciiferum* Zone (samples 122, 123), with 12 species present. The assemblages are dominated by *Bairdiacypris* (*B. triangularis* Ainsworth, *B. rectangularis* Ainsworth), *Pseudomacropyris sp. A sensu* Ainsworth and *Kinkelinella sermoisensis* (Apostolescu). Similar assemblages have been described from the Fastnet and North Celtic Sea Basins (Ainsworth, 1986; Ainsworth *et al.*, 1989).

Middle Toarcian

Twenty-one species of Ostracoda occur in the Middle Toarcian of which 10 have their originations. Notable first appearances include *Polycope discus* Fischer, *Cardobairdia toarcensis* Ainsworth, *Cytheropteron alafastigatum* Fischer, *Kinkelinella costata* Knitter and *Praeschuleridea pseudokinkelinella* Bate & Coleman. All five taxa range into the Upper Toarcian. Overall the assemblages are dominated by *Polycope sp.*, *Bairdiacypris* (*B. rectangularis* Ainsworth, *B. triangularis* Ainsworth), *Kinkelinella sermoisensis* (Apostolescu) in samples 124 and 125, and *K. costata* Knitter, in samples 127 and 128 and *Praeschuleridea pseudokinkelinella* Bate & Coleman. By the end of the Middle Toarcian, nine taxa have become extinct (Fig. 5). Many of these

taxa are common throughout northern Europe during this time.

Upper Toarcian

Thirty-one species of Ostracoda have been recovered from the Upper Toarcian of Zambujal, of which 14 taxa have their originations (Fig. 5). First appearances include *Bairdia ohmertii* Knitter, *Monoceratina scrobiculata* (Triebel & Bartenstein), *Eucytherura transversiplicata* (Bate & Coleman), *Otocythere callosa* Triebel & Klingler, *Praeschuleridea arguta magna* Ainsworth, *P. foveolata* Ainsworth and *Praeschuleridea aff. P. sp. A sensu* Ainsworth.

Throughout this interval, the assemblages are dominated by *Polycope sp.*, *Cytherella toarcensis* Bizon, *Bairdia ohmertii* Knitter, *Ektyphocythere mediodepressa* sp. nov., *Kinkelinella costata* Knitter, and to a lesser extent by *Praeschuleridea* (*P. foveolata* Ainsworth, *P. aff. P. sp. A sensu* Ainsworth), and *Monoceratina scrobiculata* Triebel & Bartenstein.

The *thouarsense* Zone (sample 129) assemblage is very similar in composition to the underlying *variabilis* Zone. A marked increase in faunal diversity and abundance occurs at the base of the *levesquei* Zone (sample 130), with the occurrence of six new species (Fig. 5). Many of the taxa have been described from northwest Europe, especially in those studies of Ainsworth (1986) and Boomer (1991) from the Toarcian and Aalenian of the Fastnet Basin and Mochras Borehole, respectively. *Praeschuleridea pseudokinkelinella* Bate & Coleman is noteworthy for its higher stratigraphical range (upper *bifrons*–*thouarsense* Zone) at Zambujal, compared with that in England (*fulciiferum*–*bifrons* Zones).

FAUNAL ANALYSIS

Changes in the faunal composition of the Ostracoda at the suborder–superfamily level in the Zambujal sequence are numerically illustrated in Fig. 6. From these data, a number of distinct 'episodes' with characteristic assemblages are noted, at least one of which is of global significance. To interpret these changes in faunal composition it is also necessary to integrate information both on diversity levels and rates of faunal turnover, as outlined in Fig. 7. It must be noted beforehand that the sampling strategy was strongly influenced by the sediment type (e.g. only marls and calcareous shales were processed). Furthermore, none of the data take into account the weight of the unprocessed sample.

The earliest sediments studied (*jamesoni* to *duvoei* Zones, samples 103–109) yield quite diverse assemblages dominated by the Cytheracea and the Metacopina. During most of the succeeding *margaritatus* Zone interval, however, there are no Metacopina recorded. These assemblages are dominated (up to 90%) by the Cladocopina (as species of *Polycope*). This undoubtedly reflects some environmental shift at the site of deposition. Not only are the Cladocopina the most abundant faunal group as a percentage of the samples during this interval, but they are also numerically abundant in absolute terms.

No modern analogue is known for such assemblages. The Cladocopina occur in almost all marine environments, however, they are rarely encountered in large numbers (R. C. Whatley, pers comm.). Diverse cladocopine assemblages have been recorded from the Quaternary of the Arctic Ocean (Joy & Clark, 1974). Lower Jurassic assemblages from other European

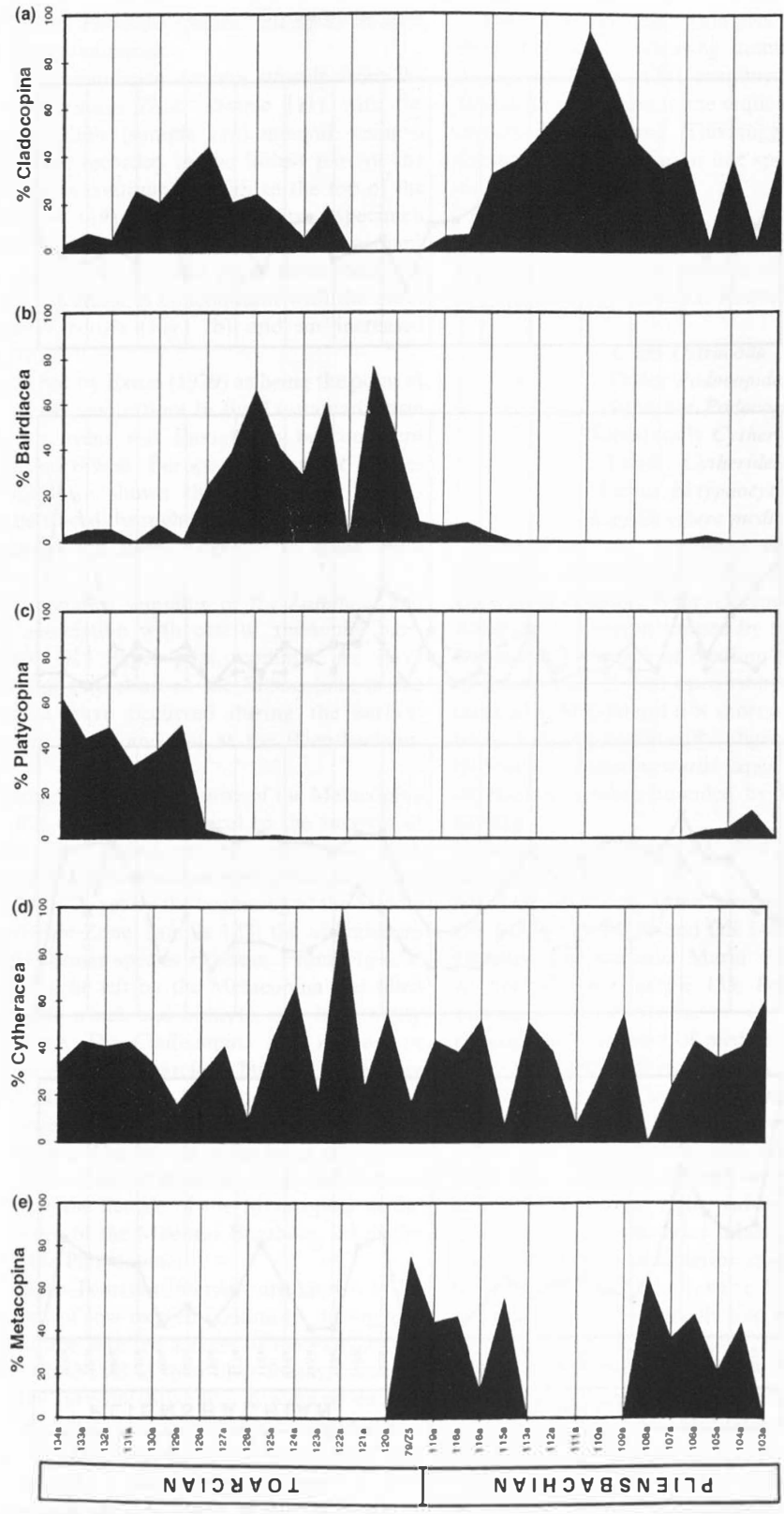


Fig. 6. The faunal composition is represented by the percentage of (a) Cladocopina, (b) Bairdiacea, (c) Platycopina, (d) Cytheracea and (e) Metacopina throughout the sequence. For detailed stratigraphy see the text and Fig. 2.

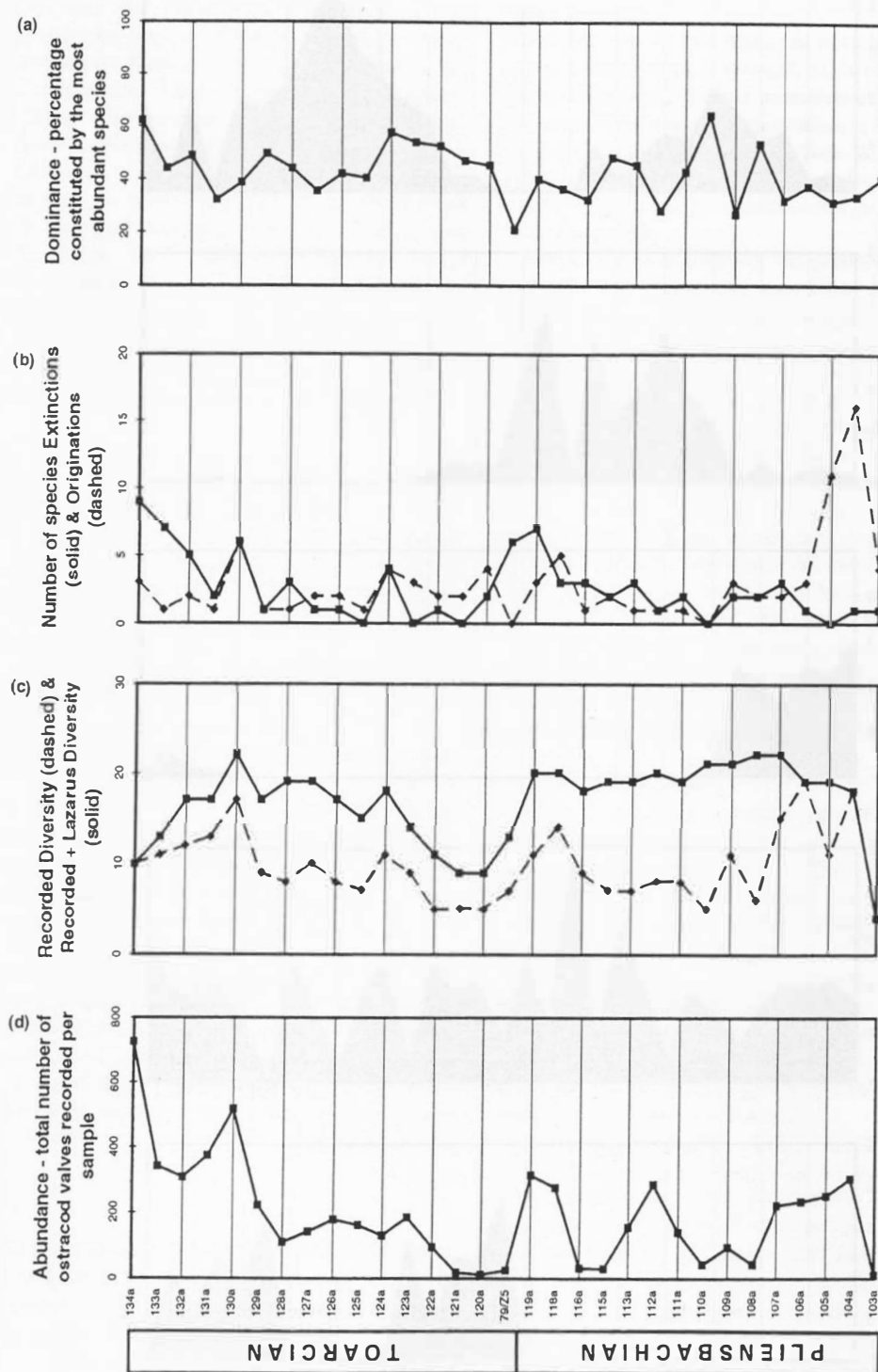


Fig. 7. Changes in the ostracod assemblages are recorded in four ways. (a) Dominance, this is calculated as the percentage, for a given sample, constituted by the single most abundant species. (b) Faunal Turnover, the number of species having their first appearance (Originations) and those with their last appearance (Extinctions) in each sample. (c) Diversity is recorded in two ways. Firstly, as the number of species present in a sample (Recorded Diversity) and secondly, as the recorded diversity plus the number of taxa, termed Lazarus species, which are apparently absent but are recorded stratigraphically above and below that sample (Compound Diversity). (d) Specimen Abundance, the number of valves per sample. For detailed stratigraphy see the text and Fig. 2.

sections commonly record *Polycope* species, but never in such high numbers or in such dominance.

The peak in *Polycope* abundance declines steadily from the lower part of the *margaritatus* Zone (sample 111), with the uppermost *margaritatus* Zone (sample 115) interval seeing a return to the assemblages recorded in the lowest part of the sequence. These conditions continue through to the top of the *spinatum* Zone (sample 119). At this junction, specimen abundance sees a marked decrease. This in itself is perhaps not significant since similar fluctuations occur throughout the sequence, however, this decrease is concomitant with the onset of a marked diversity trough (Fig. 7b) and an increased extinction rate (Fig. 7c).

This event was described by Exton (1979) as being the point at which the Metacopina became extinct in the Lusitanian Basin and the timing of this event was thought to be consistent throughout much of northwest Europe. Subsequent studies (Boomer, 1991, 1992) have shown that the timing of this extinction event can be traced through to the *tenuicostatum* and even *falciferum* zones of the Early Toarcian in some more northerly sequences.

As a result of more detailed sampling of the Zambujal and Peniche sections, in association with careful ammonite biostratigraphical control (K. Page, pers. comm.), we have established that the final extinction of the Metacopina in the Lusitanian Basin must have occurred during the earliest Toarcian (*tenuicostatum* Zone) and not at the Pliensbachian/Toarcian boundary.

Whatever events brought about the demise of the Metacopina the conditions were not completely inimical to the survival of benthonic Ostracoda. The abundance remained low, with diversity halved during the *tenuicostatum* and lower *falciferum* Zones (samples Z5, 120–122), yet by the beginning of the Middle Toarcian (upper *falciferum* Zone, sample 123) the assemblages had recovered to their former species richness. From Fig 6, it would appear that the niche left by the Metacopina was filled initially by the Bairdiacea which had hitherto only been rarely recorded in the sequence. The Cladocopina also increase in importance during the Middle Toarcian, but by the Upper Toarcian (*thouarensis* Zone, sample 129) they had begun to decrease and they, together with the Bairdiacea, had been replaced by the Platycopina. The success of the latter group is in accordance with the observations of Boomer (1991) and Boomer & Whatley (1992) where the demise of the Metacopina in the extensive Liassic sequence of the Mochras Borehole, led to the subsequent success of the Platycopina.

The Middle and Upper Toarcian intervals are known to be characterized by periods of low oxygen conditions throughout much of Northwest Europe with the success of the Platycopina during this time being attributed to their filter feeding mode of life bestowing a greater survival capability in reduced oxygen environments (Whatley, 1991). This is probably a simplification of the Lower Jurassic picture since many non-platycopids also survive these kenoxic periods. It should be noted, however, that no evidence of oxygen deficient conditions have been observed in the Toarcian sedimentary record of Portugal. It is almost incontrovertible that the loss of such an important and long ranging group as the Metacopina, led to a large niche availability which the Platycopina were best able to take advantage of.

The Upper Toarcian (samples 129–134) sequence appears to show a steadily increasing dominance of Platycopina. In the youngest sample (134) examined, the dominance (fig. 7d) is almost at its greatest in the sequence, diversity is decreasing and abundance increasing. This suggests increasing environmental stress where one group or one species is best adapted to survive and reproduce.

SYSTEMATIC DESCRIPTIONS

Figured specimens deposited in the collections of the Department of Palaeontology, Natural History Museum, London.

Class *Ostracoda* Latreille, 1806

Order *Podocopida* Müller, 1894

Suborder *Podocopina* Sars, 1866

Superfamily *Cytheracea* Baird, 1850

Family *Cytherideidae* Sars, 1925

Genus *Ektyphocythere* Bate, 1963

Ektyphocythere mediodepressa sp. nov.

(Fig. 8, figs 1–8)

1979 *Ektyphocythere* sp. 2, Exton: 59, pl. 13, figs 1, 2.

Derivation of name. With reference to the vertical depression in the mid-valve region formed by the discontinuation of ribbing.

Diagnosis. Carapace of medium size, subtriangular. Ornament of strongly developed open ribbing with few poorly developed cross-ribs. Mid-lateral ribs short and thickened, often discontinuous, forming a vertically aligned depression extending from mid-valve region towards apex of triangular ribbing. The depression is often bounded by vertically aligned elements of ribbing.

Holotype. Adult female RV; Natural History Museum (NHM), London OS 14839.

Material. 80 valves, three carapaces (Paratypes NHM, London OS 14836–OS 14838 and OS 14840–OS 14843).

Locality and horizon. Maria Pares Hill section, Zambujal, 48°2'N, 8°28'W, sample 133, Bed 50, *levesquei* Zone, Upper Toarcian, Lower Jurassic.

Description. Carapace of medium size, subtriangular in lateral view, subovate in dorsal view. Anterior margin asymmetrically rounded, extremity slightly below mid-height. Posterior margin rounded subtriangular in left valves, subtriangular in right valves, extremity below mid-height. Dorsal margin slightly convex to straight in left valves, straight with prominent cardinal angles in right valves. Posterior margin convex, tapering towards posterior. Maximum length below mid-height, maximum height at anterior cardinal angle, maximum width behind mid-length. Left valve larger than right valve, overlapping right valve dorsally and ventrally. Sexually dimorphic, male dimorph more elongate than female. Carapace strongly calcified. Ornament of strongly developed open, longitudinal ribbing with poorly defined cross-ribs forming subrounded to subovate reticulation. Mid-laterally, ribbing short and thickened, often discontinuous, forming a vertically aligned depression, extending from mid-valve region towards apex of triangular ribbing. This depression is bounded by vertically aligned elements of ribbing. Eye spot moderately well developed. Eye sulcus less well defined. Inner lamella moderately broad, line of concrescence coincides with inner margin. Radial pore canals not observed. Hinge antimerodont; right valve terminal dentate

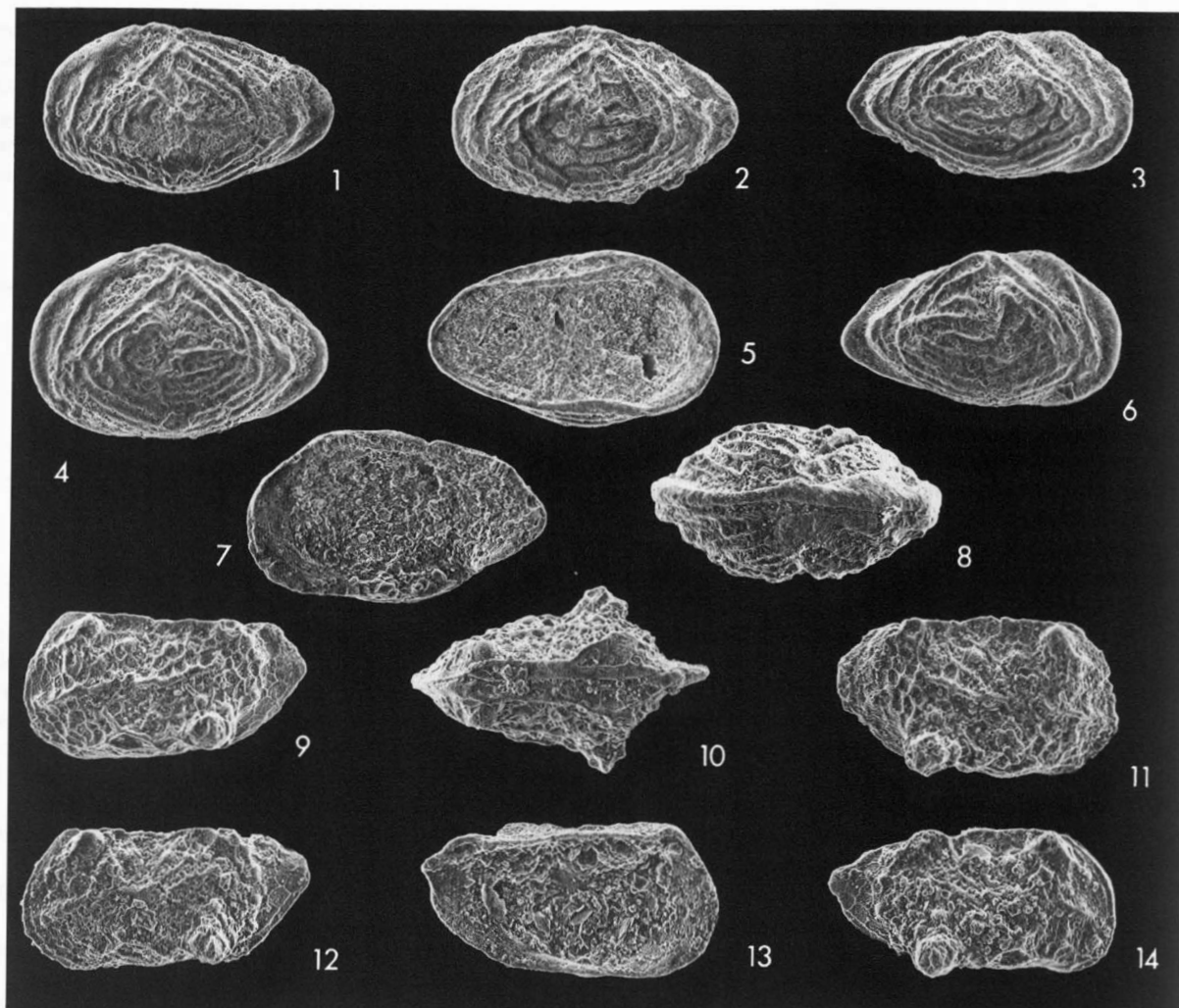


Fig. 8. F = Female, M = Male, LV = Left valve, RV = Right valve, CAR = Carapace, all external lateral views unless otherwise stated. All specimens deposited in the collections of the Department of Palaeontology, Natural History Museum, London. **figs 1–8.** *Ektyphocythere mediodepressa* sp. nov., sample 133, Bed 50, *levesquei* Zone, Upper Toarcian, Lower Jurassic of Zambujal. **1.** MLV, $\times 54$, OS 14836, paratype. **2.** FLV, $\times 63$, OS 14837, paratype. **3.** MRV, $\times 56$, OS 14838, paratype. **4.** FLV, $\times 64$, OS 14839, holotype. **5.** MLV, internal lateral view, $\times 54$, OS 14840, paratype. **6.** FRV, $\times 64$, OS 14841, paratype. **7.** FRV, internal lateral view, $\times 66$, OS 14842, paratype. **8.** FCAR, dorsal view, $\times 60$, OS 14843, paratype. **Figs 9–14.** *Eucytherura zambujalensis* sp. nov., sample 113, Bed 33, *margaritatus* Zone, Upper Pliensbachian, Lower Jurassic of Zambujal. **9.** FLV, $\times 100$, OS 14844, holotype. **10.** FCAR, dorsal view, $\times 108$, OS 14845, paratype. **11.** FRV, $\times 108$, OS 14846, paratype. **12.** MLV, $\times 101$, OS 14847, paratype. **13.** FLV, internal lateral view, $\times 116$, OS 14848, paratype. **14.** MRV, $\times 105$, OS 14849, paratype.

ridges comprising six subovate teeth, separated by a straight, finely locellate groove. Left valve complementary, but with a well-developed wide accommodation groove above median hinge element, which thins towards posterior-loculate socket. Muscle scar pattern not observed.

Dimensions. Length 600–740 μm , height 360–400 μm .

Distribution. At present, only recorded from the type locality, sample 122, bed 43, *falciferum* Zone, Lower Toarcian, samples 131–133, bed 50, *levesquei* Zone, Upper Toarcian.

Remarks. This species shows similarities to both *Ektyphocythere intrepida* Bate & Coleman, 1975 and *E. ambo* Boomer, 1992. It can be distinguished from both these species by the discontinuous median ribbing and the occurrence of a central vertically aligned depression.

Family *Cytheruridae* Müller, 1894

Genus *Eucytherura* Müller, 1894

Eucytherura zambujalensis sp. nov.

(Fig. 8, figs 9–14)

1979 ?*Cytheropteron* sp. Exton: 57, pl. 9, figs 1, 3.

Derivation of name. With reference to the occurrence of this species from the type locality of Zambujal.

Diagnosis. Carapace very small, subtriangular, strongly inflated laterally. Ornament of ribbing and reticulation similar to that of *Eucytherura transversiplicata*, Bate & Coleman, 1975 but with very prominent postero-ventral and postero-dorsal nodes and eye nodes. Well formed dorsal flange in right valve.

Holotype. Adult female LV; Natural History Museum, London OS 14844.

Material. 189 valves, five carapaces (Paratypes NHM, London OS 14845–OS 14849).

Locality and horizon. Maria Pares Hill section, Zambujal, 48°2'N, 8°28'W, sample 113, Bed 33, *margaritatus* Zone, Upper Pliensbachian, Lower Jurassic.

Description. Carapace very small, subtriangular in lateral view, inflated in dorsal view. Anterior margin slightly asymmetrically rounded, extremity immediately below mid-height. Posterior margin subtriangular, extremity above mid-height. Dorsal margin slightly sinuous. Posterior margin weakly convex, tapering upwards towards posterior margin. Maximum length above mid-height, maximum height at anterior cardinal angle, maximum width behind mid-length at posterior termination of postero-ventral nodes. Left valve slightly larger than right. Carapace moderately strongly calcified. Ornament of moderately coarse polygonal reticulation, most strongly developed centrally, weakening towards the margins. Three oblique ribs developed anteriorly, the uppermost rib joins onto a well-developed eye node, the central rib extends from below mid-anterior margin, extending to ribbed postero-dorsal node, while the ventro-lateral rib extends from antero-ventral margin along poorly inflated alae terminating immediately below ventral margin at a prominent postero-ventral node. Well formed dorsal flange extends from anterior to posterior cardinal angles in right valves. Inner lamella broad anteriorly and posteriorly. Inner margin coincides with line of concrescence. Radial pore canals not observed. Hinge lophodont. Muscle scar pattern not observed.

Dimensions. Length 360–385 µm, height 180–195 µm.

Distribution. At present, only recovered from the type locality, samples 104–113, beds 23–33, *jamesoni-margaritatus* Zones, Lower to Upper Pliensbachian.

Remarks. This species is similar to *Eucytherura transversiplicata* (Bate & Coleman, 1975) recorded from the Toarcian and Aalenian of northwest Europe, but differs in the possession of a ribbed postero-dorsal node and a very prominent postero-ventral node. *Eucytherura batei* (Ainsworth, 1986), is also similar, but can be distinguished by the absence of the oblique central rib, postero-ventral node and postero-dorsal node.

CONCLUSIONS

- In the light of more recent studies on Lower Jurassic Ostracoda, a re-examination has been undertaken on the Pliensbachian and Toarcian Ostracoda first described by Exton (1979) from the Lusitanian Basin, west-central Portugal. Eighty species of Ostracoda have now been recognised, of which two species are newly described (*Eucytherura zambujalensis* sp. nov., *Ektyphocythere medio-depressa* sp. nov.). Poor preservation precludes a complete taxonomic review of the present material. Many of the assemblages possess strong similarities to those described from Northeast Spain, France, Germany, southern England and to a lesser extent to those described from the Fastnet Basin.
- Five ostracod zones have been proposed; *Gammacythere ubiquita-Ogmoconchella gruendeli* Zone (Lower Pliensbachian), *Polycope cerasia-P. cincinnata* Zone (Uppermost Lower-lower Upper Pliensbachian), *Liasina lanceolata-Ogmoconcha convexa* Zone (uppermost Pliensbachian–lower-

most Toarcian), *Bairdiacypris rectangularis-Kinkelinella sermoensis* Zone (Lower–lowermost Middle Toarcian), and *Cytherella toarcensis-Kinkelinella costata* Zone (Uppermost Middle–Upper Toarcian).

- An analysis of the ostracod assemblages from the Zambujal sequence has revealed fluctuations in the faunal composition which almost certainly reflect environmental changes, although at this point their interpretation remains uncertain. One distinct episode in the Late Pliensbachian led to the temporary dominance of the Cladocopina, a steady rise which is followed by a steady fall. The significance of this is uncertain since no modern of fossil analogues are known. The most significant change in faunal composition is the event which brought about the extinction of the Metacopina during the *semicelatum* subzone, the lower subzone of the *tenuicostatatum* Zone of Early Toarcian age. This extinction event is similar to that which occurs throughout much of Northwest Europe at this time. Further work is required to fully understand the causes of this important event. The niche vacated by the Metacopina appears to have been initially filled by the Bairdiacea and later the Platycopina.

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