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 (Euryherura 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; Gymnocythere ubiquita-Ogmocoelina germeneli Zone, Polycype cerasia-Polycope cincinnata Zone, Liasma lanceolata-Omnonga convexa Zone, Bairdiacypris rectangularis-Kinkelina sermoensis Zone, and Cytherella toarcensis-Kinkelina 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 Polycype. A marked faunal turnover, in association with the extinction of the Metacopina occurs in the lower Subzone of the temucoiostatum 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 temucoiostatum Zone (semicellatum 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

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Fig. 1. Location of Lower Jurassic outcrops in west central Portugal.
Pliensbachian and Toarcian Ostracoda

| SYSTEM            | SUBSTAGE            | AMMONITE ZONES | BED NUMBER | APPROX. THICKNESS (metres) | GENERALISED LITHOLOGY | LITHOLOGICAL DESCRIPTION |
|-------------------|---------------------|----------------|------------|---------------------------|-----------------------|--------------------------|
| LOWER JURASSIC    | Pliensbachian       | levesquei      | 50         | 23                        | Pale grey marl        |                         |
|                   |                     | thouarsense    | 49         | 5.3                       | Pale grey marl        | Olive green marl         |
|                   |                     | variabilis     | 48         | 10.5                      | Pale grey marl        | Grey - green marl        |
|                   | MIDDLE TOARCIAN     | bifrons        | 47         | 31                        | Pale grey - buff marl |                         |
|                   |                     |                | 46         | 32.5                      | Pale grey - buff marl |                         |
|                   | LOWER TOARCIN       | falciferum     | 45         | 6.0                       | Pale grey - buff marl |                         |
|                   |                     | tenuicostatum  | 44         | 9.0                       | Pale grey - buff marl |                         |
|                   |                     |                | 43         | 9.5                       | Pale grey - buff marl |                         |
|                   |                     | spinatum       | 42         | 10.75                     | Pale grey - buff marl |                         |
|                   |                     |                | 41         | 1.5                       | Pale grey - buff marl |                         |
|                   |                     |                | 40         | 0.4                       | Pale grey - buff marl |                         |
|                   |                     |                | 39         | 2.4                       | Pale grey - buff marl |                         |
|                   | UPPER PLIENSACHIAN  | margaritatus   | 36         | 5                         | Dark grey calcareous  | Dark grey calcareous    |
|                   |                     |                | 35         | 5                         | shale                 | shale                    |
|                   |                     |                | 34         | 5                         | Dark grey calcareous  | Dark grey calcareous    |
|                   |                     |                | 33         | 5                         | shale                 | Dark grey calcareous    |
|                   |                     |                | 31         | 5                         | shale                 | Dark grey calcareous    |
|                   |                     | davoaei        | 26         | 10                        | Pale grey calcareous  | Pale grey calcareous    |
|                   |                     | ibex           | 25         | 2 - 3                     | shal                  | shal                     |
|                   |                     | jamesoni       | 23         | 5 - 10                    | Pale grey calcareous  | Pale grey calcareous    |
|                   |                     |                | 22         | 6                         | shal                  | Pale grey calcareous    |

Fig. 2. Stratigraphic summary of the Zambujal section.
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 apparently has 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 dactylioceratid ammonites. However, from the faunal lists provided by Mouterde (1955) for the Peniche coastal exposures, the underlying beds contain ammonites of the genus Tauromeniceras belonging to the enaciaticeras Zonule (K. Page, pers. comm., 1994). The underlying beds contain ammonites of the genus Tauromeniceras belonging to the enaciaticeras Zonule (K. Page, pers. comm., 1994) which is believed to be equivalent in age to the upper part of the spinatum Zone, hawkskeraense Subzone in northern Europe. The occurrence of soft blue-grey shales with dactylioceratid ammonites immediately 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 0.5 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 paltum 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 shaley 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.

Gammarcythere ubiquita–Ogmoconchella gruenedeli Ostracod Zone

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

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

Remarks. Both Gammarcythere ubiquita Malz & Lord and Ogmoconchella gruenedeli Malz are extremely common within this Zone. Common accessory species include Polycopus cerasia Blake, P. cincinnati Lord, and Omoconchella gruenedeli Malz. Also very rare in this ostracod assemblage zone.

Polycopus cerasia–P. cincinnati Ostracod Zone

Definition. Base of zone defined on the last appearance of

Fig. 3. A generalized lithostratigraphy of the Lusitanian Basin.
Ogmoconchella gruendeli Malz, with top of the zone marked by the first appearance of Ogmoconcha convexa Boomer.

Range. Uppermost Lower-lowermost Upper Pliensbachian, davoel-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 margarinatus Zone) (Fig. 5). The Metacopina are absent from many of the samples within this assemblage zone. Monoceratina amlingstadensis Triebel & Bartenstein, Monoceratina michelseni Riegraf, Eucytherura zambujalensis sp. nov., Ogmoconchella contractula Triebel, Ogmoconchella adenticulata (Pietrzenuk) and Paracypris redeeensis (Blake) have their last occurrences within this zone. Ektyphocythera quadrata Boomer & Lord, Gramannella apostolesci (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
Fig. 5. Ostracod biostratigraphy of the Zambujal section ranked by the first occurrence. Ostracod abundances above 100 are rounded to the nearest 10. Sample numbers are the same as those used in Exton (1979), except for sample 25 which is an additional sample.
Pliensbachian and Toarcian Ostracoda

Ostracods from Zambujal have been described by Exton (1979) and Boomer (1991). Several species recorded at Zambujal show strong similarities with assemblages recorded at Zambujal (Fig. 4). Notable occurrences include *Gammacythere ubiquita* Malz & Lord, *Gramannella apostolescui* (Gramann), *Ekthyphocythere quadrata* Boomer & Lord, *Monoceratina multiseperta* Ainsworth, O. inflata (Ainsworth), *Ainsworthia* sp. A (sensu Boomer, 1992, 1999), *Kinkelinel/a costata* Martin and *Bairdia carinata undulata* Herrig are restricted to this zone.

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

**Bairdiacypris rectangularis-Kinkelinel/l costata Ostracod Zone**

**Definition.** Base of zone defined on the first occurrence of *Bairdiacypris rectangularis* Ainsworth and of *Kinkelinel/l costata* Knitter, in association with large numbers of *Cytherella toarcensis* Bizon.

**Range.** Uppermost Toarcian–lowestmost Toarcian, *spina-tum*-lower *teniuscostatum* 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 cincnata* Apostolescu, *Liasina lanceolata* (Apostolescu), *L. vestibulifera* Gramann, *Bairdia hahnii* Lord & Moorley, *Ogmocyclherella aequalis* Herrig and *O. septemaria* (Gründel). *Ogmocyclherella convexa* Boomer, *O. inflata* (Ainsworth), *O. sp. A* (sensu Boomer, 1992, 1999), *Kinkelinel/a costata* Martin and *Bairdia carinata undulata* Herrig are restricted to this zone.

**Remarks.** From the base of the *falciferum* Zone (Uppermost Middle–Upper Toarcian) upwards, the assemblages are dominated by the Platycopina, mainly *Cytherella toarcensis* Bizon (Fig. 5). Accessory species within this zone include *Cytheropteron alafas1iga1um* Fischer, *Monoceratina scrobiculata* Triebel & Bartenstein, *Bairdia ohmerti* Knitter, *Eucytherura transversipli-
cata* (Bate & Coleman), *Praeschuleridea arguta magna* Ainsworth and *P. foveolata* Ainsworth. The occurrence of *Praeschuleridea pseudokinellina* 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 ZAMBUJAL SECTION**

Eighty species of Ostracoda have been recognized from the Pliensbachian and Toarcian of Zambujal, Portugal by the present authors (Fig. 4). 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), *Ekthyphocythere quadrata* Boomer & Lord, *Monoceratina multiseperta* Ainsworth, *Cardobairdia* sp. A (sensu Ainsworth, 1986) and Herrig are 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 cincnata* Blake, *P. cincnata* Apostolescu), the Metacopina (*Ogmocyclherella contractula* Triebel, *Ogmocyclherella 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 origins. Notable first appearances include *Liasina vestibulifera* Gramann, *Paradoxostoma pusillum* Michelsen, *Kinkelinel/a costata* Martin, *Ogmocyclherella 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 *margaritarus* Zone (samples 110–115), the ostracod assemblages are dominated by the Cladocopina (*Polycope cincnata* Blake, *P. cincnata* 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 vesthilulera 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–tenuiocostatum 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, Pseudomacrocypris sp. A sensu Ainsworth, Liasina? cylindrica Ainsworth, Monoceratina ungulina Triebel & Bartenstein, Ektyphocythere cf. E. intrepidus Bate & Coleman, E. mediodepressão 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 tenuiocostatum Zone (sample ZS), with the extinction of the Metacopina, in association with an abrupt decline in faunal diversity and abundance. During the upper part of the tenuiocostatum 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 falciiferal Zone (samples 122, 123), with 12 species present. The assemblages are dominated by Bairdiacypris (B. triangularis Ainsworth, B. rectangularis Ainsworth), Pseudomacrocypris 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 originsations. Notable first appearances include Polycyche discus Fischer, Cardoboaria toarcensis Ainsworth, Cytherobairdia toarcensis Ainsworth, Bairdiacypris (B. triangularis Ainsworth, B. rectangularis 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 originsations (Fig. 5). First appearances include Bairdia ohmerti Knitter, Monoceratina scrobiculata (Triebel & Bartenstein), Eucytlzerura transversiplicata (Bate & Coleman), Otocythere calllosa Triebel & Klingler, Praeschuleridea arguta magna Ainsworth, P. foewolata Ainsworth and Praeschuleridea aff. P. sp. A sensu Ainsworth.

Throughout this interval, the assemblages are dominated by Polycyche sp., Cytherella toarcensis Bizon, Bairdia ohmerti Knitter, Ektyphocythere mediodepressão sp. nov., Kinkelinella costata Knitter, and to a lesser extent by Praeschuleridea (P. foewolata 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 (falciferum–bifrons Zones).

FAUNAL ANALYSIS
Changes in the faunal composition of the Ostracoda at the sub-order–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 daveei 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 Polycyche). 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 *Polycopa* species, but never in such high numbers or in such dominance.

The peak in *Polycopa* 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 *tenuecostatum* 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 (*tenuecostatum* Zone) and not at the Plenbschian/Toarcian boundary.

Whatever events brought about the demise of the Metacopina the conditions were not completely inimical to the survival of bentonic Ostracoda. The abundance remained low, with diversity halved during the *tenuecostatum* 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 (*thouarense* 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 & Whately (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 (Whately, 1991). This is probably a simplification of the Lower Jurassic picture since many non-platycopids also survive these kenoic 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 Ektypocythere** Bate, 1963
  - **Ektypocythere mediodepressa** sp. nov.

(Fig. 8. figs 1-8)

1979 *Ektypocythere* 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°27'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 defined. 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
ridges comprising six subovate teeth, separated by a straight, finely locellate groove. Left valve complementary, with a well-developed wide accommodation groove above median hinge element, which thins towards posterior-locate socket. Muscle scar pattern not observed.

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

**Distribution.** At present, only recorded from the type locality, sample 133, Bed 50, leavesque Zone, Upper Toarcian, Lower Jurassic of Zambujal. 1. MLV, ×54, OS 14836, paratype. 2. FLV, ×63. OS 14837, paratype. 3. MRV, ×56. OS 14838, paratype. 4. FLV, ×64. OS 14839, holotype. 5. MLV, internal lateral view, ×54, OS 14840, paratype. 6. FRV, ×64. OS 14841, paratype. 7. FRV, internal lateral view, ×66, OS 14842, paratype. 8. FCAR, dorsal view, ×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, ×100, OS 14844, holotype. 10. FCAR, dorsal view, ×108, OS 14845, paratype. 11. FRV, ×108, OS 14846, paratype. 12. MLV, ×101, OS 14847, paratype. 13. FLV, internal lateral view, ×116, OS 14848, paratype. 14. MRV, ×105, OS 14849, paratype.

**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 Eucy therura transversiplicata, Bate & Coleman, 1975 but with very prominent posteromedial and posterodorsal nodes and eye nodes. Well formed dorsal flange in right valve.

**Holotype.** Adult female LV; Natural History Museum, London OS 14844.
Pliomsbachian and Toarcian Ostracoda

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 asymmetrical, rounded, extremity immediately below mid-height. Posterior margin subtriangular, extremity above mid-height. Postero-ventral node. Dorsal margin slightly sinusoidal. 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 node. 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 anterior-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 concresence. 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
1. 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 zumbyalensis sp. nov., Ektyphocysthore 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 the Fastnet Basin. Although at this point their interpretation remains uncertain.

2. Five ostracod zones have been proposed; Gammacytheridae ubiquita-Ogmoconchella grunedi Zone (Lower Pliensbachian), Polycope cerasia-P. cincinnata Zone (Uppermost Lower-Jower Upper Pliensbachian), Liasina lanceolata-Ogmoconchella convexa Zone (uppermost Pliensbachian-lowermost Toarcian), Bairdiacypri rectangulatis-Kinkelnelia sermoisensis Zone (Lower-lowermost Middle Toarcian), and Cytherella toarcensis-Kinkelnelia costata Zone (Uppermost Middle–Upper Toarcian).

3. 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 semicatellatum subzone, the lower subzone of the tenuicostatum 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 Platycedina.

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