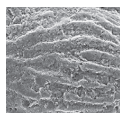# Ostracods of the Toarcian (Jurassic) of Peniche, Portugal: taxonomy and evolution across and beyond the GSSP interval

MARIA CRISTINA CABRAL, ALAN R. LORD, SUSANA PINTO, LUÍS V. DUARTE & ANA C. AZERÊDO

The stratigraphical occurrence of ostracod assemblages of the uppermost Pliensbachian (*emaciatum* Biozone) and Lower–Middle Toarcian (*polymorphum*, *leviosi* and *bifrons* biozones) at Peniche, western Portugal, is reported, an interval that encompasses the Toarcian Global Boundary Stratotype Section and Point (GSSP) and the Toarcian Oceanic Anoxic Event as represented by a Carbon Isotope Excursion (CIE). The broad pattern of ostracod faunal turnover and replacement in the Peniche GSSP section before, during and after the CIE, including "survivor" and "Lazarus" species, and the stepwise extinction of metacopine ostracods is similar to that described from elsewhere in Western Europe. Assemblage composition is closest to material described from the Fastnet Basin, offshore SW Ireland, and the Mochras Farm Borehole, Wales, Great Britain. The $\delta^{13}C$ record at Peniche and Mochras Farm facilitates a very refined comparison of ranges of species in common between the two sites. The species *Bairdia paramolesta* sp. nov. and *Kinkelinella ventrocarinata* sp. nov. are described. • Key words: Pliensbachian–Toarcian, ostracods, CIE, taxonomy, biostratigraphy, palaeobiogeography, Portugal.

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With the formal recognition of the Global Boundary Stratotype Section and Point (GSSP) for the base of the Toarcian Stage at Peniche, western Portugal (Rocha *et al*. 2016), all stages of the Early Jurassic are now defined thus providing the essential stratigraphic framework for developing understanding of global environmental conditions and biota for that period of time (201.4–174.2 Ma, Ogg *et al*. 2016). The Toarcian stage represents a very special phase of Earth history when, to cite Xu *et al*. (2018, pp. 396–397): "The Toarcian stage (~183–174 Ma) is considered to be the warmest interval of the Jurassic period encompassing a transient temperature rise of up to ~7 °C in mid-latitudes (Dera *et al*. 2011, Gradstein *et al*. 2012, Korte *et al*. 2015). The stage is also marked by one of the most intense and geographically widespread developments of anoxic/euxinic oceanic conditions of the Mesozoic era (Jenkyns 2010). This phenomenon of extreme redox changes is therefore termed the Toarcian Oceanic Anoxic Event (T-OAE, at

~183 Ma) and is marked by large-scale organic-carbon burial in shelf-sea settings, deeper marine basins, and lakes (Jenkyns 1985, 1988; Xu *et al*. 2017). The T-OAE was characterized by a severe perturbation to the global carbon cycle…". We give this quotation at length because it is an efficient introduction to Toarcian times, which are currently the subject of a large and rapidly growing literature which it is not our purpose to summarize here. Current work links the growth of a late Pliensbachian cryosphere and its decline in the early Toarcian with climate change and sea level fluctuations, broadly Pliensbachian regression and early Toarcian transgression, and freshwater input into the oceans with greenhouse gases released into the atmosphere and reflected in the carbon isotope record (Ruebsam *at al*. 2019). This phase of the Earth history also records a widely documented mass extinction (*e.g*. Hallam 1961, Little & Benton 1995, Caswell *et al*. 2009, Caruthers *et al*. 2013, Danise *et al*. 2013) which is clearly demonstrated in an important group
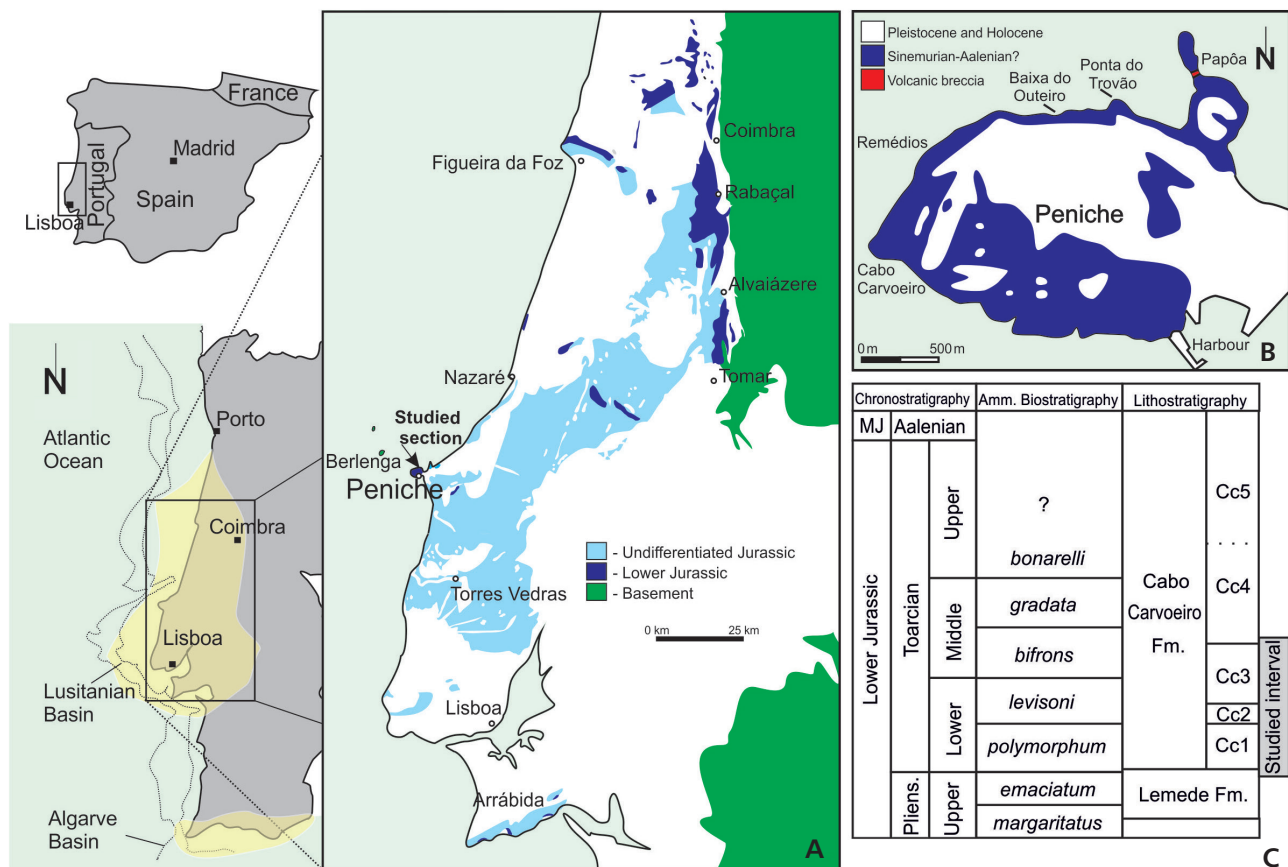
Figure 1. A – Peniche region, general location map; yellow zones: offshore area of Lusitanian and Algarve basins. • B – detail of Peniche Peninsula with location of Ponta do Trovão (GSSP). • C – chronostratigraphic, biostratigraphic (ammonite) and lithostratigraphic framework of the studied interval. Based on Duarte & Soares (2002) and Duarte *et al.* (2017). Abbreviation: Fm. – Formation.

of microbiota, Ostracoda (*e.g.* Lord 1982, Boomer *et al.* 2008). We use the term Carbon Isotope Excursion (CIE) in preference to T-OAE, as the δ¹³C signal is the primary record of an event which although broadly global in scale represented fluctuations in bottom water oxygenation and allowed the existence of relatively oxygenated refugia for species that may disappear temporarily at some localities and later reappear when conditions ameliorate, the so-called "Lazarus" taxa.

The present paper describes and discusses the occurrence pattern of ostracods across the Pliensbachian–Toarcian stage boundary (which includes the Toarcian GSSP) and through and post the CIE at Peniche, western Portugal.

The uppermost Pliensbachian–Middle Toarcian section at Peniche

The study region is located at the coastline, 80 km to the north of Lisbon (Fig. 1), where an almost complete Lower Jurassic to probably lowermost Middle Jurassic marl–

limestone succession crops out in excellent conditions. The Peniche Peninsula succession is over 450 m thick and it bears a highly important geological record that, besides its international multidisciplinary relevance (*e.g.* Rocha *et al.* 2016, Duarte *et al.* 2017, and references therein), is one of the key sections for understanding the sedimentological evolution and stratigraphy of the Lusitanian Basin (LB). This Mesozoic western Iberian basin was controlled by the geodynamic processes leading to the North Atlantic Ocean opening and was under the influence of the western Tethys Sea, as shown by the ammonite and benthic foraminifers records. The Lower and Middle Jurassic infilling of the LB represent a post-Triassic rifting stage, characterized by increasingly marine deposition over the basin, from deep- to shallow-marine limestones and marls, dolostones and organic-rich shales, developed on a carbonate ramp depositional system (*e.g.* Azerêdo *et al.* 2003, Duarte *et al.* 2010, and references therein).

At Peniche, the Lower Jurassic marl-limestone deposits range in age from the (?) early Sinemurian to the late Toarcian, comprising several formations, mostly of hemipelagic nature and thus supported by ammonite

biostratigraphy (*e.g.* Mouterde 1955, Duarte *et al.* 2018) of which only the topmost Lemede (top Pliensbachian–basal Toarcian) and part of the Cabo Carvoeiro formations (CC1 to CC4 members, Lower–Middle Toarcian) are addressed here (Duarte & Soares 2002, Duarte 2007; Figs 1, 2). At Peniche, this interval records the Toarcian GSSP and the T-OAE, reflected in both carbon and oxygen stable isotope negative excursions and important changes in the biotic record, such as for calcareous nannofossils, dinoflagellates, foraminifers, ostracods and brachiopods (*e.g.* Hesselbo *et al.* 2007; Suan *et al.* 2008, 2010; Mattioli *et al.* 2009; Cabral *et al.* 2011, 2013; Comas-Rengifo *et al.* 2015; Rita *et al.* 2016; Rocha *et al.* 2016; Correia *et al.* 2017; Duarte *et al.* 2017; Fantasia *et al.* 2019). The sharpest change is recorded in the ostracod group, with extinction of the Metacopina (Cabral *et al.* 2011, 2013; Rocha *et al.* 2016). The Lower Toarcian of Peniche shows two important negative carbon isotope events which can be globally correlated (Hesselbo *et al.* 2007, Littler *et al.* 2010, Fantasia *et al.* 2019) (Fig. 2). The first event corresponds to Horizon 1 of Hesselbo *et al.* (2007, figs 2, 3); the second event, between horizons 2 and 3 of Hesselbo *et al.* (2007, figs 2, 3) is the most important, hereafter referred as the CIE; it is particularly well defined and coincides with the early T-OAE. At the same time, this interval displays evidence of marked sedimentary changes. The Pliensbachian–Toarcian transition marks a 2nd order regressive-transgressive discontinuity over the LB (Duarte 2007, Duarte *et al.* 2010), where the onset of the CIE corresponds to clear basin wide facies changes (*e.g.* Duarte 1997, Duarte *et al.* 2004, Pittet *et al.* 2014, Rodríguez-Tovar *et al.* 2017, Fantasia *et al.* 2019). At Peniche, these changes include the occurrence of siliciclastic deposits showing turbidite features (Wright & Wilson 1984, Duarte 1997), within an otherwise regular marl-limestone succession, increasingly more limestone dominated upwards.

The levels studied for ostracods correspond to the *emaciatum* (extreme top), *polymorphum*, *levisoni* and *bifrons* ammonite biozones (Figs 1, 2). The *emaciatum* and extreme base of *polymorphum* biozones (top of Lemede Formation) are mostly represented by open marine limestones, with abundant ammonites and belemnites. The *polymorphum* Biozone encompasses the CC1 member (mb) also reflecting open marine depositional conditions, shown by highly fossiliferous greyish marls and marly limestones, with ammonites, belemnites, brachiopods, bivalves and *Zoophycos* sp. The lower part of the *levisoni* Biozone (CC2 mb) is a grey marl-dominated interval, much poorer in macrofossils, mainly ammonites and a few brachiopods, and exhibits several lenticular siliciclastic facies enriched in wood fragments. The upper part of *levisoni* through most of the *bifrons* Biozone (CC3 mb) marks the disappearance of the siliciclastic facies, being characterized by a heavily bioturbated marl-limestone

alternation enriched in ammonites with the latter lithology increasing upwards. The uppermost part of the *bifrons* Biozone (base of CC4 mb) is dominated by a marly package, but upwards the unit shows increasingly common shallower water limestones (references cited above; Fig. 2).

Material and methods

Forty seven samples from the studied section (Fig. 2) were analysed using standard micropalaeontological techniques. Along the section the sampling was focused on marl levels and its frequency higher at the Pliensbachian–Toarcian boundary, CIE interval and member boundaries.

Approximately 300 g of each sample were dried for 24 hours and then treated with kerosene and when disaggregated the sample was washed on 150 and 63 μm sieves. The 150 μm fraction was completely picked and identifiable species counted. The 150–63 μm fraction was inspected for small adult species.

The ostracod material is poorly preserved and often crushed, with Pliensbachian assemblages even less well preserved than Toarcian. Better preserved material is available from inland sections at Rabaçal (also known as Zambujal in literature) and Boca da Mata (Alvaiázere region), the former exposes all the Toarcian and the latter exposes Upper Toarcian to Aalenian (Duarte 1997, Pinto 2008, Cabral *et al.* 2013). In order to adequately figure *Kinkelinella ventrocarinata* sp. nov. we have included material from Rabaçal. Unless otherwise stated, numbers of specimens given under Material refer to Peniche and the term Occurrence refers to records from Peniche. For reasons of preservation it was not possible to make reliable assessments of relative species abundances, for example, in better preserved material it was possible to differentiate between 3 morphospecies of *Bairdiacypris*, but in many cases it was only possible to identify the genus.

Type and figured material deposited in the Senckenberg Museum, Frankfurt am Main.

Abbreviations: C = carapace(s); V = valve(s); LV = left valve; RV = right valve; L = length in mm; h = height in mm.

The ostracods – Systematic Palaeontology

Ostracods of Early Jurassic age are reasonably well-known from Northern and Western Europe (see for example Arias 2006 for a list of species and literature) and assemblages from the Pliensbachian and Toarcian of Peniche have been briefly and partially reported by Pinto *et al.* (2007) and Rocha *et al.* (2016).

All the species recorded are figured (Figs 3–10) and their biostratigraphical distribution shown in Fig. 11; for reasons

of preservation it was not possible to make absolute counts of numbers of specimens in species, the total given for each species below are for specimens where we are certain of the identification and therefore represent minimum numbers. For the same reason even relative species abundances are impossible to estimate with any reliability. The preservation problem is demonstrated in Fig. 11 by the 'Unidentifiable' column on the right.

In the section below we mostly focus on taxa that are new or of importance for biostratigraphical and palaeobiogeographical reasons. Synonymy lists are limited to the first naming of the species and key references in Iberia.

Class Ostracoda Latreille, 1806
Subclass Myodocopa Sars, 1866
Order Halocyprida Dana, 1852
Suborder Cladocopina Sars, 1866
Superfamily Cladocopoidea Sars, 1866
Family Polycopidae Sars, 1866

Genus *Polycope* Sars, 1866

Type species. – *Polycope orbicularis* Sars, 1866.

Remarks. – In Peniche *Polycope* occurs in the *emaciatum*, *polymorphum* and *bifrons* biozones, most commonly in the latter zone, but is essentially absent from the *levisoni* Biozone including the CIE. Most are too poorly preserved to identify at species level. A single specimen (Fig. 3A) comparable to *P. cerasia* Blake, 1876 described from the Hettangian–Sinemurian of Yorkshire, Great Britain was recorded in the *polymorphum* Biozone. In *emaciatum* and *polymorphum* biozones 15 specimens, adult C and V (Fig. 3B), are identified as *Polycope cincinnata* Apostolescu, 1959 described from the Pliensbachian of the Paris Basin. Abundant (>150 C, mostly adults) unidentifiable *Polycope* specimens, especially common in the *bifrons* Biozone, are referred to *Polycope* spp.

Subclass Podocopa Sars, 1866
Order Platycopida Sars, 1866
Suborder Platycopina Sars, 1866
Superfamily Cytherelloidea Sars, 1866
Family Cytherellidae Sars, 1866

Genus *Cytherella* Jones, 1849

Type species. – *Cytherina ovata* Roemer, 1841.

Remarks. – *Cytherella concentrica* Field, 1966 was described from the Hettangian of Dorset, Great Britain and is unusual because it has surface ornament, but was placed in *Cytherella* rather than *Cytherelloidea* because females show one posterior swelling not two as in the latter genus;

our rare Toarcian material (10 C, from which 2 juveniles) from *bifrons* Biozone is more heavily ornamented than the type material and we cite it as *Cytherella* cf. *C. concentrica* (Fig. 3C–E).

Cytherella praecadomensis (Knitter & Riegraf, 1984) from the Toarcian of SW Germany was originally described as belonging to *Cytherelloidea*, but females show a single posterior swelling as seen in *Cytherella*. Our material from *bifrons* Biozone (Fig. 3F–K) is abundant (>350 specimens, mostly juvenile and adult V), similar to the type material and the specimens figured by Boomer (1992) from southern Great Britain. However, it differs from material figured by Ainsworth (1986, pl. 1, figs 14–19) under the name ?*Cytherella depressum* sp. nov., regarded as a synonym of *C. praecadomensis* by Boomer (1992), in which female RV have more rounded dorsal margins.

Cytherella toarcensis Bizon, 1960 from the Toarcian of Paris Basin is characterized by its oval outline and a depression corresponding to the adductor muscle scars. The material from Peniche (Fig. 3L–P) is very similar to specimens from the type area and elsewhere in France but less similar to younger Toarcian material from other localities in Portugal and Spain (Boomer *et al*. 1998, Exton & Gradstein 1984, Arias & Lord 1999a).

In the *emaciatum* Biozone two specimens of *Cytherella* sp. (Fig. 3Q, R) were found, a large round form, the only representatives of the genus in that biozone. In contrast, *C. toarcensis* is the most abundant species in the CIE (in the *levisoni* Biozone), with *ca*. 70 adult and juvenile C and V.

Genus *Platella* Coryell & Fields, 1937

Type species. – *Platella gatunensis* Coryell & Fields, 1937.

Platella toarcensis Ainsworth, 1986
Figures 3S–U; 4A, B

> 1986 *Platella toarcensis* sp. nov.; Ainsworth, p. 293, pl. 2, figs 6–11.

Material. – *Ca*. 60 C and rare V, mostly adults.

Remarks. – The genus *Platella* was described from the Cenozoic of Central America. *P. toarcensis* from the Toarcian of the Fastnet Basin is described as a weakly ornamented cytherellid (although we only see ornament in our material in Fig. 3S, T) and in our opinion is a *Cytherella* species, however, we do not have enough evidence to create a nom. nov. to reassign it to the genus.

Occurrence. – Toarcian, *bifrons* Biozone.

Order Podocopida Sars, 1866
Suborder Metacopina Sylvester-Bradley, 1961

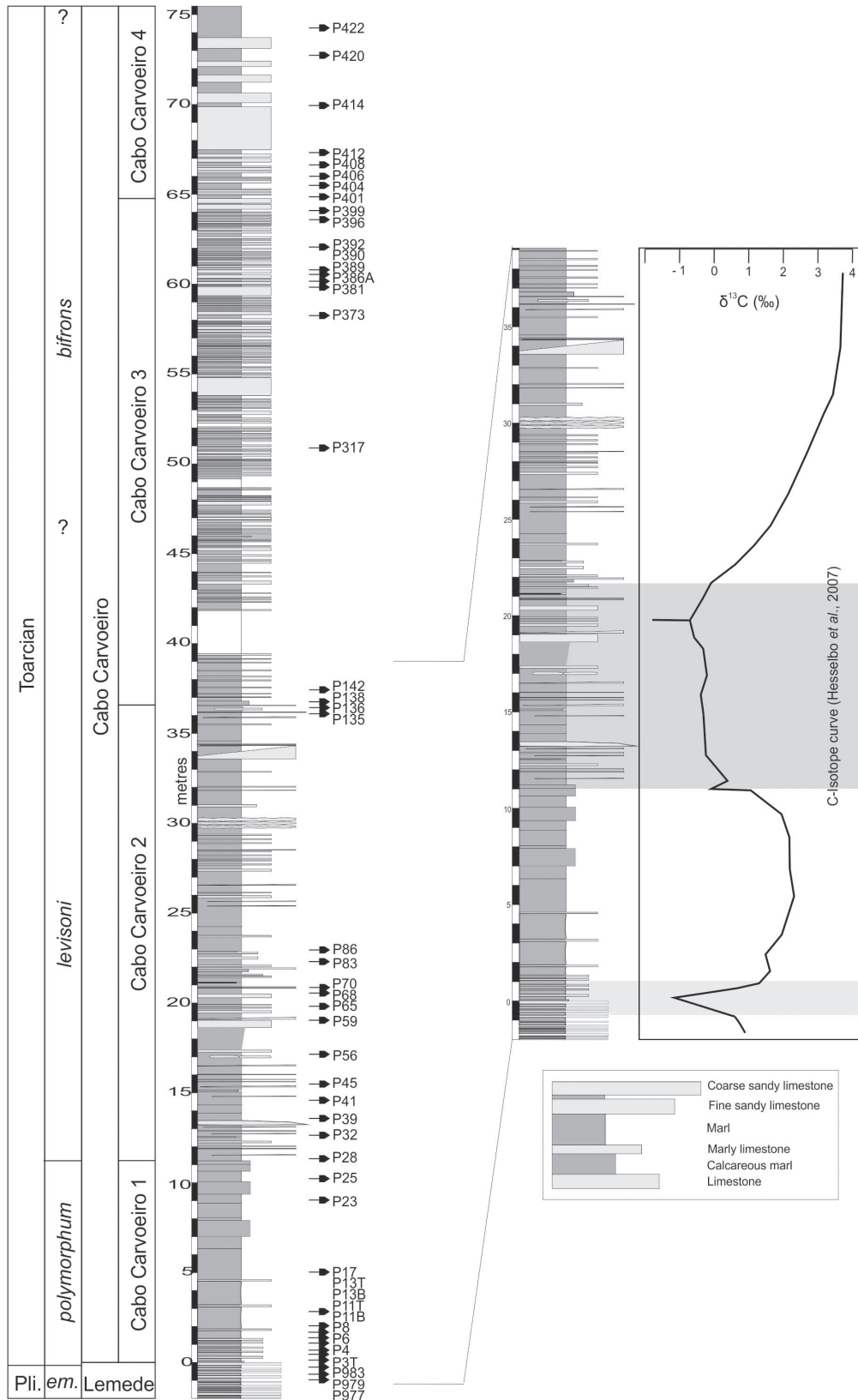**Figure 2.** Peniche section – lithostratigraphic field column (based on Duarte *et al.* 2018) with studied samples and δ¹³C isotope curve (from Hesselbo *et al.* 2007, using over 2000 samples), showing two negative intervals highlighted in grey; the main negative interval referred to in this paper as CIE (between horizons 2 and 3 of Hesselbo *et al.* 2007, figs 2 and 3) is in darker grey.

The Metacopina was defined, rather unsatisfactorily in the light of subsequent discoveries, as: 'Hinge distinct, simple to tripartite; muscle scar consisting of secondary scars assembled in a compact group; inner lamella narrow, poorly developed or unknown' (Sylvester-Bradley 1961, p. Q358). As originally defined the suborder is dominantly but not exclusively Palaeozoic, ranging from Ordovician to Cretaceous, however, as now recognized the group became extinct with the Superfamily Healdioidea in the Early Jurassic (early Toarcian). The Healdioidea (formerly Healdiacea) were more usefully defined by Shaver (1961, p. Q359) citing LV > RV overlap, with a platycopine style contact groove in the larger valve more strongly developed dorsally so as to resemble a hinge, and adductor muscle imprints consisting of numerous aggregate scars. A few healdioideans have ridges or weak surface ornament on their valves but most lack surface morphology (ridges, swellings) and are unornamented.

Unornamented calcite valves of ostracods are famously difficult to separate and identify at species level, given that ornament is a basic criterion used for species definition. This is especially a difficulty with the Metacopina as most lack ornament or surface morphology. Some species of *Ogmoconchella* show a weak netlike surface ornament when well-preserved, e.g. *Ogmoconchella propinqua* Malz, 1971, but this is clearly not a specific characteristic as several species are known to show similar patterns. These animals, although an extinct group, are unquestionably ostracods as appendages are known, albeit incompletely (Olempska *et al.* 2012). If internal information especially on muscle scar pattern is lacking then species recognition is problematic, indeed homeomorphy is unavoidable, *e.g.* the striking similarity between Silurian *Kuresaaria gotlandica* Adamczak, 1967 and Early Jurassic '*Ogmoconcha ellipsoidea* (Jones)' [= *Ogmoconchella aspinata* (Drexler, 1958)] regarded as iterative evolution by Adamczak (1976). If internal details are lacking because of poor preservation, sediment infill or only closed carapaces preserved then there is only three-dimensional shape upon which to base species definition or identification: shape of LV, shape of RV, position of smaller RV in relation to larger LV in the carapace, dorsal and ventral views, and anterior and posterior views. Carapaces are the key because they allow recognition of isolated LV and RV as belonging together, or not. There is a further complication in that juveniles of these smooth often rounded forms are rarely distinguishable below (or even at) A-1 moult stage. In these circumstances claims of recognition of sexual dimorphism in healdiids lack credibility unless the assemblage appears potentially monospecific.

One purpose of this paper is to document the extinction of the Metacopina in relation to contemporary environmental events in the Lower Toarcian. Identification proved difficult because of preservation and infilling of valves with sediment, although in many of the late Pliensbachian–early Toarcian samples examined from Peniche the preservation of the metacopes was better than that of the cytherocopes. Given these limitations, and the fact that few people now check type material, we have opted to describe and fully figure the metacopine taxa we have recognized as species, with discussion of what they are and what they are not, and to avoid describing new healdioid species.

Superfamily Healdioidea Harlton, 1933
Family Healdiidae Harlton, 1933

Genus *Ledahia* Gründel, 1964

Type species. – *Ledahia septenaria* (Gründel, 1964).

Remarks. – *Ledahia septenaria* described from the Pliensbachian of NE Germany occurs in small numbers (a total of 25 adult C) in the *emaciatum* and lower *polymorphum* biozones (Fig. 4C, D).

Genus *Ogmoconcha* Triebel, 1941

Type species. – *Ogmoconcha contractula* Triebel, 1941.

Figure 3. Ostracods from Peniche section, Portugal. • A – *Polycope* cf. *P. cerasia* Blake, 1876, carapace, right view, SMF Xe 23768; L = 0.40, h = 0.32, *polymorphum* Biozone, Toarcian, sample P6. • B – *Polycope cincinnata* Apostolescu, 1959, carapace, left view, SMF Xe 23769; L = 0.30, h = 0.25, *polymorphum* Biozone, Toarcian, sample P13T. • C–E – *Cytherella* cf. *C. concentrica* Field, 1966, *bifrons* Biozone, Toarcian; C – female carapace, right view, SMF Xe 23770, L = 0.57, h = 0.33, sample P386A; D – male carapace, dorsal view, SMF Xe 23771, L = 0.57, h = 0.32, sample P389; E – male carapace, left view, SMF Xe 23772, L = 0.58, h = 0.31, sample P408. • F–K – *Cytherella praecadomensis* (Knitter & Riegraf, 1984), *bifrons* Biozone, Toarcian; F – female RV, external view, SMF Xe 23773, L = 0.66, h = 0.43, sample P406; G – female LV, external view, SMF Xe 23774, L = 0.63, h = 0.35, sample P406; H – male RV, external view, SMF Xe 23775, L = 0.66, h = 0.40, sample P406; I – juvenile (?A-1) RV, external view, SMF Xe 23776, L = 0.58, h = 0.36, sample P406. J – male carapace, dorsal view, SMF Xe 23777, L = 0.65, h = 0.40, sample P404; K – female carapace, dorsal view, SMF Xe 23778, L = 0.65, h = 0.41, sample P404. • L–P – *Cytherella toarcensis* Bizon, 1960, *levisoni* Biozone, Toarcian, sample P32; L – female carapace, left view, SMF Xe 23779, L = 0.69, h = 0.47; M – female RV, external view, SMF Xe 23780, L = 0.69, h = 0.48; N – male carapace, right view, SMF Xe 23781, L = 0.70, h = 0.43; O – male carapace, dorsal view, SMF Xe 23782, L = 0.66, h = 0.44; P – female carapace, dorsal view, SMF Xe 23783, L = 0.67, h = 0.46. • Q–R – *Cytherella* sp., *emaciatum* Biozone, topmost Pliensbachian, sample P983; Q – female RV, external view, SMF Xe 23784, L = 0.81, h = 0.60; R – female LV, external view, SMF Xe 23785, L = 0.80, h = 0.51. • S–U – *Platella toarcensis* Ainsworth, 1986, *bifrons* Biozone, Toarcian; S – female carapace, left view, SMF Xe 23786, L = 0.68, h = 0.34, sample P422; T – female carapace, right view, SMF Xe 23787, L = 0.73, h = 0.36, sample P422; U – male carapace, right view, SMF Xe 23788, L = 0.60, h = 0.35, sample P396. Dimensions in mm. Scale bars = 100 μm.
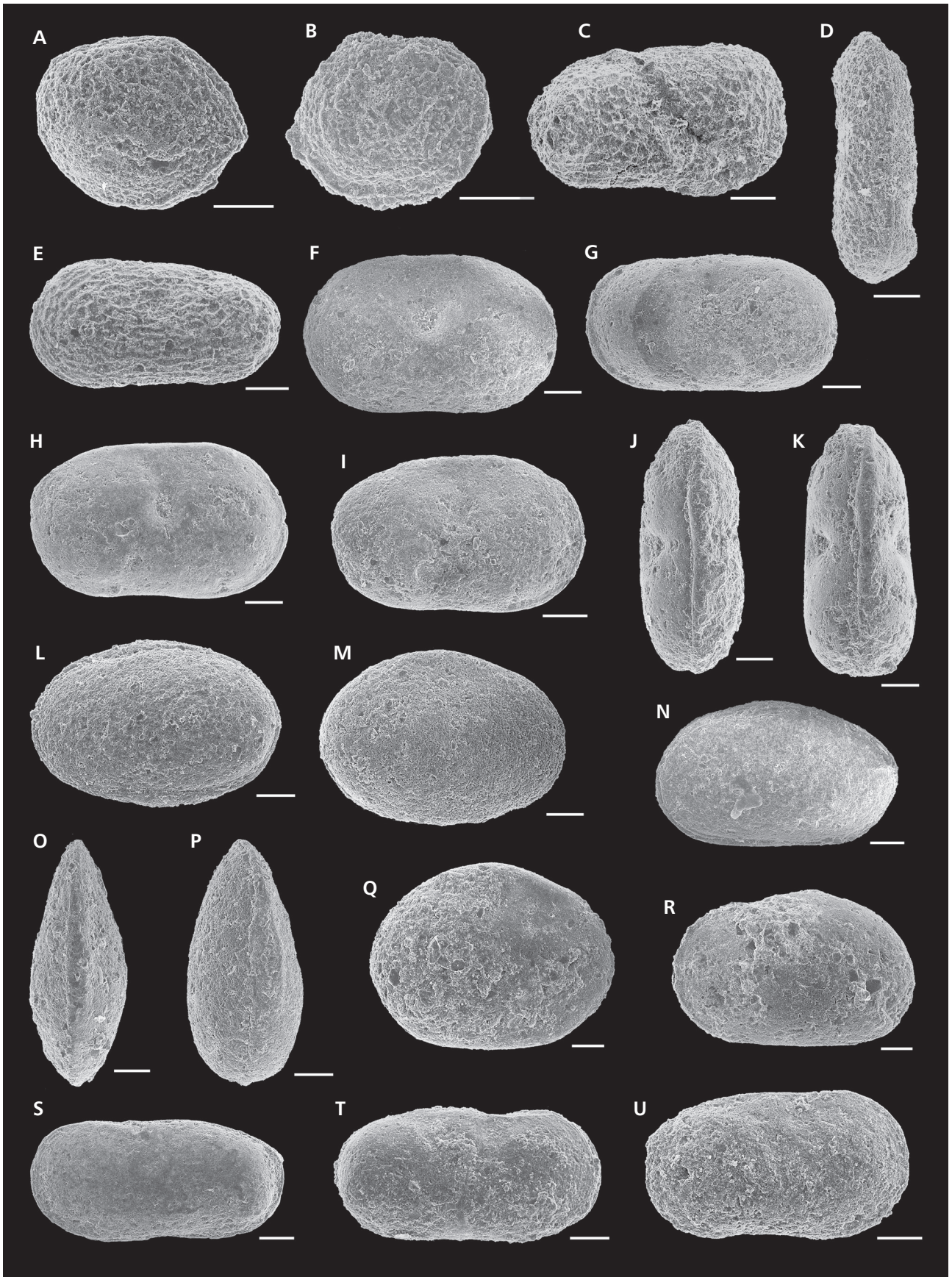
Remarks. – The genera *Ogmoconcha* and related *Ogmoconchella*, *Ledahia* and *Pseudohealdia* are the final representatives of the Suborder Metacopina, becoming extinct in the Lower Toarcian for reasons that are not entirely clear, the suborder having survived the major end Permian and end Triassic extinction events (Boomer *et al*. 2008). Certain *Ogmoconcha* species with distinctive free-margin swellings and depressions, such as *O. inflata* herein, have been separated as the genus *Hermiella* Kristan-Tollmann, 1977 (Kristan-Tollmann 1977, 1993), however, we prefer to retain them within *Ogmoconcha*, recognizing that they represent an evolutionary development of the genus with a Tethyan/Parathethyan biogeographical distribution.

Ogmoconcha convexa Boomer, 1991
Figure 4E–K

> 1991 *Ogmoconcha convexa* sp. nov.; Boomer, p. 208; pl. 1, figs 1, 5, 7, 8.
> 1998 *Ogmoconcha convexa* Boomer. – Boomer *et al*., figs 4, 5.
> 2009 *Ogmoconcha convexa* Boomer. – Boomer & Ainsworth, pl. 1, fig. 9.
> 2016 *Ogmoconcha convexa* Boomer. – Rocha *et al*., fig. 4.

Material. – *Ca*. 450 specimens, mostly V, adults and juveniles.

Original diagnosis. – "A species of *Ogmoconcha* with distinctly convex lateral surfaces in dorsal view."

Description. – As Boomer (1991, p. 208), but in our material greatest width in dorsal view is usually at midlength. Internal features not known.

Remarks. – Our material is clearly conspecific with the type material from the *tenuicostatum* Biozone of the Mochras Farm Borehole, however, we are not convinced by the possible similarity with material from the Fastnet Basin figured by Ainsworth (1987, pl. 3, figs 3, 4, 6) as *O.* aff. *O. rotunda* Dreyer as recognized by Boomer (1991). Our

material shows the same variation in adult size and shape that Boomer interpreted as sexual dimorphism, *i.e.* there appear to be two adult morphotypes that differ slightly in size and position of greatest width in dorsal view. We figure these variants as Fig. 4E–G and 4H–K. *Ogmoconcha convexa* also occurs in the Upper Pliensbachian, lower *spinatum* (= *emaciatum*) Biozone of Mochras Farm Borehole (Boomer, personal communication 2018), and in the Upper Pliensbachian, lower *spinatun* Biozone to Lower Toarcian, top *tenuicostatum* (= top *polymorphum*) Biozone of Ilminster, UK, and Fastnet Basin (Boomer & Ainsworth 2009).

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Ogmoconcha inflata (Ainsworth, 1987)
Figure 4L–S

> 1979 *Ogmoconcha ambo* Lord & Moorley. – Exton, p. 62, pl. 9, figs 6, 7.
> 1984 *Ogmoconcha* cf. *ambo* Lord & Moorley. – Exton & Gradstein, pl. 2, fig. 2.
> 1987 *Hermiella inflata* sp. nov.; Ainsworth, pp. 56, 57, pl. 2, figs 15–17, text-figs 1, 2.
> 1992 *Ogmoconcha inflata* (Ainsworth). – Boomer, p. 52, pl. 1, fig. 5.
> 1998 *Ogmoconcha inflata* (Ainsworth). – Boomer *et al*., figs 4, 5.
> 2007 *Ogmoconcha* cf. *intercedens* Dreyer. – Pinto *et al*., pl. 2, figs 1–3.
> 2009 *Hermiella inflata* Ainsworth. – Boomer & Ainsworth, pl. 1, fig. 10.
> 2016 *Ogmoconcha inflata* (Ainsworth). – Rocha *et al*., figs 4, 8.7.
> 2016 *Ogmoconcha intercedens* Dreyer. – Rocha *et al*., fig. 4.

Material. – *Ca*. 300 specimens, mostly adult V.

Original diagnosis. – "Carapace large, subovate to subcircular in lateral view, strongly inflated in dorsal view.

Figure 4. Toarcian ostracods from Peniche section, Portugal. • A, B – *Platella toarcensis* Ainsworth, 1986, *bifrons* Biozone, sample P422; A – male carapace, dorsal view, SMF Xe 23789, L = 0.59, h = 0.32; B – female carapace, dorsal view, SMF Xe 23790, L = 0.66, h = 0.35. • C, D – *Ledahia septenaria* (Gründel, 1964), *polymorphum* Biozone, sample P6; C – carapace, left view, SMF Xe 23791, L = 0.50, h = 0.28; D – carapace, dorsal view, SMF Xe 23792, L = 0.50, h = 0.28. • E–K – *Ogmoconcha convexa* Boomer, 1991, *polymorphum* Biozone, sample P23 (E–J) and sample P11T (K); E – carapace, dorsal view, SMF Xe 23793, L = 0.70, h = 0.56; F – carapace, right view, same specimen as E; G – LV, external view, SMF Xe 23794, L = 0.70, h = 0.55; H – carapace, left view, SMF Xe 23795, L = 0.68, h = 0.53; I – carapace, right view, same specimen as H; J – carapace, dorsal view, SMF Xe 23796, L = 0.70, h = 0.54; K – RV, external view, SMF Xe 23797, L = 0.64, h = 0.44. • L–S – *Ogmoconcha inflata* (Ainsworth, 1987), *polymorphum* Biozone; L – carapace, dorsal view, SMF Xe 23798, L = 0.81, h = 0.59, sample P4; M – RV, external view, SMF Xe 23799, L = 0.74, h = 0.51, sample P6; N – LV, external view, SMF Xe 23800, L = 0.80, h = 0.59, sample P3T; O – LV, external view, SMF Xe 23801, L = 0.78, h = 0.61, sample P6; P – RV, external view, SMF Xe 23802, L = 0.80, h = 0.54, sample P4; Q – carapace, right view, SMF Xe 23803, L = 0.68, h = 0.52, sample P23; R – carapace, left view, same specimen as Q; S – RV, external view, SMF Xe 23804, L = 0.67, h = 0.49, sample P23. Dimensions in mm. Scale bars = 100 μm.
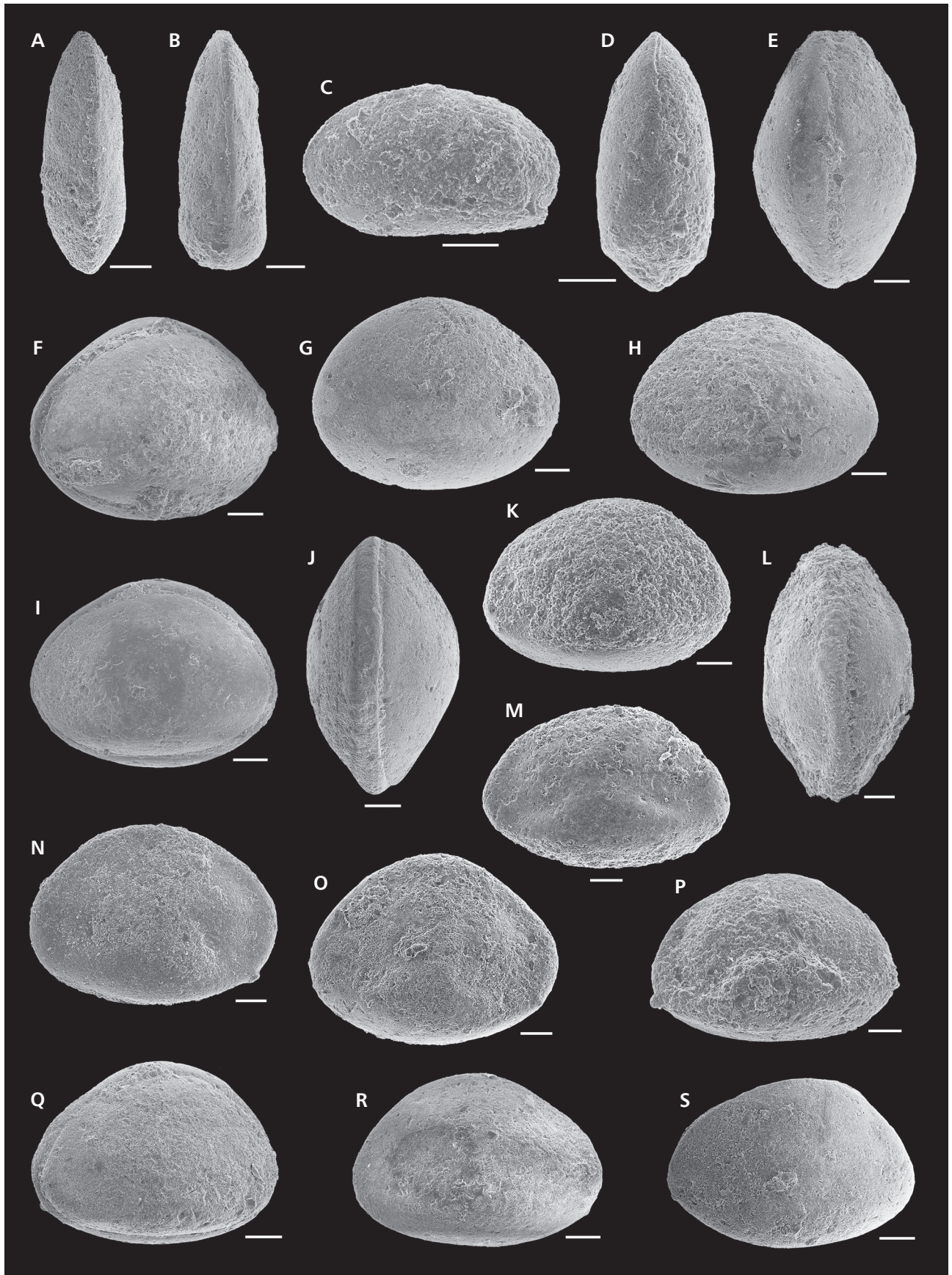
A very low moderately broad rim in an Arabic '3' pattern extends around anterior, ventral and posterior margins; between rim, two weakly formed rounded depressions situated antero-ventrally and postero-ventrally. Dorsally, rim more poorly defined, best observed in posterior view."

Description. – As Ainsworth (1987). Internal features unknown.

Remarks. – Our Toarcian material matches the description and figures of Ainsworth (1987) of the type material from the Upper Pliensbachian of the Fastnet Basin and confirms the observation that the depressions of the valve surface are less well developed in left valves than in right. We also have this species in the Pliensbachian of Peniche where the depressions and the slightly depressed connecting area beneath the dorsal margin are more clearly developed than in Toarcian specimens. Our material shows some shape variation, for example, compare LV in Fig. 4N and 4O and RV in Fig. 4M and 4P, but the characteristic '3' pattern confirms the species identification. A further problem is that specimens figured in Fig. 4Q–S show the '3' pattern in the light microscope but it is not evident in the SEM figures shown here. When these characteristic depressions are weakly developed, which is commonly the case, *O. inflata* is very easily confused with *O. intercedens* (see synonymy list above). *Ogmoconcha inflata* also occurs in the Upper Pliensbachian (*spinatum* Biozone) to Lower Toarcian (*tenuicostatum* Biozone) of Mochras Farm Borehole and Ilminster, UK, and in the Lower Toarcian (*tenuicostatum* Biozone) of Fastnet Basin (Boomer & Ainsworth 2009).

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Ogmoconcha sp. A Boomer, 1992
Figure 5A

    1992 *Ogmoconcha* sp. A; Boomer, pp. 52, 54, pl. 1, fig. 6a, b.

Material. – 2 adult LV.

Remarks. – Boomer (1992) figures a stereo-pair of a right valve from the *tenuicostatum* Biozone of southern England but unfortunately not a left valve. Our material appears similar but we cannot be certain.

Occurrence. – Toarcian, *polymorphum* Biozone.

Ogmoconcha sp.1
Figure 5B–D

    2016 *Ogmoconcha* cf. *amalthei* (Quenstedt, 1858). – Rocha *et al*., fig. 4.

Material. – *Ca*. 450 adult and juvenile V and 70 C, mostly juveniles.

Remarks. – A relatively elongate form, narrower in dorsal view than *O*. sp. 2. Internal features unknown. Lateral outline has some resemblance to that of *O. amalthei* but position of greatest length is higher in the valve (*cf*. Triebel 1950, figs 13–17) and we prefer to leave the species in open nomenclature.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.
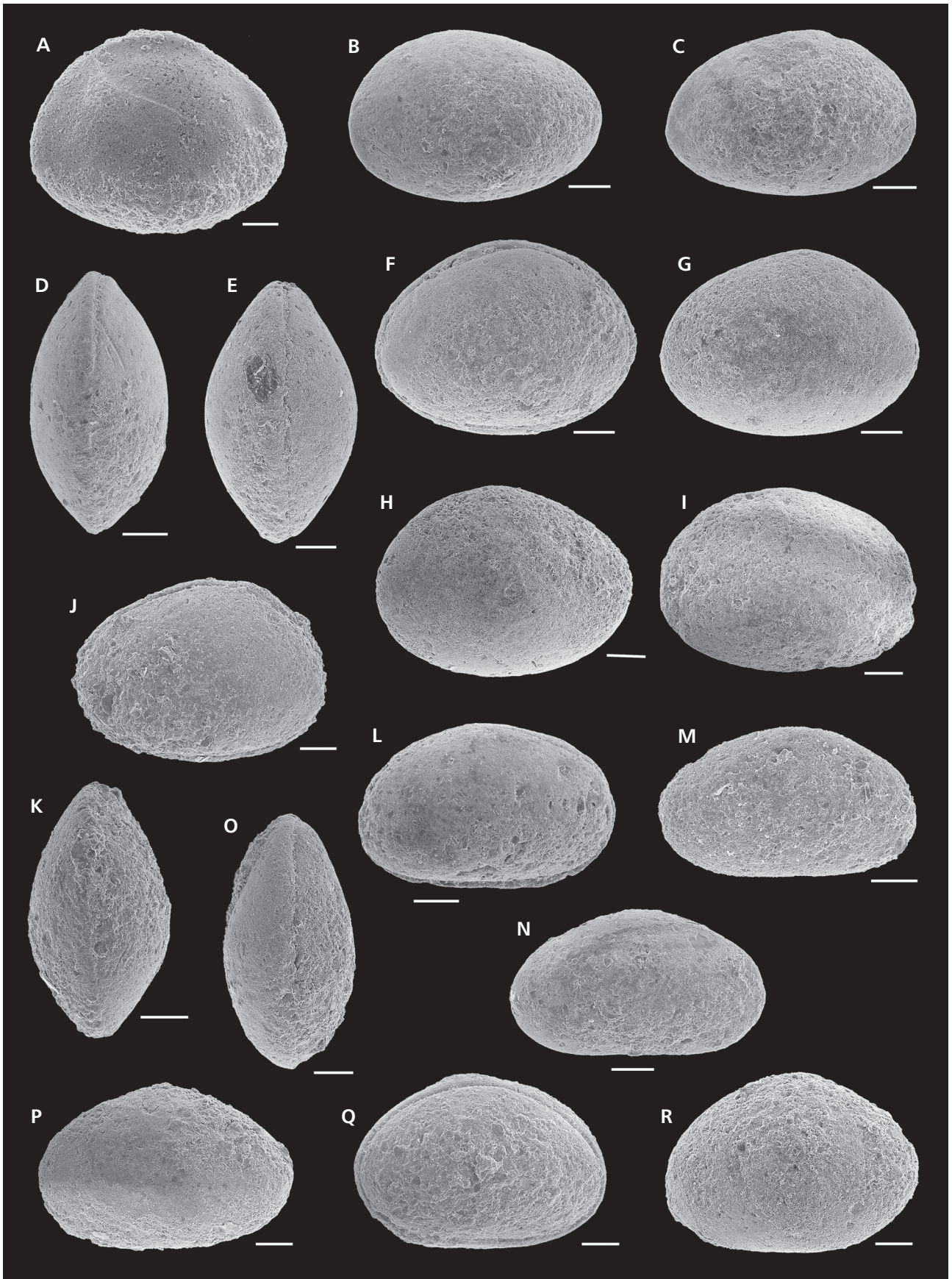
Ogmoconcha sp. 2
Figure 5E–H

    1987 *Ogmoconcha* aff. *O. rotunda* Dreyer, 1967. – Ainsworth, pp. 57, 58, pl. 3, figs 3, 4, 6.
    2016 *Ogmoconcha* cf. *hagenowi* (Drexler, 1958). – Rocha *et al*., figs 4, 8.1.

Material. – *Ca*. 300 V and 80 C, adults and juveniles.

Remarks. – A rounded, small form with a lateral outline resembling that of *O. convexa,* of which it may be a juvenile form. Internal features unknown. Compared to *O. hagenowi* in Rocha *et al*. (2016) but *hagenowi* is upper Hettangian–Lower Sinemurian and has a heavily calcified and robust carapace.

Figure 5. Toarcian (*polymorphum* Biozone) ostracods from Peniche section, Portugal. • A – *Ogmoconcha* sp. A Boomer, 1992, LV, external view, SMF Xe 23805, L = 0.75, h = 0.60, sample P11T. • B–D – *Ogmoconcha* sp. 1, sample P23; B – carapace, left view, SMF Xe 23806, L = 0.60, h = 0.42; C – RV, external view, SMF Xe 23807, L = 0.55, h = 0.39; D – carapace, dorsal view, SMF Xe 23808, L = 0.58, h = 0.39. • E–H – *Ogmoconcha* sp. 2, sample P23; E – carapace, dorsal view, SMF Xe 23809, L = 0.63, h = 0.47; F – carapace, right view, SMF Xe 23810, L = 0.60, h = 0.46; G – RV, external view, SMF Xe 23811, L = 0.60, h = 0.43; H – LV, external view, SMF Xe 23812, L = 0.64, h = 0.48. • I–K – *Ogmoconcha* sp. 3; I – carapace, left view, SMF Xe 23813, L = 0.63, h = 0.46, sample P4; J – carapace, right view, SMF Xe 23814, L = 0.64, h = 0.47, sample P4; K – juvenile (?A-2) carapace, dorsal view, SMF Xe 23815, L = 0.53, h = 0.40, sample P6. • L–N – *Ogmoconchella* cf. *O. conversa* Malz, 1971; L – carapace, right view, SMF Xe 23816, L = 0.56, h = 0.37, sample P6; M – LV, external view, SMF Xe 23817, L = 0.55, h = 0.33, sample P13T; N – RV, external view, SMF Xe 23818; L = 0.58, h = 0.34, sample P13T. • O–R – *Ogmoconchella* cf. *O. propinqua* Malz, 1971, sample P6; O – carapace, dorsal view, SMF Xe 23819, L = 0.63, h = 0.43; P – RV, external view, SMF Xe 23820, L = 0.67, h = 0.44; Q – carapace, right view, SMF Xe 23821, L = 0.66, h = 0.45; R – carapace, left view, SMF Xe 23822, L = 0.67, h = 0.47. Dimensions in mm. Scale bars = 100 μm

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Ogmoconcha sp. 3
Figure 5I–K

Material. – 10 adult and juvenile C.

Remarks. – In lateral shape *O*. sp. 3 falls between *O*. sp. 1 and *O*. sp. 2 as it is more rounded posteriorly, and in dorsal view position of greatest width is relatively more towards the posterior part compared to the other two species.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Genus *Ogmoconchella* Gründel, 1964

Type species. – *Healdia aspinata* Drexler, 1958.

Remarks. – Following the original description of *Ogmoconchella* by Gründel (1964), the definition of the genus was refined by Malz (1971) as: position of greatest valve height at or posterior of mid-length, relatively weakly excavated LV contact groove and relatively simple cluster of adductor muscle scars, as compared to *Ogmoconcha* with position of greatest height anterior of mid-length, strongly excavated LV contact groove especially along the dorsal margin, and adductor muscle scars composed of large angular scars within a ring of small rounded scars. In some species, e.g. *Ogmoconchella aspinata* (Drexler, 1958) [Rhaetian-mid Sinemurian], the position of greatest height is located very posteriorly. In the Peniche material we recognized two species based on position of greatest valve height.

Ogmoconchella cf. *O. conversa* Malz, 1971
Figure 5L–N

cf. 1971 *Ogmoconchella conversa* sp. nov.; Malz, p. 443, pl. 5, fig. 27a–d.

Material. – *Ca*. 40 specimens, mostly adult V.

Remarks. – Greatest height at mid-length, appears symmetrical around mid-length in lateral view but differs in length/height ratio to *Ogmoconchella propinqua* which is relatively higher and more triangular in lateral view. Not common but present in 8 samples. *Ogmoconchella conversa* was described from the Upper Pliensbachian (*margaritatus* Biozone) of NW Germany.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Ogmoconchella cf. *O. propinqua* Malz, 1971
Figure 5O–R

cf. 1971 *Ogmoconchella propinqua* sp. nov.; Malz, pp. 442, 443, pl. 5, figs 23–26.
1987 *Ogmoconchella propinqua* Malz. – Ainsworth, p. 57, pl. 3, fig. 8.
2016 *Ogmoconchella* cf. *aspinata* (Drexler, 1958). – Rocha *et al*., fig. 4.

Material. – *Ca*. 60 specimens, mostly adult V.

Description. – Greatest height posterior of mid-length, appears asymmetrical in lateral view with antero-dorsal margin inclined anteriorly. Internal features not seen.

Remarks. – Our specimens do not preserve the fine anastomosing ribs figured by Malz (1971, pl. 5, fig. 26) in the material from the Upper Pliensbachian (*margaritatus* Biozone) of NW Germany. This species has been compared with *Ogmoconchella aspinata* from the Hettangian, and while there are some morphological similarities, including its dimensions, which are smaller than in *O. propinqua* (*cf*. Malz 1971), it is very unlikely that they are biologically the same species as they are separated in time by 12–13 Ma. Ainsworth's (1987) figured specimen from the Upper Pliensbachian of the Fastnet Basin appears identical to our material.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Suborder Bairdiocopina Gründel, 1967
Superfamily Bairdioidea Sars, 1887
Family Bairdiidae Sars, 1887

Genus *Bairdia* M'Coy, 1844

Type species. – *Bairdia curta* M'Coy, 1844.

Remarks. – Numerous fossil species have been assigned to the genus *Bairdia s. l.* based on small differences in shape. In the present case we believe that, by comparison with other Early Jurassic species and their ranges, description of a new species is a valid and useful addition to ostracod biodiversity.
The species *Bairdia molesta* Apostolescu, 1959 described from the Lower Sinemurian to Upper Pliensbachian of the Paris Basin has been frequently cited in the literature, often as cf. and aff., most records of which in our opinion are not conspecific with *molesta*, and even the very thorough study of the species by Herrig (1979) shows LV that clearly differ in lateral outline from the figured holotype.

Bairdia aff. *B. molesta* Apostolescu, 1959
Figure 6A–D

aff. 1959 *Bairdia molesta* n. sp.; Apostolescu, p. 806, pl. 2, fig. 31.

Material. – *Ca*. 90 specimens, mostly juvenile C (70).

Remarks. – The original diagnosis (translated): "Species characterized by the general outline of its carapace and by a sulcus along the anterior margin and part of the posterior margin. Valve surface smooth." (Apostolescu 1959, p. 806). The "sulcus" is interpreted by us as depressed marginal rims. In our material the depression beside the marginal rims is not so marked and the posterior margin not so acuminate as in Apostolescu's figure (1959, pl. 2, fig. 31). The species is present in the *polymorphum* Biozone before the CIE and then reappears as a "Lazarus" species higher in the *levisoni* Biozone.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* and *levisoni* biozones.

Bairdia aff. *B. molesta* Apostolescu, 1959 *sensu* Ainsworth (1987)
Figure 6E–G

1987 *Bairdia* aff. *molesta* Apostolescu, 1959. – Ainsworth, p. 51, pl. 1, figs 4, 5, 8.

Material. – 4 adult C, 1 juvenile C.

Remarks. – The material from Peniche is identical to *Bairdia* aff. *molesta* as figured by Ainsworth (1987) from the Pliensbachian of the Fastnet Basin.

Occurrence. – Toarcian, *bifrons* Biozone.

Bairdia paramolesta sp. nov. Cabral, Lord & Pinto
Figure 6H–M

2007 *Bairdia* aff. *molesta* Apostolescu, 1959. – Pinto *et al*., pl. 1, fig. 1.
2016 *Bairdia* sp. 2. – Rocha *et al*., figs 4, 8.13.

Types. – Holotype: one adult carapace, SMF Xe 23830, L = 0.80, h = 0.45, sample P11B (Fig. 6I).
Paratypes: one adult carapace, SMF Xe 23831, L = 0.80, h = 0.46, sample P3T; one adult carapace, SMF Xe 23832, L = 0.79, h = 0.44, sample P3T; one juvenile carapace, SMF Xe 23833, L = 0.54, h = 0.30, sample P11B; one juvenile carapace, SMF Xe 23834, L = 0.53, h = 0.31, sample P11B.

Type horizon and locality. – Type-level sample P11B, Toarcian, *polymorphum* Biozone; Praia do Abalo, Peniche, Portugal.

Material. – 5 adult C, 1 adult V, 28 juvenile C. The species is also present at Rabaçal, *polymorphum* Biozone, in sample R10, with 9 C, from which 1 adult.

Etymology. – *Para* Greek "close" "beside", an allusion to the morphological similarity to *Bairdia molesta* Apostolescu.

Diagnosis. – A species of the genus *Bairdia* characterized by a "bairdiid" lateral outline modified by a broadly rounded anterior margin with a marginal rim and weakly developed anterior cardinal angle.

Description. – In lateral view the typical "bairdiid" outline is modified by a very broadly rounded anterior margin running from a weakly developed anterior cardinal angle to the ventral margin. Dorsal margin gently curved. Ventral margin almost straight in LV, weakly concave in RV. Posterior margin acuminate, located ventrally. LV > RV. Position of greatest height at mid valve length, of greatest length just below mid-height and greatest width in dorsal view at mid-length. An anterior marginal rim is present and extends into the anterior part of the ventral margin, and the posterior margin also appears as a marginal rim when viewed both laterally and dorsally and extends into the posterior part of the ventral margin. Surface unornamented. Juveniles from different ontogenic stages with exactly the same characteristics of the adults, particularly the outline. The only valve is infilled with sediment and no internal details could be observed.
Dimensions: ♀ L = 0.77–0.80, h = 0.44–0.46.

Remarks. – *Bairdia molesta* Apostolescu described from the Sinemurian–Pliensbachian of the Paris Basin is widely recorded from the Lower Jurassic (see above). Our material from the Pliensbachian–Lower Toarcian differs from *B*. *molesta* and other described Early and Middle Jurassic age *Bairdia* in the broadly rounded anterior outline in lateral view.

Occurrence. – At present known only from the topmost Pliensbachian, *emaciatum* Biozone, at Peniche and lowest Toarcian, *polymorphum* Biozone, at Peniche and Rabaçal, Portugal.

Bairdia cf. *B. rostrata* Issler, 1908
Figure 6N

cf. 1908 *Bairdia rostrata* sp. nov.; Issler, p. 95, pl. 7, fig. 345.
2007 *Bairdia* aff. *rostrata*. – Pinto *et al*., pl. 1, fig. 2.
2016 *Bairdia* aff. *rostrata*. – Rocha *et al*., figs 4, 8.10.

Material. – 1 adult C.

Remarks. – *Bairdia rostrata* was described from the Lias δ (Upper Pliensbachian) of SW Germany. Our material differs in a less rounded dorsal margin and in the higher and shorter posterior margin.

Occurrence. – Toarcian, *polymorphum* Biozone.

Bairdia sp. 1
Figure 6O–R

> 2007 *Bairdia* sp. 1; Pinto *et al.*, pl. 1, figs 3, 4.
> 2016 *Bairdia* cf. *kempfi* Ainsworth, 1989. – Rocha *et al.*, figs 4, 8.3.

Material. – *Ca*. 25 specimens, adults and juveniles, V and C.

Remarks. – A species subtrapezoidal to round in lateral view with high height/length ratio, a very low short posterior margin, and in dorsal view very rounded and strongly inflated. Right valve similar to *B. kempfi* from the Upper Pliensbachian of the Fastnet Basin but LV more rounded and overlaps RV more strongly, and more rounded in dorsal view. Resembles *B. donzei* Herrig, 1979 from the Upper Pliensbachian of E Germany but differs in shape of dorsal and posterior margins.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* Biozone.

Bairdia sp. 2
Figure 6S–U

Material. – 3 adult C, 2 juvenile C.

Remarks. – An elongate trapezoidal species with posterior margin just below mid-height, in dorsal view very slim and elongate. The species is characterized by the very narrow and extended carapace in dorsal view, which differs from other described non-Palaeozoic *Bairdia* species.

Occurrence. – Toarcian, *bifrons* Biozone.

Genus *Bairdiacypris* Bradfield, 1935

*Type species*. – *Bairdiacypris deloi* Bradfield, 1935.

Remarks. – We recognize in Peniche the species *B. rectangularis* Ainsworth, 1986 (Fig. 7A–C) and *Bairdiacypris* cf. *B. triangularis* Ainsworth, 1986 (Fig. 7D–F), both originally described from the Toarcian–Aalenian of the Fastnet Basin, but in addition we have a third form *Bairdiacypris* sp. 1 (Fig. 7G–I), less abundant (*ca*. 80 adult and juvenile C), which has a slightly convex dorsal margin inclined towards the posterior and position of greatest length at mid valve height. Our material of *Bairdiacypris* cf. *B. triangularis* resembles the figure of Boomer & Ainsworth (2009, pl. 1, fig. 3) from the Mochras Farm Borehole, Wales, rather than the type material from the Fastnet Basin which has a more triangular lateral outline. All three species appear in the *levisoni* Biozone, after the CIE, frequently together in the same sample, and *B. rectangularis* (*ca*. 450 adult and juvenile C) and *Bairdiacypris* cf. *B. triangularis* (*ca*. 180 adult and juvenile C) are abundant and dominant in the *bifrons* Biozone.

Genus *Isobythocypris* Apostolescu, 1959

Type species. – *Bairdia elongata* Blake, 1876.

Remarks. – Several poorly preserved and crushed unornamented specimens (*ca*. 25 C and V) may belong to *Isobythocypris*. We figure material that resembles *I. ovalis* Bate & Coleman, 1975 (Fig. 7J, K) from the Lower Toarcian of England.

Figure 6. Toarcian ostracods from Peniche section, Portugal. • A–D – *Bairdia* aff. *B. molesta* Apostolescu, 1959, *polymorphum* Biozone; A – carapace, right view, SMF Xe 23823, L = 0.67, h = 0.40, sample P11B; B – carapace, left view, SMF Xe 23824, L = 0.68, h = 0.40, sample P11B; C – juvenile (?A-2) carapace, left view, SMF Xe 23825, L = 0.44, h = 0.28, sample P23; D – carapace, dorsal view, SMF Xe 23826, L = 0.65, h = 0.36, sample P13B. • E–G – *Bairdia* aff. *B. molesta* Apostolescu, 1959 *sensu* Ainsworth (1987), *bifrons* Biozone; E – carapace, dorsal view, SMF Xe 23827, L = 0.33, h = 0.21, sample P404; F – carapace, right view, SMF Xe 23828, L = 0.36, h = 0.23, sample P404; G – carapace, left view, SMF Xe 23829, L = 0.35, h = 0.23, sample P406. • H–M – *Bairdia paramolesta* sp. nov. Cabral, Lord & Pinto, *polymorphum* Biozone; H – carapace, dorsal view, paratype, SMF Xe 23831, L = 0.80, h = 0.46, sample P3T; I – carapace, right view, holotype, SMF Xe 23830, L = 0.80, h = 0.45, sample P11B; J – carapace, left view, paratype, SMF Xe 23832, L = 0.79, h = 0.44, sample P3T; K – juvenile (?A-2) carapace, dorsal view, paratype, SMF Xe 23833, L = 0.54, h = 0.30, sample P11B; L – juvenile (?A-2) carapace, left view, paratype, SMF Xe 23834, L = 0.53, h = 0.31, sample P11B; M – juvenile (?A-2) carapace, right view, same specimen as L. • N – *Bairdia* cf. *B. rostrata* Issler, 1908, carapace, left view, SMF Xe 23835, L = 0.61, h = 0.37, *polymorphum* Biozone, sample P4. • O–R – *Bairdia* sp. 1, *polymorphum* Biozone, sample P4; O – RV, external view, SMF Xe 23836, L = 0.67, h = 0.45; P – LV, external view, SMF Xe 23837, L = 0.67, h = 0.50; Q – carapace, right view, SMF Xe 23838, L = 0.69, h = 0. 50; R – carapace, dorsal view, same specimen as Q. • S–U – *Bairdia* sp. 2, *bifrons* Biozone; S – carapace, dorsal view, SMF Xe 23839, L = 0.68, h = 0.36, sample P412; T – carapace, right view, SMF Xe 23840, L = 0.68, h = 0.35, sample P401; U – carapace, left view, SMF Xe 23841, L = 0.67, h = 0.36, sample P406. Dimensions in mm. Scale bars = 100 µm.
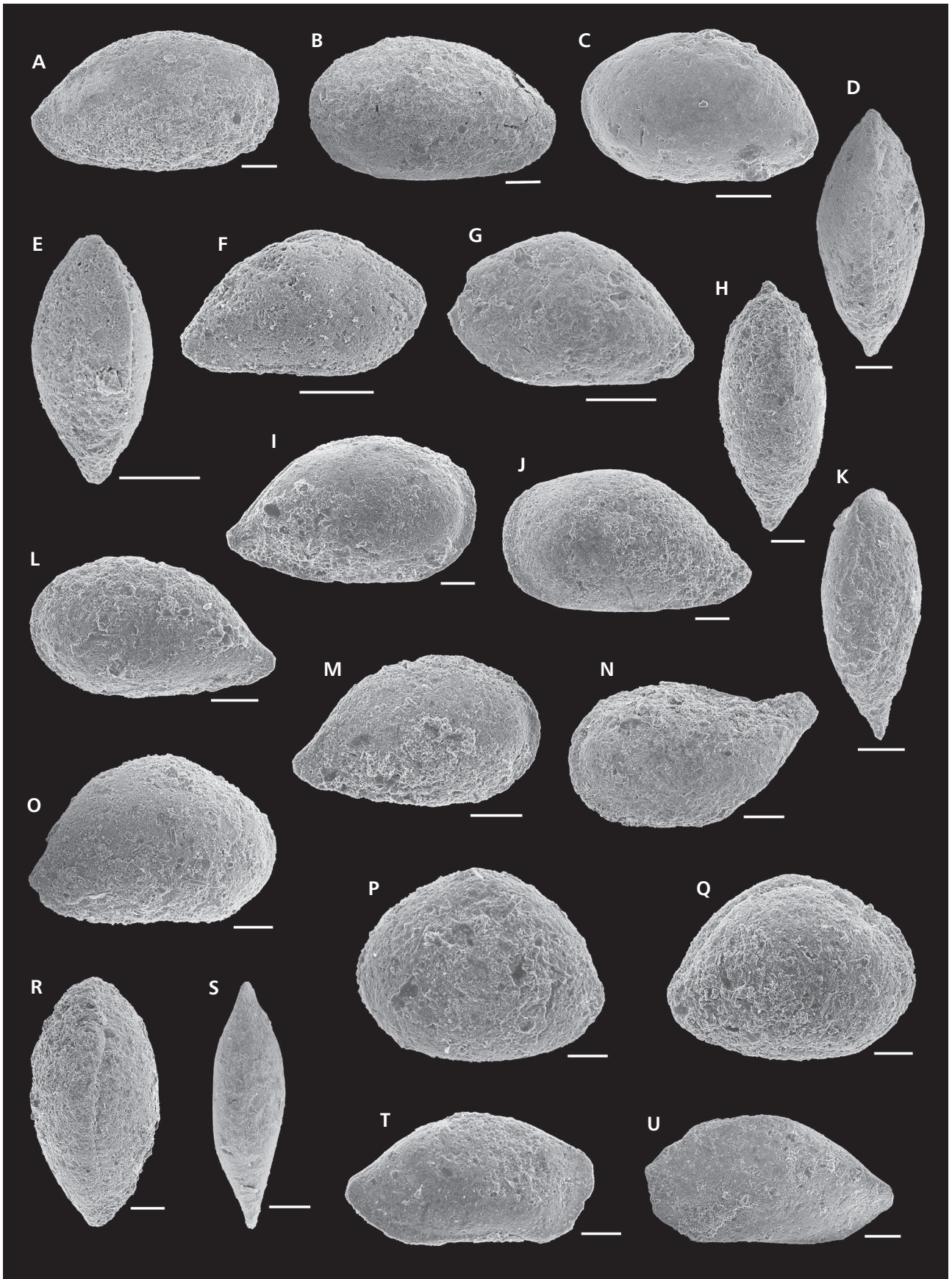
Genus *Ptychobairdia* Kollmann, 1960

Type species. – *Ptychobairdia kuepperi* Kollmann, 1960.

Ptychobairdia hahni* (Lord & Moorley, 1974)
Figure 7L–N

> 1974 *Bairdia hahni* sp. nov.; Lord & Moorley, pp. 1–4, pl. 2:1:2, 2:1:4.
> 1979 *Bairdia* sp. 2. – Exton, p. 54, pl. 9, fig. 2.
> 2007 *Ptychobairdia hahni* (Lord & Moorley). – Pinto *et al*., pl. 2, fig. 20.
> 2007 *Ptychobairdia* cf. *hahni* (Lord & Moorley). – Pinto *et al*., pl. 2, fig. 8.
> 2016 *Ptychobairdia hahni* (Lord & Moorley). – Rocha *et al*., figs 4, 8.8.

Material. – *Ca*. 80 specimens, all C, adult (32) and juveniles.

Remarks. – The species *hahni*, originally described from the Upper Pliensbachian of SW Germany, is common in Peniche until the *levisoni* biozone, though generally very worn. The species has a very distinctive lateral outline, and there is some variation in size (adults and juveniles?) and in the presence and strength of surface ornamentation (preservation).

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* and *levisoni* biozones.

Suborder Cytherocopina Baird, 1850
Superfamily Cytheroidea Baird, 1850
Family Bythocytheridae Sars, 1926

Genus *Patellacythere* Gründel & Kozur, 1971

Type species. – *Monoceratina williamsi* Stephenson, 1946.

Remarks. – Jurassic species formerly placed in *Monoceratina* Roth, 1928 have been revised, see discussion in Pais *et al*. (2016, p. 213).

**Patellacythere ungulina*
(Triebel & Bartenstein, 1938)**
Figure 7O, P

> 1938 *Monoceratina ungulina* sp. nov.; Triebel & Bartenstein, pp. 506, 508, figs 3, 4.
> 1999a *Monoceratina ungulina* Triebel & Bartenstein. – Arias & Lord, p. 92, pl. 4, fig. 6.

Material. – 18 adult C, 16 juvenile C.

Remarks. – *Patellacythere ungulina*, described originally from the Lias ζ (Upper Toarcian) of SW Germany, occurs commonly but not abundantly in Peniche, poorly preserved.

Occurrence. – Toarcian, *bifrons* Biozone.

Genus *Praebythoceratina* Gründel & Kozur, 1972

Type species. – *Bythoceratina progacilis* Kozur, 1972.

?*Praebythoceratina* sp. 1
Figure 7Q, R

> 2007 *Cytheropteron* aff. *alafastigatum* Fischer, 1962. – Pinto *et al*., pl. 2, figs 12, 13.

Material. – 4 adult C.

Remarks. – The rare specimens show a lateral spine on each valve, a weak sulcus and appear to have straight dorsal margins, indicating the genus *Praebythoceratina*.

Figure 7. Toarcian ostracods from Peniche section, Portugal. • A–C – *Bairdiacypris rectangularis* Ainsworth, 1986, *bifrons* Biozone, sample P422; A – carapace, right view, SMF Xe 23842, L = 0.48, h = 0.25; B – carapace, left view, SMF Xe 23843, L = 0.44, h = 0.24; C – carapace, dorsal view, SMF Xe 23844, L = 0.49, h = 0.26. • D–F – *Bairdiacypris* cf. *B. triangularis* Ainsworth, 1986, *bifrons* Biozone, sample P422; D – carapace, dorsal view, SMF Xe 23845, L = 0.51, h = 0.28; E – carapace, right view, SMF Xe 23846, L = 0.45, h = 0.25; F – carapace, left view, SMF Xe 23847, L = 0.49, h = 0.26. • G–I – *Bairdiacypris* sp. 1, *levisoni* Biozone; sample P142; G – carapace, right view, SMF Xe 23848, L = 0.49, h = 0.25; H – carapace, left view, SMF Xe 23849, L = 0.47, h = 0.25; I – carapace, dorsal view, SMF Xe 23850, L = 0.47, h = 0.24. • J, K – *Isobythocypris* aff. *I. ovalis* Bate & Coleman, 1975, *polymorphum* Biozone, sample P25; J – carapace, dorsal view, SMF Xe 23851, L = 0.47, h = 0.26; K – carapace, right view, SMF Xe 23852, L = 0.52, h = 0.29. • L–N – *Ptychobairdia hahni* (Lord & Moorley, 1974), *polymorphum* and *levisoni* biozones; L – juvenile (?A-2) carapace, left view, SMF Xe 23853, L = 0.44, h = 0.25, *levisoni* Biozone, sample P41; M – carapace, left view, SMF Xe 23854, L = 0.60, h = 0.29, *polymorphum* Biozone, sample P6; N – carapace, right view, SMF Xe 23855, L = 0.60, h = 0.30, *polymorphum* Biozone, sample P6. • O, P – *Patellacythere ungulina* (Triebel & Bartenstein, 1938), *bifrons* Biozone; O – juvenile (?A-1) carapace, left view, SMF Xe 23856, L = 0.47, h = 0.24, sample P392; P – carapace, right view, SMF Xe 23857, L = 0.55, h = 0.30, sample P401. • Q, R – ?*Praebythoceratina* sp. 1, *levisoni* and *bifrons* biozones; Q – carapace, left view, SMF Xe 23858, L = 0.45, h = 0.26, *bifrons* Biozone, sample P396; R – carapace, dorsal view, SMF Xe 23859, L = 0.54, h = 0.29, *levisoni* Biozone, sample P56. • S–U – ?"*Monoceratina*" sp. 1 Cabral *et al*., 2015, *bifrons* Biozone, sample P422; S – carapace, dorsal view, SMF Xe 23860, L = 0.37, h = 023; T – carapace, left view, SMF Xe 23861, L = 0.36, h = 0.23; U – carapace, right view, SMF Xe 23862, L = 0.36, h = 0.23. • V – *Tanycythere* sp., carapace, left view, SMF Xe 23863, L = 0.53, h = 0.21, *bifrons* Biozone, sample P396. • W – *Cytheropteron* cf. *C. alafastigatum* Fischer, 1962, left valve, external view, SMF Xe 23864, L = 0.51, h = 0.32 (including wing), *bifrons* Biozone, sample P406. Dimensions in mm. Scale bars = 100 μm.
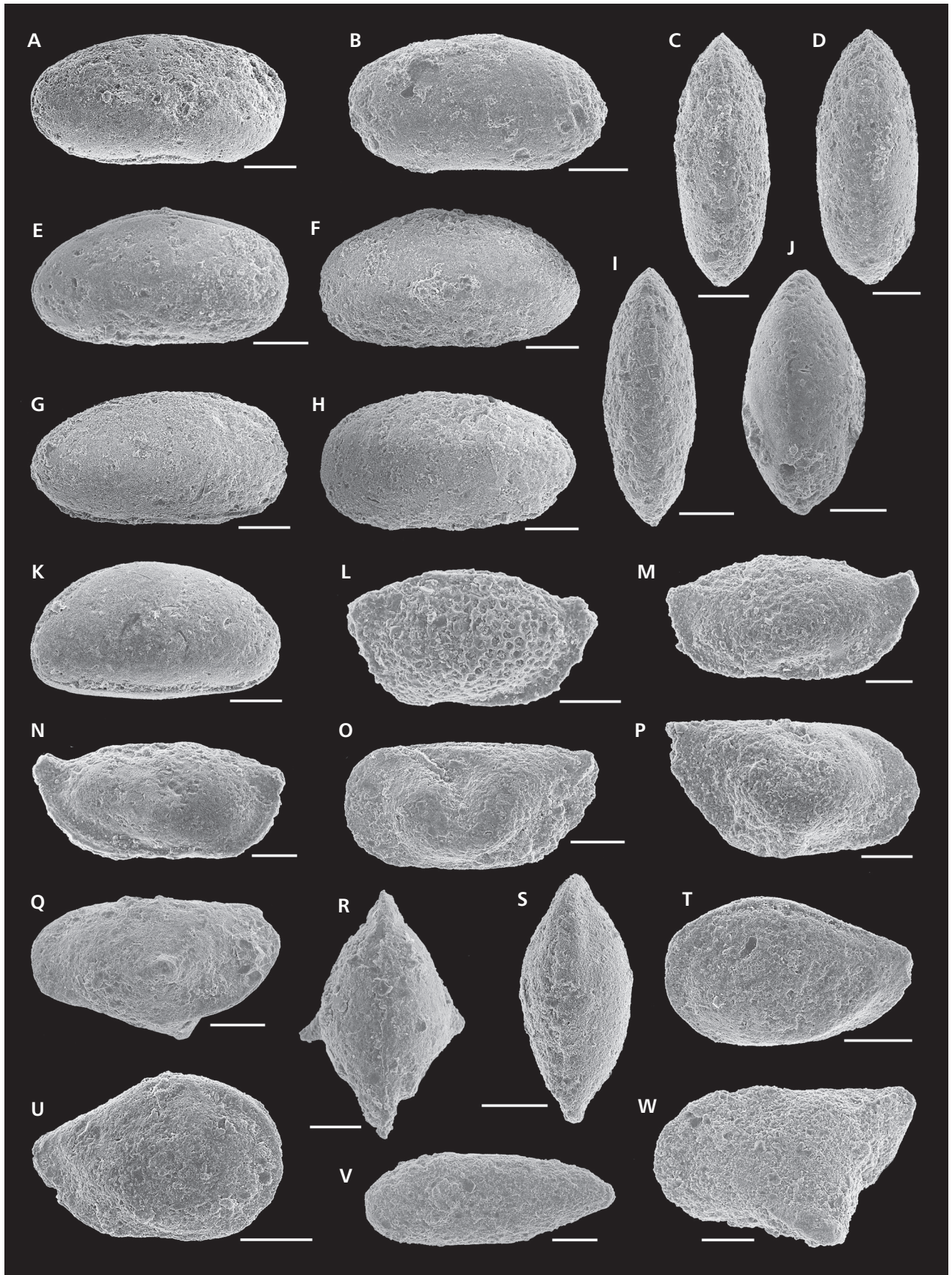
Occurrence. – Toarcian, *levisoni* and *bifrons* biozones.

Genus *Tanycythere* Cabral, Lord, Boomer & Malz, 2014

Type species. – *Tanycythere caudata* Cabral, Lord, Boomer & Malz, 2014.

Remarks. – *Tanycythere* occurs rarely (2 C) in the *bifrons* Biozone (Fig. 7V). The rare specimens seem different from all the species described in Cabral *et al.* (2014).

?"*Monoceratina*" sp. 1 Cabral *et al.*, 2015
Figure 7S–U

> 1999a *Monoceratina* sp. A; Arias & Lord, p. 94, pl. 4, fig. 7.
> 2015 "*Monoceratina*"? sp. 1; Cabral *et al.*, p. 6, pl. 1, figs 1–3.

Material. – 16 adult C.

Remarks. – Evgenij I. Shornikov (personal communication 2013) advised that this species, although relatively close to the genus *Monoceratina* Roth, represents a new genus of the Bythocytheridae. The species is recorded from the Sinemurian of western Portugal and from the Toarcian (*tenuicostatum* and *bifrons* biozones) of Cordillera Iberica (Iberian Range), NE Spain, occurs rarely in Peniche. A similar form is known in the Lower Jurassic of the Mochras Farm Borehole, Wales (Boomer, personal communication 2014) of Great Britain.

Occurrence. – Toarcian, *levisoni* and *bifrons* biozones.

Family Cytheruridae G.W. Müller, 1894

Genus *Cytheropteron* Sars, 1866

Type species. – *Cythere latissima* Norman, 1865.

Cytheropteron cf. *C. alafastigatum* Fischer, 1962
Figure 7W

> cf. 1962 *Cytheropteron alafastigatum* sp. nov.; Fischer, pp. 336–338, pl. 20, figs 1–6.

Material. – 3 adult V, 1 juvenile V.

Remarks. – Originally described from the Upper Toarcian of SW Germany; occurs rarely in Peniche; ventral wing-like extension less well developed than in original material possibly due to preservational reasons.

Occurrence. – Toarcian, *bifrons* Biozone.

Family Protocytheridae Ljubimova, 1955

Genus *Ektyphocythere* Bate, 1963

Type species. – *Procytheridea triangula* Brand *in* Brand & Malz, 1961.

Remarks. – The genus *Ektyphocythere* is present in several levels of the Peniche section, particularly in the *polymorphum* and *levisoni* biozones, sometimes well represented; however, most specimens are too poorly preserved to be identified to species level. We identified five species.

## Ektyphocythere cf. *E. bucki* (Bizon, 1960)
Figure 8A, B

> cf. 1960 *Procytheridea bucki* n. sp.; Bizon, p. 205, pl. 1, fig. 2a–e.
> 1979 *Ektyphocythere* sp. 1. – Exton, p. 58, pl. 13, figs 3–5.
> cf. 1999b *Ektyphocythere bucki* (Bizon). – Arias & Lord, p. 228, pl. 3, fig. 1.

Material. – 2 adult C.

Figure 8. Toarcian ostracods from Peniche section, Portugal. • A, B – *Ektyphocythere* cf. *E. bucki* (Bizon, 1960), *bifrons* Biozone, sample P317; A – carapace, dorsal view, SMF Xe 23865, L = 0.53, h = 0.38; B – carapace, right view, SMF Xe 23866, L = 0.61, h = 0.40. • C – *Ektyphocythere* cf. *E. dharennsourensis* Boutakiout, Donze & Oulmach, 1982, female carapace, left view, SMF Xe 23867, L = 0.76, h = 0.47, *levisoni* Biozone, sample P65. • D–F – *Ektyphocythere intrepida* (Bate & Coleman, 1975), *levisoni* Biozone, sample P86; D – juvenile (?A-1) carapace, dorsal view, SMF Xe 23868, L = 0.48, h = 0.27; E – LV, external view, SMF Xe 23869, L = 0.65, h = 0.37; F – RV, external view, SMF Xe 23870, L = 0.62, h = 0.33. • G–J – *Ektyphocythere knitteri* (Riegraf, 1984), *polymorphum* Biozone; G – male carapace, right view, SMF Xe 23871, L = 0.60, h = 0.29, sample P11T; H – female carapace, dorsal view, SMF Xe 23872, L = 0.55, h = 0.30, sample P11T; I – female carapace, right view, SMF Xe 23873, L = 0.54, h = 0.29, sample P13B; J – female carapace, left view, SMF Xe 23874, L = 0.49, h = 0.28, sample P13B. • K – *Ektyphocythere* cf. *E. lanceolata* Boomer, 1988, RV, external view, SMF Xe 23875, L = 0.60, h = 0.28, *polymorphum* Biozone, sample P23. • L–O – *Kinkelinella costata* Knitter, 1983, *bifrons* Biozone; L – LV, external view, SMF Xe 23876, L = 0.55, h = 0.42, sample P373; M – carapace, dorsal view, SMF Xe 23877, L = 0.55, h = 0.44, sample P414; N – LV, external view, SMF Xe 23878, L = 0.61, h = 0.43, sample P422; O – carapace, right view, SMF Xe 23879, L = 0.58, h = 0.40, sample P373. • P–U – *Kinkelinella sermoisensis* Apostolescu, 1959, *levisoni* and *bifrons* biozones; P – LV, external view, SMF Xe 23880, L = 0.55, h = 0.32, *levisoni* Biozone, sample P28; Q – carapace, dorsal view, SMF Xe 23881, L = 0.53, h = 0.33, *levisoni* Biozone, sample P28; R – RV, external view, SMF Xe 23882, L = 0.68, h = 0.40, *bifrons* Biozone, sample P422; S – RV, external view, SMF Xe 23883, L = 0.63, h = 0.41, *bifrons* Biozone, sample P317; T – carapace, dorsal view, SMF Xe 23884, L = 0.65, h = 0.45, *bifrons* Biozone, sample P317; U – LV, external view, SMF Xe 23885, L = 0.65, h = 0.45, *bifrons* Biozone, sample P317. Dimensions in mm. Scale bars = 100 μm.
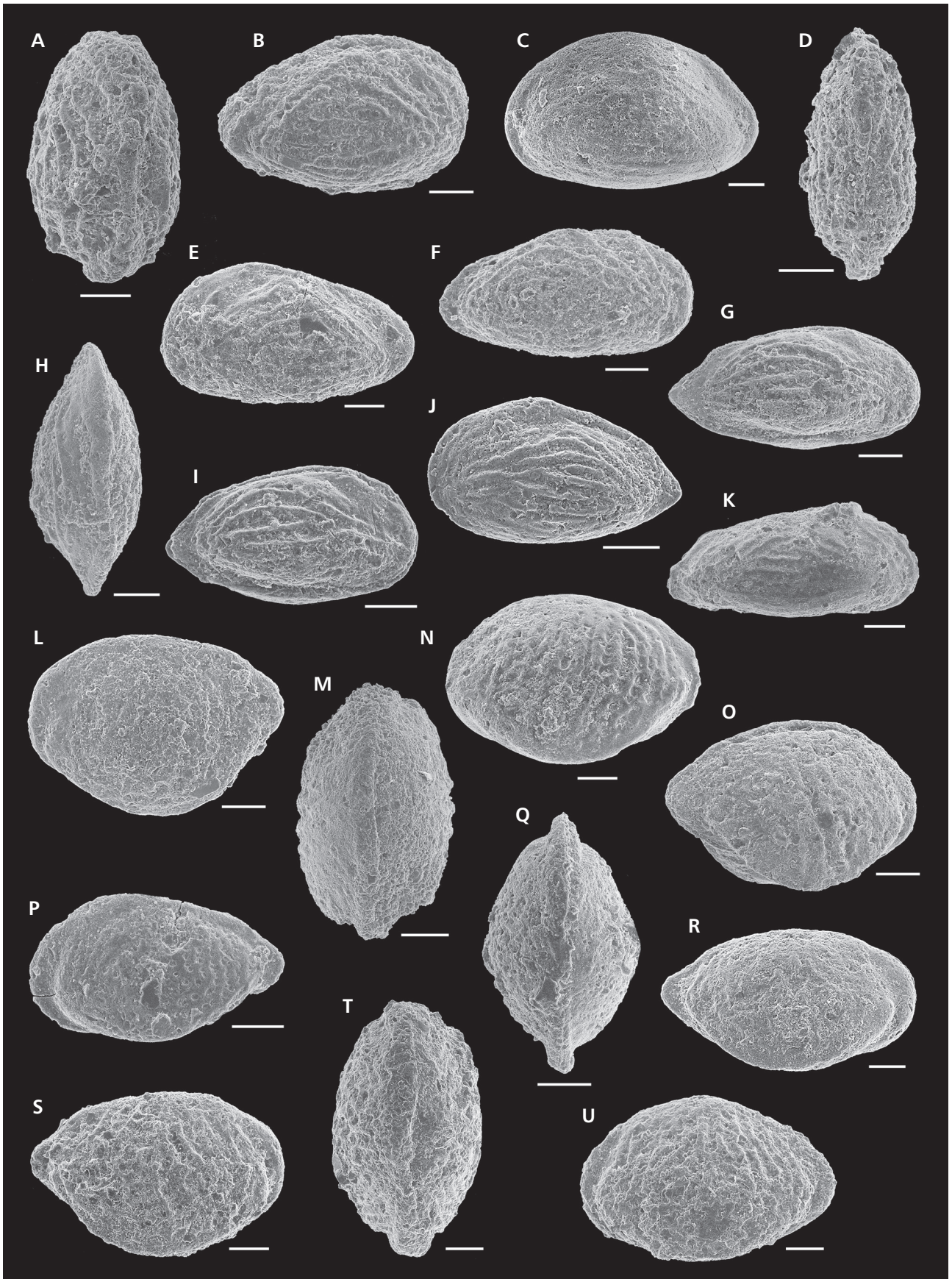
Remarks. – Originally described from the Middle–Upper Toarcian of the Paris Basin, also occurs in the Toarcian at Rabaçal and in NE Spain; it is rare in Peniche.

Occurrence. – Toarcian, *bifrons* Biozone.

Ektyphocythere cf. *E. dharennsourensis* Boutakiout, Donze & Oulmach, 1982
Figure 8C

cf. 1982 *Ektyphocythere dharennsourensis* n. sp.; Boutakiout, Donze & Oulmach, p. 97, pl. 1, figs 9, 10, 11a–c, 12a, b.
1992 *Ektyphocythere dharennsourensis* Boutakiout, Donze & Oulmach. – Boomer, p. 54, pl. 2, figs 4–6, 8, 9, 11.
1999b *Ektyphocythere* cf. *dharennsourensis* Boutakiout, Donze & Oulmach. – Arias & Lord, p. 229, pl. 3, fig. 2.
2007 *Ektyphocythere* aff. *debilis* (Bate & Coleman, 1995). – Pinto *et al*., pl. 2, figs 14, 15.

Material. – *Ca*. 60 adult and juvenile V.

Remarks. – Originally described from the Lower–Middle Toarcian of Morocco but also recorded from NE Spain (Arias & Lord 1999b) and southern Great Britain (Boomer 1992), occurs in Peniche only in the *levisoni* Biozone in the CIE; it is characterized by a weak ornamentation and a sub-quadrate to sub-triangular lateral view.

Occurrence. – Toarcian, *levisoni* Biozone.

Ektyphocythere intrepida (Bate & Coleman, 1975)
Figure 8D–F

1975 *Kinkelinella* (*Ektyphocythere*) *intrepida* sp. nov.; Bate & Coleman, pp. 20, 21, pl. 7, figs 1–5, 8–10, pl. 8, figs 7, 8, figs 10a, 11c.
2007 *Ektyphocythere* aff. *intrepida* (Bate & Coleman). – Pinto *et al*., pl. 2, figs 16, 17.

Material. – 4 adult C, 7 adult V.

Remarks. – Originally described from the Lower Toarcian of Great Britain, is rarely represented at Peniche in *levisoni* and *bifrons* biozones; easily identified by its ornamentation with the apex of the typical triangle projecting above the dorsal outline in the RV.

Occurrence. – Toarcian, *levisoni* and *bifrons* biozones.

Ektyphocythere knitteri (Riegraf, 1984)
Figure 8G–J

1984 *Kinkelinella* (*Ektyphocythere*) *knitteri* sp. nov.; Riegraf, p. 5, pl. 1, figs 4–6.

2007 *Ektyphocythere* cf. *knitteri* (Riegraf). – Pinto *et al*., pl. 1, figs 9–11.
2016 *Ektyphocythere knitteri* (Riegraf). – Rocha *et al*., figs 4, 8.12.

Material. – *Ca*. 40 specimens, mostly adults, C and V.

Remarks. – Originally described from the Lower Toarcian of SW Germany, is an important species in the *polymorphum* Biozone at Peniche, still rarely appearing in the extreme base of the *levisoni* Biozone; the Portuguese specimens are similar to the German ones.

Occurrence. – Toarcian, *polymorphum* and *levisoni* biozones.

Ektyphocythere cf. *E. lanceolata* Boomer, 1988
Figure 8K

cf. 1988 *Ektyphocythere lanceolata* sp. nov.; Boomer, pp. 89–92.

Material. – 1 ?adult RV.

Remarks. – A single specimen found at Peniche, with a particularly elongate lateral outline, tapering posteriorly, and the ornamentation with longitudinal ribs and fine intercostal punctation, seems relatively close to *E. lanceolata*, originally described from the Upper Toarcian of Mochras Farm Borehole, Great Britain.

Occurrence. – Toarcian, *polymorphum* Biozone.

Genus *Kinkelinella* Martin, 1960

Type species. – *Kinkelinella tenuicostati* Martin, 1960.

Remarks. – *Kinkelinella* appeared in the earliest Toarcian, having evolved apparently from the related genus *Ektyphocythere* Bate, 1963, and ranges to the Bathonian (Bate 2009, p. 219). Opinion differs as to the systematic relationship of the two genera with some authors considering *Ektyphocythere* a subgenus of *Kinkelinella* (*e.g.* Bate & Coleman 1975, Bate 2009), although we follow Ainsworth & Boomer (2009) in regarding them as distinct genera. At least 20 species are described.

Kinkelinella costata Knitter, 1983
Figure 8L–O

1983 *Kinkelinella* (*Kinkelinella*) *costata* sp. nov.; Knitter, p. 224, pl. 39, figs 7–10.
1979 *Kinkelinella* sp. I (Apostolescu). – Exton, p. 60, pl. 13, figs 6–12.

Material. – *Ca.* 60 adults, mostly V and 45 juvenile V.

Remarks. – *Kinkelinella costata,* originally described from the Toarcian of SW Germany, also occurs in the Toarcian at Rabaçal and at Boca da Mata. The surface ornament of *K. costata* is characterized by strong vertical ribs and a ventral alar wing both slightly varying in thickness and extension.

Occurrence. – Toarcian, *bifrons* Biozone.

Kinkelinella sermoisensis (Apostolescu, 1959)
Figure 8P–U

> 1959 *Procytheridea sermoisensis* n. sp.; Apostolescu, p. 812, pl. 3, figs 37, 38.
> 1979 *Kinkelinella sermoisensis* (Apostolescu). – Exton, p. 59, pl. 12, figs 1–4.
> 1984 *Kinkelinella sermoisensis* (Apostolescu). – Exton & Gradstein, pl. 2, fig. 8.
> 1999b *Kinkelinella sermoisensis* (Apostolescu). – Arias & Lord, pp. 232, 233, pl. 3, fig. 6.

Material. – *Ca.* 120 specimens, mostly V, adults (68) and juveniles (45).

Remarks. – *Kinkelinella sermoisensis* occurs in the Toarcian at Peniche, in *levisoni* and *bifrons* biozones and in the Toarcian at Rabaçal and Boca da Mata, and is characterized by reticulate surface ornament. In fact the species, originally described from the Toarcian and Aalenian of the Paris Basin, is characterized across Western Europe by variable strength ornament as demonstrated for example from the Paris Basin by Bizon (1960) and here (Fig. 8P–R and 8S–U). The species is present in the bottom sample of the CIE and then reappears as a "survivor" species higher in the *levisoni* Biozone and continues commonly in the *bifrons* Biozone.

Occurrence. – Toarcian, *levisoni* and *bifrons* Biozone.

Kinkelinella ventrocarinata sp. nov. Cabral, Pinto & Lord
Figure 9A–J

> 1979 *Kinkelinella* sp. – Exton, pp. 60, 61, pl. 10, figs 1–3.
> 2007 *Kinkelinella* sp. 1. – Pinto *et al.*, pl. 1, figs 12, 13.
> 2016 *Kinkelinella* sp. 1. – Rocha *et al.*, figs 4, 8.9.

Types. – Holotype: one female LV, SMF Xe 23886; L = 0.63, h = 0.42, sample R7T (Fig. 9A, F).
Paratypes: one female carapace, SMF Xe 23887, L = 0.64, h = 0.44, sample R10; one female carapace, SMF Xe 23888, L = 0.70, h = 0.43, sample R10; one female RV, SMF Xe 23889, L = 0.58, h = 0.37, sample R7T; one male RV, SMF Xe 23890, L = 0.63, h = 0.35, sample R7T.

Diagnosis. – A species of *Kinkelinella* distinguished by an inflated ornamented carapace with a swollen ventral carinate margin.

Material. – Peniche – 54 adult V, 2 adult C, 29 juvenile V, 1 juvenile C. Rabaçal – 106 adult V, 8 adult C, 72 juvenile V, 2 juvenile C.

Etymology. – A reference to the carinate ridge running roughly parallel to the ventral margin.

Type horizon and locality. – Type-level sample R7T, Toarcian, *polymorphum* Biozone; Rabaçal, Portugal.

Description. – Left valve triangular in lateral outline with position of greatest height just anterior of mid-length. Right valve appears more rectangular in lateral view with dorsal and ventral margins roughly parallel. LV > RV. Ventral alar wing well-developed and conceals ventral margin in lateral view. Anterior margin broadly rounded at about mid-valve height, posterior margin triangular and close to ventral margin; anterior and posterior marginal rims well-developed. Surface ornament comprises a strong primary rib running along the margin of the alar wing and extending anteriorly towards the anterior cardinal angle, two weaker ribs running from the mid dorsal area and curving anteriorly, and other weaker ribs running postero-ventrally from the dorsal margin; the overall impression is of a triangular pattern not uncommon in Early Jurassic cytheroid ostracods. In dorsal view greatest width is at mid-length and the marginal rims are prominent. In ventral view longitudinal grooves run from the anterior to posterior. Ocular structures are not evident externally or internally.

Valves are thick walled and heavily calcified. Internally marginal zone and line of concrescence coincide. Hingement strongly antimerodont with large terminal elements each containing 7–8 teeth in the RV and crenulated medium element; large accommodation groove in LV. Marginal and normal pore canals not known. Muscle scars not known. Sexual dimorphism evident with males relatively longer and less high than females, although in dorsal view both have greatest width at mid-length. Juveniles show weakly developed ornament.

Dimensions: Rabaçal – ♀ L = 0.58–0.70, h = 0.37–0.46; ♂ L = 0.63–0.71, h = 0.35–0.43. Peniche – ♀ L = 0.60–0.69, h = 0.41–0.46; ♂ L = 0.65–0.68, h = 0.37–0.44.

Remarks. – The species is defined and figured using

material from the Rabaçal section which is much better preserved than material of this species from Peniche.

Kinkelinella ventrocarinata sp. nov. occurs in the lowest part of the *polymorphum* Biozone prior to the appearance of *K. sermoisensis* Apostolescu. *K. ventrocarinata* sp. nov. differs from *K. sermoisensis* in having a less well-developed alar wing structure and in surface ornament which consists of a strong latitudinal carinate rib along the wing with weaker ribs radiating from the dorsal margin to form an overall triangular pattern.

Kinkelinella costata differs from *K. ventrocarinata* sp. nov. in having stronger vertical ribs and the alar wing more ventrally extended.

Occurrence. – At present known only from the lowest Toarcian at Peniche and Rabaçal, Portugal, and from the Lower Toarcian of Robinswood Hill, Gloucestershire, UK (Lord, unpublished data).

Genus unknown

Genus unknown spp.
Figure 9K–M

Material. – *Ca*. 20 specimens, mostly adults, V (13 adult) and C.

Remarks. – A group of specimens with a relatively elongate form, punctate ornament and strong triangular posterior rim represent an unknown genus and may comprise more than one species. The general outline resembles *Ektyphocythere*, although not in detail, and the ornament lacks the characteristic triangular arrangement of ribs. Similarly, the lateral outline resembles some *Kinkelinella* species but it lacks the strongly developed ventral alar wing.

Occurrence. – Toarcian, *levisoni* and *bifrons* biozones.

Family Schulerideidae Mandelstam, 1959

Genus *Praeschuleridea* Bate, 1963

Type species. – *Cytheridea subtrigona* Jones & Sherborn, 1888.

Praeschuleridea cf. *P. pseudokinkelinella* Bate & Coleman, 1975
Figure 9N–R

cf. 1975   *Praeschuleridea pseudokinkelinella* sp. nov.; Bate & Coleman, p. 24, pl. 7, figs 6, 7, 11–13, pl. 10, figs 1–7, 9–11, 13.
      1986   *Praeschuleridea* cf. *pseudokinkelinella* Bate & Coleman. – Ainsworth, p. 322, pl. 11, figs 1–8.
    1999b   *Praeschuleridea pseudokinkelinella* Bate & Coleman. – Arias & Lord, pp. 236, 237, pl. 4, fig. 5.

Material. – *Ca*. 50 adult specimens, mostly valves (43).

Remarks. – *Praeschuleridea pseudokinkelinella* was originally described from the basal Toarcian of Great Britain. Our material *P*. cf. *P. pseudokinkelinella* is similar to but not identical with the well-preserved type material; material from the Toarcian–Aalenian of the Fastnet Basin figured by Ainsworth (1986) is also similar but difficult to compare for preservational reasons of both Irish and Portuguese forms although both differ posteriorly and in length:height ratio from the types. Our material shows some variation in outline and in strength of ornamentation; however, the genus *Praeschuleridea* is defined by its paleohemimerodont hingement which cannot be observed in our specimens which probably represent more than one species (including some *Ektyphocythere*).

Occurrence. – Toarcian, *bifrons* Biozone.

Suborder Cypridocopina Baird, 1845
Superfamily Cypridoidea Baird, 1845
Family Candonidae Kaufmann, 1900

Figure 9. Toarcian ostracods from Rabaçal (A–G) and Peniche (H–T) sections, Portugal. • A–J – *Kinkelinella ventrocarinata* sp. nov. Cabral, Pinto & Lord, *polymorphum* Biozone; A – female LV, external view, holotype, SMF Xe 23886, L = 0.63, h = 0.42, sample R7T; B – female carapace, dorsal view, paratype, SMF Xe 23887, L = 0.64, h = 0.44, sample R10; C – female carapace, ventral view, paratype, SMF Xe 23888, L = 0.70, h = 0.43, sample R10; D – female RV, internal view, paratype, SMF Xe 23889, L = 0.58, h = 0.37, sample R7T; E – female RV, internal view, detail of D (hinge); F – female LV, internal view, holotype, detail of the hinge, sample R7T; G – male RV, external view, paratype, SMF Xe 23890, L = 0.63, h = 0.35, sample R7T; H – female carapace, dorsal view, SMF Xe 23891, L = 0.61, h = 0.40, sample P11B; I – female LV, external view, SMF Xe 23892, L = 0.62, h = 0.42, sample P3T; J – female carapace, right view, SMF Xe 23893, L = 0.65, h = 0.41, sample P8. • K–M – Genus unknown spp, *bifrons* Biozone; K – LV, external view, SMF Xe 23894, L = 0.50, h = 0.28, sample P406; L – LV, external view, SMF Xe 23895, L = 0.53, h = 0.20, sample P422; M – RV, external view, SMF Xe 23896, L = 0.51, h = 0.25, sample P422. • N–R – *Praeschuleridea* cf. *P. pseudokinkelinella* Bate & Coleman, 1975, *bifrons* Biozone; N – RV, external view, SMF Xe 23897, L = 0.62, h = 0.38, sample P373; O – LV, external view, SMF Xe 23898, L = 0.63, h = 0.39, sample P408; P – carapace, dorsal view, SMF Xe 23899, L = 0.60, h = 0.36, sample P408; Q – LV, external view, SMF Xe 23900, L = 0.59, h = 0.39, sample P406; R – LV, external view, SMF Xe 23901, L = 0.68, h = 0.45, sample P422. • S, T – *Paracypris* cf. *P. redcarensis* (Blake, 1876), *polymorphum* Biozone; S – carapace, dorsal view, SMF Xe 23902, L = 0.45, h = 0.23, sample P11B; T – carapace, right view, SMF Xe 23903, L = 0.44, h = 0.23, sample P23. Dimensions in mm. Scale bars = 100 μm.
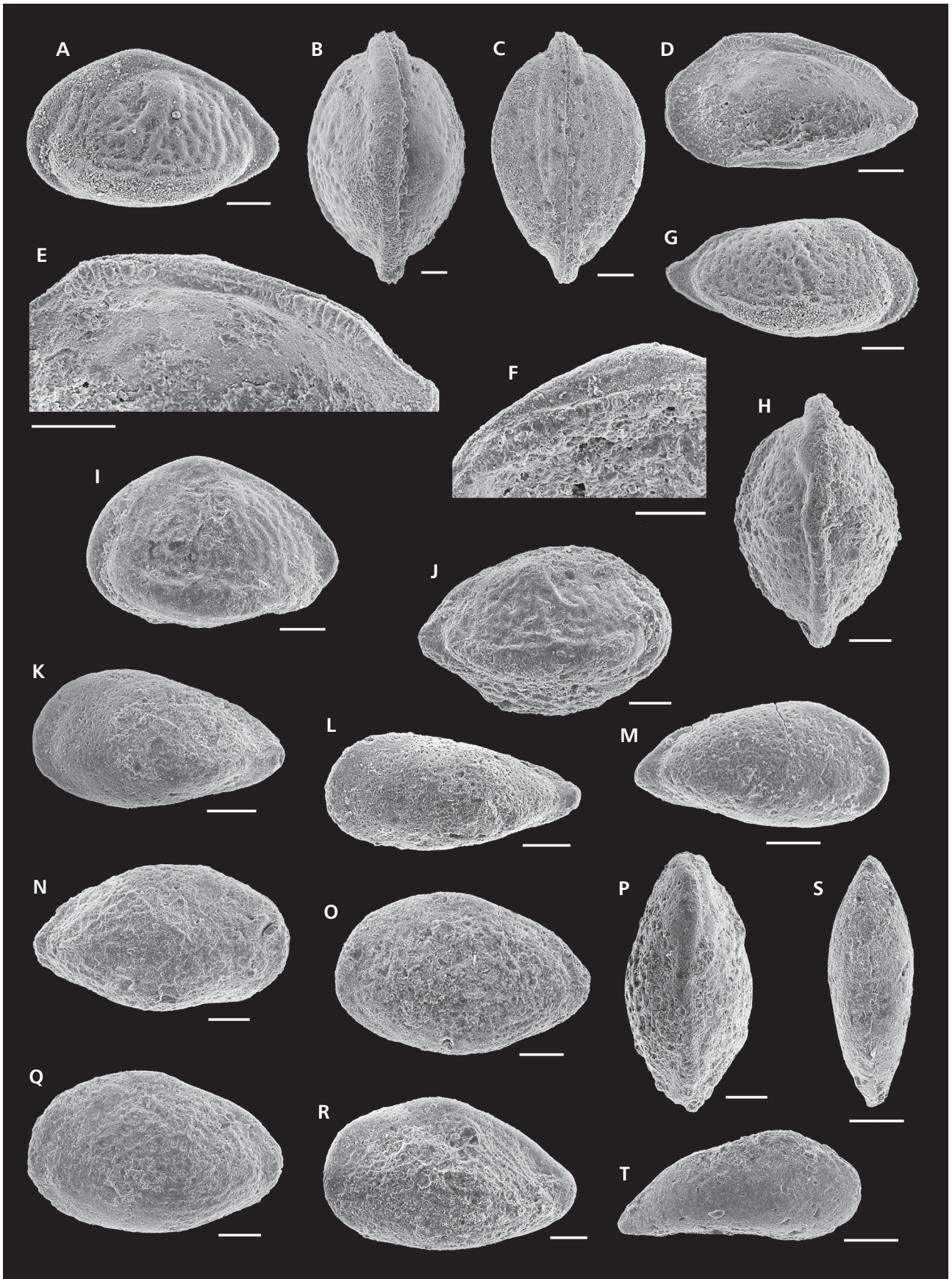
Genus *Paracypris* Sars, 1866

Type species. – *Paracypris polita* Sars, 1866.

Paracypris cf. *P. redcarensis* (Blake, 1876)
Figure 9S, T

   cf. 1876 *Bairdia redcarensis* sp. nov.; Blake, p. 431, pl. 17, fig. 4.
       2007 *Paracypris* cf. *redcarensis* (Blake). – Pinto *et al.*, pl. 2, figs 4, 5.
       2016 *Paracypris redcarensis* (Blake). – Rocha *et al.*, figs 4, 8.11.

Material. – 6 adult C, 1 juvenile C.

Remarks. – *Paracypris* cf. *redcarensis* Blake, 1876 has been frequently and probably erroneously recorded from many localities in Europe. The Peniche material consists of seven specimens in all biozones except the *levisoni* and differs from *P*. cf. *redcarensis* figured by Ainsworth (1987) from the Pliensbachian of the Fastnet Basin in being more elongate with a more concave ventral margin and an anterior margin more ventrally inclined. The original illustration of Blake, a small line drawing of a Hettangian specimen from Yorkshire, Great Britain, shows weaker cardinal angles and a less concave ventral margin than our material. This is a "Lazarus" taxon absent during the CIE and reappears in the *bifrons* Biozone.

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum* and *bifrons* biozones.

Superfamily Macrocypridoidea Müller, 1912
Family Macrocyprididae Müller, 1912

Genus *Macrocypris* Brady, 1867

Type species. – *Cythere minna* Baird, 1850.

?*Macrocypris* cf. ?*M. liassica* Bate & Coleman, 1975
Figure 10A–C

   cf. 1975 *Macrocypris*? *liassica* sp. nov.; Bate & Coleman, p. 6, pl. 9.3, 9.6, 9.7, fig. 5.

Material. – 15 adult C.

Remarks. – Our limited material is similar to the holotype (carapace right view, but not the juvenile paratypes) of ?*M. liassica* from the basal Toarcian of Great Britain but differs in being relatively shorter with a less extended posterior margin.

Occurrence. – Toarcian, *bifrons* Biozone.

Superfamily Pontocypridoidea G.W. Müller, 1894
Family Pontocyprididae G.W. Müller, 1894

Genus *Liasina* Gramann, 1963

Type species. – *Liasina vestibulifera* Gramann, 1963.

Remarks. – The species *Liasina lanceolata* (Apostolescu, 1959), described from the Sinemurian and Pliensbachian of the Paris Basin, is abundant (*ca*. 450 specimens, mostly C, adults and juveniles) in the *emaciatum*, *polymorphum* and lower *levisoni* biozones of Peniche (Fig. 10H–J), and *L. vestibulifera*, described from the Lower Pliensbachian of NW Germany, is common (*ca*. 35 specimens, mostly C, adults and juveniles) as *L*. cf. *L. vestibulifera* (Fig. 10K–M) in the *emaciatum* and *polymorphum* biozones. Internal information is lacking for both species but from external morphology we are confident about the identification of *L. lanceolata* although our specimens of *L*. cf. *L. vestibulifera* are less elongate and with a slightly convex ventral margin than in the figured type material.

Figure 10. Toarcian ostracods from Peniche section, Portugal. • A–C – ?*Macrocypris* cf. ?*M. liassica* Bate & Coleman, 1975, *bifrons* Biozone, sample P-404; A – carapace, right view, SMF Xe 23904, L = 0.40, h = 0.23; B – carapace, left view, SMF Xe 23905, L = 0.38, h = 0.19; C – carapace, dorsal view, SMF Xe 23906, L = 0.38, h = 0.20. • D–G – ?*Liasina cylindrica* Ainsworth, 1986, *polymorphum* and *bifrons* biozones; D – carapace, dorsal view, SMF Xe 23907, L = 0.38, h = 0.18, *polymorphum* Biozone, sample P11B; E – carapace, right view, SMF Xe 23908, L = 040, h = 0.19, *polymorphum* Biozone, sample P23; F – carapace, right view, SMF Xe 23909, L = 0.39, h = 0.18, *bifrons* Biozone, sample P422; G – carapace, left view, SMF Xe 23910, L = 0.40, h = 0.20, *bifrons* Biozone, sample P422. • H–J – *Liasina lanceolata* (Apostolescu, 1959), *polymorphum* Biozone, sample P23; H – LV, external view, SMF Xe 23911, L = 0.53, h = 0.25; I – carapace, right view, SMF Xe 23912, L = 0.51, h = 0.25; J – carapace, dorsal view, SMF Xe 23913, L = 0.55, h = 0.26. • K–M – *Liasina* cf. *L. vestibulifera* Gramann, 1963, *polymorphum* Biozone; K – carapace, dorsal view, SMF Xe 23914, L = 0.45, h = 0.23, sample P6; L – carapace, left view, SMF Xe 23915, L = 0.48, h = 0.23, sample P4; M – carapace, right view, SMF Xe 23916, L = 0.42, h = 0.20, sample P3T. • N, O – *Cardobairdia fastnetensis* Ainsworth, 1986, *bifrons* Biozone; N – carapace, right view, SMF Xe 23917, L = 0.45, h = 0.25, sample P386A; O – carapace, left view, SMF Xe 23918, L = 0.42, h = 0.24, sample P392. • P, Q – *Cardobairdia* aff. *C. posteroprolata* Ainsworth, 1987, *bifrons* Biozone, sample P414; P – carapace, left view, SMF Xe 23919, L = 0.44, h = 0.24; Q – carapace, right view, SMF Xe 23920, L = 0.44, h = 0.21. • R, S – *Cardobairdia* cf. *C*. sp. A Ainsworth, 1987, *polymorphum* Biozone; R – LV, external view, SMF Xe 23921, L = 0.42, h = 0.30, sample P6; S – carapace, right view, SMF Xe 23922, L = 0.41, h = 0.32, sample P11B. • T, U – *Cardobairdia* sp. 1, *bifrons* Biozone, sample P381; T – carapace, right view, SMF Xe 23923, L = 0.42, h = 0.30; U – carapace, left view, SMF Xe 23924, L = 0.43, h = 0.30. Dimensions in mm. Scale bars = 100 µm
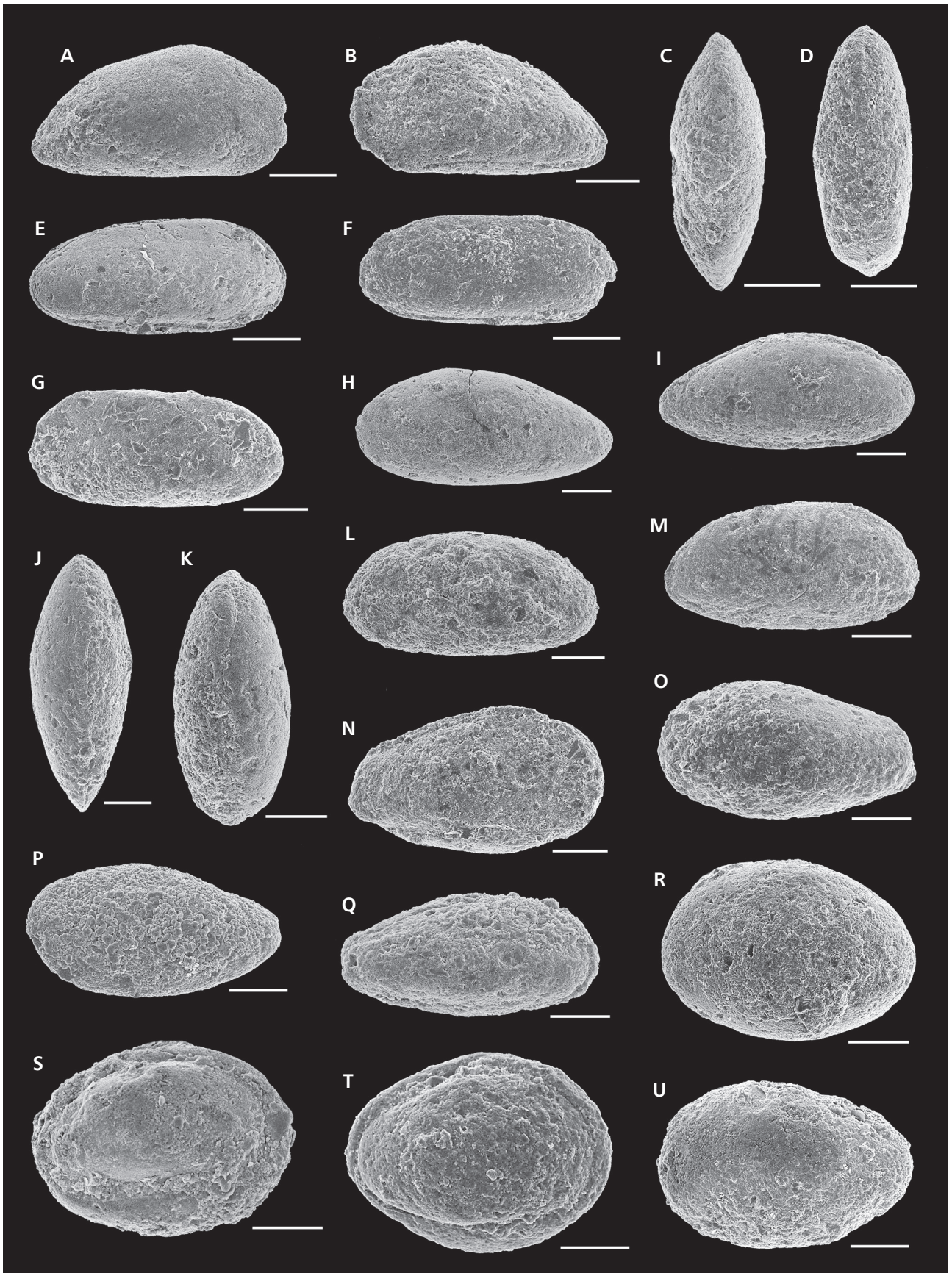
?*Liasina cylindrica* Ainsworth, 1986
Figure 10D–G

> 1986   *Liasina*? *cylindrica* sp. nov.; Ainsworth, pp. 298, 299, pl. 4, figs 1, 2, 5.
> 1999a   *Liasina* aff. *Liasina vestibulifera* Gramann, 1963. – Arias & Lord, p. 90, pl. 3, fig. 6.
> 2007   *Isobythocypris* cf. *tatei* (Coryell, 1963). – Pinto *et al.*, pl. 1, figs 7, 8.
> 2016   *Isobythocypris tatei*. – Rocha *et al.*, fig. 4.

Material. – *Ca*. 35 specimens, mostly adult and juvenile C.

Remarks. – ?*Liasina cylindrica* is an important species in the *polymorphum* Biozone at Peniche and Rabaçal; it is present in the bottom sample of the CIE and then reappears as a "survivor" species in the *bifrons* Biozone. Our material appears identical with Ainsworth's species *cylindrica* from the late Toarcian and Aalenian of the Fastnet Basin. We are uncertain if the species belongs to *Liasina* as we have no information about the internal features. The carapace shape does not match *Isobythocypris* Apostolescu.

The name "*tatei*" proposed by Coryell (1963) as a replacement for *Bairdia elongata* Blake, 1876 has become greatly confused in the literature, authors having followed Drexler's (1958, p. 515, pl. 23, fig. 1a–f, pl. 26, figs 7–9, pl. 27, figs 1, 2) incorrect identification of "*Bythocypris* cf. *elongata* (Tate & Blake 1876)".

Occurrence. – Pliensbachian, *emaciatum* Biozone; Toarcian, *polymorphum*, *levisoni* and *bifrons* biozones.

Suborder Sigilliocopina Mandelstam, 1960
Superfamily Sigillioidea Mandelstam, 1960
Family Saipanettidae McKenzie, 1968

Genus *Cardobairdia* Van den Bold, 1960

Type species. – *Cardobairdia ovata* Van den Bold, 1960.

Remarks. – A few specimens of four species of *Cardobairdia* occur in the topmost Pliensbachian (*emaciatum* Biozone) and Toarcian (*polymorphum* and *bifrons* biozones) of Peniche. In the *emaciatum* and *polymorphum* biozones a rounded form comparable to *Cardobairdia* sp. A of Ainsworth (1987) described from the Pliensbachian of the Fastnet Basin is present, represented by *ca*. 20 adult V (Fig. 10R, S). In the *bifrons* Biozone occur: an elongated form (4 adult C) with postero-ventral margin of the RV extended beyond posterior of LV, identified as *Cardobairdia fastnetensis* Ainsworth, 1986 (Fig. 10N, O), from the Toarcian of the Fastnet Basin; another elongated form (12 adult C), closer to *C. fastnetensis* but with a more convex dorsal margin

and without the postero-ventral margin of the RV extended beyond posterior of LV, identified as *C.* aff. *C. posteroprolata* Ainsworth, 1987 (Fig. 10P, Q); a rounded to subtriangular form (5 adult C), named *Cardobairdia* sp. 1 (Fig. 10T, U) which is less rounded and has weaker overlap than *Cardobairdia* sp. A of Ainsworth.

Results and discussion

Peniche ostracod assemblages

Ostracods are well represented, with more than 7,000 specimens (at least 52 species, belonging to 22 genera) found along the studied section, irregularly distributed, more abundant in *polymorphum* and *bifrons* biozones, very rare in *levisoni* Biozone. The assemblages show marked changes between the lower and upper levels (Fig. 11).

In analysing the ostracod species occurrences we distinguish between "Lazarus" and "survivor" species, although in a conventional sense both are "Lazarus" taxa in that they have migrated to a more favourable habitat, in this case presumably more oxygenated bottom waters, and returned when favourable conditions were re-established. We differentiate "Lazarus" species as those that do not occur in the CIE interval but reappear later, as opposed to "survivor" species that occur in the lowermost sample in the CIE and reappear later, post-CIE. Thus "Lazarus" species are: *Bairdia* aff. *B. molesta* (reappears higher in *levisoni* Biozone, post-CIE) and *Paracypris* cf. *P. redcarensis* (reappears in *bifrons* Biozone); "survivor" species are ?*Liasina* c*ylindrica* (reappears in *bifrons* Biozone) and *Kinkelinella sermoisensis* (reappears higher in *levisoni* Biozone, post-CIE). Note that in Fig. 11 the apparent "survivor" taxon in the left column is an artificial group (*Polycope* spp.) and that the right column showing the occurrence of unidentifiable ostracods includes specimens throughout the CIE interval.

In the Upper Pliensbachian *emaciatum* Biozone ostracods are very poorly preserved (mostly valves), making it impossible to identify many specimens and therefore the data are certainly incomplete, requiring caution in their interpretation. The assemblages showed relatively moderate diversity (= number of species) with *ca*. 14 spp., coincident with the first negative $\delta^{13}C$ excursion (Horizon 1 of Hesselbo *et al.* 2007, figs 2, 3; Littler *et al.* 2010; Fig. 2 here) and perhaps reflecting relatively low sea level towards the end of that stage (see Duarte 2007, Duarte *et al.* 2010). However, all the identified species range into the Toarcian, except *Cytherella* sp., and assemblages became more diverse in the Toarcian *polymorphum* Biozone with up to 26 species in total (*e.g.* sample P11B: 20 spp., P23: 16 spp.). Besides exhibiting high diversity,
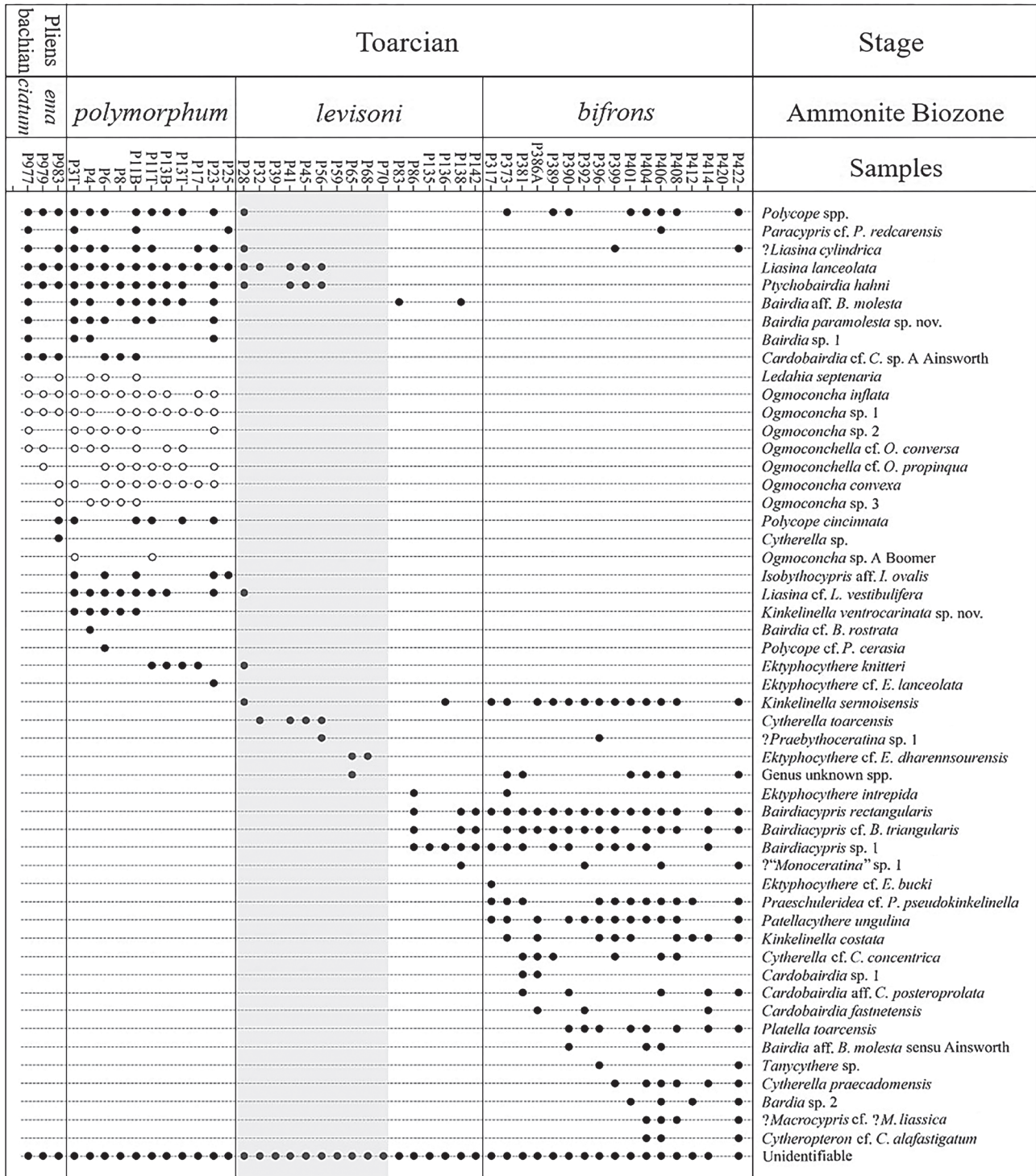
Figure 11. Ostracod distribution chart (black dots, except Metacopina represented by open circles) for the studied Peniche section. The CIE interval, as referred to in this paper, is shown in grey. Biozone divisions are not to scale.

Chart columns — Stage: Pliensbachian / Toarcian. Ammonite Biozone: *ciatum* / *ena* (Pliensbachian); *polymorphum*, *levisoni*, *bifrons* (Toarcian).

Species (top to bottom):

Polycope spp.
Paracypris cf. *P. redcarensis*
?*Liasina cylindrica*
Liasina lanceolata
Ptychobairdia hahni
Bairdia aff. *B. molesta*
Bairdia paramolesta sp. nov.
Bairdia sp. 1
Cardobairdia cf. *C.* sp. A Ainsworth
Ledahia septenaria
Ogmoconcha inflata
Ogmoconcha sp. 1
Ogmoconcha sp. 2
Ogmoconchella cf. *O. conversa*
Ogmoconchella cf. *O. propinqua*
Ogmoconcha convexa
Ogmoconcha sp. 3
Polycope cincinnata
Cytherella sp.
Ogmoconcha sp. A Boomer
Isobythocypris aff. *I. ovalis*
Liasina cf. *L. vestibulifera*
Kinkelinella ventrocarinata sp. nov.
Bairdia cf. *B. rostrata*
Polycope cf. *P. cerasia*
Ektyphocythere knitteri
Ektyphocythere cf. *E. lanceolata*
Kinkelinella sermoisensis
Cytherella toarcensis
?*Praebythoceratina* sp. 1
Ektyphocythere cf. *E. dharennsourensis*
Genus unknown spp.
Ektyphocythere intrepida
Bairdiacypris rectangularis
Bairdiacypris cf. *B. triangularis*
Bairdiacypris sp. 1
?*"Monoceratina"* sp. 1
Ektyphocythere cf. *E. bucki*
Praeschuleridea cf. *P. pseudokinkelinella*
Patellacythere ungulina
Kinkelinella costata
Cytherella cf. *C. concentrica*
Cardobairdia sp. 1
Cardobairdia aff. *C. posteroprolata*
Cardobairdia fastnetensis
Platella toarcensis
Bairdia aff. *B. molesta* sensu Ainsworth
Tanycythere sp.
Cytherella praecadomensis
Bardia sp. 2
?*Macrocypris* cf. ?*M. liassica*
Cytheropteron cf. *C. alafastigatum*
Unidentifiable

ostracods are abundant, usually more carapaces but V > C in some levels; Metacopina are dominant (9 species), Bairdidae well represented and new species appear such as *Ektyphocythere knitteri* and *Kinkelinella ventrocarinata* sp. nov., the latter recorded only in the *polymorphum* Biozone.

Of the nine metacopine species recognized eight ranged across the Pliensbachian–Toarcian boundary. All the metacopine taxa became extinct just before the *polymorphum–levisoni* boundary prior to the onset of the CIE conditions in the LB, but coincident with a previous

discrete negative pulse of the isotope curve (Fig. 12). The extinctions appear stepwise in the order: *Ledahia septenaria* and *Ogmoconcha* sp. 3, *Ogmoconcha* sp. A Boomer, *Ogmoconchella* cf. *O. conversa*, followed by simultaneous last occurrences of *Ogmoconcha inflata*, *O. convexa*, *O.* sp. 1, *O.* sp. 2, and *Ogmoconchella* cf. *O. propinqua*. However, this sequence is likely to be an artefact of sampling resolution, taphonomy, preservation and/or identification given the large number of unidentifiable specimens.

In the lower *levisoni* Biozone (= CIE, between horizons 2 and 3 of Hesselbo *et al.* 2007, figs 2, 3) there were few ostracods and diversity was drastically reduced from seven species at the base (sample P-28) and then fluctuating between four (P-56), three (P-41, P-45), two (P-32, P-65), one (P-68) and even zero (P-39, P-59, P-70); the two species *Cytherella toarcensis* and *Ektyphocythere* cf. *E. dharennsourensis* are only known in this interval and seem adapted to the bottom water conditions. Higher in the *levisoni* Biozone, post-CIE, the number of ostracods and diversity remained low with one "survivor" species (*K. sermoisensis*), one "Lazarus" species (*B.* aff. *B. molesta*) and five new species (*Bairdiacypris rectangularis*, *B.* cf. *B. triangularis*, *B.* sp. 1, *Ektyphocythere intrepida*, ?"*Monoceratina*" sp. 1). In these levels (intra and post-CIE), ostracods are mostly represented by carapaces.

In the *bifrons* Biozone ostracods are relatively abundant (mostly carapaces), diversity steadily increased from moderate to high, namely from 6 in the lower part (P-317) to 17 in the upper part (P-422), with 15 new to the zone, 8 ranging from the *levisoni* Biozone below and 3 from *polymorphum* Biozone. The most important species in this *bifrons* biozone, abundantly represented belong to the genera *Bairdiacypris*, *Kinkelinella* and *Cytherella*/*Platella*.

Ostracod palaeobiogeography and the Carbon Isotope Excursion regionally

The CIE reflects an injection of isotopically light carbon into the atmosphere which is preserved in the sedimentary and palaeontological record (*e.g.* Hesselbo *et al.* 2007, Ruebsam *et al.* 2019). While this process did not control the occurrence of ostracods directly it did ultimately affect bottom water oxygenation, which was low (dysoxic to possibly anoxic conditions) in several palaeogeographic contexts (*e.g.* Schmid-Röhl *et al.* 2002, Jenkyns 2010, Ruebsam *et al.* 2019). In northwestern and central European regions, very low or no oxygen conditions are commonly represented by "paper" shales (*e.g.* 'schistes carton' in France – *e.g.* Andreu *et al.* 1995) which lack bottom water biota and bioturbation and preserved fossils are of planktonic and nektonic organisms. At Peniche, despite the strong pertubation of the benthic, nektonic and planktonic records in this interval (Mattioli *et al.* 2009; Cabral *et al.* 2011, 2013; Comas-Rengifo *et al.* 2015; Rita *et al.* 2016; Correia *et al.* 2017), the low total organic carbon content and the absence of redox-sensitive traces confirm absence of anoxia (*e.g.* Hesselbo *et al.* 2007, Fantasia *et al.* 2019). This model is also supported by the turbiditic sedimentation recorded across the base of the *levisoni* Biozone (Wright & Wilson 1984, Duarte 1997).

For the LB the CIE is assigned to a hyperthermal event (Suan *et al.* 2008, 2010). However, the ostracods described here provide no bottom water temperature information. The genus *Cytherelloidea* Alexander conventionally regarded as a warm water indicator in modern seas did not occur in Peniche material. Gómez & Arias (2010) estimated seawater palaeotemperature variations based on stable isotope analyses of belemnite calcite from two sections located in the Iberian Range, central Spain and compared them with range data for ostracods, brachiopods and bivalves. During the Early Toarcian *tenuicostatum* (= *polymorphum*) Biozone they noted that a decrease in the number of ostracod species coincided with a warning trend, marking an "extinction interval" whose limit is located around the *tenuicostatum–serpentinum* (= *levisoni*) biozones boundary and characterized by the loss of all Metacopina Taxa (MEE, see next paragraph).

Boomer *et al.* (2008) coined the term Metacopine Extinction Event (MEE) based on assemblages from the Mochras Farm Borehole, west Wales, U.K. This borehole penetrated a very extended Lower Jurassic sequence of 1305 m of marine sediments which has been extensively studied, especially for its geochemical and microfossil records. Some ostracod data have been published (Boomer 1991) but not detailed species ranges. Ian Boomer (personal communication 2019) has generously given us access to his range data related to the CIE in the Mochras Farm Borehole, which allows direct and accurate correlation with our Peniche isotope record via the $\delta^{13}C$ curve in this interval (horizons 2 and 3 of Hesselbo *et al.* 2007; Xu *et al.* 2018) and thereby comparison of the ostracod ranges. There are surprising similarities and differences in detail of the occurrence patterns of the ostracod species common between the two sites; discussion here is limited to taxa we are confident are the same or very close. The MEE at Peniche (Fig. 12) falls at the top of the *polymorphum* Biozone, before the CIE, but coincident with the previous discrete negative pulse of the isotope curve; however, in the Mochras Farm Borehole the last metacopines became extinct within the CIE, *i.e.* at the base of the *falciferum* Biozone, equivalent to the *levisoni* Biozone used here (Boomer *et al.* 2008, fig. 2 for basic $\delta^{13}C$ plot against metacopine abundance), suggesting that the event was not synchronous between the Lusitanian Basin and the Cardigan Bay Basin and supporting the idea of the MEE becoming later northwards (see discussion in
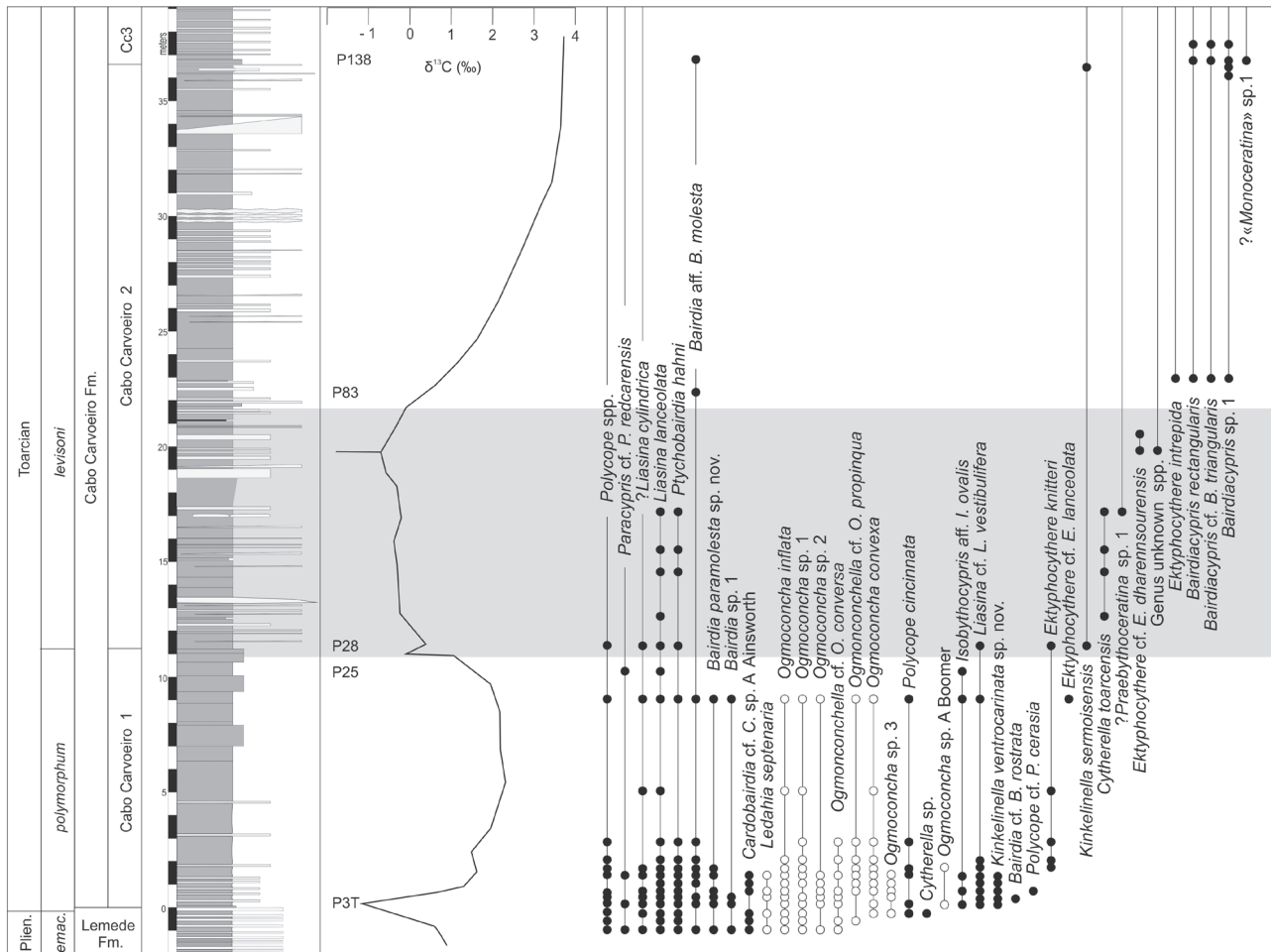
Figure 12. Stratigraphical distribution of the ostracod species (black dots, except Metacopina represented by open circles) through the *emaciatum*, *polymorphum* and *levisoni* ammonite biozones in Peniche section. The CIE as referred to in this paper (between horizons 2 and 3 of Hesselbo *et al.* 2007, figs 2 and 3) is shown in grey. The numbers to the left of the isotope curve correspond to selected samples to help follow the succession. Lithological symbols and References as in Fig. 2.

Boomer *et al.* 2008, pp. 48, 49). Even in the LB it seems not synchronous between Peniche and Rabaçal, located slightly to the North where the MEE is recorded at the *polymorphum–levisoni* boundary, as discussed in Cabral *et al.* (2013). However, as also discussed in Boomer *et al.* (2008), the comparison of the precise timing of the MEE between different sites is debatable, as it significantly depends on resolution of sampling intervals, quality of biostratigraphic control and variations in sedimentation-rate that vary with sites and authors.

Comparing ostracod records between Peniche and the Mochras Farm Borehole the following similarities occur: (i) Both *Liasina lanceolata* and *L. vestibulifera* range into the CIE and then become extinct; in both places *L. lanceolata* was relatively common in the CIE assemblages; (ii) *Paracypris redcarensis* (our *P.* cf. *P. redcarensis*) is a "Lazarus" taxon in both sites; (iii) the following species appear above the CIE at Peniche and Mochras Farm:

Bairdiacypris rectangularis, *B. triangularis* (our taxon is cf.), *Ektyphocythere intrepida*, *Kinkelinella sermoisensis* (it is a "survivor" species at Peniche where it also occurs at the base of the CIE); (iv) in both places *Cytherella praecadomensis* and *Cytheropteron alafastigatum* appear in the *bifrons* Biozone. However, there are differences in detail: (i) *Cytherella toarcensis* occurs only in the CIE interval at Peniche where, together with *L. lanceolata*, it is the most common taxon, however, at Mochras Farm *C. toarcensis* occurs much higher in the *variabilis* (= *gradata*) Biozone; (ii) *Praeschuleridea pseudokinkelinella* appears at Mochras Farm at the top of the CIE whereas in Peniche it appears at the base of the *bifrons* Biozone; (iii) *Ektyphocythere* cf. *E. lanceolata* occurs at the top of the *polymorphum* Biozone at Peniche whereas *E. lanceolata* appears higher in the *bifrons* Biozone at Mochras Farm; (iv) *Polycope cincinnata* seems to become extinct in Peniche at the top of the *polymorphum* Biozone, before

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the CIE, but at Mochras Farm it ranges into the CIE before becoming extinct.

It is unusual to be able to compare species ranges so finely over such a long distance (*ca*. 1,500 km) but the CIE provides the correlation confidence. Unfortunately, while there is an increasing number of high-resolution isotope records for early Toarcian age sections there are few detailed ostracod biostratigraphic studies to link to them to compare with Peniche. Where the isotope and other geochemical data are good the ostracod record is poor or unknown *e.g.* Yorkshire coast, Great Britain.

Arias (2006) gives isotope data and selected ostracod ranges for the Upper Pliensbachian–Lower Toarcian interval for the Almonacid de la Cuba section, Cordillera Iberica (Iberian Range), NE Spain. However, the $\delta^{13}C$ and $\delta^{18}O$ records are based on few data points and the ostracod range chart is focussed on the Pliensbachian–Toarcian boundary interval and only confirms that the MEE falls in the *mirabile* Subbiozone, *polymorphum* Biozone, that *Liasina lanceolata* ranges through the interval and that, in contrast to Peniche, *Cytherella toarcensis* appears in the Upper Pliensbachian *spinatum* (= *emaciatum*) Biozone. Also from the Cordillera Iberica, Gómez *et al*. (2008) gave ostracod ranges for the La Almunia de Doña Godina-Ricla section against the $\delta^{13}C$ curve. The ostracod ranges, modified after Arias (unpublished data 1995, 1996), show the MEE falling in the *paltum* Subbiozone (equivalent to the *mirabile* Subbiozone). The $\delta^{13}C$ is positive over the interval equivalent to the *polymorphum* Biozone at Peniche but it is possible to make some comparisons between the two sites. *Liasina lanceolata* becomes extinct at about the same level, as do *L. vestibulifera* and *Polycope cincinnata*; *Ektyphocythere sermoisensis*, *Praeschuleridea pseudokinkelinella* and *Praebythoceratina ungulina* appear at approximately equivalent levels, whereas *Cytherella toarcensis* has a local range in the *polymorphum* Biozone equivalent and *Ektyphocythere dharennsourensis* ranges through the interval but in Peniche has a short appearance at the top of the CIE. Gómez & Goy (2011) reporting on ostracods and isotopes from Sierra Palomera in the Cordillera Iberica give only $\delta^{18}O$ curves and the ostracod range chart is exactly the same as published by Gómez *et al*. (2008) for La Almunia de Doña Godina-Ricla.

Exton & Gradstein (1984) report Early Jurassic ostracods from the Grand Banks, offshore eastern Canada, and compare them with material from a number of Portuguese localities especially Rabaçal. Their record from the Pliensbachian through the Toarcian is generalized and shows a number of taxa that are the same or reinterpreted here, with a marked faunal turnover and extinction of the metacopines in the early Toarcian, however it is not possible to recognise the CIE (or T-OAE) in detail. Similarly, the record from Rabaçal (= Zambujal) in Boomer *et al*. (1998) is also rather generalized and shows

the extinction of the Metacopina in the lower *tenuicostatum* Biozone (= *polymorphum* Biozone), whereas in our material (Cabral *et al*. 2013) the final extinction level is in the upper part of the *polymorphum* Biozone at Peniche and at the *polymorphum/levisoni* boundary at Rabaçal, which shows that the ammonite zonation in Boomer *et al*. (1998) requires adjustment.

From discussion above and considering the occurrence records referred in Systematic Palaeontology it is clear that for reasons of palaeogeographical proximity and palaeoceanographical patterns the Toarcian ostracod assemblages of Peniche (and Rabaçal) are very close to those described from offshore southwest Ireland, particularly in Fastnet Basin, and the western UK and less so to those described from eastern Spain. At species level (including cf. and aff. levels) a number of taxa described from France and Germany have also been recognized. The broad pattern of faunal turnover and replacement before, during and after the CIE, including "survivor" and "Lazarus" species, and the stepwise extinction of metacopine ostracods prior to the CIE is similar but not identical to that described, for example, from the Mochras Farm Borehole (Boomer 1991, personal communication 2019) and Ilminster (Boomer *et al*. 2009), Great Britain, north-eastern Spain (*e.g.* Arias 2009), Aquitaine Basin (Andreu *et al*. 1995) and Paris Basin (Apostolescu 1959), France, SW Germany (Riegraf 1985, Franz *et al*. 2009) and NW Switzerland (Richter 1987). Riegraf (1985, fig. 14) gives a good summary of "Lazarus" taxa of ostracods and foraminifera before, during and after deposition of the early Toarcian bituminous paper shales of the Posidonienschiefer in SW Germany. A number of important taxonomic papers by Herrig (*e.g.* 1979, 1985) describe Lower Jurassic material from E Germany but lack detailed biostratigraphic data. Monostori (2008) reports that metacopes are absent in the basal Toarcian *tenuicostatum* Biozone (= *polymorphum* Biozone) of Transdanubian Hungary and attributes this to a sudden deepening of a subsiding basin in that area.

We do not discuss ostracod records from outside Europe because none has companion isotope data.

Extinction of the Suborder Metacopina

It has long been known that the extinction of a major group of ostracods, the Metacopina, occurred in the early Toarcian and appears to coincide with the initiation of the Toarcian reduced bottom water oxygen conditions (*e.g.* Boomer *et al*. 2008). At Peniche the extinction of nine metacopine species in the *polymorphum* Biozone, including five in the penultimate sample (P-23), would appear to confirm a causal relationship but in detail it can be seen that the extinctions preceded the decrease of

the bottom water oxygen conditions at a global scale, as represented by the CIE (and macrofossil impoverishment as described above) and occurred in a step-wise pattern. The relationship between the living ostracods and bottom water oxygenation is unlikely to have been simple and other factors such as bottom water temperature and pH may have played a part in the species extinctions, as discussed by previous authors about the T-OAE (*e.g.* Gómez *et al.* 2008; Suan *et al.* 2008, 2010; Gómez & Arias 2010; Trecalli *et al.* 2012). The highest *polymorphum* Biozone sample (P-25) contains ostracods but no metacopine taxa. As has been observed (Lord 1982, Boomer *et al.* 2008) an oxygen minimum zone (OMZ), no matter how global in scale it was, does not in isolation explain the metacopine extinction event when at Peniche and elsewhere, *e.g.* Mochras Farm Borehole, SW Germany, "Lazarus" taxa survived in refugia and were able to recolonize when bottom water conditions improved. The early Toarcian is now one of the most intensely studied time intervals in the Phanerozoic from a wide variety of geochemical, geophysical, palaeoclimatological, palaeoceanographical and palaeobiological perspectives but despite the wealth of data the explanation for the extinction of the metacopine ostracods remains unclear.

Having survived at least three major extinction events the question is what was unique about the early Toarcian environment that proved fatal to the group? Boomer *et al.* (2008) argued that competition for space and resources with other ostracod groups that had evolved rapidly in the Early Jurassic was a key factor, but probably not the only one, in the extinction of the group.

The fragmentation of the Pangea supercontinent undoubtedly greatly increased the area of epicontinental shelves, perhaps especially in NW Europe, which seems to have facilitated the dramatic evolutionary expansion of cytherocopes in Early Jurassic time. Cytherocopes possess smaller size and more complex marginal zones than metacopes which may have conferred an adaptive advantage. Early Jurassic cytherocopes have relatively simple, straight marginal pore canals with more complex forms developing through the Mesozoic. Similarly, normal pore canals were generally simple but more complex sieve-type pores evolved in parallel during the Early Jurassic (Lord *et al.* 2020).

Conclusions

(1) The ostracod assemblages of the uppermost Pliensbachian (*emaciatum* Biozone) and Lower–Middle Toarcian (*polymorphum*, *levisoni* and *bifrons* biozones), which encompasses the GSSP and the T-OAE as represented by the CIE, at Peniche, western Portugal, were studied in systematic detail for the first time.

(2) All the studied ostracods are typical marine as expected in this open marine marl-limestone series.

(3) The ostracods are poorly preserved and from the *ca.* 7,000 specimens found, at least 52 species (belonging to 22 genera) are identified.

(4) The following species are recognized as new: *Bairdia paramolesta* Cabral, Lord & Pinto sp. nov., *Kinkelinella ventrocarinata* Cabral, Pinto & Lord sp. nov.

(5) The ostracods from the GSSP demonstrate major faunal turnover, more clearly than in other benthic taxa: in the *polymorphum* Biozone diversity was relatively high with at least 26 species from which nine belong to the Metacopina, but in the lower *levisoni* Biozone (CIE interval) diversity was drastically reduced to seven species and then to four to one; higher in the *levisoni* Biozone (post-CIE) diversity remained low with one "survivor" species, one "Lazarus" species and five new species (three belonging to the genus *Bairdiacypris*). In the CIE three species are most common: *Liasina lanceolata*, *Ptychobairdia hahni* and *Cytherella toarcensis*; this latter species and *Ektyphocythere* cf. *E. dharennsourensis* only occur in the low oxygen zone.

(6) Metacopina species showed a stepwise extinction pattern and all disappeared before the *polymorphum–levisoni* biozonal boundary prior to the marked onset of CIE conditions. Correlation with the Mochras Farm Borehole suggests that the MEE was not synchronous and earlier at Peniche.

(7) The $\delta^{13}C$ record at Peniche and the Mochras Farm Borehole facilitates a very refined comparison of ranges of species in common between the two sites.

(8) The ostracod assemblages from Peniche are closer to those from the western Europe, particularly from Great Britain and offshore Ireland for the same age.

(9) The broad pattern of faunal turnover and replacement in the Peniche section before, during and after the CIE, including "survivor" and "Lazarus" species, and the stepwise extinction of metacopine ostracods prior to the CIE is similar to that described from elsewhere in Western Europe.

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