Research article
JM-TMS
Journal of Micropalaeontology

doi:10.1144/jmpaleo2015-035 | Vol. 35 | 2016 | pp. 205–228

Middle Jurassic Tethyan–Boreal ostracod faunal links: a case study from the Callovian of Portugal

Vanessa Pais[1], Maria Cristina Cabral[2*], Alan Lord[3], Ana Cristina Azerêdo[2] & Liam Gallagher[4]

[1] Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, C6, 4° piso, 1749–016 Lisboa, Portugal
[2] Departamento de Geologia and Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Campo Grande, C6, 4° piso, 1749–016 Lisboa, Portugal
[3] Senckenberg Forschungsinstitut, Senckenberganlage 25, D-60325 Frankfurt-am-Main, Germany
[4] Network Stratigraphic Consulting Ltd, Harvest House, Cranborne Road, Potters Bar, Hertfordshire EN6 3JF, UK
* Correspondence: mccabral@fc.ul.pt

Abstract: Late Callovian (athleta Chronozone) age sediments of Pedrógão, west coast Portugal, yielded a low diversity ostracod assemblage with relatively little in common with coeval NW European assemblages except at the weak level of comparative (cf.) species identification. Five new marine species are described (*Neurocythere multiforma* sp. nov., *Palaeocytheridea* (*Malzevia*)? *dorsocostata* sp. nov., *Praebythoceratina parascrobiculata* sp. nov., *Praeschuleridea lisensis* sp. nov., *Virgulacytheridea posteroacuminata* sp. nov.) and three previously described non-marine species recorded that so far are indigenous to Portugal (*Septacandona azeredae*, *Sinuocythere pedrogaensis*, *Theriosynoecum helmdachi*). Ostracod taxonomic links to western Tethys are evident but weak. Calcareous nannofossil assemblages were analysed for biostratigraphical control.

Keywords: Callovian, Lusitanian Basin, ostracod taxonomy, calcareous nannofossil biostratigraphy, palaeobiogeography

Supplementary material: Sample data and raw ostracod counts are available at https://doi.org/10.6084/m9.figshare.c.3271394.v1

Received 4 November 2015; **revised** 10 March 2016; **accepted** 29 March 2016

Our aim in studying the poorly known ostracods from the Callovian sequence at Pedrógão in western Portugal was to elucidate faunal links between the Tethys Ocean to the east and the epicontinental seas of western and northern Europe. In doing so we anticipated finding at least some NW European species from the classic literature of the 1950–70s. The results discussed below show weak palaeobiogeographical links with Tethys but also reveal forms with subtle morphological and therefore taxonomic differences from known Callovian taxa from France, Germany and Britain.

Callovian ostracods from Portugal are poorly known, not least because available sections are limited. Carapito (1998) analysed benthic foraminifers from the Callovian–Oxfordian transition from nearby Cabo Mondego (Farol section) and listed six ostracod species from the athleta ammonite Chronozone, Upper Callovian, but without illustrations the record has limited use. It is possible that Carapito's ostracod species *Micropneumatocythere* sp., *Lophocythere* gr. *cruciata* and *Eoschuleridea* sp. correspond to some identified species in the present work. Carapito Krausshar (2008) also recorded *Micropneumatocythere*? and *Eoschuleridea*? in the Oxfordian of Cabo Mondego (Praia section). Azerêdo *et al.* (2002*a*) similarly listed, but did not figure, marine Callovian ostracods from Pedrógão.

The Lusitanian Basin

The Lusitanian Basin of west-central Portugal is a north–south elongated basin (Fig. 1) whose genesis is linked with the opening of the North Atlantic Ocean, as with several other Mesozoic peri-Tethyan basins (e.g. Wilson *et al.* 1989). The basin is infilled by *c.* 5000 m of sediments ranging in age from the Late Triassic to Late Cretaceous, but mostly from the Jurassic. The Upper Triassic–Middle Jurassic succession corresponds to the first major cycle of basin development (Wilson *et al.* 1989; Azerêdo *et al.* 2014). During the Middle Jurassic carbonate sediments formed on a west/NW-dipping ramp system, therefore inner-marine facies dominate in the east/SE and more open-marine facies developed towards the west/NW, namely towards present-day shoreline and offshore (e.g. Azerêdo *et al.* 2003). A basinwide disconformity separates the Middle Jurassic from the Upper Jurassic, with a hiatus spanning from the Late Callovian to the Early Oxfordian time interval in the west, whereas to the east it may range from the late Bathonian (Ruget-Perrot 1961; Ramalho 1971; Mouterde *et al.* 1979; Wilson *et al.* 1989; Azerêdo *et al.* 2002*b*). The uppermost Middle Jurassic to lower Upper Jurassic sediments are associated with marked environmental changes over the basin, where depositional settings rapidly evolved from open-marine to shallow-marine, transitional and even to non-marine. This interval is interpreted as reflecting a major forced regressive episode (Azerêdo *et al.* 2002*b*), with reflooding leading to a complex pattern of depositional conditions throughout the basin, from freshwater and brackish-lagoonal to marginal- and shallow-marine settings.

In the west part of the basin, one of the most representative sections crops out on the coast at Pedrógão beach, where the Middle Jurassic below the disconformity is of Late Callovian age according to ammonite data (Ruget-Perrot 1961). The biostratigraphy of this Callovian section has been studied chiefly for macrofossils, namely ammonites and brachiopods (Ruget-Perrot 1961; Alméras *et al.* 1991). Other works covering only the topmost Callovian levels addressed ostracods (Cabral *et al.* 1998), palynology (Barrón *et al.*

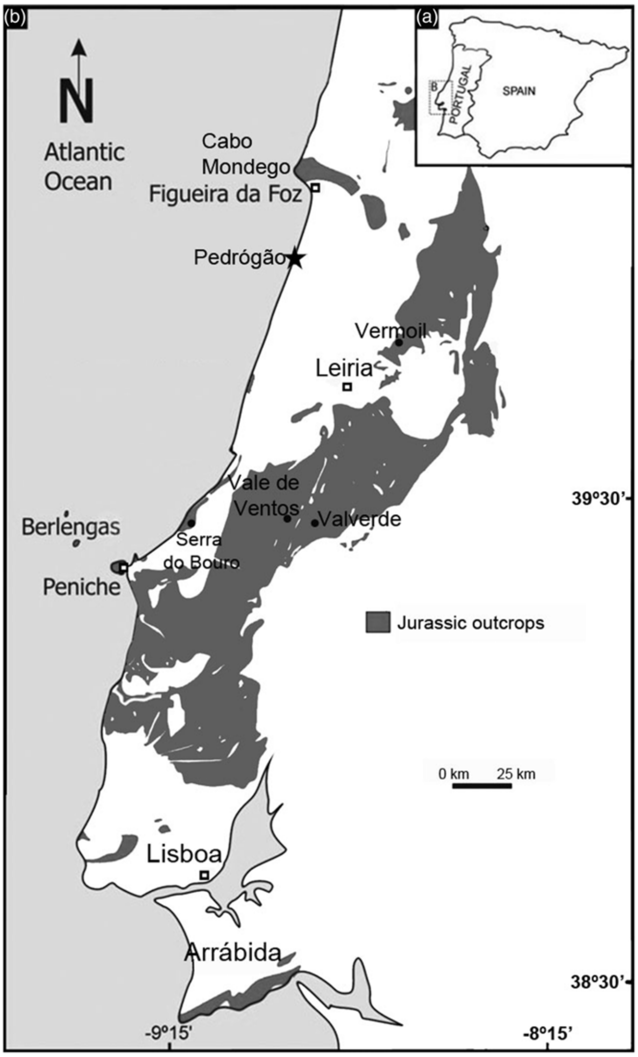

Fig. 1. Jurassic outcrop areas of the onshore Lusitanian Basin with localities mentioned in the text.

1999; Barrón & Azerêdo 2003) and palynofacies (Silva *et al.* 2014). The present study focuses in detail on the ostracod assemblages from the Pedrógão Callovian succession using samples from a larger number of beds than previously accessible (because of beach sand cover), as a result of exceptional outcrop exposure in autumn 2014 following coupled storms and high tides.

Note: ammonite chronozones used here are standard NW European zones (see Ogg & Hinnov in Gradstein *et al.* 2012) and are referred to simply as 'zones'.

The Pedrógão section

The study presented here focuses on the section at Pedrógão beach, 30 km to the south of Cabo Mondego (Fig. 1). The lower part of the section shows marine fossiliferous marls and limestones belonging to the informal Cabo Mondego formation *sensu* Azerêdo *et al.* (2003), overlain by a highly variable succession of marls, lignitic marls, bioclastic limestones, fenestral limestones, microbialites, pedogenic- and evaporite-influenced deposits, common desiccation surfaces, and dominantly non-marine fossils, interbedded with levels of restricted marine fossil content (Cabaços Formation; e.g. Ruget-Perrot 1961; Ramalho 1971, 1981; Leinfelder *et al.* 1988; Azerêdo *et al.* 2002*a*, *b*).

The lower marl–limestone succession is dated by ammonites and brachiopods as Late Callovian (Ruget-Perrot 1961; Mouterde *et al.* 1979; Alméras *et al.* 1991), the athleta Zone (the uppermost Callovian lamberti Zone is not recognized over the whole of the basin). Collating the information in Ruget-Perrot (1961), Grambast-Fessard & Ramalho (1985), Alméras *et al.* (1991) and M. Ramalho (unpublished data), our samples up to level P(7) are clearly Callovian in age (Fig. 2).

The lack of good biostratigraphic biomarkers hampers a precise age assignment of the overlying Cabaços Formation, though overall available data strongly suggest an Oxfordian age. The lowermost deposits of the Cabaços Formation have no age-diagnostic fossils; towards the intermediate part of the unit there is a consistent occurrence over the whole of the basin of the dasycladacean *Heteroporella lusitanica* (Ramalho 1970) which, coupled with other regional data, suggests a middle Oxfordian age for these levels (cf. Ruget-Perrot 1961; Ramalho 1971, 1981; Leinfelder *et al.* 1988; Azerêdo *et al.* 2002*a*, *b*).

The lower part of the Pedrógão succession (Fig. 2) is marl dominated, with marl levels much thicker (average 1.5–2 m) than limestone levels (average 0.10–0.25 m). Besides ammonites, it is rich in brachiopods, diverse bivalves (including in thin section thin-shelled marine bivalve fragments, well known in Jurassic microfacies as 'filaments'), echinoids, marine ostracods and hyaline-walled foraminifers. Towards the top, marl intervals become gradually thinner and limestones thicker, locally exhibiting irregular, ferruginous top surfaces, as at bed P(7); solitary corals, oysters, brachiopods, rare agglutinate-walled foraminifera and bioturbation occur throughout. This interval is overlain by interbedded marls, lignitic marls and bioclastic limestones, with bivalves, non-marine ostracods and charophyte gyrogonites, P(8B)–P(12), capped by a 0.5 m thick couplet (P(13B) and P(13T)) of reddish ferruginous bioclastic limestone layers separated by a highly irregular ferruginized surface, totally draped/infilled by charophyte stems (mostly) and gyrogonites. In the absence of biostratigraphical markers above P(7), the prominent P(13) irregular bed and surface were considered by Azerêdo *et al.* (2002*a*, *b*) to represent the physical boundary between the Middle and the Upper Jurassic at Pedrógão, simply as a sedimentary criterion. However, Azerêdo *et al.* (2002*b*) recognized that the marked facies change is clearly recorded earlier, marking it from P(8T) upwards. Data from this study show that the base of the Upper Jurassic must be redefined as from P(8B) upwards. Since the lower deposits of the Cabaços Formation have no age-diagnostic fossils, it is not possible to rule out the possibility that some of these beds encompass the latest Callovian and/or earliest Oxfordian time.

The calcareous nannofossil assemblages from Pedrógão reported below (Fig. 3) confirm a late Callovian age consistent with the athleta ammonite Zone.

Material and methods

Ostracods

Fifteen samples were collected from the marly beds of the Cabo Mondego 'formation' at Pedrógão, central-west coast of Portugal (Fig. 1); these samples were subsampled immediately after collection for calcareous nannofossil analysis. The main samples were processed at the Universidade de Lisboa using standard micropalaeontological techniques, including disaggregation with petroleum and washing over 63, 150, 500 µm and 2 mm sieves. Washed residues were picked for ostracods, usually 75% random splits of the >150 µm fractions obtained with a microsplitter. Abundance patterns in the range chart (Fig. 4) are recalculated from the data. Scanning electron miocroscope and light microscope images were prepared in the Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt-am-Main and in the Faculdade de Ciências, Universidade de Lisboa.

During the course of the work type and comparative materials housed in the Bundesanstalt für Geowissenschaften und Rohstoffe,

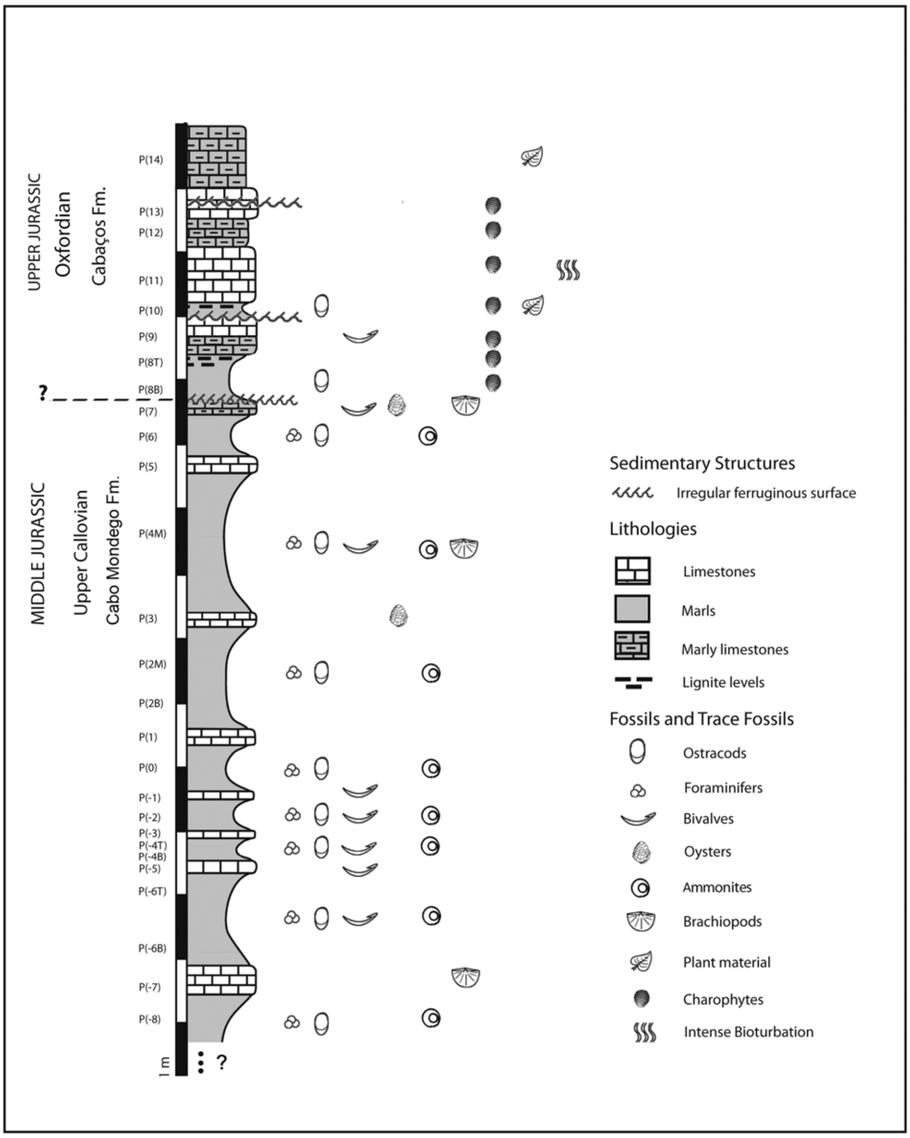

Fig. 2. Lithological log of Pedrógão section with sample points. Ammonite data based on Ruget-Perrot (1961).

Berlin, the Natural History Museum, London and in the Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt-am-Main were consulted and are discussed in the Systematic Palaeontology below.

Type and figured material from the present work is housed in the Senckenberg Forschungsinstitut und Naturmuseum, Frankfurt-am-Main and bears the catalogue numbers ‘SMF Xe’ of the Ostracod Collection. A set of comparative material is housed in the Departamento de Geologia, Faculdade de Ciências, Universidade de Lisboa.

Abbreviations: LV, left valve; RV, right valve; V, valve; C, carapace; juv, juvenile; ♂, male; ♀, female; L, length; H, height; W, width in mm.

Calcareous nannofossils

Preparation and counting

Simple smear-slides for light microscopic examination were prepared following standard procedures (e.g. Bown & Young 1998). Each smear slide was subsampled from the 1 cm^3 bulk sediment sample. A small fraction of sediment (3–6 ‘grains’) and a few drops of tap water were placed on to a glass microscope slide (76 × 26 mm), the sediment was crushed in the water and ‘smeared’ thinly across the surface of the glass slide using a plastic stirring rod, until a thin layer of rippled material was obtained. The slide was then dried on a hotplate. After drying, a glass coverslip (50 × 22 mm) was attached on to the glass slide using Norland Optical Adhesive 61 as the mounting medium, air bubbles were removed by gentle pressure, and the preparation cured under long-wave UV light for 10 min.

The counts of the nannofossil assemblages (Fig. 3) were performed on 100 different fields of view (FOV) in all slides using an Olympus BX40 polarizing light-microscope at a magnification of 1000×. In each slide, different FOV were analysed and counted first ‘systematically’, following predefined traverses along the slide, and then along random traverses on each slide. Only nannofossils that were completely within the FOV, and specimens which had their base-point within the FOV were counted (i.e. nannofossils that are truncated at the top edge of the FOV; specimens truncated at the lower edge of the FOV were not included in the counts) in order to avoid a size bias. Studied slides are housed in the collections of Network Stratigraphic Consulting Ltd.

Age determination

Reference is made to the ‘standard’ Middle to Late Jurassic nannofossil zonation of Bown & Cooper (1998) for age determination and zone assignment. This NJ (Nannofossil Jurassic) notation is an accepted standard that (at the time) stabilized biostratigraphic nomenclature for the Jurassic. The Bown *et al.* (1988) zonation scheme includes reference to

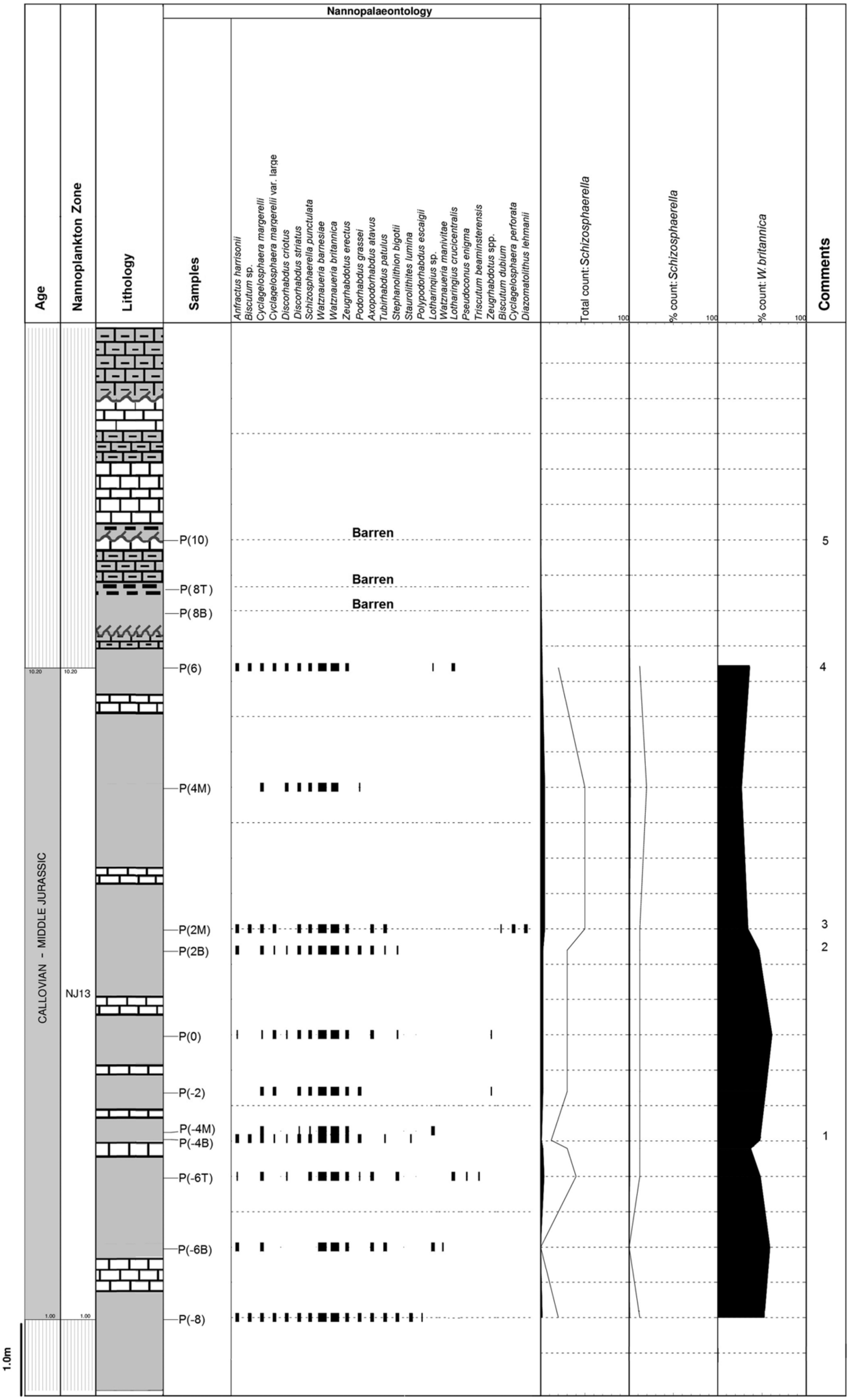

Fig. 3. Calcareous nannofossil range chart. Notes: 1. Last Occurrence Datum (LOD) *S. lumina*; 2. LOD *St. bigotii*; 3. LOD *A. atavus*, *D. lehmanii*; 4. LOD *An. harrisonii*, *C. margerelii*, *L. crucicentralis*, *Sc. punctulata*, *Z. erectus*; 5. highly organic, non-calcareous.

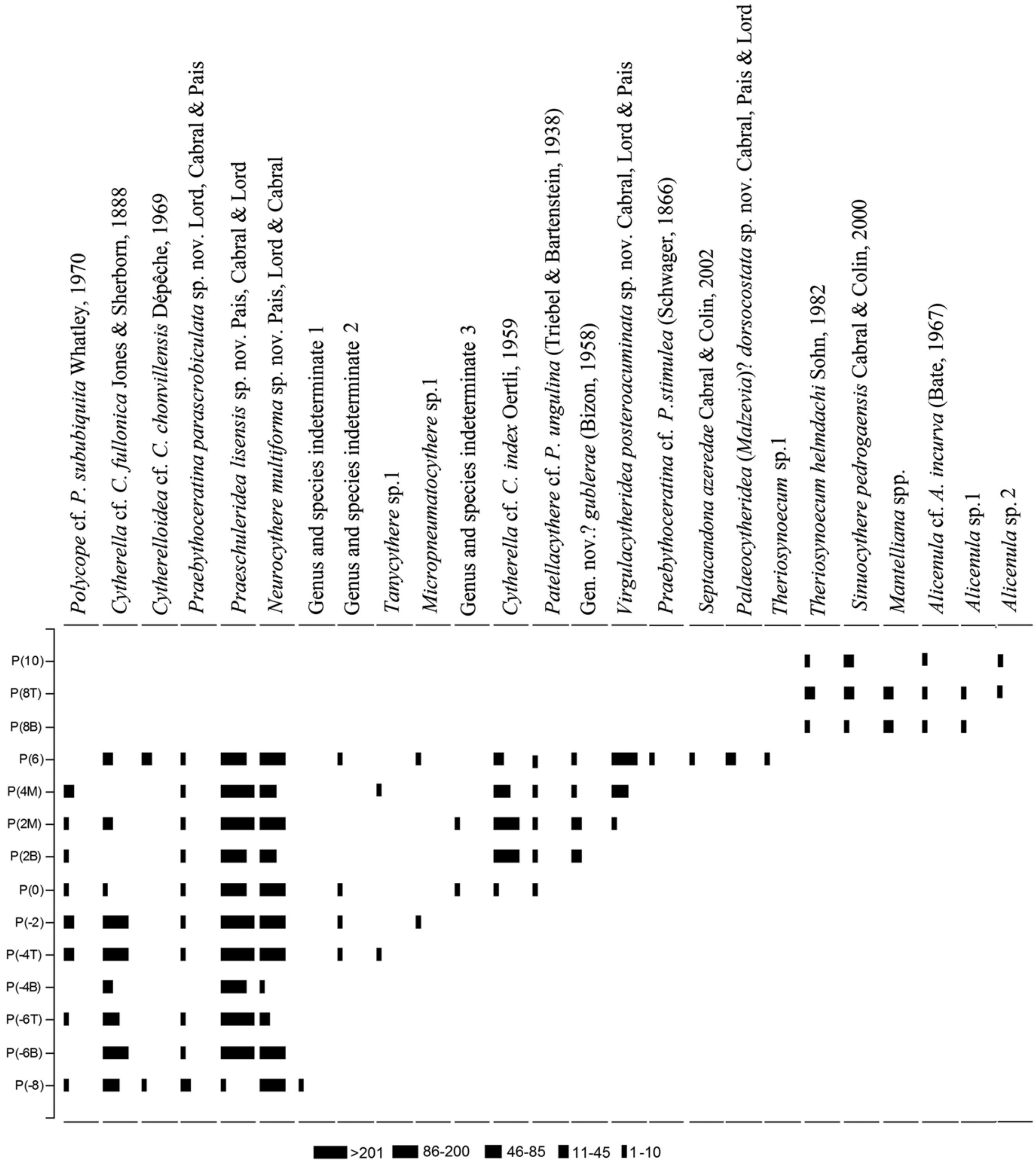

Fig. 4. Ostracod range chart.

Portugal and is the basis for the 1998 scheme of Bown & Cooper (in Bown 1998). This zonation is calibrated against Boreal ammonite zones and Tethyan nannofossil zones of Bralower *et al.* (1989) and achieves a resolution at least equal to the ammonite zonation. There is little relevant recent published nannofossil data for the Callovian–Oxfordian of Portugal; however, further reference is made to Jain (2008), Bergen *et al.* (2013) and Castellato (2010).

Ostracod systematic palaeontology

The classification of Quaternary-living ostracods of Horne *et al.* (2002) is followed with additions appropriate for Mesozoic assemblages.

Class **Ostracoda** Latreille, 1806
Order **Myodocopida** Sars, 1866
Suborder **Cladocopina** Sars, 1866
Family **Polycopidae** Sars, 1866

Genus *Polycope* Sars, 1866

Type species. *Polycope orbicularis* Sars, 1866.

Remarks. The generic concept of *Polycope* is applied in the broadest sense. In the Jurassic, specimens of *Polycope* are rarely sufficiently abundant or well preserved for reliable species identification or comparison.

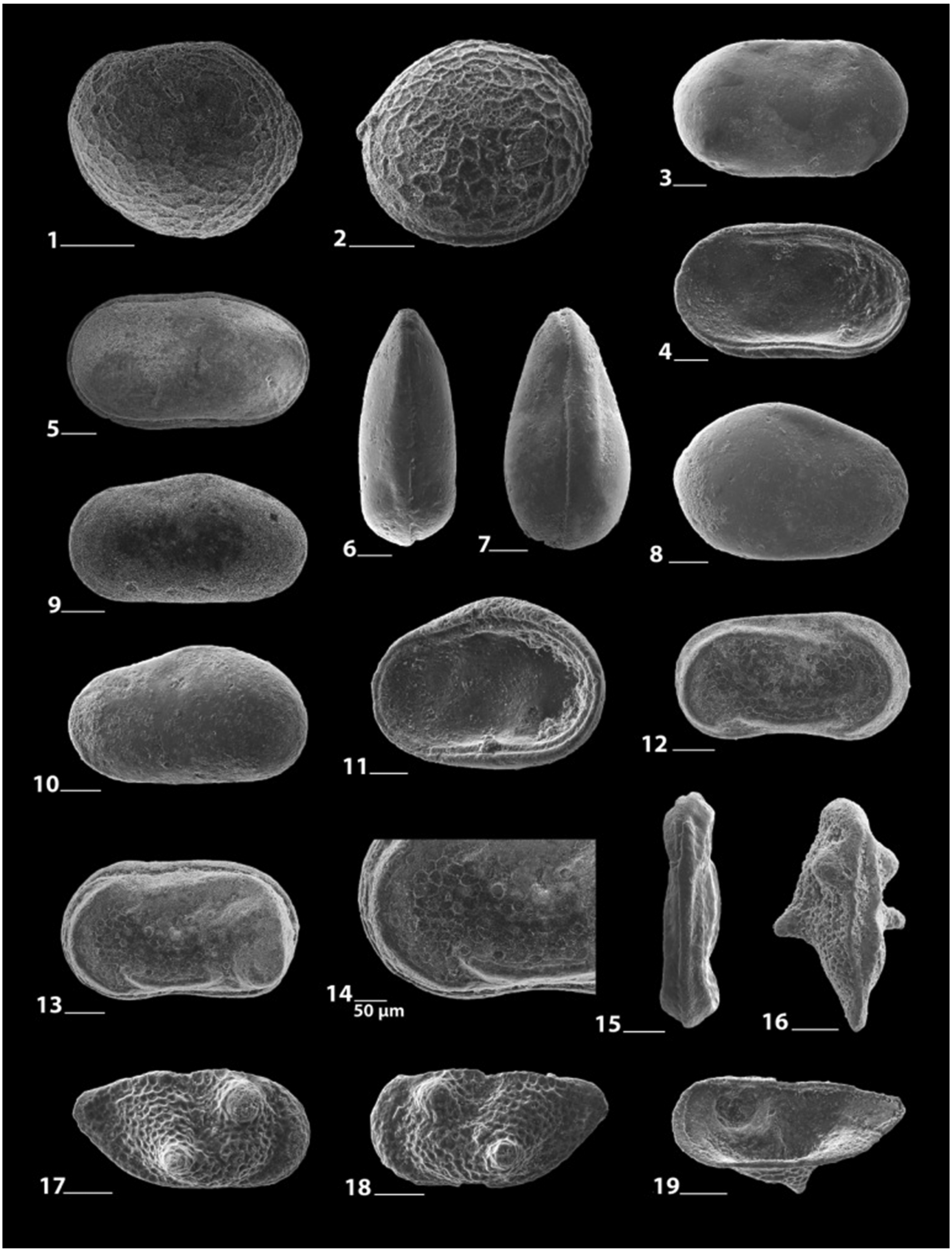

Fig. 5. (**1**, **2**) *Polycope* cf. *P. sububiquita* Whatley, 1970: **1,** C, right view, external, SMF Xe 23173, P(−2), Upper Callovian, Pedrógão, Portugal L = 0.324, H = 0.274; **2,** C, left view, external, SMF Xe 23174, P(2M), Upper Callovian, Pedrógão, Portugal, L = 0.375, H = 0.324. (**3 – 6**) *Cytherella* cf. *C. fullonica*Jones & Sherborn, 1888: **3,** ♀ RV, external, SMF Xe 23175, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.650, H = 0.375; **4,** ♀ RV, internal, SMF Xe 23176, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.675, H = 0.375; **5,** ♂ C, left view, SMF Xe 23177, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.650, H = 0.350; **6,** ♀ C, ventral view, SMF Xe 23178, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.675, H = 0.375. (**7**–**11**) *Cytherella* cf. *C. index* Oertli, 1959: **7,** ♀ C, dorsal view, SMF Xe 23179, P(2M), Upper Callovian, Pedrógão, Portugal, L = 0.600, H = 0.425; **8,** ♀ RV, external, SMF Xe 23180, P(0), Upper Callovian, Pedrógão, L = 0.600, H = 0.400; **9,** ♂ LV, external, SMF Xe 23181, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.274; **10,** ♀ LV, external, SMF Xe 23182, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.324; **11,** ♀ RV, internal, SMF Xe 23183, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.425. (**12**–**15**) *Cytherelloidea* cf. *C. chonvillensis* Dépêche, 1969: **12,** ♂ C, right view, external, SMF Xe 23184, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.300; **13,** ♀ C, left view, external, SMF Xe 23185, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.324; **14,** ♀ C (as *13*), ornament detail; **15,** ♂ C, dorsal view, SMF Xe 23186, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.550 H = 0.324. (**16**–**19**) *Praebythoceratina parascrobiculata* sp. nov. Lord, Cabral & Pais: **16,** C, dorsal view, paratype, SMF Xe 23187, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.250; **17,** RV, external, holotype, SMF Xe 23188, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.250; **18,** LV, external, paratype, SMF Xe 23189, P(2M), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.250; **19,** RV, internal, paratype, SMF Xe 23190, P(2M), Upper Callovian, Pedrógão, L = 0.500, H = 0.250. Scale bars 100 µm except where otherwise noted.

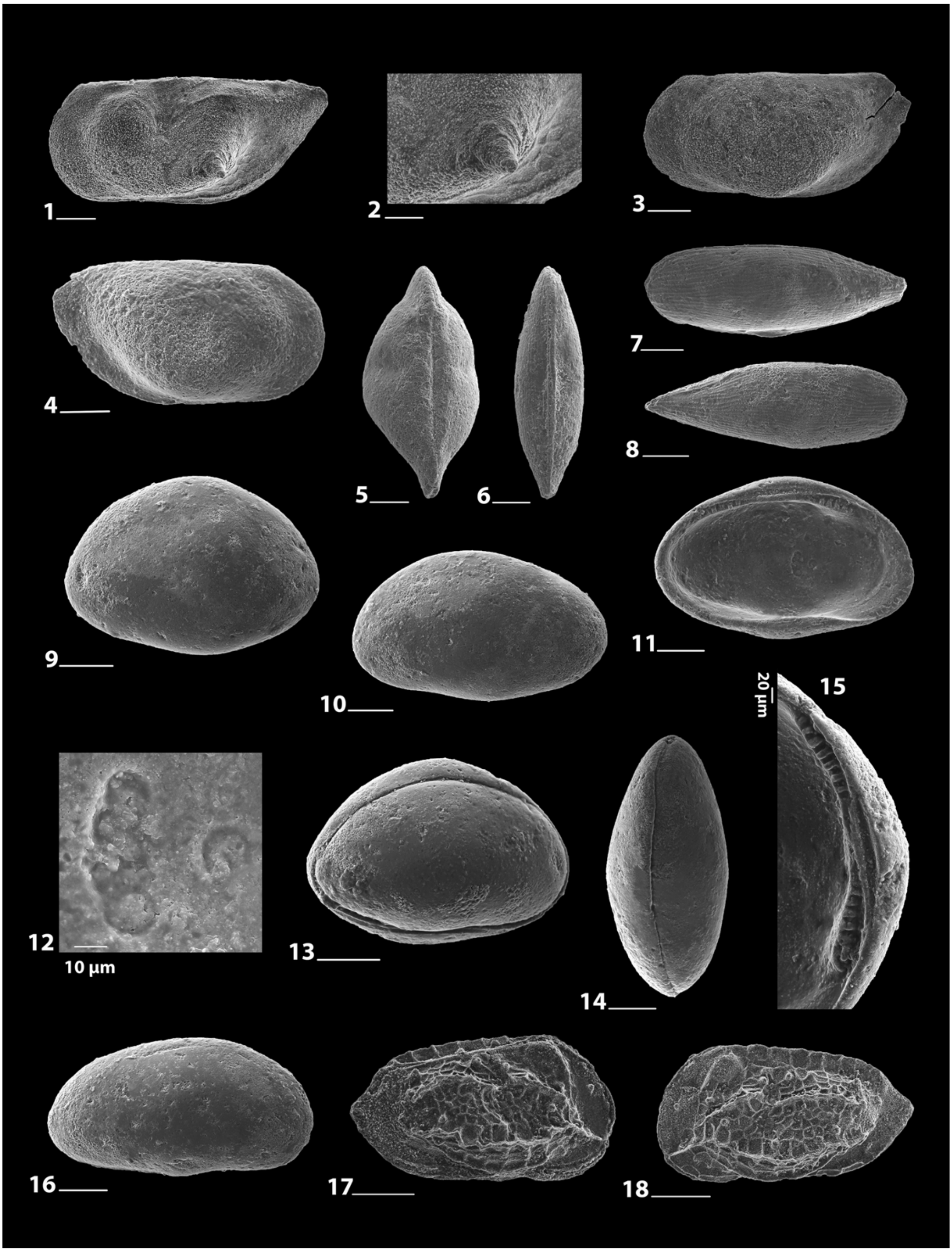

Fig. 6. (**1**, **2**) *Praebythoceratina* cf. *P. stimulea* (Schwager, 1866): **1,** LV, external, SMF Xe 23195, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.650, H = 0.3; **2,** LV (as 1), external, spine detail. (**3** – **5**) *Patellacythere* cf. *P. ungulina* (Triebel & Bartenstein, 1938): **3,** LV, external, SMF Xe 23196, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.591, H = 0.3; **4,** RV, external, SMF Xe 23197, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.274; **5,** C, dorsal view, SMF Xe 23198, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.6, H = 0.3. (**6** – **8**) *Tanycythere* sp. 1: **6,** C, dorsal view, SMF Xe 23199, P(−4T), Upper Callovian, Pedrógão, Portugal, L = 0.6, H = 0.225; **7,** C (as 6), left view; **8,** C, right view, external, SMF Xe 23200, P(4M), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.2. (**9**–**16**) *Praeschuleridea lisensis* sp. nov. Pais, Cabral & Lord: **9,** ♀ LV, external, paratype, SMF Xe 23201, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.324; **10,** ♂ LV, external, paratype, SMF Xe 23202, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.324; **11,** ♂ LV, internal, paratype, SMF Xe 23203, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.5, H = 0.3; **12,** ♂ LV (as 11), internal, muscle scars detail; **13,** ♀ C, right view external, holotype, SMF Xe 23204, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.425, H = 0.324; **14,** ♀ C, dorsal view, paratype, SMF Xe 23205, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.5, H = 0.324; **15,** ♀ LV, internal, paratype, hinge detail, SMF Xe 23206, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.324; **16,** ♂ RV, external, paratype, SMF Xe 23207, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.3. (**17**, **18**) *Palaeocytheridea* (*Malzevia*)? *dorsocostata* sp. nov Cabral, Pais & Lord: **17,** ♀ C, right view, external, holotype, SMF Xe 23208, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.4, H = 0.250; **18,** ♀ LV, external, female, paratype, SMF Xe 23209, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.250. Scale bars 100 µm except where otherwise noted.

Polycope cf. *P. sububiquita* Whatley, 1970
(Fig. 5:1–2)

cf. 1970 *Polycope sububiquita* Whatley: 312–313, pl. 1, figs 5–11, 15.
cf. 2009 *Polycope sububiquita* Whatley; Wilkinson & Whatley: 260, pl. 1, fig. 3.

Material. 60 specimens – adults and juveniles, carapaces: samples P(−8), P(−6T), P(−4T), P(−2), P(0), P(2B), P(2M), P(4M).

Description. Sublenticular outline with small dimensions; valves of similar size; greatest length at mid-height, greatest height at anterior cardinal angle, greatest width at mid-height and length. Dorsal margin slightly convex or straight, less than total length of valve; ventral margin strongly convex; anterior margin inclined at mid-height and above; posterior margin asymmetrically rounded. Anterior and posterior cardinal angles obtuse. Ornament reticulate, sometimes relatively weak or occasionally with stronger radial ribs towards the margins. Internal details and sexual dimorphism not observed.

Dimensions. L = 0.250–0.425, H = 0.200–0.325.

Occurrence. Lamberti–mariae zones, Callovian–Oxfordian, Staffin Bay and mariae Zone, Oxfordian, Port-en-Righ, Scotland; holotype from mariae Zone, Woodham, England (Whatley 1970). Athleta Zone to glosense Zone, Upper Callovian–Middle Oxfordian, England (Wilkinson & Whatley 2009). Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Whatley (1970) cites a number of records of similar Jurassic age in synonymy with *P. sububiquita* but these are unreliable because of poor illustrations. *Polycope* sp. 11 of Bizon (1958) is not illustrated and *Polycope* sp. 11 Bizon in Oertli (1959) is illustrated by a single image with no distinguishing features; the same species figured by Glashoff (1964, pl. 5, fig. 22) resembles Oertli's figure in having a rounded outline and apparently lacking ornament. *Polycope* sp. 12 of Glashoff (1964, pl. 5, fig. 21) resembles *P. sububiquita* in outline and appears ornamented. Also synonymized is *Polycope* sp. A of Donze (1962) which has a more rounded outline than *sububiquita* and has weak or no ornament. We have compared our material directly with the specimen figured by Wilkinson & Whatley (2009, catalogue number Io 5032 from the type locality) which is similar in shape, size and ornament.

Subclass **Podocopa** Sars, 1866
Suborder **Platycopina** Sars, 1866
Family **Cytherellidae** Sars, 1866

Genus *Cytherella* Jones, 1849

Type species. *Cytherina ovata* Roemer, 1841.

Remarks. Numerous fossil species of *Cytherella* have been described, differentiation of which has generally relied on a subjective assessment of three-dimensional shape, as a result of which the taxa have little biostratigraphical or palaeoecological utility and formal description of new 'species' is of little value.

Cytherella cf. *C. fullonica* Jones & Sherborn, 1888
(Fig. 5:3–6)

cf. 1888 *Cytherella fullonica* Jones & Sherborn: 274, pl. 1, figs 12a–c.
cf. 1969 *Cytherella fullonica* Jones & Sherborn; Bate: 395, pl. 5, fig. 9, pl. 6, fig. 1.
cf. 1970 *Cytherella fullonica* Jones & Sherborn; Whatley: 313, pl. 1, figs 12–14, 16, 18.
cf. 1978 *Cytherella fullonica* Jones & Sherborn; Kilenyi: pl. 1, figs 1–2.
cf. 1995 *Cytherella* cf. *fullonica* Jones & Sherborn; Mette: 266, pl. 1, figs 1–4.
cf. 2009 *Cytherella fullonica* Jones & Sherborn; Wilkinson & Whatley: 260, pl. 1, figs 4, 5.

Material. 460 specimens – adults and juveniles, valves and carapaces: samples P(−8), P(−6B), P(−6T), P(−4B), P(−4T), P(−2), P(0), P(2M), P(6).

Description. Subrectangular and elongate outline with large dimensions; RV totally overlaps LV; greatest length at mid-height, greatest height at antero-dorsal margin, greatest width near posterior margin. Dorsal margin straight to slightly concave, roughly parallel with the straight to weakly concave ventral margin, anterior margin uniformly rounded, posterior margin rounded in larger RV and may be angled near mid-height in smaller LV but in both valves there is a clear postero-dorsal slope to the margin. Valve surface smooth and unornamented. Sexual dimorphism evident, with males slightly smaller, narrower, with less pronounced overlap of the valves. Internally the larger RV has a contact groove to receive the smaller LV. Muscle scars well preserved and typical for genus.

Dimensions. ♂: L = 0.590–0.670, H = 0.350–0.370. ♀: L = 0.650–0.720, H = 0.375–0.400.

Occurrence. Described from the Bathonian of England (Jones & Sherborn 1888) and redescribed with a lectotype and paralectotypes designated by Bate (1969). Ranges from the Bathonian to Lower Kimmeridgian (Wilkinson & Whatley 2009). Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. The lectotypic material figured by Bate (1969) shows a weak median depression not present in our material but the lectotypic specimens and our material share a sloping postero-dorsal margin. The Pedrógão material is closer to the specimens from the Lower Kimmeridgian figured by Kilenyi (1978). *Cytherella fullonica* is known from Great Britain and from the Bathonian of Normandy (F. Dépêche, 1964, Université Pierre-et-Marie Curie, Paris, unpublished thesis); the present record from Portugal suggests a wider palaeobiogeographical range than previously understood.

Measurement of our material revealed sexual dimorphism in A-1 instars with ♂: L = 0.570–0.590, H = 0.330–0.350; ♀: L = 0.570–0.610, H = 0.340–0.360 (gender determination based on ♀ posterior inflation); material in Figure 5:3–6 is adult (A) stage.

Cytherella cf. *C. index* Oertli, 1959
(Fig. 5:7–11)

cf. 1958 *Cytherella* sp. 17 Bizon: 21, pl. 5, figs 7–9.
cf. 1959 *Cytherella index* Oertli: 16–17, pl. 1, figs 13–25.
cf. 1963 *Cytherella index* Oertli; Grékoff: 1720, pl. 1, figs 6–9.
cf. 1966 *Cytherella index* Oertli; Oertli in Maync: 13, pl. 9, figs 7–9.
cf. 1991 *Cytherella index* Oertli; Rosenfeld & Honigstein: 435, pl. 1, fig. 3.
cf. 1995 *Cytherella* cf. *index* Oertli; Mette: 266, pl. 1, figs 5–8.
cf. 2004 *Cytherella index* Oertli; Mette & Geiger: 81, pl. 9, figs 3, 4.
cf. 2009 *Cytherella index* Oertli; Wilkinson & Whatley: 262, pl.1, fig. 6.

Material. 245 specimens – adults and juveniles, valves and carapaces: samples P(0), P(2B), P(2M), P(4M), P(6).

Description. Suboval outline with relatively large dimensions; RV totally overlaps smaller LV; greatest length at mid-height, greatest height slightly posterior of mid-length, greatest width towards posterior. Dorsal margin strongly convex, sloping towards anterior margin from point of greatest valve height with a weak concavity, ventral margin straight to slightly convex, anterior and posterior margins well rounded with an angulation of the posterior margin at about mid-height sometimes evident. Valve surface smooth and unornamented. Sexual dimorphism evident, with males relatively more elongate than females. Internally the larger RV has a contact groove to receive the smaller LV; muscle scars not seen.

Dimensions. ♂: L = 0.550–0.600, H = 0.274–0.350. ♀: L = 0.525–0.600, H = 0.300–0.400.

Occurrence. Described originally from the Oxfordian of the Swiss Jura (Oertli 1959), *C. index* is known from the Paris Basin (Bizon 1958) and with Tethyan records from the ?Bathonian to Oxfordian of Israel (Oertli in Maync 1966) and the Callovian of Madagascar (Grékoff 1963; Mette & Geiger 2004). Upper Callovian, Vermoil (Cabral *et al.* 2003). Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Tethyan records cited above are remarkably convincing given that they are based only on subjective comparison of three-dimensional shape. It is, however, surprising that Bate (1975) did not find the species in the Callovian–Tithonian of Tanzania. Our material shows some posterior margin shape variation.

Genus *Cytherelloidea* Alexander, 1929

Type species. *Cytherella williamsoniana* Jones, 1849.

Cytherelloidea cf. *C. chonvillensis* Dépêche, 1969
(Fig. 5:12–15)

cf. 1969 *Cytherelloidea chonvillensis* Dépêche: 266–267, pl. 2, figs 1, 2.
cf. 1984 *Cytherelloidea* sp. Herngreen *et al.*: pl. 5, fig. 14.
cf. 2009 *Cytherelloidea chonvillensis* Dépêche; Franz *et al.*: 131, pl. 1, fig. 3.

Material. 27 specimens – adults, valves and carapaces: samples P(−8), P(6).

Description. Subrectangular outline, medium size; RV overlaps LV; greatest length at mid-height, greatest height towards anterior, greatest width at mid-length. Dorsal margin straight to slightly concave, ventral margin concave but overall parallel with dorsal margin, anterior and posterior margins evenly rounded. Lateral surface with four primary ribs: one bordering the anterior margin; a short one, curved, close to and parallel with ventral margin; a third rib runs around the posterior margin and along the dorsal margin terminating near the antero-dorsal border behind the anterior marginal rib; a weaker rib runs from the postero-dorsal towards the mid-valve area where a swelling corresponds to the position of the muscle scars internally; a secondary reticulate ornament is present (Fig. 5:14). Sexual dimorphism present, with females having two vertical posterior swellings and a more quadrate posterior margin. Internal features not observed.

Dimensions. ♂ L = 0.500–0.575, H = 0.250–0.300. ♀ L = 0.500–0.525, H = 0.250–0.300.

Occurrence. Described from the Callovian of the Paris Basin (Dépêche 1969) and reported from the Callovian of The Netherlands (Herngreen *et al.* 1984) and SW Germany (Franz *et al.* 2009). Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Our material is similar to *Cytherelloidea chonvillensis* but differs in the configuration of the primary ornament, especially in the development of the ventral rib.

Order **Podocopida** Sars, 1866
Superfamily **Cytheroidea** Baird, 1850
Family **Bythocytheridae** Sars, 1926

Remarks. The genus *Monoceratina* Roth (Devonian–Permian) was, for a long time, used as a repository for cytheroid ostracods with a straight dorsal margin and a posterior margin terminating close to the dorsal margin and posterior cardinal angle. More recent work (Gründel & Kozur 1971; Kozur 1972; Schornikov 1990) has demonstrated a variety of carapace shapes and internal features in post-Palaeozoic ostracods with this bauplan, in particular taxa that can be seen to be related to, but differ in carapace characteristics from, the living genus *Bythocythere* Sars. A number of Mesozoic genera have been recognized by Gründel & Kozur (1971) and Kozur (1972) and we have followed their taxonomy; however, the taxa are generally poorly defined and figured. The valuable review of Schornikov (1990) has gone some way to making sense of the situation but further work is needed at the level of individual genera.

Genus *Praebythoceratina* Gründel & Kozur, 1971

Type species. *Bythoceratina progracilis* Kozur, 1972.

Praebythoceratina parascrobiculata sp. nov. Lord, Cabral & Pais
(Fig. 5:16–19)

Etymology. From its resemblance to *Monoceratina scrobiculata* Triebel & Bartenstein, 1938.

Diagnosis. A species of *Praebythoceratina* characterized by a sinuous dorsal margin with a mid-length concavity coinciding with a median sulcus and inclined down towards the posterior extremity, and reticulate surface ornamentation.

Types. Holotype: RV, SMF Xe 23188, Figure 5:17. Paratypes: C, SMF Xe 23187, Figure 5:16; LV, SMF Xe 23189, Figure 5.18; RV, SMF Xe 23190, Figure 5:19, and four unfigured paratypes SMF Xe 23191 – 23194.

Material. 47 specimens – adults, valves and carapaces: samples P(−8), P(−6B), P(−6T), P(−4T), P(−2), P(0), P(2B), P(2M), P(4M), P(6).

Description. Relatively quadrate outline tapering posteriorly, medium size; LV and RV of similar size with minimal overlap; greatest length dorsal of mid-height, greatest height at one-third length from anterior, greatest width behind mid-length at position of ventral spinose inflation. Dorsal margin sinuous with a mid-length concavity and inclined downwards posteriorly toward the tapered posterior margin, posterior extremity above mid-height but below line of dorsal margin and may be a caudal process; anterior margin symmetrically rounded and stands out due to a curved furrow parallel to the margin which defines a marginal rim, ventral margin straight with a well-marked angle to the posterior margin. Surface morphology of a median sulcus with two adjacent oblique swellings, one spinose swelling postero-ventrally and a tubercle located antero-dorsally. Sexual dimorphism not seen. Hingement lophodont, comprising terminal sockets and a median bar in LV and complementary structures in RV, all appear smooth but hingement poorly preserved. Calcified inner lamella narrow; other internal details not observed.

Dimensions. L = 0.450–0.550, H = 0.200–0.275.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. *Monoceratina scrobiculata* Triebel & Bartenstein, 1938 should now be classified as *Praebythoceratina scrobiculata* (T&B) as it has the median dorsal sulcus and postero-ventral spine characteristic of *Praebythoceratina*. The line drawings of *scrobiculata* in Triebel & Bartenstein (1938, pl. 1, figs 5a, b; pl. 2, fig. 6) are very accurate when compared with the holotype (Senckenberg X/ε 133a), and *scrobiculata* (T&B) *sensu stricto* clearly differs from *parascrobiculata* sp. nov. in showing a straight dorsal margin with the posterior margin steeply inclined dorsally and terminating at the postero-dorsal margin; *P. scrobiculata* is significantly larger than our material (holotype L = 0.67, H = 0.35). *Bythoceratina* (*Praebythoceratina*) *scrobiculata* (T&B) from the Callovian of Poland figured by Olempska & Błaszyk (2001, fig. 13a–d) is not *scrobiculata* but is closer to *parascrobiculata* sp. nov., although differing in L:H ratio, outline of dorsal margin and possessing a relatively swollen postero-dorsal area. Similarly *scrobiculata* from the Oxfordian of England figured by Whatley (1970, pl. 3, figs 1 – 7, 9, 19) is not *scrobiculata* s.s. but does resemble *parascrobiculata* in having a comparable L:H ratio, a sinuous dorsal margin and a posterior margin terminating below the line of the dorsal margin; however, the ventral margin is concave and in two of the figured specimens the postero-ventral spine extends below the valve margin. *Praebythoceratina* ‘*scrobiculata*’ has been widely reported from the Jurassic of Western Europe and clearly represents a cryptotaxonomy.

Praebythoceratina cf. *P. stimulea* (Schwager, 1866)
(Figure 6:1–2)

cf. 1866 *Cythereis stimulea* Schwager, in Oppel & Waagen: 276, fig 1.
cf. 1938 *Monoceratina stimulea* (Schwager); Triebel & Bartenstein: 505–506, pl. 1, figs 1–2.
cf. 1970 *Monoceratina stimulea* (Schwager); Whatley: 319, pl. 3, figs 8, 11–17.
cf. 2009 *Monoceratina stimulea* (Schwager); Wilkinson & Whatley: 263, pl. 1, figs 15–16.

Material. 1 adult LV, 2 adult V fragments – same bed as sample P(6) of this work, sampled laterally (1998).

Description. Sub-rectangular outline tapering posteriorly, medium size; greatest length dorsal of mid-height, greatest height immediately posterior of mid-length, greatest width posterior at position of ventral spine. Dorsal margin straight, posterior margin extended with extremity close to the dorsal margin, anterior margin symmetrically rounded, ventral margin slightly convex anteriorly and posteriorly, with a mid-length concavity. Antero- and postero-marginal areas strongly depressed. Morphology of the valve with a prominent median sulcus and a large ventro-lateral spine. Surface almost smooth, with two weak curved ribs postero-dorsally, annular costae around the spine and very weak reticulation at its base. Sexual dimorphism not observed. Hinge adont, with a narrow groove in the RV, which seems crenulate; complementary bar in the LV. Calcified inner lamella narrow with small anterior and posterior vestibules; other internal details not observed.

Dimensions. L = 0.650, H = 0.300.

Occurrence. *Praebythoceratina stimulea* is known in Germany from the Middle to Upper Jurassic (Triebel & Bartenstein 1938) and in Great Britain, in the Lower Oxfordian of England and Scotland (Wilkinson & Whatley 2009). In Portugal it was first reported and figured by S. Pinto (2008, unpublished Master thesis, Faculty of Sciences, University of Lisbon) in the Upper Toarcian of Rabaçal and Boca da Mata; athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. As with *Monoceratina scrobiculata* Triebel & Bartenstein, *M. stimulea* should now be classified as *Praebythoceratina* as it has the dorso-median sulcus and the postero-ventral spine characteristic of that genus. According to Wilkinson & Whatley (2009), the morphological characteristics of the species *stimulea* can be variable, especially in the strength of ornamentation and of the median sulcus. However, both the Toarcian and our Callovian material from Portugal and that figured by Wilkinson & Whatley (2009) differ from the material figured by Triebel & Bartenstein (1938) in the position, strength and orientation of the mid-ventral spine, which in the type material is a more prominent and ventrally-directed spine extending below the ventral margin. For these reasons we call our material cf. *stimulea*.

Monoceratina stimulea (Schwager) figured by Fischer (1962, pl. 19, figs 8–9) from the upper Toarcian of SW Germany is of uncertain affinity.

Genus *Patellacythere* Gründel & Kozur, 1971

Type species. *Monoceratina williamsi* Stephenson, 1946.

Patellacythere cf. *P. ungulina* (Triebel & Bartenstein, 1938)
(Figure 6:3–5)

cf. 1938 *Monoceratina ungulina* Triebel & Bartenstein: 506, 508, pl. 1, figs 3, 4.

Material. 16 specimens – adults and juveniles, carapaces and valves: samples P(0), P(2B), P(2M), P(4M), and same bed as sample P(6) of this work, sampled laterally (1998).

Description. Quadrate to subrectangular outline, medium size; LV and RV of similar size with minimal overlap; greatest length dorsal of mid-height, greatest height towards anterior of mid-length, greatest width posterior of mid-length. Dorsal margin straight with marked cardinal angles, anterior margin rounded, ventral margin straight with an angle into the posterior margin which is sub-triangular to a point below the level of the dorsal margin. Adductor sulcus from mid-dorsal margin to mid-valve area, anterior and posterior marginal rims; valve surface smooth and unornamented. Internal features not visible. Sexual dimorphism not observed; however, some specimens are more elongated (males?) than others. Hinge adont, with a smooth bar in LV and the corresponding groove in RV. Marginal zone with narrow calcified inner lamella and presence of a small anterior vestibule; other internal features not visible.

Dimensions. L = 0.400–0.600, H = 0.250–0.300.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. *Patellacythere* cf. *ungulina* is similar to *P. ungulina* (T&B) s. s. from the Lower Jurassic in outline, development of the median sulcus, and in the swollen mid-ventral area extending to the ventral margin; however, it differs in dorsal view with the position of greatest width posterior of mid-length. Our material is distinguished from *Monoceratina vulsa* Jones & Sherborn, 1888; Bate 1969, pl. 7, fig. 5, lectotype; Lower Bathonian) and from *Patellacythere paravulsa* Brand, 1990; Brand 1990, pl. 2, figs 12–15; Upper Bathonian), also figured by Olempska & Błaszyk (2001,

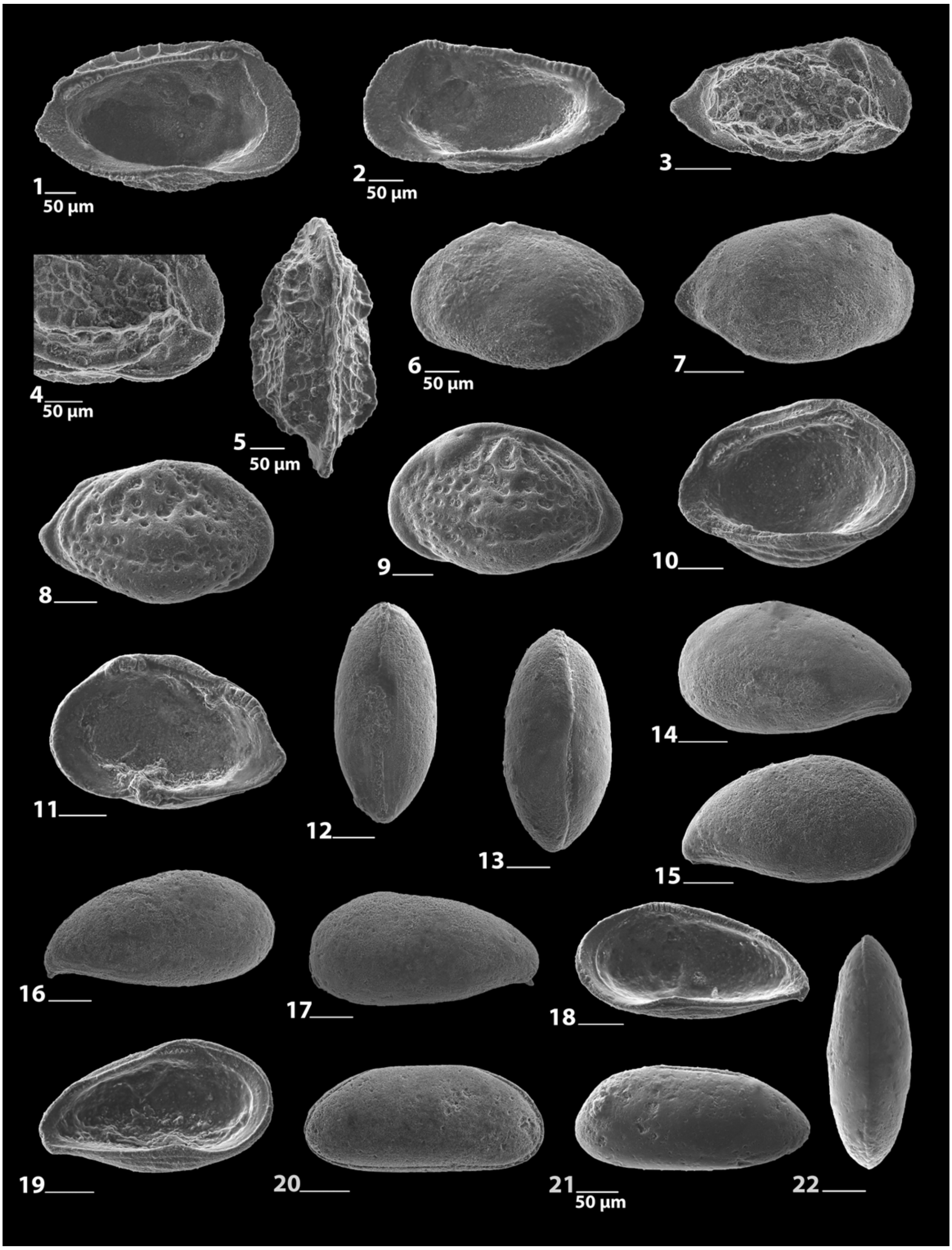

Fig. 7. (**1–5**) *Palaeocytheridea* (*Malzevia*)? *dorsocostata* sp. nov. Cabral, Pais & Lord: **1,** ♀ LV, internal, paratype, SMF Xe 23210, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.425, H = 0.250; **2,** ♂ RV, internal, paratype, SMF Xe 23211, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.225; **3,** ♂ RV, external, paratype, SMF Xe 23212, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.425, H = 0.225; **4,** ♀ C (as Fig. 6:17), right view, external, holotype, ornamentation detail; **5,** ♀ C, dorsal view, paratype, SMF Xe 23213, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.4, H = 0.2. (**6, 7**) *Micropneumatocythere* sp. 1: **6,** LV, external, SMF Xe 23214, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.4, H = 0.225; **7,** RV, external, SMF Xe 23215, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.375, H = 0.225. (**8–11**) Gen. nov.? *gublerae* (Bizon, 1958): **8,** RV, external, SMF Xe 23216, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.350; **9,** LV, external, SMF Xe 23217, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.375; **10,** LV, internal, SMF Xe 23218, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.375; **11,** RV, internal, SMF Xe 23219, P(2B), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.350. (**12–19**) *Virgulacytheridea posteroacuminata* sp. nov. Cabral, Lord & Pais: **12,** ♂ C, ventral view, paratype, SMF Xe 23220, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.274; **13,** ♀ C, dorsal view, paratype, SMF Xe 23221, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.500, H = 0.274; **14,** ♀ LV, external, paratype, SMF Xe 23222, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.274; **15,** ♀ RV, external, paratype, SMF Xe 23223, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.270; **16,** ♂ RV, external, holotype, SMF Xe 23224, P(4M), Upper Callovian, Pedrógão, Portugal, L = 0.540, H = 0.270; **17,** ♂ LV, external, paratype, SMF Xe 23225, P(4M), Upper Callovian, Pedrógão, Portugal, L = 0.540, H = 0.270; **18,** ♂ RV, internal, paratype, SMF Xe 23226, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.255; **19,** ♀ LV, internal, paratype, SMF Xe 23227, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.480, H = 0.270. (**20 – 22**) Genus and species indeterminate 2: **20,** C, right view, SMF Xe 23228, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.4, H = 0.174; **21,** C, left view, SMF Xe 23229, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.2; **22,** C (as 21), dorsal view. Scale bars 100 µm except where otherwise noted.

fig. 13e–g), by its lack of surface ornament and weaker median sulcus. *Monoceratina vulsa* figured by Bate (1963, pl. 3, figs 5–12) is similar to our material in outline and surface morphology but has a reticulate ornament.

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

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

Remarks. The disjunct stratigraphical and geographical record of *Tanycythere* reported by Cabral *et al.* (2014) is supplemented by the species below, and also by the recognition that *Cytherura striatoides* Bonnema, 1941 from the Upper Cretaceous of The Netherlands (Bonnema 1941), Baltic coast of Germany (Herrig 1966) and England (Weaver 1982) may also belong to *Tanycythere*.

Tanycythere sp. 1
(Fig. 6:6–8)

Material. Two adult carapaces: samples P(−4T), P(4M).

Description. Elongate, characteristically spindle-shaped; small size; valves of very similar size; greatest length at mid-height, greatest height just anterior of mid-length, greatest width at mid-length. Dorsal margin straight merging into the broadly rounded anterior margin, ventral margin weakly convex, posterior margin extended and pointed and merges with ventral margin, whereas there is a clear posterior cardinal angle where it joins the dorsal margin. Surface ornamented with fine longitudinal striae. Internal features unknown.

Dimensions. L: P(−4T) = 0.600, P(4M) = 0.575; H: P(−4T) = 0.200, P(4M) = 0.225.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. This is a new species of *Tanycythere* but more material is required for formal description. The two specimens figured may represent two different species.

Family **Schulerideidae** Mandelstam, 1959

Genus *Praeschuleridea* Bate, 1963

Type species *Cytheridea subtrigona* Jones & Sherborn, 1888

Praeschuleridea lisensis sp. nov. Pais, Cabral & Lord
(Fig. 6:9–16)

Etymology. From the River Lis adjacent to the sample site.

Diagnosis. A species of *Praeschuleridea* characterized by a subtriangular to suboval outline, position of greatest length in ventral half of valves, strong left valve larger than right valve overlap especially on the dorsal and ventral margins, surface smooth and unornamented.

Types. Holotype: ♀ C, SMF Xe 23204, Figure 6:13. Paratypes: ♀ LV, SMF Xe 23201, Figure 6:9; ♂ LV, SMF Xe 23202, Figure 6:10; ♂ LV, SMF Xe 23203, Figure 6:11, 12; ♀ C, SMF Xe 23205, Figure 6:14; ♀ LV, SMF Xe 23206, Figure 6:15; ♂ RV, SMF Xe 23207, Figure 6:16.

Material. 1920 specimens – adults and juveniles, valves and carapaces: samples P(−8), P(−6B), P(-−T), P(-4B), P(−4T), P(−2), P(0), P(2B), P(2M), P(4 M), P(6).

Description. Subtriangular to suboval outline, medium size; LV > RV but valves are asymmetrical with LV strongly overlapping RV especially along the dorsal and ventral margins, LV more rounded than RV especially in ♀; greatest length just ventral of mid-height, greatest height at or just anterior of mid-length, greatest width at mid-length. All margins convex, the anterior more symmetrically rounded than the posterior. Valve surface smooth and unornamented with a few depressions at normal pore canals. Sexual dimorphism pronounced with ♂ more elongate than the relatively rounded ♀. Internally hinge palaeohemimerodont typical for genus with, in LV, strong terminal loculate sockets joined by a groove along a short, smooth median bar, above which an accommodation groove is present (Fig. 6:11, 15), complementary structures in RV; muscle scars consist of four rounded adductor scars and a rounded frontal scar (Fig. 6:12; 'Type C' of Bate 1963, p. 182); marginal zone well developed, inner margin and line of concresence coincide, radial pore canals straight, approximately 12 anteriorly and 6 posteriorly.

Dimensions. ♂ L = 0.500–0.600, H = 0.250–0.300. ♀ L = 0.375–0.500, H = 0.275–0.375.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Many described species of *Praeschuleridea* are strongly ornamented with ribs or punctae whereas *P. lisensis* sp. nov. is smooth. *Praeschuleridea confossa* Sheppard, 1981 from the Bathonian of England (Sheppard 1981) and lower Callovian of France (Dépêche 1985) is similar to *P. lisensis* sp. nov. but has a more uniformly rounded outline and relatively weak and uniform LV > RV overlap; it may well be ancestral to *lisensis*. *Praeschuleridea subtrigona* (Jones & Sherborn, 1888) from the Bajocian–Bathonian of England (Bate 2009) differs from the Portuguese species in having a more triangular carapace with RV more elongate than LV and is more acuminate posteriorly. Mette (1995) figures two species of *Praeschuleridea*, *P.* sp. 1 and *P.* sp. 2, from the Callovian of Tunisia which, like *P. lisensis* sp. nov. are unornamented but differ in shape and appear to have marginal rims and eye tubercles more typical of the genus *Schuleridea* Swartz & Swain; furthermore, it is not clear if they have the palaeohemimerodont hingement characteristic of *Praeschuleridea*.

Family **Protocytheridae** Ljubimova, 1955

Genus *Palaeocytheridea* Mandelstam, 1947

Type species. *Palaeocytheridea* (*Palaeocytheridea*) *bakirovi* Mandelstam, 1947.

Remarks. Numerous species were assigned to *Palaeocytheridea* by workers in the former Soviet Union and the taxonomy is confused. Tesakova (2013*a*, *b*, *c*, 2014) has substantially revised the genus. At present the species from Western Europe formally placed in this genus are *P.* (*Malzevia*) *blaszykina* Franz *et al.*, 2009 [Bajocian–Bathonian; France, Germany, Poland], *P.* (*P.*) *carinilia* (Sylvester-Bradley, 1948) [Bathonian; England, France, south Germany], *P.* (*M.*) *parabakirovi* Malz, 1962 [Bathonian; England, The Netherlands, Germany – Malz 1962; Callovian; Ukraine, central Russia] and. *P.* (*Malzevia*) *groissi* Schudack, 1997 [Tithonian; south Germany – Schudack 1997].

Palaeocytheridea (*Malzevia*)? *dorsocostata* sp. nov. Cabral, Pais & Lord
(Fig. 6:17–18, Fig. 7:1–5)

Etymology. From the dorsal costate ridge.

Diagnosis. A species of *Palaeocytheridea* (*Malzevia*)? characterized by a dorsal blade-like costate ridge on LV, a weak, short and curved ventral rib below a longer ventral rib, two weak oblique central ribs, an eye tubercle with a weak rib below, and secondary reticulation.

Types. Holotype: ♀ C, SMF Xe 23208, Figure 6:17, Figure 7:4. Paratypes: ♀ LV, SMF Xe 23209, Figure 6:18; ♀ LV, SMF Xe 23210, Figure 7:1; ♂ RV, SMF Xe 23211, Figure 7:2; ♂ RV, SMF Xe 23212, Figure 7:3; ♀ C, SMF Xe 23213, Figure 7:5.

Material. 30 specimens – adults and juveniles, valves and carapaces: sample P(6), and same bed as sample P(6) of this work, sampled laterally (1998).

Description. Subrectangular tapered outline, small size; LV > RV; greatest length at mid-height, greatest height at anterior cardinal angle, greatest width just posterior of mid-length. Dorsal margin slightly convex and on LV formed by a blade-like costate ridge ornamented with short weak vertical ribs, anterior margin asymmetrically rounded, posterior margin triangular with extremity at mid-height. Eye tubercle present, ornamented with a short weak vertical rib. In addition to the dorsal marginal LV rib, there is a weak and curved rib running parallel and close to the ventral margin with a longer rib just above it terminating obliquely at the anterior margin; and two oblique curved ribs in the anterior and mid-dorsal areas; secondary reticulation present. Sexual dimorphism present, males differ in L:H ratio and generally appear more elongate than females. Internally, hingement is antimerodont, inner margin coincides with line of concresence; details of muscle scars and radial pore canals not seen.

Dimensions. ♂ L = 0.425 – 0.450, H = 0.225. ♀ L = 0.350 – 0.450, H = 0.200 – 0.250.
Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. *Palaeocytheridea* (*M.*)? *dorsocostata* sp. nov. is similar to *P.* (*M.*) *blaszykina* (Franz *et al.* 2009, pl. 2, figs 15–18) described from the Bathonian of SW Germany. Our material is especially close in shape and size to the juvenile figured by Franz *et al.* in their plate 2, fig. 18. However, our material is adult and differs from *P.* (*M.*) *blaszykina* in the configuration of the primary ornament in the main valve area. A number of species of *Palaeocytheridea* figured by Tesakova (2013*a*, *b*) resemble *dorsocostata* sp. nov., especially in the presence of the LV dorsal marginal blade-like ridge; however, all differ in strength and arrangement of the primary ribbing and secondary ornament.

Family **Cytherideidae** Sars, 1925

Genus *Virgulacytheridea* Oertli & Dépêche, 1987 in Dépêche *et al.* (1987)

Type species. *Virgulacytheridea sherifensis* Oertli & Dépêche, 1987 in Dépêche *et al.* (1987).

Remarks. The name *Virgulacytheridea* was first published in Maync (1966) as a nomen nudum in a list of ostracods ascribed to H. J. Oertli from the Jurassic (Lower to Middle Bathonian) of Israel. One new species was recognized as *Virgulacytheridea sherifensis* n. gen., n. sp. Oertli (nomen nudum) (Maync 1966, 13). The species was illustrated (Maync 1966, pl. X, figs 49–54) but figs 49–51 are clearly different from figs 52–54 and probably represent two different species; the figures are apparently of single specimens viewed from left, right and dorsally. Subsequently Oertli & Dépêche (in Dépêche *et al.* 1987) described and figured *V. sherifensis* from the Middle Callovian of Saudi Arabia and designated types (holotype FDO 75, paratypes FDO 76). *Virgulacytheridea sherifensis* of Oertli & Dépêche (in Dépêche *et al.* 1987) is different from the two forms figured in Maync (1966) which represent two other, undescribed, species of *Virgulacytheridea.* We have tried to locate the original material of Maync (1966) in Israel (Geological Survey of Israel and elsewhere) and in the Oertli Ostracod Collection, Muséum d'Histoire Naturelle, Genève without success.

Virgulacytheridea has been recognized in Portugal and identified as *V.* aff. *V. sherifensis* Oertli & Dépêche (Cabral *et al.* 1998, 2003) from two different localities, Pedrógão and a borehole at Vermoil. During the present work we have found many more specimens from Pedrógão and conclude that *Virgulacytheridea* Oertli & Dépêche, 1987 is a valid Middle Jurassic genus of Tethyan affinities represented by at least four species.

Virgulacytheridea posteroacuminata sp. nov. Cabral, Lord & Pais
(Fig. 7:12 – 19)

Etymology. A reference to the pointed, ventrally inclined posterior margin.

Diagnosis. A species of *Virgulacytheridea* characterized by elongate carapace with a pointed, ventrally inclined posterior margin, with a subtle ornament of two fine ribs preserved in the postero-ventral area and a small ventrally-directed posterior spine.

Types. Holotype: ♂ RV, SMF Xe 23224, Figure 7:16. Paratypes: ♂ C, SMF Xe 23220, Figure 7:12; ♂ C, SMF Xe 23221, Figure 7:13; ♀ LV, SMF Xe 23222, Figure 7:14; ♀ RV, SMF Xe 23223, Figure 7:15; ♂ LV, SMF Xe 23225, Figure 7:17; ♂ RV, SMF Xe 23226, Figure 7:18; ♀ LV, SMF Xe 23227, Figure 7:19.

Material. 175 specimens – adults, valves and carapaces: samples P (2M), P(4M), P(6).

Description. Outline in shape of a comma, medium size; LV > RV; greatest length just dorsal of ventral margin, greatest height at one-third of length from anterior, greatest width at mid-length. Dorsal margin convex sloping steeply towards posterior, anterior margin broadly and symmetrically rounded, ventral margin convex but with concave incurve posteriorly, posterior margin short and low on valve with a ventrally-directed spine. ♂ more elongate than ♀ which are shorter and more rounded. Valve surface almost smooth, in better preserved specimens two very weak postero-ventral ribs run from the mid-ventral area to the posterior extremity; these weak ribs can also be seen in ventral view. Internally hinge antimerodont, marginal zone broad and inner margin coincides with line of concrescence; details of muscle scars and radial pore canals not observed.

Dimensions. ♂L = 0.475–0.575, H = 0.225–0.275. ♀L = 0.425–0.500, H = 0.225–0.275.

Occurrence. Upper Callovian, Vermoil (Cabral *et al.* 2003); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. *Virgulacytheridea sherifensis* has a punctate surface ornament and is less elongate than the smooth *V. posteroacuminata* sp. nov. As a consequence of the different L:H ratio, *sherifensis* is more hooked posteriorly than *posteroacuminata*. Maync's (1966)

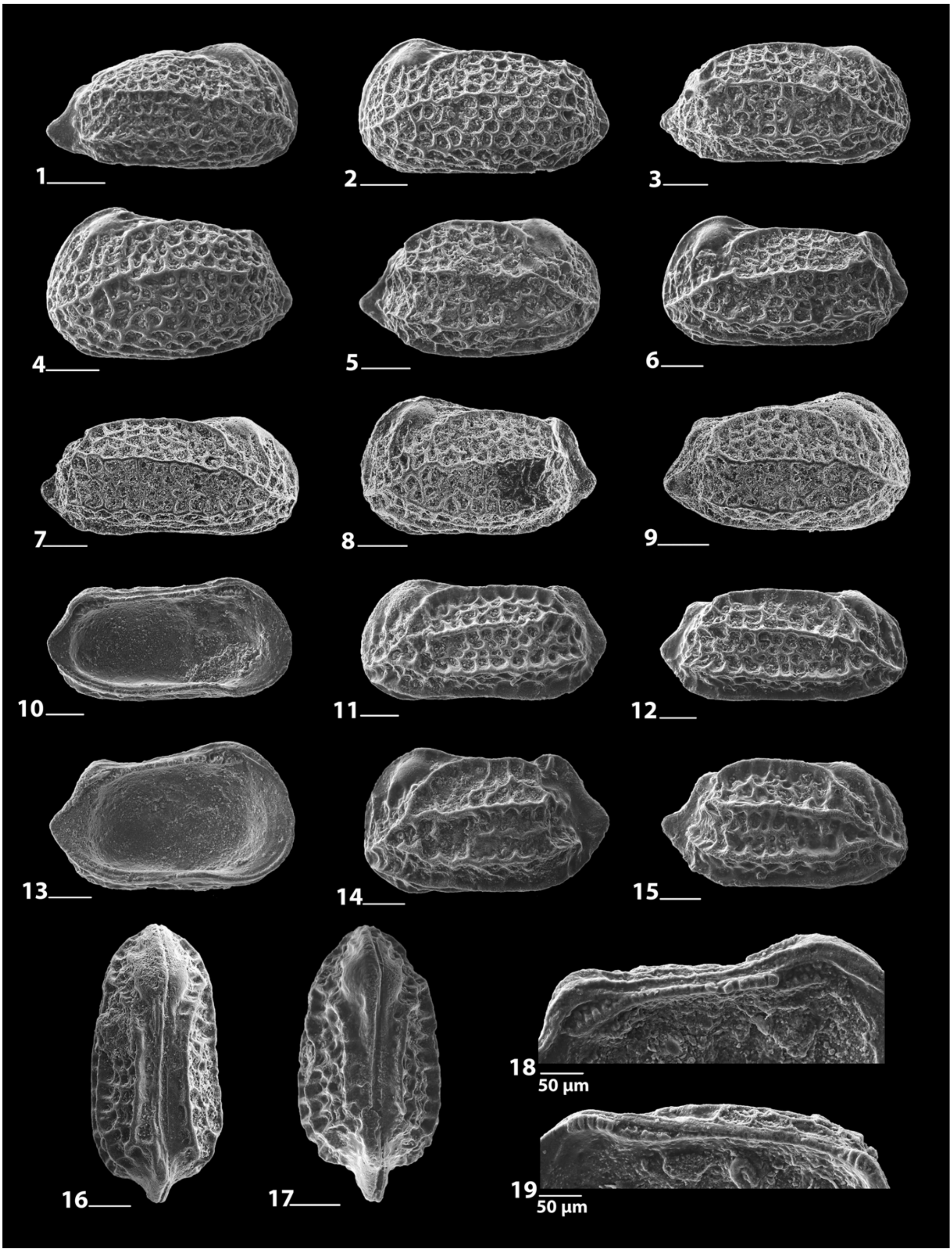

Fig. 8. (**1–19**) *Neurocythere multiforma* sp. nov. Pais, Lord & Cabral. **1.** RV, external, juv., paratype, SMF Xe 23230, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.40, H = 0.20. (**2–4**) Morphotype III: **2,** ♂ LV, external, paratype, SMF Xe 23231, P(−2), Upper Callovian, Pedrógão; Portugal, L = 0.525, H = 0.250; **3,** ♂ RV, external, paratype, SMF Xe 23232, P(−4)T, Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.274; **4,** ♀ LV, external, paratype, SMF Xe 23233 P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.274. (**5–9**) Morphotype II: **5,** ♀ RV, external, paratype, SMF Xe 23234, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.274; **6,** ♂ LV, external, paratype, SMF Xe 23235, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.250; **7,** ♂ RV, external, paratype, SMF Xe 23236, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.274; **8,** ♀ LV, external, paratype, SMF Xe 23237, P(6), Upper Callovian, Pedrógão, Portugal, L = 476, H = 0.274; **9,** ♀ C, right view, external, paratype, SMF Xe 23238, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.274. (**10–19**) Morphotype I: **10,** ♂ LV, internal, paratype, SMF Xe 23239, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.525, H = 0.274; **11,** ♂ LV, external, paratype, SMF Xe 23240, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.3; **12,** ♂ RV, external, paratype, SMF Xe 23241, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.650, H = 0.3; **13,** ♀ LV, internal, paratype, SMF Xe 23242, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.350; **14,** ♀ LV, external, holotype, SMF Xe 23243, P(−8), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.324; **15,** ♀ RV, external, paratype, SMF Xe 23244, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.6, H = 0.324; **16,** ♂ C, dorsal view, paratype, SMF Xe 23245, P(4M), Upper Callovian, Pedrógão, Portugal, L = 0.675, H = 0.350; **17,** ♀ C, dorsal view, paratype, SMF Xe 23246, P(0), Upper Callovian, Pedrógão, L = 0.550, H = 0.324; **18,** ♀ LV, internal, hinge detail, paratype, SMF Xe 23247, P(-2), Upper Callovian, Pedrógão, L = 0.5, H = 0.324; **19,** ♀ RV, internal, hinge detail, paratype, SMF Xe 23248, P(6), Upper Callovian, Pedrógão, L = 0.525, H = 0.3. Scale bars 100 µm except where otherwise noted.

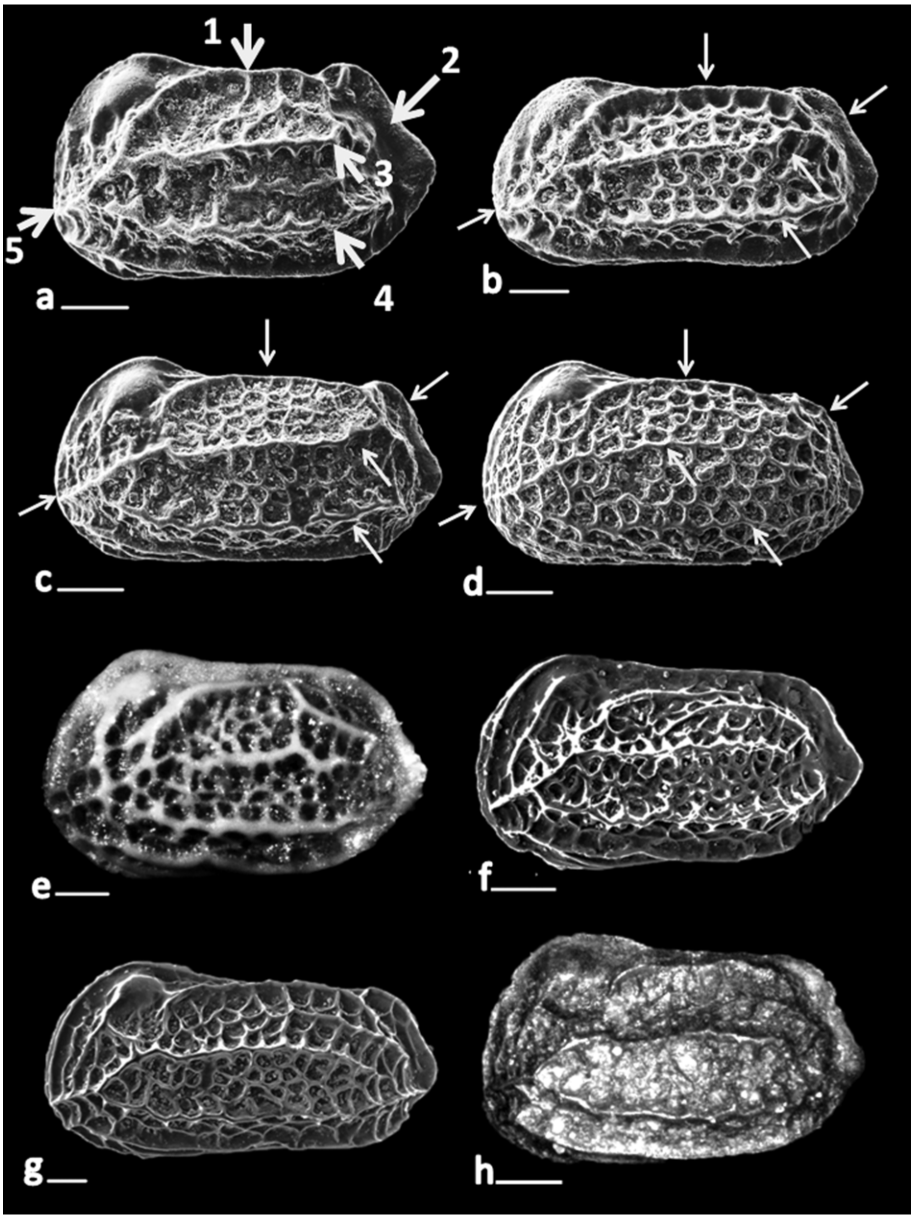

Fig. 9. *Neurocythere multiforma* sp. nov.: (**a**) Morphotype I (holotype, SMF Xe 23243, ♀ LV); (**b**) Morphotype I (paratype, SMF Xe 23240, ♂ LV); (**c**) Morphotype II (paratype, SMF Xe 23235, ♂ LV) ; (**d**) Morphotype III (paratype, SMF Xe 23231, ♂ LV) ; (**e**) *Lophocythere caesa* Triebel, 1951 (= *Neurocythere caesa caesa* (Triebel, 1959)) (holotype, SMF Xe 1799, ♀ LV). (**f**) *Neurocythere caesa* subspecies A of Wilkinson & Whatley (2009, pl. 7. fig. 15; HU.19.J.60, LV gender uncertain). (**g**) *Neurocythere caesa caesa* (Triebel, 1951) of Wilkinson & Whatley (2009, pl. 7. fig. 14; HU.19. J.53, ♂ LV). (**h**) *Neurocythere composita* (Wienholz, 1967) (holotype, X1983, ♀ C). Scale bars 100 µm. (e) Light micrograph with Helicon Focus and Leica S8 APO microscope. (h) Light micrograph with Keyence Digital Microscope VHX-100D. All other images SEM.

poor figures of *Virgulacytheridea* from Israel appear to show two species: Type 1 (Mayne 1966, pl. 10, figs 49–51) is smooth but has a different L:H:W ratio to *posteroacuminata*; Type 2 (Mayne 1966, pl. 10, figs 52–54) has a sinuous dorsal margin with a narrow width, may be ornamented and differs from both *sherifensis* and *posteroacuminata* sp. nov.

Family **Progonocytheridae** Sylvester-Bradley, 1948

Genus *Micropneumatocythere* Bate, 1963

Type species. *Micropneumatocythere convexa* Bate, 1963

Micropneumatocythere sp. 1
(Fig. 7:6–7)

Material. Nine specimens – adults, valves and carapaces: samples P(−2), P(6).

Description. Subtriangular outline, small size; LV > RV; greatest length at mid-height, greatest height and width at approximately mid-length. Dorsal margin weakly convex and inclined steeply towards posterior, posterior margin triangular at mid-height, anterior margin rounded, ventral margiun convex but hidden in lateral view by a strong ventral inflation. Valve surface smooth and unornamented other than ventral ridges under the ventral inflation. Sexual dimorphism not observed, material appears to be juvenile. Internally hinge antimerodont, as described for adults of the genus, inner margin and line of concrescence coincide, other features not seen.

Dimensions. L = 0.375 – 0.450, H = 0.200 – 0.250.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. The posterior margin of our material is not typical for *Micropneumatocythere*, in which it tends to be extended and slightly upturned (see Bate & Sheppard 1979), and we have made the assignment to the genus on the basis of the ventral inflation and antimerodont hingement. Many species have been assigned to *Micropneumatocythere* (Bate & Sheppard 1979). *Micropneumatocythere globosa* Bate, 1964 from the Bajocian (Bate 1964) is smooth to finely punctate but has a more rounded outline especially of the larger LV; *M. quadrata* Bate, 1967 is also smooth but has a more rounded outline especially in ♀ LV

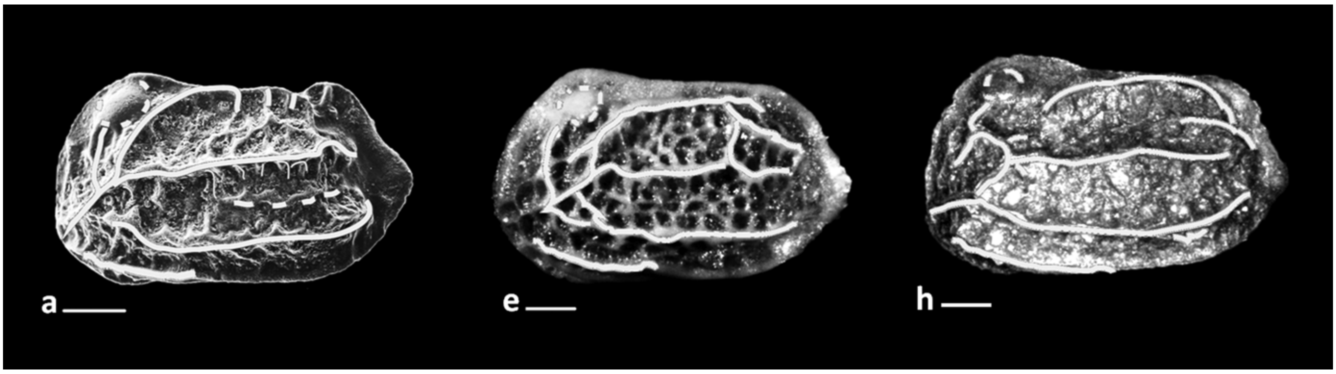

Fig. 10. Comparison of primary ornament of (**a**) *Neurocythere multiforma* sp. nov., Morphotype I (holotype, SMF Xe 23243, ♀ LV). (**e**) *Neurocythere caesa caesa* (Triebel, 1951) (holotype, SMF Xe 1799, ♀ LV). (**h**) *Neurocythere composita* (Wienholz, 1967) (holotype, X1983, ♀ C). Images from Figure 9, all left lateral views. Scale bars 100 µm.

(Bathonian, Bate 1967). *Micropneumatocythere laevireticulata* Rosenfeld & Honigstein, 1991 is slightly larger and has surface ornamentation.

Gen. nov.?

Remarks. Bizon (1958) placed his new species *gublerae* in *Progonocythere*? and his drawing (1958, pl. 4, fig. 16) indicates a four-part entomodont hinge (the median groove is clearly larger anteriorly) which at that time and with entomodont hingement made assignment to the genus *Progonocythere* Sylvester-Bradley, 1948 reasonable. However, a more clearly defined definition of that genus based on the type species *P. stilla* Sylvester-Bradley, 1948 (see Whatley & Ballent 1996, 921, and cf. Sylvester-Bradley 1948) and recognition that most but not all records of *gublerae* have a three-part merodont hinge has confused the generic placement. Subsequent authors (see synonymy list below) have mostly placed the species in *Procytheridea* Peterson. ARL considers *Procytheridea* to be represented by only two species, *P. exempla* Peterson, 1954 and *P. fraudator* Sherrington & Lord, 1975*b*, and to be restricted in distribution to North America (Peterson 1954; Lord 1972; Sherrington & Lord 1975*a*, *b*) although there is some similarity in external shape and hingement to *gublerae*. The question of a generic assignment for *gublerae* remains open as the present authors have been unable to recognize an appropriate described genus in the literature.

Gen. nov.? *gublerae* (Bizon, 1958)
(Fig. 7:8 – 11)

1958 *Progonocythere*? *gublerae* Bizon: 28, pl. 4, figs 14–16.
1959 *Procytheridea gublerae* (Bizon, 1958); Oertli: 38 – 39, pl. 6, figs 172–177, pl. 7, figs 178–180.
1962 *Procytheridea gublerae* Bizon, 1958; Donze: 139, pl. 11, figs 48–49.
?1964 *Procytheridea gublerae* (Bizon, 1958); Glashoff: 47.
1966 *Procytheridea* aff. *gublerae* Bizon; Oertli in Maync: 13, pl. 10, figs 55–57.
1985 *Procytheridea gublerae* Bizon, 1959; Dépêche: pl. 32, figs 16–18.
1987*a* *Terquemula gublerae* (Bizon, 1958); Rosenfeld *et al.*: 243, pl. 3, figs 9–10.
1987*b* *Terquemula gublerae* (Bizon, 1958); Rosenfeld *et al.*: 261, pl. 6, fig. 4.
2000 *Procytheridea gublerae* Bizon, 1958; Schudack & Schudack: pl. 4, figs 4, 5.
2001 ‘*Procytheridea*’ *gublerae* (Bizon, 1958); Olempska & Błaszyk: 560 – 561, fig. 4a–i.
2009 ‘*Procytheridea*’ *gublerae* (Bizon, 1958); Franz *et al.*: 138, pl. 3, fig. 5.

Material. 50 specimens – adults and juveniles, valves and carapaces: samples P(2B). P(2M), P(4M), P(6).

Description. Subtriangular outline, medium size; LV > RV; greatest length just below mid-valve height, greatest height just anterior of mid-length, greatest width at mid-length. Dorsal margin slightly convex and inclined steeply towards posterior, posterior margin low and triangular, ventral margin convex, anterior margin evenly rounded; anterior and posterior cardinal angles evident. Marked anterior marginal rim. A swelling just below the anterior cardinal angle in LV or adjacent in RV may be an eye tubercle. Sexual dimorphism not observed. In well-preserved material (e.g. Olempska & Błaszyk 2001, figs 4a, f) the primary ornament consists of a roughly triangular network linked by weaker secondary ribs creating a background reticulate network; in the smaller RV the apex of the primaray rib triangle reaches the dorsal margin; instars appear punctate. Internally hingement is antimerodont, marginal zone well developed and inner margin coincides with line of concrescence; details of muscle scars and radial pore canals not observed.

Dimensions. L (adults) = 0.500–0.625, H = 0.325–0.375. L (juveniles) = 0.350–0.475, H = 0.225–0.300.

Occurrence. Widely recorded in the Callovian–Oxfordian of Western and Central Europe (see synonymy); the records from Israel (Oertli in Maync 1966) and adjacent areas (Rosenfeld *et al.* 1987*a*, *b*) are convincing. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Published figures show some variation in ornament but this appears to be taphonomic rather than original variation.

Genus *Neurocythere* Whatley, 1970

Type species. *Cythere bradiana* Jones, 1884.

Remarks. Whatley & Ballent (2004) have made a helpful revision of *Lophocythere* and related genera including *Neurocythere* which provides an insight into the tortuous taxonomic history of these animals.

Neurocythere multiforma sp. nov. Pais, Lord & Cabral
(Fig. 8:1–19, Figs 9 and 10)

Etymology. An allusion to the systematic variation in primary and secondary ornament.

Diagnosis. A quadrate species of *Neurocythere* with a primary ornament of three longitudinal ribs and secondary reticulation, the relative strengths of which are variable between three morphotypes.

Types. Holotype: ♀ LV, SMF Xe 23243, Figure 8:14. Paratypes: juv RV, SMF Xe 23230, Figure 8:1; ♂ LV, SMF Xe 23231, Figure 8:2; ♂ RV, SMF Xe 23232, Figure 8:3; ♀ LV, SMF Xe 23233, Figure 8:4; ♀ RV, SMF Xe 23234, Figure 8:5; ♂ LV, SMF Xe 23235, Figure 8:6; ♂ RV, SMF Xe 23236, Figure 8:7; ♀ LV, SMF Xe 23237, Figure 8:8; ♀ C, SMF Xe 23238, Figure 8:9; ♂ LV, SMF Xe 23239, Figure 8:10; ♂ LV, SMF Xe 23240, Figure 8:11; ♂ RV, SMF Xe 23241, Figure 8:12; ♀ LV, SMF Xe 23242, Figure 8:13; ♀ RV, SMF Xe 23244, Figure 8:15; ♂ C, SMF Xe 23245, Figure 8:16; ♀ C, SMF Xe 23246, Figure 8:17; ♀ LV, SMF Xe 23247, Figure 8:18; ♀ RV, SMF Xe 23248, Figure 8:19.

Material. 710 specimens – adults and juveniles, valves and carapaces: samples P(−8), P(−6B), P(−6T), P(−4B), P(−4T), P(−2), P(0), P(2B), P(2M), P(4M), P(6).

Description. Quadrate outline especially in females; juveniles taper posteriorly. Greatest length at or just below mid-height, greatest height at anterior in LV but mid-length in RV, greatest width in posterior third of length in both ♀ and ♂. Anterior margin broadly rounded, ventral margin straight to weakly concave, posterior margin a low triangular rim. Dorsal margin variable posterior of anterior cardinal angle and eye tubercle: LV dorsal margin straight to slightly concave, RV convex with margin in lateral view formed by the dorsalmost rib.
Based on shape and surface ornament, three morphotypes are recognized, all with adults (♀ ♂):

Morphotype I (Fig. 8:10–19): primary ornament of three strong, blade-like ribs, one forming the dorsal margin and running anteriorly below the eye tubercle to join the median rib at anterior, a median rib running diagonally from postero-dorsal area to antero-ventral margin, and a third rib running parallel to but above the ventral margin and meeting the median rib anteriorly; secondary reticulate ornament. Posterior marginal rim strong, especially in ♀ and extends to dorsal margin where it forms the posterior cardinal angle as a bladed extension. Eye tubercles present in all three morphotypes, with a weak ventral rib.

Morphotype II (Fig. 8:5–9): primary ornament as in I but difference in relative strengths of primary ribs and secondary reticulation less marked; postero-dorsal extension recognizable but weaker.

Morphotype III (Fig. 8:2–4): primary ornament of three ribs recognizable but only slightly more strongly developed than the ‘secondary’ reticulation; posterior margin triangular but no longer a strong rim (although this is seen in juveniles, Fig. 8:1). The relative strengths of primary and secondary ornament in Morphotypes II and III are clear in the SEM but less obvious in reflected light microscopy. From relative dimensions, Morphotype III might appear to be the A-1 instar of Morphotype II; however, internally the hingement and marginal zone are adult.

Juveniles (A-1 and smaller; Fig. 8:1) are closest in surface ornament to Morphotype III, demonstrating that the morphological variation (I to III) is an adult phenomenon in one species. The juvenile instars cannot be differentiated into the three morphotypes.

The ornamental development of the three morphotypes is compared in Figure 9. Figure 9a is Morphotype I (♀) where arrow 1 indicates the dorsal primary rib, arrow 2 the posterior rim and blade-like posterodorsal extension, arrow 3 the diagonal median rib and weak connection to the dorsal rib posteriorly, arrow 4 is the ventral primary rib and arrow 5 marks where the three primary ribs are joined and reach the antero-ventral margin. Figure 9b is Morphotype I (♂). Figure 9c is Morphotype II (♂) and Figure 9d is Morphotype III (♂) – arrows indicate comparison with Morphotype I. Figure 9e–h are discussed under Remarks.

Sexual dimorphism recognized in all three morphotypes based on L:H ratio and posterior inflation, ♂ being relatively longer than ♀.

Internally all morphotypes are the same: marginal zone relatively wide, inner margin coincides with line of concresence. Marginal pore canals difficult to observe because of recrystallization but appear short and straight. Muscle scars consist of four rounded adductor scars with a round frontal scar typical of the genus. Hingement entomodont, strongly developed, with in LV loculate sockets anteriorly and posteriorly and a median dentate ridge more strongly developed anteriorly, complementary structures in RV (Fig. 8:18–19).

Dimensions.
♂ L: Morphotype I = 0.525 – 0.750, Morphotype II = 0.525 – 0.600, Morphotype III = 0.500 – 0.525; H: I = 0.300 – 0.325, II = 0.275 – 0.325, III = 0.250 – 0.275.
♀ L: I = 0.550 – 0.625, II = 0.475 – 0.525, III = 0.425 – 0.500; H: I = 0.275 – 0.374, II = 0.250 – 0.300, III = 0.225 – 0.275.
Juveniles L = 0.375 – 0.425, H = 0.200 – 0.250.

Occurrence. Athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. When first assessing this material we considered several options, that it represents:

1. three species, each with sexually dimorphic adults plus juveniles; however, all occur together in 11 stratigraphically sequential samples, all share the same internal features and basic ornamental pattern and juveniles cannot be differentiated;
2. three subspecies; however, there is no stratigraphical or geographical separation to justify subspecific distinction and the ‘species’ is, as yet, not known elsewhere;
3. three ‘varieties’ of one species – the model adopted here with Morphotypes I to III, supported by the fact that the juveniles are all the same.

Neurocythere multiforma sp. nov. is represented by over 700 specimens with adults and juveniles occurring in 9 m of sediment. It is difficult to accurately assess the time represented by 9 m of marl–limestone deposition in the absence of good time markers, but comparison with comparable depositional environments suggests a rate of deposition of the order of *c.* 5 cm ka^{-1}, i.e. a maximum of 180 ka, although allowing for compaction of the sediments the time represented could be at least double, i.e. 360–400 ka. (Note that the species is present in the oldest sampled horizon and ranges through the marine part of the section, its occurrence at Pedrógão truncated by the onset of non-marine conditions, thus its actual time range is longer than represented by our samples.) These individuals appear to represent contemporaneous interbreeding populations over an extended period of time, if the carapace characteristics reflect genuine biological species. It is possible that in life they were separated by niche-partitioning and their co-occurrence in the samples is a taphonomic phenomenon; however, given the time span represented by the samples this seems unlikely. See Discussion below.

Given the number of *Neurocythere* species recognized (Whatley & Ballent 2004, 97–101, list almost 40 species and subspecies), it seems unlikely that our material is new. However, inspection of the literature and of type and comparative material from Berlin, Frankfurt and London shows that no described taxon is an exact match in terms of specific characteristics of ornament and valve shape. Figure 9 compares *multiforma* sp. nov. (a–d) with the holotype of *Neurocythere caesa* (Triebel, 1951) (e), *N. caesa* subsp. A of Wilkinson & Whatley (2009) (f), *N. caesa caesa* (Triebel, 1951) in

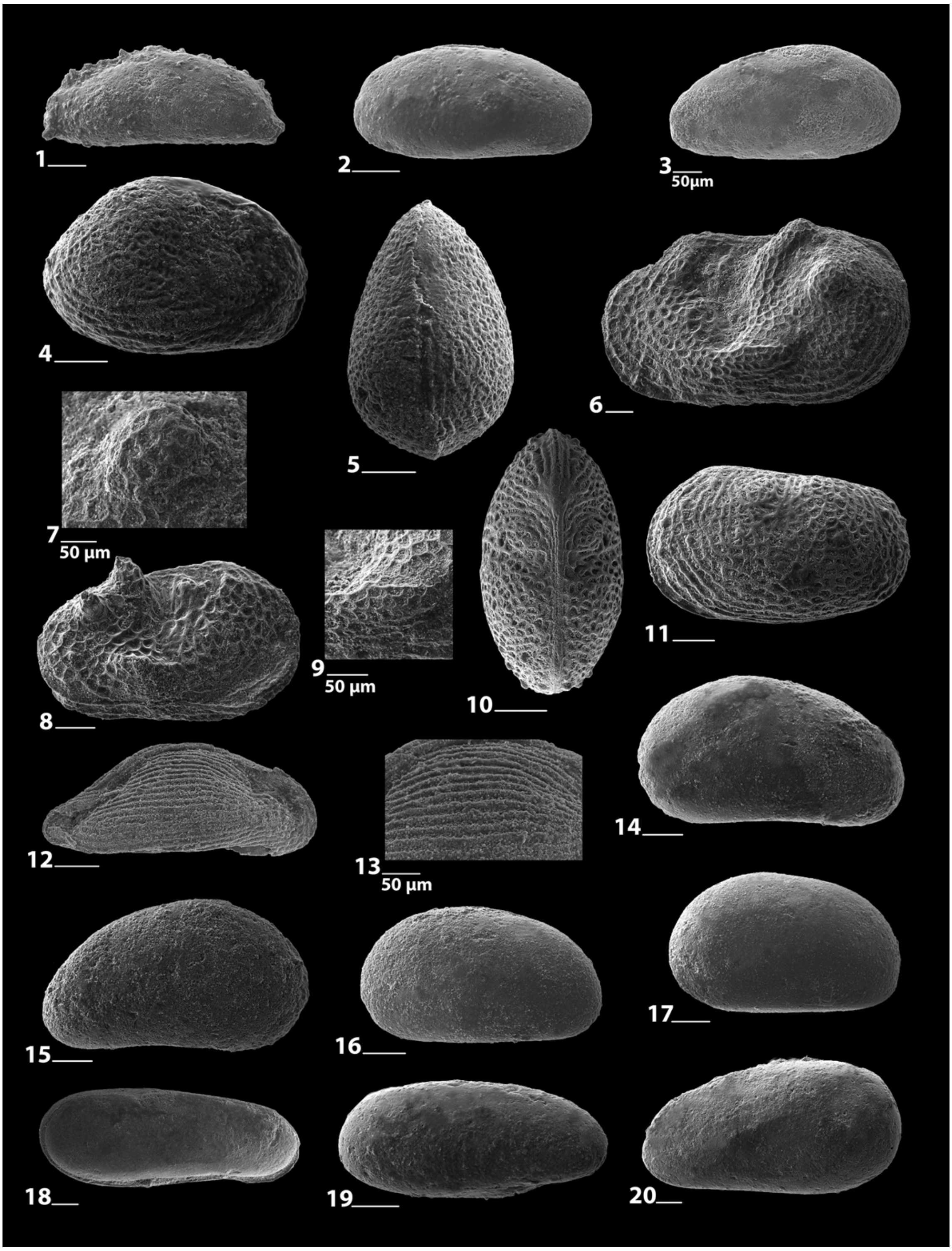

Fig. 11. (**1**) Genus and species indeterminate 1: C, left view, external, SMF Xe 23249, P(−8), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.250. (**2, 3**) Genus and species indeterminate 3: **2,** C, left view, external, SMF Xe 23250, P(0), Upper Callovian, Pedrógão, Portugal, L = 0.5, H = 0.225; **3,** C, right view, external, SMF Xe 23251, P(−2), Upper Callovian, Pedrógão, Portugal, L = 0.425, H = 0.2. (**4, 5**) *Sinuocythere pedrogaensis* Cabral & Colin, 2000 in Colin *et al.* (2000): **4,** ♀ RV, external, SMF Xe 23252, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.476, H = 0.324; **5,** ♀ C, dorsal view, SMF Xe 23253, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.450, H = 0.274. (**6–9**) *Theriosynoecum helmdachi* Sohn, 1982: **6,** ♀ C, left view, external, SMF Xe 23254, P(8B), Upper Callovian, Pedrógão, Portugal, L = 1.1, H = 0.650; **7,** ♀ C (as 6), external, ornament detail, posterior tubercle; **8,** RV, external, juv., SMF Xe 23255, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.650, H = 0.4; **9,** ♀ C (as 6), external, ornament detail, ventral lateral ridge. (**10, 11**) *Theriosynoecum* sp. 1: **10,** C, dorsal view, juv., SMF Xe 23256, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.675, H = 0.4; **11,** C, left view, juv. SMF Xe 23257, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.375. (**12, 13**) *Septacandona azeredae* Cabral & Colin, 2000: **12,** C, right view, external, SMF Xe 23258, P(6), Upper Callovian, Pedrógão, Portugal, L = 0.625, H = 0.225; **13,** C (as 12), external, ornament detail. (**14–17**) *Mantelliana* spp.: **14,** ♀ LV, external, SMF Xe 23259, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.350; **15,** ♀ RV, external, SMF Xe 23260, P(10), Upper Callovian, Pedrógão, Portugal, L = 0.624, H = 0.350; **16,** ♂ C, left view, external, SMF Xe 23261, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.324; **17,** ♀ C, left view, external, SMF Xe 23262, P(8T), Upper Callovian, Pedrógão, Portugal, L = 0.575, H = 0.350. (**18**) *Alicenula* cf. *A. incurva* (Bate, 1967): C, right view, external, SMF Xe 23263, P(10), Upper Callovian, Pedrógão, Portugal, L = 1.024, H = 0.425. (**19**) *Alicenula* sp. 1: C, right view, external, SMF Xe 23264, P(10), Upper Callovian, Pedrógão, Portugal, L = 0.550, H = 0.250. (**20**) *Alicenula* sp. 2: LV, external, SMF Xe 23265, P(10), Upper Callovian, Pedrógão, Portugal, L = 1.0, H = 0.525. Scale bars 100 μm except where otherwise noted.

Wilkinson & Whatley (2009) (g) and *N. composita* (Wienholz, 1967) (h); arrows indicate points for comparison. Even allowing for some variation between ♀ and ♂, it is clear that the LVs of *multiforma* sp. nov. are closest to *N. caesa caesa* of Wilkinson & Whatley, especially the dorsal rib (1) but differ in ornament posteriorly; neither is closely comparable with Triebel's holotype (e). *Neurocythere caesa* subsp. A of Wilkinson & Whatley (f) is the closest to the holotype (e). Another apparently close form is *N. composita* (Wienholz, 1967) from the Callovian of NE Germany (h). Figure 10 compares the holotype of *N. composita* of Wienholz (Fig. 10h) with the holotype of *N. caesa caesa* (Triebel, 1951) (Fig. 10e) and *multiforma* sp. nov. (Fig. 10a) – the fundamental rib patterns of the three taxa clearly differ, especially in relation to the dorsalmost rib.

Family **Limnocytheridae** Klie, 1938

Genus *Sinuocythere* Colin, Cabral, Dépêche & Mette, 2000

Type species. *Metacypris sinuosa* Mette, 1995.

Sinuocythere pedrogaensis Cabral & Colin, 2000 in Colin *et al.* (2000)

(Fig. 11:4 – 5)

2000 *Sinuocythere pedrogaensis* Cabral & Colin, in Colin *et al.*: 126, pl. 2, figs 11–14, pl. 3, figs 1–7.

Material. 18 valves and carapaces: samples P(8B), P(8T), P(10).

Description. See Colin *et al.* (2000, 126).

Dimensions. L = 0.375–0.500, H = 0.250–0.325.

Occurrence. Described from the Oxfordian of Pedrógão by Cabral & Colin (in Colin *et al.* 2000), also reported from the Upper Callovian and Oxfordian of Vermoil (Cabral *et al.* 2003) and in the Oxfordian of Serra do Bouro (Azerêdo *et al.* 2010); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. At present known only from Portugal.

Genus *Theriosynoecum* Branson, 1936

Type species. *Morrisonia wyomingensis* Branson, 1935.

Theriosynoecum helmdachi Sohn, 1982

(Fig. 11:6 – 9)

non 1935 *Morrisonia wyomingensis* Branson: 521, pl. 57, figs 17–21.
1971 *Theriosynoecum wyomingensis* (Branson); Helmdach: 62, text-figs 5–7.
1974 *Theriosynoecum wyomingensis* (Branson); Helmdach: 14, text-fig. 4.
1982 *Theriosynoecum helmdachi* Sohn: 312–313.
2002*a* *Theriosynoecum wyomingensis* (Branson); Azerêdo *et al.*: 161, pl. 2, fig. 1.

Material. 17 specimens – adults and juveniles, valves and carapaces: samples P(8B), P(8T), P(10).

Dimensions. L = 1.125–1.175, H = 0.575–0.625.

Occurrence. Originally reported from the Kimmeridgian of the Guimarota mine (1 km south of Leiria, Fig. 1) and Callovian–Oxfordian of Pedrógão, Portugal (e.g. Helmdach 1971, 1974), *T. helmdachi* is known from other Portuguese Jurassic outcrops, being particularly abundant in the Oxfordian (Cabral *et al.* 1998, 1999, 2001, 2003; Azerêdo *et al.* 2002*a*); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. In carapace morphology our material resembles *T. wyomingensis* (Branson, 1935), a species described from the Upper Jurassic–Lower Cretaceous of the North American west and refigured by Sylvester-Bradley (1973) using material provided by Branson. For many years authors, particularly Helmdach (e.g. Helmdach 1971, 1974), Schudack (e.g. 2000) and Azerêdo *et al.* (2002*a*), ascribed Portuguese material to the North American taxon. Sohn (1982) described a new species, *T. helmdachi*, based on some morphological differences between the Portuguese and the North American specimens. The Portuguese species differs from the American one in 'having a more subdued ventrolateral ridge and a curved liplike offset of the overlapping valve on the ventral margin in front of midlength' (Sohn 1982, 313) and also in its weaker and shorter median sulcus; moreover, in all the studied Portuguese material, particularly in the specimens from the Oxfordian (M.C. Cabral ongoing work; Azerêdo *et al.* 2002*a*) the second, more posterior vertical sulcus is less pronounced than in the American ones. As these morphological differences are evident, allowing for the morphological variability considered normal for the genus, we prefer to follow the Sohn classification. Material not well preserved.

Theriosynoecum sp. 1

(Fig. 11:10–11)

Material. 5 specimens – juveniles, carapaces: sample P(6). athleta Zone, Upper Callovian, Pedrógão (this work).

Description. Quadrate, weak dorso-median sinus, reticulate; internal features unknown.

Dimensions. L = 0.625–0.700, H = 0.400–0.450.

Remarks. This is probably juvenile material of *T. fluxans spiculata* (Helmdach, 1972) already recorded from Pedrógão at the same horizon (Azerêdo *et al.* 2002*a*, 161).

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

Genus *Septacandona* Cabral & Colin, 2002

Type species. *Septacandona ramalhoi* Cabral & Colin, 2002.

Septacandona azeredae Cabral & Colin, 2002

(Fig. 11:12–13)

2002 *Septacandona azeredae* Cabral & Colin: 68, figs 6A–K.
2002*a* *Septacandona azeredae* Cabral & Colin; Azerêdo *et al.*: 161, pl. 3, fig. 7.
2010 *Septacandona azeredae* Cabral & Colin; Azerêdo *et al.*: 9, pl. 2, figs 12–13.

Material. 1C, same bed as sample P(6) of this work, sampled laterally (1998).

Description. See Cabral & Colin (2002, 68, 70).

Dimensions. L = 0.600, H = 0.260 (deformed).

Occurrence. Described from the Oxfordian of Vale de Ventos, Lusitanian Basin, Portugal, was later found in Valverde (Cabral *et al.* 2001) and in Serra do Bouro (Azerêdo *et al.* 2010), the three outcrops exhibiting similar facies types. The occurrence in the athleta Zone, Upper Callovian, Pedrógão (this work) is the oldest record of the species and the first one in the west of the basin, with more margino-marine facies.

Remarks. The only specimen is poorly preserved and deformed, but it is certainly *S. azeredae,* regarding its typical trapezoidal lateral outline, ornamentation represented by horizontal ribs in the central part of the valves and presence of a very weak median vertical sulcus.

Family **Cyprididae** Baird, 1845

Genus *Mantelliana* Anderson, 1966

Type species. *Candona mantelli* Jones, 1888.

Mantelliana spp.
(Fig. 11:14–17)

Material. 39 specimens – adults, carapaces and valves: samples P (8B), P(8T).

Dimensions. L = 0.550–0.675, H = 0.275–0.375.

Remarks. The material appears to represent two species (one species shown in Fig. 11:14–15 and a second species in Fig. 11:16–17) although the latter is crushed – athleta Zone, Upper Callovian, Pedrógão (this work). Gen. ind. n. sp. O-16 of Azerêdo *et al.* (2002*a*, 2010) is a *Mantelliana*.

Suborder **Darwinulocopina** Brady & Norman, 1889
Superfamily **Darwinuloidea** Brady & Norman, 1889
Family **Darwinulidae** Brady & Norman, 1889

Genus *Alicenula* Rossetti & Martens, 1998

Type species. *Darwinula serricaudata* Klie, 1935.

Alicenula cf. *A. incurva* (Bate, 1967)
(Fig. 11:18)

cf. 1967 *Darwinula incurva* Bate: 28 – 29, pl. 1, figs 7–12.
cf. 1994 *Darwinula incurva* Bate, 1967; Wakefield: 64, pl. 11, figs 1–4, 7.
2002*a* *Darwinula* n. sp. 2 Azerêdo *et al.*: 161; pl. 3, fig 2.
cf. 2009 *Alicenula incurva* (Bate, 1967); Wakefield: 239, pl. 1, fig. 17.

Material. 8 specimens – valves and carapaces: samples P(8B), P (8T), P(10).

Description. Elongate outline; LV overlaps RV around all margins; greatest length at mid-height, greatest height and greatest width at mid-length. Dorsal margin straight to slightly convex, anterior and posterior margins rounded, ventral margin straight becoming slightly concave anteriorly. Valve surface smooth. Internal features unknown.

Dimensions. L = 1.025–1.125, H = 0.425–0.500.

Occurrence. Oxfordian of Pedrógão (Cabral *et al.* 1998; Azerêdo *et al.* 2002*a*); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Material poorly preserved but with some similarity to *A. incurva* from the Bathonian of Britain (figured material of Wakefield (1994) compared). *Alicenula incurva* is larger than our material with a stronger ventral marginal concavity.

Alicenula sp. 1
(Fig. 11:19)

?2010 *Darwinula* n. sp. 2 Azerêdo *et al.*: 8, pl. 2, fig 15.

Material. About 11 specimens – carapaces and valves: samples P (8B), P(8T).

Description. Elongate outline, valves of similar size; greatest length just below mid-height, greatest height towards posterior, greatest width at mid-length. Dorsal margin weakly convex, anterior margin rounded incurvate, posterior margin rounded, ventral margin weakly convex. Internal features unknown.

Dimensions. L = 0.375–0.550, H = 0.250–0.300.

Occurrence. ?Oxfordian of Serra do Bouro (Azerêdo *et al.* 2010); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. *Alicenula incurva*, *A*. sp. 1 and *A*. sp. 2 differ from each other in L:H ratio and position of greatest height posteriorly. Poorly preserved.

Alicenula sp. 2
(Fig. 11:20)

2002*a* *Darwinula* n. sp. 1 Azerêdo *et al.*: 161, pl. 3, fig 1.
2010 *Darwinula* n. sp. 1 Azerêdo *et al.*: 8, pl. 2, fig 14.

Material. 3 RV: samples P(8T), P(10).

Description. Elongate subovate outline; greatest length ventral of mid-height, greatest height posterior, greatest width at two-thirds of length. Dorsal margin convex, anterior margin rounded incurvate, posterior margin rounded, ventral margin slightly concave. Valve surface smooth. Internal features unknown.

Dimensions. L = 0.900–1.000, H = 0.500–0.525.

Occurrence. Oxfordian of Pedrógão (Cabral *et al.* 1998; Azerêdo *et al.* 2002*a*), of Vale de Ventos (Cabral *et al.* 1999; Azerêdo *et al.* 2002*a*), of Vermoil (Cabral *et al.* 2003) and of Serra do Bouro (Azerêdo *et al.* 2010); athleta Zone, Upper Callovian, Pedrógão (this work).

Remarks. Poorly preserved.

Indeterminate taxa

Genus and species indeterminate 1
(Fig. 11:1)

Material. 1 carapace: sample P(-8).

Dimensions. L = 0.624, H = 0.250.

Remarks. With its straight ventral margin and continuously curved convex anterior, dorsal and posterior margins this form may be related to *Acratia* Delo. Valve surface appears smooth but poorly preserved. Internal features unknown.

Genus and species indeterminate 2
(Fig. 7:20 – 22)

Material. 17 carapaces: samples P(−4T), P(−2), P(0), P(6).

Description. Subovate and elongate outline, small size; LV > RV except along dorsal margin where RV > LV; greatest length just ventral of mid-height, greatest height at anterior cardinal angle, greatest width at mid-length. Dorsal and ventral margins straight and almost parallel. Anterior margin rounded and infracurvate, posterior subtriangular. Some variation in the posterior margin observed, from subtriangular to subrounded. Valve surface smooth. Sexual dimorphism not observed. Internal features unknown.

Dimensions. L = 0.400–0.425, H = 0.200–0.225.

Remarks. Rounded podocopid species of uncertain affinity.

Genus and species indeterminate 3
(Fig. 11:2 – 3)

Material. 3 carapaces: samples P(0), P(2M).

Dimensions. L = 0.375–0.500, H = 0.200–0.225.

Remarks. Rounded podocopid species, internal features unknown, affinity uncertain.

Discussion

The Pedrógão section yielded marine ostracods and calcareous nannoplankton from samples P(−8) to P(6) and few, poorly preserved and reworked non-marine ostracods from overlying samples P(8B) to P(10).

Taxonomic problems

When undertaking this study we anticipated finding ostracod taxa from the classic literature on the marine Callovian of NW Europe. At the genus level this was true, as represented by cytheroids *Micropneumatocythere*, *Neurocythere*, *Palaeocytheridea*, *Patellacythere*, *Praebythoceratina*, *Praeschuleridea* and *Tanycythere* accompanied by *Cytherella*, *Cytherelloidea* and *Polycope*; however, noteworthy absences included *Eucytherura* Müller and related taxa, *Fastigatocythere* Wienholz, *Fuhrbergiella* Brand & Malz, *Galliaecytheridea* Oertli, *Glyptocythere* Brand & Malz, *Lophocythere* Sylvester-Bradley, *Pleurocythere* Triebel, *Progonocythere* Sylvester-Bradley, and other small cytheroids, no bairdioids and only a single marine cypridoid. Indeed, the marine assemblages are of notably low diversity compared with coeval material from NW Europe, which may reflect a nearshore environment with lowered and/or fluctuating salinity. At the species level we were able to identify only a single previously described taxon (Gen. nov.? *gublerae*), all other species were either new, indigenous to Portugal or could be compared (cf.) only with described taxa.

The taxonomic difficulties are well illustrated by *Neurocythere multiforma* sp. nov. which presented two problems: (1) similarity to but not precise identity with known species of the genus (discussed in Systematic Palaeontology), and (2) the presence of a range of morphological variation that we interpret as three forms of a single species. As discussed above, *N. multiforma* occurs as Morphotypes I–III with males and females in 11 successive samples and may represent contemporaneous, interbreeding populations. We are aware of current thought about taxonomic harmonization for ‘near time’ Quaternary–Recent species as a practical way to increase the utility of ostracod species for environmental monitoring and reconstruction (a heueristic approach: Horne *et al.* 2011, 2015; Danielopol *et al.* 2015). With ‘deep time’ taxa the palaeontologist lacks information on (1) genetic characteristics, and usually (2) appendages and soft part anatomy, and (3) reproductive strategies, and must rely on the features of the calcified valve to define a species, an approach where differences are more apparent than similarities. Based solely on carapace characteristics, *N. multiforma* sp. nov. represents a single biological species. How did the three morphotypes live together? One possible model of niche-partitioning is provided by Ikeya & Shimura (1995) who reported three species of *Spinileberis* Hanai from a tidal zone environment in Japan. Based on appendage and carapace characteristics the three species are distinct and were not observed to interbreed. The co-occurrence of three biological species of the same genus was explained by the possession of different reproductive and growth strategies, and also by the possibility that some very local bottom-water habitats were close to freshwater salinity. Other examples of sympatric speciation, perhaps less clear because from non-marine environments, concern Miocene *Cyprideis* Jones from Amazonia (Gross *et al.* 2014) where up to 12 species are considered to occur sympatrically, and *Cyprideis* from Austria (Gitter *et al.* 2015) where four apparently co-existing *Cyprideis* species are referred to different microhabitats based on salinity preferences. Whatever the biological or ecological rationale behind these cases, on present evidence we prefer to recognize three morphotypes of *multiforma* which may, or may not, represent three co-existing sympatric species reflecting some kind of original niche-partitioning and not a simple taphonomic signal. However, the morphological distinction between *N. multiforma* sp. nov. Morphotypes III and II is much less clear than between Morphotype I and the others, and III and II could be interpreted as reflecting a range of variation while I is polymorphic with them (see Neil (2000) for an overview).

Palaeobiogeography, faunal links and faunal dynamics

In recent years knowledge of Middle and Upper Jurassic ostracods from the eastern Tethys has steadily increased and there is now a reasonably sized database for reconstruction of palaeobiogeographical and stratigraphical distribution patterns, although time correlations are often imprecise through lack of ammonite-based zonation schemes. Andreu *et al.* (2012) list material from Kachchh, India and analyse ostracod distribution patterns at genus and species levels from sites around the coast of East and West Gondwana and compare them with more boreal areas including Europe (they also provide a good reference list). The cytheroids evolved rapidly during the Jurassic and are thus key comparators. Our Portuguese material has little in common with the Indo-East African Province fauna of Andreu *et al.* (2012), i.e. of Australia, East Africa, India and Madagascar, with the absence of key genera such as *Majungaella* Grékoff, *Mandawacythere* Bate and *Trichordis* Grékoff. For the Callovian, Andreu *et al.* (2012, figs 19–20) list three genera in common between the Indo-East African Province and Europe, namely *Fastigatocythere* Wienholz, *Procytheridea* Peterson and *Progonocythere* Sylvester-Bradley, none of which is present in our material. *Fastigatocythere* and *Progonocythere* were originally described from Europe. *Fastigatocythere* is particularly diverse in eastern Tethys, e.g. India. A number of Tethyan species have been assigned to *Progonocythere* but probably require re-examination in light of the revision of the genus by Whatley & Ballent (1996). A number of Indian and other species have been placed in *Procytheridea* but may also require revision if Lord (1972) and Sherrington & Lord (1975*a*, *b*) are correct that genus is restricted to North America.

The Pedrógão assemblages have cytheroid elements in common with Saudi Arabia (*Virgulacytheridea*), Israel (Gen. nov? *gublerae*) and Tunisia (*Sinuocythere*) but it is striking how different and less diverse the Portuguese material is when compared with Callovian material from, for example, Tunisia (Mette 1995, 1997). Thus, links between Portugal and NW Europe at species level are weak (only cf. species), at genus level slightly better but from low diversity assemblages, and to the western Tethys also weak.

We encountered a number of species which exhibited subtle morphological differences with described material with obvious consequences for taxonomy. The difficulty was compounded when type material was compared with our current and published material. Many minor, and not so minor, morphological differences became clear amongst published figured material which indicate that there is considerable variation amongst established species yet to be explored.

Conclusions

Ostracod assemblages from the upper Callovian of western Portugal yielded (1) a marine association of 17 species: 5 species described as new (*Praebythoceratina parascrobiculata*, *Praeschuleridea lisensis*, *Neurocythere multiforma*, *Virgulacytheridea posteroacuminata*, *Palaeocytheridea* (*M.*)? *dorsocostata*), 1 previously described species (Gen. nov.? *gublerae*), 6 species compared with described taxa (*Polycope* cf. *P. sububiquita*, *Cytherella* cf. *C. fullonica*, *C.* cf. *C. index*, *Cytherelloidea* cf. *Ca. chonvillensis*, *Patellacythere* cf. *P. ungulina*, *Praebythoceratina* cf. *Pr. stimulea*), and 5 species in open nomenclature; and (2) a non-marine association of 8 species: 3 species previously described (*Septacandona azeredae*, *Theriosynoecum helmdachi*, *Sinuocythere pedrogaensis*), 1 species compared with a described taxon (*Alicenula* cf. *A. incurva*), and 4 species in open momenclature. The non-marine component in samples P(8B) to P(10) is generally poorly preserved and reworked and contains three species indigenous to Portugal. The number of new marine taxa was surprising. These conclusions are based on subtle morphological differences with described marine taxa, which were also unexpected. In the last two decades ostracod research has focused on Quaternary–Recent material and the reconstruction of environmental change in near time. Our results demonstrate that there are research opportunities in Mesozoic ostracod biodiversity, faunal interchange, biogeographical patterns and the controlling biotic and abiotic influences. This is especially true for ostracods of the superfamily Cytheroidea, which has been a particular focus of dynamic speciation since the early Jurassic (200 Ma), and whose rates of evolution and speciation dynamics require examination.

Acknowledgements and Funding

We are indebted to many colleagues for help and discussion: D.L. Danielopol (Graz), F. Dépêche (Paris), A. Honigstein (Geological Survey of Israel, Jerusalem), D.J. Horne (London), J. Sauvagnat (Geneva), E. Tesakova (Moscow), and for the loan of material to: A. Ehling (Bundesanstalt für Geowissenschafter und Rohstoffe, Berlin) and S. Stukins (The Natural History Museum, London). We thank C. Franz and M. Ricker (Senckenberg Forschungsinstitut) and Vera Lopes and Telmo Nunes (Universidade de Lisboa) for preparation of diagrams and help with scanning and light microscopy. We thank the constructive comments of two anonymous reviewers.

VP gratefully acknowledges the support of the Senckenberg Forschungsinstitut during a six-month ERASMUS traineeship in Frankfurt.

This is a contribution to Project PDCTE/CTA/44907/2002 funded by Fundação para a Ciência e Tecnologia, Portugal.

Scientific editing by Elisabeth Brouwers

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