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New charophytes from the Upper Jurassic of the Lusitanian Basin (Portugal)

RICARDO PEREIRA[1], MONIQUE FEIST[2] & ANA. C. AZERÊDO[3]
[1]Partex Oil & Gas, Av. Republica, 50, 4° Lisbon 1050-196, Lisbon, Portugal and Centro de Geologia da Universidade de Lisboa, Campo Grande, Ed. C2 - 5° Piso, 1749-016, Lisbon, Portugal (e-mail: ricardo.pereira@petroprimo.pt)
[2]Laboratoire de Paléobotanique, Université Montpellier, Place Eugène Bataillon F-34095 Montpellier Cedex 05, France (e-mail: mofeist@isem.univ-montp2.fr)
[3]Departamento de Geologia and Centro de Geologia, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, Ed. C2 - 5° Piso, 1749-016, Lisbon, Portugal (e-mail: aazeredo@fc.ul.pt)

ABSTRACT – In the Lusitanian Basin (west-central Portugal), Upper Jurassic (Oxfordian) sediments were investigated in order to identify palaeontological assemblages of charophytes. Systematic studies were undertaken on specimens obtained from four field sections (Pedrógão, Vale de Ventos, Memória and Valverde). These studies revealed the presence of new forms of *Porocharaceae* (*Porochara pedunculata* n. sp) and of forms previously unknown in this region (*Auerbachichara* cf. *saidakovskyi*), as well as *P. raskyae*, *P. minima*, *P. fusca*, *P. sulcata*, *P. kimmeridgensis*, *Aclistochara longiformis* and *Porochara* sp. Comparison of the charophyte palaeofloras recognized in all of the studied sections has allowed the definition of three different assemblages which, coupled with other data, help to correlate these successions of Early (?) to Middle (Late?) Oxfordian age. *J. Micropalaeontol.* **22**(2): 113–126, November 2003.

INTRODUCTION

The lowermost Upper Jurassic deposits of the Lusitanian Basin are very rich in charophytes, as has been recognized for a long time. However, as a result of the perceived low biostratigraphical potential of these algae, only a few studies that include systematic descriptions of this palaeoflora exist (Helmdach, 1971; Ramalho, 1971a; Thulborn, 1973; Grambast-Fessard & Ramalho, 1985; Pereira *et al*., 1998, 1999; Pereira, 2002). This charophyte analysis was undertaken within the scope of a broader, basin-scale, sedimentary, palaeoclimatic and micropalaeontological study, focused on the formations related to the Middle–Upper Jurassic disconformity in the Lusitanian Basin (Research Project PRAXIS XXI-PCNA/P/CTE/6/96). The main results of this project, involving the detailed analysis of facies assemblages, foraminifera, calcareous algae, ostracods, palynomorphs, palaeoenvironmental and palaeogeographical interpretations, have been presented elsewhere (Azerêdo *et al.,* 1997, 1998, 2000, 2002a,b; Wright *et al.,* 1997; Cabral *et al*., 1998, 1999a,b, 2001; Pereira *et al*., 1998, 1999; Barron *et al*., 1999; Colin *et al*., 2000; Cabral & Colin, 2002; Pereira, 2002).

The aim of this paper is to present the systematic description of the charophyte species recognized in the Oxfordian deposits of the studied region (locally possibly uppermost Callovian), within a regional sedimentary and palaeoecological framework. The vertical distribution of the identified species in the studied successions is also presented.

The abundance of charophyte specimens and the well-known high intraspecific diversity of the gyrogonites led us to try a twofold approach, integrating both morphological analysis and comparative populational analysis (see below). The charophyte data, presented here, refer to four field sections in the Lusitanian Basin (Fig. 1): Pedrógão (shoreline S of Figueira da Foz), Vale de Ventos, Valverde and Memória (all three at Serra dos Candeeiros, in the east of the basin).

GEOLOGICAL SETTING

The Lusitanian Basin, in West-Central Portugal (Fig. 1), is one of the marginal basins associated with the opening of the North Atlantic Ocean. While most of the basin fill is Jurassic in age, sediments from the Upper Triassic to the Upper Cretaceous are found, overlain by a cover of Tertiary sediments. The basin is bounded to the east by uplifted Hercynian basement and to the west (offshore) by small basement horsts. Two main episodes of extension and rifting are recorded in the basin: the first one, in the late Triassic, which only developed the early rift-stage and a later one, which gave rise to ocean opening, ranging from the Late Jurassic through the Early Cretaceous (Ribeiro *et al*., 1979; Wilson, 1988). The basin was subjected to tectonic inversion in the Tertiary and, consequently, a great part of its pre-, syn and post-rift sequences became exposed (Ribeiro *et al.*, 1979; Wilson, 1988).

The Triassic to lowermost Jurassic succession comprises red siliciclastic deposits, gradually passing westwards and upwards into red clays, evaporites and dolomites. These are followed by increasingly marine deposits of the corresponding post-rift stage (Lower and Middle Jurassic), namely bituminous shales, hemipelagic marls and limestones in the west of the basin, and shallower-water limestones in the east (e.g. Mouterde *et al.,* 1979; Azerêdo, 1993). The Middle Jurassic is separated from the Upper Jurassic by a basinwide hiatus (disconformity and/or stratigraphical gap), spanning at least from the late Callovian to the early Oxfordian (e.g. Ruget-Perrot, 1961; Ramalho, 1971a, 1981; Mouterde *et al.*, 1979; Azerêdo *et al.*, 1997, 1998, 2000). This disconformity is widespread around Atlantic marginal basins, with both eustatic and tectonic explanations for its origin having been proposed (e.g. Vail *et al.*, 1987; Floquet *et al*., 1989; Legarreta, 1991; Aurell *et al*., 1994; Azerêdo *et al*., 2002b).

STRATIGRAPHICAL SETTING

The Middle–Upper Jurassic disconformity in the Lusitanian Basin is marked by a stratigraphical gap that spans at least from the latest Callovian to the earliest Oxfordian, because the Lamberti, Mariae and Cordatum Zones have not been recorded over the whole of the basin. The next documented ammonite fauna (from Serra de Montejunto) belongs to the Plicatilis Zone

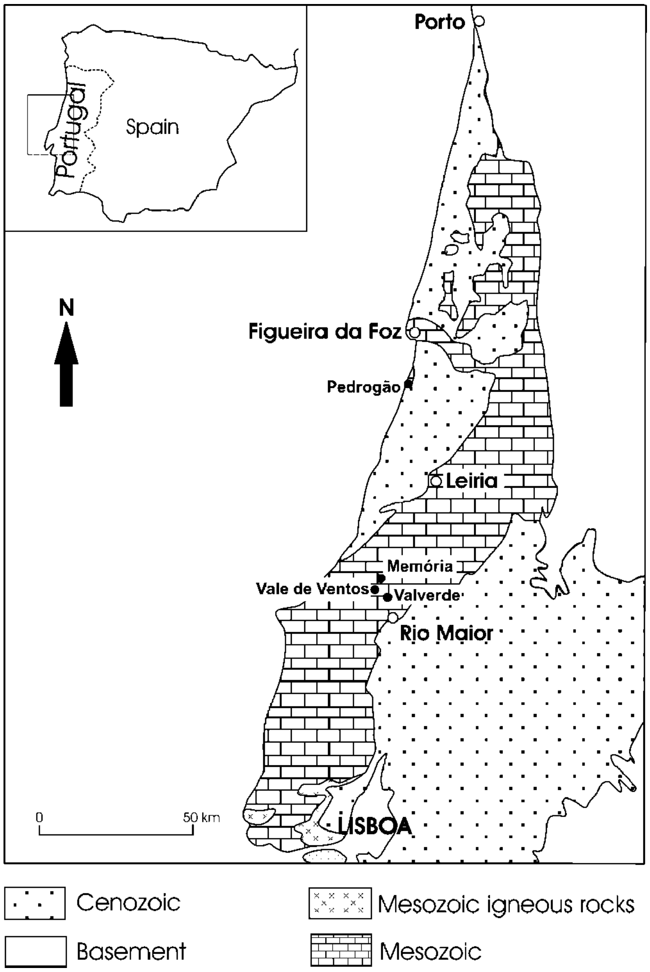


Fig. 1. Simplified onshore geology of the Lusitanian Basin and location of the studied sections.

(Middle Oxfordian), according to Mouterde *et al.* (1979) and Rocha (1996). However, in places (as is the case in the Vale de Ventos, Memória and Valverde sections, at Serra dos Candeeiros; Figure 1) the missing interval is much longer, as the Upper Jurassic deposits directly overlie Upper Bathonian lagoonal limestones that are dated by the foraminiferid *Meyendorffina bathonica* Aurouze & Bizon, 1958 (Azerêdo, 1993; Azerêdo *et al.*, 1998). In the west of the basin (namely, at Pedrogão; Figure 1), the last datable deposits below the disconformity are outer marine marls and limestones of late Callovian age (Athleta Zone), as indicated by the ammonoid and brachiopod faunas (Ruget-Perrot, 1961; Alméras *et al.*, 1991).

The Upper Jurassic deposits above the discontinuity are traditionally assigned to the Cabaços formation (though often quoted as a Formation, it is not formally described), which basically corresponds to the Cabaços Beds (*sensu* Choffat, 1893a,b, and followed by Ruget-Perrot (1961) and Ramalho (1971a,b)). These are also known as the Cabaços Limestones (e.g. Mouterde *et al.*, 1979). The charophyte data presented here were obtained from marly levels within this formation (see below).

The Cabaços formation lacks good biostratigraphical markers, especially in its lower part. It unevenly overlies Middle Jurassic limestones ranging in age from the late Bathonian to the late (but not latest) Callovian. Over the whole of the basin, the lower (locally) to intermediate (mostly) part of the successions are typified by the presence of the dasycladacean alga *Heteroporella lusitanica* (Ramalho, 1970), which is attributed to the Middle Oxfordian in Portugal (Ramalho, 1970, 1971a,b, 1981). This species was also found by Ramalho (1971b) in the Torres Vedras region (where the original descriptions of the unit by Choffat were made), in levels where a few ammonite records attributed to the Transversarium Zone have been recorded (cf. Ruget-Perrot, 1961; Ramalho, 1971a,b). In places, Middle Oxfordian or Upper Oxfordian ammonites are documented from levels well above those containing *H. lusitanica* (Ruget-Perrot, 1961; Mouterde *et al.*, 1979; Rocha, 1996). It is also worth mentioning that the lituolid foraminiferids *Alveosepta jaccardi* (Schrodt) and/or *Pseudocyclammina parvula* Höttinger, 1967 (Middle Oxfordian to Kimmeridgian) always appear, all over the basin, in the more marine facies which succeed, or laterally replace, the transitional lagoonal facies with *H. lusitanica* (Ramalho, 1971a, b, 1981; Azerêdo *et al.*, 2000, 2002a,b).

BRIEF DESCRIPTION OF THE STUDIED SECTIONS

The studied sections (Fig. 1) are representative of the typical eastern (Vale de Ventos, Memória, Valverde) and western (Pedrógão) Middle–Upper Jurassic transitional successions in the Lusitanian Basin. These successions are mostly composed of marls and limestones, and both thin sections and washed residues were used for petrographical and micropalaeontological studies. For the charophytes, of course, only the marly sediments were subjected to a detailed analysis and the studied levels are indicated in the logs of Figs 2 and 3.

Pedrógão

The Pedrógão section is excellently exposed along the coastline of Pedrógão beach, 30 km to the South of Cabo Mondego (Figueira da Foz; Figure 1) and displays an Upper Callovian to Middle–Upper(?) Oxfordian succession. The first detailed field study of this section was made by M. Ramalho (unpublished), with further work included within the scope of this research project (Azerêdo *et al.*, 2000). The principal works referring to the Pedrógão section include data on the Callovian ammonoid and brachiopod fauna (Ruget-Perrot, 1961; Alméras *et al.*, 1991) and the Callovian and/or Oxfordian foraminifera, ostracods, charophytes, dasycladaceans, palynomorphs, sedimentary facies and palaeodepositional settings (Ruget-Perrot, 1961; Grambast-Fessard & Ramalho, 1985; Azerêdo *et al.*, 1998, 2000, 2002a,b; Cabral *et al.*, 1998, 1999a; Pereira *et al.*, 1998, 1999; Barrón *et al.*, 1999; Colin *et al.*, 2000; Pereira, 2002; Azerêdo & Cabral, in press).

The Pedrógão succession can be summarized as follows (Fig. 2).

- At the base, the section shows the uppermost beds of probable late Callovian age (levels P1 to P8), composed of mid-outer ramp marls and limestones with ammonites, brachiopods, bivalves (including the typical thick-shelled remains known as ‘filaments’), echinoids, marine ostracods,

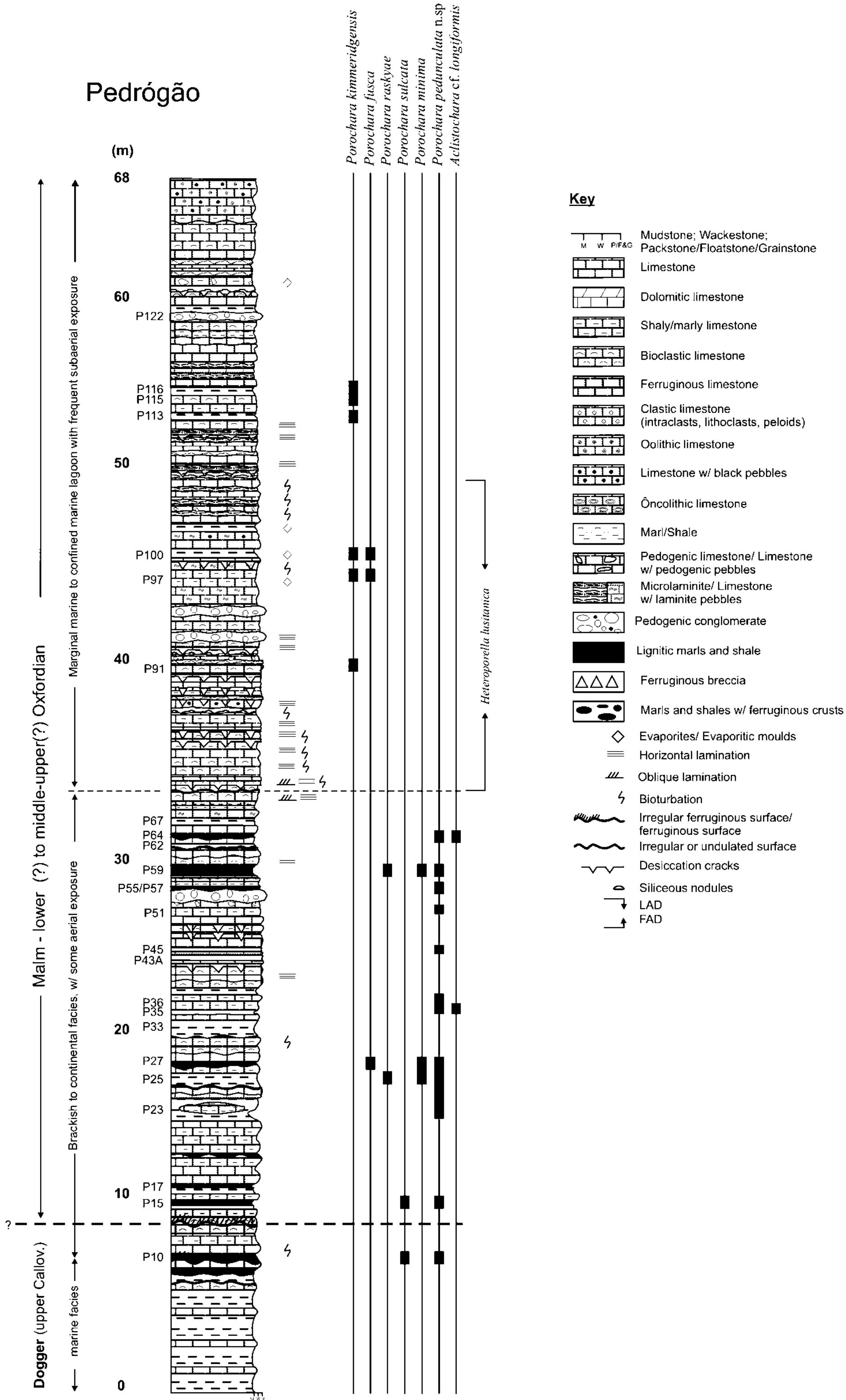


Fig. 2. Schematic lithostratigraphical column of the Pedrógão section, with charophyte distribution.

hyaline-walled foraminifera and, towards the top, solitary corals, oysters, and rare agglutinated foraminifera. These levels are overlain by interbedded marls, lignitic marls and bioclastic limestones, with mixed marine and non-marine ostracods and charophyte gyrogonites (*Porochara sulcata* Grambast-Fessard, 1985, and *Porochara pedunculata* n. sp),

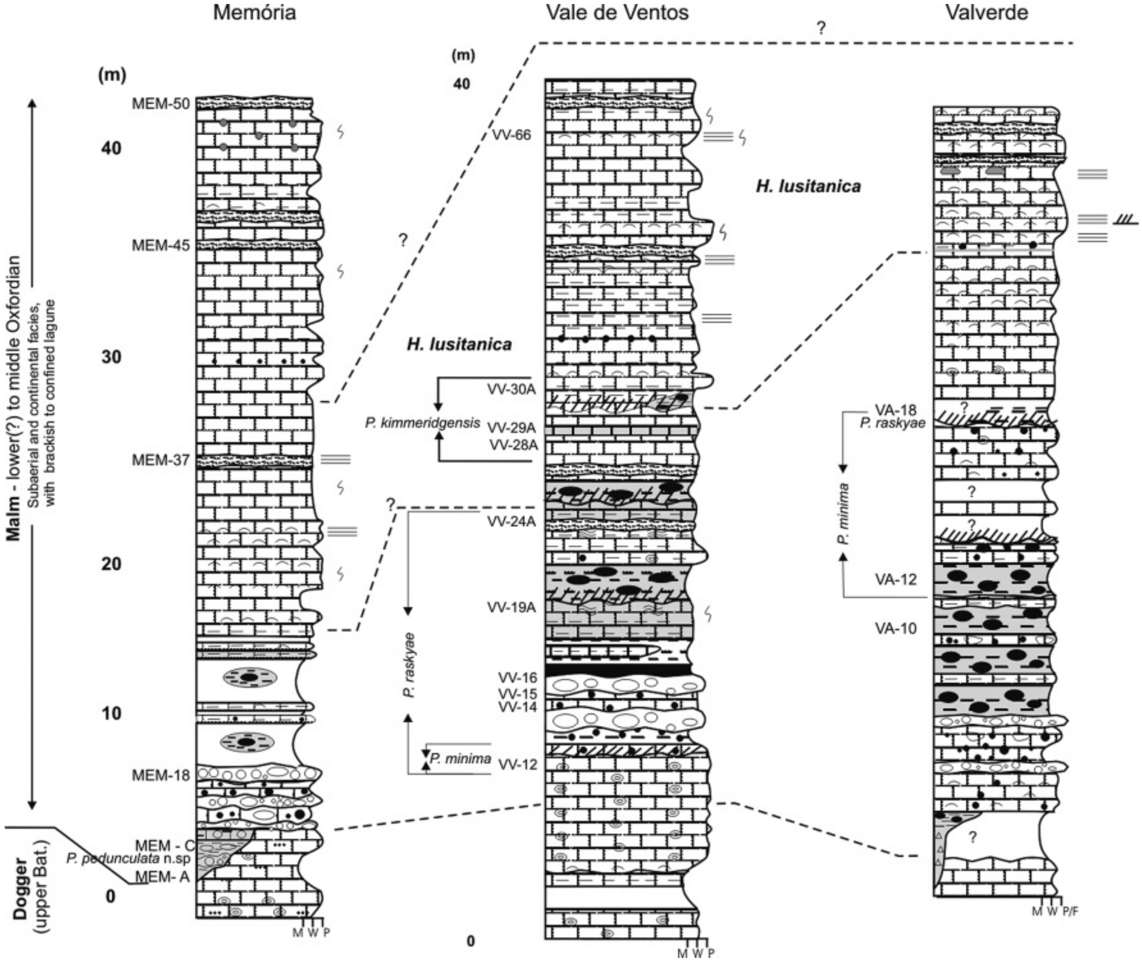


Fig. 3. Lithostratigraphical successions and correlation of the Memória, Vale de Ventos and Valverde sections (after Azerêdo *et al.*, 2000, 2002a, b), with charophyte distribution.

capped by a 0.5 m thick couplet of reddish ferruginous bioclastic limestone layers separated by an highly irregular ferruginized surface, totally draped by charophyte stems (mostly) and gyrogonites (P13b and P13t). In the absence of biostratigraphical markers, Azerêdo *et al.* (2000) have proposed that this major sedimentary discontinuity (and not the top of P8) should be considered the stratigraphical boundary between the uppermost Callovian and the Oxfordian, which is followed here.

- From P14 to P72, the succession is composed of alternating marls/clays, often lignitic, marly limestones and fossiliferous/bioclastic limestones, sometimes ferruginous, commonly bounded by ferruginous surfaces or desiccation cracks on bedding planes; a few pedogenic conglomerates, fenestral micrites and rare thin, bioclastic layers with plane and very low-angle cross-lamination (event deposits) are found. These sediments are rich in gastropods, bivalves, non-marine ostracods, charophyte stems and gyrogonites (*Porochara sulcata*, *P. minima* (Mädler, 1952) Shaikin, 1976, *P. raskyae* (Mädler, 1952) Mädler, 1955, *P. pedunculata* n. sp., *P. fusca*? (Mädler, 1952) Mädler, 1955, *Aclistochara* cf. *longiformis* Wang & Yang, 1983) and palynomorphs; a few teeth, bone and plant fragments are also present.
- The overlying levels up to P90 are dominated by fossiliferous and bioturbated limestones, with some marly interbeds and microbial laminites, frequently bounded by desiccation cracks. These levels are marked by the appearance and usually abundant occurrence of *Heteroporella lusitanica*, together with abundant ostracods, less frequent charophyte gyrogonites, some agglutinated foraminifera, serpulids, gastropods and bivalves.
- From P91 upwards, massive and fossiliferous limestones and less common marly limestones are increasingly intercalated with microbial laminites, pedogenic conglomerates and evaporite relict levels. *H. lusitanica* becomes rarer towards its last occurrence at P106. The fossil content varies from moderately diverse assemblages of restricted marine influence (euryhaline and marine ostracods and molluscs, rare echinoids, Porostromata, several benthic foraminifera, namely *Pseudocyclammina parvula*, charophytes namely, *P. kimmeridgensis* (Mädler, 1952) Mädler, 1955, *P. fusca*?, a few acritarchs) to low-diversity or even monospecific assemblages of euryhaline ostracods (ostracodites, closely related to the microbial laminites or to the evaporites).

The Pedrógão succession depositional environments are interpreted as having developed from an open marine setting (at the

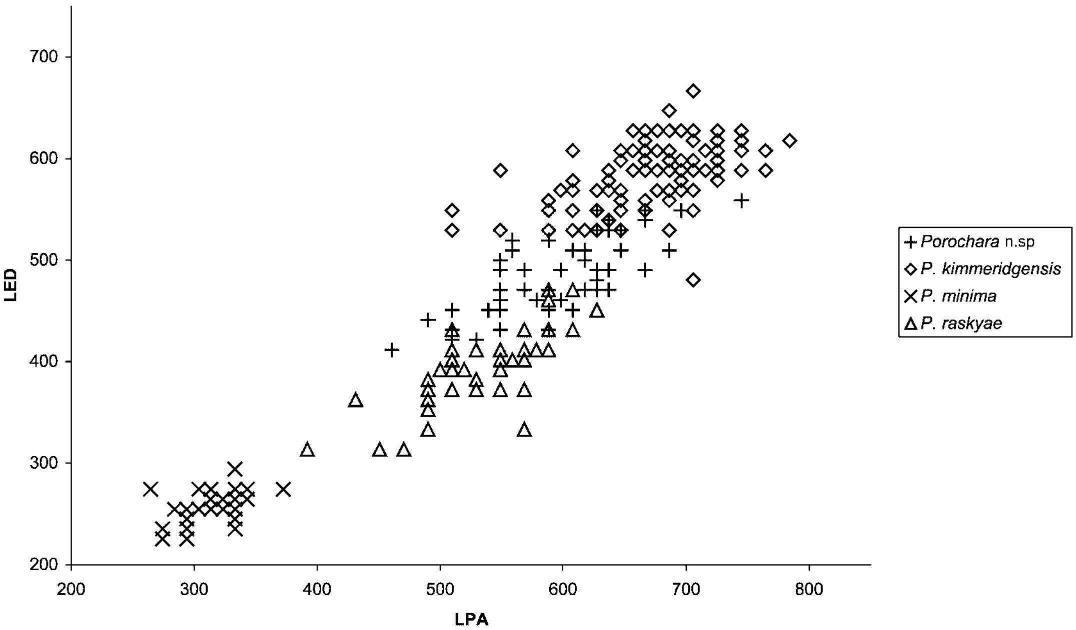


Fig. 4. Graphical analysis of selected gyrogonite populations.

base) to fresh-brackish water and marginal-restricted marine settings, with fluctuating salinity and frequent subaerial exposure (Azerêdo *et al.*, 1998, 2000; Azerêdo & Cabral, in press).

Vale de Ventos, Memória and Valverde

These field sections are located at Serra dos Candeeiros, a range of hills in the eastern zone of the Lusitanian Basin (Rio Maior-Alcobaça-Fátima region; see Fig. 1). The successions observed at these three locations are broadly similar and time-equivalent, as shown in Figure 3. A detailed field study of these sections was originally made by Azerêdo and Ramalho (unpublished), and later descriptions were presented by Azerêdo *et al.* (1998, 2000, 2002a,b). The Vale de Ventos and Valverde outcrops have also been particularly mentioned in relation to systematic studies of ostracods (Cabral *et al.*, 1999b, 2001; Colin *et al.*, 2000; Cabral & Colin, 2002). The charophytes from Vale de Ventos are described in Pereira *et al.* (1998, 1999) and Pereira (2002). A summarized description of the Vale de Ventos (SE of Alcobaça), Memória (SW of Fátima, to the north of Vale de Ventos) and Valverde (NW of Rio Maior, to the SE of previous ones) sections is given below.

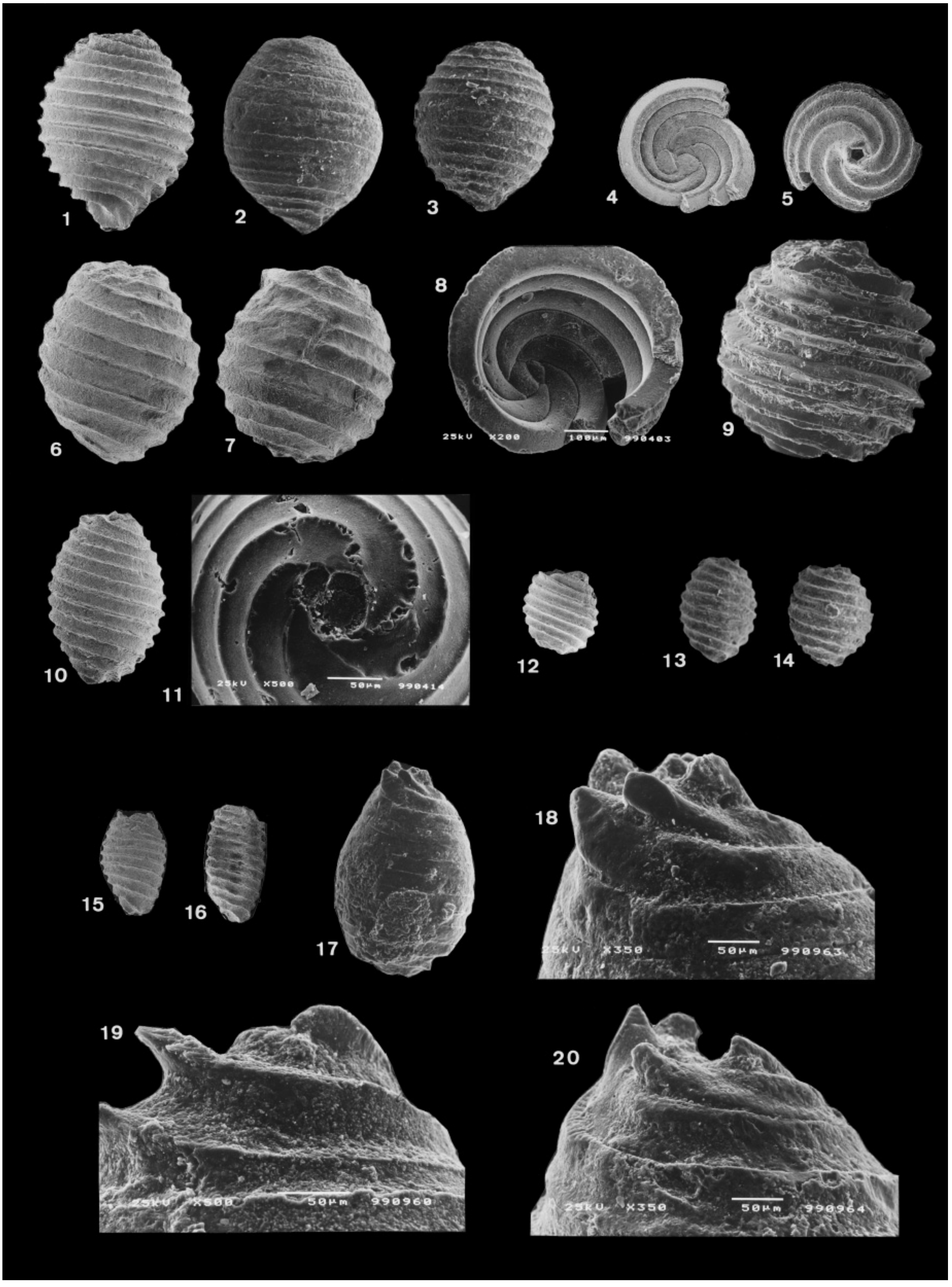
These successions (Fig. 3) comprise, at the base, Middle Jurassic (Upper Bathonian) mudstone-wackestone and floatstone limestones with abundant Porostromata and 'algal' nodules, diverse benthic foraminifera (including the biostratigraphical marker *Meyendorffina bathonica*), *Thaumatoporella parvovesiculifera* Raineri, *Salpingoporella* sp. and dasyclad fragments, ostracods, charophyte gyrogonites and stem (?) fragments, gastropods, bivalves (Azerêdo, 1993). The top of this unit is marked by a ferruginous palaeokarst surface, locally (Vale de Ventos) coupled with an angular unconformity relative to the overlying levels, which are attributed to the Upper Jurassic (Lower?–Middle Oxfordian).

The lowermost of these Upper Jurassic deposits (Fig. 3) are thick-bedded pedogenic conglomerates and limestones, black-pebble limestones and lignitic or ferruginous marls, with abundant fresh and fresh-brackish water ostracods and charophytes (*Porochara raskyae*, *P. minima, P. pedunculata* n. sp and an indeterminate genus). Immediately above these, ferruginous argillaceous limestones and marls, with black-pebbles, ferruginous crusts, fenestrae and sparse microbial laminites dominate the successions. These deposits contain abundant fresh-brackish water ostracods, several species of charophytes (*Porochara kimmeridgensis*, *P. raskyae*, *Auerbachichara* cf. *saidakovskyi* Kisielevsky, 1967 and undetermined fragments), Porostromata, gastropods, bivalves. From these levels upwards, the limestone/marl ratio gradually increases, and the succession is characterized by thin to medium-bedded bioclastic/fossiliferous wackestones and packstones, intercalated with microbial laminites (more common towards the top), displaying desiccation cracks, fenestrae, *Heteroporella lusitanica*, very abundant ostracods, charophyte gyrogonites, Porostromata, agglutinated foraminifera, gastropods, bivalves, bioturbation; the microfossils and macrofossil remains sometimes accumulate within microbial-algal mats and/or form event deposits.

These successions reflect evolution from shallow marine, lagoonal environment (Middle Jurassic), to continental and transitional settings (subaerial exposure, freshwater to brackish lacustrine, perilacustrine and restricted lagoon).

POPULATION ANALYSIS

All the charophyte samples were studied using a simple quantitative analysis with Microsoft Excel as a complement to the morphological description (for example, Feist & Grambast-Fessard, 1982). This analysis uses the morphometric parameters most widely accepted by several authors (e.g. Horn af Rantzien, 1959; Bonnet & Soulié-Märsche, 1971; Schudack, 1996a).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25kV X500 50μm 990414
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25kV X350 50μm 990963
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25kV X500 50μm 990960
20
25kV X350 50μm 990964

n=686	LPA (μm)	LED (μm)	NC	AND (μm)	ISI	ANI	APD (μm)	ECD (μm)
Mean	653	534	12	314	123	48	111	51
Median	667	549	12	314	122	48	108	59
Mode	686	549	12	314	120	50	118	59
Standard deviation	70	61	1	37	8	2	18	12
Minimum	392	304	8	186	102	40	59	29
Maximum	882	667	15	431	144	60	196	78

LPA, length of polar axis (μm); LED, length of equatorial diameter (μm); ISI, isopolarity index; ANI, anisopolarity index; AND, anisopolarity distance (μm); NC, number of convolutions; ECD; equatorial cell diameter (μm).

Table 1. Statistics for morphometric parameters of *Porochara pedunculata* n. sp.

The use of this analysis has proved to be very useful in separating different populations of charophytes, when using graphical plotting of the morphometric parameters (LPA × LED or sphericity index (ISI) × symmetry index (ANI)).

In Figure 4, four populations of various samples are plotted, showing elongated clouds that merge in restricted areas. These areas are evidence of populational variation that only strengthens this analysis, for which the highest number of gyrogonites as possible must be used (Soulié-Märsche & Joseph, 1991) to avoid erroneous classification of few samples, which can be located in mergence areas.

SYSTEMATIC DESCRIPTIONS

Family **Porocharaceae** Grambast, 1962
Subfamily **Porocharoideae** Grambast, 1962
Genus *Porochara* Mädler, 1955 *emend.* Schudack, 1986

Porochara pedunculata sp. nov.
(Pl. 1, figs 1–5)

1985 *Porochara jargaraensis* Shaikin & Saidakovsky; Grambast-Fessard & Ramalho: 62, pl. 2, figs 1–2.
1999 *Porochara* n. sp. Pereira *et al.*: fig. 2.

Derivation of name. From its basal pedunculate character.

Diagnosis. Medium-sized *Porochara* gyrogonite with an inverted pear shape, marked by a basal necking (larger at apical half), concave spiral cells (8–15, usually 12–13) and a pentagonal basal pore (about 40 μm in diameter); segmented basal plate, not visible from the outside. Major axis ranges from 392 to 882 μm, minor axis from 304 to 667 μm, apical pore about 100 to 130 μm and equatorial cells around 50–60 μm. ISI shows an elliptical gyrogonite (102–144) and ANI shows an asymmetrical shape with a larger apical half of 48, up to 60 in some samples.

Holotype. Plate 1 (fig. 1) from level P25, collection Pereira/Azerêdo deposited at the Department of Geology, Faculty of Sciences, University of Lisbon.

Paratype. Plate 1 (figs 2, 3) – about 30 specimens from the collection Pereira/Azerêdo deposited at the Department of Geology, Faculty of Sciences, University of Lisbon.

Material. About 700 specimens.

Type-horizon and type-locality. Brown marls (level P25) of the Lower?–Middle Oxfordian (Upper Jurassic); Pedrógão beach, 30 km south of Figueira da Foz; 39°55'N 9°25'W; Portugal.

Dimensions. Table 1 details the morphometric parameters.

Occurrence. Upper Callovian of Pedrógão (P10), and Lower(?)–Middle Oxfordian of Pedrógão (P17, P23, P25, P27, P35, P51, P59, P62, P64, P67) and Memória (MEM-C).

Remarks. These gyrogonites were previously described as *Porochara jargaraensis* Shaikin & Saidakovsky, 1976 by Grambast-Fessard & Ramalho (1985). However, compared with Shaikin's (1976) original description and drawings, this new form clearly shows a basal neck that is not present in *P. jargaraensis*. The size and number of spiral cells of both species are similar, but *P. pedunculata* n. sp gyrogonites show stronger variation, different ISI values (more elliptical), the ANI indicates a larger apical half and the apical pore is smaller.

P. kimmeridgensis, *P. westerbeckensis* (Mädler, 1952) Mädler, 1955 or *P. raskyae* are clearly different in size, number of spiral cells and ratio indexes and none of these forms show the pedunculate character of *P. pedunculata* n. sp.

Explanation of Plate 1.

figs 1–5. *Porochara pedunculata* n. sp: **1**, holotype, lateral view (×48), from Pedrógão section (level P25); **2**, paratype, lateral view (×52); **3**, paratype, lateral view (×50) (P25); **4**, basal cells (×48) (P25); **5**, pentagonal basal pore (×51) (P25). **figs 6–8.** *Porochara kimmeridgensis* (Mädler, 1952) Mädler, 1955: **6**, **7**, lateral view (×49), Pedrógão section (level P91); **8**, divided basal cells Pedrógão section (level P97). **fig. 9.** *Porochara sulcata* Grambast-Fessard, 1985, lateral view (×41), Pedrógão section (level P15). **figs 10, 11.** *Porochara raskyae* (Mädler, 1952) Mädler, 1955: **10**, lateral view (×48), Vale de Ventos section (level VV-12); **11**, internal mould of divided basal cells. **fig. 12.** *Porochara minima* (Mädler, 1952) Shaikin, 1976, lateral view (×48), from Vale de Ventos section (VV-12). **figs 13, 14.** *Porochara fusca* (Mädler, 1952) Mädler, 1955, lateral view (×53), Pedrógão section (level P97). **figs 15, 16.** *Aclistochara longiformis* Wang & Yang, 1983, lateral view (×48), Pedrógão section (level P64). **figs 17–20.** *Auerbachichara* cf. *saidakovskyi* Kisielevsky, 1967: **17**, lateral view (×51), from Vale de Ventos section, level VV-30A; **18–20**, details of apical 'spines' forming a crown, from Vale de Ventos section (level VV-30A). The Scanning Electron Microscope photographs were taken at the Centro de Biologia Ambiental (Faculdade de Ciências da Universidade de Lisboa) by Drs Mónica Martins and Raquel Costa and in the Laboratoire de Paléontologie, Université Montpellier II, France.

N=73	LPA (μm)	LED (μm)	NC	AND (μm)	ISI	ANI
Mean	525	421	10	277	126	53
Median	529	422	10	284	126	52
Minimum	324	265	8	157	108	48
Maximum	627	520	12	353	149	60

For abbreviations see Table 1.

Table 2. Statistics for morphometric parameters of *Porochara fusca.*

n=650	LPA (μm)	LED (μm)	NC	AND (μm)	ISI	ANI
Mean	654	557	9	333	118	51
Median	647	569	9	333	117	51
Minimum	431	353	6	216	90	39
Maximum	843	667	14	451	186	68

For abbreviations see Table 1.

Table 3. Statistics for morphometric parameters of *Porochara kimmeridgensis.*

Porochara fusca Mädler
(Pl. 1, figs 13, 14)

1952 *Aclistochara fusca* Mädler: 19, pl. A, figs 22–25.
1955 *Porochara fusca* Mädler; Mädler: 271.
1976 *Porochara fusca* Mädler; Shaikin: 79.
1982 *Porochara fusca* Mädler; Mädler; Liu: 101.
1985 *Porochara fusca* Mädler; Mädler; Grambast-Fessard & Ramalho: 62, pl. 2, figs 8–9.
1987 *Porochara fusca* Mädler; Mädler; Schudack: 116, figs 1–8.
1989b *Porochara fusca* Mädler; Mädler; Mojon: 512, fig. A–C.
1993 *Porochara fusca* Mädler; Mädler; Schudack: 50, figs 2, 1–4.
1996b *Porochara fusca* Mädler; Mädler; Schudack: 30.
1998 *Porochara fusca* Mädler; Mädler; Schudack *et al.*: 406, pl. 3, fig. 1.

Diagnosis. Small *Porochara* of concave spiral cells (8–12) and elliptical asymmetrical shape (larger at basal half) and with an apical pore of about 80–100 μm diameter.

Locality. Pedrógão (P27, P59, P100).

Dimensions. Table 2 details the morphometric parameters.

Occurrence. *P. fusca* is a widely occurring species. In the Pedrógão section (P27, P59, P100), it occurs from the uppermost Callovian to the Middle Oxfordian. It has been reported from the Lower Kimmeridgian of Tonel, in Algarve, south Portugal (Grambast-Fessard & Ramalho, 1985) and, outside Portugal, from the Bathonian of southern France (Schudack, 1990), the Kimmeridgian of northwestern Germany and of northwestern Spain (Mädler, 1952, 1955; Schudack, 1987), the Kimmeridgian of the North American Morrisson Formation (Schudack *et al.*, 1998), the Upper Jurassic of Sichuan, China (Liu, 1982), the Berriasian of northern Germany (Schudack, 1990) and the French and Swiss Jura (Mojon, 1989a), and the Upper Jurassic from the Pre-Dobrogean depression of Ukraine and Moldavia (Shaikin, 1976).

Porochara kimmeridgensis Mädler
(Pl. 1, figs 6–8)

1952 *Aclistochara kimmeridgensis* Mädler: 26, pl. B, figs 13–19.
1955 *Porochara kimmeridgensis* Mädler; Mädler: 271.
1976 *Porochara kimmeridgensis* Mädler; Mädler; Brenner: 121, pl. 1, fig. 13.
1985 *Porochara kimmeridgensis* Mädler; Mädler; Grambast-Fessard & Ramalho: 64, pl. 2, figs 4–7.
1990 *Porochara kimmeridgensis* Mädler; Mädler; Schudack: 216, pl. 1, figs 5–7.
1996b *Porochara kimmeridgensis* Mädler; Mädler; Schudack: 31, fig. 2.
1998 *Porochara kimmeridgensis* Mädler; Mädler; Schudack *et al.*: 406, pl. 3, fig. 1.

Diagnosis. Medium-sized charophyte gyrogonites usually with 9 to 10 concave to convex spiral cells of elliptical to spherical shape and symmetrical halves.

Locality. Pedrógão (P91, P97, P100, P113, P116, P123 ?) and Vale de Ventos (VV29A, VV30A).

Dimensions. Table 3 details the morphometric parameters.

Occurrence. Middle Oxfordian of Pedrógão (P91, P97, P100, P113, P116, P123 ?) and of Vale de Ventos (VV29A, VV30A), Kimmeridgian of the Pedrógão section (Grambast-Fessard & Ramalho, 1985), Oxfordian of the French and Swiss Jura (Mojon, 1989a), Kimmeridgian and Tithonian of northern Germany (Schudack, 1996a,b), Upper Jurassic of the Ukraine (Saidakovsky & Shaikin, 1976) and Kimmeridgian of the North American Morrisson Formation (Schudack *et al.*, 1998).

Remarks. These gyrogonites show a large variation in size and shape, and this has led some authors (for example Mojon, 1989b) to include *P. kimmeridgensis* and *P. westerbeckensis* within a single form. However, the forms found in the studied sections have more affinities with *P. kimmeridgensis* as regards the general shape (rounder) and average size.

Porochara minima (Mädler) Shaikin
(Pl. 1, fig. 12)

1952 *Aclistochara minima* Mädler: 21, pl. A, figs 30–35.
1976 *Porochara minima* Mädler; Shaikin: 80.
1990 *Aclistochara minima* Mädler; Lu & Luo: 70, pl. 8, fig. 2.
1990 *Porochara minima* Mädler; Shaikin; Schudack: 217, pl. 1, figs 10–11.
1993 *Porochara minima* Mädler; Shaikin; Schudack: 50, pl. 2, figs 5–6.
1996b *Porochara minima* Mädler; Shaikin; Schudack: 30, fig. 3.

n=116	LPA (µm)	LED (µm)	NC	AND (µm)	ISI	ANI
Mean	292	228	8	141	129	48
Median	294	225	8	137	127	48
Minimum	216	147	5	69	96	38
Maximum	529	412	12	255	167	70

For abbreviations see Table 1.

Table 4. Statistics for morphometric parameters of *Porochara minima.*

Diagnosis. Small gyrogonite with 8–10 spiral cells (more common) of elliptical symmetrical shape, sometimes larger at apical half, with the major axis around 300 µm and the minor axis around 230 µm.

Locality. Pedrógão (P25, P27, P59) and Vale de Ventos (VV12, VV12bis)

Dimensions. Table 4 details the morphometric parameters.

Occurrence. Lower and Middle Oxfordian of Pedrógão (P25, P27, P59) and Vale de Ventos (VV12, VV12bis), Oxfordian and Kimmeridgian of the south of France and the Swiss Jura (Oertli & Ziegler, 1958; Mojon, 1989a), Kimmeridgian and Tithonian of northwestern Germany as well as the Pre-Dobrogean Depression (Ukraine, Moldavia, Crimea; Shaikin, 1976) and of the Tarim Basin (Xinjiang, China; Lu & Luo, 1990).

Remarks. Some of the samples are larger, but these must correspond to size variation within the species population.

Porochara raskyae Mädler
(Pl. 1, figs 10, 11)

1952 *Aclistochara raskyae* Mädler: 29, pl. B, figs 26–29.
1955 *Porochara raskyae* Mädler nov. comb.; Mädler: 271.
1976 *Porochara raskyae* Mädler; Mädler; Shaikin: 78.
1987 *Porochara raskyae* Mädler; Mädler; Schudack: 124, pl. 2, figs 13–16.
1985 *Porochara raskyae* Mädler; Mädler; Grambast-Fessard & Ramalho: pl. 2, fig. 3.
1996a *Porochara raskyae* Mädler; Mädler; Schudack: 158, pl. 1, fig. 8.

Diagnosis. Medium-sized gyrogonites with concave spiral cells (8–15 in some samples, but 11 is more common) and with an elliptical asymmetrical shape (larger at basal half).

Locality. Pedrógão (P25, P59, P27?), Vale de Ventos (VV12, VV12bis, VV16bis, VV24A) and Valverde (VA-18A)

Dimensions. Table 5 details the morphometric parameters.

Occurrence. Kimmeridgian of Pedrógão (P25, P59, P27?) and the Vale de Ventos (VV12, VV12bis, VV16bis, VV24A) and Valverde (VA-18A). Also known from the Kimmeridgian and Berriasian of northwestern Germany (Mädler 1952, 1955; Schudack, 1996a,b), Kimmeridgian of the Ukraine (Saidakovsky & Shaikin, 1976) and of north-central Spain (Schudack, 1987) and the Sequanian of the Swiss Jura (Oertli & Ziegler, 1958).

n=123	LPA (µm)	LED (µm)	NC	AND (µm)	ISI	ANI
Mean	532	402	11	277	133	52
Median	529	402	11	275	133	52
Minimum	392	314	8	196	95	43
Maximum	647	529	15	343	171	59

For abbreviations see Table 1.

Table 5. Statistics for morphometric parameters of *Porochara raskyae.*

n=41	LPA (µm)	LED (µm)	NC	AND (µm)	ISI	ANI	APD (µm)	ECD (µm)
Mean	1001	996	8	511	101	51	152	137
Median	1000	1000	8	510	100	51	157	132
Minimum	882	892	7	431	83	45	118	118
Maximum	1118	1078	9	627	115	56	196	176

For abbreviations see Table 1.

Table 6. Statistics for morphometric parameters of *Porochara sulcata.*

Porochara sulcata Grambast-Fessard
(Pl. 1, fig. 9)

1985 *Porochara sulcata* Grambast-Fessard *in* Grambast-Fessard & Ramalho: 61, pl. 1, figs 6–9.
1993 *Porochara sulcata* Grambast-Fessard; Schudack: 55, pl. 2, figs 15–18.

Diagnosis. Large-sized gyrogonites with 7 to 9 deep concave spiral cells, spherical to elliptical and mostly with symmetrical form. Apical pore is about 155 µm in diameter and ECD from 118 to 176 µm.

Locality. Pedrógão (P8?, P10, P15).

Dimensions. Table 6 details the morphometric parameters.

Occurrence. Upper Callovian (P8?, P10) to Lower(?)–Middle Oxfordian of Pedrógão (P15), which is the type-locality of the species; referred by Grambast-Fessard & Ramalho (1985) in the Upper Oxfordian. Recent studies (Azerêdo *et al.*, 2000; Pereira, 2002), also record the presence of this form in the upper Callovian of the Pedrógão section.

Family **Porocharaceae**
Subfamily **Porocharoideae**
Genus *Auerbachichara* Kisielevsky & Saidakovsky *emend.* Bilan, 1988

Auerbachichara cf. *saidakovskyi* Kisielevsky
(Pl. 1, figs 17–20)

1967 *Auerbachichara saidakovskyi* Kisielevsky: 38, pl. 1, figs 1–2.

n=26	LPA (µm)	LED (µm)	NC	AND (µm)	ISI	ANI	APD (µm)	ECD (µm)
Mean	597	473	10	312	126	52	67	67
Median	598	480	10	314	124	52	69	69
Minimum	490	353	8	245	117	50	39	59
Maximum	745	510	12	412	146	56	88	78

For abbreviations see Table 1.

Table 7. Statistics for morphometric parameters of *Auerbachichara* cf. *saidakovskyi.*

n=50	LPA (µm)	LED (µm)	NC	AND (µm)	ISI	ANI
Mean	384	254	10	189	151	49
Median	392	255	10	196	150	50
Minimum	275	216	7	127	117	39
Maximum	441	294	12	255	174	62

For abbreviations see Table 1.

Table 8. Statistics for morphometric parameters of *Aclistochara* cf. *longiformis.*

1968 *Auerbachichara saidakovskyi* Kisielevsky; Saidakovsky: pl. 15, figs 18–19.

Diagnosis. Medium-sized gyrogonites with apical spines forming a crown. Major axis ranges from 490 to 745 µm, minor axis from 353 to 510 µm, apical pore about 70 µm in diameter and equatorial cell diameter from 59 to 78 µm. Cells are mostly concave in a number, about 8 to 12, but 10 are usually observed. Gyrogonites are elliptical and are larger at the basal half. Basal pore is rarely seen.

Locality. Vale de Ventos (VV28?, VV30)

Dimensions. Table 7 details the morphometric parameters.

Occurrence. Middle Oxfordian of Vale de Ventos (VV28?, VV30) and the Triassic of Ukraine (Kisielevsky, 1967; Saidakovsky, 1968). The Oxfordian age of the Portuguese locality extends the stratigraphical range of the genus *Auerbachichara* to the Upper Jurassic, as it was only previously known from the Triassic.

Remarks. These charophytes have larger dimensions than those described by Kisielevsky (1967), but are very similar to that author's description and drawings, mainly in respect of the apical spines. The larger size of the studied species of *A. saidakovskyi*, might represent an evolutionary character, which may be interpreted as related to migration and growth during the time period corresponding to the gap between the Ukrainian forms and those found in the Lusitanian Basin.

Family **Characeae** Peck, 1937
Subfamily **Charoideae**
Genus *Aclistochara* (Von Leonardi) Robinson 1906 *emend.* Peck, 1957

Aclistochara cf. *longiformis* Wang *ex* Yang
(Pl. 1, figs 15, 16)

1983 *Aclistochara longiformis* Wang *ex* Yang sp. nov., *in* Hao *et al.*: 169, pl. 41, figs 14–15.

1985 *Aclistochara longiformis* Wang *ex* Yang: Yang, pl. 1, fig. 21.

Diagnosis. Small gyrogonites of marked elliptical form, symmetrical to slightly larger at apical half, with 7–12, often 10, concave spiral cells. No basal plate could be observed.

Locality. Pedrógão (P35, P64)

Dimensions. Table 8 details the morphometric parameters.

Occurrence. Lower?–Middle Oxfodian of Pedrógão (P35, P64), Middle Jurassic of the Xining, Minhe and Tarim Basins of China (Hao *et al.*, 1983; Yang, 1985).

ASSOCIATION WITH OTHER MICROFOSSILS AND ENVIRONMENTAL INTERPRETATION

The charophytes always occur associated with other microfossils, as mentioned above. Among these, the most commonly represented in these sections are the ostracods, which often form very rich assemblages. Foraminifera, dasycladaceans, palynomorphs and some osteological remains are also present. These microfossil assemblages, in particular the ostracods, allow the definition of associations with palaeoecological significance, mainly based on the Pedrógão and Vale de Ventos sections (Cabral *et al.*, 1998, 1999a,b; Azerêdo *et al.*, 2000, 2002a; Azerêdo & Cabral, in press).

At Pedrógão, in the lowermost levels of Callovian age, marine faunas are found but, towards the Callovian–Oxfordian boundary, some non-marine ostracods occur. The marine ostracods include *Cytherella* cf. *fullonica* Jones & Sherborn, 1888, *sensu* Mette, 1995; *Cytherella* cf. *index* Oertli, 1959, *sensu* Mette, 1995; *Cytherelloidea* cf. *C.* aff. *jugosa* (Jones, 1884) *in* Mette, 1995; *Patellacythere* n. sp. 1, *Bythoceratina* (*Praebythoceratina*) n. sp. 1, *Procytheridea* cf. *gublerae* Bizon, 1958, *Polycope* sp. 1, *Neurocythere* (*Neurocythere*) cf. *composita* Wienholz, 1967, *Praeschuleridea* aff. *subtrigona magna* Bate, 1964, *Virgulacytheridea* aff. *sherifensis* Oertli & Depêche, 1987 and *Rutlandella* n. sp. 1. (Cabral *et al.*, 1998, 1999a). Hyaline-walled foraminifera (Nodosariidae, mainly *Lenticulina* morphotypes), rare agglutinated foraminifera (*Ammobaculites* sp., *Reophax* sp.) and rare miliolids (Azerêdo *et al.*, 2000, 2002a) occur also. The palynological content of these beds is dominated by *Spheripollenites* sp. and the achritarch *Mychrystidium* (Barrón *et al.*, 1999).

The basal Upper Jurassic successsion shows a clear continental influence, with *Theriosynoecum* gr. *forbesii* (Jones, 1885), *T. fluxans spiculata* (Helmdach, 1972), *T.* gr. *wyomingense* (Branson, 1935) and *T. levis* (Helmdach, 1972), *Darwinula* spp., *Klieana* spp. and a new genus with two new species: *Sinuocythere candeeirosensis* Cabral & Colin (*in* Colin *et al.*, 2000) at Vale de Ventos, Memória, Valverde and *S. pedrogaensis* Cabral & Colin (*in* Colin *et al.*, 2000) at Pedrógão. In the east of the basin, there are also abundant, mainly freshwater ostracods, of

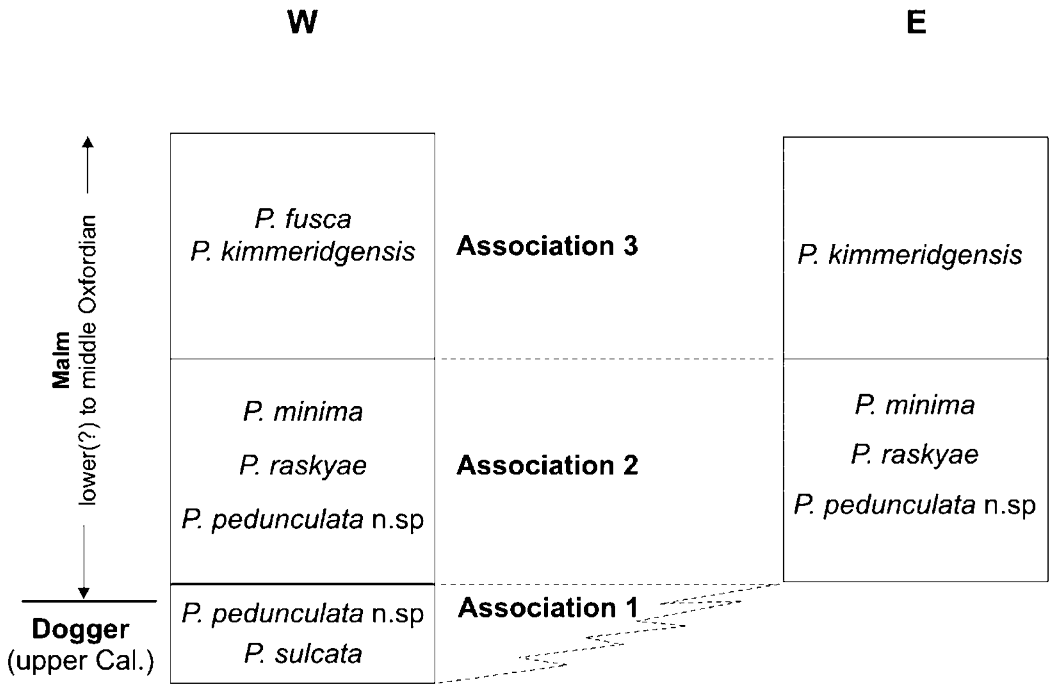

Fig. 5. Simplified correlation between western (Pedrógão) and eastern (Vale de Ventos, Valverde and Memória) sections, according to the charophyte associations.

the Candonidae (Cabral & Colin, 2002). This assemblage is typical of freshwater to oligohaline conditions, in lacustrine to restricted lagoonal environments (cf. Colin *et al*., 2000; Azerêdo *et al*., 2000, 2002a; Cabral & Colin, 2002). The palynomorph association shows an increase of continental influence with the presence of *Botryococcus* sp., abundant *Spheripollenites* sp., an increasing percentage of spores (>1%) and a higher percentage of *Corollina* cf. *torosus* (Barrón *et al*., 1999). Also present at Pedrógão, as previously described by Thulborn (1973), the remains of ornithischian dinosaurs, as well as the teeth of fishes, reptiles and (?)sharks record the osteological content (H. Capetta, pers. comm.).

The alternating brackish and restricted lagoonal/marginal-marine sediments characterizing the upper part of the successions, with more marine influence in the west (Pedrógão), is recognized in the ostracod assemblages by the disappearance of *Theriosynoecum* coupled with the dominance of *S. candeeirosensis* and *S. pedrogaensis* (the latter sometimes in monospecific populations), and the presence of *Galliaecytheridea* n. sp. 1 (marine species, only found at Pedrógão), *Klieana* spp. and others (Cabral *et al*., 1998, 1999a). In the other microfossil groups, this association is characterized by *H. lusitanica* (dasyclad) and diverse foraminifera, namely *Kurnubia palastiniensis* Henson, Verneuilinidae, *Valvulina* sp., Epistominidae, *Ammobaculites* sp., *Pseudocyclammina parvula, P.* sp., *Nautiloculina oolithica* Mohler, 1938 (Azerêdo *et al*., 1998, 2000, 2002a), as well as by rare achritarchs and a decrease of the palynomorphs (Barrón *et al.,* 1999).

The charophyte associations (Fig. 5) have allowed the definition of three major units for the Late Callovian–Middle Oxfordian interval. For this interpretation, only the most common or more important forms were considered. Thus, Association 1, which is only observed in the western sections of the studied area, is characterized by the presence of *Porochara pedunculata* n. sp and *Porochara sulcata*, ranges from the Late Callovian to Early(?)–Middle Oxfordian, and defines a brackish to freshwater palaeoenvironment. Association 2 is characterized by *Porochara pedunculata* n. sp, *P. raskyae* and *P. minima*. Association 3 corresponds to levels with a greater marine influence and shows a change in the charophyte assemblages to one that is mainly composed of *P. kimmeridgensis* and *P. fusca*.

At Pedrógão and Vale de Ventos there is a difference in the palaeontological content, with the presence of *P. kimmeridgensis* only in the upper part of the section, together with *Auerbachichara* cf. *saidakovskyi*. The underlying beds at Pedrógão have *Aclistochara* cf. *longiformis,* which is usually associated with stronger freshwater conditions (Schudack, 1993).

The presence of *P. pedunculata* n. sp both in the west (at Pedrógão) and in the east (at Memória) reinforces the inferred spatial and temporal distribution of this species in the basin, allowing the correlation between the two sections and placing them at the Lower–Middle Oxfordian interval. The palaeoenvironmental interpretation for this part of the successions suggests brackish to freshwater-dominated conditions. The correlation with the European charophyte biozones (Riveline *et al*., 1996) is not completely defined, but the absence of the forms proposed for the closest time intervals (*Porochara palmeri* Feist & Grambast-Fessard, 1984) of Bathonian age and Clavatoraceae for Late Oxfordian) reinforces the Lower?–Middle Oxfordian age suggested for the studied sections.

CONCLUSIONS

The study of four uppermost Callovian to Oxfordian sections in the Lusitanian Basin (Pedrógão, Memória, Valverde and Vale de Ventos) has contributed to the detailed knowledge of the charophytes in this region and showed the presence of a new species, *Porochara pedunculata* n. sp, and the occurrence of a previously unknown form in this area, *Auerbachichara* cf. *saidakovskyi*.

This study, coupled with studies on the facies types, ostracods, palynomorphs, foraminifera and dasycladaceans, has contributed to the definition of three zones for the Pedrógão section: *Porochara sulcata* and *Porochara* sp. (at the base), *Porochara pedunculata* n. sp, *P. raskyae*, *P. minima* and *Aclistochara longiformis* (mid-zone) and *P. kimmeridgensis* and *P. fusca* (top). This succession shows an environmental change from more marine-influenced facies at the base, to restricted lagoonal facies and then more marine influence towards the top. The forms *Porochara raskyae*, *P. minima*are also present at the base of Vale de Ventos section and, at the top, *P. fusca, P. kimmeridgensis*, *Auerbachichara* cf. *saidakovskyi* and *Porochara* sp. occur. The Memória section is only comparable to the middle part of the Pedrógão section, as indicated by the occurrence of *P. pedunculata* and *P. raskyae.*

Auerbachichara cf. *saidakovskyi* was previously known from Caspian formations of Triassic age, described by Kisielevsky (1967). However, its presence in the Lusitanian Basin raises a problem on the dispersion and morphological evolution of this species. The Portuguese form is larger than the one described by Kisielevsky (1967) and the interval of time between the two occurrences is very long. Considering these facts, we may interpret the geographical distance of these occurrences as reflecting a migration of this form from eastern regions towards the west, allowing the species to grow, but conserving the distinctive apical crown character. The apparent absence of this form in intermediate regions may be simply related to the relative lack of knowledge of the charophyte floras of the Lower and Middle Jurassic formations of Europe.

This study used traditional systematics and comparative statistical analysis to help separating the new forms and to strengthen the classification of other specimens.

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