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

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ABSTRACT – In the Lusitanian Basin (west-central Portugal), Upper Jurassic (Oxfordian) sediments were investigated in order to identify palaeofloristic assemblages of charophytes. Systematic studies were undertaken on specimens obtained from four field sections (Pedrógao, Vale de Vento, Memória and Valverde). These studies revealed the presence of new forms of Pororcharaceae (Pororchara pedunculata n. sp) and of forms previously unknown in this region (Auerbachichara cf. saidakovskyi), as well as P. raskyae, P. minina, P. fusca, P. sulcata, P. kimmeridgensis, Aclistochara longiformis and Pororchara 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 & Colin, 1999a,b, 2001; Pereira, 2002). This charophyte analysis was undertaken within the scope of a broader, basin-scale, palaeoclimatic and micro-palaeontological 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; 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 Vento, Valverde and Memória (all three at Serra dos Candeelos, 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.
(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 *Meyendorfina bathonica* Aurouze & Bizon, 1958 (Azerêdo, 1993; Azerêdo et al., 1998). 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-oceanic ramp marls and limestones with ammonites, brachiopods, bivalves (including the typical thick-shelled remains known as ‘filaments’), echinoids, marine ostracods,
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),
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

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**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.
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 Rainieri, 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-beded 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-beded 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, perialcuvine 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 & Soulé-Märsche, 1971; Schudack, 1996a).

Fig. 4. Graphical analysis of selected gyrogonite populations.
Jurassic charophytes from Portugal

<table>
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<tr>
<th>n=686</th>
<th>LPA (µm)</th>
<th>LED (µm)</th>
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<tr>
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<td>667</td>
<td>15</td>
<td>431</td>
<td>144</td>
<td>60</td>
<td>196</td>
<td>78</td>
</tr>
</tbody>
</table>

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 (Soulé-Märsche & Joseph, 1991) to avoid erroneous classification of few samples, which can be located in mergence areas.

SYSTEMATIC DESCRIPTIONS

Family Porocharaceae Grumbast, 1962
Subfamily Porocharoidae Grumbast, 1962

Porochara pedunculata sp. nov.
(Pl. 1, figs 1–5)
1985 Porochara jargaraensis Shaikin & Saidakovskv; Grumbast-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 symmetry index (ANI) indicates a larger apical half and the apical pore is smaller.

Porochara kimmeridgensis (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.

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 & Saidakovskv, 1976 by Grumbast-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.

Porochara fusca Mädler
(Pl. 1, figs 13, 14)
1955 Porochara fusca Mädler; Mädler: 271.
1976 Porochara fusca Mädler; Shaikin: 79.
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; Schudack: 50, pl. 2, figs 5–6.
1996b Porochara fusca Mädler; Schudack: 30, fig. 3.
1998 Porochara fusca 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 Lower Kimmeridgian of the North American Morrison Formation (Schudack et al., 1998), the Upper Jurassic of Sichuan, China (Liu, 1982), the Berriasian of northern Germany (Schudack, 1990) and of the French and Swiss Jura (Mojon, 1989a), the Kimmeridgian and Tithonian of northern Germany (Schudack, 1996a,b), the Upper Jurassic of the Ukraine (Saidakovsky & Shaikin, 1976) and Kimmeridgian of the North American Morrison 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 kimmeridgensis Mädler
(Pl. 1, figs 6–8)
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; 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.


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), the Upper Jurassic of the Ukraine (Saidakovsky & Shaikin, 1976) and Kimmeridgian of the North American Morrison 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)
1976 Porochara minima Mädler; Shaikin: 80.
1990 Aclistochara minima Mädler; Lu & Luo: 70, pl. 8, fig. 2.
1990 Porochara minima Mädler; Schudack: 217, pl. 1, figs 10–11.
1993 Porochara minima Mädler; Shaikin; Schudack: 30, pl. 2, figs 5–6.
1996b Porochara minima Mädler; Shaikin; Schudack: 30, fig. 3.

Table 2. Statistics for morphometric parameters of Porochara fusca.

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Table 3. Statistics for morphometric parameters of Porochara kimmeridgensis.

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<td>451</td>
<td>186</td>
<td>68</td>
</tr>
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</table>

For abbreviations see Table 1.
Jurassic charophytes from Portugal

Table 4. Statistics for morphometric parameters of Porochara minima.

<table>
<thead>
<tr>
<th></th>
<th>LPA</th>
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<th>ANI</th>
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<tbody>
<tr>
<td>Mean</td>
<td>292</td>
<td>228</td>
<td>8</td>
<td>141</td>
<td>129</td>
<td>48</td>
</tr>
<tr>
<td>Median</td>
<td>294</td>
<td>225</td>
<td>8</td>
<td>137</td>
<td>127</td>
<td>48</td>
</tr>
<tr>
<td>Minimum</td>
<td>216</td>
<td>147</td>
<td>5</td>
<td>69</td>
<td>96</td>
<td>38</td>
</tr>
<tr>
<td>Maximum</td>
<td>529</td>
<td>412</td>
<td>12</td>
<td>255</td>
<td>167</td>
<td>70</td>
</tr>
</tbody>
</table>

For abbreviations see Table 1.

Table 5. Statistics for morphometric parameters of Porochara raskyae.

<table>
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<tr>
<td>Mean</td>
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<td>402</td>
<td>11</td>
<td>277</td>
<td>133</td>
<td>52</td>
</tr>
<tr>
<td>Median</td>
<td>529</td>
<td>402</td>
<td>11</td>
<td>275</td>
<td>133</td>
<td>52</td>
</tr>
<tr>
<td>Minimum</td>
<td>392</td>
<td>314</td>
<td>8</td>
<td>196</td>
<td>95</td>
<td>43</td>
</tr>
<tr>
<td>Maximum</td>
<td>647</td>
<td>529</td>
<td>15</td>
<td>343</td>
<td>171</td>
<td>59</td>
</tr>
</tbody>
</table>

For abbreviations see Table 1.

Table 6. Statistics for morphometric parameters of Porochara sulcata.

<table>
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<tr>
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<th>ANI</th>
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<tr>
<td>Mean</td>
<td>1001</td>
<td>996</td>
<td>8</td>
<td>511</td>
<td>101</td>
<td>51</td>
<td>152</td>
<td>137</td>
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<tr>
<td>Median</td>
<td>1000</td>
<td>1000</td>
<td>8</td>
<td>510</td>
<td>100</td>
<td>51</td>
<td>157</td>
<td>132</td>
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<tr>
<td>Minimum</td>
<td>882</td>
<td>892</td>
<td>7</td>
<td>431</td>
<td>83</td>
<td>45</td>
<td>118</td>
<td>118</td>
</tr>
<tr>
<td>Maximum</td>
<td>1118</td>
<td>1078</td>
<td>9</td>
<td>627</td>
<td>115</td>
<td>56</td>
<td>196</td>
<td>176</td>
</tr>
</tbody>
</table>

For abbreviations see Table 1.

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)
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).

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

Auerbachichara cf. saidakovskyi Kisielevsky
(Pl. 1, figs 17–20)
1967 Auerbachichara saidakovskyi Kisielevsky: 38, pl. 1, figs 1–2.
1968 *Auerbachichara saidakovskyi* Kislevsky; 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 (Kislevsky, 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 Kislevsky (1967), but are very similar to that author’s description and drawings, mainly in respect of the author’s description and drawings, mainly in respect of the morphological content of these beds is dominated by *Spheripollenites* sensu Oertli, 1959, *Polycope* sensu Mette, 1995, *Bizon*, 1958, *Neurocythere* (Neurocythere) cf. composita Wienholz, 1967, *Praebythoceratina* cf. subtrigona magna Bate, 1964, *Virgulacythereidae* aff. sherifensis Oertli & Depêche, 1987 and *Rutlandella* n. sp. 1, (Cabral et al., 1998, 1999a,b; Azerêdo et al., 2000, 2002a; Azerêdo & Cabral, in press).


The basal Upper Jurassic succession 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., *Kleina* spp. and a new genus with two new species: *Sinocythere candecirrosensis* 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

<table>
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<th>NC (µm)</th>
<th>AND (µm)</th>
<th>ISI (µm)</th>
<th>ANI (µm)</th>
<th>APD (µm)</th>
<th>ECD (µm)</th>
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<tbody>
<tr>
<td>Mean</td>
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<td>473</td>
<td>10</td>
<td>312</td>
<td>126</td>
<td>52</td>
<td>67</td>
<td>67</td>
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<tr>
<td>Median</td>
<td>598</td>
<td>480</td>
<td>10</td>
<td>314</td>
<td>124</td>
<td>52</td>
<td>69</td>
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<tr>
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<td>355</td>
<td>8</td>
<td>245</td>
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<td>12</td>
<td>412</td>
<td>146</td>
<td>56</td>
<td>88</td>
<td>78</td>
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</table>

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

<table>
<thead>
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<th>n=50</th>
<th>LPA (µm)</th>
<th>LED (µm)</th>
<th>NC (µm)</th>
<th>AND (µm)</th>
<th>ISI (µm)</th>
<th>ANI (µm)</th>
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<tbody>
<tr>
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<td>254</td>
<td>10</td>
<td>189</td>
<td>151</td>
<td>49</td>
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<td>392</td>
<td>255</td>
<td>10</td>
<td>196</td>
<td>150</td>
<td>50</td>
</tr>
<tr>
<td>Minimum</td>
<td>275</td>
<td>216</td>
<td>7</td>
<td>127</td>
<td>117</td>
<td>39</td>
</tr>
<tr>
<td>Maximum</td>
<td>441</td>
<td>294</td>
<td>12</td>
<td>255</td>
<td>174</td>
<td>62</td>
</tr>
</tbody>
</table>

Table 8. Statistics for morphometric parameters of *Aclistochara* cf. *longiformis*.
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 Theriosynoeicum coupled with the dominance of S. candeirosensis and S. pedrogaensis (the latter sometimes in monospecific populations), and the presence of Galliaecytheridea n. sp. 1 (marine species, only found at Pedrógão), Kliesa 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 Karnubia palai- stimiensis Henson, Verneullinidae, Valvulina sp., Ammobaculites sp., Pseudocyclammina parvula, P. sp., Nautilo- culina oolithica Mohler, 1938 (Azerêdo et al., 1998, 2000, 2002a), as well as by rare achniarchs 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 Auerbachicha cf. saidakovskiyi. 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. minimna and Aclistochara longiformis (mid-zone) and P. kimmeridgensis and P. fusca (top). This succession shows an environmental change from marine-influenced facies at the base, to restricted lagoonal facies and then more marine influence towards the top. The forms Porochara raskyae, P. minimna 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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The authors wish to thank Prof. M. Ramalho (Instituto Geológico e Mineiro and University of Lisbon) for the permission to study his charophyte collection, Prof. M. C. Cabral (University of Lisbon) for her helpful contribution and discussion and the Fundação para a Ciência e Tecnologia for funding the research project PRAXIS XXI- PCNA/P/CTE/6/96. We thank the anonymous referees for their constructive reviews, and the Journal Editor, Prof. M. Hart (Plymouth University), for his helpful suggestions.

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