

Ammonite succession at the Bajocian/Bathonian boundary in the Cabo Mondego region (Portugal)

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The Cabo Mondego outcrops exposed along the cliffs, on the western margin of the Iberian Plate, show an expanded stratigraphic section of Lower Bathonian deposits containing abundant ammonoids. Upper Bajocian deposits correspond to similar facies, of muddy limestones alternating with marlstones, although ammonoids are scarce. A detailed succession of ammonites across the Bajocian/Bathonian boundary has been recognized at Cabo Mondego, which can form a useful bio- and chronostratigraphic standard for the Lusitanian Basin. The revision of previous collections from the classical section and new field samplings of two other separate sections allow the recognition through up to twenty metres of thickness, the highest zone of Bajocian (Parkinsoni Zone) and the lowest zone of Bathonian (Zigzag Zone). The Parkinsoni and the Zigzag zones established for NW European areas and belonging to the Northwest European Province, can be identified in the Lusitanian Basin, although the ammonite fossil assemblages are composed of Submediterranean taxa. However, a subdivision of the Parkinsoni Zone is not possible, due to the scarcity of well preserved ammonoids. The Zigzag Zone can be recognized and characterized as composed of two subunits (Parvum and Macrescens subzones) as represented in diverse European basins of the Submediterranean Province. Ammonite fossil assemblages of the Parvum Subzone may be grouped into two successive horizons, which are biochronostratigraphically equivalent to the subdivisions of the Convergens Subzone distinguished in the Digne-Barrême area (SE France). New biochronostratigraphic data on the Bigotitinae, youngest members of Leptosphinctinae and oldest members of Zigzagiceratinae are relevant in understanding the evolution and faunal turnover of the West Tethyan Perisphinctidae during earliest Bathonian. The ammonite succession at the Bajocian/Bathonian boundary in the Cabo Mondego region (Portugal) represents one of the most complete biostratigraphic records so far recognized on the Iberian Plate. □ *Ammonoids, biostratigraphy, chronostratigraphy, Iberia, Lusitanian Basin, Middle Jurassic, palaeobiogeography.*

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Ammonites of the Bajocian/Bathonian boundary at the Cabo Mondego region are scarce in Upper Bajocian, but common in Lower Bathonian deposits. They are recorded in an expanded stratigraphic section which can be studied along several kilometres of coastal outcrops (Fig. 1). Several papers have described Lower Bathonian ammonites from the classical section of Cabo Mondego, 200 m WNW of the lighthouse (Section 90 in Fig. 1): Ruget-Perrot 1961; Elmi 1967, 1971; Elmi *et al.* 1971; Mangold 1971bc, 1990; Rocha *et al.* 1981, 1987; Mangold & Rioult 1997. This classical section was modified and became difficult to access in 1990 due to the mining operations of several stone quarries. At the present time, there are two other outcrops which allow

the study in detail of the Bajocian/Bathonian boundary of this region. The first, 500 m SW of the lighthouse, on the coastline and studied by Fernández-López & Henriques (2002) (Section 02; Figs 1 & 2). The second, 700 m N of the lighthouse, Section 04, was located at an active quarry front after 2004. At the present time, Cabo Mondego is of great geo-heritage significance because of its stratigraphic relevance for global correlation and other scientific issues; these range from educational purposes to purely aesthetic factors (Henriques & Ramalho 2005).

The aim of this paper is to describe the ammonite succession at the Bajocian/Bathonian boundary in the Cabo Mondego region, taking into account data

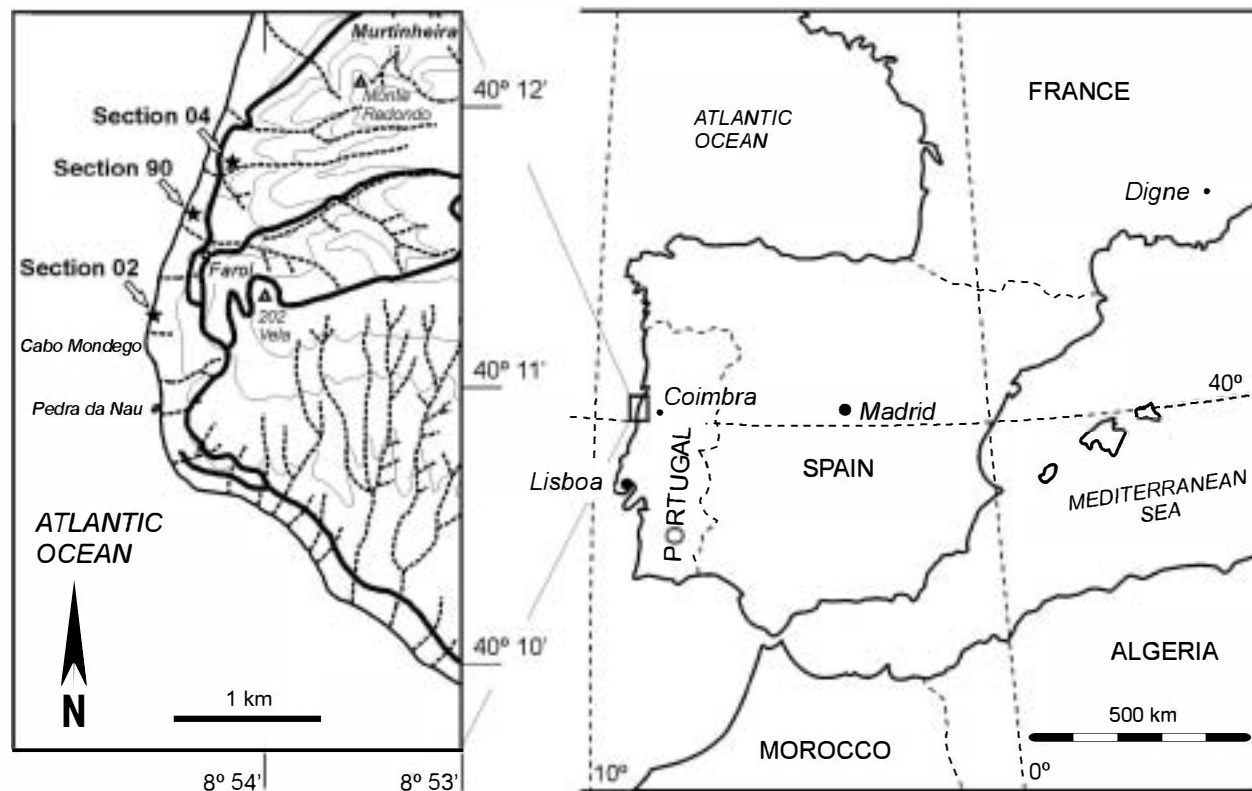


Fig. 1. Location maps of the three stratigraphic sections referring to the Bajocian/Bathonian boundary in the Cabo Mondego region (Portugal). From south to north, Section 02 ($40^{\circ}11'17''$, $8^{\circ}54'34''$), Section 90 ($40^{\circ}11'33''$, $8^{\circ}54'25''$) and Section 04 ($40^{\circ}11'52''$, $8^{\circ}54'9''$).

recorded in the three observable sections. The biochronostratigraphic data obtained in this region are interpreted and compared with those of other European basins.

Ammonite taphonomy

Upper Bajocian and Lower Bathonian deposits correspond to similar litho- and biofacies in the region of Cabo Mondego. They have been informally referred to the Brenha facies (Watkinson 1989; Azerêdo *et al.* 2002; Azerêdo & Wright 2004), and formally included in the Cabo Mondego Formation (Soares *et al.* 1993; Azerêdo *et al.* 2003). Muddy limestones alternate with marlstones. Beds are normally under 50 cm thick, and marly intervals under 70 cm. Thickening upwards sequences, of metric thickness, are common. Fining upwards sequences are scarce. Several planar based turbidites have been identified near the boundary between the Garantiana and Parkinsoni zones (such as the brown limestone bed named 106 in Fig. 3). Macrofossils include ammonoids, bivalves (*Bositra*), rhynchonellid brachiopods, crinoids and belemnites. Carbonized wood fragments of centimetric size are also present. Bioturbation structures are common (*Zoophycos* and *Chondrites*, in particular). These fossiliferous deposits were devel-

oped in an open sea, on a distal and outer environment of carbonate ramp, below wave base.

In the Cabo Mondego region, the total number of studied Lower Bathonian ammonites is around 600. Ammonoid remains are dominated by shells. Aptychi are very scarce and less than 1%. Ammonoid shells are commonly recorded throughout the studied sections, but they rarely exceed 500 mm in diameter (less than 1%). Ammonoids are commonly preserved as concretionary internal moulds of resedimented shells. The sedimentary infill is similar in petrologic composition and texture to the sedimentary matrix. Internal moulds of shells partially filled with homogeneous sediments are predominant. Sedimentary infill of the ammonoid shells is generally absent in the innermost whorls and phragmocones without sedimentary infill (i.e. hollow ammonites) are common. Pyritic internal moulds of the innermost whorls or pyrite linings of some portions of whorl or flank, millimetric in size, occur (less than 10%) in some levels. Concretionary internal moulds without septa, indicative of syndimentary dissolution of septa are absent. However, aragonitic septa and shells have been dissolved during later diagenetic processes. Moldic porosity resulting from dissolution processes of shells and septa has been partially filled by spar cement in these deposits.



Fig. 2. Cabo Mondego Section 02. Marly interval 123 indicates the base of the Bathonian. Scale bar 1 m.

Ammonite shells and internal moulds normally appear scattered in the sediment, showing no pattern of imbricate or encased regrouping. Ammonoid fossil assemblages show a high proportion of incomplete phragmocones and scarce complete shells with peristome. Ammonoid associations are dominated by reworked elements (i.e. resedimented and reelaborated elements *sensu* Fernández-López 1991, 1995). Accumulated elements, showing no evidence of reworking after laying on the seafloor, are virtually absent. Fragmented specimens of resedimented shells, displaced on the seafloor before their burial, are abundant, but generally bearing no signs of rounding, encrustation or bioerosion, due to low turbulence near the water/sediment surface. Internal moulds of resedimented shells usually display traces of continuous or discontinuous deformation by diagenetic compaction. Undeformed reelaborated internal moulds (i.e. exhumed and displaced before their final burial) are locally dominant, often showing disarticulation surfaces along septa with sharp margins or geopetal sedimentary infill reversed in position, but no evidence of compaction. The degree of removal (i.e. the ratio of reelaborated and resedimented elements to the whole of recorded elements) generally reach 100%, but the degree of taphonomic

heritage (i.e. the ratio of reelaborated elements to the whole of recorded elements) is low. There is no evidence for taphonomic condensation (i.e. mixture of fossils of different age or different chronostratigraphic units) in the ammonoid fossil assemblages. Ammonite mixed assemblages composed of specimens representing several biohorizons in a single bed or clay interval have not been identified.

Over 40 successive ammonite fossil assemblages have been recognized in the lowest Bathonian subzone. The degree of ammonite packing (estimated by the difference between the number of specimens and the number of fossiliferous levels divided by the number of fossiliferous levels) display low values, and the ammonite stratigraphical persistence (proportion of fossiliferous levels) display high values. Taphonic populations of type 3 are dominant but types 1 and 2 very scarce (Fernández-López 1991, 2000a). Taphonic populations of type 3 show uni- or polymodal and asymmetric distribution of size-frequencies, with negative skew, shells of juveniles are absent and adults are predominant. In contrast, taphonic populations of type 1, composed of monospecific shells showing unimodal and asymmetric distribution of size-frequencies, with positive skew, indicative of eudemic taxa and autochthonous biogenic production have been recognized among Leptosphinctinae of the *Planisphinctes* [m] – *Lobosphinctes* [M] group. Taphonic populations of type 2 are composed of mono- or polyspecific shells of the same genus, which show unimodal and normal distribution of size-frequencies, with a high degree of kurtosis. Populations of type 2 contain a low proportion of microconchs and scarce shells of juvenile individuals, whereas shells of adult individuals are common, and they have been identified among Hecticoceratinae of the *Nodiferites* [m] – *Zeissoceras* [M] group.

Deposits of this ammonoid taphofacies are interpreted as having been developed in an hemipelagic environment, below wave base. The presence of resedimented and reelaborated ammonoids implies that some form of current flow, bypassing or winnowing affected the burial of concretionary internal moulds. However, the abundance of incomplete sedimentary internal moulds of ammonoid shells is indicative of a high rate of accumulation of sediment during biostratinomic processes.

Ammonite bio- and chronostratigraphy

Revising of previous collections belonging to the classical section (Fig. 3) and new field samplings of two separate sections (Fig. 4), along up to 20 metres of

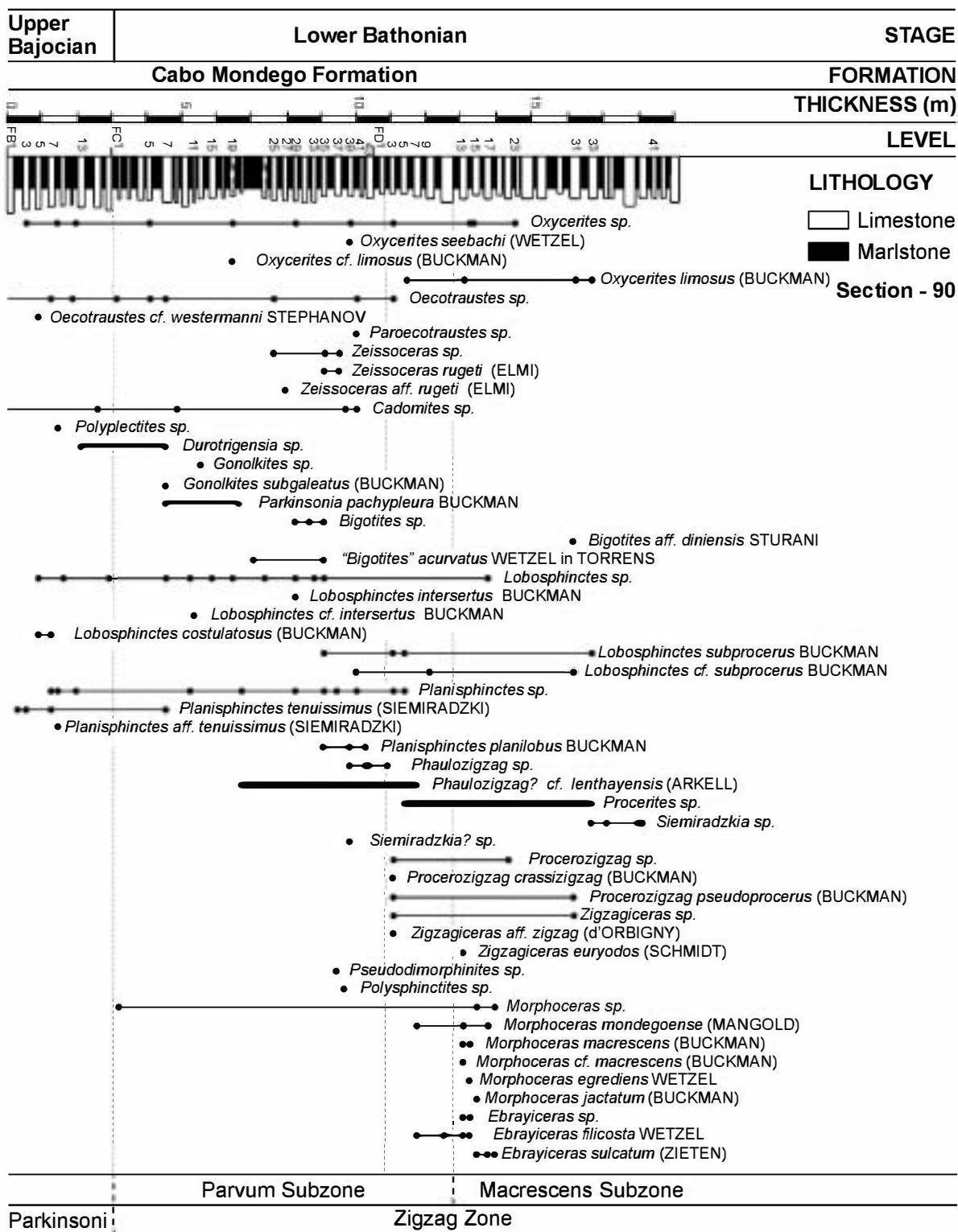


Fig. 3. Ammonite biochronostratigraphic data at the Bajocian/Bathonian boundary in Section 90 of Cabo Mondego.

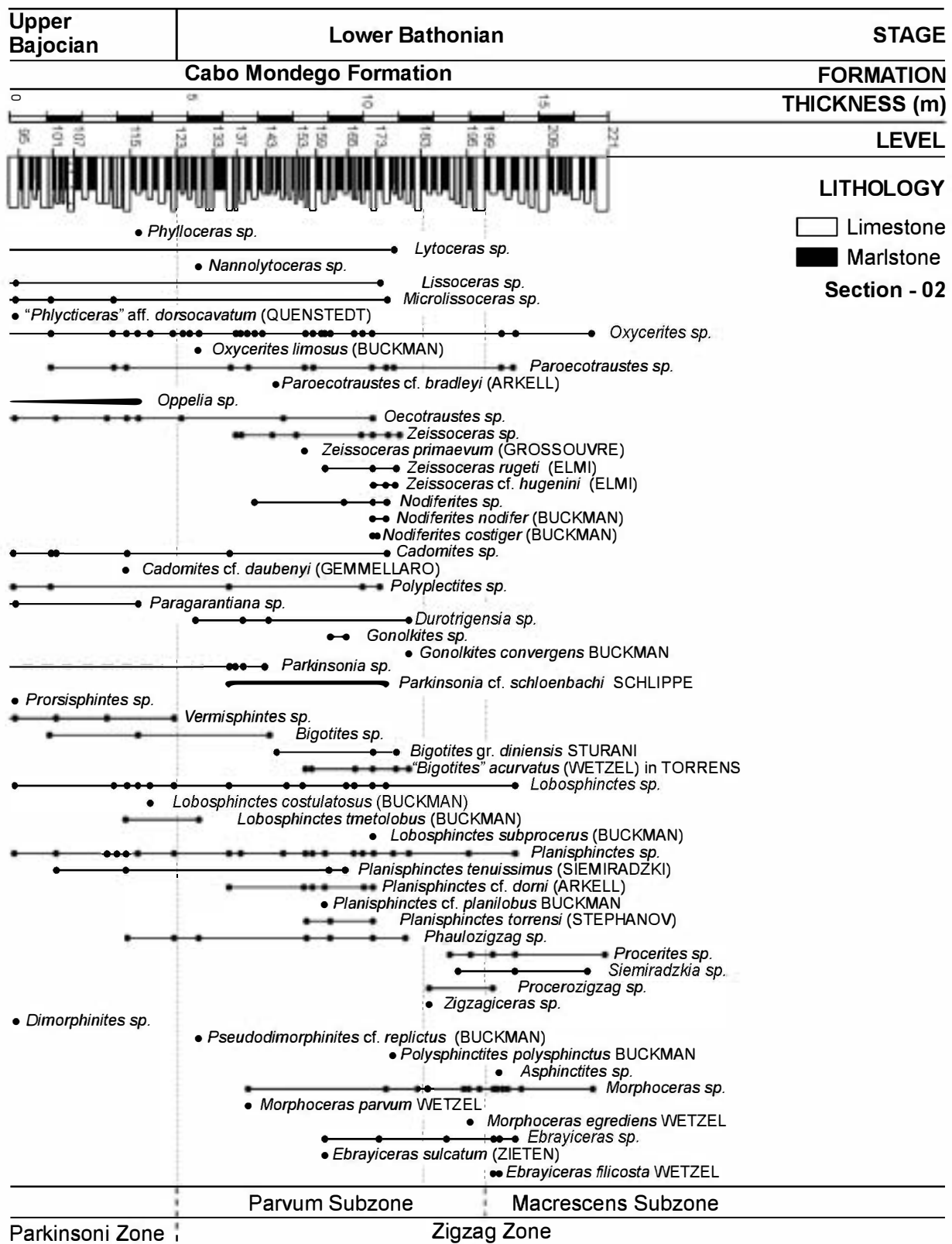


Fig. 4. Ammonite biostratigraphic data at the Bajocian/Bathonian boundary in Section 02 of Cabo Mondego.

thickness, have allowed the recognition of the highest zone of Bajocian (Parkinsoni Zone) and the lowest zone of Bathonian (Zigzag Zone), taking into account ammonite taxonomic data. The dimorphic status and abundance of specimens will be indicated by [M] and [m] macroconch and microconch forms. R, C and VC indicate scarce, common and very common respectively.

Upper Bajocian

The Parkinsoni Zone is characterized by scarce specimens of *Parkinsonia* [m] *Durotrigensia* [M] and *Paragarantiana* [M], according to Gauthier 2003, which occur associated with the youngest representatives of *Vermisphinctes* [m] *Prorsisphinctes* [M] and *Oppelia* [M]. In Section 02, two specimens of *Dimorphinites* [M] have been identified (level 02CM94 in Fig. 4). However, the scarcity of ammonites in the Parkinsoni Zone prevents recognition of subzones. In the three studied sections, the Parkinsoni Zone attains a minimum thickness of 5.0 m (interval 02CM94–02CM122 in Fig. 4) and is overlaid by the Zigzag Zone, which attains a thickness of up to 16.0 m (interval 90FC1–90FD45 in Fig. 3; interval 02CM123–02CM221 in Fig. 4). The following taxa have been identified:

Phylloceras sp. (R)
Lissoceras sp. [M] (C)
Microliissoceras sp. [m] (R)
‘*Phlycticeras*’ aff. *dorsocavatum* (Quenstedt) [M] (R)
Oppelia sp. [M] (R)
Oecotraustes sp. [m] (R)
Oecotraustes cf. *westermanni* Stephanov [m] (R)
Oxycerites sp. [M] (R)
Cadomites sp. [M] (C)
Cadomites cf. *daubenyi* (Gemmellaro) [M] (R)
Polyplectites sp. [m] (C)
Paragarantiana sp. [M] (R)
Durotrigensia sp. [M] (R)
Parkinsonia sp. [m] (R)
Prorsisphinctes sp. [M] (R)
Vermisphinctes sp. [m] (R)
Bigotites sp. [M + m] (R)
Lobosphinctes sp. [M] (R)
Lobosphinctes costulatus (Buckman) [M] (R)
Lobosphinctes tmetolobus (Buckman) [M] (R)
Planisphinctes sp. [m] (C)
Planisphinctes tenuissimus (Siemiradzki) [m] (R)
Planisphinctes aff. *tenuissimus* (Siemiradzki) [m] (R)
Phaulozigzag sp. [m] (R)
Dimorphinites sp. [M] (R)

Lower Bathonian

The Lower Bathonian boundary may be established by the lowest occurrence of the dimorphic group *Morphoceras* [M] *Ebrayiceras* [m]. Ammonites allow recognition of the Parvum and Macrescens subzones of the Zigzag Zone, defined in the Submediterranean Province (Cariou *et al.* 1985; Mangold & Rioult 1997). The lowermost subzone of the Bathonian yields common perisphinctids, oppelids and hectococeratids: *Planisphinctes* [m] *Lobosphinctes* [M], *Oxycerites* [M] *Paroecotraustes* [m] and *Nodiferites* [m] *Zeissoceras* [M]. The Parvum Subzone attains a thickness of 10 m (interval 90FC1–90FD11 in Fig. 3; interval 02CM123–02CM188 in Fig. 4). The following taxa have been identified:

Lytoceras sp. (R)
Nannolytoceras sp. (R)
Lissoceras sp. [M] (R)
Microliissoceras sp. [m] (R)
Oecotraustes sp. [m] (R)
Oxycerites sp. [M] (C)
Oxycerites limosus (Buckman) [M] (R)
Oxycerites cf. *limosus* (Buckman) [M] (R)
Oxycerites seebachi (Wetzel) [M] (R)
Paroecotraustes sp. (C)
Paroecotraustes cf. *bradleyi* (Arkell) [m] (R)
Zeissoceras sp. [M] (C)
Zeissoceras primaevum (Grossouvre) [M] (R)
Zeissoceras rugeti (Elmi) [M] (C)
Zeissoceras aff. *rugeti* (Elmi) [M] (R)
Zeissoceras cf. *hugenini* (Elmi) [M] (R)
Nodiferites sp. [m] (C)
Nodiferites nodifer (Buckman) [m] (R)
Nodiferites costiger (Buckman) [m] (R)
Cadomites sp. [M] (R)
Polyplectites sp. [m] (R)
Durotrigensia sp. [M] (R)
Gonolkites sp. [M] (R)
Gonolkites subgaleatus (Buckman) [M] (R)
Gonolkites convergens Buckman [M] (R)
Parkinsonia sp. [m] (R)
Parkinsonia pachypleura Buckman [m] (R)
Parkinsonia cf. *schloenbachi* Schlippe [m] (R)
Bigotites sp. [M] (R)
Bigotites gr. *diniensis* Sturani [M] (R)
‘*Bigotites*’ *acurvatus* (Wetzel) in Torrens [m] (R)
Lobosphinctes sp. [M] (R)
Lobosphinctes tmetolobus (Buckman) [M] (R)
Lobosphinctes intersertus Buckman [M] (R)
Lobosphinctes cf. *intersertus* Buckman [M] (R)
Lobosphinctes subprocerus (Buckman) [M] (R)
Lobosphinctes cf. *subprocerus* (Buckman) [M] (R)

Planisphinctes sp. [m] (C)
Planisphinctes tenuissimus (Siemiradzki) [m] (C)
Planisphinctes cf. *dorni* (Arkell) [m] (R)
Planisphinctes planilobus Buckman [m] (R)
Planisphinctes cf. *planilobus* Buckman [m] (R)
Planisphinctes torrensi (Stephanov) [m] (R)
Phaulozigzag sp. [m] (R)
Phaulozigzag? cf. *lenthayensis* (Arkell) [m] (R)
Siemiradzki? sp. [m] (R)
Pseudodimorphinites sp. [M] (R)
Pseudodimorphinites cf. *replictus* (Buckman) (R)
Polysphinctites sp. [m] (R)
Polysphinctites polysphinctus Buckman [m] (R)
Morphoceras sp. [M] (R)
Morphoceras parvum (Wetzel) [M] (R)
Ebrayiceras sp. [m] (R)
Ebrayiceras sulcatum (Zieten) [m] (R)

The following taxa have been identified in the upper part of the Parvum Subzone, through 1.5–2 m of thickening upwards beds, in the stratigraphic interval beginning with the lowest occurrence of *Zigzagiceras* [m] – *Procerozigzag* [M] and underlying the lowest occurrence of *Morphoceras macrescens* (interval 90FD3–90FD11 in Fig. 3; interval 02CM183–02CM198 in Fig. 4):

Oxycerites sp. [M] (R)
Oxycerites limosus (Buckman) [M] (R)
Oecotraustes sp. [m] (R)
Lobosphinctes subprocerus (Buckman) [M] (R)
Lobosphinctes cf. *subprocerus* (Buckman) [M] (R)
Planisphinctes sp. [m] (R)
Phaulozigzag sp. [m] (R)
Phaulozigzag? cf. *lenthayensis* (Arkell) [m] (R)
Procerites sp. [M] (R)
Siemiradzki sp. [m] (R)
Procerozigzag sp. [M] (R)
Procerozigzag crassizigzag (Buckman) [M] (R)
Procerozigzag pseudoprocerus (Buckman) [M] (R)
Zigzagiceras sp. [M] (R)
Zigzagiceras aff. *zigzag* (d’Orbigny) [m] (R)
Morphoceras sp. [M] (C)
Morphoceras egrediens Wetzel [M] (R)
Morphoceras mondegoense (Mangold) [M] (R)
Ebrayiceras sp. [m] (C)
Ebrayiceras filicosta Wetzel [m] (R)

The second subzone of the Zigzag Zone (interval from levels 90FD13 in Fig. 3 and from 02CM199 in Fig. 4), characterized by the lowest occurrence of *Morphoceras macrescens* (Buckman), belongs to the Submediterranean Macrescens Subzone:

Oxycerites sp. [M] (C)
Oxycerites limosus (Buckman) [M] (R)
Paroecotraustes sp. [m] (R)
Bigotites aff. *diniensis* Sturani [M] (R)
Lobosphinctes sp. [M] (R)
Lobosphinctes subprocerus (Buckman) [M] (R)
Lobosphinctes cf. *subprocerus* (Buckman) [M] (R)
Planisphinctes sp. [m] (R)
Procerites sp. [m] (C)
Siemiradzki sp. [m] (C)
Procerozigzag sp. [M] (R)
Procerozigzag pseudoprocerus (Buckman) [M] (R)
Zigzagiceras sp. [m] (R)
Zigzagiceras euryodos (Schmidt) [m] (R)
Asphinctites sp. [M] (R)
Morphoceras sp. [M] (C)
Morphoceras macrescens (Buckman) [M] (C)
Morphoceras cf. *macrescens* (Buckman) [M] (R)
Morphoceras mondegoense (Mangold) [M] (R)
Morphoceras egrediens Wetzel [M] (R)
Morphoceras jactatum (Buckman) [M] (R)
Ebrayiceras sp. [m] (C)
Ebrayiceras filicosta Wetzel [m] (C)
Ebrayiceras sulcatum (Zieten) [m] (R)

Palaeobiogeographical and evolutionary remarks

Diverse zonal schemes have been established in Europe, for the Upper Bajocian and Lower Bathonian, due to faunal differences within the West Tethyan Subrealm (Fig. 5). A northern European faunal region or North-west European Province, from Britain to southern Germany, has been distinguished by several authors (Westermann 1958; Hahn 1969, 1970; Callomon *et al.*

NW European Province		Submediterranean Province		Mediterranean Province		
NW Europe: England, Lorraine, Alsace, Germany.		Centre-west France, Nièvre, Jura, Mâconnais, Portugal, Iberian Basin		Betic Basin		
Lower Bathonian	Zigzag	Tenuiplicatus	Aurigerus	Tenuiplicatus	Zigzag	Postpollubrum
		Yeovilensis		Recinctus		Yeovilensis
		Macrescens		Macrescens		Macrescens
		Convergens		Parvum		Dimorphitiformis
Upper Bajocian	Parkinsoni	Bomfordi	Parkinsoni	Bomfordi	Parkinsoni	Dimorphus
		Truellei		Densicosta		Daubenyi
				Acris		

Fig. 5. Ammonite zones and subzones of the Uppermost Bajocian and Lower Bathonian in the so-called Northwest European (Westermann & Callomon 1988; Callomon & Cope 1995), Sub-Mediterranean (Mangold 1990; Rioult *et al.* 1997; Mangold & Rioult 1997) and Mediterranean (Sandoval 1983, 1990) provinces of Europe.

1987; Westermann & Callomon 1988; Callomon & Cope 1995; Page 1996a, b; Dietze & Chandler 1997; Dietze & Schweigert 2000; Dietze *et al.* 2002, 2004) giving particular relevance to the abundance of Parkinsonids. In contrast, Phylloceratina and Lytoceratina characterizing the Mediterranean or West Tethyan Province (Cariou *et al.* 1985) are very common in the Subbetic Basin (Mangold 1981; Sandoval 1983, 1990; Sandoval *et al.* 2001), Sicily (Wendt 1963, 1971; Galácz 1999; Pavia *et al.* 2002; Martire & Pavia 2004), Subalpine Basin (Sturani 1967; Pavia 1973; Torrens 1987; Innocenti *et al.* 1988; Olivero *et al.* 1997), Alps (Krystyn 1972), Western Carpathians (Schlögl & Rakús 2004; Schlögl *et al.* 2005), Hungary (Galácz 1980, 1994; Geczy & Galácz 1998), Serbia (Mihajlovic 1969) and Bulgaria (Stephanov 1966, 1972). Parkinsonids characterizing the North-west European Province, as well as Phylloceratids and Lytoceratids characterizing the Mediterranean Province, are very scarce in the Sub-Mediterranean areas, such as Portugal, Iberian Basin, centre-west France, Nièvre, Mâconnais, Jura, Central Poland and Caucasus (Tserethely 1968; Elmi & Almérás 1984; Mangold 1990; Beznosov & Mitta 1993, 1998, 2000; Rioult *et al.* 1997; Mangold & Rioult 1997; Fernández-López 2000b; Matyja & Wierzbowski 2000; Mitta & Seltzer 2002; Moyne *et al.* 2004; Zaton & Marynowski 2004).

In the Lusitanian Basin, Upper Bajocian and Lower Bathonian Phylloceratina and Lytoceratina represent less than 1% of the whole of ammonoids and parkinsonids are very scarce (less than 5.0%). The uppermost Bajocian zone, the Parkinsoni Zone, is poorly characterized due to the scarcity of well preserved ammonoids. Specimens of *Dimorphinites* [M] occur in the Cabo Mondego region, but possibilities for correlation of the youngest Bajocian ammonoids with those from Mediterranean and NW European provinces remain quite limited.

Specimens of the family Perisphinctidae are very common (41.5% in Section 90, 37.7% in Section 02, Fig. 6) and correspond to three subfamilies: Leptosphinctinae (Buckman 1929), Bigotitinae (Westermann, 1956) and Zigzagiceratinae (Buckman, 1920) (Fig. 9). *Bajocisphinctes* and *Bigotites* represent two successive taxonomic groups of West Tethyan Perisphinctidae. *Bajocisphinctes* [M] – *Microbajocisphinctes* [m], the earliest forms of Bigotitinae derived by proterogenesis from *Leptosphinctes* [M] – *Cleistosphinctes* [m], occur in the Garantiana Zone (Fernández-López 1985, 1987; Rocha *et al.* 1987). *Bigotites* [M + m], showing relatively simple sutures and shells larger in size, represents a hypermorphic and palingenetic change from *Bajocisphinctes* during the Garantiana Biochron. Perisphinctidae of the dimorphic couple *Bigotites* gr. *diniensis* Sturani [M] – ‘*Bigotites*’ *acurvatus* (Wetzel) in Torrens [m], with suspensive lobe not strongly retracted, have been recently discovered, although they are scarce (Figs 7–8). These

Parkinsoni Zone

Phylloceratinae (1.0%)
Lissoceratinae (16.3%)

Oppeliinae (22.1%)
Strigoceratinae (1.0%)
Cadomitinae (16.3%)
Garantianinae (2.9%)
Parkinsoniinae (1.0%)

Leptosphinctinae (34.6%)

Bigotitinae (2.9%)
Morphoceratinae (1.9%)

Zigzag Zone

Lytoceratinae (0.7%)
Lissoceratinae (0.3%)

Oppeliinae (29.5%)

Hecticoceratinae (16.2%)
Cadomitinae (1.7%)
Parkinsoniinae (5.0%)

Leptosphinctinae (28.1%)

Bigotitinae (6.3%)
Zigzagiceratinae (3.3%)
Morphoceratinae (8.9%)

Fig. 6. Distribution of percentage of ammonite taxonomic groups in the Parkinsoni Zone (104 specimens) and Zigzag Zone (302 specimens) from Section 02 of Cabo Mondego. Similar percentages have been obtained in the Zigzag Zone from Section 90: Oppeliinae 20.0%, Hecticoceratinae 16.9%, Cadomitinae 3.1%, Parkinsoniinae 4.6%, Leptosphinctinae 4.6%, Zigzagiceratinae 36.9%, Morphoceratinae 13.9%.

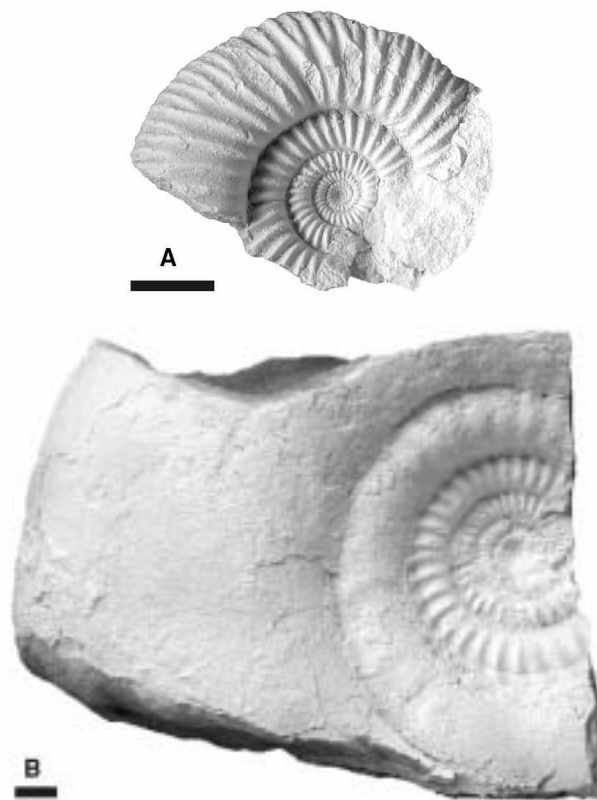


Fig. 7. Incomplete phragmocones of *Bigotites* gr. *diniensis* Sturani [M] from the Cabo Mondego region (Portugal). Parvum Subzone, Zigzag Zone, Bathonian. Scale bars 1 cm. □ A. Specimen 02CM172/9; D = 45.0. H = 14.3 (0.32). W = 16.0 (0.35). U = 19.5 (0.43). W/H = 1.12. Ni/2 = 18. □ B. Specimen 02CM146/2. D = 18.0. H = 79.0 (0.44). W = 62.0 (0.34). U = 72.0 (0.40). W/H = 0.78.



Fig. 8. Incomplete phragmocones of '*Bigotites*' *acurvatus* (Wetzel) in Torrens [m] from the Cabo Mondego region (Portugal). Parvum Subzone, Zigzag Zone, Bathonian. Scale bar 1 cm. □ A. Specimen 02CM172/6. \bullet = 43.0 H = 15.0 (0.35). W = 14.0 (0.32). U = 17.5 (0.41). W/H = 0.93. Ni/2 = 19. □ B. Specimen 02CM180/5. \bullet = 40.0. H = 14.0 (0.35). W = 12.0 (0.30). U = 17.0 (0.42). W/H = 0.86. Ni/2 = 18. □ C. Specimen 02CM172/115. \bullet = 49.0. H = 16.0 (0.33). W = 13.0 (0.26). U = 21.5 (0.44). W/H = 0.81. Ni/2 = 18.

microconch forms are more strongly ribbed than *Planisphinctes planilobus* Buckman, show nodes in the bifurcation of the primary ribs, and are less stoutly whorled than '*Bigotites*' *acurvatus* (Wetzel 1937, p. 96, pl. 10, fig. 12). They are also known in the stratigraphic interval from bed 23 to bed 14, in the Ravin du Bés section, at Bas Auran district (cf. Sturani 1967, pp. 9, 39, pl. 7, Fig. 3; Torrens 1987, pp. 106–107, pl. 4, figs. 1, 5, 6). It is important to remark for chronocorrelation purposes that this dimorphic couple present a distribution restricted to the Parvum Subzone, homotaxial and similarly positioned in the type area of the species (Digne-Barrême area; Horizon (1a) with *Bigotites diniensis* in Innocenti *et al.* 1988). The youngest Bathonian records of *Bigotites* [M+m] appear to be from Portugal, at the lower part of the Macrescens Subzone (level 90FD31, Fig. 3). *Planisphinctes* [m] – *Lobosphinctes* [M], with relatively complex sutures and well retracted suspensive lobe, are the most common ammonites in the Parvum Subzone. *Lobosphinctes* has been believed as derivative of *Bigotites* and comprising the oldest Zigzagiceratinae (cf. Arkell *et al.* 1957; Arkell 1958; Sturani 1967; Mangold 1971ab; Sandoval 1983) as well as the youngest Leptosphinctinae (Torrens 1987; Innocenti *et al.* 1988). *Lobosphinctes* lack the parabolic nodes or zigzag stage of ribbing characteristic of the earliest whorls of Zigzagiceratinae. However, they also lack the smooth band on external region enlarging segmentally after the constrictions characteristic of *Vermisphinctes* [m] – *Prorsisphinctes* [M], as well as the relatively simple sutures and the nodes in the bifurcation of the primary ribs characteristic of *Bigotites* [M+m]. Therefore, in accordance with the sutural complexity, ornamentation and biochronostratigraphic distribution, it seems more probably that the dimorphic group *Planisphinctes* [m] – *Lobosphinctes* [M] represents a direct derivative of some Late Bajocian species of the group of *Vermisphinctes* [m] – *Prorsisphinctes* [M], as

suggested by Stephanov (1966). *Procerites* [M] and *Siemiradzka* [m], showing parabolic nodes in the earliest whorls as proterogenetic character, are common in the Macrescens Subzone and occur in the upper part of the Parvum Subzone. Involute and fine-ribbed *Phaulozigzag* [m], with close ribbing, without parabolic nodes, larger in size and older than *Siemiradzka* [m] occur at the Bajocian/Bathonian boundary, associated with involute

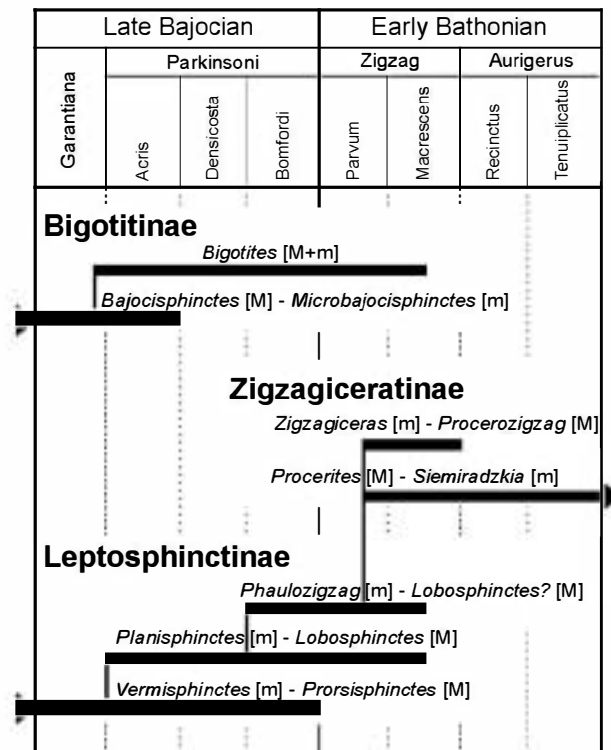


Fig. 9. Phylogenetic scheme of the last genera of Leptosphinctinae, two genera of Bigotitinae and initial members of Zigzagiceratinae recorded at the Bajocian/Bathonian transition in the Cabo Mondego region (Portugal).

and rather finely ribbed macroconchs provisionally attributed to *Lobosphinctes*? [M] (Fig. 9). Specimens of the dimorphic couple *Zigzagiceras* [m] - *Procerozigzag* [M] are very scarce, showing relatively complex sutures also and being the earliest forms from the upper part of the Parvum Subzone. Representatives of *Franchia* [M + m] have not been so far identified in Cabo Mondego. However, the phylogenetic derivation of *Zigzagiceras* [m] - *Procerozigzag* [M] from *Franchia* [M + m] is not firmly established. On the one hand, the relative age of *Franchia* [M + m] proposed as older than the first appearance datum of *Zigzagiceras* [m] - *Procerozigzag* [M] (Torrens 1987; Innocenti *et al.* 1988) needs to be tested in diverse regions. In Bas Auran, this particular genus occurs in association with the youngest representatives of *Lobosphinctes tmetolobus* and *Lobosphinctes subprocerus*, overlaying the Horizon with *Bigotites diniensis*, but it is also recorded below and in the lowest occurrence level of *Morphoceras macrescens* (in the stratigraphic interval from bed 13 to bed 12 at the Ravin du Be's, Bas Auran). Being bed 12 the level of lowest occurrence of *Morphoceras macrescens*, after new results obtained by several members of the Bathonian Working Group, the upper horizon (1b) of the Convergens (=Parvum) Subzone characterized by the onset of Zigzagiceratinae of the subgenus *Zigzagiceras* (*Franchia*) corresponds exclusively to the bed 13, and can be biochronostratigraphically correlated with the Cabo Mondego intervals 90FD3-90FD11 (Fig. 3) and 02CM183-02CM198 (Fig. 4). Consequently, *Franchia* [M + m] in Bas Auran show a homotaxial distribution with regard to the lowest occurrence of *Zigzagiceras* [m] - *Procerozigzag* [M] in Cabo Mondego. On the other hand, taking into account the greater sutural complexity of *Zigzagiceras* [m] - *Procerozigzag* [M], the immediate predecessor of *Franchia* [M + m] can be probably identified in a primitive species of *Zigzagiceras* [m] - *Procerozigzag* [M], rather than in a derived species of *Bigotites*, from the Parvum Subzone.

Among the Morphoceratidae (13.9% in Section 90, 8.9% in Section 02), *Morphoceras* [M] - *Ebrayiceras* [m] are one of the most common ammonites in the lower part of the Macrescens Subzone, but they are scarce at the Bajocian/Bathonian boundary. Rare *Pseudodimorphinites* [M, according to Seyd-Emami *et al.* 1989; Mangold 1997; Dietze *et al.* 2002], *Asphinctites* [M] and *Polysphinctites* [m] occur in the Zigzag Zone also. Bathonian parkinsoniids of the genera *Parkinsonia* [m], *Durotrigensia* [M] and *Gonolkites* [M] are scarce (4.6% in Section 90, 5.0% in Section 02).

Representatives of the family Oppeliinae, *Oxycerites* [M] - *Paroecotraustes* [m], are common (20.0% in Section 90, 29.5% in Section 02). Representatives of Hecticoceratinae, *Nodiferites* [m] - *Zeissoceras* [M] are abundant in some beds of the middle part of the

Parvum Subzone (16.9% in Section 90, 16.2% in Section 02), being a conspicuous component of the Submediterranean faunas of Western Tethys. The oldest identified species of *Zeissoceras* [M] from Portugal correspond to *Z. primævum* (Grossouvre) at the lower part of the Parvum Subzone (02CM154). *Z. rugeti* (Elmi) associated with *Z. cf. hugenini* (Elmi) are abundant at the middle part of the Parvum Subzone. Very scarce are the families Stephanoceratidae (3.1% in Section 90, 1.7% in Section 02) and Lissoceratidae (0.3% in Section 02). Consequently, the Parkinsoni Zone (Upper Bajocian) and the lowermost Zigzag Zone (Lower Bathonian) established for NW Europe areas can be identified in the Cabo Mondego region, although the ammonite fossil assemblages are composed of Submediterranean taxa.

Conclusions

The ammonite succession at the Bajocian/Bathonian boundary in the Cabo Mondego region (Portugal) provides one of the most complete biostratigraphical records recognized on the Iberian Plate. Over 40 successive assemblages have been recognized in the lowest Bathonian subzone (the Parvum Subzone). These successive ammonite fossil assemblages are composed of Submediterranean taxa, but they allow a correlation to the zonal scale with diverse basins of the Mediterranean and NW European provinces. The occurrence of *Bigotites* gr. *diniensis* [M + m] in Cabo Mondego in the Parvum Subzone represents a new criterion for chronocorrelation with the Digne-Barre'me area, and is also useful for understanding the evolution of the West Tethyan Perisphinctidae during earliest Bathonian. These results are crucial for the establishment of a Bathonian global stratotype section and point (GSSP) of which the Ravin du Be's section (Bas Auran district) is the leading candidate.

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