

TOARCIAN NANNOBIOHORIZONS FROM LUSITANIAN BASIN (PORTUGAL) AND THEIR CALIBRATION AGAINST AMMONITE ZONES

NICOLA PERILLI¹ & LUIS VITOR DUARTE²

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Abstract. The calcareous nannofossil content of the Toarcian succession, widespread in the Lusitanian Basin (Central Portugal), has been studied on the basis of a closely spaced sampling and a refined lithostratigraphic frame dated by ammonites. The almost continuous calcareous nannofossil record allows to calibrate the biohorizons and zone boundaries (NJ5/NJ6, NJ6/NJ7, NJ7/NJ8) with respect to the ammonite zones, and to characterize Toarcian nannofossil zones. The easily recognizable events include the LCO of *Calcivasularis jansae* (Levisoni Zone), the FOs of *Carinolithus cantaluppii* and *Carinolithus superbus* (Levisoni Zone), the FO of *Discorhabdus striatus* (Bifrons Zone), the AE of *Lotharingius hauffii* (Gradata Zone) and the FO of *Watznaueria contracta* (Aalensis Zone). The other events are helpful to increase the biostratigraphic resolution, albeit they are defined by taxa with a low abundance and discontinuous occurrence. They comprise the LOs of *Biscutum grande* and *Biscutum finchii* (Levisoni Zone) and the FOs of *Discorhabdus criotus* (Gradata Zone), *Retecapsa incompta* (Bonarelli Zone) and *Triscutum sullivanii* (Speciosum Zone). Both biohorizons and zone boundaries are compared with previous findings from the Basque-Cantabrian area and Iberian Range (Spain) as well as from NW Europe and Italy/S France.

Riassunto. Sulla base di una fitta campionatura delle sezioni di riferimento del Toarciano del Bacino Lusitano e di una eccellente litostratigrafia è stato possibile ricostruire il record completo delle associazioni a nannofossili calcarei per l'intervallo di tempo studiato. Le associazioni a nannofossili calcarei determinate in oltre 700 smear slides, consentono di calibrare, rispetto alle zone ad ammoniti, gli eventi ed i limiti di zona (NJ5/NJ6, NJ6/NJ7, NJ7/NJ8) riconosciuti e di caratterizzare tutte le zone del Toarciano. La riduzione di abbondanza di *Calcivasularis jansae* (Zona a Levisoni), le comparse di *Carinolithus cantaluppii* e *Carinolithus superbus* (Zona a Levisoni), la comparsa di *Discorhabdus striatus* (Zona a Bifrons), la riduzione d'abbondanza di *Lotharingius hauffii* (Zona a Gradata) e la comparsa di *Watznaueria contracta* (Zona ad Aalensis) sono i bioorizzonti principali riconosciuti. Gli altri eventi, sebbene basati su specie che sono meno abbondanti e discontinuamente presenti, comprendono le scomparse di *Biscutum*

grande e *Biscutum finchii* (Zona a Levisoni), le comparse di *Discorhabdus criotus* (Zona a Gradata), *Retecapsa incompta* (Zona a Bonarelli) e *Triscutum sullivanii* (Zona a Speciosum). Eventi e limiti di zona vengono comparati con i dati disponibili per la Spagna (area Basco-Cantabrica e Cordillera Iberica), per l'Europa nordoccidentale e l'area Mediterranea.

Introduction

Since the 50's, palaeontological studies on Lower Jurassic sediments (Fig. 1) cropping out in the Lusitanian Basin (LB) mainly focus on ammonoid biostratigraphy. Also microfossils were investigated in order to improve the biostratigraphy of these sediments. So far, the majority of the investigations were based on a limited number of samples, collected in few and often discontinuous sections.

The first ammonite zonation proposed by Mouterde (1967) is based on the pioneer works on ammonites recovered from the Jurassic succession of the Lusitanian Basin by Mouterde (1955), Mouterde & Ruget (1967a, b) and Mouterde et al. (1964-65, 1979, 1980). Their Toarcian ammonite zones were correlated by Elmi et al. (1989) with those utilized in the Iberian (Central Spain) and Betic (Southern Spain) Ranges. Furthermore, the Tethyan affinity of ammonite assemblages recovered from the Lusitanian Basin and the repetitive occurrence also of NW European taxa is documented by Mouterde et al. (1979), Elmi et al. (1989) and Mouterde & Elmi (1991). Among microfossil groups, foraminifera were studied by Perrot (1985). Ostracod assemblages recovered from the Zambujal (Rabaçal) section, studied by Exton (1979), were re-examined by

1 Dipartimento di Scienze della Terra, Via Maria 53, 56126 Pisa, Italy. E-mail: perilli@dst.unipi.it.

2 Departamento de Ciências da Terra, Centro de Geociências da Universidade de Coimbra, 3000-272 Coimbra, Portugal. E-mail: lduarte@ci.uc.pt.

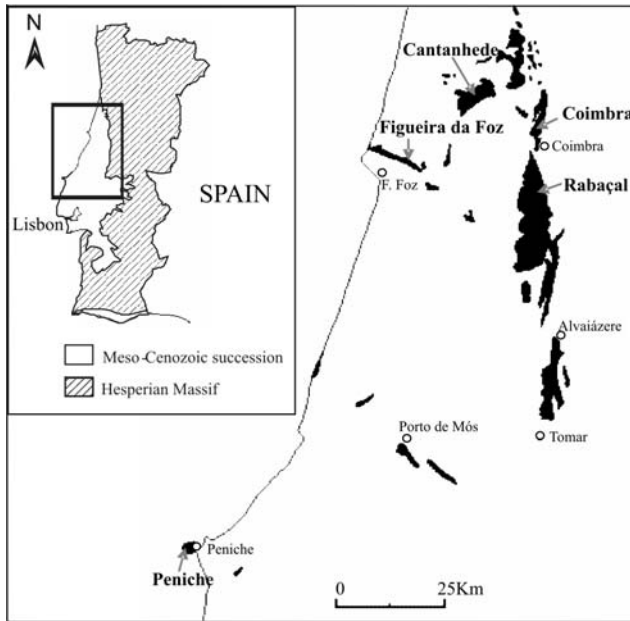


Fig. 1 - Outcropping area of the Meso-Cenozoic succession in central (Lusitanian Basin) and southern (Algarve) Portugal overlying the Iberian Variscan Massif (Hesperia Massif). In the enlarged area, the Lower Jurassic outcrops (in bold) in the northern and central Lusitanian Basin, and location of the studied successions.

Boomer et al. (1998). Though based on a low number of samples, Boomer et al. (1998) described the Toarcian ostracod zones and pointed out the strong NW European affinity of the faunal associations.

The earlier papers on the calcareous nannofossil content of the Lower Jurassic succession cropping out in the Lusitanian Basin are those of Hamilton (1977, 1979). Later, Bown (1987) and de Kaenel & Bergen (1993) studied the calcareous nannofossils recovered from the Brenha section, and Henriques et al. (1994) the assemblages of the Aalenian/Bajocian transition exposed at Cabo Mondego. Though not supported by range charts, the succession of Late Sinemurian-Callovia events recognized in Portugal by Bergen (unpublished data) is reported in de Kaenel et al. (1996) and Bown & Cooper (1998). Bown (1987) was the first to point out the Tethyan affinity of the assemblages recovered from these Portuguese sections, as later evidenced by de Kaenel et al. (1996).

The aim of our paper is to discuss calcareous nannofossil biohorizons and zones identified in the Toarcian succession of the Lusitanian Basin. Events and zones will be correlated with those recognized in the Basque-Cantabrian area (Perilli 1999a; Perilli et al. 2004), Iberian Range (Perilli 1999b, 2000), NW Europe (Bown & Cooper 1998) and Italy/S France (Mattioli & Erba 1999). Moreover, the correlation between ammonite zones utilized in Portugal and the Iberian Range (including Basque-Cantabrian area) as proposed by Elmi et al. (1989) will be enlighten.

Lithostratigraphy

Lateral and vertical facies variations across the whole LB, allows the recognition of different tectono-paleogeographic settings, showing characteristic lithostratigraphic features (Duarte 1997; Duarte & Soares 2002). In the two most important of them, crop out the units below described (Fig. 2). For the conservation of space Ammonite Zone and Ammonite Subzone are quoted as AZ and ASz, respectively.

Stages	Substages	Ammonites Zones	Lithostratigraphy		
			Northern and Central part of the LB	Peniche area	
Toarcian	Upper	Aalenensis	Póvoa da Lomba Formation		
		Meneghinii			
		Speciosum	São Gíão Formation	Cabo Carveiro Formation	CC5 Member
		Bonarelli			Marls and Marly Limestone with brachiopods Member (MMLB)
		Gradata			Marls and Marly Limestone with sponges bioconstructions Member (MMLSB)
	Middle	Bifrons	Marls and Marly Limestones with <i>Hildaites</i> and <i>Hildoceras</i> Member (MMLHH)		CC3 Member
		Levisoni (Serpentinus)	Thin Nodular Limestone Member (TNL)		CC2 Member
	Lower	Polymorphum (Semicelatum)	Marly Limestone with " <i>Leptaena</i> " facies Member (MLLF)	CC1 Member	

Fig. 2 - Lithostratigraphy and ammonite biostratigraphy of the Toarcian in the LB. Semicelatum and Serpentinus are the ammonite zones names utilized by Elmi et al. (1989).

Northern and Central Lusitanian Basin

The sampled Toarcian successions belong to the S. Gíão Formation and to the lowermost part of the Póvoa da Lomba Formation. They are well exposed at Porto de Mós, Alvaiázere, Rabaçal, Coimbra, Cantanhede and Figueira da Foz sectors (Mouterde et al. 1964-65, 1980, 1998; Mouterde & Ruget 1967a, b; Duarte 1995, 1997; Almeras et al. 1995; Duarte & Soares 2002). Both formations were deposited on a distal carbonate ramp dipping westwards and containing a rich and diverse nektonic (e.g., belemnites and ammonoids) and benthic (e.g., brachiopods, bivalves, crinoids, siliceous sponges) macrofauna (Duarte 1997). The S. Gíão Formation is subdivided into five informal members (Fig. 2) on the basis of facies arrangements and fossil content (Duarte 1995, 1997; Duarte & Soares 2002).

Marly limestones with "*Leptaena*" facies Member (MLLF). Assigned to the Polymorphum AZ, this 3 m to 20 m thick unit is characterised by greyish marl and marly limestone decimetre-thick alternations, and is very rich in benthic and nektonic macrofauna. Tiny brachiopods such as *Koninckella liasina* and *Nannirhynchia pygmoea* (Couches à "*Leptaena*" of Choffat

1880), belemnites and ammonites (Dactylioceratids) are dominant.

Thin Nodular Limestones Member (TNL). This 8-15 m thick peculiar interval belongs to the lowermost part of the succession assigned to the Levisoni AZ. Very poor of macro- and microfauna, it consists of a monotonous, well-bedded, thin, calcilititic to fine calcarenitic lithofacies (sometimes with lamination, cross bedding, symmetrical and current ripples) with grey to brownish marl or marly limestone intercalations.

Marls and marly limestones with *Hildaites* and *Hildoceras* Member (MMLHH). This 25 m to 95 m thick member spans from the Levisoni to the Bifrons AZs. Composed of marl/limestone decimetre to metre-thick alternations, the nektonic (ammonites) and benthic (brachiopods and bivalves) faunal associations show a low diversity. In the eastern sector of the LB (Alvaiázere-Rabaçal), the base of this unit shows levels rich in rhynchonellids and terebratulids, whilst in the central-western sector (Coimbra-Figueira da Foz), the portion below the Levisoni/Bifrons AZ boundary is very rich in thin-shelled bivalves, with common remains of *Bositra* sp.

Marls and marly limestones with sponge bioconstructions Member (MMLSB). Ranging from the Bifrons to the Bonarelli AZs, this 20 m to 60 m thick unit is characterised by regular decimetre to metre-thick marl and marly limestone alternations. In places, it shows siliceous sponge mud mounds (Duarte et al. 2001) rich in benthic macrofauna, along with high concentration of ammonoids, rhynchonellids, crinoids and bivalves.

Marls and marly limestones with brachiopods Member (MMLB). This member, referable to Bonarelli p.p. and Speciosum AZs, ranges from 3 to 40 m, moving from the southeastern to the northwestern sector. Mainly composed of marls with rare centimetre-thick argillaceous limestone beds, it is characterised by the massive occurrence of brachiopods (*Soaresirhynchia renzi*, *Nannirhynchia cotteri*, *Zeilleria sharpei*).

The Póvoa da Lomba Formation (Upper Toarcian-Lower Bajocian; Barbosa et al. 1988) consists of thin to medium bedded marls and limestone alternations, with a calcareous enrichment towards the top. The lower portion of the formation, belonging to the Meneghinii-Opalinum AZs, ranges in thickness from 15 m to 51 m (MST4B in Duarte 1997). Also this deeply bioturbated and sometimes very fossiliferous unit is characterised by the presence of decimetre-thick siliceous sponge mud mounds (Duarte et al. 2001).

Peniche area

In the southwestern sector of the LB, the Toarcian succession, belonging to the Cabo Carvoeiro Formation, is superbly exposed along the coast nearby Pe-

niche. It consists of a thick carbonate succession, increased in siliciclastics and oolitic/peloidal content upwards (Wright & Wilson 1984; Duarte 1995, 1997). According to Wright & Wilson (1984), these facies are associated with a submarine fan system, fed by the Berlingas igneous massif, located west of Peniche. The Cabo Carvoeiro Formation (Lower Toarcian-Aalenian?, Duarte & Soares 2002), correlatable to the S. Gião and Póvoa da Lomba p.p. Formations, comprises five members (Fig. 2).

Cabo Carvoeiro Member 1 (CC1). This nearly 11-12 m thick unit, belongs to the Polymorphum AZ and consists of regular alternations of decimetre-thick marls and centimetre-thick limestones. It is the lateral equivalent of MLLF. The macrofauna is very abundant and diverse, being particularly rich in brachiopods, bivalves, belemnites and ferruginous ammonites (Dactylioceratids).

Cabo Carvoeiro Member 2 (CC2). This 24 m thick unit is assigned to the lower part of the Levisoni AZs. It is composed by a marl-limestone succession that includes centimetre to decimetre-thick siliciclastic-rich intervals, along with rare microconglomerates and coarse to thin subarkosic sandy marls and limestones, sometimes rich in terrestrial plant materials. The detrital facies show groove and fining-upward structures, representing a turbiditic deposition. The benthic macrofauna consists of rare rhynchonellids.

Cabo Carvoeiro Member 3 (CC3). Spanning from the Levisoni p.p. to the Bifrons p.p. AZ, this 30 m thick unit is correlatable to the middle-upper part of the MMLHH. It consists of bioturbated centimetre to decimetre-thick marl-limestone alternations, at the base richer in fine siliciclastic constituents such as quartz and micaceous minerals. The benthic macrofauna is very rare. Ammonites are common in the whole unit, showing levels particularly rich in Hildoceratids.

Cabo Carvoeiro Member 4 (CC4). The basal portion of this member is composed by thick bedded marls, which alternate with centimetre-thick marly limestones. Progressively, this last facies gives place gradually to a thin-bedded coarser, peloidal-oolitic facies (grainstones), sometimes fining upwards. In this unit the macrofauna is very poor, but at its base ammonites are particularly common. Along the Peniche coast, the CC4 54 m thick unit spans from the upper part of the Bifrons to the lowermost part of the Speciosum AZs.

Cabo Carvoeiro Member 5 (CC5). With the exception of the extreme base (Duarte 1995, 1997), at Peniche the upper portion of the Toarcian is devoid of marly facies. Thicker than 100 m, it consists of fine oolitic, bioclastic or sandy limestones, and calcareous sandstones, which occasionally are very coarse and show lateral thickness variations. The shallow-water

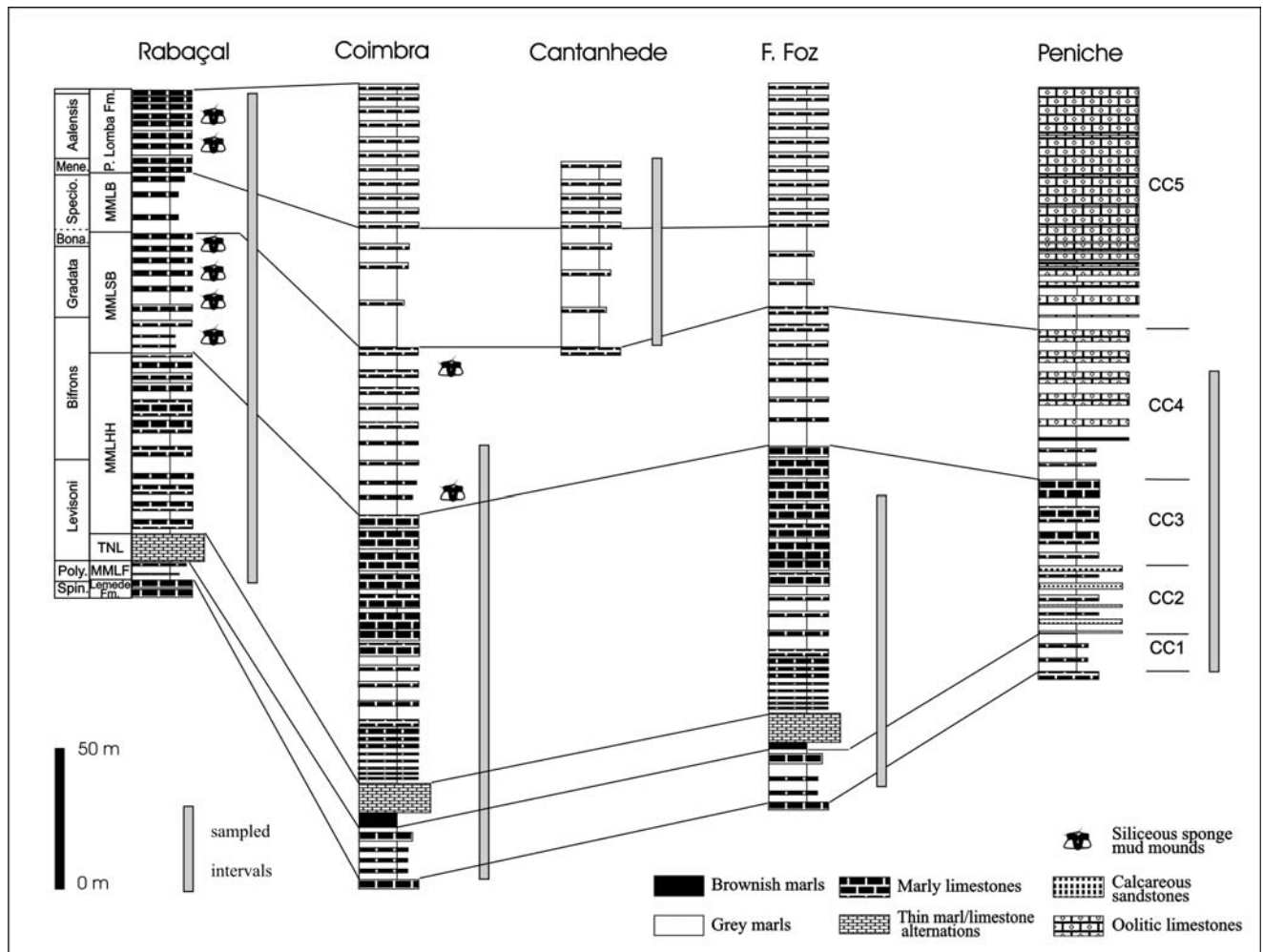


Fig. 3 - Facies and lithological features of the Toarcian succession sampled in the investigated areas (based on Duarte 1995, 1997; Duarte et al. 2002). Spin.= Spinatum; Poly.= Polymorphum; Bona.= Bonarelli; Specio.= Speciosum; Mene.= Meneghinii; for member names see Fig. 2.

macrofauna is represented by bivalves, echinoids, crinoids and corals. The absence of ammonites does not allow an accurate dating of the unit.

Sampled sections and relevant previous studies

The reference sections of the distal part of the LB are sampled at Rabaçal, Coimbra, Cantanhede, Figueira da Foz and Peniche (Fig. 3). Unfortunately, the successions outcropping in the Coimbra and Figueira da Foz areas are neither continuous nor complete.

Rabaçal section. The type locality of S. Gião Formation (Duarte & Soares 2002) is the best-studied continuous Toarcian succession of the LB (Exton 1979; Rocha et al. 1987; Duarte 1995, 1997; Exton 1979; Boomer et al. 1998; Duarte et al. 2001). In this 160 m thick section, all Toarcian ammonite zones have been recognized (Mouterde et al. 1964-65) and the ostracods zones were described by Boomer et al. (1998).

Coimbra composite section. In the Coimbra area, the widespread Lower Jurassic deposits are usually

badly exposed (Duarte 1995; Duarte et al. 2004). Nevertheless, in the Ribeiro, Fornos, Marmeleira and Cabeço da Azevêda sub-sections, the Polymorphum, Levisoni, Bifrons and Gradata p.p. AZs have been sampled. In this sector of the LB, the Upper Liassic succession is very thick and the Toarcian portion can reach more than 265 m. The only biostratigraphic data available for this area are based on calcareous nannofossils (Duarte et al. 2004).

Cantanhede composite section. The scattered distribution of Toarcian sediments in the Cantanhede area and the bad exposures allow to sample only the uppermost part of the S. Gião and the lower part of the Póvoa da Lomba Formations. At the Póvoa da Lomba and S. Gião sub-sections, the nicely exposed succession contains a good ammonite record that allows the recognition of the Bonarelli p.p., Speciosum, Meneghinii and Aalenensis AZs (Mouterde et al. 1998; Henriques 2000). In the S. Gião sub-section, the Toarcian/Aalenian boundary is superbly exposed.

Figueira da Foz composite section. Located in the northwest part of the LB, it includes the Vale das Fontes

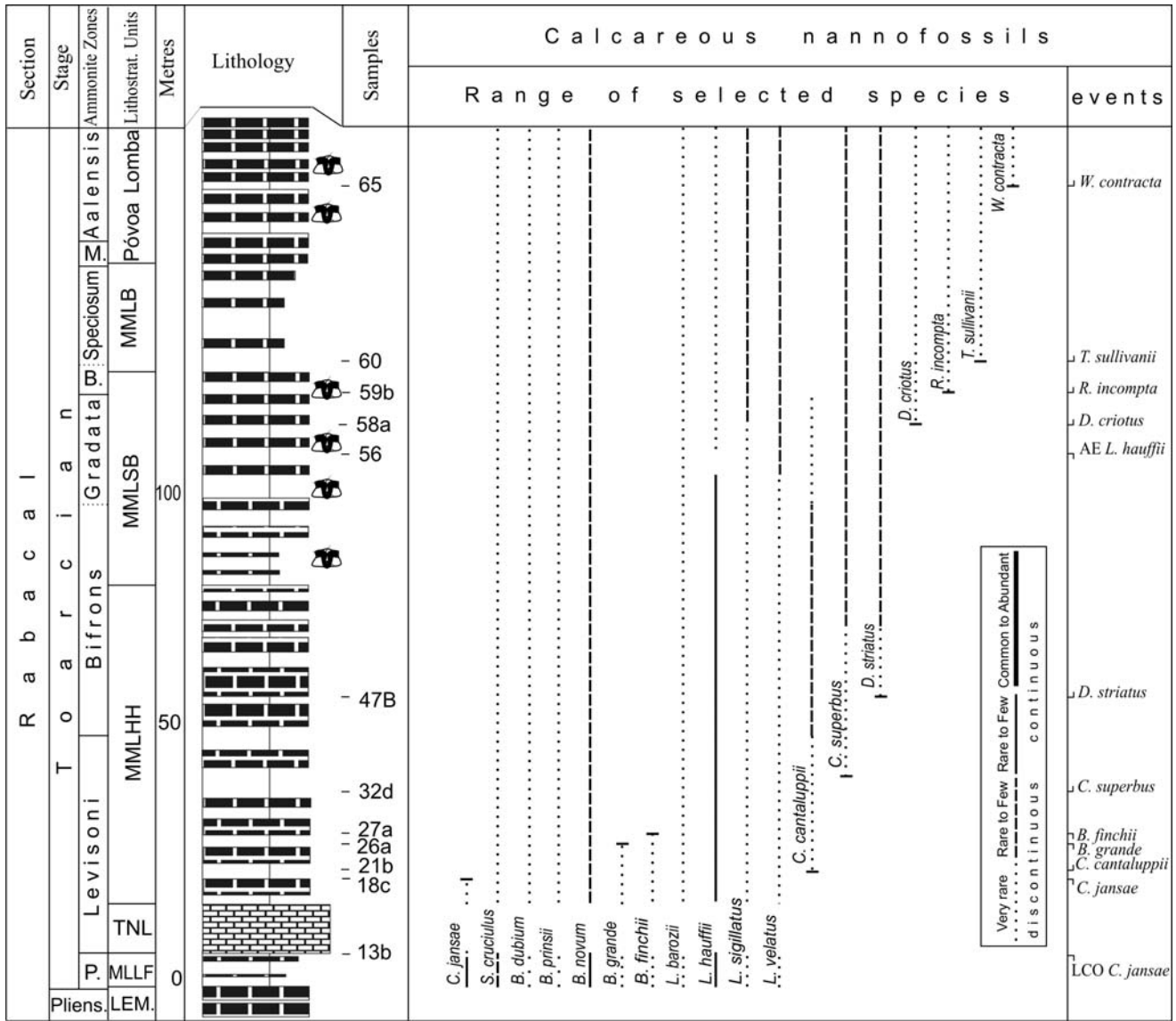


Fig. 4 - Range of some calcareous nanofossil species and events recognized in the Rabaçal section; species abundance is figured by the different type of lines; discontinuous and continuous lines correspond to discontinuous and continuous occurrence, respectively. Lithostrat.= Lithostratigraphic; P.= Polymorphum; B.= Bonarelli; M.= Meneghinii; Povoá Lomba= Povoá da Lomba Formation; LCO= Last Common Occurrence; AE= Acme End; for member names see Fig. 2.

and Brenha sub-sections. In this composite section, thicker than 120 m, part of the Levisoni and the Bifrons AZs are badly exposed, nevertheless the Polymorphum AZ, the Levisoni and the Bifrons AZs have been recognized (Mouterde et al. 1980; Duarte 1995, 1997). At Brenha, also calcareous nanofossils have been studied (Hamilton 1977, 1979; Bown 1987; de Kaenel & Bergen 1993).

Peniche section. This superbly exposed section has been sampled along the coast of Cabo Carvoeiro. Among others, the papers of Wright & Wilson (1984) and Duarte (1995, 1997) should be mentioned. In this section, only the Lower and Middle Toarcian ammonite zones are documented (Mouterde 1955; Almeras et al. 1995).

Material and methods

Although the Toarcian outcrops are scattered, due to the dominance of the marly lithotypes and antropic activities, the collected samples are correctly placed with respect to the lithostratigraphic units defined by Duarte (1995, 1997) and Duarte & Soares (2002). Based on lithostratigraphy both composition changes and biohorizons are calibrated against the ammonite zones recognized in the Rabaçal, Cantanhede, Figueira da Foz and Peniche sections (Rocha et al. 1996, and bibliography therein).

In order to retain the original calcareous nanofossil assemblages and to obtain a uniform rippled distribution, getting comparable sediment density, simple smear slides were prepared, scraping and smearing onto a cover glass small amount of sediment. Dried on a hot plate, the cover glass was permanently mounted onto a glass slide with Permout. To achieve comparable data with those available for Northern and Central Spain (Perilli et al. 2004 and bibliography there-

in), a semiquantitative analysis was performed using a Leitz Light Microscope at magnification of 1250X.

For each smear slide at least 10 complete longitudinal random transverses were analysed (1 transverse = 170 fields of view) and to check for rare or very rare taxa, in some smear slides more than 2000 fields of view have been observed. Taxa here considered and quoted are listed in Appendix 1. Their bibliographic references are found in Bown & Cooper (1998). Since in this paper only the ranges of some selected taxa are reported (Figs. 4-8), the paper of Perilli & Duarte (submitted) can be consulted for the range charts of the complete assemblages. The meaning of the assemblage abundance, species abundance and preservation classes quoted in the text are reported below.

Assemblage abundance. Abundant: 10-15 specimens in each field of view; Common: 1-10 specimen/s in 1 field of view; Few: 1 specimen in 1-10 field/s of view; Rare: 1 specimen in 11-100 fields of view; Very Rare: 1 specimen >101 fields of view.

Species abundance. Abundant: 1-5 specimen/s in each field of view; Common: 1 specimen in 2-10 fields of view; Few: 1 specimen in 11-30 fields of view; Rare: 1 specimen in 31-100 fields of view; Very Rare: 1 specimen >101 fields of view.

Abundance and preservation of assemblages vs adequacy of the record

This work is based on a high number of samples (more than 700) in order to get a continuous calcareous nannofossil record. This strategy is particularly profitable for successions or intervals that contain calcareous nannofossil assemblages depleted by a diagenetic overprint. Almost all the samples collected from the Peniche section and Cantanhede composite section provide common and nicely preserved assemblages. The continuous calcareous nannofossil content from the Rabaçal section albeit scarce and badly preserved, is age-significant. Indeed, the intervals from the lowermost (MLLF) and middle (part of MMLSB) Toarcian portions contain common and moderately preserved assemblages.

Based on the abundance and preservation of the assemblages, the samples from the Coimbra and Figueira da Foz composite section could be divided into three groups. Those collected from the MLLF cropping out at Ribeiro and Vale das Fontes sub-sections provide common, diverse and nicely preserved assemblages. Due to a diagenetic overprint, some of the samples collected at Fornos sub-section from the TNL are barren; others furnish impoverished but age-significant assemblages, which are the best preserved assemblages recovered from this member. The samples collected at Marmeleira and Brenha sub-sections from MMLHH, and at Cabeço da Azevêda sub-section from the MMLB are quite similar. They contain depleted but still age-significant assemblages, with a low number of species, and assemblage abundance ranging from few to common. Below further abbreviations are adopted: First Occurrence (FO); Last Occurrence (LO); Last Common Occurrence (LCO); Acme End (AE).

Calcareous nannofossil biostratigraphy

Events

On the basis of reproducibility and reliability, the main events are the LCO of *C. jansae*, the FO of *Carinolithus superbus*, the FO of *D. striatus*, the AE of *L. hauffii* and the FO of *W. contracta*. These events are easily recognizable and useful to identify and characterize nannofossil zones and subzones. The other events are helpful to improve the biostratigraphic resolution, but are based on species which are rare and characterised by a discontinuous distribution. As a consequence the appearance and disappearance of such species should be carefully checked, particularly in their initial and final ranges.

LO of *Calciavascularis jansae* (Fig. 4, 5, 7, 8). At Peniche, the LO of *C. jansae* has been identified within the Levisoni AZ (within the CC2). It is preceded by the sharp abundance decrease of the nominate taxon just above the Polymorphum-Levisoni AZ boundary. *C. jansae* is frequent to common in the Polymorphum AZ of the Vale das Fontes and Ribeiro (within the MLLF). At Fornos, the sharp abundance decrease of this taxon has been recognized above the Polymorphum-Levisoni AZ boundary (within the TNL). Upwards this species is absent from the Levisoni AZ at Marmeleira and Brenha (from lowermost part of the MMLHH). A similar trend is observed in the lowermost portion of the Rabaçal section.

LOs of *Biscutum grande* and *Biscutum finchii* (Fig. 4, 5, 7, 8). Although the low abundance of these, easily recognizable, large *Biscutum* species further decreases in their final range, *B. grande* and *B. finchii* are present up to the Levisoni AZ at Peniche (upper part of CC2) as well at Marmeleira and Brenha (lowermost part of the MMLHH). Hence, the LOs of *B. grande* and *B. finchii*, comprised between the FOs of *C. cantaluppii* and of *C. superbus*, lie within the Levisoni AZ. Their placement at Rabaçal is difficult.

FOs of *Carinolithus cantaluppii* and *Carinolithus superbus* (Fig. 4, 5, 7, 8). The FO of *C. cantaluppii* is preceded by the occurrence of transitional forms (like *Calculus noelae recondita* and *Calculus noelae depressa*) between the genera *Calculus* and *Carinolithus*. It lies close to the Polymorphum/Levisoni AZ boundary at Peniche (lowermost part of the CC2) and within the Levisoni AZ at Fornos (within the TNL) and Brenha (lowermost part of the MMLHH). In this ammonite zone, the FO of *C. superbus* has been recognized either at Peniche (lowermost part of the CC3) or at Marmeleira and Brenha (lower part of the MMLHH). The relative abundance of *C. cantaluppii* and *C. superbus* sharply increases below the appearance of *D. striatus*.

FO of *Discorhabdus striatus* (Fig. 4, 5, 7, 8). The first occurrence of this taxon, rare in its initial range, has

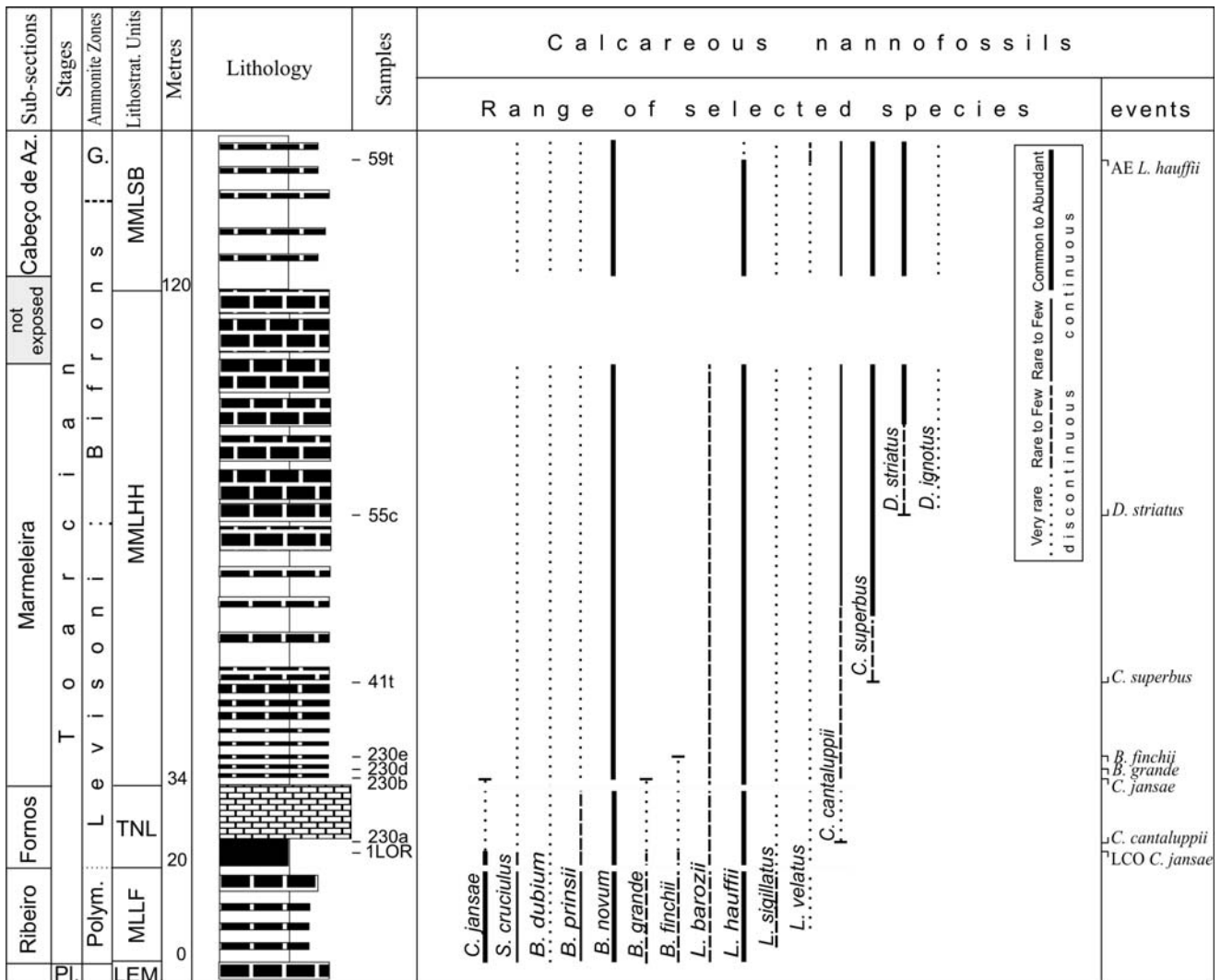


Fig. 5 - Range of some calcareous nannofossil species and events recognized in the Coimbra composite section, species abundance is figured by the different type of lines; discontinuous and continuous lines correspond to discontinuous and continuous occurrence, respectively. Lithostrat.= Lithostratigraphic; Az.= Azevêda; Polym.= Polymorphism; G.= Gradata; LEM.= Lemede; LCO= Last Common Occurrence; AE= Acme End; for member names see Fig. 2.

been recognized within the Bifrons AZ at Rabaçal, Marmeleira and Brenha (middle part of the MMLHH) and Peniche (middle part of CC3). In this latter section, the earlier rare specimens of *D. striatus* first occur just above the Levisoni/Bifrons AZ boundary, whilst from the Sublevisoni ASz it being a common species of the assemblages. The presence of this taxon is noticeable also in the assemblages recovered at Rabaçal section. Along with *D. striatus*, *D. ignotus* is discontinuously present and ranges in abundance from very rare to few.

AE of *Lotharingius hauffii* (Fig. 4, 5, 8). The solution resistant and cosmopolitan *L. hauffii* is common up to the Bifrons/Gradata AZ boundary. Its relative abundance sharply decreases within the Gradata AZ at Peniche (middle part of the CC4), Rabaçal and Cabeço da Azevêda (middle part of MMLSB). Upwards, *L. hauffii* is extremely rare or absent in the Upper Toarcian assemblages recovered from Cantanhede composite sec-

tion. The AE of *L. hauffii* is a reliable and easily recognizable event, placed at the end of the continuous range of *L. hauffii*, when its relative abundance decreases from few/rare to very rare (Perilli 1999a).

FO of *Lotharingius velatus* (Fig. 4, 5, 6, 7, 8). Rare and discontinuously present from the Polymorphism AZ, *L. velatus* is one of the main components of the Upper Toarcian assemblages recovered from the upper part of the S. Gião Formation and the lower part of the CC4. This medium-sized species dominates the *Lotharingius* population from the Gradata AZ upwards at Rabaçal, Cabeço da Azevêda and Peniche sections. On the basis of the present results, the abundance increase of *L. velatus* seems to be more useful than its first occurrence.

FO of *Discorhabdus criotus* (Fig. 4, 8). This easily recognizable taxon, although characterised by low abundance, occurs almost continuously from the Bonarelli (topmost part of the MMLSB) to the Aalensis (Pó-

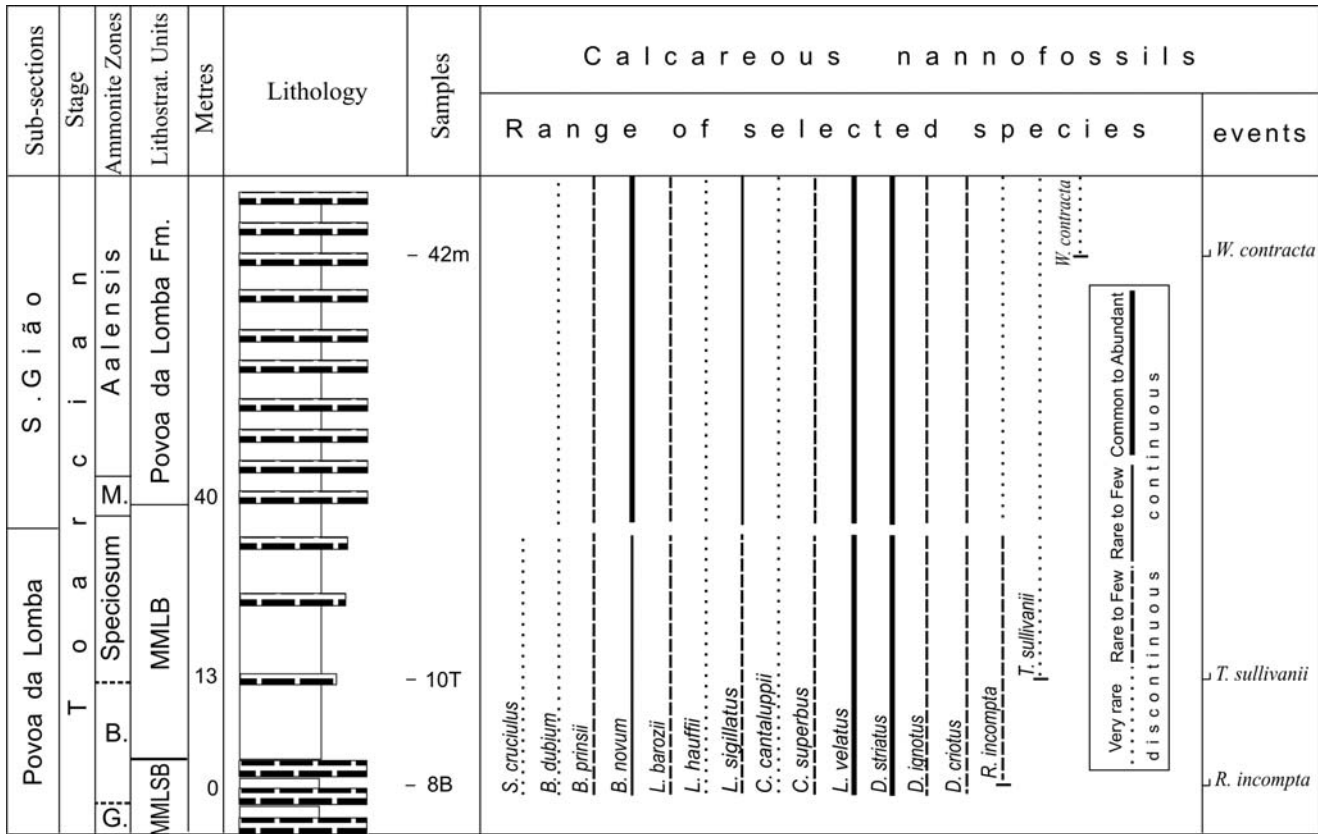


Fig. 6 - Range of some calcareous nannofossil species and events recognized in the Cantanhede composite section; species abundance is figured by the different type of lines; discontinuous and continuous lines correspond to discontinuous and continuous occurrence, respectively. Lithostrat.= Lithostratigraphic; G.= Gradata; B.= Bonarelli; M.= Meneghinii; Fm.= Formation; for member names see Fig. 2.

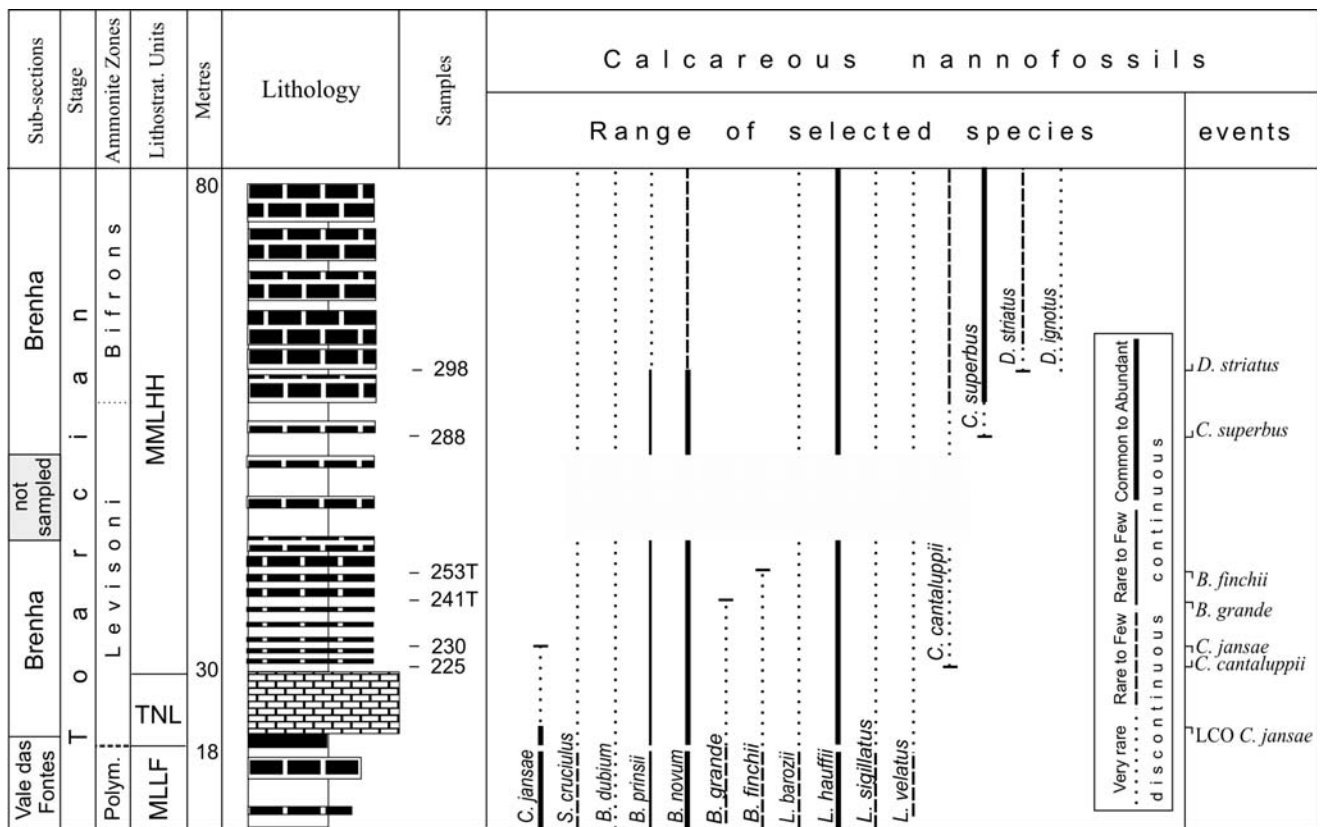


Fig. 7 - Range of some calcareous nannofossil species and events recognized in the Figueira da Foz composite section; species abundance is figured by the different type of lines; discontinuous and continuous lines correspond to discontinuous and continuous occurrence, respectively. Lithostrat.= Lithostratigraphic; Polym.= Polymorphum; LCO= Last Common Occurrence; for member names see Fig. 2.

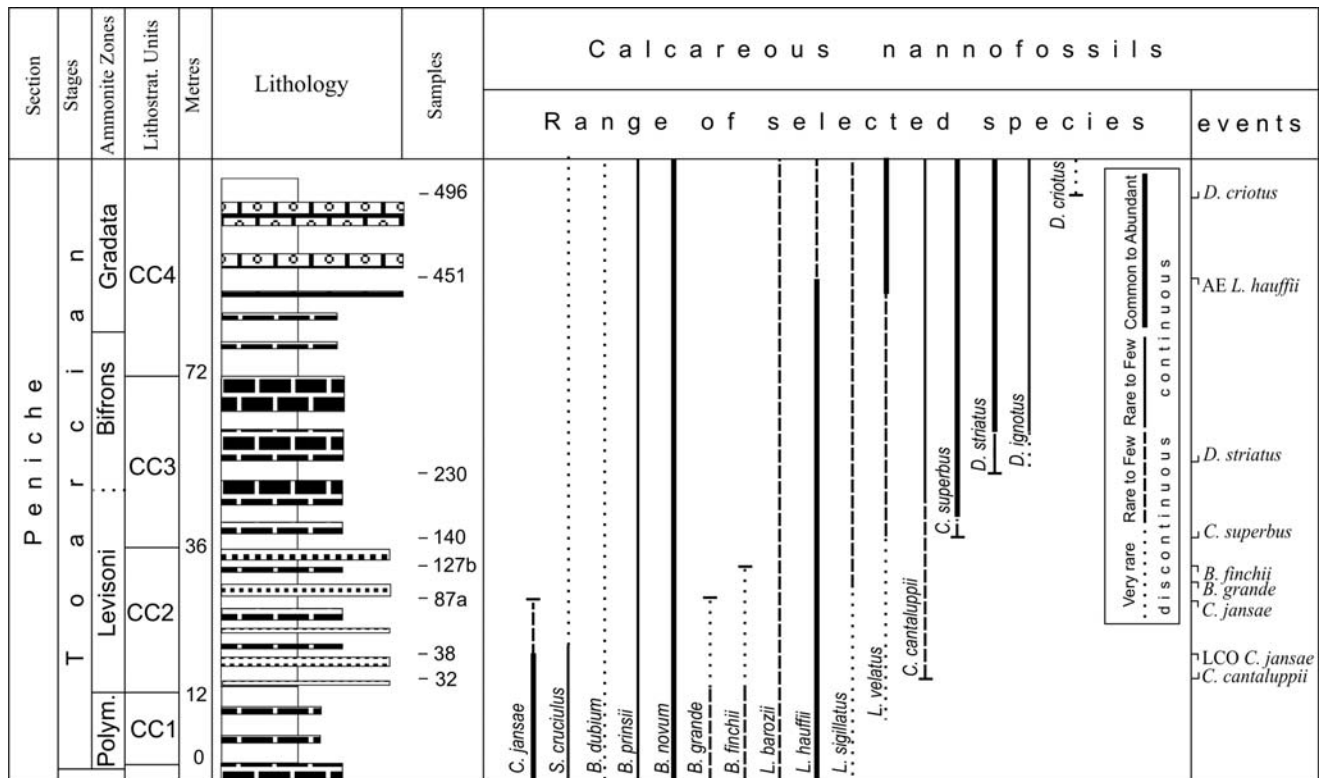


Fig. 8 - Range of some calcareous nannofossil species and events recognized in the Peniche section; species abundance is figured by the different type of lines; discontinuous and continuous lines correspond to discontinuous and continuous occurrence, respectively. Lithostrat.= Lithostratigraphic; Polym.= Polymorphism; LCO= Last Common Occurrence; AE= Acme End; for member names see Fig. 2.

voa da Lomba Formation) AZs sampled at the Cantanhede composite section. Very rare specimens of *D. criotus* are present from the Gradata AZ sampled at Rabaçal (upper part of the MMLSB) and Peniche (upper part of CC4). Hence, it lies between the AE of *L. hauffii* (Rabaçal and Peniche) and the FO of *R. incompta* (S. Gião).

FO of *Retecapsa incompta* (Fig. 4, 6). Very rare specimens of *R. incompta* are present from the Bonarelli AZ sampled at Cantanhede (uppermost part of the MMLSB). Consequently, it is not excluded that the first specimens of *R. incompta* are present from the uppermost part of the Gradata AZ. Unfortunately, the only section where the entire Gradata AZ is exposed is Rabaçal, but the assemblages recovered from this section are depleted by diagenesis.

FO of *Triscutum sullivanii* (Fig. 4, 6). *T. sullivanii* is an other characteristic Upper Toarcian taxon, nicely recognizable from the Speciosum AZ sampled at Póvoa da Lomba sub-section. Albeit it is rare and discontinuously present, the first specimens of *T. sullivanii* appear close to the Bonarelli/Speciosum AZ boundary (lowermost part of MMLB) at Rabaçal and Cantanhede. Therefore, a slightly older first appearance is possible also for this species.

FO of *Watznaueria contracta* (Fig. 4, 6). The presence of *W. contracta* has been detected from the upper part of the Aalensis AZ (i.e. Buckmani ASz) sampled at

Rabaçal and S. Gião (lower part of the Póvoa da Lomba Formation). Its appearance is preceded by the occurrence of medium-sized transitional specimens between *Lotharingius* and medium-sized *Watznaueria* (i.e. *Watznaueria* aff. *W. contracta*) from the Aalensis AZ. Upwards, *W. contracta* is continuously present from the overlying Early Aalenian Opalinum AZ and, from the Middle Aalenian Bradfordensis AZ, being one of the main constituents of the Middle Jurassic assemblages (Perilli et al. 2002).

Zones

The described succession of the biohorizons allows the identification of the Toarcian nannofossil zones (Fig. 9) proposed for NW Europe (Bown 1987; Bown et al. 1988; Bown & Cooper 1998), also recognized in the Basque-Cantabrian area (Perilli et al. 2004).

NJ5 *Lotharingius hauffii* Zone.

Author: Bown (1987).

Definition: FO of *Lotharingius hauffii* to the FO of *Carinolithus superbus*.

Range in this study: only the uppermost (Toarcian) portion of the zone has been studied.

Remarks. This zone is divided into two subzones in NW Europe and Italy/S. France. The Toarcian por-

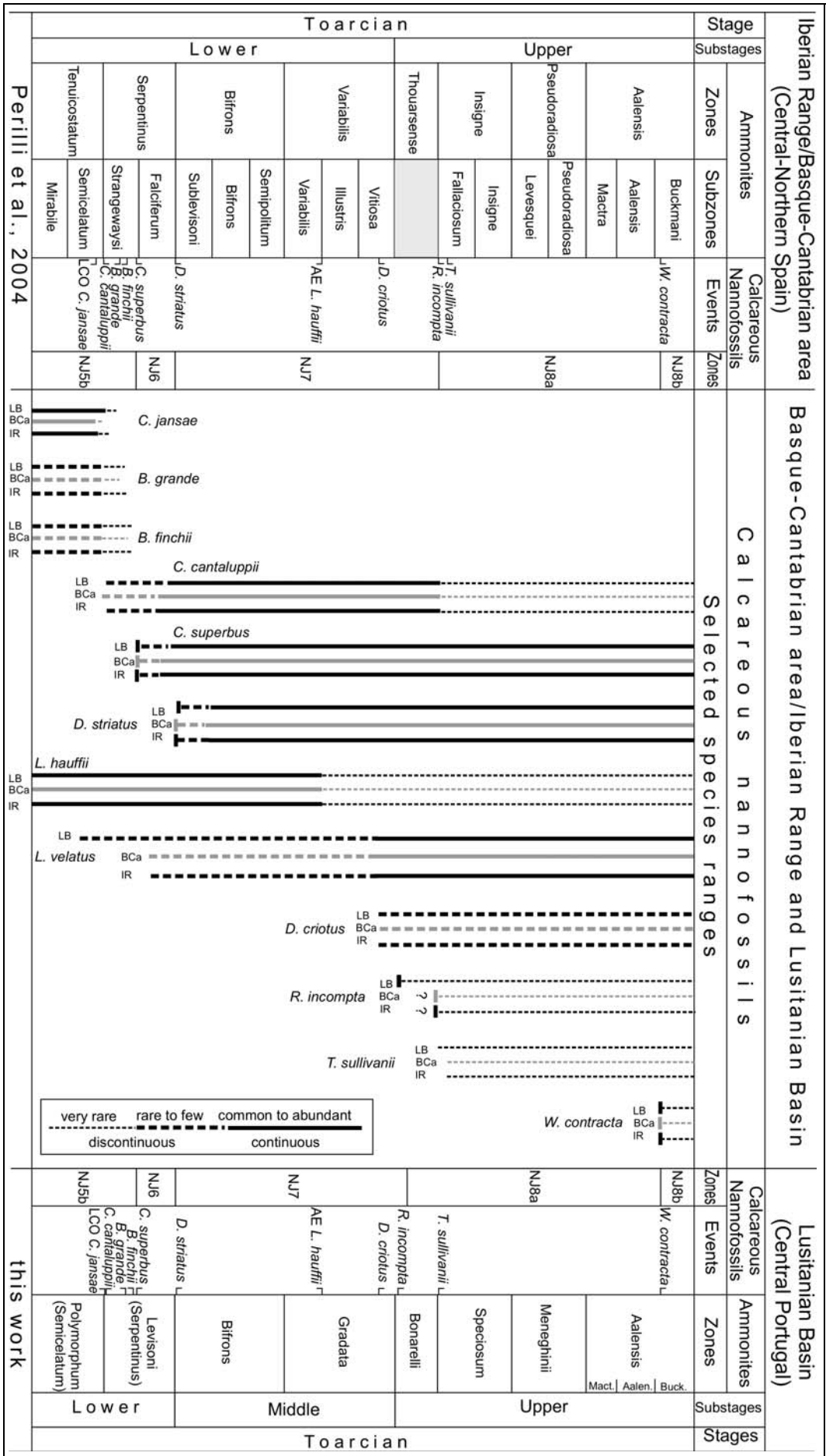


Fig. 9 - Range of some calcareous nannofossil species and events recognized in the Iberian Range/Basque-Cantabrian area and Lusitanian Basin; the ammonite subzones of the Aalensis AZ are from Perilli et al. 2002 with Mact = Mactra, Aalen = Aalensis and Buck = Buckmani; LB = Lusitanian Basin; BCa = Basque-Cantabrian area; IR = Iberian Range.

tion corresponds to the upper part of NJ5b (Bown & Cooper 1998) and includes the uppermost part of NJT5a and entire NJT5b (Mattioli & Erba 1999). In the LB, the assemblages of the upper portion of Zone NJ5 are characterised by the common co-occurrence of *L. hauffii* and *C. jansae*, along with *Schizosphaerella* spp., *C. crassus*, *B. novum*, *S. cruciulus*, *T. patulus*, *B. finchii*, *B. grande*, *B. prinsii*, *L. umbriensis* and *L. sigillatus*. In the assemblages recovered from the uppermost portion of Zone NJ5, the occurrence of *C. noelae recondita* and *C. noelae depressa*, the FO of *C. cantaluppii*, the LCO of *C. jansae*, and the LOs of *B. grande*, *B. finchii* and *C. jansae* are nicely detectable.

NJ6 *Carinolithus superbus* Zone.

Author: Bown (1987).

Definition: FO of *Carinolithus superbus* to the FO of *Discorhabdus striatus*.

Range in this study: Lower Toarcian (Levisoni AZ to Levisoni/Bifrons AZ boundary).

Remarks. Utilized in both NW Europe and Mediterranean Province, this zone is comprised within the Serpentinus AZ either the IR/BCa or the LB. In the studied sections, the FO of *C. superbus* could be overlooked because it is rare in its initial range. Nonetheless the NJ5/NJ6 Zone boundary has been recognized in all

the sections where the Levisoni AZ crops out. In the upper portion of Zone NJ6, the relative abundance of *Carinolithus* sharply increases and the presence of *L. velatus* is easily detectable.

NJ7 *Discorhabdus striatus* Zone.

Author: Bown (1987).

Definition: FO of *Discorhabdus striatus* to the FO of *Retecapsa incompta*.

Range in this study: Lower Toarcian (Levisoni/Bifrons AZ boundary) to Upper Toarcian (Bonarelli AZ).

Remarks. Adopted by Bown & Cooper (1998) and Mattioli & Erba (1999), this zone, is recognizable also in the Basque Cantabrian area. In the LB, the lower part of the Zone NJ7, the assemblages are still dominated by the presence of *L. hauffii* along with the genera *Carinolithus* and *Discorhabdus*. In the upper portion of Zone NJ7, the genera *Carinolithus* and *Discorhabdus* occur along with *L. velatus* and scattered specimens of *D. criotus*.

NJ8 *Biscutum intermedium* Zone.

Author: Bown (1987), Bown et al. (1988).

Definition: FO of *R. incompta* to the FO of *Watznaueria britannica*.

		NW Europe Bown & Cooper (1998)			Central-Northern Spain Perilli et al. (2004)					Central Portugal <i>this paper</i>				Italy/S France Mattioli & Erba (1999)															
Stage	Substages	Ammonites		Calcareous Nannofossils		Ammonites		Calcareous Nannofossils			Calcareous Nannofossils		Ammonites		Calcareous Nannofossils		Ammonites		Substages	Stage									
		Zones	Sub.z	Zones	Sub.z	Zones	Sub.z	Events	Events	Zones	Sub.z	Zones	Sub.z	Zones	Sub.z	Zones	Sub.z												
Toarcian	Upper	Levesquei	NJ8	NJ8a	Aalensis	Buckmani	NJ8b	<i>W. contracta</i>	<i>W. contracta</i>	NJ8b	NJ8b	NJ8b	Aalensis	NJT8	NJT8a	Meneghinii	NJT8	NJT8a	Meneghinii	Upper									
																						Pseudoradiosa	Pseudoradiosa	NJ8a	NJ8a	Meneghinii	NJT7b	<i>D. criotus</i>	Erbaense
																						Insigne	Insigne	NJ8a	NJ8a	Meneghinii	NJT7b	<i>D. criotus</i>	Erbaense
	Thouarsense	Thouarsense	NJ8a	NJ8a	Meneghinii	NJT7b	<i>D. criotus</i>	Erbaense																					
									Thouarsense	Thouarsense	NJ8a	NJ8a	Meneghinii	NJT7b	<i>D. criotus</i>	Erbaense													
	Variabilis	Variabilis	NJ7	NJ7	NJ7	NJ7	NJ7	NJ7									NJ7	NJ7	NJ7	NJ7	NJ7	NJ7	NJ7	NJ7	NJ7	Middle	Toarcian		
									Bifrons	Bifrons	NJ7	NJ7	NJ7	NJ7	NJ7	NJ7												NJ7	NJ7
	Falciferum	C. superbus	Serpentinus	Falciferum	NJ6	C. superbus	<i>C. superbus</i>	<i>C. superbus</i>									<i>C. superbus</i>	NJ6	C. superbus	Levisoni (Serpentinus)	NJT6	C. superbus	Serpentinus	NJT6	C. superbus	Serpentinus	Lower		
Tenuicostatum									NJ5	L. hauffii	NJ5b	C. imponius	NJ5	L. hauffii	NJ5b	C. imponius												NJ5	L. hauffii
	Mirabile	NJ5	L. hauffii	NJ5b	C. imponius	NJ5	L. hauffii	NJ5b									C. imponius	NJ5	L. hauffii	NJ5b	C. imponius	Polymorphum (Semicelatum)	NJT5	L. hauffii	NJT5b	L. sigilli	Tenuicostatum		

Fig. 10 - Toarcian biostratigraphic zones and events recognized in the IR/BCa and LB and their calibration with respect to the ammonite zones and subzones and correlation scheme proposed for NW Europe and Italy/S France. Subz.= Subzones; L. sigill.= L. sigillatus.

Range in this study: only the Lower (Toarcian) portion of the zone has been studied.

Remarks. The zone is divided in two subzones in NW Europe and in three subzones in Italy/S France. In the LB the assemblages belonging to lowermost portion of Zone NJ8 are dominated by the genera *Schizosphaerella* spp., *Carinolithus* and *Discorhabdus* together with medium-sized *Lotharingius* (mainly *L. velatus* and *L. crucicentralis*), and the mentioned transitional forms between *Lotharingius* and *Watznaueria*. Within this zone, *R. incompta* and *T. sullivanii* are rare or extremely rare, particularly in their initial ranges. The first specimens of *W. contracta* (i.e. *Lotharingius contractus*) allow the recognition of the NJ8a/NJ8b or NJT8a/NJT8b Subzone boundaries of Bown & Cooper (1998) and Mattioli & Erba (1999), respectively.

Biostratigraphic potential of calcareous nannofossils

In order to evidence the potential of calcareous nannofossils for biocorrelation, the distribution pattern of age-significant taxa and the events recognized in the LB are compared with those identified in central-northern Spain (Fig. 9). In the expanded sections of the Iberian Range (IR) and Basque-Cantabrian (BCa) area the samples are directly calibrated with respect to the ammonite zones and subzones (Perilli 1999a, 2000; Perilli et al. 2004). The succession of biohorizons is also compared with previous findings from other tethyan and boreal sections. Furthermore, it is here evidenced the correspondence between nannofossils zones/subzones and ammonite zones/subzones utilized in LB, IR/BCa, NW Europe and Italy/S France (Fig. 10).

In the LB, the LCO and LO of *C. jansae* lie above the Polymorphum/Levisoni AZ boundary. In the IR/BCa, the LCO *C. jansae* took place within the Semicelatum ASz and the LO of *C. jansae* is recognized slightly below (BCa) or above (IR) the Tenuicostatum/Serpentinus AZ boundary. Hence the abundance decrease of *C. jansae* may be helpful to divide the Toarcian interval of Zone NJ5 into two parts. Nearly coinciding to the Polymorphum or Tenuicostatum AZ, the lower ones is still dominated by *C. jansae*. In the upper part, corresponding to the lower portion of the Levisoni or Serpentinus AZ, it is extremely rare or absent. The LO of *C. jansae* is placed within the Tenuicostatum AZ by Bown (1987) and Bown et al. (1988) and within the Serpentinus AZ or Serpentinus/Falciferum by Mattioli & Erba (1999) and de Kaenel et al. (1996), respectively.

The subsequent set of events includes the LOs of *B. grande* and *B. finchii* and the FO of *C. superbis*. A similar distribution pattern has been recognized in the IR/BCa as in NW Europe (Bown & Cooper 1998). It is

not excluded that the NJ5/NJ6 Zone boundary, lying above the disappearance of *B. finchii*, may be helpful to identify the Exaratum/Falciferum (Howart 1992; Elmi et al. 1994, 1997) or Elegantulum/Falciferum (Elmi et al. 1997) ASz boundaries in NW Europe. In Morocco and Switzerland, the LO of *B. finchii* and the FO of *C. superbis* lie within the Falciferum/Serpentinus (de Kaenel et al. 1996). In Italy/S France, the FO *C. superbis* is comprised within the Tenuicostatum AZ, and *B. grande* and *B. finchii* disappear in the Aalenian Concavum AZ (Mattioli & Erba 1999).

In the Sublevisoni ASz has been recognized the appearance and the abundance increase of the *D. striatus*. This increase has been identified within the Sublevisoni ASz also in the IR/BCa, where the FO of *D. striatus* coincides with the Serpentinus/Bifrons AZ boundary. The placement of the NJ6/NJ7 Zone boundary about the Levisoni/Bifrons (LB) and the Serpentinus/Bifrons (IR/BCa) AZ boundary is consistent with the proposed correlation between these boundaries suggested by Elmi et al. (1989). The FO of *D. striatus* nearly approaches the Levisoni/Bifrons (Bown & Cooper 1998), as well the Serpentinus/Bifrons or Falciferum/Bifrons AZ boundary (Mattioli & Erba 1999; de Kaenel et al. 1996). Consequently, the NJ6/NJ7 or NJT6/NJT7 Zone boundaries are useful to identify the base of the Bifrons AZ in tethyan or boreal sections (see discussion in Perilli et al. 2004).

Though the calibration against ammonite zones of the FOs of *D. criotus*, *R. incompta* and *T. sullivanii* should be further tested, they are comprised between the Variabilis/Gradata and the Insigne/Speciosum AZs. In particular, the FO of *D. criotus* took place within the Gradata (LB) or Variabilis (IR/BCa) AZs. Also in NW Europe it lies in the Variabilis AZ (Bown & Cooper 1998). In Italy/S France the FO of *D. criotus*, placed within the Erbaense AZ, define the NJT7a/NJT7b Subzone boundary. In the LB and IR/BCa, the correspondent Zone NJ7 could be more easily divided based on the AE of *L. hauffii*, lying within the Gradata (LB) or Variabilis (IR/BCa) AZs. It has been placed within the Variabilis AZ as well in NW Europe (Bown & Cooper 1998), Switzerland and Morocco (de Kaenel et al. 1996).

The FO of *R. incompta* recognized within the Bonarelli AZs in LB, is comprised between the Variabilis and Insigne AZs in IR/BCa (see discussion in Perilli et al. 2004). Consequently, the NJ7/NJ8 Zone boundary undoubtedly occupies a lower position with respect to the placement of both NJ7/NJ8 and NJT7/NJT8 Zone boundaries in NW Europe and Italy/S France, respectively. The FO of *R. incompta* is placed in the Levesquei (Bown & Cooper 1998) or the Meneghinii (Mattioli & Erba 1999) AZs. In Switzerland and Morocco, it is recognized within the Aalensis or the

Aalenian Opalinum AZs, respectively (de Kaenel et al. 1996).

The FO of *T. sullivanii*, that in the LB lies in the Speciosum AZ, should be further improved in the IR/BCa, where it is apparently present from the Insigne AZ. This biohorizon is recognized within the Erbaense AZ in Italy/S France (Mattioli & Erba 1999) and the Aalenian Murchisonae AZ of Morocco (de Kaenel et al. 1996). The FO of *T. sullivanii* is correlatable with the FO of *Triscutum* sp., placed within the Levesquei AZ of NW Europe (Bown & Cooper 1998).

The FO of *W. contracta* lies within the Buckmani ASz in both LB (Perilli et al. 2002) and IR/BCa (Perilli 1999b), that is in a lower position with respect to the previous findings from other boreal and tethyan sections. The NJ8a/NJ8b and the NJT8a/NJT8b Subzone boundaries are placed in the Aalenian Murchisonae (Bown & Cooper 1998) or Opalinum AZs (Mattioli & Erba, 1999), respectively. In Switzerland and Morocco, the FO of *W. contracta* is recognized within the Opalinum AZ (de Kaenel et al. 1996). It is not excluded that this biohorizon could be useful to roughly approach the Toarcian/Aalenian Stage Boundary at least in LB, IR/BCa and Italy/S France as well as in Switzerland and Morocco.

Conclusive remarks

In the light of more recent studies on Lower Jurassic calcareous nannofossils recovered from sections located in different areas of the Iberian Peninsula, the Toarcian biohorizons recognized in the LB are here discussed for the first time.

The distribution pattern of age-significant taxa and the calibration of the zonal markers with respect to the ammonite zones are similar in the LB and IR/BCa. The succession of events, related to the same remarkable assemblage changes, are noticeable in well-preserved and depleted assemblages. This confirms the reproducibility and reliability of the Toarcian events recognized all along the western and northeastern margins of the Iberian Peninsula. Though based only on semiquantitative analysis, also abundance increases and abundance decreases are helpful to improve biostratigraphic resolution.

As stressed in this paper, it is not excluded that some discrepancies between the ranges of the age-significant taxa documented for the LB and IR/BCa and previous findings from NW Europe and Italy/S France are apparent. Probably, the evidenced different calibration with respect to the ammonite zones of some Toarcian nannofossil biohorizons is related to the very low abundance and discontinuous occurrence of the marker species in their final (e.g., *C. jansae*, *B. grande*, *B. finch-*

ii) or initial (e.g., *R. incompta*, *W. contracta*) ranges. The discrepancies could be amplified by wide sample-spacing as well as by a discontinuous or incomplete ammonite record.

Nonetheless, the calcareous nannofossil zones proposed for NW Europe are reproducible along the western and northeastern margins of the Iberian Peninsula and both the NJ5/NJ6 and NJ6/NJ7 Zone boundaries occupy the same position with respect to the ammonite zones. The NJ7/NJ8 Zone boundary and the NJ8a/NJ8b Subzone boundary lie in a lower position, within the Bonarelli (LB) or Insigne (IR/BCa) AZ and the Aalensis AZ (LB and IR/BCa), respectively.

Among the other events utilized by Bown & Cooper (1998), the AE of *L. hauffii* and the FO of *D. criotus* could be helpful to improve biocorrelations between NW Europe, LB and IR/BCa. On the contrary, the LOs of *Crucirhabdulus primulus* and *Orthogonoides hamiltoniane* are neither reproducible nor reliable, since these are species extremely rare. Also the FO of *Biscutum intermedium* is not reliable because this species is discontinuously present since the lowermost Toarcian of both LB and IR/BCa.

With respect to the biostratigraphic framework proposed by Mattioli & Erba (1999), both the succession of the events and the calibration of the nannofossil zone boundaries against ammonite zones (except the NJT6/NJT7 Zone boundary) are quite different in the LB and IR/BCa. The Lower Toarcian assemblage compositional change, which in Italy/S France has been recognized within the Tenuicostatum AZ, in the LB and IR/BCa took place within the Levisoni or Serpentinus AZ, respectively. On the other hand, compared to the findings from Italy/S France (Mattioli & Erba 1999), the FOs of *R. incompta* and *W. contracta* lie in a lower position with respect to the ammonite zones along the western and northeastern margin of the Iberian Peninsula.

Furthermore, the FO of *L. sigillatus*, that defines the Toarcian NJT5a/NJT5b Subzone boundary (Mattioli & Erba 1999), in the LB and BCa lies below the Pliensbachian/Toarcian Stage boundary (Perilli et al. 2004; Veiga de Oliveira et al. 2005). The FO of *C. cantaluppii* occupies a higher position approaching the Polymorphum/Levisoni or the Tenuicostatum/Serpentinus in the LB and the AZ IR/BCa, respectively. It is not excluded that this event could be useful to better define the base of the NJ6 or NJT6 Zone than the FO of *C. superbus*. However, the FO of *C. cantaluppii* along with the FOs of *D. criotus*, *T. sullivanii* and *W. contracta* could be useful to refine biocorrelation between sections cropping out in LB, IR/BCa and Italy/S France.

Taxonomic Appendix

References for the cited taxa can be found in Bown & Cooper (1998).

- Biscutum dubium* (Noël, 1965) Grün in Grün et al., 1974
Biscutum finchii (Crux, 1979) Bown, 1987
Biscutum grande Bown, 1987
Biscutum intermedium Bown, 1987
Biscutum novum (Goy, 1979) Bown, 1987
Bussonius prinsii (Noël, 1973) Goy, 1979
Calyculus spp. indet.
Calyculus noelae depressa (Goy in Goy et al., 1979) Crux, 1987
Calyculus noelae recondita (Goy in Goy et al., 1979) Crux, 1987
Carinolithus cantaluppii Cobiانchi, 1990
Carinolithus poulabronnei Mattioli, 1996
Carinolithus superbus (Deflandre, 1954) Prins in Grün et al., 1974
Crepidolithus crassus (Deflandre, 1954) Noël, 1965
Crucirhabdulus primulus Rood et al., 1973 Wiegand, 1984
Discorhabdus ignotus (Gorka, 1957) Perch-nielsen, 1968
Discorhabdus striatus Moshkovitz & Ehrlich, 1976
Lotharingius barozii Noël, 1973
Lotharingius crucicentralis (Medd, 1971) Grün & Zweili, 1980
Lotharingius hauffii Grün & Zweili in Grün et al., 1974
Lotharingius sigillatus (Stradner, 1961) Prins in Grün et al., 1974
Lotharingius velatus Bown & Cooper, 1989
Lotharingius umbriensis Mattioli, 1996
Calcivascularis jansae (Wiegand, 1984) Bown & Young in Young et al., 1986
Orthogonoides hamiltoniane Wiegand, 1984
Parhabdolithus liasicus Deflandre, 1952
Retecapsa incompta Bown & Cooper, 1989
Schizosphaerella spp. indet.
Similiscutum cruciulum de Kaenel & Bergen, 1993
Tubirhabdus patulus Prins ex Rood, Hay & Barnard, 1973

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PLATE 1

All light micrographs crossed nicols approximately X 6000.

- Fig. 1, 2 - *Calcivascularis jansae* (sample 21, Polymorphum Zone, Ribeiro sub-section).
 Fig. 3 - *Biscutum grande* (sample 23a, Polymorphum Zone, Ribeiro sub-section).
 Fig. 4 - *Biscutum grande* (sample 21, Levisoni Zone, Ribeiro sub-section).
 Fig. 5 - *Carinolithus cantaluppii* (sample 241B, Levisoni Zone, Brenha sub-section).
 Fig. 6 - *Carinolithus superbus* (sample 236, Bifrons Zone, Peniche section).
 Fig. 7 - *Biscutum finchii* (sample 20b, Polymorphum Zone, Ribeiro section).
 Fig. 8 - *Biscutum finchii* (sample 23a, Polymorphum Zone, Ribeiro section).
 Fig. 9 - *Carinolithus cantaluppii* (sample VLR40, Levisoni Zone, Fornos sub-section).

- Fig. 10 - *Carinolithus superbus* (sample 241C, Levisoni Zone, Peniche section).
 Fig. 11 - *Discorhabdus striatus* (sample 58f, Bifrons Zone, Rabacal section).
 Fig. 12 - *Discorhabdus criotus* (sample 60m, Gradata Zone, Rabacal section).
 Fig. 13 - *Discorhabdus striatus* (sample 298, Bifrons Zone, Brenha sub-section).
 Fig. 14 - *Discorhabdus criotus* (sample 65+9, Gradata Zone, Cantanhede sub-section).
 Fig. 15 - *Crepidolithus granulatus* (sample 15b, Polymorphum Zone, Peniche section).
 Fig. 16 - *Retecapsa incompta* (sample 25, Speciosum Zone, Cantanhede sub-section).
 Fig. 17 - *Triscutum sullivani* (sample 29, Speciosum Zone, Povoa da Lomba sub-section).
 Fig. 18 - *Triscutum tiziense* (sample 36, Aalensis Zone, Povoa da Lomba sub-section).

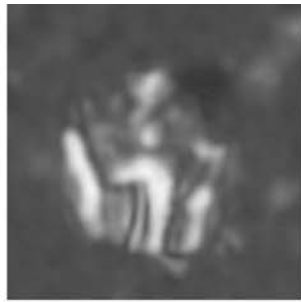
PLATE 2

All light micrographs crossed nicols approximately X 6000.

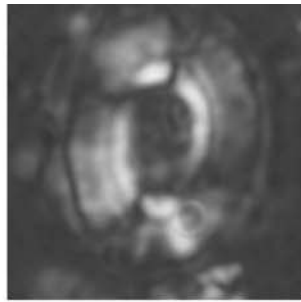
- Fig. 1 - *Similiscutum cruciulum* (sample LOR1, Levisoni Zone, Fornos sub-section).
 Fig. 2 - *Similiscutum cruciulum* (sample 23b, Polymorphum Zone, Ribeiro sub-section).
 Fig. 3 - *Calyculus noelae depressa* (sample 230, Levisoni Zone, Brenha sub-section).
 Fig. 4 - *Calyculus* spp. (sample 225, Levisoni Zone, Brenha sub-section).
 Fig. 5 - *Tubirhabdus patulus* (sample 40B, Levisoni Zone, Brenha sub-section).
 Fig. 6 - *Carinolithus poulabronnei* (sample LOR1, Levisoni Zone, Fornos sub-section).
 Fig. 7 - *Calyculus noelae recondita* (sample 230d, Levisoni Zone, Fornos sub-section).
 Fig. 8 - *Calyculus noelae recondita* (sample 230, Levisoni Zone, Brenha sub-section).
 Fig. 9 - *Orthogonoides hamiltoniae* (sample 27, Polymorphum Zone, Peniche section).
 Fig. 10 - *Carinolithus poulabronnei* (sample LOR14, Levisoni Zone, Fornos section).
 Fig. 11 - *Mitrolithus elegans* (sample 27, Polymorphum Zone, Peniche section).
 Fig. 12 - *Mitrolithus elegans* (particular of the spine, same specimens figured in Fig. 12).
 Fig. 13 - *Biscutum dubium* (sample 230-FB, Levisoni Zone, Fornos sub-section).
 Fig. 14 - *Biscutum dubium* (sample 228, Bifrons Zone, Peniche section).
 Fig. 15 - *Parhabdolithus liasicus liasicus* (sample 178, Levisoni Zone, Brenha sub-section).
 Fig. 16 - *Crepidolithus cavus* (sample 18R, Polymorphum Zone, Ribeiro sub-section).
 Fig. 17 - *Biscutum novum* (sample 214, Levisoni Zone, Peniche section).
 Fig. 18 - *Calyculus* spp. (sample 228, Bifrons Zone, Peniche section).



1 *Calcivascularis jansae*



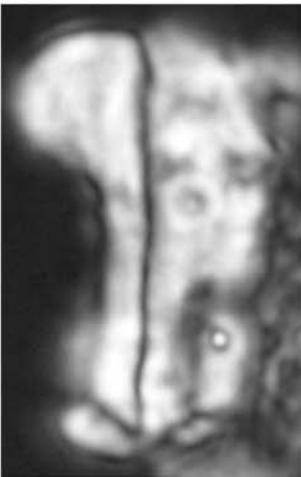
2 *Calcivascularis jansae*



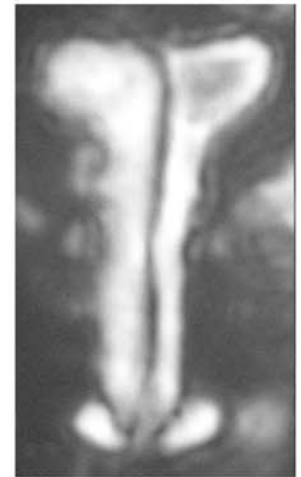
3 *Biscutum grande*



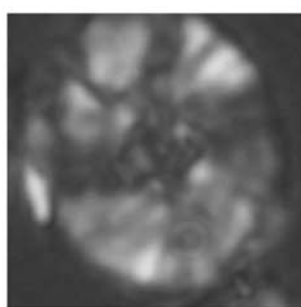
4 *Biscutum grande*



5 *Carinolithus cantaluppii*



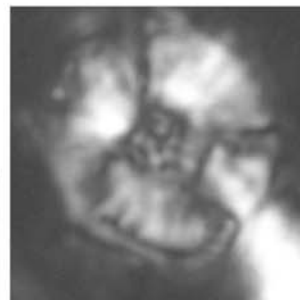
6 *Carinolithus superbus*



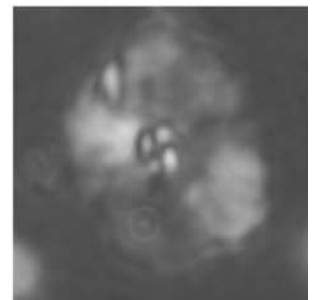
7 *Biscutum finchii*



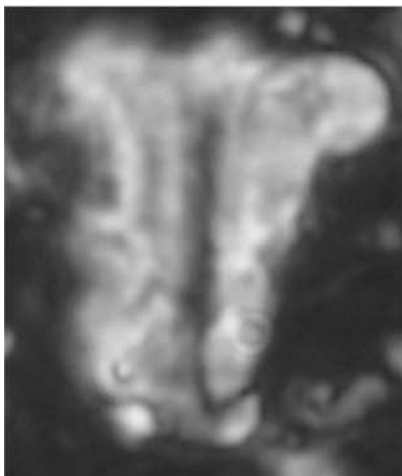
8 *Biscutum finchii*



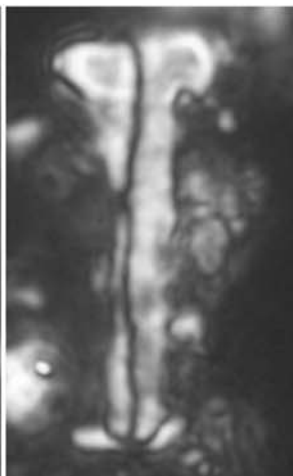
11 *Discorhabdus striatus*



12 *Discorhabdus criotus*



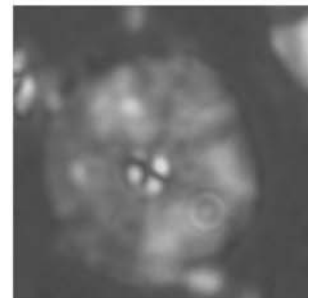
9 *Carinolithus cantaluppii*



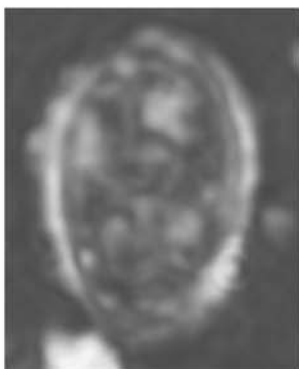
10 *Carinolithus superbus*



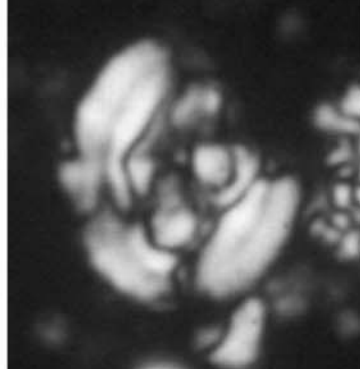
13 *Discorhabdus striatus*



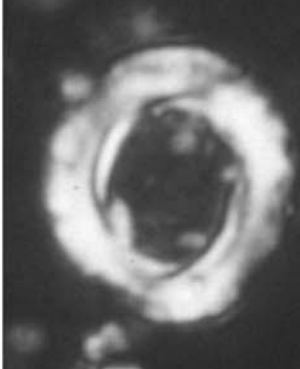
14 *Discorhabdus criotus*



15 *Crepidolithus granulatus*



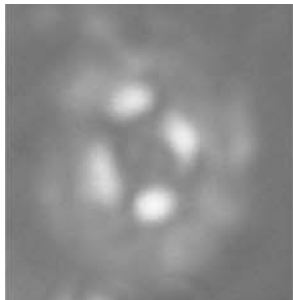
16 *Retecapsa incompta*



17 *Triscutum sullivanii*



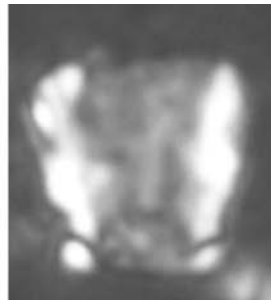
18 *Triscutum tiziense*



1 *Similiscutum cruciulus*



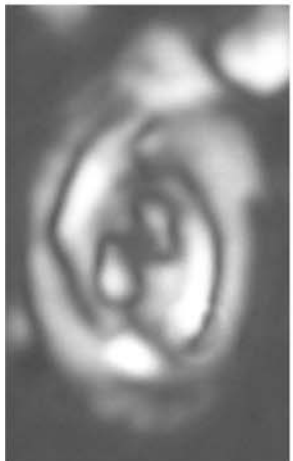
2 *Similiscutum cruciulus*



3 *C. noeale depressa*



4 *Calyculus* spp.



5 *Tubirhabdus patulus*



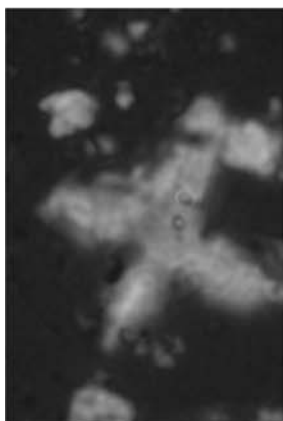
6 *Carinolithus poulabrounei*



7 *C. noeale recondita*



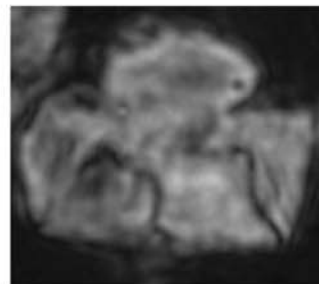
8 *C. noeale recondita*



9 *O. hamiltoniae*



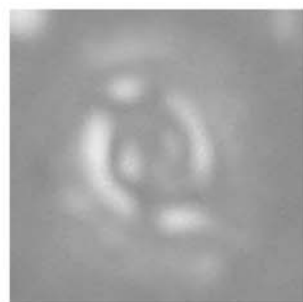
10 *Carinolithus poulabrounei*



11 *Mitrolithus elegans*



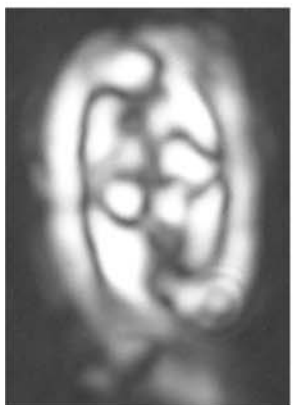
12 *Mitrolithus elegans*



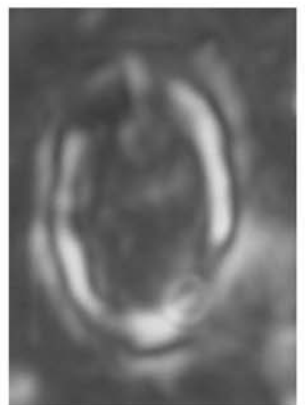
13 *Biscutum dubium*



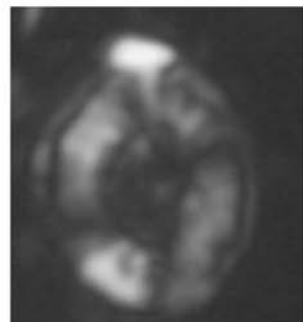
14 *Biscutum dubium*



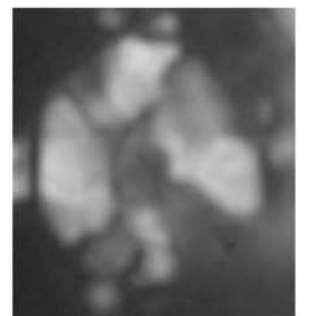
15 *P. liasicus liasicus*



16 *Crepidolithus cavus*



17 *Biscutum novum*



18 *Calyculus* spp.

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