

CALIBRATION OF PLIENSCHACHIAN CALCAREOUS NANNOFOSSIL EVENTS IN TWO AMMONITE-CONTROLLED SECTIONS FROM NORTHERN SPAIN (BASQUE-CANTABRIAN AREA)

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Riassunto. Due sezioni continue ed espanse del Pliensbachiano, affioranti nell'area Basco-Cantabrica e già datate in base alle ammoniti, sono state campionate per lo studio dei nannofossili calcarei. Entrambe hanno fornito nannoflore calcaree ricche e diversificate che hanno permesso di descrivere, per questo settore sud-orientale del Dominio Boreale, i cambiamenti principali delle associazioni e di calibrare, rispetto alle zone ad ammoniti, gli eventi riconosciuti.

Il primo significativo cambio è rappresentato dalla comparsa e dall'incremento in abbondanza del genere *Similiscutum* che, insieme ai generi *Crepidolithus* e *Parhabdololithus*, è un costituente comune delle associazioni a nannofossili calcarei fino al Domeriano inferiore. Sebbene al passaggio Carixiano/Domeriano si registri la comparsa dei generi *Biscutum* e *Bussonius*, è solo nel Domeriano inferiore che si verifica l'altro significativo cambio della composizione delle associazioni a nannofossili calcarei. Questo cambio è legato all'aumento repentino in abbondanza del genere *Calcivascularis* ed alla comparsa del genere *Lotharingius*, che subito diventa un costituente dominante nelle associazioni del Domeriano superiore, caratterizzate anche dalla significativa presenza del genere *Biscutum*.

Questi cambiamenti forniscono una successione di bioorizzonti facilmente riconoscibili ed attendibili, che comprendono la comparsa di *Similiscutum avitum* e *Similiscutum cruciulus* (Zona a Jamesoni), di *Lotharingius barozii* e *Lotharingius hauffii* (limite tra le Zone Stokesi/Margaritatus) e il netto incremento in abbondanza di *Lotharingius hauffii* (limite tra le Zone Margaritatus/Spinatum). Anche l'aumento in abbondanza di *Calcivascularis jansae* (limite tra le Zone Stokesi/Margaritatus) sembra essere un evento utile ed attendibile, almeno alla scala regionale. Al contrario la comparsa di *Biscutum dubium*, *Bussonius prinsii* (Zona a Davoei), *Biscutum novum*, *Biscutum grande* e *Biscutum finchii* (Stokesi Zone) risulta difficile da calibrare con precisione rispetto alle zone ad ammoniti, in quanto queste specie sono generalmente rare e caratterizzate da presenza discontinua, soprattutto all'inizio della loro distribuzione.

Abstract. Common and diverse calcareous nannofossil assemblages were found in two continuous and expanded successions, sedimented on hemipelagic carbonate ramp. Based on refined ammonite biostratigraphy, closely spaced sampling and semiquantitative analysis, the main purpose of this paper is to calibrate against ammonite zones and subzones, the nannofossil composition changes and the identified biohorizons.

In the study area, the first notable composition change is in the lower Carixian, with the appearance and abundance increase of the genus *Similiscutum*, that represents a large amount of the assemblages up to the lower Domerian. Although, the appearance of the genera *Biscutum* and *Bussonius* is easily detectable around the Carixian/Domerian Zone boundary, the other relevant Pliensbachian composition changes took place in the lower Domerian. It includes the sharp abundance increase of *Calcivascularis* and the abundance appearance of the genus *Lotharingius*, that dominate the upper Domerian assemblages, also characterized by the significant presence of the genus *Biscutum*.

The set of easily recognizable and reliable events includes the First Occurrences (FOs) of *Similiscutum avitum* and *Similiscutum cruciulus* (Jamesoni Zone), the FOs of *Lotharingius barozii* and *Lotharingius hauffii* (Stokesi/Margaritatus Zone boundary), the First Common Occurrence (FCO) of *Lotharingius hauffii* (Margaritatus/Spinatum Zone boundary) and, probably, the FCO of *Calcivascularis jansae* (Stokesi/Margaritatus Zone boundary). Instead, the FOs of *Biscutum dubium*, *Bussonius prinsii* (Davoei Zone), *Biscutum novum*, *Biscutum grande* and *Biscutum finchii* (Stokesi Zone) are slightly difficult to calibrate against ammonite zones.

Introduction

After first appearing in the Late Triassic, the calcareous nannoplankton became a significant component of phytoplankton in the Early Jurassic and their skeletal remains are one of the main constituents of Mesozoic and Cenozoic marine carbonate sediments (Bown et al. 1992). In the Hettangian-Sinemurian, the appearance of the genera *Schizosphaerella*, *Parhabdololithus*, *Crepidolithus* and *Mitrolithus* took place. During the Pliensbachian, the genera *Similiscutum*, *Bussonius*, *Biscutum* and *Lotharingius* first appeared and became important assemblage components. These evolutionary events provides a succession of age-diagnostic nannobiohorizons, that includes, amongst others, the first occurrences of *Similiscutum cruciulus*, *Biscutum novum*, *Bussonius prinsii*, *Biscutum dubium*, *Biscutum finchii*, *Lotharingius hauffii* and *Lotharingius sigillatus* and the last occurrences of *Crepidolithus pliensbachiensis*, *Parhabdololithus robustus* and *Parhabdololithus liasicus liasicus* (de Kaenel et al.

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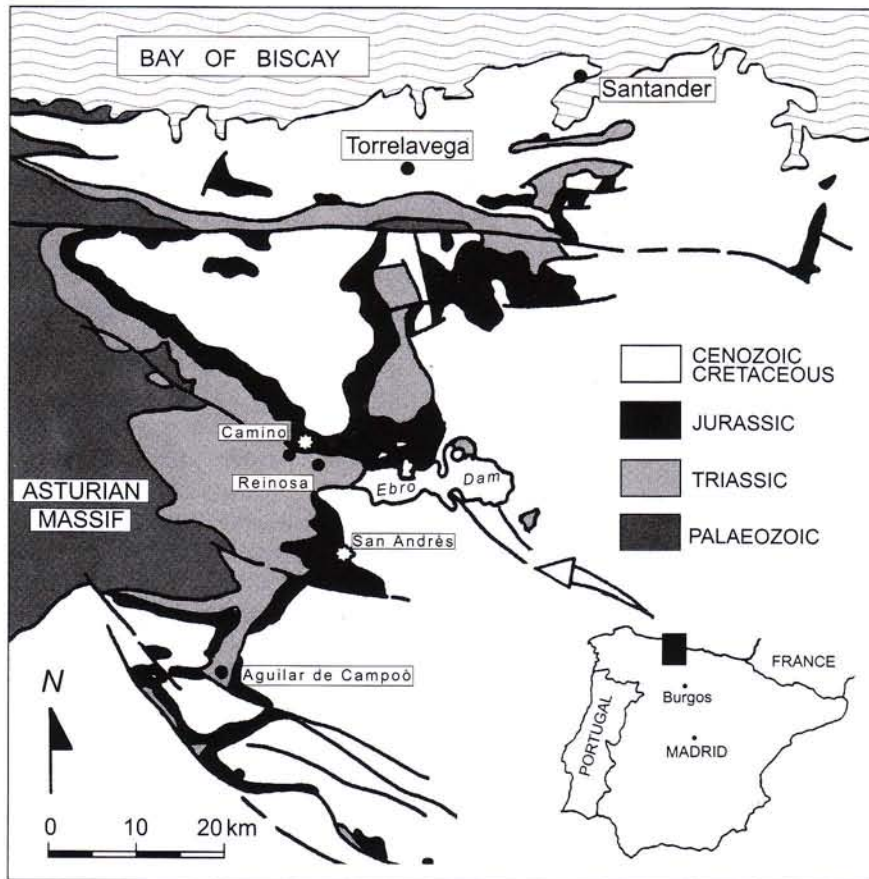


Fig. 1 - Geological sketch of Basque-Cantabrian area and location (white asterisks) of the Camino and San Andrés sections (simplified from Robles et al. 1988).

1996; Bown & Cooper 1998; Mattioli & Erba 1999).

Unfortunately, some of these events are not yet well calibrated to the ammonite biostratigraphy because of either the miscalibration of the collected samples with respect to the ammonite zones or the absence of a refined ammonite biostratigraphy. The different placements of nannobiohorizons by various authors, when they are not related to diachroneity or to an incomplete palaeontological and/or lithostratigraphic record, could be also due to sample spacing or reworking. Nevertheless, many authors agree to place both the appearance of the radiate two-shield placoliths in the lower Carixian and the major radiation of the placolith coccoliths in the lower Domerian. Furthermore, the first occurrences of *Similiscutum cruciulus*, *Biscutum novum*, *Biscutum finchii* and *Lotharingius hauffii* seem to be the main relevant Pliensbachian nannobiohorizons utilized in both Boreal and Tethyan sections. On the other hand, the precise order and the calibration of other proposed events remain problematic since they are utilized only in some areas or have been recognized only by some authors (see tab. III of de Kaenel et al. 1996; fig. 4 of Bown & Cooper 1998, and figs. 6-10 of Mattioli & Erba 1999). It is not excluded that some discrepancies could be related to paleoprovinciality.

Up to now Early Jurassic calcareous nannofossils have been investigated in Great Britain (Prins 1969; Barnard & Hay 1974; Hamilton 1982; Crux 1987; Bown 1987; Bown et al. 1988), Germany (Prins 1969; Crux

1984; Bown 1987; Bown et al. 1988), Northern France (Prins 1969; Barnard & Hay 1974; Bown 1987; Bown et al. 1988), Southern France (Bown 1987; Erba 1990; Lozar 1995; Mattioli & Erba 1999), Switzerland (de Kaenel in de Kaenel et al. 1996), Italy (Cobianchi 1992; Reale et al. 1992; Lozar 1995; Mattioli & Erba 1999), Portugal (Hamilton 1977, 1979; Bown 1987; de Kaenel & Bergen 1993; Bergen in de Kaenel et al. 1996) and Morocco (de Kaenel, in de Kaenel et al. 1996). In addition, Early Jurassic calcareous nannofossils from sediments drilled at Site 547B of DSDP Leg 79 on the northwest African margin of Morocco have been also studied (Wiegand 1984; Bown 1987; de Kaenel & Bergen 1993).

In Spain, calcareous nannofossils have been recently investigated in some Toarcian-Aalenian successions cropping out in the Iberian Range (Central Spain) and Basque-Cantabrian area (Northern Spain). In the Iberian Range, the studied sections are Almonacid de la Cuba (Comas-Rengifo et al. 1999), La Amunia de Doña Godina and Rambla del Salto (Perilli 2000a), and Fuentelsaz (Perilli 1999). In the Basque-Cantabrian area, the sampled sections are Tudanca and Santotis (Perilli & Comas-Rengifo in progress), Camino and San Andrés. The lower and middle Toarcian calcareous nannofossils of Camino and San Andrés have been already studied and the results have been recently published (Perilli 2000b). This paper is a result of the detailed investigation on calcareous nannofossils of the Pliensbachian succession cropping out at Camino and San Andrés, in

order to calibrate the main assemblage composition changes and the succession of the calcareous nannofossil events against ammonite zones.

Since in the majority of quoted papers the use of Carixian (= Lower Pliensbachian) and Domerian (= Upper Pliensbachian) is common, also in this work they are still preferred.

Geological setting

Post-Hercynian evolution of the Basque-Cantabrian area is linked to the geodynamic evolution of the North Atlantic domain (Ziegler 1989 for a concise summary). The first extensional Permo-Triassic rift pulse involved the western margin of the European and Iberian Plates (Masson & Miles 1986; Rat 1988; Hiscott et al. 1990). As recorded in other basins on both sides of the proto-Atlantic region, this episode was followed by a slowly progressive and essentially thermal subsidence that, without significant tectonic activity, gave rise to the Early Jurassic transgressive sedimentation (Wilson 1975). At that time, the Basque-Cantabrian area was part of an extensive epiroic sea, which covered large parts of Western Europe and the Iberian margins (Quesada & Robles 1995). As supported by paleontological data (Braga et al. 1988; Comas-Rengifo et al. 1988; Fernández-López et al. 1988) and figured in paleogeographic maps (Yilmaz et al. 1996, Olivet 1990), during the Early Jurassic the Basque-Cantabrian area was a sector of the southern part of Boreal realm, temporarily connected with the Tethys.

Broken by a series of discontinuities that bound different tectono-sedimentary units (Braga et al. 1988), the Lower-Middle Jurassic marine sequence cropping out in the Basque-Cantabrian area is extensively exposed along the border of the Paleozoic Asturian Massif (Fig. 1). The Lower Jurassic portion comprises probably Rhaetian to lower Sinemurian shallow-marine carbonate ramp sediments, unfortunately without ammonites, and upper Sinemurian-Toarcian hemipelagic ramp deposits, with a good ammonite contents and the presence of euxinic facies, deposited in anoxic troughs (Braga et al. 1988; Comas-Rengifo et al. 1988; Robles et al. 1988; Quesada et al. 1995 and ref. therein).

Based on lithostratigraphic features, the upper Sinemurian-Toarcian succession can be divided into three units. The 10-90 m thick upper Sinemurian carbonate unit is made up of limestone (mudstone and packstone) with thin intercalations of marlstone and marly limestone. The overlying 30-100 m thick Pliensbachian unit, mainly consists of marly and marly limestone alternations, with lower Carixian and lower Domerian intercalations of both organic-rich marlstone and black shale, and an upper Domerian marly limestone bioclastic member. It grades into the 60-66 m thick

Toarcian unit, that is a regular marlstone and limestone alternation, characterized by a thin intercalation of organic-rich sediments in its lower portion and the progressive thickness reduction of the marlstone towards the Toarcian/Aalenian boundary.

Location and lithostratigraphy of the studied sections

The investigated composite Camino and San Andrés sections are located in the Reinosa area, 70 Km S of Santander (Perilli 2000b). Unfortunately, the lowest portion of Camino section (4° 10' 00" W and 43° 01' 25" N; sheet n° 83 "Reinosa" of the Mapa Geológico de España), discontinuously crops out westwards and within the Camino village, whereas the largest part of the section is well-exposed east of the village (3.5 Km NE of Reinosa). Both parts of the San Andrés section (4° 11' 50" W and 42° 54' 30" N; sheet n° 108 "Las Rozas" of the Mapa Geológico de España) lie along the Puerto de Pozazal-San Andrés road (1 Km W of San Andrés village, 10 Km SE of Reinosa).

Early references to the Jurassic sedimentary succession of the Reinosa area can be found in Dahm (1965), Ramírez del Pozo (1971a, 1971b), Meléndez Hevia (1976) and Carreras et al. (1978). Later, Braga et al. (1985) described the Pliensbachian deposits exposed at Camino and its ammonite content, and Braga et al. (1988) documented the stratigraphy and ammonite biostratigraphy of the Lower and Middle Lias succession, outlining the sedimentary evolution of the south-western sector of the Basque-Cantabrian area. References to lithostratigraphy and organic-rich deposits of the "Marine Jurassic Succession" cropping out in the Basque-Cantabrian area can also be found in Robles et al. (1988), Quesada et al. (1991, 1993) and Quesada & Robles (1995).

Camino section

In the Camino area, the 283 m thick Hettangian-lower Sinemurian shallow carbonate ramp deposits grade into 212 m of upper Sinemurian-Pliensbachian hemipelagic ramp deposits (Braga et al. 1988; Quesada et al. 1993).

The Pliensbachian portion (Fig. 2), corresponding to the L-R Units of Braga et al. (1988), is mainly composed of a regular alternation of grey to dark grey limestone (mudstone and skeletal wackestone) and marlstone, with a moderate percentage of organic matter (the TOC value ranges between 0.54 and 1.48% t.w.), strong bioturbation and abundant fossil contents, chiefly represented by benthic organisms, that suggest aerobic environment.

Part of Unit L (Jamesoni Zone), Unit M (from the upper part of the IbeX Zone to the lowermost part of the

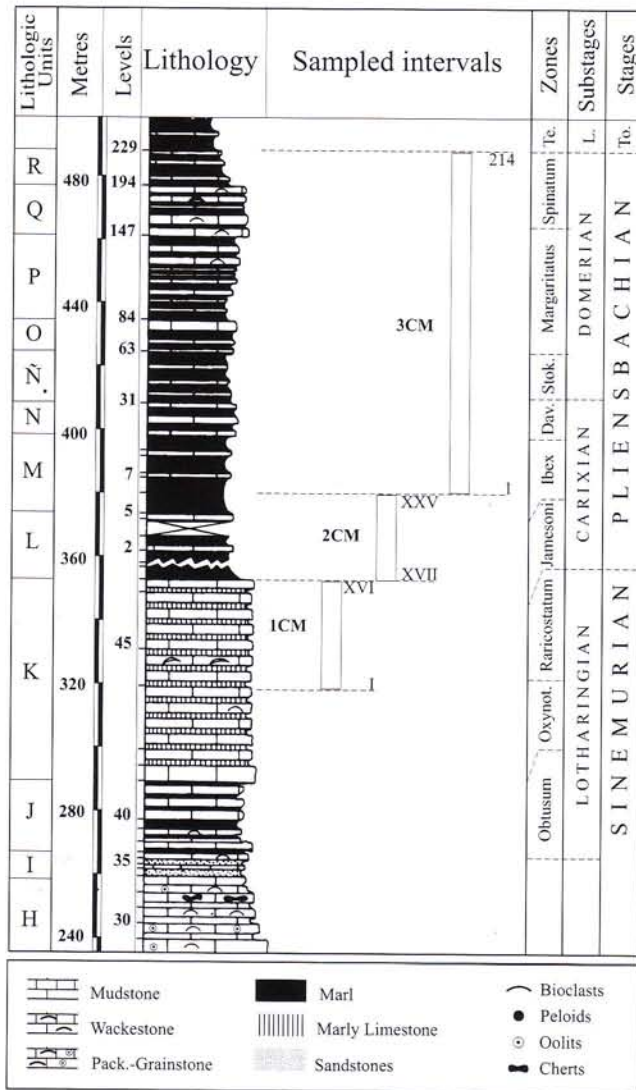


Fig. 2 - Lithostratigraphy of the upper Sinemurian-Pliensbachian succession cropping out at Camino section (slightly modified from Comas-Rengifo et al. 1988) and sampled intervals (1CM, 2CM, 3CM). The position of the samples 1CM I-XVI and 2CM XVII-XXIII is reported in Fig. 4, and the position of the samples 3CM 1-214 are reported in Fig. 6; due to the scale of the figure, the black shale are not reported. Abbreviations: Oxynot.=Oxynotum; Dav.=Davoei; Stok.=Stokesi; Te.=Tenuicostatum; L.=Lower; To.=Toarcian.

Davoei Zone) and the lower part of Unit P (lower part of the Margaritatus Zone) consist of laminated black shale and dark grey to black organic marlstone with thin intercalations of dark grey limestone (mudstone or skeletal wackestone). These lithologies are very rich in organic matter (TOC ranges from 1.62 and 4.8% t.w.) and are characterized by scarce fossil contents, represented by ammonites, belemnites and thin shell bivalves, with subordinated foraminifers and ostracods; these features indicate a benthic environment ranging from anaerobic to dysaerobic condition.

The upper part of the Domerian, corresponding to Units Q and R (Spinatum Zone), is chiefly made up of

bioclastic limestone (skeletal wackestone) intercalated with grey to dark grey marlstone with a low organic matter contents (TOC value ranges between 0.47 and 0.80 % t.w.), moderate to strong bioturbation, and rich benthic and nektonic assemblages, that support aerobic conditions through the water column.

San Andrés section

Never described before, the Pliensbachian succession of the San Andrés composite section is very similar to the coeval portion cropping out at Camino and is characterized by the occurrence of the same three lithological units previously described. Divided into 7 lithologic units (from A to G), the 90 m thick San Andrés succession comprises two portions: the lower portion ranges from Davoei Zone to the Margaritatus/Spinatum Zone boundary whilst the upper portion is entirely within the Spinatum Zone (Comas-Rengifo & Perilli in progress).

As recognized in the Camino sections, the Pliensbachian mainly consists of a regular alternation of grey to dark grey limestone and grey to dark grey marlstone with a low percentage of organic matter (TOC value ranges between 0.45 and 1.12% t.w.). The laminated black shale and dark grey to black organic-rich marlstone with an high organic matter content (TOC value ranges between 1.54 and 3.65% t.w.) characterize the upper part of the Unit C and the overlying lowermost portion of Unit D (Margaritatus Zone). Also at San Andrés, the upper part of the Domerian succession is represented by a bioclastic limestone member, chiefly consisting of limestone (mudstone and skeletal wackestone) and grey to dark grey marlstone with a low organic matter content (TOC value below 0.80% t.w.).

Materials and methods

In the investigated sections, 312 samples have been collected usually every 50-100 cm; 138 samples at Camino and 174 at San Andrés. The sampled lithologies are mainly marlstone and marly limestone. At Camino, 26 samples were discontinuously collected from the upper part of Raricostatum (cropping out westwards of the village) and the Jamesoni Zone (outcropping in the village), whilst the other closely-spaced and continuous sampling belong to the Ibex, Davoei, Stokesi, Margaritatus and Spinatum Zones. At San Andrés, the lower set of 93 samples belong to the Davoei, Stokesi and Margaritatus Zones, whilst the upper set of 48 samples have been collected from the uppermost part of the Margaritatus and Spinatum Zones. According to Braga et al. (1983) the adopted ammonite zones are well calibrated to Tethyan ammonite zones of the Betic Ranges (Fig. 3)

Simple smear slides were prepared as homogeneously as possible to get comparable sediment density on different slides. Neither centrifugation nor ultra-

Iberian Range			Betic Ranges				
Sub-stage	Zones	Subzones	Subzones	Zones	Sub-stage		
Upper Pliensbachian	Spinatum	Hawskerense	Elisa	Ema- ciatum	Upper Pliensbachian		
		Solare	Solare				
	Margaritatus	Gibbosus	Levidorsatum	Meneghinii		Algovianum	
			Accuratum	Bertrandi			
		Subnodosus	Ragazzonii				
			Celebratum	Cornacaldense			
	Stokesi	Monestieri	Portisi	Lavinia- num		?	
	Lower Pliensbachian	Davoei	Figulinum			Dilectum	Lower Pliensbachian
			Capricornus				
Maculatum							
Ibex		Luridum		Demonense	?		
		Valdani					
		Masseanum					
Jamesoni		Jamesoni		Aenigma- ticum	?		
		Brevispina					
		Taylori					

Fig. 3 - Correlation between ammonite zones and subzones utilized in the Iberian Range (central Spain) and Betic Ranges (southern Spain) as proposed by Braga et al. (1983).

sound was applied, in order to retain the original ratio between calcareous nannofossils and other components (e.g., micarbs, large carbonate fragments, quartz, micas, etc.). In order to obtain a uniform rippled distribution, a small amount of sediment was scraped and then smeared on a cover glass, dried on a hot plate, and permanently mounted on a microscope slide with Permount.

Semiquantitative analysis was performed using a Leitz light microscope at 1250 magnification. For each smear slide at least 10 complete longitudinal random transverses were analyzed (1 transverse = 170 fields of view). In order to check for the presence of rare or very rare taxa, in some smear slides more than 2000 fields of view have been observed.

Calcareous nannofossil assemblages

The majority of the samples, including those collected from the organic-rich intervals, yield common,

moderately preserved and relatively diverse assemblages, whereas the limestones usually provide rare and poorly preserved assemblages. Totally, 11 genera and 23 species have been recognized (see Appendix 1).

In the Camino section, the first fossiliferous samples, from the uppermost part of the *Raricostatum* Zone and the lowermost part of the *Jamesoni* Zone, are characterized by the exclusive presence of *Schizosphaerella* spp. The assemblages from the middle part of the *Jamesoni* Zone are still scarce but include, along with *Schizosphaerella* spp., extremely rare specimens of *S. avitum*, *S. cruciulus*, *C. crassus*, *C. jansae*, *P. liasicus distinctus* and *P. liasicus liasicus*. However, the samples from the upper part of the *Jamesoni* and the overlying *Ibex* Zones provide nicely preserved and diverse assemblages, characterized by the frequent occurrence of *Schizosphaerella* spp., *C. crassus*, *P. liasicus distinctus*, *P. liasicus liasicus*, *S. avitum* and *S. cruciulus*, along with extremely rare specimens of *C. jansae*, *C. cavus*, *C. granulatus*, *Crepidolithus* aff. *C. crassus*, *C. primulus*, *M. lenticularis* and *T. patulus*. Doubtless, the appearance and the sharp increase in abundance of the genus *Similiscutum* spp. represent the first significant composition change in Pliensbachian assemblages.

Always dominated by *Similiscutum*, *Crepidolithus* and *Parhabdolithus*, the nannofloras of the *Davoei* Zone also include extremely rare specimens of *B. dubium*, *M. lenticularis* and *M. elegans*. From the upper part of this zone, the size of *Similiscutum* slightly increases and *Bussonius* aff. *B. prinsii* and *B. prinsii* first appear, whilst the first specimens of *B. novum*, *B. grande* and *B. finchii* are observed in the overlying *Stokesi* Zone. Unfortunately, due to the low abundance and discontinuous occurrence of *B. dubium*, *B. prinsii*, *B. novum*, *B. grande* and *B. finchii* the precise order of their appearances is not yet precisely dated with respect to the ammonite zones.

At the *Stokesi*/*Margaritatus* Zone boundary, another significant assemblage composition change took place. It is related to the sharp increase in abundance of *C. jansae*, the first appearance of rare specimens of *L. barozii* and *L. hauffii*, and the notable abundance decrease of the genera *Similiscutum* and *Crepidolithus* in the lower part of the *Margaritatus* Zone. Although the abundance of genera *Lotharingius* and *Biscutum* increases in this zone, *Schizosphaerella* spp. and *C. jansae* frequently represent the bulk of the assemblages. With a sharp abundance increase of *L. hauffii* across the *Margaritatus*/*Spinatum* Zone boundary, and the further increase of *B. novum* in the lower part of the *Spinatum* Zone, the assemblage composition changes significantly again. Hence, the main constituents of the upper *Domerian* assemblages are *Schizosphaerella* spp., *C. jansae*, *L. hauffii* and *B. novum*, whilst the genera *Crepidolithus*, *Parhabdolithus* and *Similiscutum* are reduced. The genus *Bussonius* is rare to extremely rare and dis-

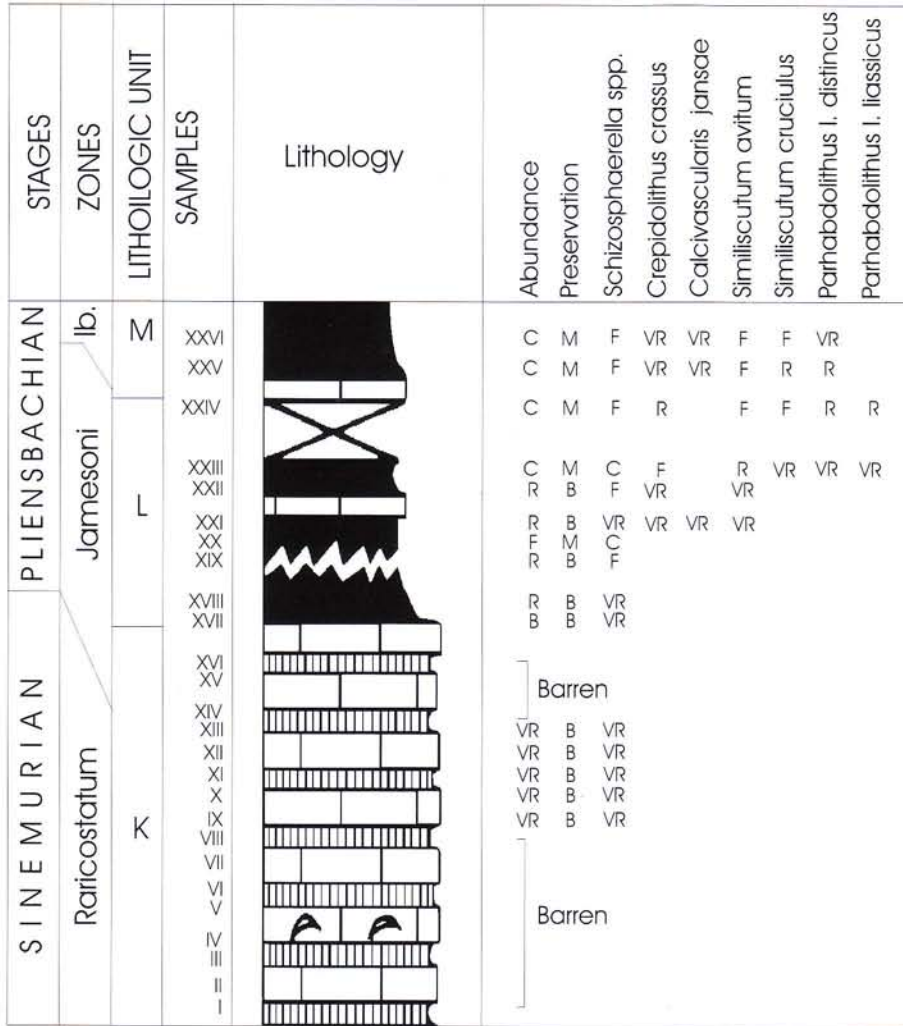
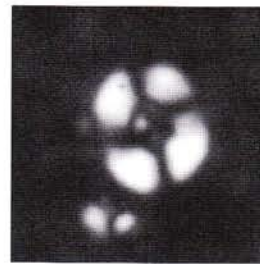
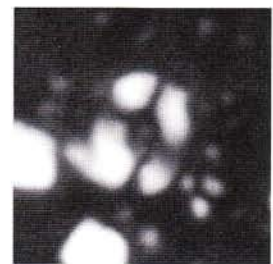
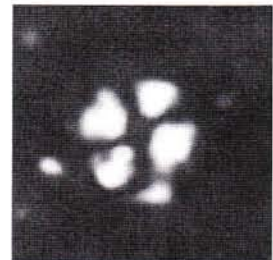


Fig. 4 - Lithostratigraphy of the Sinemurian-Pliensbachian boundary cropping out at Camino section (enlarged from Fig. 2); position of the samples 1CM I-XVI (collected westward of the village) and 2CM XVII-XXVI (collected in the village); abundance and preservation degree of the nannofossil assemblages and relative abundance of the species recognized (for assemblages abundance, preservation and relative abundance classes see Tab. I).

PLATE 1

All micrographs crossed nicols, approximately X4500 magnification

- Fig. 1 - *Lotharingius barozii* (sample 174 3CM, Spinatum Zone, Camino section)
- Fig. 2 - *Lotharingius barozii* (sample 76 3CM, Stokesi Zone, Camino section)
- Fig. 3 - *Lotharingius hauffii* (sample 77 3CM, Stokesi Zone, Camino section)
- Fig. 4 - *Lotharingius hauffii* (sample 77 3CM, Margaritatus Zone, Camino section)
- Fig. 5 - *Calcivascularis jansae* (sample 64 3CM, Margaritatus Zone, Camino section)
- Fig. 6 - *Calcivascularis jansae* (sample 64 3CM, Stokesi Zone, Camino section)
- Fig. 7 - *Calcivascularis jansae* (sample 53 1SAD, Margaritatus Zone, San Andrés section)
- Fig. 8 - *Lotharingius hauffii* (sample 53 1SAD, Margaritatus Zone, San Andrés section)
- Fig. 9 - *Bussonius prinsii* (sample 154 3CM, Spinatum Zone, Camino section)
- Fig. 10 - *Bussonius prinsii* (sample 28 1SAD, Stokesi Zone, San Andrés section)
- Fig. 11 - *Biscutum grande* (sample 148 3CM, Margaritatus Zone, Camino section)
- Fig. 12 - *Biscutum finchii* (sample 142 3CM, Margaritatus Zone, Camino section)
- Fig. 13 - *Tubirhabdus patulus* (sample 154 3CM, Spinatum Zone, Camino section)
- Fig. 14 - *Parhabdolithus liasicus distinctus* (sample 70 3CM, Margaritatus Zone, Camino section)
- Fig. 15 - *Parhabdolithus liasicus distinctus* (sample 56 3CM, Stokesi Zone, Camino section)
- Fig. 16 - *Calyculus* spp. (sample 82 3CM, Margaritatus Zone, Camino section)
- Fig. 17 - *Crepidolithus crassus* (sample 110 3CM, Margaritatus Zone, Camino section)
- Fig. 18 - *Crepidolithus granulatus* (sample 22 1SAD, Davoei Zone, San Andrés section)
- Fig. 19 - *Crepidolithus granulatus* (sample 60 3CM, Stokesi Zone, Camino section)
- Fig. 20 - *Mitrolithus lenticularis* (sample 64.2 1SAD, Margaritatus Zone, San Andrés section)
- Fig. 21 - *Similiscutum avitum* (sample 4 3CM, Jamesoni Zone, Camino section)
- Fig. 22 - *Similiscutum avitum* (sample 4 3CM, Jamesoni Zone, Camino section)
- Fig. 23 - *Similiscutum cruciulus* (sample 4 3CM, Jamesoni Zone, Camino section)
- Fig. 24 - *Similiscutum cruciulus* (sample 4 3CM, Jamesoni Zone, Camino section)

1. *L. barozii*2. *L. barozii*3. *L. hauffii*4. *L. hauffii*5. *C. jansae*6. *C. jansae*7. *C. jansae*8. *L. hauffii*9. *B. prinsii*10. *B. prinsii*11. *B. grande*12. *B. finchii*13. *T. patulus*14. *P. l. distinctus*15. *P. l. distinctus*16. *Calyculus* spp.17. *C. crassus*18. *C. granulatus*19. *C. granulatus*20. *M. lenticularis*21. *S. avitum*22. *S. avitum*23. *S. cruciulus*24. *S. cruciulus*

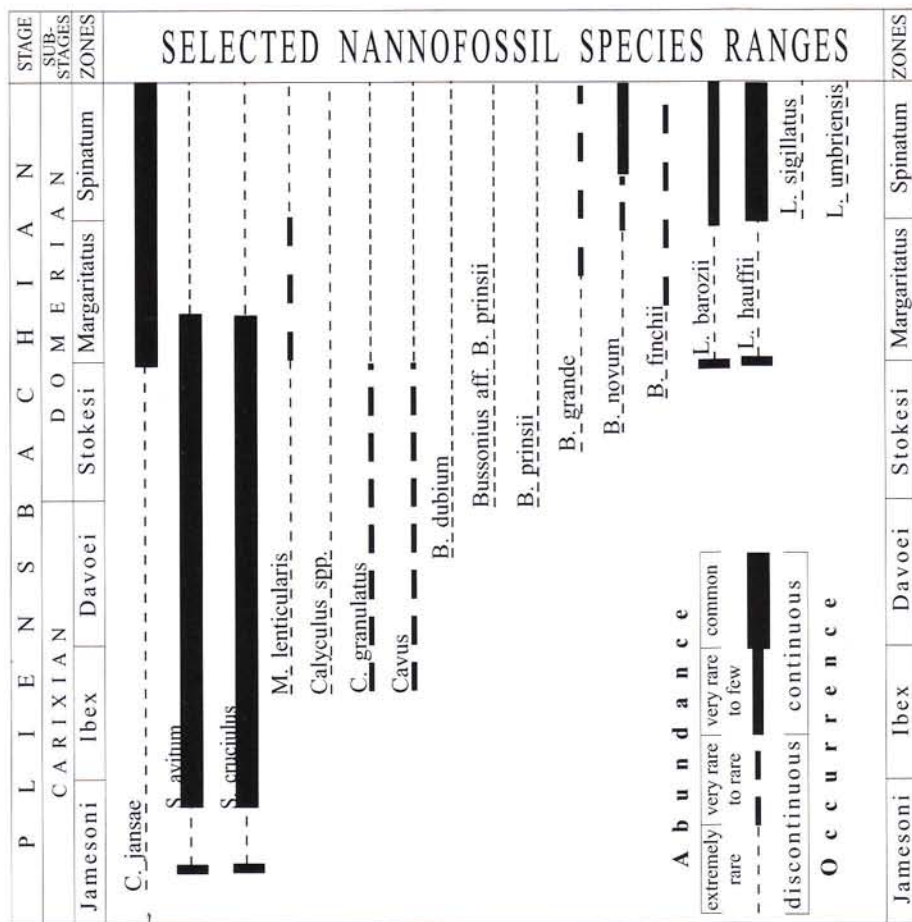


Fig. 5 - Abundance and range of some selected taxa.

ly recognizable slightly below the Stokesi/Margaritatus Zone boundary at San Andrés section and slightly above this boundary (i.e. Subnodosus Subzone) at Camino. In both sections, it nearly coincides with FO of *L. hauffii*. From the upper part of the Margaritatus Zone, *L. barozii* becomes a significant constituent of the upper Domerian assemblages.

FO and FCO of *L. hauffii*. At San Andrés, the FO of *L. hauffii* takes place slightly below the Stokesi/Margaritatus Zone boundary, whilst at Camino it lies slightly above this boundary (i.e. Subnodosus Subzones). Due to the sharp increase in abundance of this taxon, slightly below the Margaritatus/Spinatum Zone boundary (i.e. Gibbosus Subzone) at Camino section and slightly above it at San Andrés, the FCO of *L. hauffii* is a useful and easily recognizable event. It is placed in the lowermost part of the continuous range of *L. hauffii*, in correspondence to the relative abundance increase of the nominate species from very rare to rare/few.

Other events

FO of *B. prinsii*. First occurring around the Davoei/Stokesi Zone boundary in the Camino (i.e. Celebratum Subzone) and San Andrés sections, *B. prinsii* is very rare and discontinuously present in both sections.

Hence, the precise placement of this biohorizon is difficult and its biostratigraphic value doubtful.

FO of *B. dubium*. This event lies in the upper part of the Davoei Zone at Camino and in the lower part of the Stokesi Zone at San Andrés section. Unfortunately, due to its small size, low abundance and scattered occurrence, *B. dubium* can be overlooked in routine work. Consequently, its first occurrence is difficult to precisely locate and its reliability poor.

FO of *B. novum*. The first extremely rare specimens of *B. novum* have been identified in the Stokesi Zone of both Camino and San Andrés sections, below the FOs of *B. grande* and *B. finchii*. Discontinuously present up to the Margaritatus/Spinatum Zone boundary, the occurrence of *B. novum* is easily detectable in the Spinatum Zone of both sections.

FO of *B. grande*. In the studied sections, the first occurrence of this very easily recognizable large species lies within the Stokesi Zone and below the FOs of *L. barozii* and *L. hauffii*. Though *B. grande* is very rare in its initial range, the presence of this taxon is well documented from the upper Domerian of both sections.

FO of *B. finchii*. First appearing in the Stokesi Zone of Camino and San Andrés sections, the placement of this biohorizon should be carefully checked because only extremely rare specimens of *B. finchii* have been

identified below the FOs of *L. barozii* and *L. hauffii*. The relative abundance of the species slightly increases in the overlying Margaritatus and Spinatum Zones.

FCO of *C. jansae*. Recognized from the Jamesoni Zone of Camino section, *C. jansae* is extremely rare and discontinuous up to the Stokesi Zone, whilst its relative abundance sharply increases slightly below the Stokesi/Margaritatus Zone boundary of the Camino and San Andrés sections. Based on the distribution pattern of this species, the easily recognizable FCO of *C. jansae* is placed when the relative abundance of the species rises from very rare to few/common in the lower part of its continuous range.

Discussion

In this section, the reproducibility and reliability of the nannofossil events recognized in the Camino and San Andrés sections will be discussed, along with the consistencies and discrepancies with previous findings from other Boreal and Tethyan sections (Tab. VI-VII). However, comparison between sections from different faunal/floral realms and which often utilized different ammonite zonation is clearly problematic. In this study only the papers published in the last two decades will be considered, because they significantly improve the knowledge on Jurassic calcareous nannofossil biostratigraphy (for earlier findings see Bown 1987 and Mattioli & Erba 1999).

In the Basque-Cantabrian area, the FO of *S. cruciulus* is a reliable lower Carixian event lying in the Jamesoni Zone, as previously recognized in other Boreal and Tethyan sections by de Kaenel & Bergen (1993), de Kaenel et al. (1996), Bown & Young (1997), Bown & Cooper (1998) and Mattioli & Erba (1999) that locate this biohorizon in the Jamesoni Zone. Also the FO of *S. avitum* (including *S. orbiculus*) is a proven and useful biohorizon, which lies in the Jamesoni Zone according to Bown & Young (1997), de Kaenel & Bergen (1993, Morocco), de Kaenel et al. (1996, Morocco) and Mattioli & Erba (1999). Instead, de Kaenel & Bergen (1993, Portugal) placed the FO of *S. orbiculus* above the Jamesoni/Ibex Zone boundary. On the basis of the achieved results, the appearance of the genus *Similiscutum*, including the FOs of *S. cruciulus* and *S. avitum*, could be a more practical and useful event, reliable for inter-regional correlations.

Present from the Ibex Zone of the Camino section, a Carixian occurrence of *C. granulatus* is here con-

firmed. This record is consistent with Bown (1987) and Bown et al. (1988) that locate the FO of *C. granulatus* in the Ibex Zone, and de Kaenel et al. (1996, Morocco) that place this event at Ibex/Davoei Zone boundary. However, due to its low and scattered occurrence, a Sinemurian FO of *C. granulatus* is not excluded, as reported by Bown & Young (1997) and de Kaenel et al. (1996, Portugal and Switzerland) that place this event in the Oxynotum and Raricostatum Zone respectively.

In the Camino section, a Carixian occurrence of *C. cavus* is also proved, because the species is present from the Ibex Zone. On the contrary, Bown (1987), Bown & Young (1997) and Bown & Cooper (1988) locate the FO of *C. cavus* (i.e. *C. impontus*) in the Domerian Spinatum Zone.

The FO of *Calyculus* spp. is not utilized herein, being the genus rare and discontinuous in both sections; however, it is present from the Ibex Zone of the Camino section. A Carixian occurrence of the genus *Calyculus* spp., from the underlying Jamesoni Zone, is documented also by Bown & Young (1997) and Bown & Cooper (1998). Instead, the FO of *Calyculus* spp. is considered a Domerian event and placed in the Spinatum Zone by Bown (1987), Bown et al. (1988), Cobianchi (1992) and Mattioli & Erba (1999), or at Emaciatum/Tenuicostatum Zone boundary by Reale et al. (1992). Actually, Bown (1987) identified specimens of *Calyculus* spp. in the Ibex (Mochras borehole) or Davoei (Brenha section, Portugal) Zone.

Although the entry of the imbricating three-shield palcoliths genus *Bussonius* is not yet precisely located, a Carixian FO of *B. prinsii* is proved in both sections below the FO of *L. hauffii*. Nevertheless, a lower occurrence of this taxon is not excluded, according to de Kaenel & Bergen (1993, Portugal), de Kaenel et al. (1996, Portugal) and Bown & Cooper (1998) that locate this event in the Jamesoni Zone. Conversely, the FO of *B. prinsii* is placed higher, in the Domerian Spinatum Zone and above the FO of *L. hauffii* by Bown (1987), Bown et al. (1988) and Mattioli & Erba (1999).

In this work, the scarce biostratigraphic value of the FO of *B. dubium* is inferred, and its distribution pattern could partly explain the inconsistent previous findings. De Kaenel & Bergen (1993) and de Kaenel et al. (1996, Portugal and Morocco) place the FO of *Palaeopontosphaera dubia* (i.e. *B. dubium*) in the Margaritatus or Lavinianum Zone. Instead, the presence of *B. dubium* is documented from the lower Toarcian FalCIFerum Zone by Bown (1987), Bown et al. (1988) and Bown & Cooper (1998), though Bown (1987) recognized specimens of this species from the Davoei Zone (Brenha section, Portugal).

In the Basque-Cantabrian area, the FO of *B. novum* lies in the Stokesi Zone, although a Carixian first appearance is not excluded, as reported by Mattioli & Erba (1999) that locate this biohorizon in the Jamesoni

Fig. 6 - Lithology, TOC value and calcareous nannofossil events recognized in the Camino and San Andrés sections, and position of the samples (3CM 1-214, 1SAD 1-106 and 2SAD 1-56); the grey areas within the lithozone E of San Andrés section, correspond to a possible overlap between the top of the 1SAD and the bottom of the 2SAD.

FO <i>Similiscutum cruciulus</i>		
Bown & Young (1997)	lower part	Jamesoni
Bown & Cooper (1998)	lower part	Jamesoni
de Kaenel & Bergen (1993, Portugal)	middle part	Jamesoni
de Kaenel et al. (1996, Portugal)	middle part	Jamesoni
de Kaenel et al. (1996, Switzerland)	upper part	Jamesoni
de Kaenel & Bergen (1993, Morocco)	boundary	Jamesoni-Ibex
de Kaenel et al. (1996, Morocco)	upper part	Jamesoni
Mattioli & Erba (1999)	lower part	Jamesoni
This paper	middle part	Jamesoni
FO <i>Similiscutum avitum</i> (* <i>Similiscutum orbiculus</i>)		
Bown & Young (1997)*	lower part	Jamesoni
de Kaenel & Bergen (1993, Portugal)*	lower part	Ibex
de Kaenel et al. (1993, Morocco)	boundary	Jamesoni/Ibex
de Kaenel & Bergen (1993, Morocco)*	boundary	Oxyrotum/Jamesoni
de Kaenel et al. (1996, Morocco)*	boundary	Oxyrotum/Jamesoni
Mattioli & Erba (1999)*	lower part	Jamesoni
This paper	middle part	Jamesoni
FO <i>Crepidolithus granulatus</i>		
Bown (1987)	lower part	Ibex
Bown et al. (1988)	lower part	Ibex
Bown & Young (1997)	upper part	Oxyrotum
de Kaenel (1996, Portugal)	upper part	Raricostatum
de Kaenel (1996, Switzerland)	lower part	Raricostatum
de Kaenel (1996, Morocco)	boundary	Ibex/Davoei
FO <i>Crepidolithus cavus</i> (* <i>Crepidolithus impontus</i>)		
Bown (1987)	lower part	Spinatum
Bown & Young (1997)*	lower part	Spinatum
Bown & Cooper (1998)*	lower part	Spinatum
FO <i>Calyculus</i> spp.		
Bown (1987, Mochras borehole)		Ibex
Bown (1987, Brenha section)		Davoei
Bown (1987)	lower part	Spinatum
Bown et al. (1988)	lower part	Spinatum
Bown & Young (1997)	lower part	Jamesoni
Bown & Cooper (1998)	lower part	Jamesoni
Reale et al. (1992)	boundary	Emaciatum/Tenuicostatum
Cobianchi (1992)	upper part	Spinatum
Mattioli & Erba (1999)	upper part	Spinatum
FO <i>Bussonius prinsii</i>		
Bown (1987)	lower part	Spinatum
Bown et al. (1988)	lower part	Spinatum
Bown & Cooper (1998)	lower part	Jamesoni
de Kaenel & Bergen (1993, Portugal)	upper part	Jamesoni
de Kaenel et al. (1996, Portugal)	upper part	Jamesoni
Mattioli & Erba (1999)	upper part	Spinatum
This paper	boundary	Davoei/Stokesi
FO <i>Biscutum dubium</i> (* <i>Paleopontosphaera dubia</i>)		
Bown (1987, Brenha section Portugal)		Davoei
Bown (1987)	middle part	Falciferum
Bown et al. (1988)	middle part	Falciferum
Bown & Young (1997)	boundary	Tenuicostatum/Falciferum
Bown & Cooper (1998)	lower part	Falciferum
de Kaenel & Bergen (1993, Portugal)*	middle part	Lavinianum
de Kaenel et al. (1996, Portugal)*	lower part	Lavinianum
de Kaenel & Bergen (1993, Morocco)*	lower part	Margaritatus
de Kaenel et al. (1996, Morocco)*	lower part	Lavinianum
This paper	boundary	Davoei/Stokesi

◀ Tab. VIa

▼ Tab. VI b

FO <i>Biscutum novum</i> (* <i>Discorhabdus novus</i>)		
Bown & Young (1997)	lower part	Margaritatus
Bown & Cooper (1998)	lower part	Margaritatus
de Kaenel & Bergen (1993, Portugal)*	middle part	Margaritatus
de Kaenel & Bergen (1996, Portugal)*	upper part	Lavinianum
de Kaenel & Bergen (1993, Morocco)*	upper part	Lavinianum
de Kaenel (1996, Morocco)*	lower part	Algovianum
Mattioli & Erba (1999)	lower part	Jamesoni
This paper	lower part	Stokesi
FO <i>Biscutum grande</i> (* <i>Biscutum grandis</i>)		
Bown (1987, Brenha section Portugal)		Jamesoni
Bown (1987)*	lower part	Spinatum
Bown et al. (1988)*	lower part	Spinatum
Bown & Young (1997)	lower part	Spinatum
Bown & Cooper (1998)	lower part	Spinatum
Mattioli & Erba (1999)	boundary	Stokesi/Margaritatus
This paper	lower part	Stokesi
FO <i>Biscutum finchii</i> (* <i>Similiscutum finchii</i>)		
Bown (1987)	upper part	Margaritatus
Bown et al. (1988)	upper part	Margaritatus
Bown & Young (1997)	boundary	Margaritatus/Spinatum
Bown & Cooper (1998)	lower part	Margaritatus
de Kaenel & Bergen (1993, Portugal)*	middle part	Davoei
de Kaenel & Bergen (1993, Morocco)*	lower part	Lavinianum
de Kaenel et al. (1996, Morocco)*	boundary	Davoei-Lavinianum
Cobianchi (1992)	upper part	Spinatum
Reale et al. (1992)	lower part	Emaciatum
Mattioli & Erba (1999)	lower part	Spinatum
This paper	upper part	Stokesi
FO <i>Calcivascularis jansae</i> (* <i>Mitrolithus jansae</i>)		
Bown (1987)*	upper part	Raricostatum
Bown et al. (1988)*	upper part	Raricostatum
Cobianchi (1992)*	upper part	Davoei
Reale et al. (1992)*	upper part	Davoei
Lozar (1995)*	lower part	Bucklandi
Mattioli & Erba (1999)*	lower part	Bucklandi
FCO <i>Calcivascularis jansae</i>		
This paper	boundary	Stokesi/Margaritatus
FO <i>Lotharingius barozii</i>		
Cobianchi (1992)	lower part	Spinatum
Mattioli & Erba (1999)	upper part	Spinatum
This paper	boundary	Stokesi/Margaritatus
FO <i>Lotharingius hauffii</i>		
Bown (1987)	upper part	Margaritatus
Bown et al. (1988)	upper part	Margaritatus
Bown & Young (1997)	upper part	Margaritatus
Bown & Cooper (1998)	upper part	Margaritatus
de Kaenel (1996, Portugal)	lower part	Algovianum
de Kaenel (1996, Morocco)	lower part	Algovianum
de Kaenel (1996, Switzerland)	lower part	Algovianum
Cobianchi (1992)	lower part	Spinatum
Reale et al. (1992)	middle part	Emaciatum
Mattioli & Erba (1999)	middle part	Spinatum
This paper	boundary	Stokesi/Margaritatus
FCO <i>Lotharingius hauffii</i>		
This paper	boundary	Margaritatus/Spinatum

Tab. VI - Previous findings of *S. cruciulus*, *S. avitum*, *C. granulatus*, *C. cavus*, *Calyculus* spp., *B. prinsii* and *B. dubium* in Tab. VIa, and of *B. novum*, *B. grande*, *B. finchii*, *C. jansae*, *L. barozii* and *L. hauffii* in Tab. VIb (as reported by Bown 1987, Bown et al. 1988, de Kaenel & Bergen 1993, Cobianchi 1992, Reale et al. 1992, Bown & Young 1997, Bown & Cooper 1998 and Mattioli & Erba 1999). Note: because of in the original papers are utilized only ammonite zone, the reported lower, middle and upper part, or boundary, is a geometric approximation (see scaling in de Kaenel et al. 1996).

Zone. However, the FO of *B. novus* (i.e. *D. novum*) is considered a Domerian event and placed in the Lavinianum or Margaritatus by de Kaenel & Bergen (1993), de Kaenel et al. (1996, Portugal), Bown & Young (1997), Bown & Cooper (1998), or in the Algovianum Zone by de Kaenel et al. (1996, Morocco). Certainly, some of these discrepancies could be related to the documented initial rare and discontinuous occurrence of *B. novum*,

but also taxonomic biases should be taken in account (see discussion in de Kaenel et al. 1996, Bown & Cooper 1998 and Mattioli & Erba 1999).

In the studied sections, the FO of *B. grande* lies in the lower Domerian Stokesi Zone, below the FO of *L. hauffii*. Also Mattioli & Erba (1999) placed this event below the FO of *L. hauffii*, but around the Stokesi/Margaritatus Zone boundary. Bown (1987), Bown et al.

its occurrence is well-documented from the Margaritatus Zone as recognized in other Boreal and Tethyan sections. Bown (1987), Bown et al. (1988), Bown & Young (1997) and Bown & Cooper (1998) place the FO of *L. hauffii* in the Margaritatus Zone, whilst de Kaenel et al. (1996) located this biohorizon in the Algovianum Zone. The FO of *L. hauffii*, instead, is located in the overlying Spinatum or Emaciatum Zone by Cobianchi (1992), Reale et al. (1992) and Mattioli & Erba (1999). In addition, in the Basque-Cantabrian area, also the FCO of *L. hauffii* is a useful biohorizon, which could be correlated with the sharp increase in abundance of *L. hauffii* reported by Bown & Cooper (1998) within the Spinatum Zone.

Conclusions

As part of a multidisciplinary study focused on the Lower Jurassic "Marine Succession" of the Basque-Cantabrian area (Northern Spain), two continuous and expanded Pliensbachian sections have been sampled in the south-western sector of this area in order to investigate the nannofossil contents.

The composition changes of nannofossil assemblages during the Pliensbachian are characterized by first occurrences (mainly within the Jamesoni, Stokesi and Margaritatus Zones) and abundance variation (within the Jamesoni, Margaritatus and Spinatum Zones) of both genera and species. Undoubtedly, the first appearance and the abundance increase of the genera *Similiscutum* (lower Carixian) and *Lotharingius* (lower Domerian) are the main identified composition changes. Between them, the appearance of the genera *Biscutum* and *Bussonius* (upper Carixian) and the sharp increase in abundance of the genus *Calcivascularis* (lower Domerian) took place. The Domerian is also characterized by the significant decrease in abundance of the genera *Similiscutum*, *Parhabdolithus* and *Crepidolithus*, and the abundance increase of the genus *Biscutum*.

On the basis of both reproducibility and reliability, the recognized biohorizons are distinguished into two groups. Including the FOs of *S. avitum*, *S. cruciulus*, *L. barozii*, *L. hauffii* and the FCO of *L. hauffii*, the "main" events are quite easily recognizable, nicely calibrated with respect to the ammonite zones, consistent in both sections, and based on solution-resistant taxa. Certainly, the FOs of *S. cruciulus* and *L. hauffii* are the most proven and reliable biohorizons and, according to the literature, they are key-events for long-distance correlations. Proposed for the first time in this paper, also the FO of *L. barozii* and the FCO of *L. hauffii* are reliable biohorizons or at least useful for regional correlations.

In contrast, the FOs of *B. dubium*, *B. prinsii*, *B.*

novum, *B. grande*, and *B. finchii*, here labelled as "other" events, are not yet well calibrated against ammonite zones, probably because they are dissolution-susceptible taxa, rare or very rare and discontinuous, particularly in their initial ranges. Nevertheless, their reciprocal position as well as their placement with respect to main events are quite consistent in both Camino and San Andrés sections. The FOs of *B. dubium*, *B. novum* and *B. prinsii* lie above the FOs of *S. avitum* and *S. cruciulus* and below the FOs of *B. grande* and *B. finchii*. These latter events certainly precede the FOs of *L. barozii* and *L. hauffii*. Hence, the pre-Domerian FOs of *B. dubium* and *B. prinsii* and the lower Domerian FOs of *B. novum*, *B. finchii* and *B. grande* are in this paper documented.

The "other events" also include the FCO of *C. jansae*, that nearly coincides with the Stokesi/Margaritatus Zone boundary and precedes the FOs of *L. barozii* and *L. hauffii*. Although its reliability should be further proved, this event seems to be useful at least for regional correlations. Instead, a pre-Pliensbachian FO of *C. jansae* and its questionable biostratigraphic value is here hinted. The gathered data also point out the poor biostratigraphic value of the FOs of *C. granulatus*, *C. cavus* and *Calyculus* spp.; nevertheless, in the Basque-Cantabrian area, *C. granulatus*, *C. cavus* and *Calyculus* spp. occur from the early Carixian.

Based on the adopted boreal ammonite zones, the following correspondences are another achievement of this paper: the FOs of *S. avitum* and *S. cruciulus* lie above the Raricostatum/Jamesoni Zones boundary, and their abundance increase lies below the Jamesoni/Ibex Zone boundary, the FOs of *L. barozii* and *L. hauffii* roughly coincide with the Stokesi/Margaritatus Zone boundary, and the FCO of *L. hauffii* nearly corresponds to the overlying Margaritatus/Spinatum Zone boundary. Furthermore, the Davoei/Stokesi Zone boundary nearly coincides with the FO of *B. prinsii*, whilst the FCO of *C. jansae* roughly approaches the Stokesi/Margaritatus Zone boundary.

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Appendix 1

- Calcareous nannofossil species recognized or quoted in the text, bibliography reference for cited taxa can be found in Bown & Young (1997) and Bown & Cooper (1998)
- Biscutum dubium* (Noel, 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* (Noel, 1973) Goy, 1979
- Bussonius* aff. *Bussonius prinsii* (Noel, 1973) Goy, 1979
- Calciavascularis jansae* Wiegand, 1984
- Calyculus* spp. indet.
- Crepidolithus* spp.
- Crepidolithus crassus* (Deflandre, 1954) Noel, 1965
- Crepidolithus* aff. *C. crassus* (Deflandre, 1954) NOEL, 1965
- Crepidolithus cavus* Rood, Hay and Barnard, 1973
- Crepidolithus granulatus* Bown, 1987
- Crepidolithus plienschachensis* Crux, 1985
- Crepidolithus primulus* Prins 1969 ex Rood, Hay and Barnard, 1973
- Lotharingius barozii* Noel, 1973
- Lotharingius hauffii* Grün and Zweili, 1980 in Grün et al., 1974
- Lotharingius sigillatus* (Stradner, 1961) Prins in Grün et al., 1974
- Lotharingius umbriensis* Mattioli, 1996
- Mitrolithus elegans* Deflandre in Deflandre & Fert 1954
- Mitrolithus lenticularis*, Bown, 1987
- Pararhabdolithos liasicus distinctus* (Deflandre, 1952) Bown, 1987
- Pararhabdolithos liasicus liasicus* Deflandre, 1952
- Pararhabdolithos robustus* Noel, 1965
- Schizosphaerella* spp.
- Similiscutum avitum* De Kaenel and Berger, 1993
- Similiscutum cruciulus* De Kaenel and Berger, 1993
- Tubirhabdus patulus* Prins 1969 ex Rood, Hay and Barnard, 1973