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PLIENSBACHIAN CALCAREOUS NANNOFOSSILS OF THE SANTOTIS SECTION (BASQUE-CANTABRIAN BASIN, N SPAIN)

Abstract - The target of this paper is to study the succession of the Pliensbachian calcareous nannofossil assemblages recovered from the Santotis section (Northern Spain) in order to calibrate the biohorizons against the ammonite zones. In this section, one hundred nineteen marly and carbonate-dominated levels have been recognized and forty-one of them have been sampled. The semiquantitative analysis has been carried out on smear slides and reveals that the majority of the assemblages show a bad to moderate degree of preservation and the species abundance varies from rare to frequent. In the studied section, the most relevant Pliensbachian composition changes of the assemblages are the first appearances of the genera *Similiscutum* (Jamesoni Zone) and *Lotharingius* (Stokesi Zone). The assemblages further change due to the appearance of the species belonging to the genus *Biscutum*. The succession of the assemblages have allowed the identification of two main events, the FOs of *Similiscutum cruciulus* (Jamesoni Zone) and *Lotharingius hauffii* (Stokesi Zone) as well as four secondary events, the FOs of *Biscutum novum* (Davoei Zone), *Biscutum grandis* (Stokesi Zone), *Biscutum finchii* (Stokesi Zone) and *Lotharingius barozii* (Stokesi Zone). Assemblages and biohorizons have allowed the identification of the upper part of the NJ3 Crepidolithus crassus Zone, the complete NJ4 Similiscutum cruciulus Zone and the almost complete NJ5 Lotharingius hauffii Zone.

Key words - Calcareous nannofossils, biostratigraphy, semiquantitative analysis, Pliensbachian, Lower Jurassic, Basque-Cantabrian Basin, Northern Spain.

Riassunto - *Nannofossili calcarei del Pliensbachiano della sezione di Santotis (Bacino Basco-Cantabrico, N Spagna).* Gli obiettivi principali di questo lavoro sono lo studio delle associazioni del Pliesbachiano recuperate nella sezione di Santotis (Spagna Settentrionale) e la calibrazione dei bio-orizzonti rispetto alle zone ad ammoniti. Dei 119 orizzonti riconosciuti in questa sezione sono stati campionati 41 livelli. L'analisi semiquantitativa delle smear slide ha rivelato che la maggior parte delle associazioni a nannofossili calcarei mostrano un grado di preservazione variabile da pessimo a moderato, che le associazioni sono relativamente diversificate e le abbondanze delle specie variano da rara a frequente. I cambiamenti principali registrati nelle associazioni sono la comparsa dei generi *Similiscutum* (Zona a Jamesoni) e *Lotharingius* (Zona a Stokesi) e la comparsa delle specie appartenenti al genere *Biscutum* (Zone a Davoi e Stokesi). Gli eventi principali riconosciuti sono le comparse di *Similiscutum cruciulus* (Zona a Jamesoni) and *Lotharingius hauffii* (Zona a Stokesi) e gli eventi secondari sono le comparse di *Biscutum novum* (Zona a Davoei), *Biscutum grandis* (Zona a Stokesi), *Biscutum finchii* (Zona a Stokesi) e *Lotharingius barozii* (Zona a Stokesi). Questi hanno permesso di riconoscere e caratterizzare la porzione superiore della Zona NJ3 Crepidolithus crassus, l'intera Zona NJ4 Similiscutum cruciulus e la porzione inferiore della Zona NJ5 Lotharingius hauffii.

Parole chiave - Nannofossili calcarei, biostratigrafia, analisi semiquantitativa, Pliensbachiano, Giurassico inferiore, Bacino Basco-Cantabrico, Spagna Settentrionale.

Introduction

Since their earliest known appearances in the Late Triassic and markedly during the Lower Jurassic, the calcareous nannofossils are one of the main components of the phytoplankton and consequently are a significant constituent of the marly to carbonate lithologies. This group is considered a very useful biostratigraphic tool for the Lower Jurassic. Biostratigraphic schemes based on calcareous nannofossils and calibrated against the ammonite zones, have been proposed for the Boreal Realm by Bown & Cooper (1998) and for the Mediterranean Province by Mattioli & Erba (1999). In order to date and correlate different stratigraphic successions and due to the high potential resolution of the ammonite group, the calcareous nannofossil events are usually calibrated against the ammonite zones. Actually, due to the discontinuity of the ammonite record, which is affected by provincialism, this calibration could be problematic (Perilli *et al.,* 2004). A boreal affinity of the Basque-Cantabrian ammonites is suggested by the paleontological data, although tethyan fauna have been recognized in some stratigraphic levels (Braga *et al.*, 1988; Comas-Rengifo *et al.*, 1988; Fernández-López *et al.*, 1988; *Goy et al.*, 1994; Rosales *et al.*, 2006). Hence, the Basque-Cantabrian Basin has been interpreted as a link area between the Boreal and Tethyan Domains.

In the last two decades, the Pliensbachian calcareous nannofossils have been studied in three expanded successions cropping out along the north-eastern margin of the Asturian Massif. Two sections are located in Reinosa area (Perilli, 1999, 2000; Perilli & Comas-Rengifo, 2002; Perilli *et al.*, 2004) and the third Tudanca section, is situated north-westwards of the Reinosa area, and is exposed in the Rio Nansa Valley (Fraguas *et al.*, 2007). This work is the result of a detailed investigation of calcareous nannofossils from the Santotis section, also located in the Rio Nansa Valley, in order to calibrate the Pliensbachian calcareous nannofossil zone boundaries and biohorizons against the ammonite zones defined by Braga *et al.* (1988) for the Basque-Cantabrian Basin.

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Geological and geographical settings

During the Lower Jurassic, the Basque-Cantabrian Basin was affected by the mild extension of the basement faults caused by the thermal subsidence comprised between the Triassic and Late Jurassic-Early Cretaceous rifting periods (Rat, 1988; Robles *et al.*, 1989; Aurell *et al.*, 2002; Quesada *et al.*, 2005), which explains the deepening upward evolution and the subsequent transition from a shallow carbonate to hemipelagic ramp depositional system of the studied area. During the Lower Jurassic, the Basque-Cantabrian Basin was located in subtropical latitudes, in an epicontinental seaway between the Iberian and Armorican massifs (Stampfli *et al.*, 2001; Quesada *et al.*, 2005), and, as aforementioned, at that time the basin was affected by intermittent and sometimes persistent connections with the Tethys.

The Santotis section belongs to the Lower Jurassic marine sequence sedimented on a broad epireic carbonate ramp bordering the Asturias Massif (Fig. 1), which is broken by some discontinuities that bound different tectono-sedimentary units. These units can be grouped in two main depositional systems: the Rhaetian-lower Sinemurian shallow-marine carbonate ramp deposits and the upper Sinemurian-Toarcian hemipelagic ramp sediments. The upper Sinemurian-Toarcian portion includes a Lotharingian limestone-dominated unit and a Pliensbachian-Toarcian marl-dominated unit. The Pliensbachian portion is characterized by organic rich marl and black shales and ends with a bioclastic-bearing limestone portion.

Location and lithostratigraphy of the Santotis section

The Santotis section (4° 22' 7"W and 43° 9' 41"N; sheet n. 82 «Tudanca» of the «Mapa Geológico de España» 1:50.000) is located in the Rio Nansa Valley, 96 km SW of Santander and 35 km NW of Reinosa. Up to present, the stratigraphical data of this section located in the Basque Cantabrian Basin were not yet published. Preliminary biostratigraphic data on this section were published by Perilli & Comas-Rengifo (1998). The ammonite-controlled studied section belongs to the Marly Member of the Camino Formation (Quesada *et al.*, 2005) which is characterized by the presence of organic-rich levels. The composite investigated section spans from the Jamesoni to the Margaritatus Zone, and consists of an alternation of hemipelagic marlstones and limestones, sedimented on a deepening carbonate ramp (Fig. 2). The Jamesoni Zone is represented by marlstones with thin intercalations of limestones and marly limestones that grade into the 9 m thick marly limestone interval belonging to the Ibex Zone. The overlying Davoei Zone is characterized by an 8 m thick marly interval topped by a 6 m thick covered interval. The upper portion of the Davoei Zone consists of marly limestones with thin to very thin intercalations of limestones. The Stokesi Zone is represented by an alternation of marly limestone and thin limestone, that grade into a marly interval with thin intercalations of limestones corresponding to the Margaritatus Zone. Three organic-rich intervals constituted by dark grey to black laminated shales and marlstones with high TOC values ranging from 0.55 to 4.35% t.w., have been identified. They lie within the Jamesoni, the Ibex and the Margaritatus Zones corresponding to the calcareous nannofossil zones: NJ3 Crepidolithus crassus, NJ4 Similiscutum cruciulus and NJ5 Lotharingius hauffii.

Materials and methods

The 41 Pliensbachian calcareous nannofossil assemblages studied, were recovered from both marlstones and marly limestones usually every 30-50 cm; 19 of them were recovered from the Jamesoni Zone, 7 from the Ibex Zone, 3 from the Davoei Zone, 7 from the Stokesi Zone and 5 from the Margaritatus Zone. The closely-spaced and continuous sampling has been performed with Comas-Rengifo, in order to have a precise calibration with the ammonite zones and their boundaries. Standard smear slides were prepared by scraping a small amount of the sediment and adding a drop of distilled water on a cover glass. The sediment suspension obtained was smeared with a toothpick on the surface of the cover glass, then dried on a hot plate, and mounted on a microscope slide using an optical mounting medium. The semiquantitative analysis has been carried out with a Leica DMLP light microscope (1250X magnification) using both phase-contrast illumination and cross-polarized light. A Leica DFC420 camera integrated in the microscope has been used to take pictures (Plate 1). For each smear slide more than 2000 fields of view have been analyzed in 12 complete longitudinal transverse, in order to check the presence of rare and very rare taxa. The following abbreviations have been used for the assemblages preservation and abundance and for the relative abundance of the species represented in the range chart (Tab. 1).

Calcareous nannofossil assemblages abundance: C = common (1-10 specimens in 1 field of view), F = frequent (1 specimen in 2-10 fields of view), R = rare (1 specimen in 11-100 fields of view), VR = very rare (1 specimen in > 101 fields of view).

Relative abundance of the species: A = abundant (1-5 specimens in each field of view), C = common (1 specimen in 2-10 fields of view), F = frequent (1 specimen in 11-30 fields of view), R = rare (1 specimen in 31-100 fields of view), VR = very rare (1 specimen in > 101 fields of view).

State of preservation: M = moderate (the majority of the specimens are recognizable, even if part of them are etched and/or overgrown and/or fragmented), B = bad (the majority of the specimens are heavily etched and/or overgrown and/or fragmented and the identification of the species is sometimes difficult).

Results

Assemblages

The calcareous nannofossil assemblages recovered from the Santotis section are relatively diverse and show a

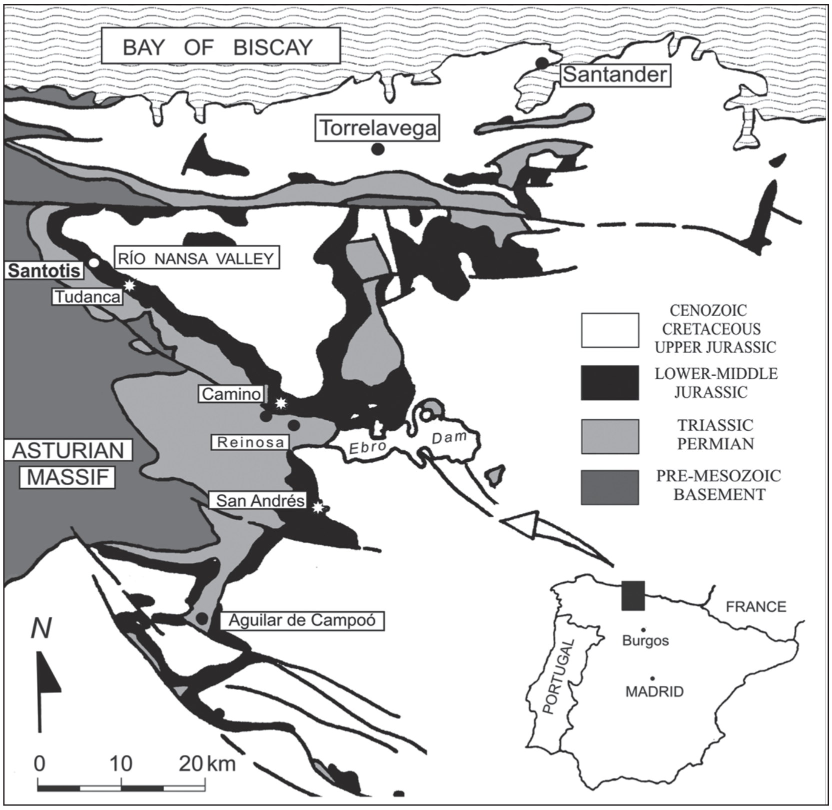

Fig. 1 - Geological sketch map of the Basque-Cantabrian Basin with the location of the Santotis section (white point) and the Tudanca, Camino and San Andres sections (white asterisks). Modified from Perilli & Comas-Rengifo (2002).

bad to moderate state of preservation. The number of the species identified in the smear slides increases along the section, recognizing less than 10 species in the first analyzed sample (Jamesoni Zone), and more than 20 in the last studied sample (Margaritatus Zone). The relative abundance of the species is mainly low and it varies from rare to frequent. The semiquantitative analyses have allowed the identification of 2 divisions, 2 classes, 5 orders, 7 families, 1 subfamily, 13 genera and 25 species. The genera *Schizosphaerella*, *Orthogoniodes*, *Crepidolithus*, *Parhabdolithus* and *Tubirhabdus* show a relatively high abundance and a continuous record across the studied succession. The Appendix 1 contains the list with the mentioned taxa.

Based on the species abundance and the fossil record: 1) *Schizosphaerella* spp., *O. hamiltoniae* and *C. crassus* have been identified in all the studied samples with a frequent to common relative abundance; 2) *Crepidolithus* spp., *C. perforatus*, *Parhabdolithus* spp., *P. liasicus liasicus*, *P. liasicus distinctus* and *S. cruciulus* show a relatively continuous record and a rare to frequent relative abundance; 3) *T. patulus*, *C. cavus*, *Similiscutum* spp., *B. grandis*, *B. finchii* and *L. barozii* have a relatively continuous record and a very rare to rare relative abundance; 4) *C. granulatus*, *M. elegans*, *P. robustus*, *C. primulus*, *C. jansae*, *C. minutus*, *C. pliensbachiensis*, *M. lenticularis*, *S. orbiculus*, *S. avitum*, *Calyculus* spp., *B. prinsii*, *B. novum* and *L. hauffii* show a discontinuous record and a very rare relative abundance.

According to the assemblage succession, the first significant compositional change is the appearance and the immediate abundance increase of the genus *Similiscutum*, including *S. cruciulus* which is the zonal marker of the NJ4 Zone. Within this zone, the first specimens belonging to the genera *Calyculus*, *Bussonius* and *Biscutum* have been identified. The main change observed in the assemblages of the NJ5 Zone is the first appearance of the genus *Lotharingius*, including the species *L. hauffii*, which defines the base of the this zone, and *L. barozii*.

Events

The nannobiohorizons recognized in the Santotis sections have been distinguished as main and secondary events. The main events are based on widespread and common taxa with a continuous record, whilst the secondary events are related to taxa with a discontinuous record and a low abundance, in particular in their initial and final ranges. The two main events are the FO of *S. cruciulus* within the Jamensoni Zone and the FO *L. hauffii* within the Stokesi Zone. The four secondary events are the FO of *B. novum*, which takes place slightly below the Davoei/Stokesi Zone boundary; the FO of *B. grandis* which has been located slightly above this

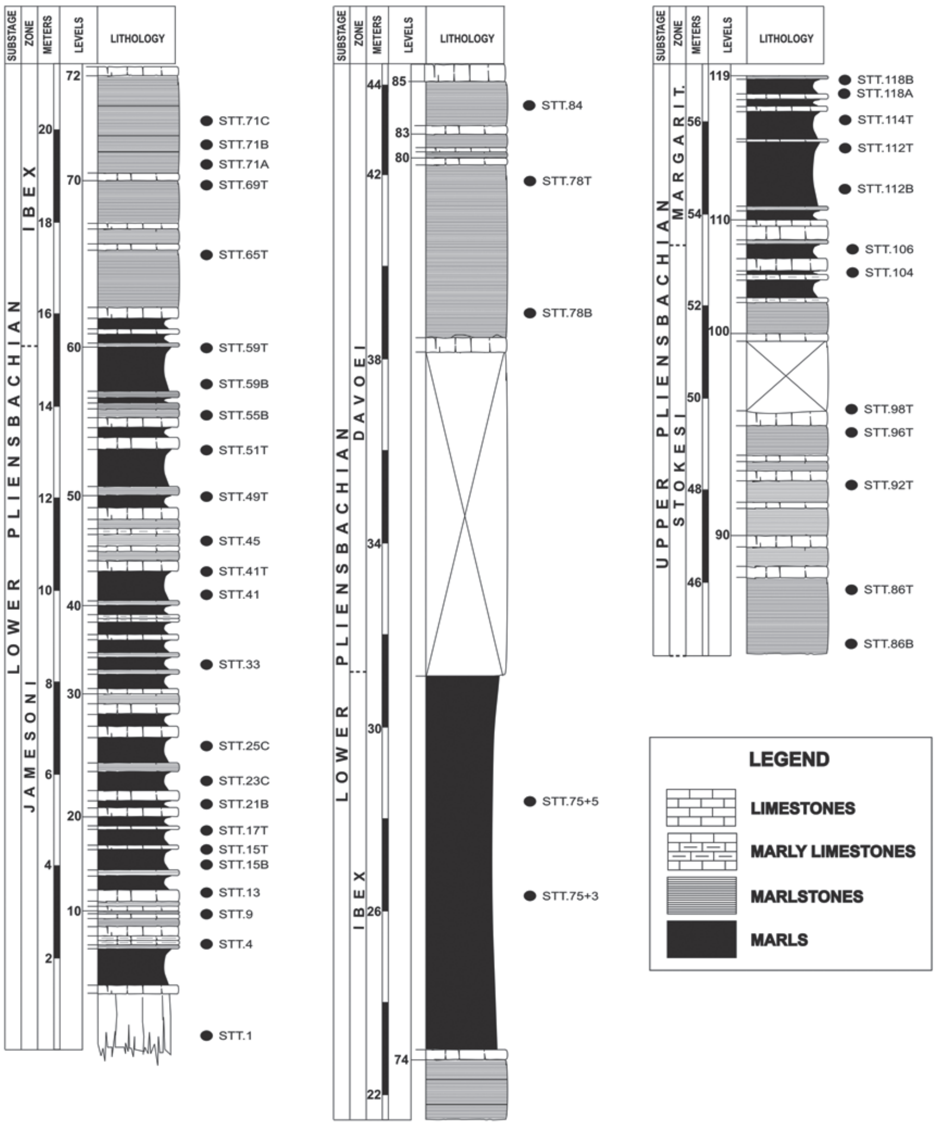

Fig. 2 - Santotis stratigraphic section with the corresponding Ammonite Zones. All the stratigraphic levels studied have been numbered.

boundary, the FO of *B. finchii* which is located within the Stokesi Zone slightly above the FO of *B. grandis* and the FO of *L. barozii* which takes place within the Stokesi Zone and below the NJ4/NJ5 Zone boundary.

Zones

Based on the main composition changes of the assemblages and the succession of the events we have identified in the Santotis section all the Pliensbachian calcareous nannofossil Zones proposed for NW Europe (Bown, 1987; Bown *et al*., 1988; Bown & Cooper, 1998) and the Mediterranean area (Mattioli & Erba 1999). Our data are consistent with Perilli & Comas-Rengifo (2002), Perilli *et al*. (2004) and Fraguas *et al*. (2007).

NJ3 Crepidolithus crassus Zone
Author. Barnard & Hay (1974), Bown & Cooper (1998).
Definition. FO of *Crepidolithus crassus* to the FO of *Similiscutum cruciulus*.
Range in this work. The lower boundary of this zone has not been recognized because it is located stratigraphically below the first studied sample. The upper boundary lies within the uppermost levels of the Jamesoni Zone.

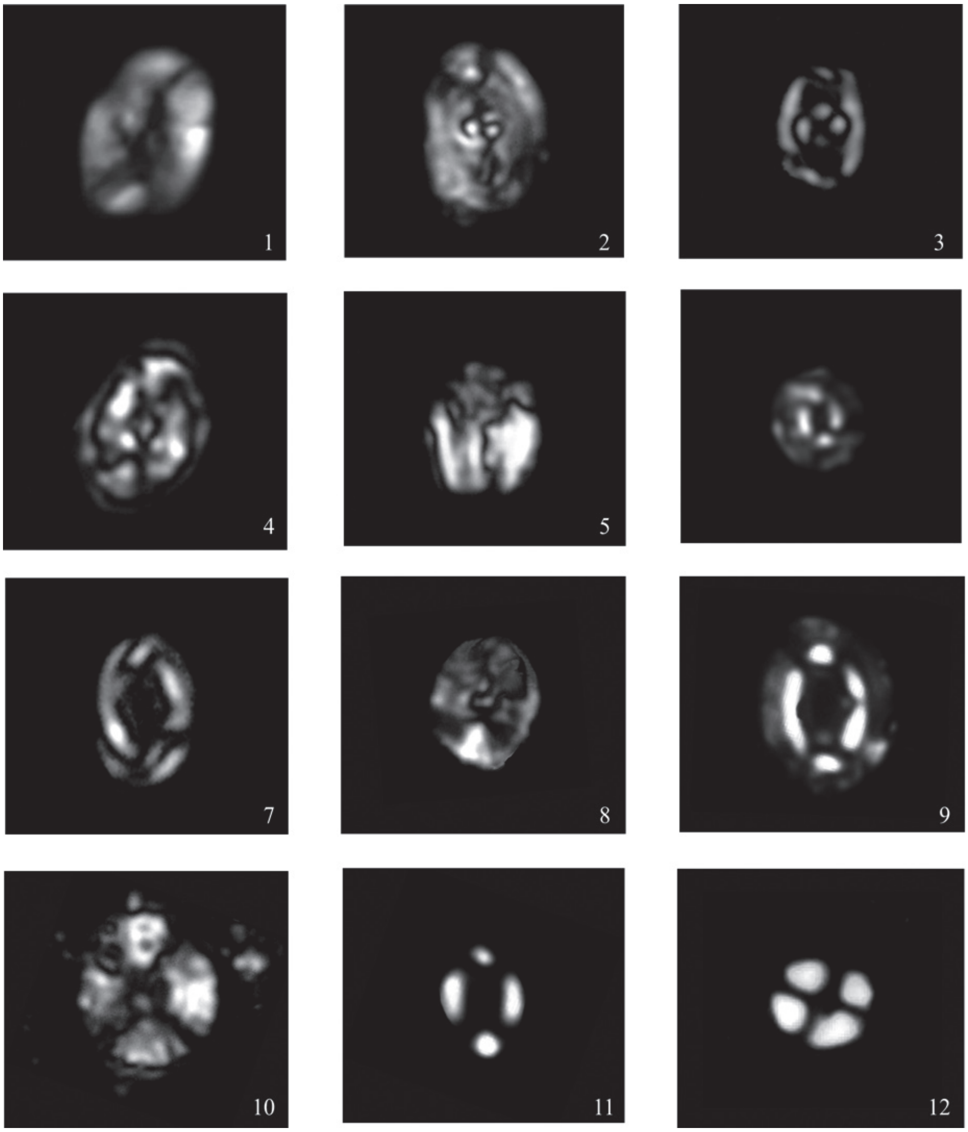

Plate 1
1. *Crepidolithus crassus* (Deflandre, 1954) Noël, 1965. STT.41. Jamesoni Zone. 2. *Crepidolithus pliensbachiensis* Crux, 1985 *emend*. Bown, 1987b. STT.59B. Jamesoni Zone. 3. *Parhabdolithus liasicus distinctus* (Deflandre, 1952) Bown, 1987b. STT.21B. Jamesoni Zone. 4. *Mitrolithus elegans* Deflandre *in* Deflandre & Fert, 1954. STT.41T. Jamesoni Zone. 5. *Calcivascularis jansae* Wiegand, 1984b. STT.86T. Stokesi Zone. Lateral view. 6. *Similiscutum cruciulus* de Kaenel & Bergen, 1993. STT.114T. Margaritatus Zone. 7. *Bussonius prinsii* (Noël, 1973) Goy, 1979. STT.84. Davoei Zone. 8. *Biscutum novum* (Goy, 1979) Bown, 1987. STT.118A. Margaritatus Zone. 9. *Biscutum grandis* Bown, 1987. STT.98T. Stokesi Zone. 10. *Biscutum finchii* Crux, 1984 emend. Bown, 1987. STT.104. Stokesi Zone. 11. *Lotharingius barozii* Noël, 1973, *emend*. Goy, 1979. STT.112T. Margaritatus Zone. 12. *Lotharingius hauffii* Grün & Zweili *in* Grün, Prins & Zweili, 1974, *emend*. Goy, 1979. STT.106. Stokesi Zone.
All figures have been made with crossed nicols, and approximately 1200X.

Remarks: First used by Prins (1969) as a subzone within the Crepidolithus Subzone, which spanned the Davoei and Margaritatus Zones. Barnard & Hay (1974), described the Crepidolithus crassus Zone as the time interval from the FO of *C. crassus* to the FO of *P. cylindratus,* spanning the Raricostatum, Jamesoni and Ibex Zones. However, Bown (1987) considered the Crepidolithus crassus Zone as the time interval between the FO of *C. crassus* and the FO of *B. novum*. Bown & Cooper (1998) modified its upper boundary, making it coincide with the FO of *S. cruciulus*.
The assemblages belonging to the Crepidolithus crassus Zone are scarce and include *Schizosphaerella* spp., *O. hamiltoniae*, rare specimens of *C. crassus*, *C. granulatus*, *C. cavus*, *C. perforatus*, *C. pliensbachiensis*, *Crepidolithus* spp., *M. elegans*, *P. liasicus distinctus*,

Tab. 1 - Sketch with the data collected from the semiquantitative analysis. The column in the right represents the Calcareous nannofossil Zones identified in the Santotis section, calibrated against the ammonite Zones located in the left column. The main and secondary events identified in the Santotis section are also represented.

Ammonite Zones	Samples	Abundance	Preservation	N° species	*Schizosphaerella* sp.	*O. hamiltoniae*	*C. crassus*	*C. granulatus*	*Crepidolithus* spp.	*M. elegans*	*P. liasicus distinctus*	*P. liasicus liasicus*	*P. robustus*	*Parhabdolithus* spp.	*T. patulus*	*C. primulus*	*C. jansae*	*C. cavus*	*C. minutus*	*C. perforatus*	*C. pliensbachensis*	*Similiscutum* spp.	*M. lenticularis*	*S. cruciulus*	*S. orbiculus*	*S. avitum*	*Calyculus* spp.	*B. prinsii*	*B. novum*	*B. grandis*	*B. finchii*	*L. barozii*	*L. hauffii*	Main events	Secondary events	Calcareous nannofossil Zones
Margaritatus	STT 118B	F	M	20	R	F	F		R		VR	R		VR	R	VR		VR		R		R	VR	C		VR	VR		R	R	R	VR				NJ5 L. hauffii
Margaritatus	STT 118A	F	M	21	F	F	F		VR		VR	R		VR	VR			F		VR		R		C	R	VR	R		R	VR	R	R	VR			NJ5 L. hauffii
Margaritatus	STT 114T	F	M	22	R	F	R		R		VR	R		R	R		VR	R		R		F	VR	C	VR	R	VR		VR	F	R	R	VR			NJ5 L. hauffii
Margaritatus	STT 112T	C	M	15	F	C	A	VR	F		R	F			R	VR		R		F		VR		VR							VR	R				NJ5 L. hauffii
Margaritatus	STT 112B	R	M	16	R	F	VR	VR	R		VR	R		VR	VR			VR				VR	VR	VR			VR			VR	VR					NJ5 L. hauffii
Stokesi	STT 106	R	M	18	C	F	R	VR				VR			R			VR		VR		VR		VR	VR	VR	R		VR	VR	VR	VR	VR	L. hauffii		NJ5 L. hauffii
Stokesi	STT 104	F	M	18	F	R	F	VR	R		R	F		VR	F	VR			VR	VR		VR							VR	VR	R	VR	VR	↑		NJ5 L. hauffii
Stokesi	STT 98T	F	M	18	F	F	VR		VR		VR	R		VR				VR		VR		R		F	VR	VR	VR		VR	F	VR	VR				NJ4 S. cruciulus
Stokesi	STT 96T	F	M	18	F	R	R	VR	R		VR	R		VR	VR	VR	VR			VR		R	VR	VR				VR		VR		VR			L. barozii	NJ4 S. cruciulus
Stokesi	STT 92T	F	M	16	R	F	F	VR	R		VR	R		VR	VR	VR			VR	R		VR		R			VR		VR							NJ4 S. cruciulus
Stokesi	STT 86T	F	M	15	F	F	R	R	R			F		R	R	VR		VR				VR		VR				R	VR		VR				B. finchii	NJ4 S. cruciulus
Stokesi	STT 86B	F	M	16	F	R	F	VR	F	VR	VR	R		R	VR	VR	VR			R		R				VR				VR					B. grandis	NJ4 S. cruciulus
Davoei	STT 84	C	M	16	F	R	C	VR	C		R	R		R	VR	VR		VR	VR	F							VR	VR	VR							NJ4 S. cruciulus
Davoei	STT 78T	F	M	17	F	F	C	R	F	VR	VR	R	VR	VR	VR	VR				R		VR	VR					VR	VR						B. novum	NJ4 S. cruciulus
Davoei	STT 78B	F	M	16	F	F	F		R	VR	VR	R	VR	VR	VR	VR	VR			VR		R	VR		VR											NJ4 S. cruciulus
Ibex	STT 75+5	VR	B	6	VR	F	VR		VR															VR			VR									NJ4 S. cruciulus
Ibex	STT 75+3	VR	B	8	R	VR	VR		VR			VR								VR			VR	VR												NJ4 S. cruciulus
Ibex	STT 71C	F	M	15	F	F	C		F	VR	R	F	VR	R	R	VR		VR	VR	F	VR															NJ4 S. cruciulus
Ibex	STT 71B	F	M	15	C	F	R		VR		F	F	VR	F		VR	VR	VR	VR			VR	VR		VR											NJ4 S. cruciulus
Ibex	STT 71A	F	M	14	C	F	VR			VR	F	R	VR	R	R	VR	VR		VR		VR			VR												NJ4 S. cruciulus
Ibex	STT 69T	F	M	13	F	R	VR		VR		F	F	VR	F	VR	R		VR	R		VR															NJ4 S. cruciulus
Ibex	STT 65T	R	M	17	R	F	VR	VR		VR	R	VR	VR	VR		VR		VR	VR	VR	R	VR		R	VR											NJ4 S. cruciulus
Jamesoni	STT 59T	R	M	11	F	F	VR			VR		VR				VR		VR		VR		VR		R	VR											NJ4 S. cruciulus
Jamesoni	STT 59B	R	M	16	F	R	VR		VR	VR	VR	R		R	VR	R			VR	R	VR	VR		VR	VR											NJ4 S. cruciulus
Jamesoni	STT 55B	F	M	13	C	C	F		F		VR	VR	VR	VR	VR	VR				R	VR		VR													NJ4 S. cruciulus
Jamesoni	STT 51T	C	M	16	F	F	C	VR	C	R	VR	VR		VR	VR	VR		R	VR	R	VR				VR											NJ4 S. cruciulus
Jamesoni	STT 49T	C	M	16	R	F	C	VR	F	VR	VR	VR		VR	VR			VR	VR	R	VR		VR													NJ4 S. cruciulus
Jamesoni	STT 45	F	M	17	F	C	F	VR	R	R	R	VR		VR	VR	VR		VR		R	VR	VR	VR			VR								S. cruciulus		NJ4 S. cruciulus
Jamesoni	STT 41T	F	M	18	F	F	C		F	VR	R	VR	VR	VR	VR	VR		R	VR	R	VR		VR	VR	VR									↑		NJ4 S. cruciulus
Jamesoni	STT 41	F	M	13	F	R	F	VR	F	VR	VR	VR			VR	VR		VR		R			VR													NJ3 C. crassus
Jamesoni	STT 33	F	M	12	F	R	C		F		VR	VR	VR		VR		VR	VR	VR	R																NJ3 C. crassus
Jamesoni	STT 25C	F	M	16	F	F	F		F	VR	VR	VR	VR	VR	R	VR		R	VR	F	VR		R													NJ3 C. crassus
Jamesoni	STT 23C	C	M	14	F	F	C		F		VR	VR		VR	VR	VR		R	VR	F	VR	VR														NJ3 C. crassus
Jamesoni	STT 21B	F	M	17	C	F	R		R	R	R	F	R	VR	VR	VR	R	VR	VR	VR	VR	VR														NJ3 C. crassus
Jamesoni	STT 17T	R	B	10	F	F				VR	VR	VR		VR	VR	VR			VR		VR															NJ3 C. crassus
Jamesoni	STT 15T	R	M	12	F	F	VR			VR	R	F	VR	VR	VR	R	VR		VR																	NJ3 C. crassus
Jamesoni	STT.15B	F	M	14	F	F	VR		VR	VR	R	R	VR	R	VR	F	VR		R	VR																NJ3 C. crassus
Jamesoni	STT.13	R	M	14	F	VR	R	VR	R	VR	VR	VR	VR	VR	VR	VR	VR		VR																	NJ3 C. crassus
Jamesoni	STT.9	R	M	11	R	VR	R		VR	VR	R	R	VR		VR		VR	VR																		NJ3 C. crassus
Jamesoni	STT.4	F	M	11	C	R	VR		VR		VR	VR	VR	VR	VR	VR	VR																			NJ3 C. crassus
Jamesoni	STT.1	R	M	7	VR	F	VR	VR	VR	VR	VR																									NJ3 C. crassus

P. liasicus liasicus, *P. robustus*, *Parhabdolithus* spp., *T. patulus*, *C. primulus*, *C. minutus*, *C. jansae*, *M. elegans* and *M. lenticularis*.

NJ4 Similiscutum cruciulus Zone

Author. Bown (1987), emended by Bown & Cooper (1998).

Definition. FO of *Similiscutum cruciulus* to the FO of *Lotharingius hauffii*.

Range in this study. From the uppermost levels of the Jamesoni Zone to the uppermost levels of to the Stokesi Zone.

Remarks: First described by Bown (1987) as the time interval between the FO of *B. novum* and the FO of *L. hauffii*, this zone was modified by Bown & Cooper (1998), which supported that the FO of *S. cruciulus* defines the base of the NJ4 Similiscutum cruciulus Zone. Up to present, several authors have divided this zone into two subzones on the basis of the FO of *P. robustus* (Bown, 1987; Bown *et al*., 1988; Bown & Cooper, 1998; Mattioli & Erba, 1999; Veiga de Oliveira *et al*., 2007).

The studied samples of the NJ4 Similiscutum cruciulus Zone contain better preserved and more diverse assemblages with respect to the previous zone. They include abundant *Schizosphaerella* spp., *O. hamiltoniae*, *C. crassus*, *Crepidolithus* spp., *C. perforatus*, *Parhabdolithus* spp., *P. liasicus distinctus* and *P. liasicus liasicus* which show a continuous record. The other species *C. granulatus*, *C. cavus*, *C. pliensbachiensis*, *P. robustus*, *T. patulus*, *C. primulus*, *C. minutus*, *C. jansae*, *M. elegans*, *M. lenticularis*, *Similiscutum* spp., *S. avitum*, *S. orbiculus*, *S. cruciulus*, *Calyculus* spp., *B. prinsii*, *B. novum*, *B. grandis* and *B. finchii* are rare or extremely rare and show a discontinuous record.

Within the NJ4 Similiscutum cruciulus Zone the FOs of

B. prinsii, *B. novum* and *B. grandis* approach the Davoei/Stokesi Zones boundary that lies slightly below the FO of *B. finchii*. In the upper part of this zone, the first small-sized *Lotharingius* have been recognized along with the FO of *L. barozii*. Within the NJ4 Similiscutum cruciulus Zone, the LO of *C. pliensbachensis* has been situated in the Ibex Zone, the LO of *P. robustus* has been located within the Davoei Zone, and the last specimens of *M. elegans* and *B. prinsii* have been identified within the Stokesi Zone.

NJ5 Lotharingius hauffii Zone
Author. Bown (1987).
Definition. FO of *Lotharingius hauffii* to the FO of *Carinolithus superbus*.
Range in this study. The lower boundary lies within the uppermost levels of the Stokesi Zone. The upper boundary of this zone has not been identified because it is located above the last studied samples which belong to the Margaritatus Zone.
Remarks: Bown (1987) and Bown & Cooper (1998) propose that the time interval spanned by this zone coincides with the stratigraphic distribution of the species *B. finchii*. Several authors have divided this zone in two subzones on the basis of the FO of *C. impontus* (Bown & Cooper, 1998; Veiga de Oliveira *et al.*, 2007).
The assemblages belonging to the NJ5 Lotharingius hauffii Zone show a high diversity of species but with respect to the NJ3 and NJ4 Zones the relative abundance of the species decreases. The assemblages of the NJ5 Zone include *Schizosphaerella* sp., *O. hamiltoniae*, *C. crassus*, *Crepidolithus* spp., *C. perforatus*, *C. cavus*, *T. patulus*, *Parhabdolithus* spp., *P. liasicus distinctus*, *P. liasicus liasicus*, *Similiscutum* spp., *S. cruciulus*, *B. grandis*, *B. finchii* and *L. barozii* with a high abundance and a continuous record, along with rare or extremely rare specimens of *C. granulatus*, *C. primilus*, *C. minutus*, *C. jansae*, *M. lenticularis*, *S. avitum*, *S. orbiculus*, *Calyculus* spp., *B. prinsii* and *B. novum*, these species show a discontinuous record.
The base of the NJ5 Lotharingius hauffii Zone is defined by the FO of *L. hauffii*, species that in the Santotis section has a low abundance and a discontinuous record. In this zone an increase in the abundance of the genera *Tubirhabdus*, *Similiscutum* and *Biscutum* and a decrease of the genera *Crepidolithus*, *Parhabdolithus* and *Crucirhabdus*, have been identified.

Conclusive remarks

The semiquantitative analysis carried out on forty-one smear slides has allowed us to discover that the majority of the calcareous nannofossil assemblages are relatively diverse with a rare to frequent relative abundance of the species, showing a bad to moderate state of preservation. According to the assemblages succession and the biohorizons sequence during the Pliensbachian: 1) the main assemblages composition changes are the first appearances of the genera *Similiscutum* and *Lotharingius* and the appearance of the species belonging to genera *Biscutum*; 2) the two main events, based on easily recognizable taxa showing a continuous biostratigraphic record are the FO of *S. cruciulus* (Jamensoni Zone) and the FO *L. hauffii* (Stokesi Zone); 3) the four secondary events, based on species that show a low relative abundance and a discontinuous record, are the FO of *B. novum* (Davoei Zone), the FO of *B. grandis* (Stokesi Zone); the FO of *B. finchii* (Stokesi zone) and the FO of *L. barozii* (Stokesi Zone).
The succession of these biohorizons allowed the identification of 1) the upper part of the NJ3 Crepidolithus crassus Zone, the complete NJ4 Similiscutum cruciulus Zone and the lower part of NJ5 Lotharingius hauffii Zone and, as well as the recognition of 2) the NJ3/NJ4 and NJ4/NJ5 Zone boundaries. The position of the biohorizos and of the calcareous nannofossil zone boundaries nearly coincide with those recognized in the Tudanca section (Fraguas *et al.*, 2007), which is exposed slightly south-eastwards of the Santotis section, as well as with those identified in the Camino and San Andrés sections located in the Reinosa area (Perilli & Comas-Rengifo, 2002).

Appendix 1

Calcareous nannofossil taxa mentioned in the text with an alphabetical order:

Biscutum dubium (Noël, 1965) Grün *in* Grün, Prins & Zweili, 1974
Biscutum finchii (Crux, 1984) Bown, 1987
Biscutum grandis Bown, 1987
Biscutum novum (Goy *in* Goy, Noël & Busson, 1979) Bown, 1987
Biscutum prinsii (Noël, 1973) Goy, 1979
Calcivascularis jansae Wiegand, 1984
Crepidolithus spp.
Crepidolithus cavus Prins *ex* Rood, Hay & Barnard, 1973
Crepidolithus crassus (Deflandre, 1954) Noël, 1965
Crepidolithus granulatus Bown, 1987
Crepidolithus impontus (Prins & Zweili *in* Grün, Prins & Zweili, 1974) Goy, 1979
Crepidolithus perforatus (Medd, 1979) Grün & Zweili, 1980
Crepidolithus pliensbachensis (Crux, 1985) Bown, 1987
Crepidolithus primulus (Prins *ex* Rood, Hay & Barnard, 1973) Bown, 1987
Crepidolithus minutus Jafar *ex* Bown, 1987
Lotharingius hauffii (Grün & Zweili, 1974) Goy, 1979
Lotharingius barozii (Noël, 1973) Goy, 1979
Mitrolithus elegans Deflandre *in* Deflandre & Fert, 1954
Mitrolithus lenticularis Bown, 1987
Parhabdolithus cylindratus
Parhabdolithus liasicus liasicus (Deflandre, 1952) Bown, 1987
Parhabdolithus liasicus distinctus Bown, 1987
Parhabdolithus robustus Noël, 1965
Similiscutum avitum de Kaenel & Bergen, 1993
Similiscutum cruciulus de Kaenel and Bergen, 1993
Similiscutum orbiculus de Kaenel & Bergen, 1993
Orthogonoides hamiltoniae Wiegand, 1984
Schizosphaerella spp.

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