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Calcareous nannofossil assemblages across the Pliensbachian/Toarcian boundary at the Peniche section (Ponta do Trovão, Lusitanian Basin)

Samuel Mailliot[1a], Serge Elmi[†], Emanuela Mattioli[1b] & Bernard Pittet [1c]

[1] UMR 5125 PEPS, CNRS, France; Université Lyon 1, Campus de la DOUA, Bâtiment Géode, 69622 Villeurbanne Cedex, France;
[a] ligne-de-mire@netcourrier.com; [b] mattioli@univ-lyon1.fr; [c] Bernard.Pittet@univ-lyon1.fr

Resumo

Palavras-chave: Limite Pliensbaquiano/Toarciano, Corte de Peniche, Biostratigrafia, Nanofósseis calcários, Biocalcificação, Produção carbonatada

No corte de Peniche foram recolhidas associações de nanofósseis calcários na passagem Pliensbaquiano/Toarciano que apresentam uma preservação média a boa. Este registo permitiu o estabelecimento de um bom esquema biostratigráfico de pormenor. O limite entre os dois andares, definido a partir de faunas de amonites, foi colocado na subzona de nanofósseis NJ5b *C. impontus* (estabelecida para o NW europeu por BOWN & COOPER, 1998) ou, alternativamente, na subzona NJT5b *L. sigillatus* (definida na Tétis mediterrânica; MATTIOLI & ERBA, 1999). Uma vez que as associações da Bacia Lusitaniana mostram características mistas, com táxones típicos quer da bordadura norte do Mar de Tétis, quer da bordadura sul, ambas as escalas biozonais acima indicadas podem ser utilizadas. Certos acontecimentos (particularmente o aparecimento de certas formas) observam-se precocemente na Bacia Lusitaniana, em comparação com outros locais da Tétis ocidental; há que verificar se estes acontecimentos correspondem realmente a primeiras ocorrências. Uma fase de diversificação caracteriza o limite Pliensbaquiano/Toarciano.

Esta fase está bem marcada em Peniche, onde as associações dominadas por murolitos passam, acima do limite, a associações dominadas por placolitos. A quantificação do número de nanofósseis por grama de rocha mostra que estes são mais abundantes nas camadas à volta do limite; com efeito, aqui, a abundância de nanofósseis é maior em comparação com níveis correlativos de outros cortes europeus. A fracção pelágica dos carbonatos (produzida pelos nanofósseis) é importante nos interleitos margosos de Peniche; nestes níveis, os nanofósseis representam mais de 50% da fracção carbonatada total.

Résumé

Mots-clés: Limite Pliensbachien/Toarcien, Coupe de Peniche, Biostratigraphie, Nannofossiles calcaires, Biocalcification, Production carbonatée

La section de Peniche a livré des assemblages de nannofossiles calcaires montrant une préservation moyenne à bonne dans l'intervalle correspondant à la transition Pliensbachien / Toarcien. Ce bon enregistrement a permis l'établissement d'un schéma biostratigraphique détaillé. La limite d'étage, définie par les ammonites, est placée dans la sous-zone à nannofossiles NJ5b *C. impontus* (établie pour le Nord-ouest européen par BOWN & COOPER, 1998) ou, alternativement, dans la sous-zone NJT5b *L. sigillatus* (définie dans la Téthys Méditerranéenne; MATTIOLI & ERBA, 1999). Puisque les assemblages du Bassin Lusitanien montrent des caractères mixtes, avec des taxons typiques à la fois de la marge nord et sud de la Téthys, les deux schémas de zonation cités ci-dessus peuvent être utilisés. Certains événements des nannofossiles (surtout des premières apparitions) sont observés précocement dans le Bassin Lusitanien par rapport à d'autres localités dans la Téthys occidentale. Il reste à vérifier si ces événements correspondent à des réelles premières apparitions. Une phase de diversification caractérise la limite Pliensbachien/Toarcien.

Cette phase est bien enregistrée à Peniche en passant du Pliensbachien, où les assemblages sont dominés par les murolithes, au Toarcien inférieur caractérisé par des assemblages avec d'abondants placolithes. Une quantification des nannofossiles par gramme de roche montre que les abondances sont les plus fortes autour de la limite Pliensbachien/Toarcien. En effet, à Peniche les abondances des nannofossiles sont très élevées par rapport à des niveaux équivalents d'autres coupes européennes. La fraction pélagique des carbonates (produite par les nannofossiles) est importante dans les interbancs marneux de Peniche. Dans certains niveaux, les nannofossiles représentent plus de 50% de la fraction carbonatée totale.

Abstract

Key-words: Pliensbachian/Toarcian boundary, Peniche section, Biostratigraphy, Calcareous nannofossil assemblages, Biocalcification, Carbonate production

The Peniche section has revealed moderately-to-well preserved calcareous nannofossil assemblages across the Pliensbachian/Toarcian boundary. This good record has allowed the proposition of a refined biostratigraphic scheme. The stage boundary, as defined by ammonites, is comprised within the NJ5b *C. impontus* (NW Europe; BOWN & COOPER, 1998) or the NJT5b *L. sigillatus* (Mediterranean Tethys; MATTIOLI & ERBA, 1999) nannofossil subzones. Since in the Lusitanian Basin a mixing of N- and S-Tethyan taxa is observed, both biozonation schemes can be applied. Some nannofossil events (mainly first occurrences) are observed earlier in Portugal than in other Tethyan settings. It is still unclear if these events are real first occurrences. A diversification phase occurred across the Pliensbachian/Toarcian boundary.

This phase is well recorded at Peniche, where a change is observed passing from the Pliensbachian, when assemblages are dominated by muroliths, to the Toarcian showing assemblages where placoliths are abundant. A quantification of nannofossils per gram of rock shows that absolute abundances are the highest across the Pliensbachian/Toarcian boundary. Indeed, Peniche exhibits nannofossil abundances very high with respect to correlative levels in other Tethyan settings. The pelagic carbonate fraction (produced by nannofossils) is important in the marly hemi-couplets of Peniche. In some levels, nannofossils account for more than 50% of the total carbonate fraction.

1. Introduction

The Peniche section, located about 80 Km to the north of Lisbon, beautifully outcrops on the Atlantic seaside. It exhibits a continuous sedimentary succession recording almost the entire Lower Jurassic, from the Sinemurian to the Aalenian for a thickness of more than 450 meters. In particular, the Peniche section provides an excellent, continuous sedimentary succession at the Pliensbachian/Toarcian boundary, which is often very condensed or lacunose in the northwest European domain (GUEX & *al*., 2001) (fig. 1). The section presents numerous fossiliferous horizons and has been the object of several biostratigraphic studies, mainly based upon ammonites, since the 19th century (CHOFFAT, 1880; MOUTERDE, 1955, 1967; ELMI, 2005; ELMI & *al*., 1996, 2005, 2006). The Pliensbachian/Toarcian boundary (bed 15e of MOUTERDE, 1955, Figs 1b and 2) is defined on the basis of the massive appearance of a diversified ammonite fauna mainly composed of specimens of the genus *Dactylioceras* (*Eodactylites*). The bed 15e correlates with the north-west European Paltus horizon, and is followed by an ammonite fauna of the genus *Orthodactylites* (ELMI, 2005; ELMI & *al*., 2005, fig. 2).

Although the standard biochronology of the Early Jurassic is essentially based upon ammonites, in the last decades various biostratigraphic frameworks using other fossil groups like calcareous nannofossils or dinoflagellate cysts have been proposed for dating and correlating Jurassic rocks. In the Lusitanian Basin, biostratigraphic studies of calcareous nannofossils were performed since the 1970s (HAMILTON, 1977, 1979; BERGEN, 1987; de KAENEL & BERGEN, 1993; de KAENEL & *al*., 1996; DUARTE & *al*., 2002, 2004; PERILLI & DUARTE, 2002, 2003; OLIVEIRA & *al*., 2005ab, 2007). Calcareous nannofossils, which represent a major component of pelagic carbonates, are recorded continuously in the Peniche sedimentary record. They are abundant and well-preserved across the Pliensbachian/Toarcian boundary. The goal of this work is to precisely describe the evolution of calcareous nannofossil assemblages, and to evaluate their carbonate production across the Pliensbachian/Toarcian boundary at Peniche.

2. The Pliensbachian/Toarcian boundary at Peniche

The Upper Pliensbachian of Peniche (Lemede and Vale das Fontes formations, DUARTE & SOARES, 2002, fig. 2) is about 40 meters thick (MOUTERDE, 1955) and is made up by marl-limestone alternations with intercalation of centimetric organic matter-rich shales. The last 24 meters of the Upper Pliensbachian, corresponding to the Spinatum Zone, show marl-limestone alternations dominated by carbonates (MOUTERDE, 1955; WILSON & *al*., 1983). The “Transition beds” (*Couches de passage* of MOUTERDE, 1955) mark the transition from the Pliensbachian to the Toarcian. These beds are characterized by local accumulations of belemnite rostra, which are often coated by serpulids and small oysters, indicating sedimentary condensation. The base of the Toarcian is characterized by dark-clays, with low carbonate content (Cabo Carvoeiro Formation, Duarte & Soares, 2002; figs 1 and 2). The Lower Toarcian of Peniche (about 38 meters) is organized in 20 depositional sequences that resulted from orbitally-tuned sea-level changes which in turn controlled carbonate fluctuations and the observed stacking pattern of marl-limestone alternations (Pittet, 2006). In the present work, we will focus on the sequences across the Pliensbachian/ /Toarcian boundary. The first Toarcian sequence (To1 at the base of the Polymorphum Zone, figs 1 and 2) displays well-marked alternations of argillaceous limestones and marls. These are blue (at the base, To1.1 to To1.3) to light grey (at the top, To1.4) bituminous marls, enriched in mica. Pyritized, small-sized ammonites and brachiopods are commonly recorded in this interval.

3. Material and methods

The calcareous nannofossils content of 18 samples is here presented. Absolute abundance of nannofossils per gram of rock was estimated using the ‘Random Settling Technique’ (Geisen & *al*., 1999). In synthesis, a small quantity of dried rock-powder (30 mg), mixed to water in a homogeneous suspension is let settle for 24 hours on a cover slide in a settling box. The slide is then recovered and dried, and it is mounted with Rhodopass to a microscope slide. Slides were observed with an optical microscope in both natural and cross-polarized light at a magnification of 1225x. Nannofossil taxa were identified and their relative (percentage) and absolute abundances were quantified. Coccolith percentage was calculated over the number of total coccoliths. The identification of taxa is based on standard taxonomy (Bown, 1987; Mattioli, 1996; Bown & Young, 1997; Bown & Cooper, 1998; Mattioli & *al*., 2004b). For each sample, an average of 250 nannofossils was counted, according to the richness of the assemblages. Preservation of nannofossils was visually estimated under the optical microscope in cross-polarized light. According to P. Roth (1984) and P. Bown & J. Young, (1998), three preservation classes (from good to poor) were established on the basis of the etching, overgrowth and fragmentation of both coccoliths and the *incertae sedis Schizosphaerella* spp., a probable calcareous dinoflagellate (Kälin & Bernoulli, 1984).

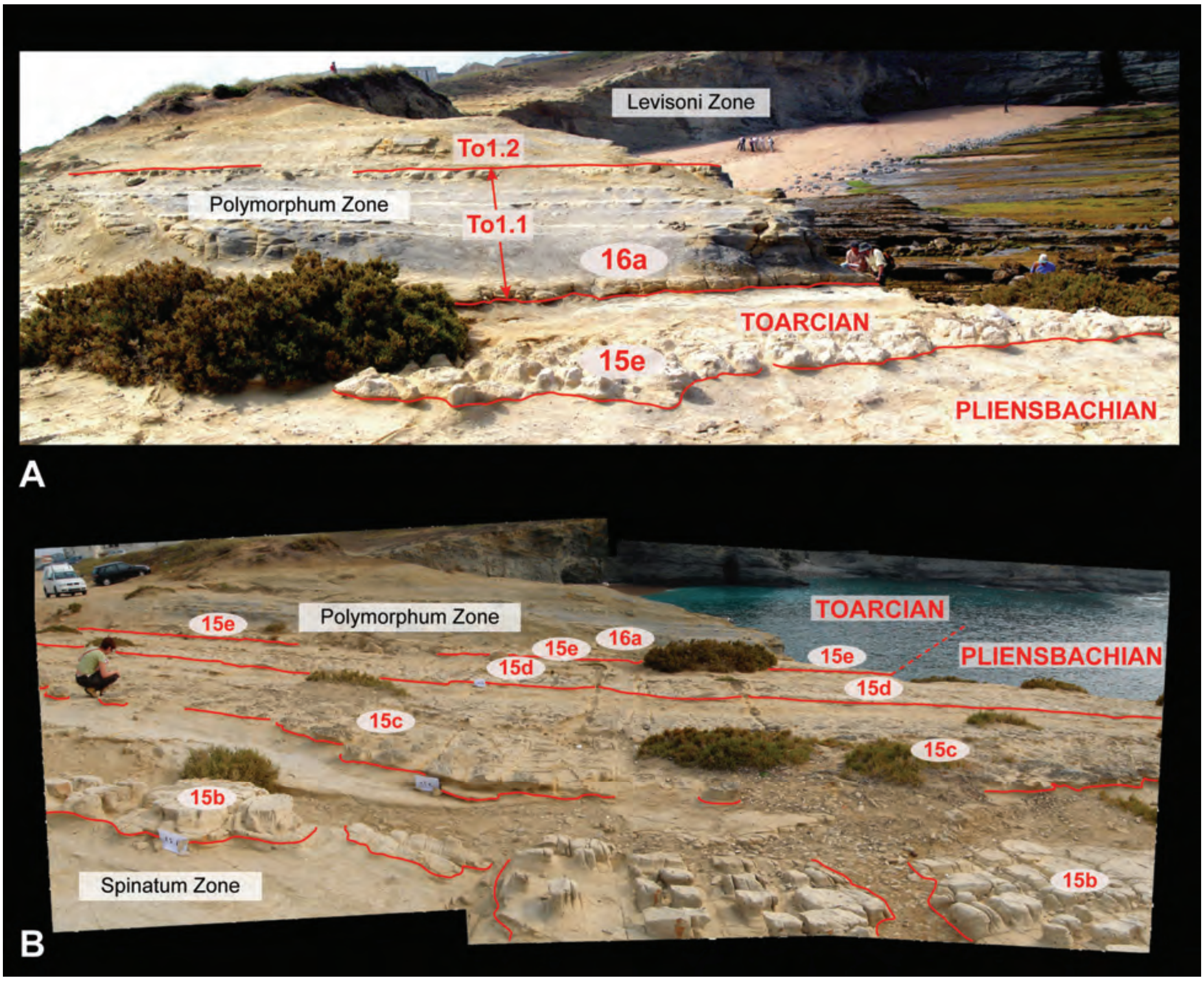

Fig. 1 – Pictures illustrating the Pliensbachian/Toarcian boundary at Peniche (Ponta do Trovão): A. Detail of the boundary level (base of the bed 15e of Mouterde, 1955) and of the first depositional sequence of the Toarcian (To1, according to Pittet, 2006); B. Detail of the 'Transition beds' of R. Mouterde (1955).

Thirty specimens per sample of *Schizosphaerella* spp. were measured and average volume was estimated according to the method described in E. MATTIOLI & B. PITTET (2002). A total of 300 specimens of the most robust (namely, *Crepidolithus crassus* and *Mitrolithus jansae*) and the most common (Biscutaceae and the genus *Lotharingius*) coccolith taxa were also measured in randomly selected samples. The average volume of these taxa was therefore estimated for the Peniche samples. By combining volume estimation with their absolute abundance, it was possible to measure the pelagic carbonate production (MATTIOLI & PITTET, 2002). This was eventually compared to wt% $CaCO_3$ measured in the bulk rock with a Dietrich-Frühling calcimeter.

4. The record of calcareous nannofossils

4.1. Preservation of calcareous nannofossils

In palaeoecological studies, nannofossil preservation has to be carefully evaluated in order to differentiate between a primary signal, such as fluctuations in abundances depending on variations of environmental parameters, and secondary diagenetic overprint. The majority of the samples analysed in this study displays a good to moderate preservation (fig. 2). The Upper Pliensbachian marl-limestone alternations of Peniche (Spinatum Zone) are generally characterized by a moderate preservation of nannofossils. Overgrowth is generally more important than etching. The basal Toarcian marl-limestone alternations (Polymorphum Zone) generally display a good preservation. In this interval, delicate forms of coccoliths are commonly observed.

Between the different nannofossil taxa, the forms that are most often affected by overgrowth are the schizospheres and the most robust coccoliths, like *Crepidolithus* spp. Biscutaceae appear sometimes affected by etching, although well-preserved specimens of *B. dubium* were observed in samples characterized by a moderate preservation. The species of the genus *Lotharingius* seem to be generally less affected by etching than other coccoliths, in particular the small species such as *L. hauffii* and *L. frodoi*. In samples with high carbonate content (Upper Pliensbachian), *Schizosphaerella* generally shows a partial or complete infilling of valve porosity by carbonate microcrystals (*i.e.*, the organically-induced nanocrystals of NOËL & BUSSON, 1990). This diagenetic feature does not produce overgrowth, so that *Schizosphaerella* size is not increased. In samples with a moderate preservation, the valves of the schizospheres may be entirely filled by sparry calcite or framboidal pyrite.

In the same sample, signs of both dissolution and overgrowth may be observed on different specimens. This can be explained by differential processes of dissolution / overgrowth of nannofossils. In particular, delicate, small coccoliths may have been partially or totally dissolved, functioning as 'donors’. Conversely, the most resistant coccoliths or *Schizosphaerella* spp. may have acted as ‘receptors', in a way similar to the process described by C. ADELSECK *& al.* (1973). However, in our samples, very small and solution susceptible coccoliths are systematically observed, and dissolution (when present) only affected their central area structures. It is more likely therefore that the source of calcium carbonate for nannofossil overgrowth was different. Because ammonite specimens recorded at Peniche are essentially inner casts, we speculate that the dissolution of the aragonite that constituted their original shells might have provided considerable amounts of calcium carbonate to interstitial, diagenetic waters. According to our record (overgrowth dominating over etching, sparry calcite infilling the schizosphere valves), the nannofossils of Peniche underwent an after-burial diagenesis rather than dissolution at the water-sediment interface.

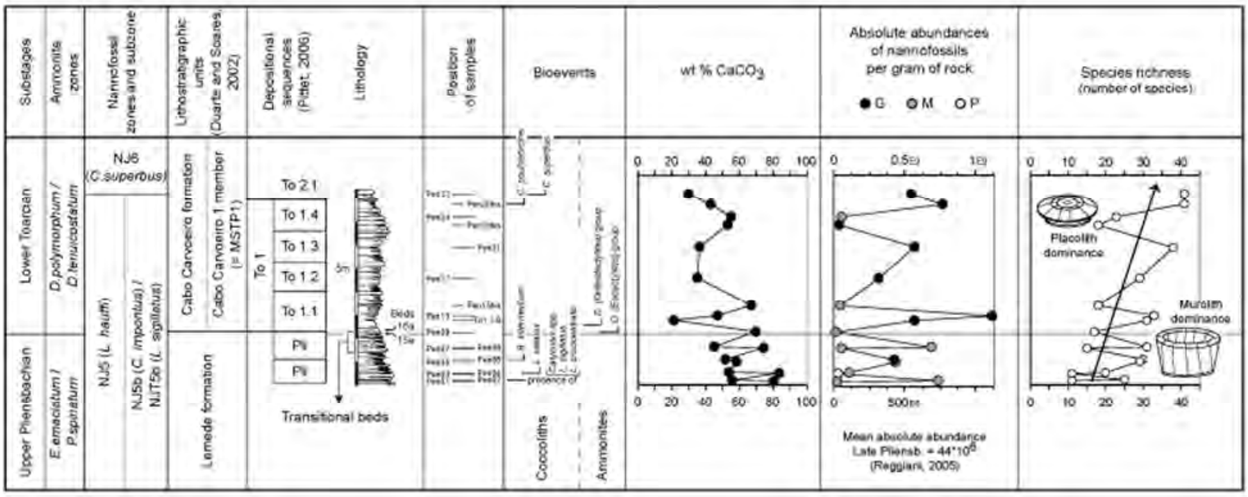

Fig. 2 – Lithostratigraphy of the Peniche section (after MOUTERDE, 1955; DUARTE & SOARES, 2002) with the stratigraphic position of the studied samples, and the depositional sequences (PITTET, 2006). Biostratigraphy is reported on the left, whilst ammonite and nannofossil events are shown in the column in the middle. Note that the presence of *L. sigillatus*, *L. crucicentralis* et *Calyculus* spp. Is recorded from the base of the section. Evolution of wt% $CaCO_3$ and of absolute abundances of nannofossils per gram of rock, with indication of the preservation (G = good, M = moderate, P = poor). Evolution of the species richness across the Pliensbachian/Toarcian boundary, illustrating the diversification trend of calcareous nannofossils.

4.2. Bioevents of calcareous nannofossils at the Pliensbachian/Toarcian boundary

As presented above, the Pliensbachian/Toarcian boundary is well characterized by the massive occurrence of different species of the *Eodactylites* group in the banc 15e, followed by the occurrence of several species of the *Orthodactylites* group in the banc 16a (figs 1 and 2). Within the nannofossils, a gradual and progressive diversification is observed at Peniche and this represents a common trend within the western Tethys (BOWN & *al*., 2004). Species richness significantly increases across the Pliensbachian/Toarcian boundary (fig. 2). Nannofossil diversification at that stage mainly concerns the placoliths (coccoliths which have two sub-horizontal shields separated by a tube, BOWN & YOUNG, 1998). This evolutionary trend has produced a major change in the coccolith community: the assemblages were dominated by muroliths (coccoliths having a wall-like, sub-vertical rim; BOWN & YOUNG, 1998) in the Pliensbachian, whilst placoliths became more common in the Toarcian (fig. 2).

At the basis of the studied interval, the First Occurrences (FO) of *Calyculus* spp. and *L. crucicentralis* are recorded just below the "Transition beds" (fig. 2). Slightly afterwards, we report the FO of *B. intermedium* (fig. 2). *Lotharingius sigillatus* and *Lotharingius* aff. *L. velatus* (having the same diagnostic characters of *L. velatus* but smaller in size and with a thinner rim) are already present within the Spinatum Zone, according to L. OLIVEIRA & *al*. (2007). Whilst the FOs of *Calyculus* and of *L. sigillatus* have been already reported from the uppermost Pliensbachian in sections from central Italy and Spain (MATTIOLI & ERBA, 1999; PERILLI & COMAS-RENGIFO, 2002), the FOs of *L. crucicentralis* and *B. intermedium* were previously referred to as Early or Middle Toarcian (BOWN, 1987; BOWN & COOPER, 1998; MATTIOLI & ERBA, 1999; PERILLI & COMAS-RENGIFO, 2002; MATTIOLI & *al*., 2004b). Although a real FO of *L. crucicentralis* and *B. intermedium* in the Lusitanian Basin (westernmost Tethys), followed by their eventual migration to other sedimentary basins cannot be completely excluded, the record of these species earlier than in other western Europe settings may be tentatively interpreted in a different way. The Peniche section presents an exceptionally continuous record of the Pliesbachian/Toarcian boundary. Condensation or hiatuses that are common features in this interval in many Tethyan settings may have hidden the real FOs of these two species. An alternative hypothesis implies the different ammonite zonation used in various Tethyan areas. As illustrated above, the Pliesbachian/Toarcian boundary at Peniche is defined in a way similar to the Oppel zone (OPPEL, 1856-58) by a massive occurrence of *Dactylioceras* (MOUTERDE, 1955; ELMI & *al*., 1996, 2005). However, very rare specimens of ammonite belonging to this genus are already present in the Late Pliensbachian (MOUTERDE, 1955; ELMI & *al*., 1996, 2005). In central Italy, the base of the Toarcian (Polymorphum Zone) is defined on the basis of the first occurrence of the genus *Dactylioceras* (see VENTURI, 1999). It is therefore not excluded that the base of the first ammonite zone of the Toarcian as defined by the different authors is slightly diachronous in the two regions, whilst the FOs of *L. crucicentralis* and *B. intermedium* may be considered as synchronous events.

The Pliensbachian/Toarcian boundary at Peniche is comprised within the NJT5b *L. sigillatus* nannofossil subzone of E. MATTIOLI & E. ERBA (1999; South Tethyan margin) or in the NJ5b *C. impontus* of P. BOWN & M. COOPER (1998; North Tethyan margin). As the Peniche nannofossil assemblages show characters intermediate between the N and S Tethyan assemblages, both biostratigraphic schemes can be used. Finally the FOs of *Carinolithus superbus*, defining the base of the NJT6 Zone, is recorded in the present work at the boundary between the sedimentary sequences To 1 and To 2 (fig. 2).

4.3. Trends in nannofossil assemblages

Absolute and relative abundance of the most common taxa recorded across the Pliensbachian/Toarcian boundary are reported in fig. 3. In synthesis, albeit absolute abundance of the different taxa co-varies with total nannofossil abundance, some trends can be observed for relative abundance. Absolute and relative abundances of *Schizosphaerella* spp. significantly decrease just above the Pliensbachian/Toarcian boundary (fig. 3). This decrease in abundance parallels a reduction in size of this taxon occurring in two different steps, namely below the "Transition beds" and just above the Pliensbachian/ /Toarcian boundary (fig. 4). A decrease in the percentage of *M. jansae* matches with an increase in relative abundance of all the *Biscutaceae*, the sum of *Lotharingius*, and of *Bussonius*. This trend explains the dominance of placoliths over muroliths observed in the Early Toarcian.

Over-calcified specimens of *L. frodoi* are observed in various samples (indicated with a white cross in fig. 3; Plate 1). This form displays higher birefringence colours than *L. frodoi*. These specimens are probably forms transitional between *Lotharingius* and *Watznaueria britannica*, whose first occurrence is commonly reported at the Aalenian/Bajocian boundary (MATTIOLI & ERBA, 1999). The presence of these transitional forms, similar to the morphotype 'F' of *W. britannica in* F. GIRAUD & *al.* (2006), may explain the fact that G. HAMILTON (1977, 1979, pl. 1, fig. 1-2) reports the presence of *Ellipsagellosphaera* (=*Watznaueria*) *britannica* (that are very likely over-calcified *L. frodoi*) from the Early Toarcian of the Lusitanian Basin. The presence of over-calcified, robust coccoliths seems to be a common pattern in Peniche, mainly in the uppermost Pliensbachian interval. Conversely, in the Early Toarcian under-calcified, tiny coccoliths are observed. These include *Lotharingius* aff. *L. velatus*, *L. barozii*, and *Similiscutum finchii* (Plate 1). These taxa do not show reduced dimensions (i.e., coccolith length and width) with respect to the holotype descriptions, but a very thin ring and an enlarged central area.

Although the Lusitanian Basin was located at a latitude intermediate between the Mediterranean Tethys and the NW European Domain, nannofossil assemblages show a clear S-Tethyan affinity in the studied interval. In particular, the schizosphaeres and *Mitrolithus jansae*, which have a clear affinity for the southern margin of Tethys (BOWN, 1987; PALLIANI & *al*., 2002), are very abundant at Peniche. The species of the genus *Similiscutum* are more common in Portugal, Morocco (de KAENEL & BERGEN, 1993), and Sicily (MATTIOLI & *al.*, 2004b) than in other western Tethys settings.

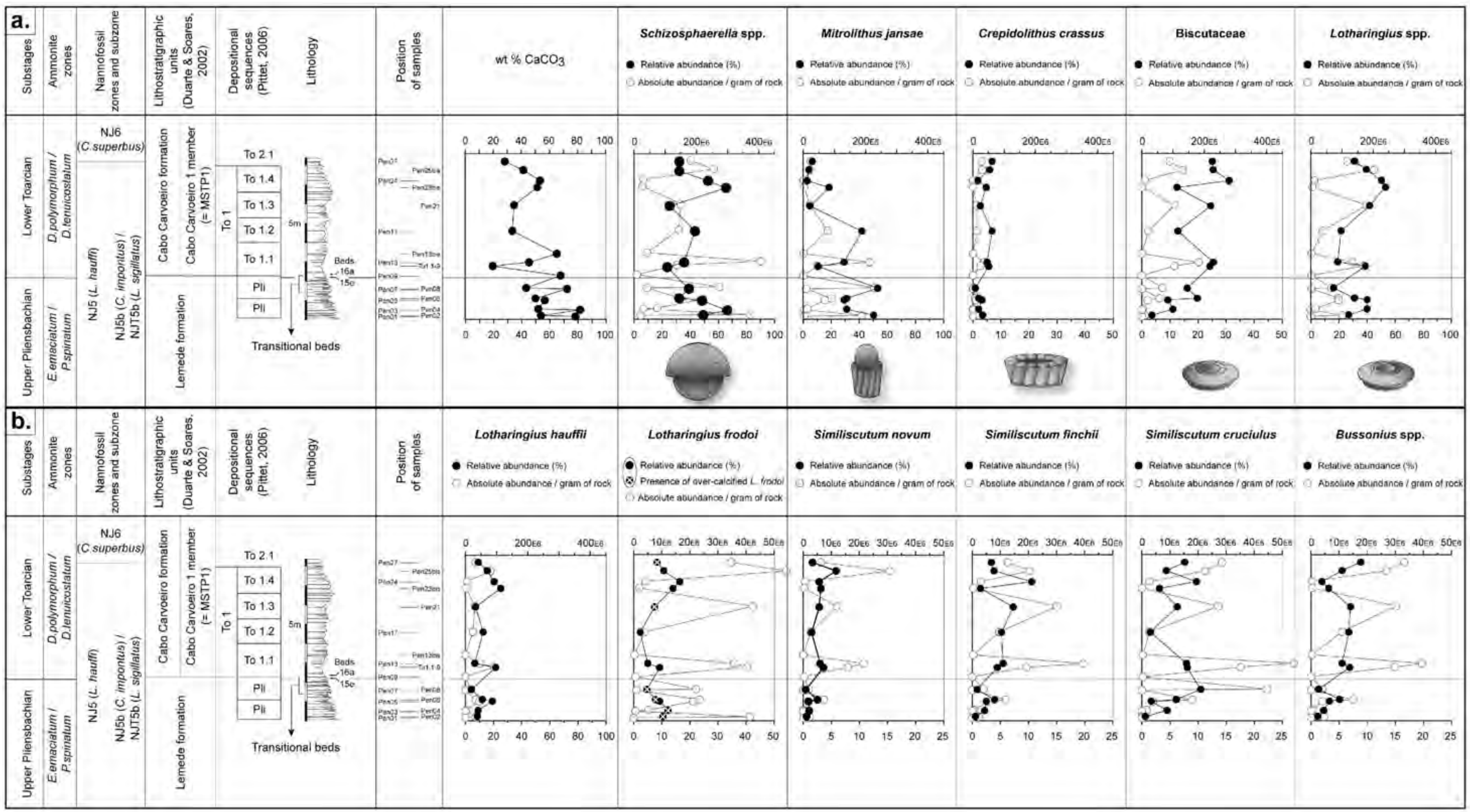

Fig. 3a – Stratigraphic evolution of wt % $CaCO_3$ and of relative and absolute abundances of the main pelagic carbonate producers across the Pliensbachian/Toarcian boundary (*Schizosphaerella* spp., *Crepidolithus crassus*, *Mitrolithus jansae*, Biscutaceae and *Lotharingius* spp.).
b – Relative and absolute abundance of the most common species belonging to the genus *Lotharingius* (*L. hauffii* and *L. frodoi*), *Similiscutum* (*S. novum*, *S. finchii* and *S. cruciulus*), and of *Bussonius* spp. The occurrence of over-calcified specimens of *Lotharingius frodoi* is marked by a white cross.

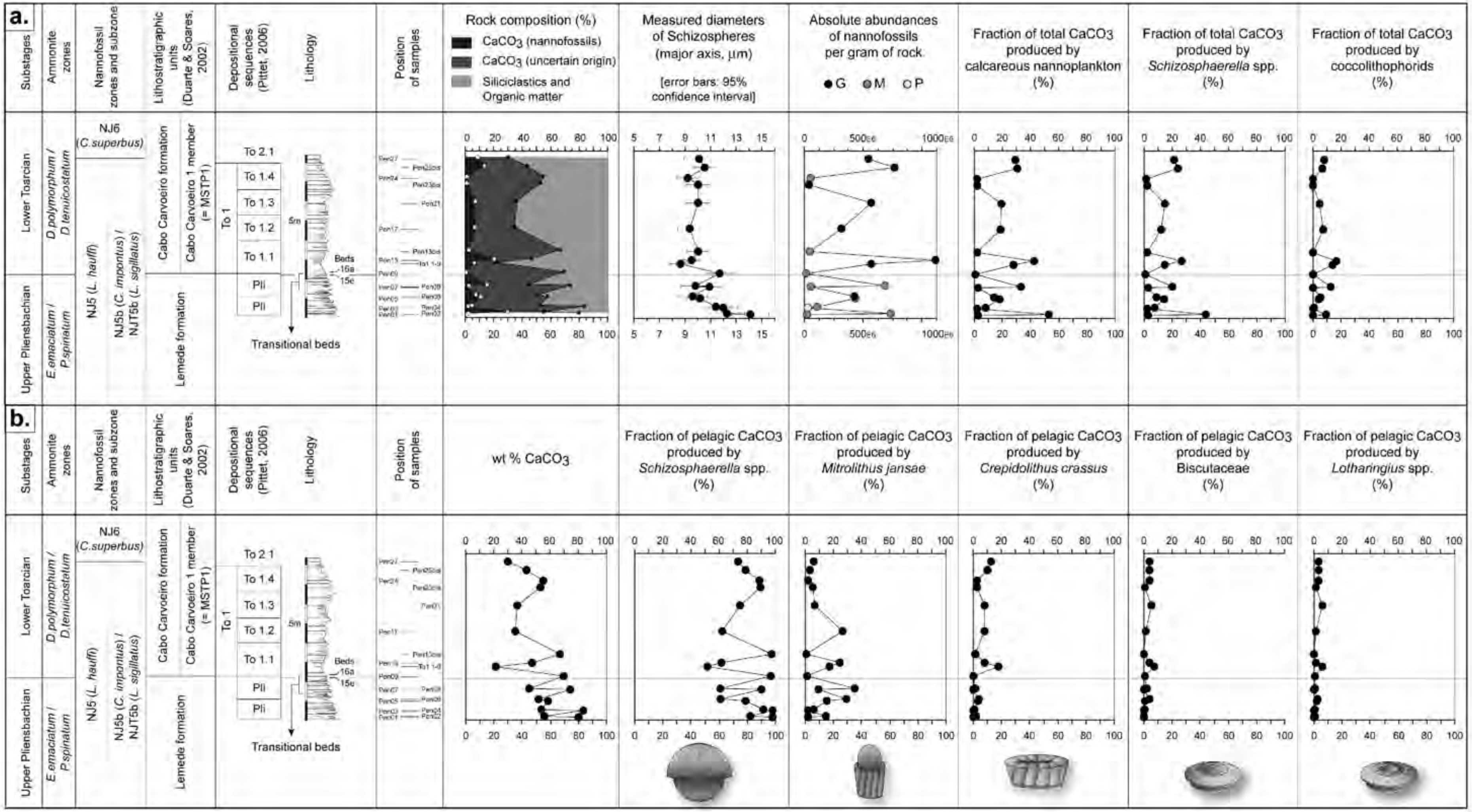

Fig. 4a – Stratigraphic evolution of total $CaCO_3$ in the bulk rock and of pelagic $CaCO_3$ produced by calcareous nannofossils; stratigraphic trend of *Schizosphaerella* spp. sizes (average dimension of major axis measured in μm; error bars = 95% confidence interval) and of absolute abundances of nannofossils per gram of rock (with indication of the preservation: G = good, M = moderate, P = poor). The total $CaCO_3$ produced by calcareous nannoplankton is shown with the detail of the fraction produced by *Schizosphaerella* spp. and by coccoliths.
b – Wt % $CaCO_3$ and the relative contribution of the main producers of pelagic $CaCO_3$ (*Schizosphaerella* spp., *Crepidolithus crassus*, *Mitrolithus jansae*, Biscutaceae and *Lotharingius* spp.).

4.4. Nannofossil contribution to the carbonate production

Absolute abundance (nannofossils per gram of rock) records very high values in the uppermost Pliensbachian and in particular in the “Transition beds” (fig. 2). The average abundance in marl-limestone alternation of the underlying interval (Margaritatus and Spinatum Zones) is 44 x 10^6 specimens per gram of rock (REGGIANI, 2005), whilst 250 x 10^6 specimens per gram of rock on average, with peaks at $\sim 1*10^9$, are recorded in the interval at the Pliensbachian/Toarcian boundary. It must be noted, however, that such absolute abundances should be corrected by the accumulation rate. As the “Transition beds” are affected by condensation, the very high nannofossil abundances recorded there may be in part the effect of a low dilution of nannofossils by sedimentary flux. The same phenomenon controlling nannofossil abundance has been already described in Toarcian (MATTIOLI & PITTET, 2002), Oxfordian (PITTET & *al.*, 2000) and Lower Cretaceous (REBOULET & *al.*, 2003; GIRAUD & *al.*, 2003) sections. An increase in nannofossil abundance passing from the Pliensbachian to the Toarcian is a common pattern in the western Tethys (MATTIOLI & *al.*, 2004a), and it has been interpreted as an increase in nannoplankton production.

Wt% $CaCO_3$ values are quite high in the Late Spinatum Zone, namely 75-85% in limestones and 50-60% in marls (fig. 4a). These high values decrease through pulses across the Pliensbachian/Toarcian boundary, and carbonate content is quite low in the Polymorphum Zone. An inverse trend with respect to wt% $CaCO_3$ is observed for nannofossil absolute abundance within the Spinatum Zone. Abundances are the highest in marly hemi-couplets (fig. 4a). The stratigraphic evolution of total wt% $CaCO_3$ *versus* the pelagic $CaCO_3$ produced by calcareous nannofossils across the Pliensbachian/Toarcian boundary is shown in fig. 4a. The pelagic carbonate fraction was obtained by combining the average volume per sample of the most robust and common taxa in the studied interval, namely *Schizosphaerella* spp., *Crepidolithus crassus*, *Mitrolithus jansae*, the Biscutaceae (both *Biscutum* spp. and *Similiscutum* spp.), and all the species of the genus *Lotharingius*. The calcium carbonate produced by nannofossils may attain 20 to 30 % of the total rock components, or 30 to 52 % of the total carbonate content mainly in the uppermost Pliensbachian and base of the Toarcian. The highest proportion of pelagic carbonates is recorded in the marls where the lithogenetic role of calcareous nannoplankton is significant. This pattern is in agreement with the record documented by various authors for marl-limestone alternations of the Toarcian (MATTIOLI & PITTET, 2002), Oxfordian (OLIVIER & *al.*, 2004) and Early Cretaceous (REBOULET & *al.*, 2003; GIRAUD & *al.*, 2003). Conversely, in limestones the pelagic carbonate fraction is limited, contrarily to what is inferred in some works (NOËL & BUSSON, 1990; NOËL & *al.*, 1993, 1994; MATTIOLI, 1997; TREMOLADA & *al.*, 2005), and the origin of a major proportion of carbonates stays uncertain. *Schizosphaerella* spp. is the main producer in the nannofossil fraction (figs 4a and b). The contribution of *C. crassus* and, mainly, *M. jansae* may be significant in some levels of the uppermost Pliensbachian and base of the Toarcian, whilst the placolith-coccoliths (Biscutaceae and the sum of the *Lotharingius* species), because of their small dimensions, produce very little carbonate (fig. 4b).

5. Concluding remarks

The good nannofossil record of the Peniche section, coupled to ammonite biostratigraphy, allows a characterization of the Pliensbachian/Toarcian boundary. This corresponds to a diversification phase of coccoliths, with new species and genera appearing, namely *Calyculus* spp., *L. crucicentralis*, *B. intermedium*, and *Carinolithus* spp. This phase of diversification essentially affected the placolith-coccoliths. It resulted in a change from assemblages dominated by muroliths to a clear dominance of placoliths in the Early Toarcian. This is a common pattern observed in many other Tethyan settings. The stage boundary lies within the NJ5b nannofossil subzone that spans the latest Pliensbachian to the earliest Toarcian. Some nannofossil events (*L. crucicentralis*, *L.* aff. *L. velatus* and *B. intermedium*) are recorded at Peniche earlier than in other areas (OLIVEIRA & *al.*, 2007; this work). It is unclear if these early occurrences are real, or they are the result of different ammonite zonations used in various sections.

Alternatively, the excellent continuity of the Peniche section in a period (the Pliensbachian/Toarcian boundary), in which condensations or hiatuses affect the majority of the Western Europe settings, may be responsible for the observed nannofossil record. Over-calcified coccoliths are commonly recorded at Peniche and some of them are typical of the Lusitanian Basin. These forms comprise specimens of *Lotharingius frodoi*, which seem to be transitional forms between *Lotharingius* and *Watznaueria britannica*. It is probable that the *Ellipsagelosphaera* (=*Watznaueria*) *britannica* noticed by G. HAMILTON (1977, 1979) in the Toarcian of the Lusitanian Basin corresponds to over-calcified *Lotharingius frodoi*.

Although works on absolute quantification of nannofossils are still limited, abundance per gram of rock is higher at Peniche than in correlative levels of other Tethyan sections (MATTIOLI & *al.*, 2004a). The highest values of abundance are found in the marly hemi-couplets across the Pliensbachian/Toarcian boundary, conversely the carbonate-rich levels contain less nannofossils. This pattern is not related to a diagenetic impoverishment of the assemblages in limestones, as demonstrated by the analysis of nannofossil preservation. The pelagic carbonate fraction is conspicuous in the marls, where in some cases more than a half of the carbonate is produced by nannofossils. Amongst the producers, *Schizosphaerella* spp. has the most important lithogenetic impact, accounting between 50 and 100% of the pelagic carbonate fraction. *Crepidolithus crassus* and *Mitrolithus* *jansae* are also important producers whilst the placolith-coccoliths (such as the Biscutaceae and the species of the genus *Lotharingius*) produce very low quantities of carbonate because of their small sizes, albeit they can be abundantly recorded in the assemblage.

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Species list

List of the genera and species cited in this work with appropriate reference:

Biscutum BLACK *in* BLACK & BARNES, 1959
Biscutum dubium (NOËL, 1965) GRÜN *in* GRÜN & *al*., 1974
Biscutum intermedium BOWN, 1987
Bussonius GOY, 1979
Calyculus NOËL, 1973
Carinolithus (PRINS *in* GRÜN & *al*., 1974) BOWN, 1987
Carinolithus poulnabronei MATTIOLI, 1996
Carinolithus superbus (DEFLANDRE *in* DEFLANDRE & FERT, 1954) PRINS *in* GRÜN & *al*., 1974
Crepidolithus NOËL, 1965
Crepidolithus cavus PRINS *ex* ROOD & *al*., 1973
Crepidolithus crassus (DEFLANDRE *in* DEFLANDRE & FERT, 1954) NOËL, 1965
Crepidolithus impontus (GRÜN & *al*., 1974) GOY, 1979
Lotharingius NOËL, 1973 emend. GOY, 1979
Lotharingius crucicentralis (MEDD, 1971) GRÜN & ZWEILI, 1980
Lotharingius frodoi MATTIOLI, 1996
Lotharingius hauffii GRÜN & ZWEILI *in* GRÜN & *al*., 1974
Lotharingius sigillatus (STRADNER, 1961) PRINS *in* GRÜN & *al*., 1974
Lotharingius velatus BOWN & COOPER, 1989
Mitrolithus DEFLANDRE, 1954
Mitrolithus jansae (WIEGAND, 1984) BOWN *in* YOUNG & *al*., 1986
Schizosphaerella DEFLANDRE & DANGEARD, 1938
Similiscutum (de KAENEL & BERGEN, 1993) MATTIOLI & *al*., 2004
Similiscutum cruciulus de KAENEL & BERGEN, 1993
Similiscutum finchii (CRUX, 1984 emend. BOWN, 1987) de KAENEL & BERGEN,1993
Similiscutum novum (GOY, 1979) MATTIOLI & *al*., 2004
Watznaueria britannica (STRADNER, 1963) REINHARDT, 1964

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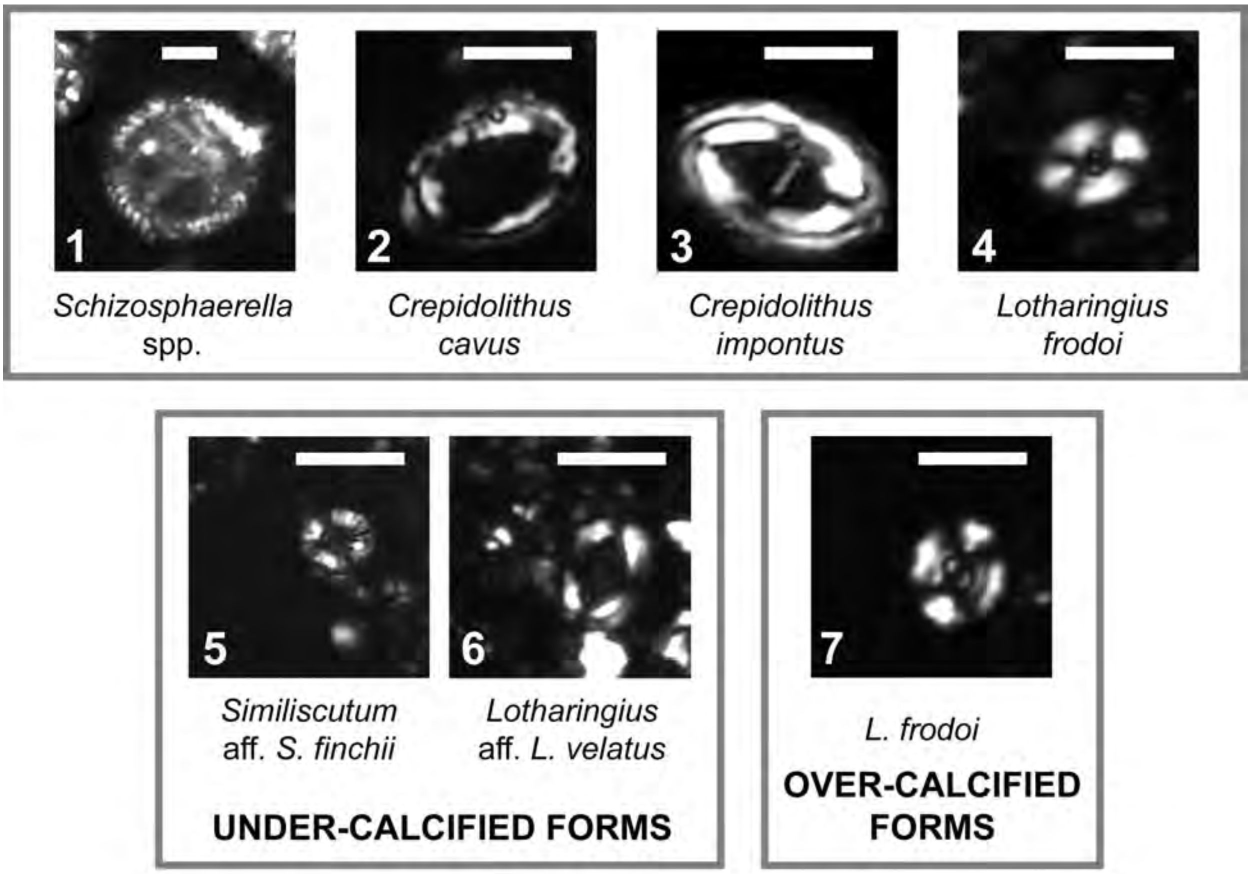
Plate 1



Some nannofossil taxa recorded at Peniche. All pictures are in optical microscope, crossed polars.
White bar = 5 µm.

Fig. 1 – *Schizosphaerella* spp., sample PEN 02 (Spinatum Zone).
Fig. 2 – *Crepidolithus cavus*, sample PEN 21 (Plymorphum Zone).
Fig. 3 – *Crepidolithus impontus*, sample PEN 25bis (Polymorphum Zone).
Fig. 4 – *Lotharingius frodoi*, sample PEN 25bis (Polymorphum Zone).
Fig. 5 – *Similiscutum* aff. *S. finchii*, sample PEN 08 (Spinatum Zone).
Fig. 6 – *Lotharingius* aff. *L. velatus*, sample PEN 08 (Spinatum Zone).
Fig. 7 – *Lotharingius frodoi*, sample PEN 08 (Spinatum Zone).