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CALIBRATION OF THE PLIENSBACHIAN-TOARCIAN CALCAREOUS NANNOFOSSIL ZONE BOUNDARIES BASED ON AMMONITES (BASQUE-CANTABRIAN AREA, SPAIN)

NICOLA PERILLI[1], MARÍA JOSÉ COMAS-RENGIFO[2] & ANTONIO GOY[2]

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Abstract. Based on a continuous succession of ammonite and calcareous nannofossil assemblages, the main purpose of this paper is the correlation between ammonite and calcareous nannofossil zone boundaries in two expanded sections from the Basque-Cantabrian area. The ammonite assemblages show clear euroboreal features and allow the identification of Pliensbachian-Toarcian zones and subzones established for NW Europe. Due to the presence of Mediterranean taxa documented at different levels, they are also helpful to improve the biocorrelations between Boreal and Tethyan successions. The calcareous nannofossil assemblage changes provide a useful set of easily recognizable events that facilitate the recognition of all the Pliensbachian-Toarcian zones described for NW Europe and Mediterranean Province. Based on the FO *Similiscutum cruciulus* (Jamesoni Zone), FO of *Lotharingius hauffii* (Stokesi/Margaritatus Zone boundary), FO of *Carinolithus superbus* (Serpentinus Zone), FO of *Discorhabdus striatus* (Serpentinus/Bifrons Zone boundary) and FO of *Retecapsa incompta* (Insigne Zone), the NJ3/NJ4, NJ4/NJ5, NJ5/NJ6, NJ6/NJ7 and NJ7/NJ8 Zone boundaries have been recognized. Besides, NJ4, NJ5 and NJ6 span almost the same ammonite-defined time interval in both NW Europe and Basque-Cantabrian area. With respect to the ammonite zone, the zone boundaries NJ3/NJ4 and NJ6/NJ7 coincides with NJT3/NJT4 and NJT6/NJT7 proposed for Mediterranean Province. Instead, the zone boundaries NJ4/NJ5 and NJ5/NJ6 not coincides with NJT4/NJT5 and NJT5/NJT6 proposed for Mediterranean Province. Furthermore, in NW Europe and Mediterranean Province the FO of *Retecapsa incompta* is placed in the Levesquei Zone or Meneghinii Zone respectively, whilst in the Basque Cantabrian area it lies in the Insigne Zone.

Riassunto. La correlazione tra le zone e le subzone ad ammoniti e quelle a nannofossili calcarei, riconosciute in due sezioni continue ed espanse localizzate nell'area Basco-Cantabrica, è l'obiettivo principale di questo lavoro. Le associazioni ad ammoniti, chiaramente euroboerali, permettono di riconoscere tutte le zone e sottozone ad ammoniti stabilite per l'Europa nord-occidentale; inoltre la presenza di taxa mediterranei permette di migliorare le biocorrelazioni tra le successioni boreali e quelle tetidee. I cambiamenti delle associazioni a nannofossili calcarei forniscono una successione di bioorizzonti che permette di riconoscere e caratterizzare le zone del Pliensbachiano e del Toarciano stabilite per l'Europa nord-occidentale. Tra questi la FO di *Similiscutum cruciulus* (Zona a Jamesoni), la FO di *Lotharingius hauffii* (limite tra le Zone Stokesi/Margaritatus), la FO di *Carinolithus superbus* (Zona a Serpentinus), la FO di *Discorhabdus striatus* (limite tra le Zone Serpentinus/Bifrons) e la FO di *Retecapsa incompta* (Zona a Insigne) permettono di riconoscere i seguenti limiti di zona: NJ3/NJ4, NJ4/NJ5, NJ5/NJ6, NJ6/NJ7 e NJ7/NJ8. Rispetto alle zone ad ammoniti, le Zone NJ4, NJ5 e NJ6 definiscono lo stesso intervallo di tempo sia per l'Europa nord-occidentale che per l'area Basco-Cantabrica. Sempre rispetto alla zone ad ammoniti, i limiti di zona NJT3/NJT4 e NJT6/NJT7 definiti per la Provincia Mediterranea coincidono con la posizione occupata dai limiti di zona NJ3/NJ4 e NJ6/NJ7, mentre i limiti di zona NJT4/NJT5 e NJT5/NTJ6 non coincidono con i rispettivi limiti di zona NJ4/NJ5 e NJ5/NJ6 riconosciuti nell'area Basco-Cantabrica.

Introduction

The utility of Jurassic calcareous nannofossils in biostratigraphy is well known and the papers of de Kaenel et al. (1996), Bown (1996), Bown & Cooper (1998) and Mattioli & Erba (1999) could be consulted for a comprehensive reviews of the current literature on Jurassic biostratigraphy and of the different biozonations proposed for various areas. Actually, two are the reference biostratigraphic zonations proposed for NW Europe and Mediterranean Province by Bown & Cooper (1998) and Mattioli & Erba (1999), respectively. In both schemes the zonal markers are correlated with the standard ammonite zonations estabilished for the two areas. However, as well pointed out by de Kaenel et al. (1996) and stressed by Mattioli & Erba (1999), the calibration of calcareous nannofossil biohorizons based on ammonite could be problematic,

1 Dipartimento Scienze della Terra, Università degli Studi di Pisa, Via S. Maria, 53, 56100 Pisa (Italy). E-mail: perilli@dst.unipi.it
2 Departamento de Paleontología, Facultad de Ciencias Geológicas, UCM, Ciudad Universitaria, 28040 Madrid (Spain).
E-mail: mjcomas@geo.ucm.es; angoy@geo.ucm.es

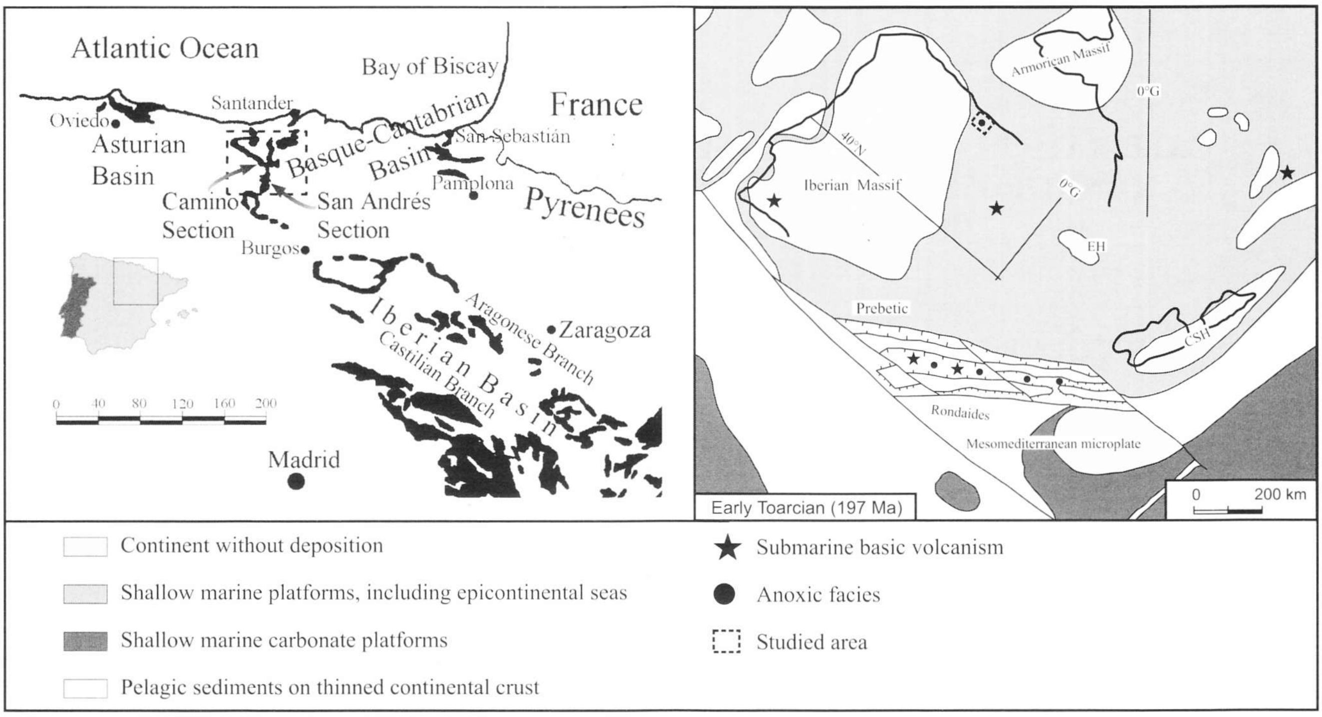

Fig. 1 - To the left the Jurassic outcrops of in the northern basins of Spain as well as the location of the studied sections are shown. To the right, the Early Toarcian palaeographic map (slightly modified from Vera 2001); CSH, Corsica-Sardinian High; EH, Ebro High.

particularly when the ammonite record is discontinuous or affected by provincialism. Furthermore, the number of Lower Jurassic sections with a continuous ammonite and calcareous nannofossil record is limited and the direct calibration of some calcareous nannofossil events against ammonites zones should be improved.

Based on well preserved and continuous ammonite and nannofossil assemblages, recovered from two expanded sections located in the Basque-Cantabrian area (Dahm 1966; Braga et al. 1985, 1988; Goy et al. 1994; Perilli 1999a; Perilli & Comas-Rengifo 2002), the main objective of this paper is the calibration of the Pliensbachian-Toarcian calcareous nannofossil zone boundaries, against ammonite zone and subzones, estabilished for the northern margin of the Iberian Plate, a link area between Boreal and Tethyan Domains.

During the Early Jurassic, the shallow carbonate platform, extending over the northern (Asturian and Basque-Cantabrian areas) and northeastern (Iberian Range) parts of the Iberian Plate, was affected by the widespread transgression, that involved also the northwestern part of the Europe Plate (Jacquin et al. 1998). At that time, even the southern (Betic Range) and western (Lusitanian Basin) parts of the Iberian Plate were interested by a rapid transgression as a consequence of the Early Jurassic maximum flooding (Vera 1988, 2001). Although the connections between Boreal (Asturian and Basque-Cantabrian area) and Tethyan (Betic Range and Lusitanian Basin) Domains are not well understood, paleontological data support intermittent, and sometimes persistent, connections between these regions (Braga et al. 1988; Comas-Rengifo et al. 1988; Fernández-López et al. 1988).

Consequently, the ammonite assemblages allow to identify and characterize all the zones and subzones established for NW Europe and to support the correlation between the standard zonations adopted in NW Europe and Mediterranean Province. Hence, on the basis of this meaningful ammonite record, the recognized nannofossil zone boundaries will be compared with those proposed for NW Europe by Bown & Cooper (1998) and Italy/S France by Mattioli & Erba (1999). On the other hand, the cosmopolitan features of calcareous nannofossil assemblages, and the widespread diffusion of nannofossil species can be used to test the correlation between ammonite zone boundaries adopted in different paleobioprovinces. Calcareous nannofossils are a good biostratigraphic tool, and in some cases even more powerful than ammonites, to reconstruct a biostratigraphic framework aimed to resolve many geological problems on land and offshore (i.e. regional geology, stratigraphy, sequence analysis, borehole correlations).

Lithostratigraphic and sedimentological features of the studied sections

The Lower-Middle Jurassic succession is extensively exposed in the Basque-Cantabrian area (Fig. 1) and consists of: 1) Rhaetian to Lower Sinemurian shallow-

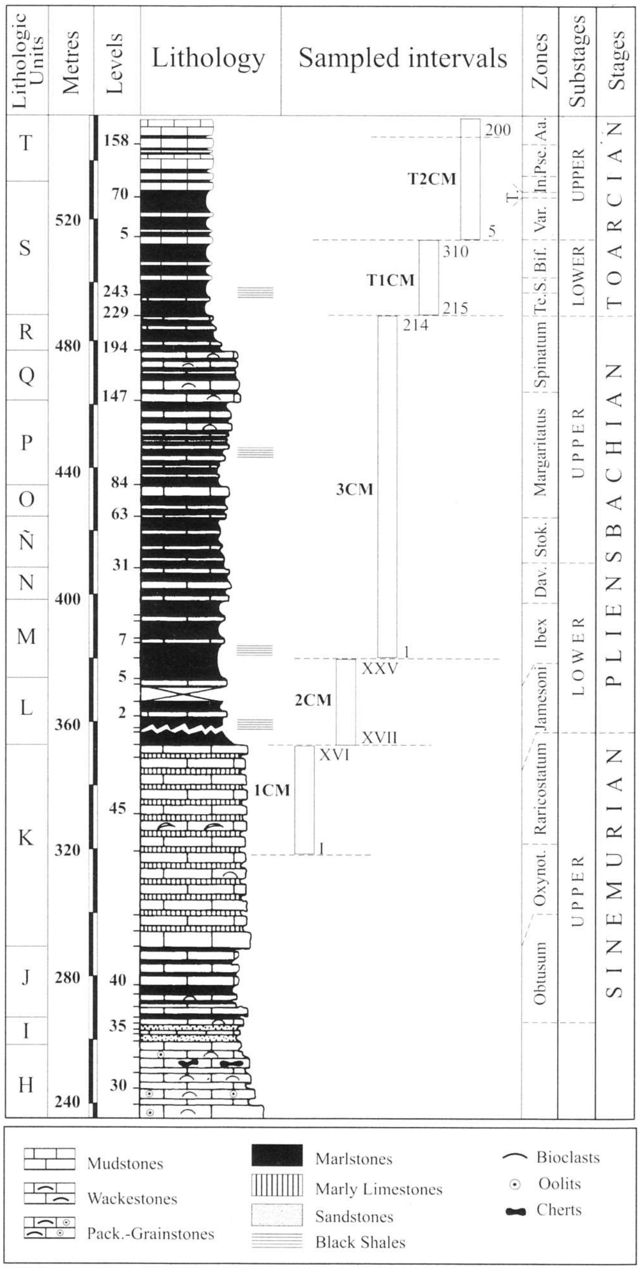

Fig. 2 - Lithostratigraphy of the Upper Sinemurian-Toarcian succession of the Camino section and sampled intervals: 1CM, 2CM, 3CM, T1CM, T2CM (slightly modified from Comas-Rengifo et al. 1988; Goy et al. 1994; both papers could be consulted for the reported numbers). Abbreviations: Oxynot.= Oxynotum; Dav.= Davoei; Stok.= Stokesi; Te.= Tenuicostatum; S.= Serpentinus; Bif.= Bifrons; Var.= Variabilis; T.= Thouarsense; In.= Insigne; Pse.= Pseudoradiosa; Aa.= Aalensis.

marine carbonate ramp sediments, 2) Upper Sinemurian-Toarcian hemipelagic ramp deposits (Fig. 2) with euxinic facies sedimented in anoxic troughs and 3) Aalenian-Bajocian neritic to hemipelagic sediments with sponge-bearing bioconstructions (Braga et al. 1985, 1988; Schaaf 1986; Goy et al. 1994; Quesada et al. 1991, 1993, 1997; Gómez & Goy 2000).

Due to the complete and superbly exposed lithologic record, the Camino and San Andrés sections are considered among the most representative outcrops of Northern Spain. The ammonite biostratigraphy have been established by Dahm (1966), Braga et al. (1985, 1988) and Goy et al. (1994) and the calcareous nannofossils were studied by Perilli (1999a) and Perilli & Comas-Rengifo (2002).

With a maximum thickness of 100/130 m, the Pliensbachian succession (Camino Formation, Robles et al. 2002) mainly consists of a regular marlstone/limestone alternations, with a significant macro- (ammonites, belemnites, bivalves, brachiopods and echinoderms) and microfossil (ostracods, foraminifera and calcareous nannofossils) contents. The limestones, mainly represented by mudstone, are sometimes very iron-rich, and frequently show concentration of bioclasts and pyrite. Present throughout the entire Pliensbachian succession, bioclastic wackstones are particular abundant in the uppermost portion. According to Braga et al. (1988), the Pliensbachian succession was deposited below storm wave base, on an intra-shelf usually characterized by aerobic conditions as supported by the presence of benthic organisms. By Early (Jamesoni and Ibex Zones) and Late (Margaritatus Zone) Pliensbachian the development of anaerobic to dysaerobic conditions was estabilished. The uppermost part of the Pliensbachian succession (Spinatum Zone) is characterized by shallowing sequences with significant benthic organisms that indicate aerobic conditions through the water column.

The Toarcian succession (Castillo Pedroso Formation, Robles et al. 2002) is 60-66 m thick and consists of a regular decimetre marls/limestone alternance, that attenuated in its upper portion (Pseudoradiosa and Aalensis Zones). The limestones are usually represented by mudstones rich in ammonites, belemnites, thin-shelled bivalves; sometimes they are also characterized by the occurrence of brachiopods and infaunal bivalves, in its lower portion. Present throughout the entire Toarcian time interval, wackstones are more abundant in the upper portion, that is also characterized by the reduction of marlstone thickness. As pointed out by Comas-Rengifo et al. (1988), the Toarcian succession was deposited on an intra-shelf epicontinental platform, with the sea floor usually lying below the fair weather wave base. The pelagic sedimentation was influenced by terrigenous and calcareous inputs from the shallowest zones of the platform. The proportion of the calcareous/terrigenous fine fraction increases towards the top and the bioclasts abundance increases within the limestones, although they never become abundant. Probably, the bottom conditions were unfavourable for benthic life, hence benthic organism remains are scarce for the entire Toarcian interval. The lower portion (upper part of the Tenuicostatum Zone) is dominated by sedimentation under anoxic/dysoxic condition.

Biostratigraphic reference scale

The stratigraphic discontinuities observed in the Pliensbachian-Toarcian sedimentary record of the western Basque-Cantabrian area are insignificant. The ammonoid biozones have a conspicuous development, except for the Thouarsense Zone, which may be locally absent, and there is a tendency to increase in thickness northwards. The zonal reference scale used in this paper has been established on the basis of the partial scales proposed by Braga et al. (1985, 1988) and Goy et al. (1994).

Pliensbachian

The most complete Pliensbachian succession cropping out in the whole Basque-Cantabrian area is exposed near Camino village. Unfortunately, the boundaries of the first two Pliensbachian ammonite zones, Jamesoni and Ibex, are difficult to identify and their thickness are hard to evaluate, due to the dominance of marly sediment that are covered with vegetation. Although specimens typical of the Taylori, Brevispina and Jamesoni Subzones, have been recognized, the first significant ammonite assemblages belong to the upper Jamesoni Subzone, and are characterized by the occurrence of *Polymorphites* and *Uptonia*. Also, specimens belonging to the Valdani and Masseanum Subzones (Ibex Zone) are scarce and discontinuous, whilst assemblages referable to the overlying Luridum Subzone are characterized by the presence of *Acanthopleuroceras*, *Liparoceras* and *Radstockiceras*.

The Davoei Zone is 12 m thick and starts with the first occurrence of the genus *Aegoceras*, and the first occurrence of *Aegoceras maculatum* (Young & Bird), *Aegoceras capricornus* (Schlotheim) and *Oistoceras figulinum* (Simpson) allow the recognition of the three subzones utilized in regions of the Euroboreal Domain. In the middle and upper part of the Figulinum Subzone two biohorizons are characterized by the occurrence of *Prodactylioceras* [(*P. aurigeriense* Dommergues, Faure & Mouterde and *P. davoei* (Sowerby)]. In the Basque-Cantabrian area these taxa are more frequent than in other parts of the Iberian Peninsula.

Coinciding with the appearance of Harpoceratinae along with the first specimens belonging to the genus *Amaltheus*, the base of the Upper Pliensbachian is easily recognizable. The Stokesi Zone is 16 m thick and, as in the Iberian Range, it includes two subzones. The Monestieri Subzone is characterized by the development of *Protogrammoceras* (*Matteiceras*) with thick ornamentation together with the first morphology referable to the genus *Amaltheus* [*A. stokesi* (Sowerby), *A. bifurcus* Howarth] and *Fuciniceras* [*F. portisi* (Fucini)]; whilst the dominance of species belonging to *Protogrammoceras* s.s. and *Protogrammoceras* (*Fieldingiceras*) characterized the overlying Celebratum Subzone.

The thick Margaritatus Zone (38 m thick in the Camino section) includes two subzones. Unfortunately the ammonites are scarce and scattered, but still richer than other sections of the Iberian Peninsula. Both the Subnodosus and overlying Gibbosus Subzones are characterized by the presence of all characteristic morphologies referable to the genus *Amaltheus*. The assemblages referable to the Gibbosus Subzone also include very rare Harpoceratinae, and frequent species belonging to the genus *Arieticeras* [(*A. amalthei* (Oppel), *A. disputabile* (Fucini)].

In the Basque-Cantabrian area, even the Spinatum Zone is quite thick, and in the Camino section it reaches 22.5 m. Its lower limit coincides with the sharp appearance of the genus *Pleuroceras* [*P. transiens* (Frentzen) followed by the appearance of *P. solare* (Phillips)] that is abundant throughout the entire ammonite zone. The appearance of *P. solare* (Phillips) and *P. hawskerense* (Young & Bird) allows to recognize the Solare and Hawskerense Subzones, respectively. In the lower part of the Solare Subzone, *P. solare* (Phillips) occurs with the last species belonging to the genus *Amaltheus* along with rare specimens of Harpoceratinae (*Neolioceratoides* and *Lioceratoides*). In the Hawskerense Subzone, the genus *Pleuroceras* [(*P. spinatum* (Bruguière), *P. hawskerense* (Young & Bird), *P. apyrenum* (Howarth)] occurs in the lower part of the subzone, whilst in its upper part is replaced by *Emaciaticeras* and *Canavaria*.

Toarcian

Continuously exposed NNW of Reinosa, the Lower Toarcian is 25 m thick and provides the most complete ammonite record, that allows the recognition of the Tenuicostatum, Serpentinus and Bifrons Zones. The lower boundary of the Toarcian is defined by the first occurrence of *Dactylioceras* (*Eodactylites*).

The Tenuicostatum Zone is 8 m thick and, as in the Iberian Range, it could be divided into the Mirabile and the Semicelatum Subzones. The former includes *D.* (*E.*) *simplex* (Fucini) and *D.* (*E.*) *mirabile* (Fucini) horizons, whilst the latter comprises only *Dactylioceras* (*Orthodactylites*), mainly represented by *D.* (*O.*) *semicelatum* (Simpson). This ammonite zone is also characterized by the occurrence of *Protogrammoceras*, belonging to the *P. paltus* (Buckman) group in the lower part, and to *P. madagascariense* (Thévenin) group in the upper part of the zone. Both groups are useful for the biocorrelations of the NW Europe and Mediterranean Provinces.

The thin Serpentinus Zone, in the Reinosa area ranges in thickness between 3.5 and 5.5 m, and includes the Serpentinus and Falciferum Subzones. This zone starts with the first levels, which yield *Harpoceras serpentinus* (Reinecke). The genus *Hildaites* is frequent.

The thickness of the Bifrons Zone ranges between 11.5 and 12.5 m. The lower boundary of the zone is placed with first *Hildoceras*, and is correlatable with uppermost part of the Falciferum Zone utilized in NW Europe. The Bifrons Zone includes the Sublevisoni, Bifrons and Semipolitum Subzones.

Ranging in thickness from 35 to 40 m, the Upper Toarcian is relatively complete in the Camino area as well as SW of San Andrés, and its lower boundary is placed with the first levels providing *Haugia*. It could be subdivided in the Variabilis, Thouarsense, Insigne, Pseudoradiosa and Aalensis Zones.

The 12.5 m thick Variabilis Zone starts with the levels yielding *Haugia* [*H. variabilis* (D'Orbigny)] and can be divided into the Variabilis, Illustris and Vitiosa Subzones. The assemblages referable to the middle part of the Variabilis Zone include also *Podagrosites* and *Merlaites*, which support the biocorrelations between Basque-Cantabrian and other Tethyan basins.

The Thouarsense Zone has not been recognized in the studied sections, even if it has been recognized in two nearby sections. At the Castillo Pedroso section (22 km NW of Camino), 0.5 m of limestone with *Grammoceras* and *Protogrammoceras* cf. *differens* (Ernst) have been identified by Comas-Rengifo et al. (1988) just above a discontinuity, whilst at Cillamayor section (18 km of SW of San Andrés), 1.2 m of sediments with *Grammoceras* sp. and *Protogrammoceras* cf. *bigmanni* (Denckmann) has been identified by Bernad (1993).

Ranging in thickness from 3.5 to 7.5 m, the Insigne Zone starts with the levels yielding *Pseudogrammoceras fallaciosum* (Bayle). This zone can be divided in the Fallaciosum and Insigne Subzones. The assemblages belonging to the Insigne Zone are characterized by the presence of Mediterranean Hammatoceratidae (*Geczyceras*) and Harpoceratidae (*Polyplectus* and *Osperlioceras*).

The Pseudoradiosa Zone, 9.5 to 10.5 m thick, can be divided into the Levesquei and Pseudoradiosa Subzones (Goy el al. 1994). Its lower boundary is identified by the first occurrence of *D. levesquei* (D'Orbigny).

The Aalensis Zone is 11 m thick at Camino and 8 m at San Andrés, and can be divided into the Mactra, Aalensis and Buckmani Subzones (Goy et al. 1994). Its lower boundary is identified by the first occurrence of *Pleydellia mactra* (Dumortier).

Paleobiogeographic implications

The ammonoid assemblages that characterize the Pliensbachian-Toarcian succession cropping out in the Basque-Cantabrian area mainly comprise taxa that are characteristic of the NW Europe Province. Nevertheless, Mediterranean species have been recognized at different levels.

The ammonoid assemblages of the Pliensbachian succession outcropping in the central sector of the Basque-Cantabrian area are dominated by taxa of the NW Europe Province. Ammonitina group dominate the assemblages. Although relatively more abundant than in the Iberian Range, Phylloceratina and Lytoceratina are rare, and characteristic of the uppermost part of the Lower Pliensbachian as well as of the lowermost part of the Upper Pliensbachian (Braga et al. 1985). The Lower Pliensbachian assemblages are characterized by the occurrence of Eoderocerataceae, that are typical of the euroboreal domain (Meister & Stampfli 2000). Coinciding with a maximum transgressive episode during the Stokesi Zone, the Tethyan features of the assemblages become significant due to the occurrence of Harpoceratinae, including Tethyan groups, along with Amaltheidae. Significant but episodic increases of Mediterranean Hildoceratidae species have also been recognized in both Margaritatus and Spinatum Zones. However, it is within the uppermost Spinatum Zone that the Tethyan features of the assemblages become important, due to the replacements of the Amaltheidae by Arieticeratinae that dominate the assemblages.

In the Tenuicostatum Zone, the Mediterranean influence is represented by the dominance of the Dactylioceratidae [*D.* (*Eodactylites*) and *D.* (*Orthodactylites*)] over the Harpoceratidae (*Lioceratoides*, *Neolioceratoides* and *Protogrammoceras*). The occurrence of taxa common to European and Mediterranean Provinces is probably due to the Tethys expansion towards W and NW Europe, during the Tenuicostatum Biochron.

There is no evidence that the Toarcian ammonoid species lived permanently in the Basque-Cantabrian area. However, during the Serpentinus and Bifrons Zones, coinciding with the Toarcian transgressive maximum, few species belonging to the genera *Orthildaites* and *Hildoceras* colonized the deepest parts of the basin (Gómez & Goy 2000). In the Insigne Zone, the presence of Mediterranean Hammatoceratidae (*Geczyceras*) and Harpoceratidae (*Polyplectus* and *Osperlioceras*) is related to a transgressive episode as well.

Others intervals allowing a biocorrelation between the Boreal and Tethyan Provinces and, in particular, between ammonite assemblages of other Iberian basins, are based on the occurrence of *Podagrosites* and *Merlaites* in the middle part of Variabilis Zone, and of *Pleydellia* and *Catulloceras* in the Aalensis Zone.

Calcareous nannofossils

Assemblages

In the Basque-Cantabrian area, the first notable assemblage compositional change is the Lower Carixian appearance and the immediate abundance increase of the genus *Similiscutum*, that along with the genera *Crepidolithus* and *Parhabdolithus* represents a large proportion of the assemblages up to the Lower Domerian (Fig. 3). Across the Carixian/Domerian substage boundary, the first appearance of the genera *Bussonius* and *Biscutum* is

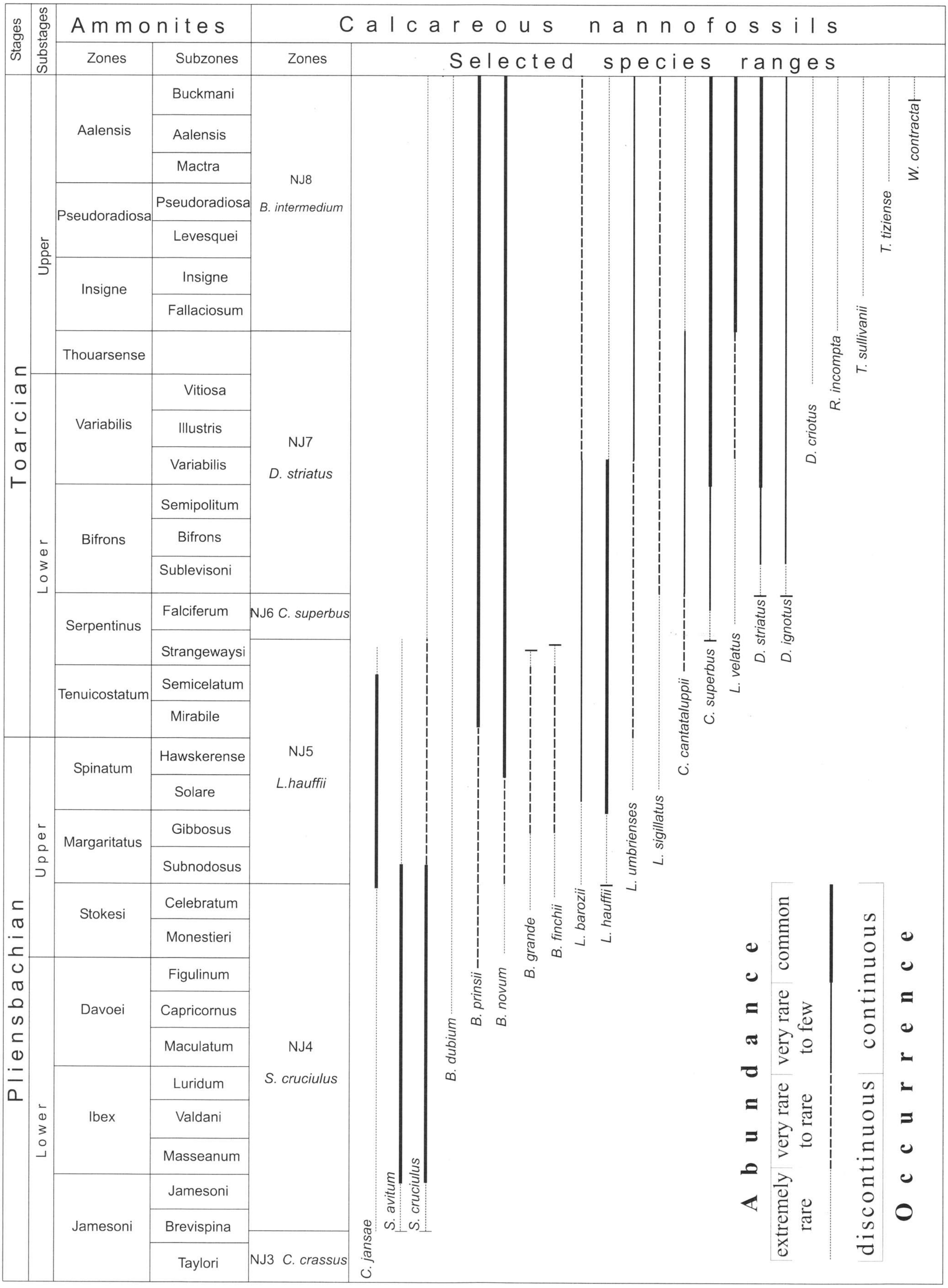

Fig. 3 - Abundance and stratigraphic range of selected calcareous nannofossils species. Lower Pliensbachian = Carixian; Upper Pliensbachian = Domerian.

easily detectable, but the other relevant compositional change took place across the Stokesi/Margaritatus Zone boundary. It includes the sharp abundance increase of the genus *Calcivascularis* and the appearance of the genus *Lotharingius*, that from the Margaritatus/Spinatum Zone boundary dominates the uppermost Pliensbachian-lowermost Toarcian assemblages along with the genera *Calcivascularis* and *Schizosphaerella*.

The Lower Toarcian is characterized by the abundance increase of the genera *Bussonius* and *Biscutum*, the sharp abundance decrease and disappearance of *Calcivascularis*, the disappearance of the large *Biscutum* species (i.e. *B. grande* and *B. finchii*) and the appearance of the genus *Carinolithus*. There is also a conspicuous abundance increase of the genus *Carinolithus*, and the appearance and subsequent increase of the genus *Discorhabdus*.

Up to the Insigne Zone, the genera *Schizosphaerella*, *Lotharingius*, *Biscutum*, *Discorhabdus* and *Carinolithus* represent the bulk of the assemblages, and although the appearance of the genera *Retecapsa* and *Triscutum* have also been detected, it is the abundance variation of the *Lotharingius* that characterizes the Upper Toarcian nannofossil assemblages. It includes the sharp abundance decrease of *L. hauffii* and the remarkable relative abundance increase of the medium to larger specimens of *L. velatus*. Small transitional morphotypes between *Lotharingius* and *Watznaueria*, referable to *L. umbriensis*, are present from the Upper Pliensbachian, but are significantly present from the Upper Toarcian.

Zones

Based on the main composition changes and the succession of the zonal markers proposed for NW Europe (Bown 1987; Bown et al. 1988; Bown & Cooper 1998) and Mediterranean Province (Mattioli & Erba 1999), also in the Basque-Cantabrian area, all the Pliensbachian-Toarcian nannnofossil zones have been recognized. For a more complete discussion on the biohorizons recognized in Camino and San Andrés sections, the papers of Perilli (1999a) and Perilli & Comas-Rengifo (2002) are referred.

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: Lower Pliensbachian (Brevispina Subzone) to Upper Pliensbachian (Celebratum/Subnodosus Subzone boundary).

Remarks. The zonal marker of this zone is also utilized by Mattioli & Erba (1999). Lying within the Brevispina Subzone (Jamesoni Zone), even in Basque-Cantabrian area the appearance of radiate, two shield placoliths is a useful early Carixian event. The genus *Similiscutum* almost immediately (Jamesoni Subzone) began to dominate the assemblages, and up to the Margaritatus Zone, is one of the main constituent of the nannofloras. Within the Zone NJ4, the FO of *B. prinsii* (Figulinum Subzone) and the FO of *B. novum*, sensu Bown 1987 (Monestieri Subzone) approach the Davoei/Stokesi Zone boundary, that certainly lies below the FOs of *B. grande* and *B. finchii* (Celebratum Subzone).

NJ5 *Lotharingius hauffii* Zone.

Author: Bown (1987).

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

Range in this study: Upper Pliensbachian (Celebratum/Subnodosus Subzone boundary) to Lower Toarcian (Strangewaysi Subzone).

Remarks. Adopted also by Bown & Cooper (1998) and Mattioli & Erba (1999), the FO of *L. hauffii* is the other reliable Pliensbachian zonal marker, lying around the Stokesi/Margaritatus Zone boundary in both Camino and San Andrés sections. In both sections, the sharp abundance increases of *C. jansae* and the FO of *L. barozii* also approximate the NJ4/NJ5 Zone boundary. Within this long nannofossil zone, that nearly coincides with the range of *B. grande* and *B. finchii*, the FCO of *L. hauffii* (Solare Subzone), the LO of *C. jansae* (Semicelatum Subzone) and the FO of *C. cantaluppii* (Semicelatum Subzone) have been recognized. Consequently, the lower portion of the Zone NJ5 (Margaritatus Zone) is characterized by the common occurrence of *C. jansae*, the assemblages referable to the middle and upper portion (Spinatum and Tenuicostatum Zones) are dominated by both *C. jansae* and *L. hauffii*, whilst the topmost part of the zone is characterized by the dominance of *L. hauffii*.

NJ6 *Carinolithus superbus* Zone.

Author: Bown (1987).

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

Range in this study: Lower Toarcian (Strangewaysi Subzone to Falciferum/Sublevisoni Subzone boundary).

Remarks. Utilized in both NW Europe and Mediterranean Province, in the Basque-Cantabrian area, the first specimens of *C. superbus* should be carefully checked, due to the discontinuous occurrence of the nominate species in its initial range. However, the NJ5/NJ6 Zone boundary lies slightly above the LOs of *B. grande* and *B. finchii* (Strangewaysi Subzone). Within this very short nannofossil zone, *L. velatus* first occurs and the abundance of the genus *Carinolithus* remarkable increases. The Zone NJ6, comprised within the Serpentinus Zone, almost corresponds to the Falciferum Subzone.

NJ7 *Discorhabdus striatus* Zone.

Author: Bown (1987).

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

Range in this study: Lower Toarcian (Falciferum/Sublevisoni Subzone boundary) to Upper Toarcian (Insigne Zone).

Remarks. Adopted also by Bown & Cooper (1998) and Mattioli & Erba (1999), the base of the Zone NJ7 is quite well recognizable because the abundance of the marker species suddenly increases within the Sublevisoni Subzone. Related to the sharp abundance decrease of small-sized *Lotharingius* species, the assemblages remarkably change within the Zone NJ7, and the AE (Acme End) of *L. hauffii* may be useful to divide the longest Toarcian nannofossil zone in two portions. In the lower part of the Zone NJ7, *L. hauffii* is still significantly present, whilst in its upper part, the genera *Carinolithus* and *Discorhabdus* dominated the assemblages. Though with a low abundance, the FO of *D. criotus* has been recognized in the uppermost part of this zone, and it is almost continuously present up to the Toarcian/Aalenian Stage boundary.

NJ8 *Biscutum intermedium* Zone.

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

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

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

Though *R. incompta* is a rare species in Boreal and Tethyan sections, it is utilized as zonal marker either by Bown & Cooper (1989) and Mattioli & Erba (1999). In the selected sections, it

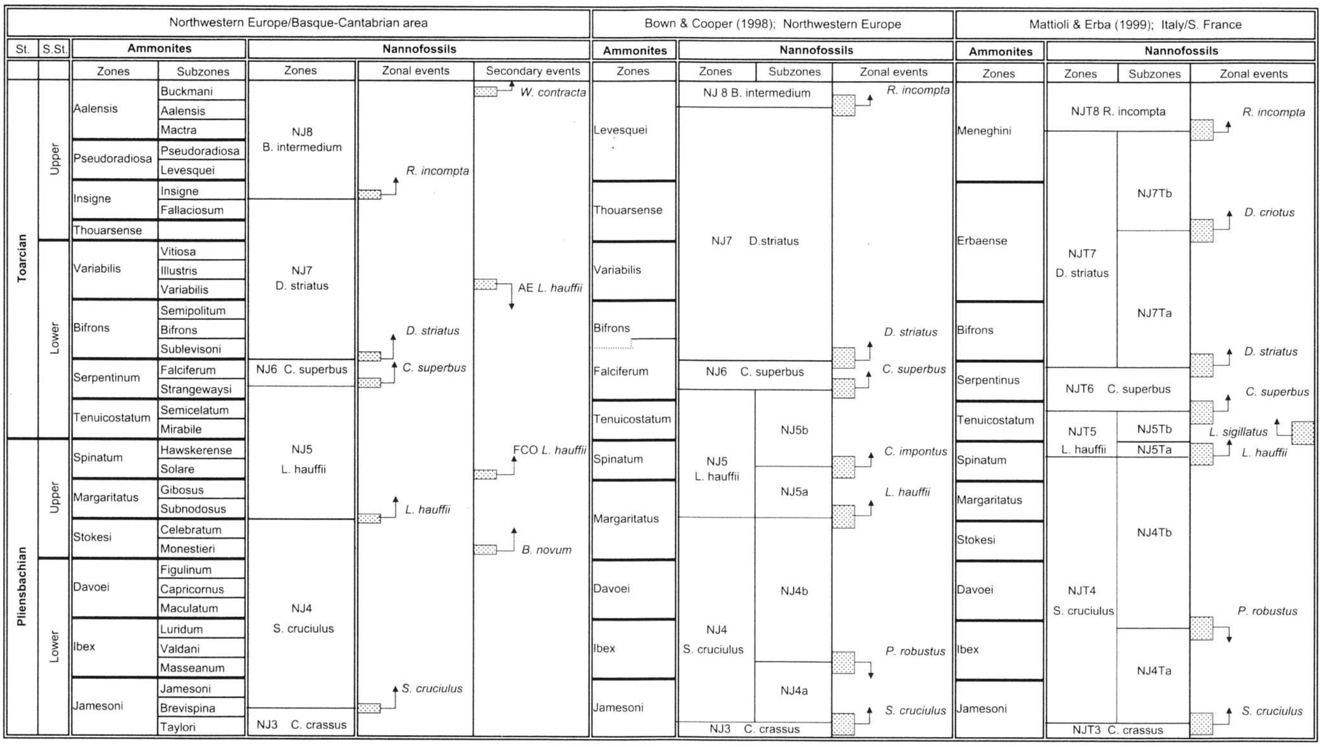

Fig. 4 - Ammonite and nannofossil biozonation schemes proposed for the Basque-Cantabrian area (Northwestern Europe) compared to the scheme proposed by Bown & Cooper (1998) and Mattioli & Erba (1999).

is present from the Insigne Zone, though due to the wide spacing of the sampling and the low abundance of *R. incompta*, even in the Basque-Cantabrian area, a lower appearance of this species, is not excluded. Within the Zone NJ8, the FOs of *T. sullivanii* and of *T. tiziense* have been recognized; unfortunately, also these two taxa are extremely rare up to the Torcian/Aalenian Stage boundary. From the lower portion of the Zone NJ8, the abundance of *L. velatus* remarkably increases and, based on the ongoing work on Upper Toarcian-Aalenian succession of Spain (Perilli, Goy & Ureta, in progress), the first specimens of *W. contracta* has been detected in the uppermost part of the Aalensis Zone.

Discussion

Based on the presence of ammonite taxa characteristic of the NW Europe and the presence of Mediterranean species at different level of the studied succession, the Pliensbachian-Toarcian calcareous nannofossil zone boundaries are compared with those proposed for NW Europe and Italy/S France (Fig. 4). In order to improve the readability of the text, we always refer only to Bown & Copper (1998) and Mattioli & Erba (1999), but Bown (1987) and Bown et al. (1988) for NW Europe as well as Reale et al. (1992) and Cobianchi (1992) for Tethyan sections, should be referred to for further information. Since the succession of the biohorizons recognized in Portugal, Switzerland and Morocco is neither supported by range charts nor extensively discussed, the paper of de Kaenel et al. (1996) is partly quoted.

Corresponding the Jamesoni Zone utilized in both Basque-Cantabrian area and NW Europe to the Taylori Zone of Mediterranean Province, the base of the Zones NJ4 and NJT4 is consistent with respect to the ammonite scales adopted in both domains. The appearance of *S. cruciulus* is placed within the Jamesoni Zone also by de Kaenel et al. (1996). On the basis of the LO of *P. robustus*, the first long Pliensbachian nannofossil zone has been further divided in two subzones (i.e. NJ4a and NJ4b; NJT4a and NJT4b) by both Bown & Cooper (1998) and Mattioli & Erba (1999). In the studied sections, this subzonal boundary is not recognizable because the marker species is extremely rare. Actually, though the calibration of the FO of *B. novum* should be further verified and its reproducibility tested in other nearby sections, it is not excluded that, in Northern Spain, this biohorizon could be proposed to subdivide the Zone NJ4.

Because the lower part of the Margaritatus Zone established for NW Europe corresponds to the Stokesi Zone utilized in the Basque-Cantabrian area, with respect to ammonite zones, the NJ4/NJ5 Zone boundary is consistent in both regions. Placed within the Emaciatum Zone by Mattioli & Erba (1999), the FO of *L. hauffii* (an easily recognizable and solution-resistant species) and hence the NJT4/NJT5 Zone boundary lies higher in Italy/S France, because the Emaciatum Zone roughly corresponds to the Hawskerense Subzone (i.e. upper part of the Spinatum Zone) adopted in Basque-Cantabrian area. In de Kaenel et al. (1996), the FO of *L. hauffii* has been placed either in the upper part of the Margaritatus Zone or in the lowermost part of Spinatum Zone. Unfortunately, the FO of *C. impontus* and the FO of *L. sigillatus* utilized by Bown & Cooper (1998) and Mattioli & Erba (1999), respectively, are not useful as subzonal markers because in the studied sections, both species are extremely rare in their initial range. Probably, in the Basque-Cantabrian area, the easily recognizable FCO of *L. hauffii* could be helpful to approximate the NJ5a/NJ5b Subzone boundary adopted in NW Europe.

Due to the correspondence between the lower part of the Falciferum Zone utilized in NW Europe and the Strangewaysi Subzone adopted in Basque-Cantabrian area, the FO of *C. superbus* and hence the calibration of the NJ5/NJ6 Zone boundary, with respect to the ammonite zones, is consistent in both areas. According to the achieved results, also de Kaenel et al. (1996) placed the FO of *C. superbus* within the Serpentinus/Falciferum Zone. The correlation between the NJ5/NJ6 and NJT5/NJT6 Zone boundaries, instead, is debatable because Mattioli & Erba (1999) place the FO of *C. superbus* in the Tenuicostatum Zone (see fig. 5 and p. 356 of Mattioli & Erba 1999), but report the base of the Zone NJT6 within the Zone NJ6 of Bown & Cooper (1998) (see fig. 12 and p. 368 of Mattioli & Erba 1999).

Always referring to the ammonite zones, even the base of the Zone NJ7 is consistent in NW Europe and Basque-Cantabrian area because the NJ6/NJ7 Zone boundary is placed by Bown & Cooper (1998) slightly below the Falciferum/Bifrons Zone boundary, which lies within the Sublevisoni Subzone of the adopted ammonite scheme. In Italy/S France, the FO of *D. striatus* is placed within the Serpentinus Zone and the NJT5/NJT6 Zone boundary slightly below the Serpentinus/Bifrons Zone boundary (Mattioli & Erba 1999). Consequently, on the base of the present paper and published data, including de Kaenel et al. (1996), the FO of *D. striatus* is reliable to approach either the Serpentinus/Bifrons or the Falciferum/Bifrons Zone boundaries, in both Boreal and Tethyan sections. The Zone NJT7 is divided by Mattioli & Erba (1999) in two subzones (i.e. NJT7a and NJT7b) on the basis of the FO of *D. criotus*. In the Basque-Cantabrian area, probably the AE of *L. hauffii* could be helpful to divide the Zone NJ7. Proposed by de Kaenel et al. (1996), the acme end of *L. hauffii* is also utilized by Bown & Cooper (1998).

The NJ7/NJ8 Zone boundary of Bown & Cooper (1998) and the NJT7/NJT8 Zone boundary of Mattioli & Erba (1999) lie within the Levesquei Zone in NW Europe and the Meneghinii Zone in Italy/S France. In the Basque-Cantabrian area, the base of the NJ8 is placed lower, that is in the Insigne Zone, which is correlatable with the upper part of the Thouarsense or the Erbaense Zones adopted in NW Europe and Italy/S France, respectively. In de Kaenel et al. (1996), the FO *R. incompta* ranges from Levesquei Zone to Opalinum Zone. The long NJ8 Zone is distinguished in NW Europe in two subzones (NJ8a and NJ8b) based on FO of *L. contractus*, whilst in Italy/S France, the FO of *W. contracta* (= *L. contractus*) and the FO of *C. margerelii* allow to subdivide the Zone NJT8 in three subzones (NJT8a, NJT8b and NJT8c). According to Perilli (1999b), also in Northern Spain the FO of *W. contracta* (Buckmani Subzone) lies within the Aalensis Zone, that corresponds to the upper part of Levesquei or Meneghinii Zones.

Consequently, on the basis of the above reported remarks, the NJ4, the NJ5 and the NJ6 span almost the same ammonite-defined time interval as in NW Europe as well as in Basque-Cantabrian area. Always with respect to the standard ammonite zonations, the NJT3/NJT4 and the NJT6/NJT7 boundaries proposed by Mattioli & Erba (1999) coincides with the NJ3/NJ4 and the NJ6/NJ7 Zone boundaries, respectively. On the contrary, the NJT4/NJT5 and the NJT5/NJT6 Zone boundaries proposed for Mediterranean Province do not coincides with the NJ4/NJ5 and the NJ5/NJ6 Zone boundaries, respectively. Furthermore, the calibration of the zone boundaries NJ7/NJ8 and the NJT7/NJT8 against ammonite zones should be further tested, due to the low abundance of the zonal markers in Boreal as well as in Tethyan sections.

Nonetheless, excluding miscalibration of the samples or sample-spacing, on the basis of the cosmopolitan features of the calcareous nannofossils, it is not excluded that some discrepancies are apparent and could probably be related to an incomplete ammonite or calcareous nannofossil record. However, taxonomic and methodological biases, instead, should be excluded because all the Pliensbachian-Toarcian marker species are either easily recognizable or (except *R. incompta*) common and solution resistant.

Conclusions

The Pliensbachian-Toarcian calcareous nannofossil zones recognized in two expanded sections in the Basque-Cantabrian area are for the first time described. The cornerstone of this paper is a continuous lithologic succession, a complete boreal ammonite record characterized, at different stratigraphic levels, by the presence of Mediterranean taxa and a significant succession of calcareous nannofossil assemblages. The refined ammonite biostratigraphy supports the dating, at subzone level, of all the nannofossil zone boundaries recognized and their correlation with those proposed for NW Europe and Mediterranean Province.

In the Basque-Cantabrian area, all the nannofossil zones adopted in NW Europe and Mediterranean Province have been recognized and, excluding *R. incompta*, the marker species are common and easily detectable. With respect to the standard ammonite zones adopted in

NW Europe and Basque-Cantabrian area, the NJ3/NJ4, NJ4/NJ5, NJ5/NJ6, NJ6/NJ7 Zone boundaries lie in the same position in both areas, and the different placement of NJ7/NJ8 Zone boundary could probably be related to the discontinuous and rare occurrence of *R. incompta.*

Based on a reliable correlation between the ammonite schemes utilized in Basque-Cantabrian area and Mediterranean Province, the calibration of the base of the Zones NJ4 and NJ7 and that of NJT4 and NJT7 proposed for Italy/S France, with respect to the ammonite zones, is consistent in both areas. In Basque-Cantabrian area, the NJ4/NJ5 Zone boundary coincides with the Stokesi/ Margaritatus Zone boundary, whilst in Italy/S France, the NJT4/NJT5 Zone boundary lies in the overlying Spinatum Zone. On the contrary, the FO of *C. superbus*, that define the base of Zone NJT6, in Italy/S France, lies in the Tenuicostatum Zone, whilst in the Basque-Cantabrian area, this biohorizon and hence the base of the Zone NJ6 lies in the overlying Serpentinus Zone. Concerning the FO of *R. incompta*, even in the Mediterranean Province, the nominate species is extremely rare, and both reliability and reproducibility of this biohorizon are debatable.

Unfortunately, the nannofossil subzonal boundaries proposed for NW Europe and Mediterranean Province are not reproducible in the Basque-Cantabrian area, mainly because the marker species are extremely rare, particularly in their age-significant initial or final range (i.e. in the case of first or last appearance, respectively). Hence, for the investigated time interval, 4 calcareous nannofossil zones and 5 zone boundaries have been recognized and the resulting biostratigraphic resolution based on calcareous nannofossil is lower than that provided by ammonites. Nevertheless, the biostratigraphic value of the zone boundaries is high because they are based on widespread, common and easily recognizable taxa, in both Boreal and Tethyan sections, and some of them approach ammonite zone or subzone boundaries. This correspondence is particularly helpful when ammonite assemblages, though with high biostratigraphic value, show paleoprovincialism. Consequently, calcareous nannofossils are in turn powerful to test the reliability of the proposed correlation between standard ammonite zonations utilized in different areas.

In particular, the base of the *Similiscutum cruciulus* Zone lies within the Brevispina Subzone, that is above the Raricostatum/Jamesoni Zone boundary; the *Carinolithus superbus* Zone, comprised within the Serpentinus/ Falciferum Zone in Boreal and many other Tethyan sections, in the Basque-Cantabrian area almost correspond to the Falciferum Subzone; the base of the *Discorhabdus striatus* Zone approximates the Serpentinus/Bifrons or Falciferum/Bifrons Zone boundary in Boreal and Tethyan sections.

Though both reproducibility and reliability should be verified in other areas of Iberian Plate (i.e. Lusitanian Basin in Portugal and Betic Range in Southern Spain), in the Basque-Cantabrian area, some other events seem to be helpful to divide the Zones NJ4, NJ5 and NJ7 and to approach ammonite zone boundaries. The FO of *B. novum* nearly coincides with the Davoei/Stokesi Zone boundary, the FCO of *L. hauffii* approximates the Margaritatus/Spinatum Zone boundary, the LO of *C. jansae* lies slightly below the Tenuicostatum/Serpentinus Zone boundary and the AE of *L. hauffii* almost corresponds to the Variabilis/Illustris Subzone boundary.

Because calcareous nannofossils is frequently one of the main constituent of the sediments and some species represent conspicuous component of the nannofacies, immediately detectable even when based on a semiquantitative analysis, the following correspondences are particularly helpful to date successions that contain scarce and/or not significant ammonite record.

The common occurrence of the genus *Similiscutum* characterizes the assemblages referable to the Ibex, Davoei and Stokesi Zones. Those belonging to the Margaritartus Zone are characterized by the common occurrence of the genus *Calcivascularis*. The assemblages referable to the Spinatun and Tenuicostatum Zones are dominated by the co-occurrence of the genus *Calcivascularis* along with small-sized *Lotharingius* species. The common occurrence of small sized *Lotharingius* allow the identification of the assemblages referable to the Serpentinus, Bifrons and Variabilis pro parte Zones; on the basis of the presence the genus *Carinolithus* or the co-occurrence of the genera *Carinolithus* and *Discorbadus*, the middle and upper part of this ammonite-defined interval can be distinguished. The relative low abundance of the genus *Lotharingius* and common co-occurrence of the genera *Carinolithus* and *Discorhabdus* allow the identification of the overlying interval up to the Insigne Zone. The common occurrence of the medium-sized *Lotharingius* species characterizes the assemblages referable to the Insigne, Pseudoradiosa and the Aalensis Zones.

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