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AGES OF THE ONSET OF MARLY SEDIMENTATION AND OF THE BLACK SHALES IN THE TUSCAN BASIN (NORTHERN APENNINES, ITALY)

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Abstract. In this paper is for the first time dated the inception of the Lower Jurassic marly sedimentation and the lower Toarcian black shales in the Tuscan Nappe, based on semiquantitative analysis of the calcareous nannofossils recovered from the Calcare selcifero di Limano/Calcari e marne a Posidonia transition and the lower part of this latter unit. The boundary between these formations lies within the nannofossil NJT5 Lotharingius hauffii Zone (uppermost Pliensbachian to lower Toarcian), the lower portion of the Calcari e marne a Posidonia ranges from the nannofossil NJT5 Lotharingius hauffii Zone to the NJT7 Discorhabus striatus Zone (middle Toarcian) and the organic-rich interval lies in the nannofossil NJT6 Carinolithus superbus Zone (lower Toarcian). Consequently, the changes from carbonate-dominated to marly-dominated sedimentation (NJT5 Zone) and the black shales accumulation (NJT6 Zone) in the Tuscan and Umbria-Marche basins are two coeval sedimentary events.

Riassunto. In questo studio sono descritte le associazioni a nannofossili calcarei recuperate nella parte alta del Calcare selcifero di Limano e nella porzione inferiore dei Calcari e marne a Posidonia, con lo scopo di datare l'inizio della sedimentazione marnosa del Giurassico inferiore e delle black shales del Toarciano inferiore nella Falda Toscana. I dati acquisiti permettono di collocare il passaggio tra le due formazioni nella Zona NJT5 Lotharingius hauffii (Pliensbachiano superiore-Toarciano inferiore) e di attribuire la porzione basale dei Calcari e marne a Posidonia ad un intervallo compreso tra la Zona NJT5 Lotharingius hauffii e la Zona NJT7 Discorhabus striatus (Toarciano medio). Inoltre, è stato possibile stabilire che il livello ricco di sostanza organica giace all'interno della Zona NJT6 Carinolithus superbus (Toarciano inferiore). Quindi in base ai nannofossili calcarei, nel bacino Toscano e in quello Umbro-Marchigiano, l'inizio della sedimentazione marnosa (Zona NJT5) e la deposizione dell'intervallo ricco di sostanza organica (Zona NJT6) sono due eventi sedimentari coevi.

Introduction

For the last two decades Italian geologists have been involved in the CARG Project to realize the new Geological Map of Italy at scale 1:50.000 (http://www.apat.gov.it). The objectives of this project include datings and regional correlations of the lithostratigraphic mapped units, and also the timing of the sedimentary evolution of the basins where they were deposited. In the frame of the new cartographic work for the draft of Castelnuovo Garfagnana and Pistoia Geological Maps (northern Tuscany), new datations have been acquired for the transition between Calcare selcifero di Limano and Calcari e marne a Posidonia and for the lower portion of this last unit, which is characterized by the presence of organic rich lithologies (Puccinelli et al. 2006a, 2006b; Perilli 1996). Based on a continuous calcareous nannofossil record, it is possible for the first time to date the Lower Jurassic onset of hemipelagic/pelagic marly sedimentation and the accumulation of the black shales in the Tuscan basin. In the nearby Umbria-Marche basin, the beginning of the upper Pliensbachian-lower Toarcian marly sedimentation corresponds to the Corniola/Marne di Monte Serrone Fm. boundary and the lower Toarcian oceanic anoxic event (TOAE see Jenkyns 1980, 1985; Jenkyns & Clayton 1986, 1997) lies within the Marne di Monte Serrone Fm. (Bartolini et al. 1992). Both events have been documented in many others tethyan and boreal sections. For a comprehensive review and discussion on the inferred biotic and abiotic factors inducing these sedimentation changes, and the

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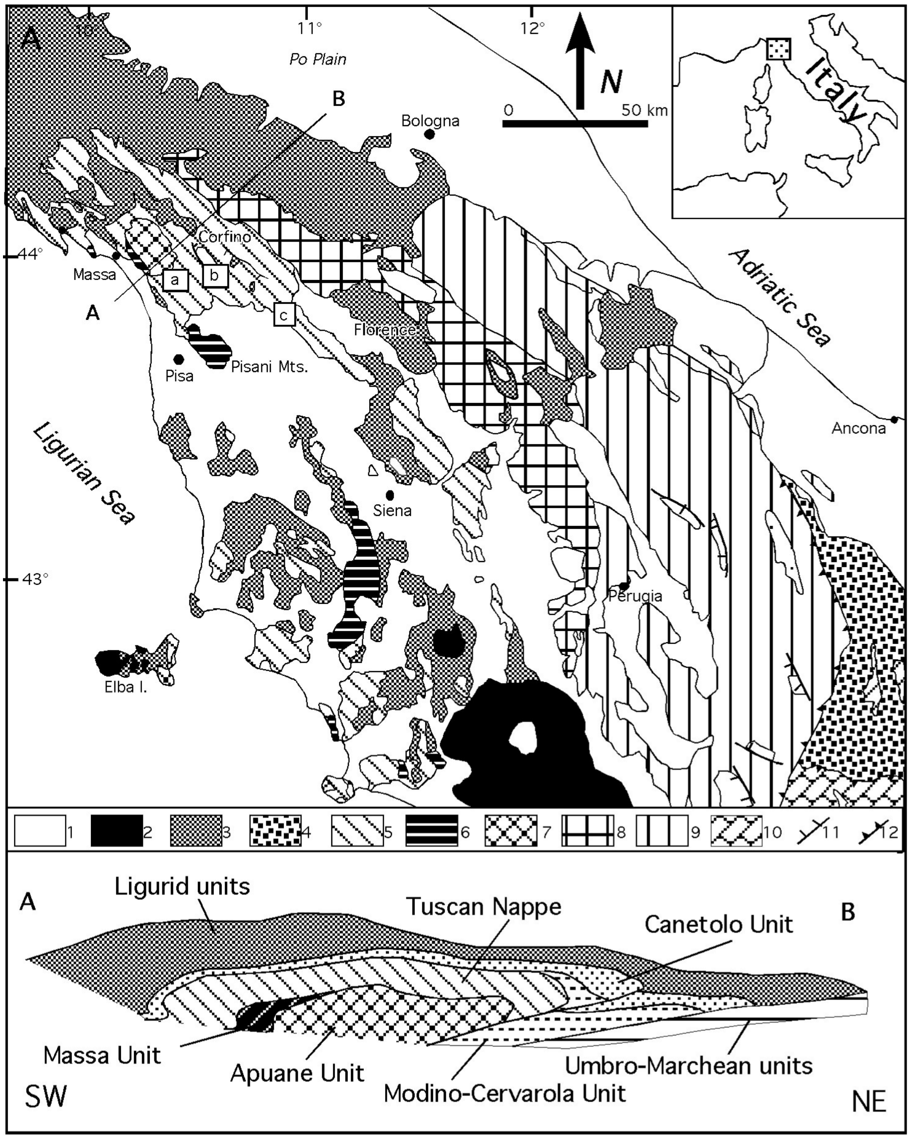

Fig. 1 - Geological sketch map and simplified cross section (A-B) of the Northern Apennines (Carosi et al. 2004). Location of the study areas: (a) Roggio area (b); Serchio Valley, (c) Montecatini-Monsummano area. 1) Neogene-Quaternary sediments; 2) igneous rocks; 3) Ligurids Units; 4) Tortonian "Molasse", Laga and Pliocene external sediments; 5) Tuscan Nappe; 6) Massa Units; 7) Metamorphic Tuscan Unit; 8) Cervarola-Falterona Units; 9) Umbria-Marche Units; 10) Lazio-Abruzzi sequences; 11) main normal faults; 12) main external thrust.

ages assigned to both events, the recent papers of Cobianchi & Picotti (2001), Jenkyns et al. (2002), Mattioli & Pittet (2002, 2004), Erba (2004) and Hesselbo et al. (2000, 2007) should be consulted (including therein bibliography) among others. The debate is open on both topics. Concerning the dating of these sedimentary events, and in particular about the lower Toarcian black shales, it is still unclear whether they are synchronous or not (Maillot et al. 2006; Wignall et al. 2006).

In the Umbria-Marche succession, the inception of the marly sedimentation (i.e. the Corniola/Marne di Monte Serrone Fm. boundary) lies in the uppermost part of the nannofossil NJT5 Lotharingius hauffii Zone (between the FOs of *Lotharingius sigillatus* and *Lotharingius crucicentralis*) and the lower part of Tenuicostatum Ammonite Zone; whereas the lower Toarcian black shales are comprised within the nannofossil NJT6 C. superbus Zone (between the FOs of *Carinolithus superbus* and *Discorhabdus ignotus*) and lies in the upper part of the Tenuicostatum Ammonite Zone (Reale et al. 1992; Bartolini et al. 1992; Monaco et al. 1994; Bucefalo Palliani & Mattioli 1994, 1998; Parisi et al. 1998). Based on a semiquantitative analysis of the continuous calcareous nannofossil records of five continuous sections located in the Tuscan Apennine, this work is aimed 1) to date the Calcare selcifero di Limano/Calcari e marne a Posidonia transition and the black shales intercalated within the Calcari e marne a Posidonia of the Tuscan Nappe, 2) to refine the correlation between the upper Pliensbachian-middle Toarcian sediments of the Tuscan and Umbria-Marche basins and 3) to verify if it is isochronous or diachronous the age of the change from carbonate-dominated to marly-dominated sedimentation and the age of the black shales accumulation in these two nearby basins of Tethys.

Geological setting

The study areas belong to the Northern Apennine (Fig. 1), a fold-and-thrust belt derived from the collision between the Corsica-Sardinia Block and the Adriatic Plate during the late Oligocene-Miocene times (Boccaletti et al. 1971). Due to the eastwards tectonic transport, the Ligurid and Canetolo Units emplaced onto the Tuscan Nappe, which detached at level of Norian evaporites, thrusted over the (Tuscan metamorphic) Massa and Apuane Units. In the Tuscan Apennine, the Tuscan Nappe is well exposed in the Roggio-Corfino, Serchio Valley, and Monsummano-Montecatini areas (Fig. 2). In the Serchio Valley, the nappe shows the maximum thickness and comprises: 1) Upper Triassic-Lower Jurassic shallow-water carbonates, that is the Calcare a *Rhaetavicula contorta* and the Calcare massiccio; 2) Lower Jurassic-Lower Cretaceous deepening upward pelagic succession, including the Rosso ammonitico, the Calcare selcifero di Limano, the Calcari e marne a Posidonia (Posidonia Marls auct.), Calcare selcifero della Val di Lima, the Diaspri and the Maiolica; 3) Lower Cretaceous-Upper Paleogene basinal to ramp deposits of the Scaglia toscana and 4) foredeep siliciclastic turbidites of the Macigno ranging in age from latest Oligocene to earliest Miocene (Bortolotti et al. 1970; Dallan Nardi & Nardi 1972; Fazzuoli et al. 1985). In the Roggio area (Lucca Province), the thin and discontinuous Lower Jurassic portion of the Tuscan Nappe, topped by the Scaglia Toscana, also comprises the Calcari ad Angulati overlain by the Rosso ammonitico or the Calcari e marne a Posidonia (Boccaletti & Bortolotti 1965). In the Montecatini-Monsummano area (Pistoia Province), the Lower Jurassic to Lower Cretaceous formations are thin and lens-shaped (Azzaroli 1948; Fazzuoli & Maestrelli-Manetti 1973). In close similitude with the Umbria-Marche succession, the Tuscan Nappe accumulated on the Tethys continental margin, which was formed by a complex of half-graben structures. The Early Jurassic transgression together with differential subsidence of these structures created increasingly deep basins, separated by structural highs (Bernoulli et al. 1979). Consequently, due to the irregular physiography of the Tuscan basin, thick and continuous Jurassic-Cretaceous successions accumulated in the depressed areas (i.e. Serchio Valley), while in the uplifted areas (i.e. Roggio and Montecatini-Monsummano areas) thin and discontinuous successions were deposited (Boccaletti & Sagri 1967; Dallan Nardi & Nardi 1972; Fazzuoli et al. 1985).

Materials and methods

The five investigated sections are located in the areas of Montecatini-Monsummano (Fig. 3) and Roggio (Fig. 4). Two of these sections lie 700 m NE of Marliana (Torbola creek) and 900 m NE of Monsummano (C. Pellegrini). The other three sections are located 900 m SW of Roggio (Colle di Santa Cristina), 600 m SE of Roggio (Rapinala creek) and 1 Km ESE of Roggio (Lorenzana creek). In the Marliana and Monsummano sections, 119 samples were collected from the uppermost part of the Calcare selcifero di Limano and the lower part of the Calcari e marne a Posidonia, whereas in the Roggio area, the 59 samples were all collected from the Calcari e marne a Posidonia. Simple smear slides were prepared using standard techniques and semi-quantitative analysis was performed under a transmission light microscope at 1250X. A preliminary analysis (on 500 fields of view) allowed to recognize the fossiliferous samples and additional 1000-1500 fields have been observed for each select smear slide to establish the age of the assemblages. Most of the samples (mainly from marly levels) are fossiliferous, but roughly 50% of them provide rare to very rare and poorly preserved assemblages, which are characterized by a limited number of species and specimens. The preservation degree and the species richness are very variable from sections to another. A differential diagenesis, mainly linked to pressure solution, is in fact inferred for the different sections, due to the variable tectonic deformation in the study areas. Preservation is not homogeneous in each section according to changes in lithology. Samples productive in calcareous nannofossils alternate with samples poorly preserved or barren. However, a detailed study of the age significant assemblages allowed the recognition of 11 genera and 25 species including the age-diagnostic taxa for the investigated time interval (see Appendix). Hereafter First Occurrence = FO, Last Occurrence = LO and Ammonite Zone = AZ.

Calcari e marne a Posidonia (POD)

The formation frequently consists of marlstones and marly or siliceous clay, intercalated with limestones which show rare cherty nodules and lenses; in places, it crops out as a regular alternace of medium-thick beds of marlstones and limestones. The microfacies of the marly to siliceous calcilutites and fine-grained calcarenites are dominated by pellets and bioclasts, which range from 10 to 40% and are mainly represented by radiolaria and pelagic pelecypods. The fine-grained fraction of the calcilutites was probably pristinely rich in calcareous nannofossils, eventually dissolved during diagenesis, because as pointed out by Kälin et al. (1979), in some of our samples a large part of the micrite fraction is made up of coccoliths and nannoliths. Thickness of the Calcari and marne a Posidonia notably varies and ranges from 75-100 to 200-250 m in the sectors where the Lower Jurassic pelagic succession is thickest (i.e. Serchio Valley); due to the action of tectonics, it is not impossible to exclude that the highest values are probably apparent thickness. Conversely, in the sectors where the whole Lower Jurassic pelagic succession is thin and discontinuous, the maximum thickness of this formation reaches up to 20-30 m (i.e. Roggio) or even 20-60 m (i.e. Montecatini-Monsummano); the reduced thickness or the absence of Calcari and marne a Posidonia can be related to stratigraphic or tectonic causes.

Since the Calcari and marne a Posidonia represents one of the decollement levels of the Tuscan Nappe, the marly to clayey intervals frequently show scaly fabric or penetrative foliation, limestone beds are disrupted, stratification is faint and there are few localities where the formation is well exposed. Consequently, it is difficult to reconstruct a refined lithostratigraphic frame of the Calcari and marne a Posidonia. However, an or-

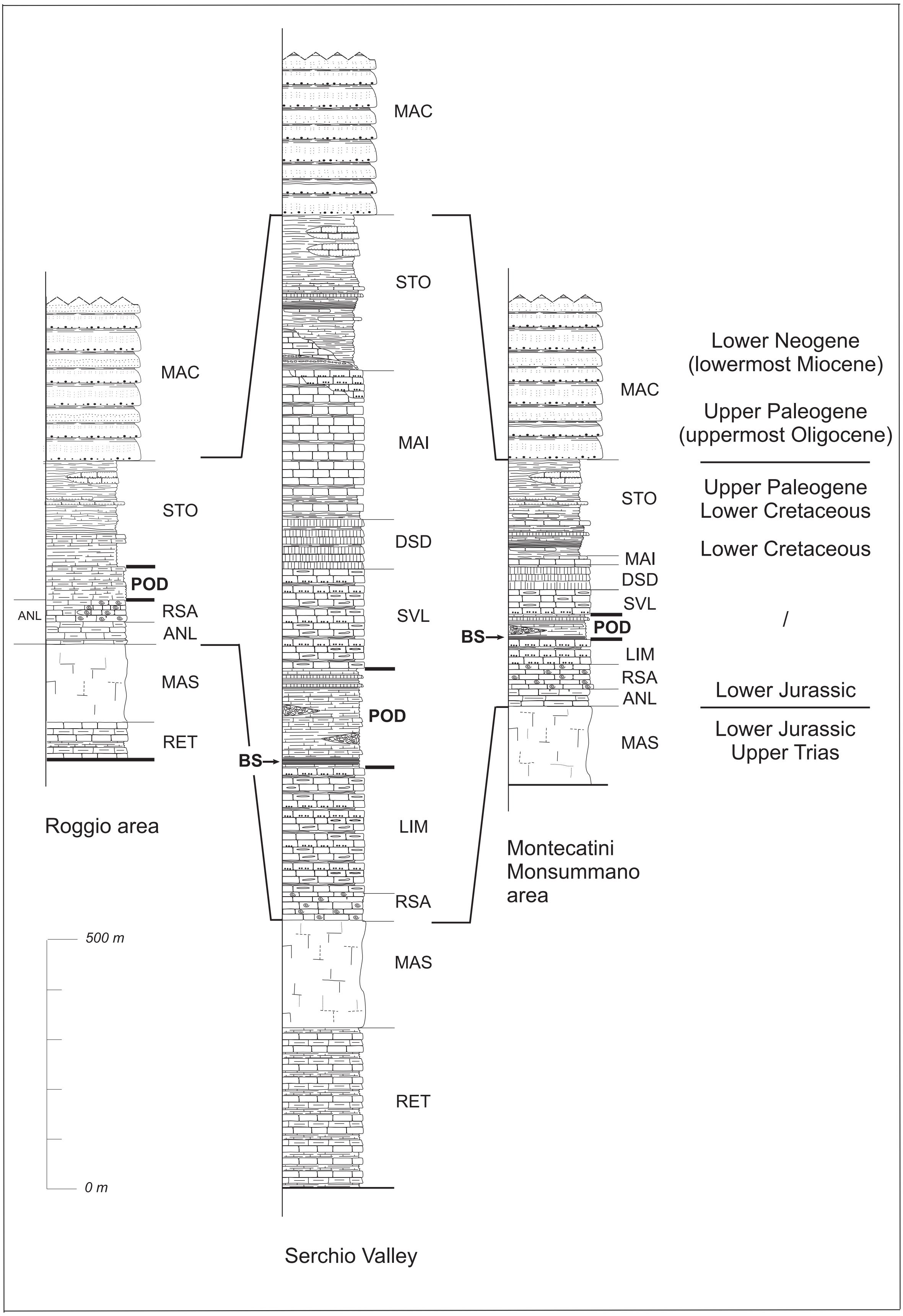

Fig. 2 - Lithostratigraphy of the Tuscan Nappe in the Roggio area (Perilli, unpublished data), Serchio Valley (Puccinelli et al. 2006a) and Montecatini-Monsummano area (Puccinelli et al. 2006b). RET = Calcare a *Rhaetavicula contorta*; MAS = Calcare massiccio; ANL = Calcari ad Angulati; RSA = Rosso ammonitico; LIM = Calcare selcifero di Limano (or Calcare selcifero a selci chiare); POD = Calcari e marne a Posidonia; BS = organic-rich interval; SVL = Calcare selcifero della Val di Lima (or Calcare selcifero a selci scure); DSD = Diaspri; MAI = Maiolica; STO = Scaglia toscana; MAC = Macigno.

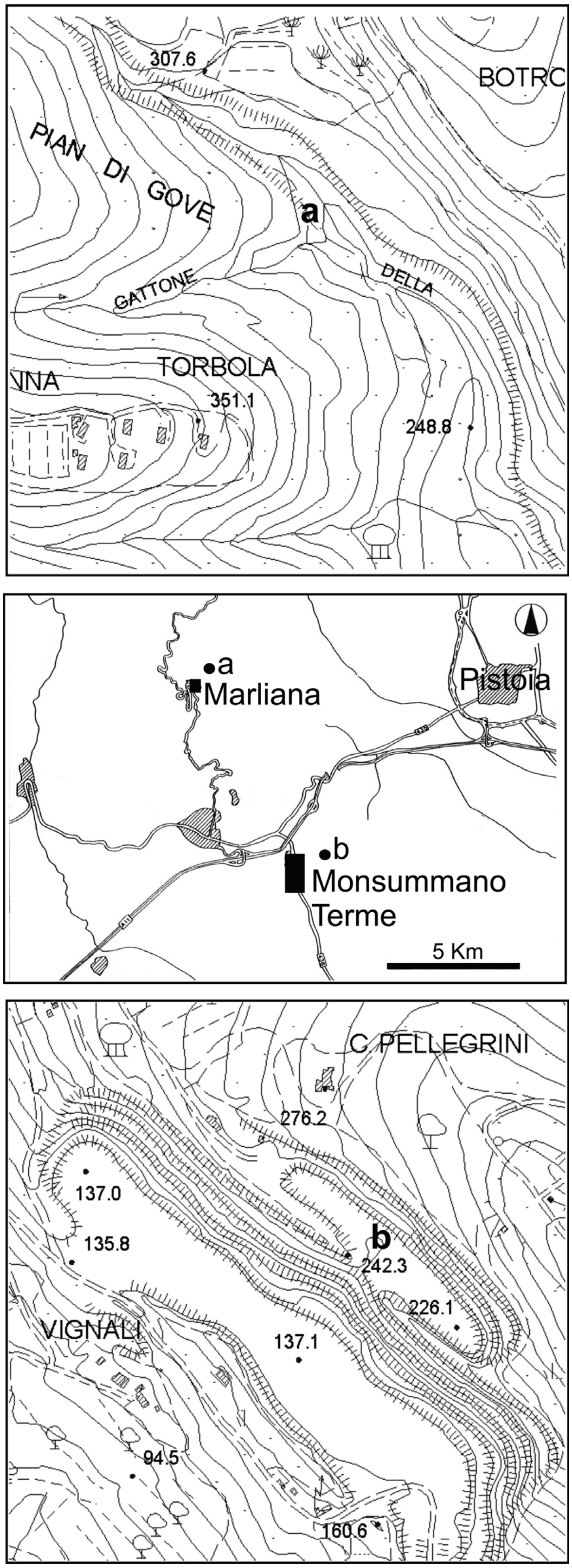

Fig. 3 - Location of the sections in the Montecatini-Monsummano area (Pistoia Province): (a) the Marliana section is located north of the Torbola (see CTR Regione Toscana, Marliana n° 262060, scale 1:10.000); (b) the Monsummano sections is located south of C. Pellegrini (see CTR Regione Toscana, Monsummano n° 262060, scale 1:10.000)

ganic-rich black interval has been recognized in the lower part of this formation, in the areas of Montecatini-Monsummano, Serchio Valley and Rontano (Perilli 1996). It consists of an alternation of well-laminated marlstone and claystone, with Total Organic Carbon (TOC) values comprised between 1.06 and 2.49%, and a variable thickness which ranges from 10-30 centimetres to 5 metres in the different sections (Perilli et al. 2007). In the Montecatini-Monsummano area and in the Serchio Valley, the uppermost part of the formation consists of thin-laminated red siliceous marlstones or siliceous clay (Marne Diasprine auct.); this metric to decametric lithofacies grading into the Calcare selcifero della Val di Lima or the Diaspri (Giannini & Nardi 1964; Boccaletti et al. 1969). In some areas, clast-supported calcareous breccias occur within the Calcari and marne a Posidonia, including the Montecatini-Monsummano area and the Serchio Valley (Fazzuoli & Maestrelli-Manetti 1973; Dallan et al. 1991).

Nowadays, the ages of the Calcare selcifero di Limano/Calcari e marne a Posidonia transition and the lower portion of this latter formation are mainly based on few and scattered ammonites and ammonite fragments, collected from the Calcare selcifero di Limano and the lower portion of the Calcari e marne a Posidonia (Tab. 1). Though in the literature the stratigraphic position and/or the locality where the fossil remains have been collected is not mentioned, the Calcare selcifero di Limano and the lower portion of the Calcari e marne a Posidonia could be referred to the late Pliensbachian-middle Toarcian time interval. Consequently, it is unreliable the speculative latest Toarcian/earliest Aalenian age, assigned to the basal portion of the Calcari e marne Posidonia by Federici (1967); it is also unreliable because of the inferred stratigraphic position of the specimen *Catulloceras dumortieri*. Some other paleontological available data for the Calcari e marne a Posidonia are: the remains and/or the moulds of specimens belonging to the genus *Posidonia*; and few aptychus assemblages recovered from the upper portion of the formation by Kälin et al. (1979) and dated as the Callovian p.p.

Adopted biostratigraphic scale

Since the '90s calcareous nannofossil biostratigraphic studies have also been focused on Lower-Middle Jurassic successions that crop out in the Lombardy basin (Erba & Cobianchi 1989; Cobianchi 1990, 1992) and in the Umbria-Marche basin (Baldanza & Mattioli 1992; Reale et al. 1992). On the basis of the data presented in these papers integrated to other biostratigraphic data coming from sections located in SE France, northern Italy and central Italy, Mattioli and

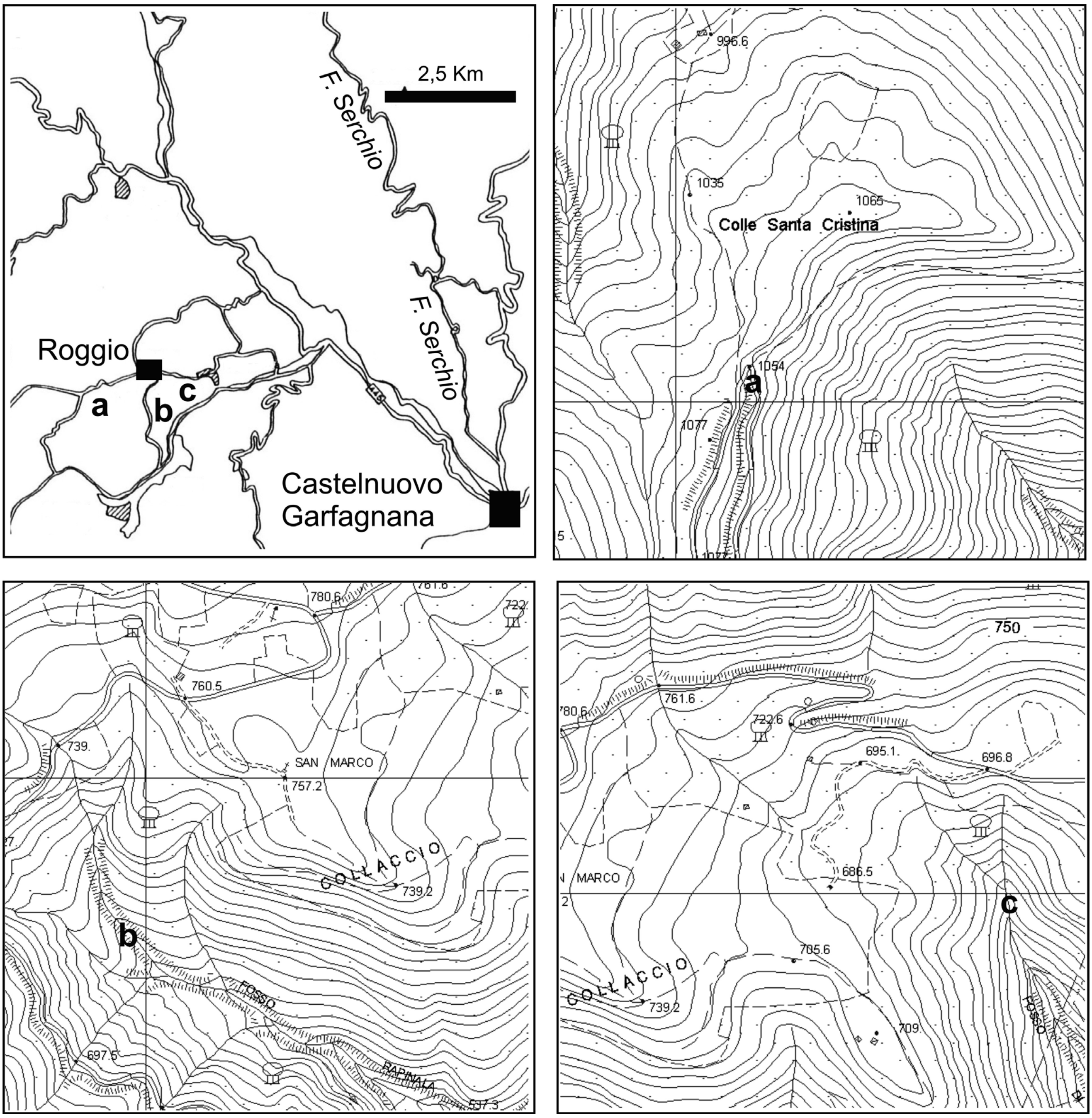

Fig. 4 - Location of the sampled sections in the Roggio area (Lucca Province): (a) the S. Cristina section is located south-west of the Colle Santa Cristina; (b) the Rapinala section is located west of the Collaccio, (c) the Lorenzana section is located east of the Collaccio (for all these localities see CTR Regione Toscana, Roggio n° 249080, scale 1:10.000)

Erba (1999) defined the calcareous nannofossil zones for the Lower to Middle Jurassic of the Mediterranean area. Their scheme is adopted in this study, and the upper Pliensbachian-middle Toarcian portion (Fig. 5) is compared to the biostratigrapic events of age-significant species recorded in NW Europe by Bown & Cooper (1998) and in N Spain by Perilli et al. (2004). Taking into account the time interval studied, the FO of *L. hauffii* lies within the Spinatum AZ in Italy/S France, while in NW Europe and N Spain it has been recognized in the underlying Margaritatus AZ. The FO of *C. superbus* is placed within the Tenuicostatum AZ in Italy/S France and in the Serpentinus/Falciferum AZ in NW Europe and N Spain. In all these areas, the FO of *D. striatus* nearly approaches the boundary between the Serpentinus/Falciferum and Bifrons AZ. Consequently, in boreal and tethyan sections, the (NJ5/NJT5) Lotharingius hauffii Zone contains the Pliensbachian/Toarcian Stage boundary. The overlying (NJ6/NJT6) Carinolithus superbus Zone encompasses part of the Tenuicostatum and part of the Serpentinus AZ in Italy/S France, whereas it is com-

Calcare selcifero di Limano	
Amalteus margaritatus	Canavari 1882 Canavari et al. 1882 Fucini 1896 Lotti 1910
Amalteus spinatum	Fucini 1896 Masini 1932 Bellincioni 1959
Hildoceras algoviamun	Meneghini 1881 De Stefani 1882 Fucini 1896, 1908 Lotti 1910
Hildoceras domarense	Fucini 1908
Hildoceras ruthense	Fucini 1908 Azzaroli 1948
Arieticeras bertrandi	Fucini 1902, 1908 Azzaroli 1948
Lithoceras fimbriatum	Meneghini 1881
Bettinoceras italicum	Boccaletti et al. 1969
Calcari e marne a Posidonia (lower part)	
Hildoceras bifrons	Canavari 1888 Fucini 1905
Hildoceras levisoni	Fucini 1905
Lilia comense	Fucini 1905
Ammonite discoides	Zaccagna 1932
Phymatoceras lilli	Passerini 1964
Hildoceras semipolitum	Fazzini et al. 1968
Posidonia alpina	Bellincioni 1959 Giannini 1950 Boccaletti & Bortolotti 1965 Decandia et al. 1968 Dallan Nardi & Nardi 1972 Fazzuoli & Maestrelli-Manetti 1973 Kalin et al. 1979
Posidonia bronni	Lotti 1882, 1886, 1910 Fucini 1903 Azzaroli 1948 Zaccagna 1932
Posidonia sp.	Passerini 1964 Giannini & Nardi 1965a, 1965b Boccaletti & Sagri 1967 Mucchi et al. 1968

Tab. 1 - List of the taxa recovered from the Calcare selcifero di Limano and the lower portion of the Calcari e marne a Posidonia.

prised within the Serpentinus/Falciferum AZ in NW Europe and N Spain. However, this nannofossil zone spans a very short time interval in boreal and tethyan sections.

Studied sections and biostratigraphic results

Marliana section (Fig. 6). The uppermost portion of the Calcare selcifero di Limano is a regular succession of medium-thick beds of siliceous calcilutites and fine-grained calcarenites with very thin intercalations of marly clay and marlstone. The abrupt increase in frequency and thickness of the marly intervals defines the boundary with the Calcari e marne a Posidonia; which consists of marlstones interbedded with thin to medium-thick siliceous calcilutites and fine-grained calcarenites. Most of the fossiliferous samples provide poorly preserved assemblages with rare specimens. However, many of them are age diagnostic and allow us to recognize the Zones NJT5 and NJT6 and to locate the NJT5/NJT6 Zone boundary slightly above the Calcare selcifero di Limano/Calcari e marne a Posidonia boundary, according to the presence of *L. hauffii* and *C. jansae* from the bottom of the section and of *C. cantaluppii* and *C. superbus* from the lowermost portion of the Calcari e marne a Posidonia (Tab. 2). The lowest occurrence of *D. ignotus* has been identified above the 30 cm thick, well-laminated organic-rich black interval.

Monsummano section (Fig. 7). In this section, the Calcare selcifero di Limano consists of medium-thick calcilutites and calcarenites (both with nodules and lenses of chert) intercalated with very thin silty marlstones. The Calcari e marne a Posidonia is made up of siliceous to marly calcilutites and rare fine-grained calcarenites with thin to medium-thick intercalations of grey marlstones and siliceous marlstones. The sudden occurrence of the thin intercalations of marlstones marks the boundary between the two formations. The poorly preserved assemblages recovered from this section contain a limited number of species and of specimens (Tab. 3). Nevertheless, the assemblages from the lower portion of the section allow to identify the Zone NJT5, due to the presence of *Lotharingius* spp., *C. jansae* and *B. grande*. The overlying assemblages are assigned to the Zone NJT6, based on the first occurrence of *C. superbus*, just above the Calcare selcifero di Limano/Calcari e marne a Posidonia boundary.

S. Cristina section (Fig. 8). The ammonite-bearing nodular calcilutites of the Rosso ammonitico of this section, become slightly marly close to the contact with the Calcari e marne a Posidonia. The sampled portion of this latter formation is a regular alternance of nodular marlstones and marly limestones, with thin intercalations of siliceous calcilutites and very fine-grained calcarenites. The very rare and poorly preserved assemblages from the Calcari e marne a Posidonia are referable to the Zones NJT6 and NJT7 (Tab. 4). The Zone NJT6 has been recognized from the bottom of the section, based on the presence of *L. hauffii*, *C. jansae, C. cantaluppii* and *C. superbus.* Some metres above the base of Calcari e marne a Posidonia, the occurrence of

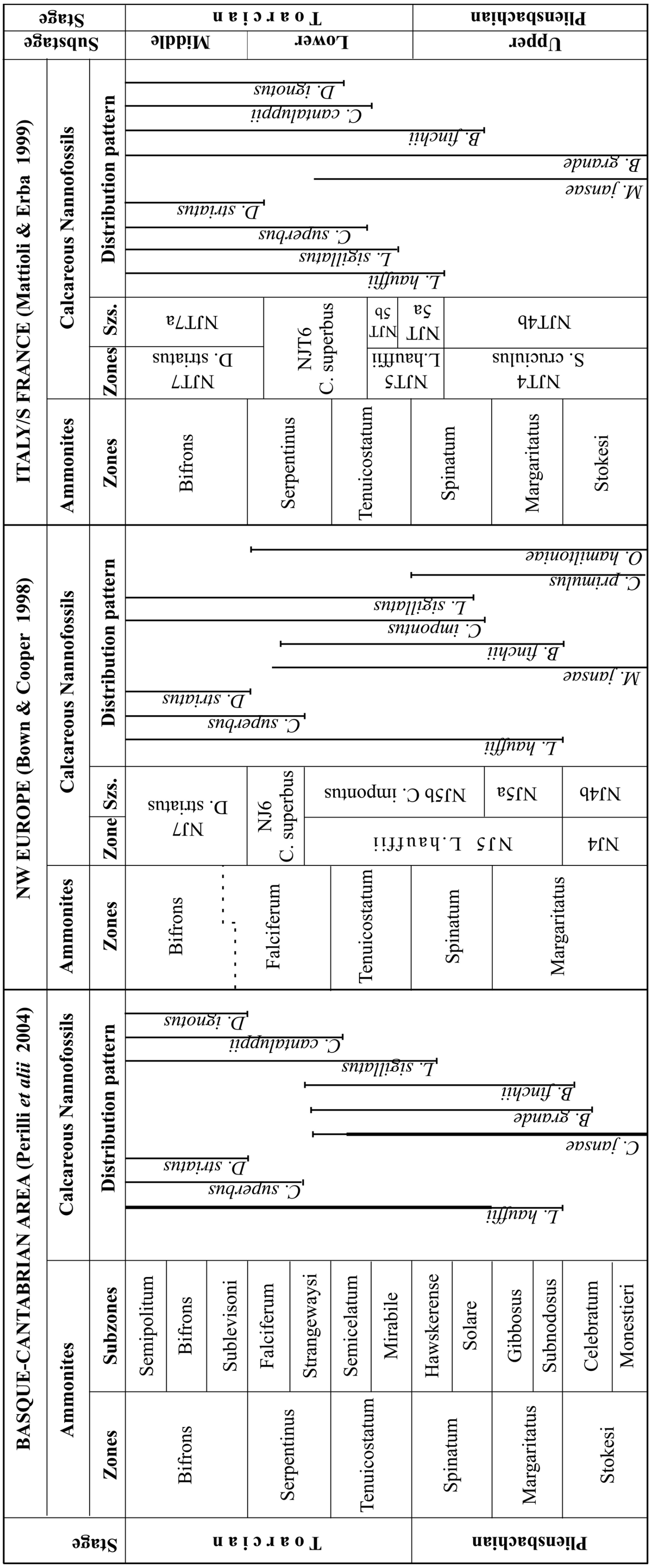

Fig. 5 - Adopted biostratigraphic scheme (Mattioli & Erba 1999) and its correlation with the scheme proposed by Bown & Copper (1998), and both zone boundaries and events recognized in Northern Spain (Basque-Cantabrian area) by Perilli et al. (2004); *Mitrolithus jansae* = *Calcivascularis jansae*. Szs = Subzones.

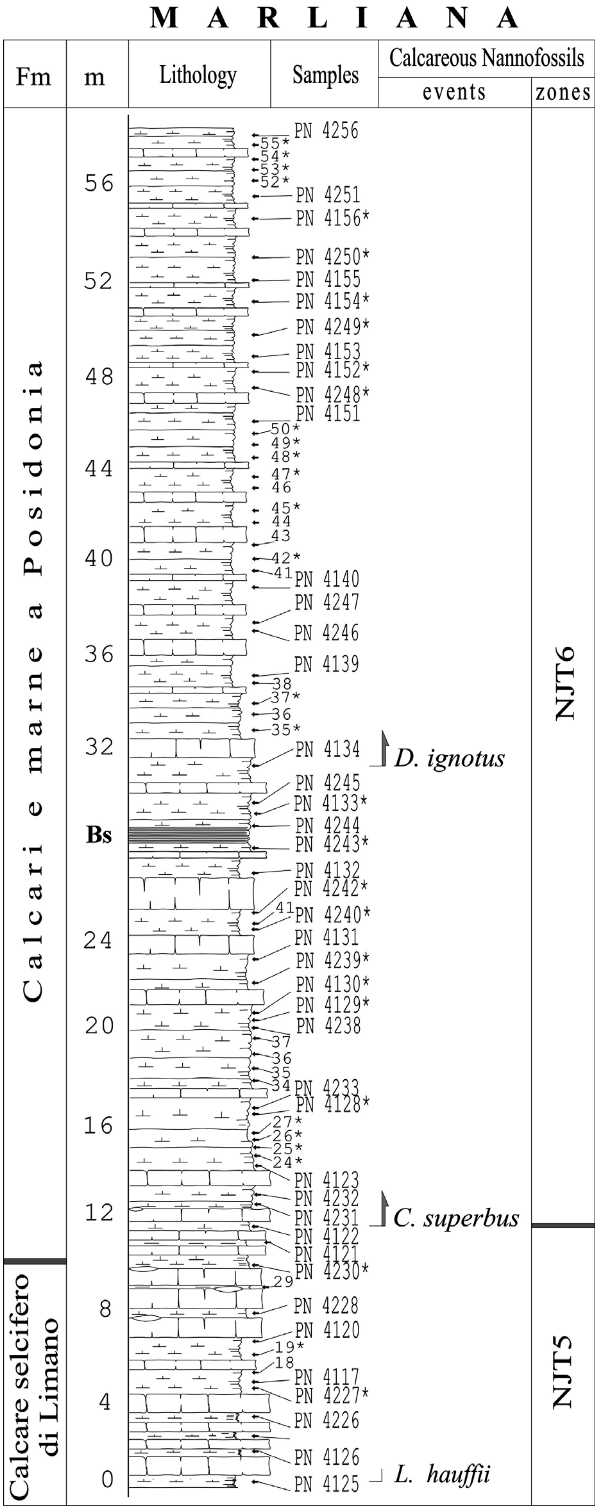

Fig. 6 - Lithostratigraphy, nannofossil events and zones recognized in the Marliana section (43° 56' 00N, 10° 46' 59E). Fm = Formations; m = Metres; **Bs**=Blake Shales; barren samples are indicated by asterisk.

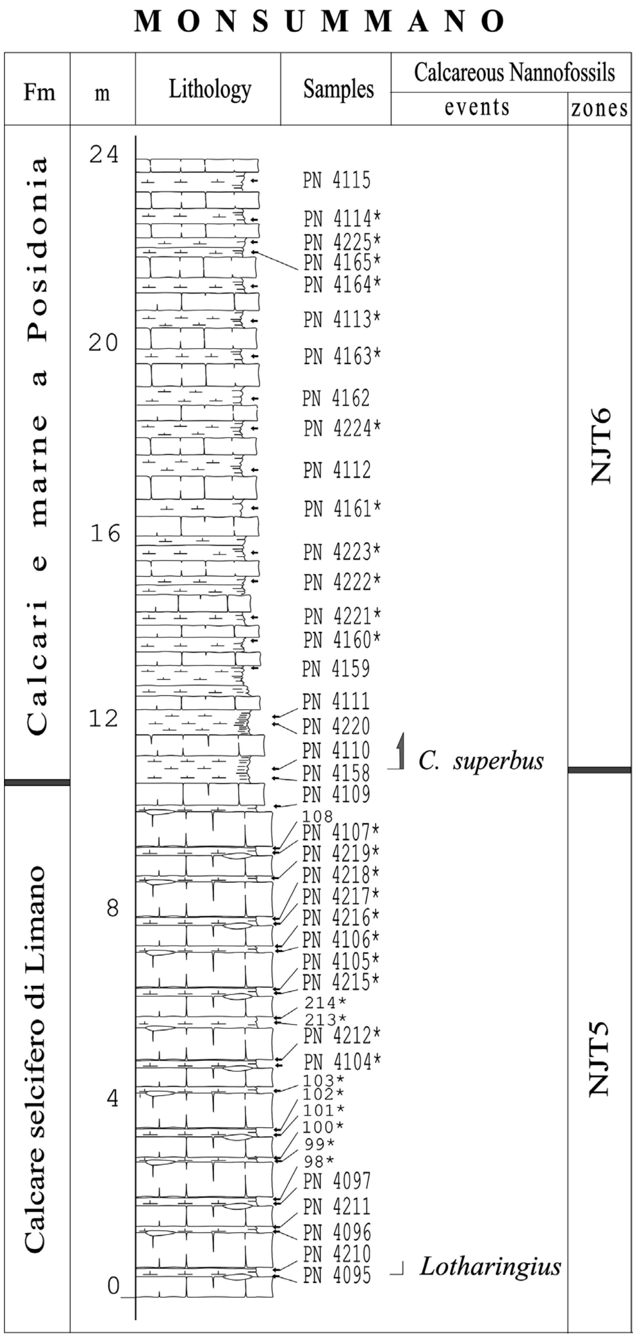

Fig. 7 - Lithostratigraphy, nannofossil events and zones recognized in the Monsummano section (43° 52' 94N, 10° 49' 25E). Fm = Formations; m = Metres; barren samples are indicated by asterisk.

D. striatus allows us to document the middle Toarcian Zone NJT7.

Rapinala section (Fig. 9). The uppermost part of the Calcari ad Angulati consists of white calcilutites, with rare ammonite fragments, and very thin silty beds. It sharply grades to the Calcari e marne a Posidonia, which is a monotonous alternance of pelecypod-bearing siliceous marlstones and marly limestones, with rare intercalations of calcilutites and fine-grained calcarenites. The two lower samples of this section are referable to the Zone NJT5, due to the presence of *L. hauffii* and *C. jansae* (Tab. 5). The overlying assemblages are better preserved and relatively more diversified and allow to recognize the Zone NJT6, due to the occurrence of *L. hauffii*, *C. jansae*, *C. cantaluppii* and *C. superbus*.

Formations	Samples	Abundance	Preservation	*Schizosphaerella* spp.	*Parhabdolithus* spp.	*Crepidolithus* spp.	*C. crassus*	*M. elegans*	*C. jansae*	*Biscutum* spp.	*B. novum*	*B. grande*	*B. finchii*	*Lotharingius* spp.	*L. hauffii*	*L. barozii*	*L. sigillatus*	*Calyculus* spp.	*Carinolithus* spp.	*C. cantaluppii*	*C. superbus*	*D. ignotus*	Zones
Calcari e marne a Posidonia	PN 4256	VR	VP											VR						**VR**	**R**	**F**	**NJT6**
	PN 4251	VR	VP																	**VR**	**R**		
	PN 4155	VR	P											F						**VR**	**VR**	**F**	
	PN 4153	VR	VP											VR	**VR**								
	PN 4151	VR	P	VR											**VR**	VR						**VR**	
	PN 4146	VR	VP	F										R						**VR**	**VR**	**VR**	
	PN 4144	VR	VP	VR					**R**											**VR**	**VR**		
	PN 4143	VR	VP	R					**VR**			VR		VR	**VR**				VR		**VR**		
	PN 4142	VR	VP	F											**VR**						**VR**	**VR**	
	PN 4141	VR	VP							VR	VR										**VR**		
	PN 4247	VR	P	VR			VR		**VR**	VR	VR			VR	**VR**			VR		**VR**	**VR**	**VR**	
	PN 4246	VR	VP											VR								**VR**	
	PN 4139	VR	VP											F	**VR**								
	PN 4138	VR	VP	R																	**VR**	**VR**	
	PN 4136	VR	VP	R										VR	**VR**								
	PN 4134	VR	P	R					**VR**					F	**F**	VR		VR	F	**VR**	**F**	**R**	
	PN 4245	VR	VP	VR	VR	VR	VR		**VR**						**VR**			R					
	PN 4244	VR	P	VR					**VR**	VR								VR					
	PN 4132	VR	P						**VR**					VR	**VR**			VR	VR	**R**	**VR**		
	PN 4241	VR	P				VR							VR	**VR**			VR					
	PN 4131	VR	VP			VR									**R**								
	PN 4238	VR	VP	R										R	**VR**								
	PN 4237	VR	P	F											**VR**			VR					
	PN 4236	VR	VP						**VR**					R	**VR**								
	PN 4235	VR	P	VR					**F**														
	PN 4234	VR	VP								VR			R									
	PN 4233	R	M	F					**F**		F			R	**F**			VR		**VR**			
	PN 4123	VR	P	F					**VR**					VR						**R**	**VR**		
	PN 4231	VR	P	VR										F	**R**			VR					
	PN 4122	VR	P						**VR**						**R**		VR	R		**R**	**VR**		
	PN 4121	VR	P	R					**VR**						**R**			VR					**NJT5**
Calcare di Limano	PN 4229	VR	VP	VR										R									
	PN 4228	VR	VP	VR											**VR**								
	PN 4120	VR	VP											VR	**VR**								
	PN 4118	VR	P	R				VR			VR	VR	VR	VR	**R**			VR					
	PN 4117	VR	P						**VR**		VR				**F**								
	PN 4226	VR	VP								VR			VR	**VR**								
	PN 4232	VR	VP	F											**VR**			VR					
	PN 4125	VR	VP	R				VR	**VR**					F	**VR**			VR					

Tab. 2 - Range chart of the species recognized in the Marliana section. The assemblages and the species abundances, and preservation classes utilized are as follows: Assemblage abundance - Common = (C): when the calcareous nannofossils were more than 25% and less than 50%, compared to the total of particles; Few = (F): >10% and < 25%; Rare = (R): >1% and < 10%; Very Rare = (VR): <1%. Species abundance - Common = (C): =1 specimen in 2-10 fields of view; Few = (F): 1 specimen in 11-100 fields of view; Rare = (R): 1 specimen in 101-200 fields of view; Very Rare = (VR): 1 specimen in > 201 fields of view. Preservation - Good = (G) all the specimens are determinable at specific levels; Moderate = (M), the majority of the specimens are determinable at specific levels; Poor = (P) several specimens are determinable at specific levels; Very Poor = (VP) only some specimens are determinable at specific levels. *Calcivascularis jansae* = *Mitrolithus jansae*.

Formations	Samples	Abundance	Preservation	*Schizosphaerella* spp.	*Parhabdolithus* spp.	*Crepidolithus* spp.	*C. crassus*	*M. elegans*	*M. lenticularis*	*C. jansae*	*Biscutum* spp.	*B. grande*	*Lotharingius* spp.	*Calyculus* spp.	*C. superbus*	Zones
Calcari e marne a Posidonia	PN 4115	VR	P	F						**VR**	VR				**VR**	**NJT6**
	PN 4162	VR	VP							**VR**			**VR**			
	PN 4112	VR	VP							**VR**			**VR**		**VR**	
	PN 4111	VR	P			VR				**VR**	VR			VR	**VR**	
	PN 4159	VR	VP							**VR**					**VR**	
	PN 4220	VR	VP	VR			VR			**VR**				VR	**VR**	
	PN 4110	VR	P	VR						**VR**					**VR**	
	PN 4158	VR	VP							**VR**						**NJT5**
	PN 4109	VR	P	VR						**VR**	VR					
	PN 4108	VR	P	VR						**VR**						
	PN 4105	VR	VP							**VR**				VR		
	PN 4105	VR	VP				VR	VR		**VR**	VR					
Calcari selcifero di Limano	PN 4102	VR	VP							**VR**						
	PN 4098	VR	P	VR	VR	VR	VR	VR	VR	**VR**				VR		
	PN 4097	VR	P	R		VR	VR	VR			VR		**VR**	VR		
	PN 4211	VR	P	R								VR		VR		
	PN 4096	VR	P	VR						**VR**				VR		
	PN 4210	VR	VP	R										VR		
	PN 4095	VR	P	VR			VR	VR		**VR**	VR		**VR**	VR		

Tab. 3 - Range chart of the species recognized in the Monsummano section (see symbols in Tab. 2).

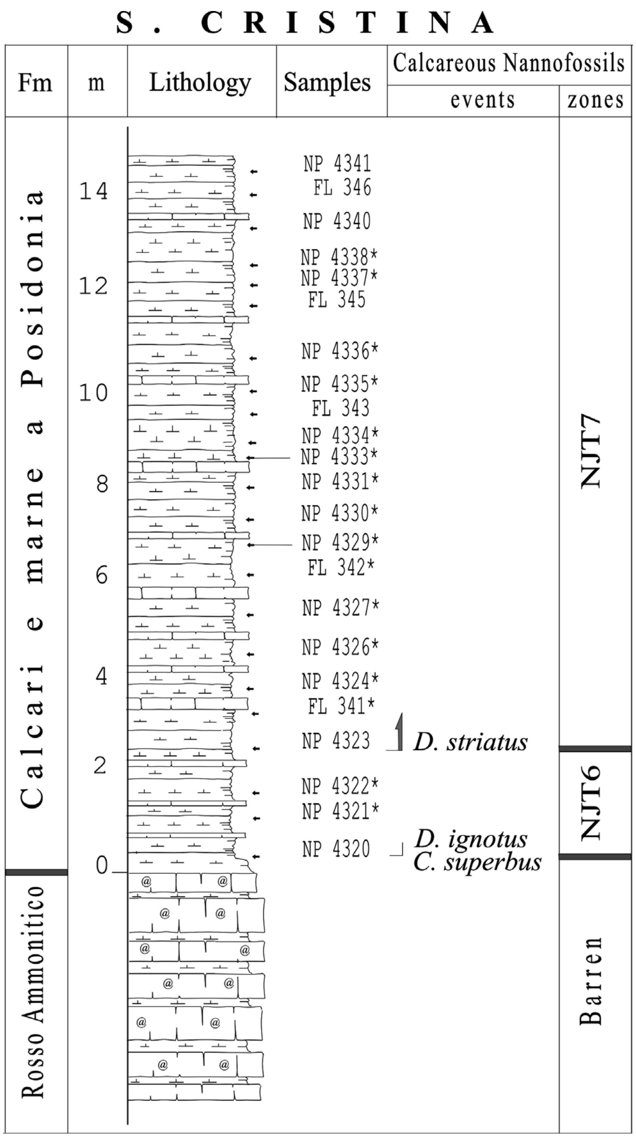

Fig. 8 - Lithostratigraphy, nannofossil events and zones recognized in the S. Cristina section (44° 07' 58N, 10° 17' 24E). Fm = Formations; m = Metres; barren samples are indicated by asterisk.

Lorenzana section (Fig. 10). In this section, the Calcari ad Angulati is a regular alternance of medium-thick beds of calcilutites and thin intercalations of silty marlstone and silty clay. The notable increase of the marly intervals defines the boundary with the Calcari e marne a Posidonia. This latter formation consists of a regular alternance of marlstones, siliceous marlstones and marly calcilutites with rare intercalations of calcilutites and fine-grained calcarenites. The very rare and poorly preserved assemblages from the lowermost sampled portion, are assignable to the Zone NJT6 according to presence of *L. hauffii*, *C. jansae*, *C. cantaluppii* and *C. superbus* (Tab. 6). The occurrence of *D. striatus* permits to identify also the Zone NJT7.

Conclusive remarks

The onset of the upper Pliensbachian-lower Toarcian marly deposition and the accumulation of the lower Toarcian black shales are two widespread sedimentation changes recorded in boreal and tethyan areas, including the Tuscan and Umbria-Marche basins. Despite the publication of many papers in the last decade concerning the causes that induced these sedimentary changes and the timing of both events, several questions are still unsolved. Among them, there are the discrepancies between the dating and the correlation of these events recognized in different sedimentary basins, and the difficulty to establishing if they are synchronous or diachronous. Up to present, the standard biochronology of Jurassic is still based on ammonite due to their high potential of resolution, though the provincialism of ammonite faunas. However, in many Jurassic sections the biostratigraphic signal is weak and the time resolution low, because the ammonite record is discontinuous and/or the assemblages do not include the marker species. In the Northern Apennine and in particular in the

Formation	Samples	Abundance	Preservation	*Schizosphaerella* spp.	*P. liasicus*	*C. crassus*	*M. lenticularis*	*C. jansae*	*B. novum*	*Similiscutum* spp.	*L. hauffii*	*L. barozii*	*L. sigillatus*	*L. velatus*	*Calyculus* spp.	*C. cantaluppii*	*C. superbus*	*D. ignotus*	*D. striatus*	Zones
Calcari e marne a Posidonia	NP 4341	VR	VP						VR		**VR**									NJT7
	NP 4340	VR	VP						VR		**VR**							**VR**		
	FL 345	VR	VP								**VR**									
	FL 343	VR	VP								**VR**						**VR**			
	NP4327	VR	VP								**R**									
	NP 4326	VR	VP	R	VR		VR		R	VR	**F**					**VR**	**VR**	**VR**	**VR**	
	NP 4324	VR	VP	F	VR	VR		**VR**	VR		**R**				VR	**VR**	**VR**	**VR**		
	NP 4323	R	P	F	VR	VR	VR		C		**F**	R	R	F	VR		**VR**	**F**	**VR**	
	NP 4320	VR	VP						VR		**VR**	VR			VR		**VR**	**VR**		**NJT6**

Tab. 4 - Range chart of the species recognized in the S. Cristina section (see symbols in Tab. 2).

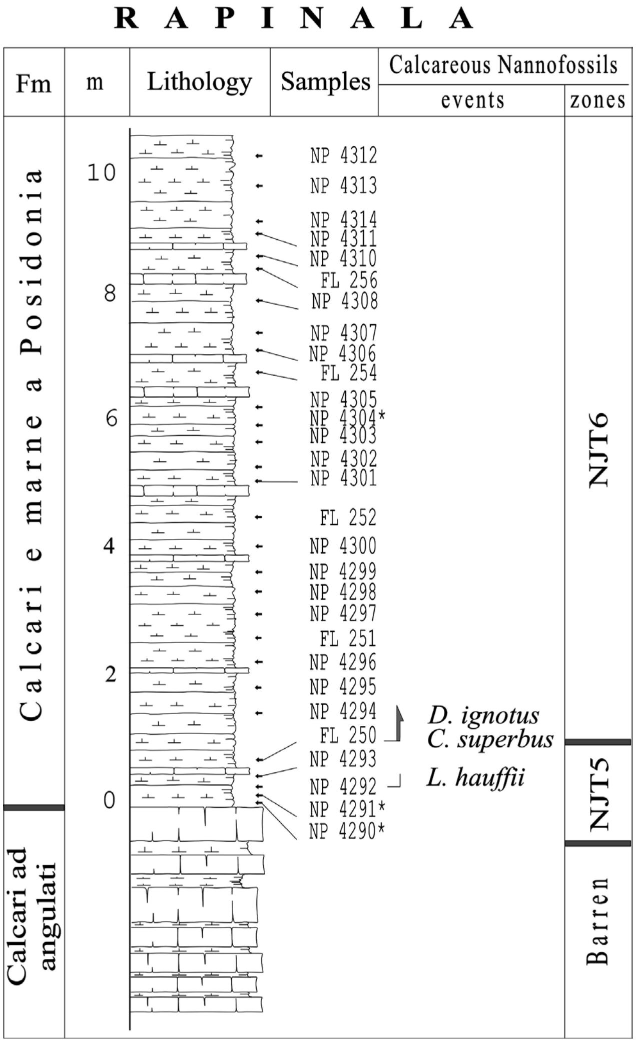

Fig. 9 - Lithostratigraphy, nannofossil events and zones recognized in the Rapinala section (44° 08' 13N, 10° 18' 31E). Fm = Formations; m = Metres, barren samples are indicated by asterisk.

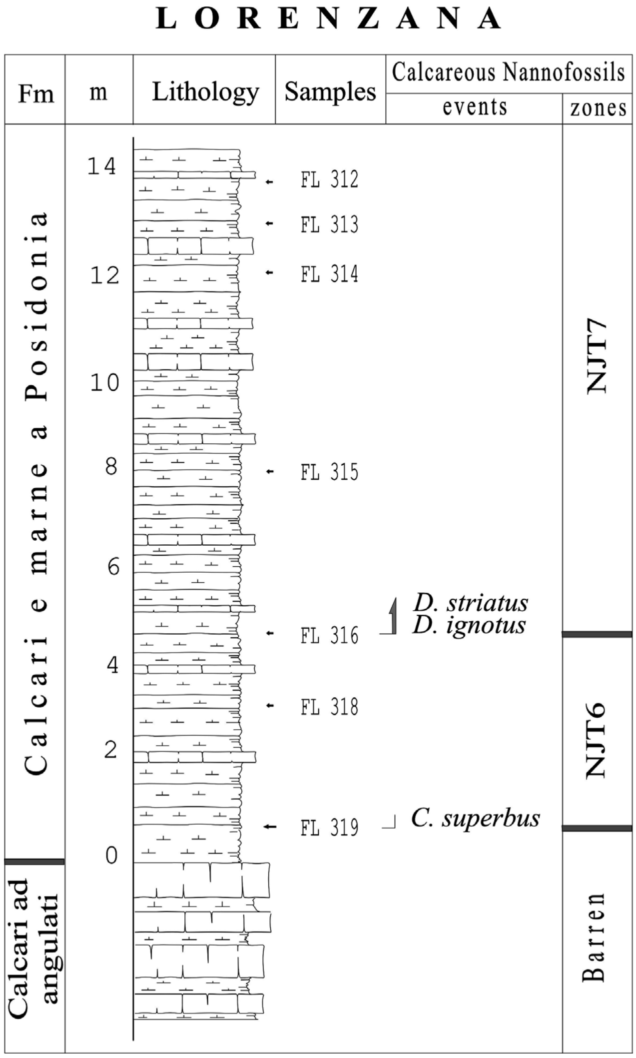

Fig. 10 - Lithostratigraphy, nannofossil events and zones recognized in the Lorenzana section (44° 08' 92N, 10° 18' 27E). Fm = Formations; m = Metres.

Tuscan Apennine, the ammonites collected from the Lower Jurassic portion of Tuscan Nappe mainly consist of few specimens or fragments of specimens, and some of them with questionable geographic and/or stratigraphic position. Consequently, the previous findings based on this fossil group are inadequate to date the transition between Calcare selcifero di Limano and the Calcari e marne a Posidonia and the organic-rich interval present in the lower portion of the Calcari e marne a Posidonia.

In recent years, calcareous nannofossils are increasingly used to date and correlate lower-Middle Jurassic successions, because coccoliths and nannoliths are important constituent of the hemipelagic/pelagic marly to calcareous sediments, providing a reliable biostratigraphical signal. Since the '90s, this fossil group allowed to refine the dating and the correlation of the Lower Jurassic deposits of the Umbria-Marche succession, including the upper Pliensbachian-middle Toarcian increment of the clay input corresponding to the Corniola/Marne di Monte Serrone Fm. boundary and the Lower Toarcian anoxic event intercalated within the Marne di Monte Serrone Fm. This paper documents for the first time a continuous biostratigraphic signal, that helps to date the changes from carbonate-dominated to marly-dominated sedimentation and the accumulation of the lower Toarcian organic rich lithologies in the Tuscan basin. The achieved results are based on semiquantitative analysis of the calcareous nannofossil assemblages recovered from five continuous sections, where the transition between the Calcare selcifero di Limano and the Calcari e marne a Posidonia and the lower portion of this last unit are well exposed. Consequently, we propose here an accurate correlation of the boundary between the Calcare selcifero di Limano/Calcari e marne a Posidonia and between the Corniola/Marne di Monte Serrone Fm. and the black shales present in the Tuscan Nappe and the Umbria-Marche succession.

Formation	Samples	Abundance	Preservation	*Schizosphaerella* spp.	*P. liasicus*	*C. crassus*	*C. pliensbachensis*	*M. elegans*	*M. lenticularis*	*C. jansae*	*B. novum*	*B. intermedium*	*B. grande*	*B. finchii*	*L. hauffii*	*L. barozii*	*L. sigillatus*	*L. velatus*	*Calyculus* spp.	*C. cantaluppii*	*C. superbus*	*D. ignotus*	Zones
Calcari e marne a Posidonia	NP 4312	R	P							**VR**	R								VR		**F**	**VR**	NJT6
	NP 4313	VR	VP								VR								VR			**VR**	
	NP 4314	R	M	F		VR	VR				R										**VR**	**VR**	
	NP 4311	VR	VP								VR				**VR**					**VR**	**VR**	**R**	
	NP 4310	VR	VP													VR			VR		**VR**		
	FL 256	VR	P	R	VR			VR		**VR**	R			VR	**F**				VR	**VR**	**F**	**VR**	
	NP 4308	F	M	R	VR	R		VR	VR	**VR**	F			VR	**F**	R	VR	VR		**VR**	**R**	**VR**	
	NP 4307	VR	VP	VR							VR				**F**				VR	**VR**	**VR**	**R**	
	NP 4306	R	P					VR		**VR**	R				**R**				VR	**VR**	**R**	**R**	
	FL 254	VR	VP	VR	VR	VR		VR		**VR**	R				**R**		VR		VR	**VR**	**R**	**VR**	
	NP 4305	VR	P								R				**R**								
	NP 4303	R	P	R					VR	**VR**	R		VR		**R**	F				**R**	**F**	**F**	
	NP 4302	R	VR	VR		VR				**VR**	R	VR			**R**				VR	**VR**	**VR**	**R**	
	NP 4301	VR	P								VR				**F**							**VR**	
	FL 252	VR	P	F	VR	VR				**VR**	R			VR	**VR**				VR	**VR**	**R**	**VR**	
	NP 4300	VR	P												**F**								
	NP 4299	F	M								R				**F**						**F**		
	NP 4298	VR	P								R				**F**					**VR**	**R**	**VR**	
	NP 4297	VR	VP								R				**R**								
	FL 251	VR	VP							**VR**		VR			**R**				VR		**VR**	**VR**	
	NP 4296	R	M								R				**R**						**F**	**R**	
	NP 4295	R	M	VR	VR			VR		**VR**	R				**R**	VR			VR	**VR**	**VR**	**VR**	
	NP 4294	F	M			VR	VR	VR			R				**F**				VR	**VR**	**R**	**VR**	
	FL 250	R	P							**cf**					**R**				VR		**F**	**R**	
	NP 4293	VR	P								VR				**VR**								NJT5
	NP 4292	VR	VP												**R**								

Tab. 5 - Range chart of the species recognized in the Rapinala section (see symbols in Tab. 2).

Formation	Samples	Abundance	Preservation	*Schizosphaerella* spp.	*P. liasicus*	*C. crassus*	*M. lenticularis*	*C. jansae*	*Biscutum* spp.	*B. novum*	*S. cruciulum*	*L. hauffii*	*L. barozii*	*L. crucicentralis*	*Calyculus* spp.	*C. cantaluppii*	*C. superbus*	*D. ignotus*	*D. striatus*	Zones
Calcari e marne a Posidonia	FL 312	VR	VP						VR		VR									NJT7
	FL 314	VR	VP						VR		VR									
	FL 315	R	P	R			VR				VR	**VR**	VR	VR				**VR**	**VR**	
	FL 316	R	P	R	R	VR		**VR**		F	VR			VR	VR	VR	VR	**F**	**VR**	
	FL 318	R	VP				VR	**VR**				**F**				VR	**VR**			NJT6
	FL 319	VR	VP					**VR**				**F**					**VR**			

Tab. 6 - Range chart of the species recognized in the Lorenzana section (see symbols in Tab. 2).

The inception of the marly calcareous sedimentation is comprised within the Zone NJT5 (upper Pliensbachian-lower Toarcian), and the NJT5/NJT6 Zone boundary lies in the lowermost portion of the Calcari e marne a Posidonia in both Montecatini-Monsummano and Roggio areas. At Marliana, the laminated, organic-rich black interval is comprised within the NJT6 Carinolithus superbus Zone (lower Toarcian). In the S. Cristina and Lorenzana sections, the presence of Zone NJT7 (middle Toarcian) has been documented from the lowermost portion of the Calcari e marne a Posidonia. Consequently, in Umbria-Marche and Tuscan basins, the abrupt increases of the clay input took place within the Zone NJT5. Actually, the onset of the marly dominated sedimentation of the Marne di Monte Serrone Fm. and of the Calcari e marne a Posidonia took place just before the appearance of the genus *Carinolithus*. In both units, the black shales lying within the Zone NJT6, are comprised between the FOs of *Carinolithus superbus* and *Discorhabus ignotus* (Fig. 11). Hence based on calcareous nannofossils, in Tuscan and Umbria-Marche basins the changes from mainly carbonate to marly sedimentation and the deposition of the black shales (TOAE) are two coeval events.

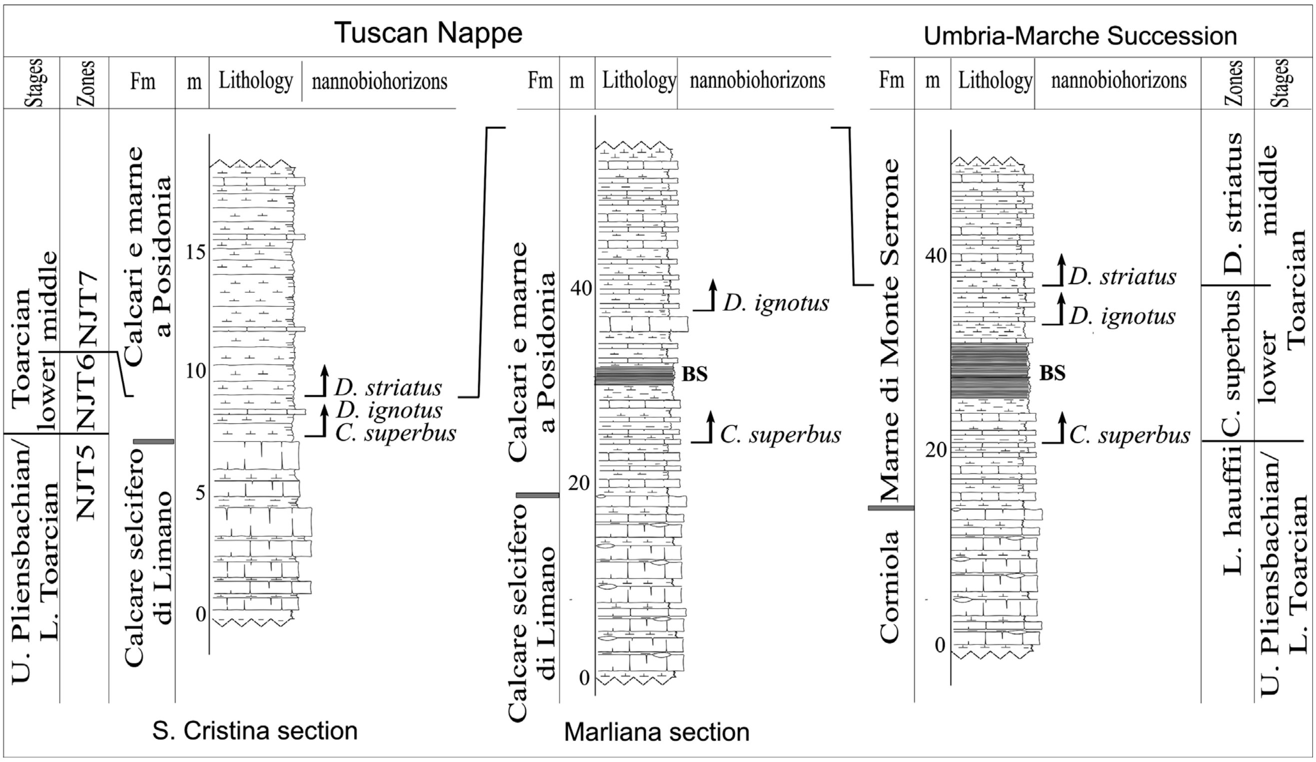

Fig. 11 - Correlation of the lower portion of the Calcare e marne a Posidonia (S. Cristina and Marliana sections) with the lower portion of the Marne di Monte Serrone Fm. (Reale et al., 1992; Bucefalo Palliani and Mattioli 1994; 1998). Fm = Formations; m = Metres; **BS** = Black Shales.

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Taxonomic Appendix

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

Genus *Biscutum* Black in Black & Barnes, 1959
Biscutum finchii (Crux, 1979) Bown, 1987
Biscutum grande Bown, 1987
Biscutum intermedium Bown, 1987
Biscutum novum (Goy, 1979) Bown, 1987
Biscutum spp. indet.
Genus *Calyculus* Noël, 1973
Calyculus spp. indet.
Genus *Calcivascularis* Bown & Young, 1986
Calcivascularis jansae (Wiegand, 1984) de Kaenel & Bergen, 1993
Genus *Carinolithus* (Prins in Grun et al., 1974) Bown, 1987
Carinolithus cantaluppii Cobianchi, 1990
Carinolithus superbus (Deflandre, 1954) Prins in Grün et al., 1974
Carinolithus spp. indet.
Genus *Crepidolithus* Noël, 1965
Crepidolithus pliensbachensis Crux, 1985
Crepidolithus crassus (Deflandre, 1954) Noël, 1965
Crepidolithus spp. indet.
Genus *Discorhabdus* Noël, 1965
Discorhabdus ignotus (Gorka, 1957) Perch-Nielsen, 1968
Discorhabdus striatus Moshkovitz & Ehrlich, 1976
Genus *Lotharingius* Noël, 1973 emend. Goy,1979
Lotharingius barozii Noël, 1973
Lotharingius crucicentralis (Medd, 1971) Grün & Zweili, 1980
Lotharingius hauffii Grün & Zweili in Grün et al., 1974
Lotharingius sigillatus (Stradner, 1961) Prins in Grün et al., 1974
Lotharingius velatus Bown & Cooper, 1989
Lotharingius spp. indet.
Genus *Mitrolithus* (Deflandre, 1954) Bown & Young. 1986
Mitrolithus elegans Deflandre in Deflandre & Fert,1954
Mitrolithus lenticularis Bown,1987
Genus *Parhabdolithus* Deflandre, 1952
Parhabdolithus liasicus Deflandre, 1952
Parhabdolithus spp. indet.
Genus *Similiscutum* de Kaenel & Bergen,1993
Similiscutum cruciulum de Kaenel & Bergen, 1993
Similiscutum spp. indet.
INCERTAE SEDIS
Genus *Schizosphaerella* Deflandre & Dangeard,1938
Schizosphaerella spp. indet.

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