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CALCAREOUS NANNOFOSSILS: THE KEY TO REVEALING THE RELATIONS BETWEEN THE MACIGNO AND MONTE MODINO SANDSTONE, TWO WIDESPREAD CLASTIC WEDGES OF THE NORTHERN APENNINES

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Abstract. Since the '60s geologists have discussed if the Tuscan Nappe includes the Macigno, the Mt. Modino Sandstone and the olistostromes interposed between these two clastic wedges or instead the foredeep deposits of the Tuscan Nappe is the Macigno and, therefore, the Mt. Modino Sandstone sedimented in a distinct basin and belongs to a different tectonic unit. One of the main difficulties to unraveling the Macigno-Mt. Modino Sandstone relationships is the absence of continuous biostratigraphic records, helpful in dating these formations and the underlying units. To fill this gap, a quantitative biostratigraphical analysis of calcareous nannofossils was performed on a large number of smear slides. The results confirm the stratigraphic continuity between the Tuscan Shale and the Macigno, and prove the stratigraphic continuity between the Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone (Mt. Modino Unit auctt.), supporting the tectonic superposition of the Mt. Modino Unit onto the Tuscan Nappe. In fact, the upper portion of the Tuscan Nappe ranges from the Late Eocene (MNP19/20) to the lower Miocene (MNN1c) and the Tuscan Shale-Macigno boundary lies within the upper Rupelian-Chattian (MNP24-MNP25a), whilst the sampled part of the Mt. Modino Unit spans in age the middle Eocene-lower Miocene (MNP15-MNN1c), and the Fiumalbo Shale-Marmoreto Marl and Marmoreto Marl-Mt. Modino Sandstone boundaries lie within the Rupelian (MNP23) and the uppermost Chattian (MNP25b-MNN1a).

Riassunto. Dagli anni 60 si discute se la Falda Toscana comprenda il Macigno, le Arenarie di M. Modino e gli olistostromi interposti tra questi due cunei clastici oppure le Arenarie di M. Modino si sarebbero sedimentate in un distinto bacino ed apparterrebbero quindi ad una diversa unità tettonica. Uno degli ostacoli principali per chiarire la natura dei rapporti (stratigrafici o tettonici) tra il Macigno e le Arenarie di M. Modino è l'assenza di un record biostratigrafico continuo, utile a datare queste due formazioni ed i rispettivi depositi sottostanti. Al fine di rimuovere quest'ostacolo, in questo lavoro sono presentati i risultati dello studio quantitativo dei nannofossili calcarei presenti in un elevato numero di smear slides. Sulla base dei risultati acquisiti viene provata la sovrapposizione tettonica dell'Unità di Monte Modino sul Macigno della Falda Toscana perché la parte superiore della Falda Toscana è riferibile all'intervallo di tempo compreso tra l'Eocene superiore (MNP19/20) e il Miocene inferiore (MNN1c) ed il limite tra la Scaglia Toscana ed il Macigno giace nel Rupeliano superiore-Chattiano (MNP24-MNP25a), mentre la porzione campionata dell'Unità di Monte Modino è riferibile all'intervallo compreso tra l'Eocene medio e il Miocene inferiore (MNP15-MNN1c), con il limite tra le Argille di Fiumalbo e le Marne di Marmoreto che giace entro il Rupeliano (MNP23) ed il limite tra le Marne di Marmoreto e le Arenarie di M. Modino che giace entro il Chattiano sommitale (MNP25b-MNN1a).

Introduction

Wide sectors of the Northern Apennines are characterized by Oligocene-Miocene, very thick siliciclastic successions belonging to the Macigno, the Mt. Modino Sandstone, the Mt. Cervarola Sandstone and the Marnoso Arenacea formations. They represent the sedimentary filling of longitudinal foredeep basins externally located on the front of the Northern Apennines thrust and fold belt (Figs. 1, 2). Since the Oligocene, the progressive eastward migration of the orogenic front toward the Adria foreland has caused the shortening of the foredeep basins and the deformation of their deposits, later involved in the tectonic stack as thrust-sheets detached from their substrate and overthrusted by the Ligurian and Subligurian units (Cerrina et al. 2004). Deciphering the evolution of this complex foredeep system is fundamental to constraining the timing of the Northern Apennines geological evolution. Due to the lithological, sedimentological and petrographic similarities between these clastic wedges, it is difficult to recon-

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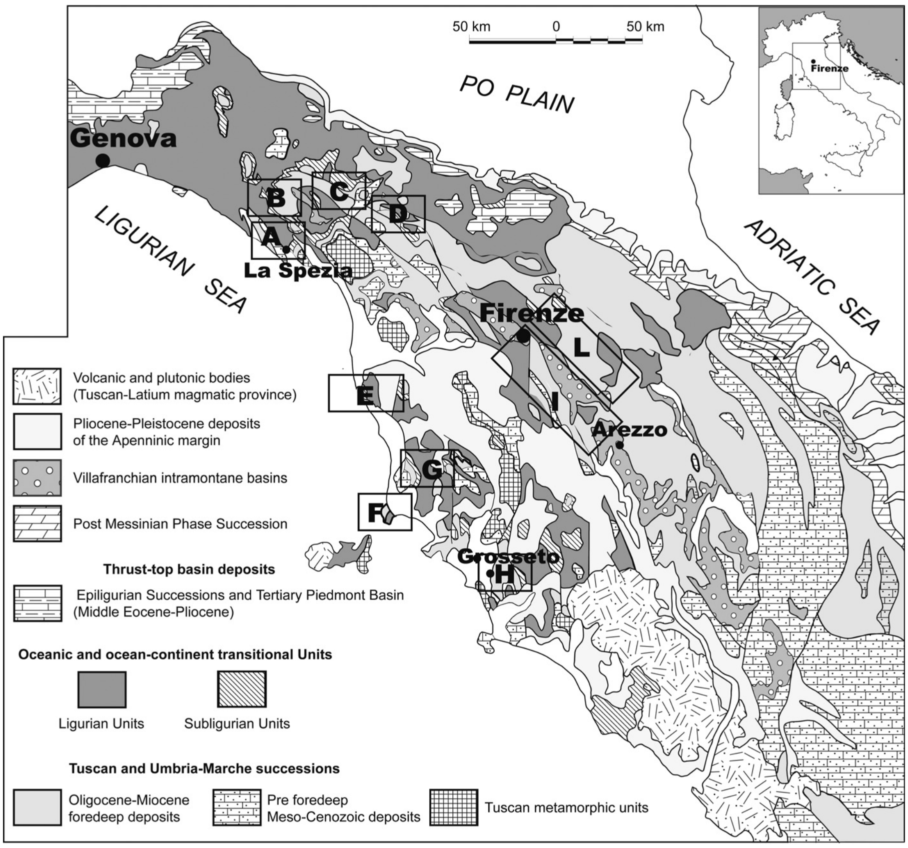


Fig. 1 - Geological sketch-map of the Northern Apennines (modified from Cerrina Feroni et al. 2004). The squares are the areas quoted in figures 14B and 15: A) La Spezia; B) Pontremoli; C) Pracchiola-Mt. Orsaro; D) Mt. Cisa; E) Calafuria; F) Piombino; G) Sassetta and Metalliferous Hills; H) Grosseto area; I) Firenze and Pratomagno areas; L) Chianti area.

struct the stratigraphy of these units and to correlate these turbiditic successions, particularly without any physical continuity of the outcrops or precise dating. Therefore, it is also difficult to recognize the relations (stratigraphic vs. tectonic) between these formations and to locate their paleogeographic areas. The Macigno-Mt. Modino Sandstone relations have remained a matter of debate since the early geological survey of these units in the Abetone-Mt. Modino type area (Tuscan-Emilian Apennines).

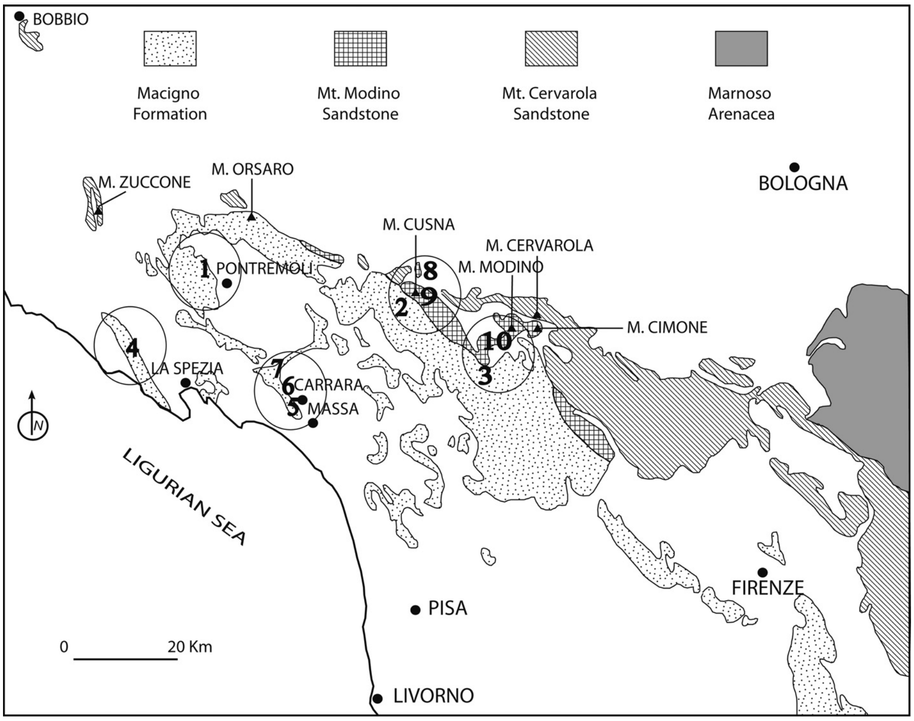
According to a still largely shared conventional view, the Macigno-Mt. Modino Sandstone superposition is stratigraphic and the Mt. Modino Sandstone represents a resumption of the turbiditic sedimentation, after the olistostromes emplacement, deriving from the Ligurian nappes, which interrupted the Macigno deposition (Abbate & Bortolotti 1961; Nardi 1965; Dallan Nardi & Nardi 1974; Sagri 1975; Bruni et al. 1994). In contrast with the previously stated, the other hypotheses recognize tectonic relations between the Macigno and the Mt. Modino Sandstone and place the paleogeographic area of the Mt. Modino Unit in an internal position with respect to the Tuscan Nappe (Plesi 1975; Reutter & Groscurth 1978; Bettelli et al. 1987; Plesi et al. 2000). The Macigno-Mt. Modino Sandstone tectonic superposition has been explained also as having occurred in the context of a flower structure related to the Northern Apennines transpressive fault zone and the basin of the Mt. Modino Unit placed along the northwestward longitudinal extension of the Macigno basin (Catanzariti et al. 1996; Cerrina et al. 2002; Cerrina et al. 2004).

To reveal the relations between the Macigno and the Mt. Modino Sandstone, the aim of this paper is to refine the ages of these two clastic wedges and their underlying deposits. In particular, we have analyzed or reanalyzed samples coming from the Tuscan-Emilian Apennines and have reassessed the data from La Spezia and Carrara areas (Catanzariti et al. 1996), in order to reconstruct the distribution patterns of the age-diagnostic species and the biostratigraphic signal which are helpful in dating the two sampled successions composed by the Tuscan Shale and the Macigno and by the Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone. Our data are compared with previous findings of Cornamusini et al. (1999), Costa et al. (1992, 1997), Costantini et al. (1993), Ferrini & Pandeli (1985) and Plesi et al. (1998, 2000).

Geological setting of Northern Apennines

The Northern Apennines is a NE-verging thrust and fold belt developed during the Late Cretaceous-middle Eocene convergence and the early Oligocene-early Pleistocene continental collision between the Europe and the Adria Plates (Cerrina et al. 2004). The tec-

Fig. 2 - Geological sketch-map showing the outcrops of the Macigno, Mt. Modino Sandstone, Mt. Cervarola Sandstone and Marnoso Arenacea formations and location of the studied sections: 1) Val Gordana; 2) Mt. Le Porraie and Rio Re; 3) Val di Lima; 4) Val Pignone; 5) Percorso Salute; Vallecchia and Rizieri; 6) Maestà di Castelpoggio; 7) Mt. Olivero; 8) Mt. Cisa; 9) Mt. Cusna-Il Passone; 10) Mt. Modino; Mt. Modino-Ca' Bicci; Mt. Modino-Capannella and Fiumalbo.



tonic units of the nappe pile derive from different domains. The Middle Jurassic-middle Eocene Ligurian units include ophiolites slices and their sedimentary cover, which have accumulated onto the oceanic and transitional crust of the Ligurian-Piedmont basin (Marroni et al. 2001). The Subligurian units sedimented in a transitional domain located between the Ligurian oceanic basin and the Adria Plate continental margin, and they comprise an Upper Cretaceous-middle Eocene sedimentary substrate, unconformably covered by upper Eocene slope succession which grades to the lower Oligocene-lower Miocene foredeep deposits (Elter et al. 1999; Cerrina et al. 2002). The Tuscan and Umbria-Marche units accumulated on the Adria Plate continental margin. They are composed of Triassic evaporites, Lower Jurassic-Lower Cretaceous shallow-water to deep pelagic deposits, overlain by Lower Cretaceous to Upper Paleogene slope successions which grade to Oligocene-Miocene foredeep deposits (Fazzuoli et al. 1985; Colacicchi et al. 1988; Ricci Lucchi 1986). The relationships between these units are sealed by the upper Eocene-upper Miocene unconformable deposits of the Epiligurian and Tertiary Piedmont basins (Ricci Lucchi & Ori 1985; Ricci Lucchi 1990; Gelati & Falletti 1996). In the Tuscan-Emilian Apennines, the Tuscan Shale and the Macigno are the topmost part of the NE-verging monoclines or overturned anticlines, which are topped by the Mt. Modino Sandstone and the underlying successions between Mt. Cusna and Mt. Cimone (Nardi 1965; Reutter 1969; Bettelli et al. 1987; Chicchi & Plesi 1992). West of the Apuan Alps, in the anticlines of Castelpoggio (De Candia et al. 1988) and La Spezia (Abbate 1969) the Subligurian or the Ligurian units overlay the Macigno or the Tuscan Shale (Catanzariti et al. 1996).

Lithostratigraphy of sampled units

The sampled units are: the Tuscan Shale and the Macigno (Bortolotti et al. 1970; Dallan Nardi & Nardi 1974; Bruni et al. 1992); the Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone (Nardi 1965; Reutter 1969; Bettelli et al. 1987; Chicchi & Plesi 1992; Plesi et al. 2000). The Tuscan Shale consists of varicoloured clay and siliceous to marly clay, interbedded with thin to medium calcilutites, fine calcarenites, and coarse grained bioclastic calcarenites. Its upper part is mainly made up of silty clay to silty marlstones, intercalated with fine-grained arenaceous turbidites. Locally, the uppermost part of the Tuscan Shale is represented by the Rovaggio Marl, which consists of grey to green or reddish marls, upwards grading to silty marls with fine-grained turbidites (Catanzariti et al. 1996). The Macigno is made up of thin to thick beds of medium- to very coarse-grained, quartz-feldspatic turbidites, intercalated with metric arenaceous-pelitic alternance, which shows shalely to marly clay siltitic intervals (Valloni & Zuffa 1984; Costa et al. 1992; Bruni et al. 1994). In some areas, the Macigno is topped by the poorly stratified grey marls and silty marls of the Ponteccio Marl (Gunther 1966). The Fiumalbo Shale is made up of grey-green to reddish siliceous marly clay, intercalated with thin- to medium-bedded, silty to arenitic turbidites. The Marmoreto Marl is a monotonous formation consisting of hemipelagic marls and calcareous marls, intercalated with thin to medium thick beds of silty sandstones or sandstones. This formation sometimes includes mud-supported debris flows and in its uppermost part could be present canalized arenaceous turbidites (Sagri 1975; Perilli 1984, 1994). The lower part of the Mt. Modino Sandstone consists of thin bedded and fine-grained quartz-feldspatic turbidites with thin to medium intercalations of silty clay to silty marls, and its upper part is represented by thick to very thick turbidites with coarse-grained quartz-feldspatic arenites and thin intercalations of silty clay (Bruni et al. 1994; Plesi et al. 1998).

Study material and methods

The selected sections are located in the La Spezia and Carrara areas and the Tuscan-Emilian Apennines (Fig. 2). We have analyzed or reanalyzed 352 samples coming from the Gordana Valley, Mt. Le Porraie, the Lima Valley, the Rio Re creek, Mt. Cisa, Mt. Cusna and Mt. Modino, and we have reassessed the data from the La Spezia and Carrara areas (Catanzariti et al. 1996). In order to investigate the calcareous nannofossil assemblages, smear-slides were prepared following standard preparation techniques (Bown & Young 1998) and were examined with a polarizing optical microscope at 1250X magnification. According to Backman & Shackleton (1983) and Rio et al. (1990), the percentage data reported in Figures 4-12 have been evaluated by counting the index species, in approximately 500 specimens of the entire assemblage, and the index species relative to a prefixed number of taxonomically related forms (species of sphenoliths relative to 50-100 sphenoliths). Nannofossil taxonomy is in accordance with Perch-Nielsen (1985) and Bown (1998). The turbiditic nature of the sediment does not affect the results because the very low percentage of reworked specimens is exclusively represented by Cretaceous taxa.

Adopted biostratigraphic scheme and recognized biozones

The Mediterranean area has been characterized by palaeogeographic and palaeocological controlling factors (Rogl 1999) which influenced the distribution of organisms, since the Eocene. Therefore, the standard zonations of Martini (1971) and Okada & Bukry (1980), based on oceanic taxa, are difficult to apply to the Mediterranean area. Thus regional biostratigraphic schemes have recently been proposed by Catanzariti (1993) for the middle Eocene, by Catanzariti et al. (1997) for the late Eocene-early Oligocene, and by Fornaciari & Rio (1996) for the late Oligocene-early Miocene. The majority of the biohorizons utilized in these schemes are based on species common in the Mediterranean area, and the succession of zones and subzones improve time resolution with respect to the previous standard zonations. In the following we briefly comment on the biohorizons utilized and the zones recognized according to the species present in the studied middle Eocene-lower Miocene sampled slope and foredeep deposits. The abundance distributions of selected taxa have been summarized in Figure 3.

Among the placoliths: *Coccolithus pelagicus* and *Cyclicargolithus floridanus* are dominant; *Dictyococcites bisectus*, *Dictyococcites scrippsae, Cyclicargolithus abisectus*, *Ericsonia formosa* and *Reticulofenestra umbilicus* are common and continuously occurring; *Cribrocentrum reticulatum* is rare and sporadic. The genus *Sphenolithus* is present and common through the investigated time interval: the Eocene species *Sphenolithus furcatolithoides, Sphenolithus spiniger* and *Sphenolithus obtusus* are common and continuous; the Oligocene species *Sphenolithus ciperoensis*, *Sphenolithus distentus*, *Sphenolithus predistentus* are discontinuously present and the Miocene *Sphenolithus delphix* is frequent. Among discoasterids: *Discoaster barbadiensis, Discoaster saipanensis* and *Discoaster deflandrei* are continuously present, but rare. Helicoliths are scarce and represented by few specimens of *Helicosphaera euphratis*, *Helicosphaera recta* and *Helicosphaera carteri*. Chiasmoliths do not occur and *Istmolithus recurvus* is extremely rare.

The MNP15 Zone has been recognized on the basis of the presence of *Nannotetrina* spp., *S. furcatolithoides* and *S. spiniger*. The FO of *Nannotetrina* spp. is suggested as an alternative zonal marker for the NP15 by Perch-Nielsen (1985), and *S. furcatolithoides* and *S. spiniger* are common in the succession belonging to this zone (Proto Decima et al. 1975; Parisi et al. 1988; Firth 1989; Catanzariti 1993; Mita 2001; Bralower 2005). The assemblages assigned to the MNP15 Zone also show the presence of *D. saipanensis*, *D. barbadiensis* and *S. predistentus* (Fig. 4).

The MNP16 Zone has not been recognized. In other Italian sections (Catanzariti 1993; Bolla 2003), it covers the interval from the FO of *R. umbilicus* (> 14 μm) to the FO of *D. bisectus.* According to Backman (1987), the FO of *R. umbilicus* (> 14 μm) is an alternative event for the CP14 Zone, and the FO of *D. bisectus* is considered a good biohorizon in which to place the lower limit of the NP17 Zone (Perch-Nielsen 1985; Berggren et al. 1995; Bralower & Mutterlose 1995).

The biozones MNP17 and MNP18 have been combined, because in the studied sections, the genus *Chiasmolithus* is missing and hence it is impossible to recognize the NP17/NP18 Zone boundary defined by the FO of *Chiasmolithus oamaruensis*. Thus it is also difficult to recognize this boundary based on the Acme Beginning of *C. reticulatum* of Catanzariti (1993), as this taxon is rare and discontinuously present. The MNP17/MNP18 combined Zone ranges from the FO of *D. bisectus* to the FO of *I. recurvus* and is characterized by the presence of *S. obtusus, E. formosa, R. umbilicus, D. scrippsae, D. barbadiensis*, *D. saipanensis* and

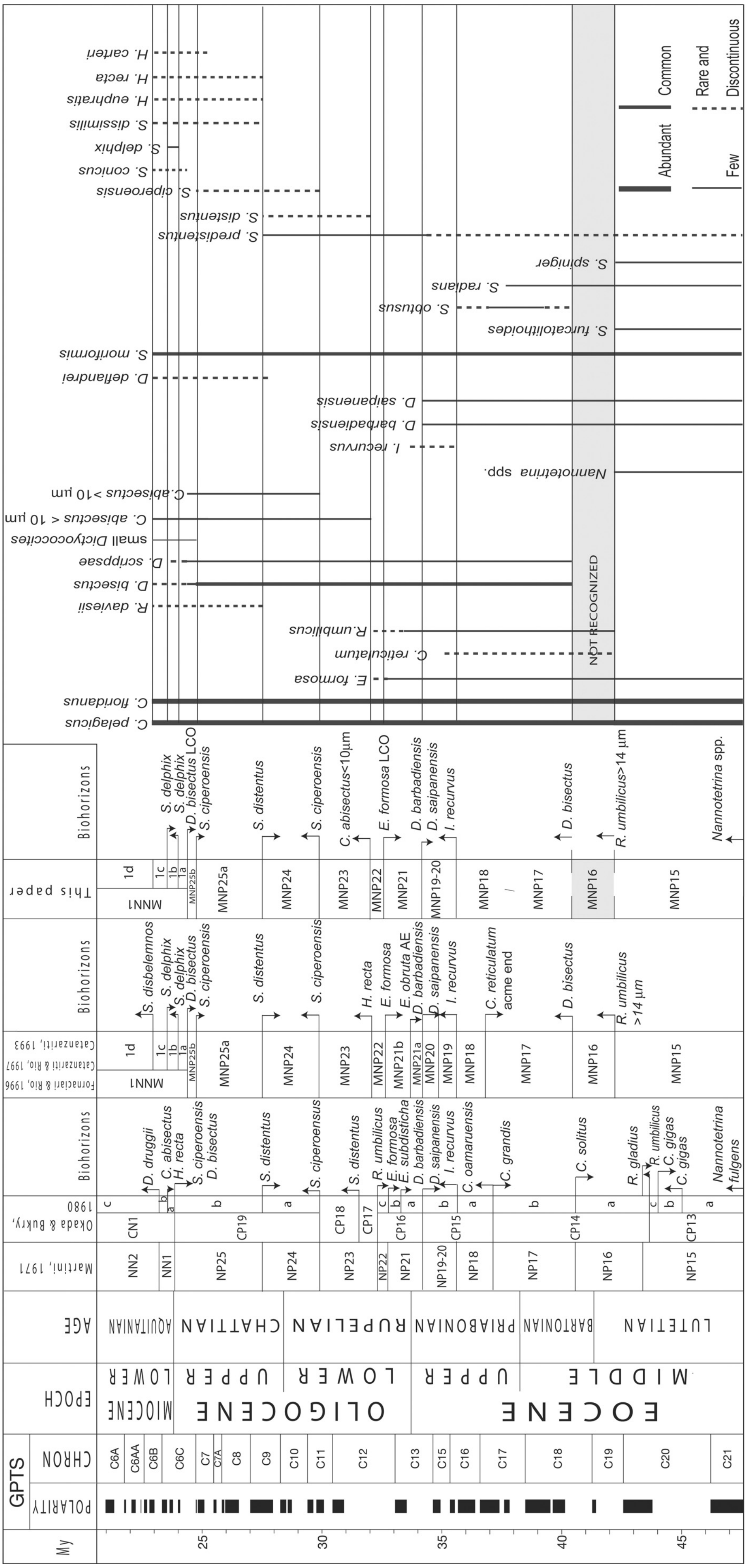
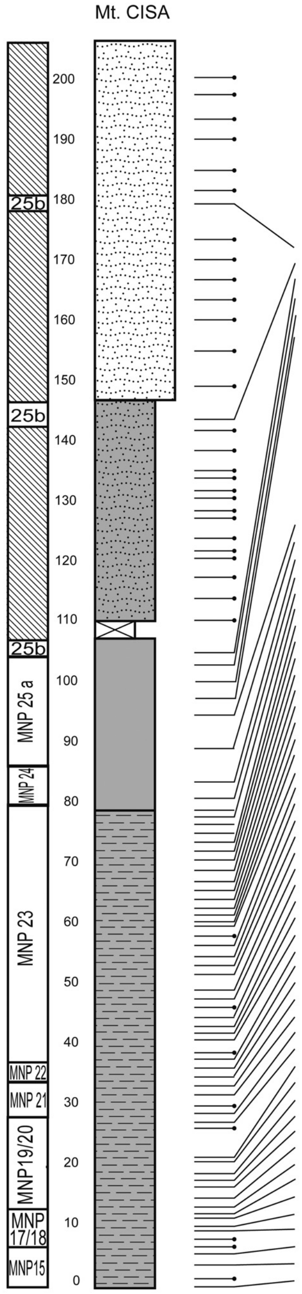


Fig. 3 - Correlation between the adopted biostratigraphic scheme based on the distribution pattern of the species recognized in the sampled sections with the regional schemes of Fornaciari & Rio (1996), Catanzariti & Rio (1997), Catanzariti (1993) and the standard schemes of Martini (1971) and Okada & Bukry (1980). Chronostratigraphy after Berggren et al. (1995).



Sample	Counted specimens	*Coccolithus pelagicus*	***Cyclicargolithus abisectus***	*Cyclicargolithus floridanus*	***Dictyococcites bisectus***	*Dictyococcites scrippsae*	*Dictyococcites* sp.	*Discoaster deflandrei*	*Reticulofenestra daviesii*	*Reticulofenestra* sp.	Reworking	*Sphenolithus* sp.	Counted Sphenoliths	***Spenolithus ciperoensis***	*Sphenolithus distentus*	*Sphenolithus predistentus*
M10	500	48,2	**7,0**	23,0	**1,0**	1,0	9,8	0,2	0,4	0,2	4,8	4,4	100	/	/	/
M18	500	40,2	**7,2**	34,0	**1,2**	1,2	5,0	0,6	0,2	0,4	2,6	3,0	100	/	/	/
M37	500	36,0	**10,0**	24,3	**1,0**	0,8	/	0,2	0,2	0,2	0,0	27,3	100	/	/	/
M40	500	52,0	**11,0**	14,0	**6,2**	4,6	/	0,2	0,2	0,2	0,6	10,8	100	**3,0**	/	/
M41	500	41,0	**4,2**	14,8	**5,0**	4,2	/	0,2	0,2	/	/	30,0	100	**3,0**	/	/
M42	500	29,0	**17,6**	15,6	**4,2**	3,0	/	0,2	/	/	0,2	30,0	100	**5,0**	/	/

MNP 25 b
MNP 25 a
Modino
Marmoreto

Sample	Counted specimens	*Chiasmolithus* sp.	*Coccolithus pelagicus*	*Cribrocentrum reticulatum*	***Cyclicargolithus abisectus***	*Cyclicargolithus floridanus*	***Dictyococcites bisectus***	*Dictyococcites scrippsae*	***Discoaster barbadiensis Discoaster saipanensis***	***Ericsonia formosa***	*Istmolithus recurvus*	***Nannotetrina* sp.**	*Reticulofenestra* sp.	***Reticulofenestra umbilicus***	Reworking	*Sphenolithus* sp.	*Zygrhablithus bijugatus*	Counted Sphenoliths	***Sphenolithus ciperoensis***	***Sphenolithus distentus***	*Sphenolithus furcatolithoides*	***Sphenolithus obtusus***	*Sphenolithus predistentus*	*Sphenolithus radians*	***Sphenolithus spiniger***
C0	500	/	43,0	/	**2,2**	34,5	**1,0**	7,2	/	/	/	/	/	/	/	12,0	/	100	/	/	/	/	/	/	/
C1	500	/	47,6	/	/	24,0	**5,2**	9,0	/	/	/	/	/	**0,2**	/	14,0	/	100	**3,0**	/	/	/	/	/	/
C2	500	/	35,0	/	**9,2**	21,5	**11,4**	5,4	/	**0,2**	/	/	/	/	0,8	16,6	/	100	**2,0**	**1,0**	/	/	/	/	/
C3	500	/	37,0	/	**7,0**	19,0	**9,0**	6,0	/	/	/	/	0,6	/	/	21,0	/	100	/	/	/	/	/	/	/
C4	500	/	34,0	/	**6,6**	21,6	**11,6**	6,8	/	/	/	/	0,2	/	/	19,2	/	100	/	/	/	/	1,0	/	/
C5	500	/	30,0	/	**9,5**	31,0	**8,0**	2,0	/	/	/	/	/	/	0,4	19,0	/	100	/	**4,0**	/	/	3,0	/	/
C6	500	/	53,0	/	**7,0**	11,6	**4,8**	4,6	/	/	/	/	/	/	0,2	8,8	/	100	/	**1,0**	/	/	0,5	/	/
C7	500	/	47,8	/	**3,6**	22,3	**8,8**	2,2	/	/	/	/	/	/	0,2	15,0	/	100	/	**1,0**	/	/	1,0	/	/
C8	500	/	36,4	/	**4,0**	28,6	**10,0**	3,4	/	/	/	/	/	/	/	17,6	/	100	/	/	/	/	/	/	/
C9	500	/	28,4	/	**2,6**	18,2	**13,4**	8,0	/	/	/	/	0,8	/	/	28,6	/	100	/	/	/	/	/	/	/
C10	500	/	41,0	/	**4,0**	43,0	**2,2**	0,8	/	**0,2**	/	/	1,4	/	0,2	7,2	/	100	/	/	/	/	1,0	/	/
C11	500	/	36,6	/	**13,4**	36,0	**3,0**	1,8	/	/	/	/	0,2	/	0,2	8,8	/	100	/	/	/	/	1,0	/	/
C12	500	/	43,6	/	**6,0**	30,6	**7,6**	1,8	/	/	/	/	0,6	/	/	8,8	/	100	/	/	/	/	3,0	/	/
C13	500	/	28,4	/	**6,0**	40,0	**15,4**	1,4	/	**0,2**	/	/	1,8	/	0,2	6,6	/	100	/	/	/	/	/	/	/
C14	500	/	34,2	/	**3,0**	44,0	**8,8**	1,2	/	**0,2**	/	/	0,6	**0,2**	/	7,8	/	100	/	/	/	/	5,0	/	/
C15	500	/	40,0	/	**3,6**	32,0	**10,6**	3,4	/	/	/	/	1,6	/	0,2	8,6	/	100	/	/	/	/	8,0	/	/
C17	500	/	61,4	/	**4,4**	20,2	**13,0**	2,6	/	/	/	/	0,8	/	/	7,6	/	100	/	**1,0**	/	/	2,0	/	/
C18	500	/	36,6	/	**3,2**	30,6	**7,6**	4,0	/	**0,4**	/	/	6,4	/	3,2	8,0	/	100	/	/	/	/	2,0	/	/
C19	500	/	35,6	/	**2,6**	40,0	**9,4**	3,0	/	**0,2**	/	/	3,6	/	1,6	4,0	/	100	/	**1,0**	/	/	7,0	/	/
C20	500	/	48,6	/	**3,2**	27,2	**8,0**	6,6	/	/	/	/	1,0	/	0,4	5,0	/	100	/	/	/	/	4,0	/	/
C21	500	/	41,4	/	**1,4**	32,0	**7,8**	5,4	/	/	/	/	2,0	/	1,4	8,4	0,2	100	/	/	/	/	5,0	/	/
C22	500	/	47,2	/	**1,2**	22,6	**4,8**	3,2	/	/	/	/	5,4	/	5,0	10,6	/	100	/	/	/	/	3,0	/	/
C24	500	/	46,0	/	**1,4**	24,4	**7,8**	6,6	/	/	/	/	5,4	/	1,4	7,0	/	100	/	/	/	/	/	/	/
C25	500	/	50,0	/	**cf**	19,8	**7,8**	4,6	/	/	/	/	7,8	**0,2**	2,2	7,6	/	100	/	/	/	/	1,0	/	/
C26	500	/	48,0	/	**2,5**	39,3	**3,2**	1,8	/	**0,2**	/	/	0,8	**0,2**	1,0	12,9	/	100	/	/	/	/	2,0	/	/
C27	500	/	51,0	/	**cf**	14,0	**3,6**	3,6	/	**0,2**	/	/	15,0	/	4,2	7,8	/	100	/	/	/	/	1,0	/	/
C29	500	/	41,0	0,2	**cf**	12,4	**10,4**	0,8	/	**0,4**	/	/	24,4	/	3,6	6,8	/	100	/	/	/	/	/	/	/
C30	500	/	35,0	/	/	16,8	**15,0**	5,2	/	**0,2**	/	/	8,4	**1,6**	4,0	13,8	/	100	/	/	/	/	2,0	/	/
C31	500	/	44,0	/	/	10,0	**10,2**	2,8	/	**0,2**	/	/	19,2	/	3,8	9,8	/	100	/	/	/	/	2,0	/	/
C32	500	/	46,6	0,2	/	18,8	**10,8**	7,0	/	**1,2**	/	/	4,6	**0,2**	1,4	9,2	/	100	/	/	/	/	1,0	/	/
C33	500	/	39,7	/	/	30,3	**6,2**	4,4	/	**1,0**	**0,2**	/	7,8	**0,2**	2,6	7,6	/	100	/	/	/	/	5,0	/	/
C35	500	/	46,2	0,2	/	6,4	**13,2**	3,6	/	/	/	/	17,8	**1,0**	0,2	11,4	/	100	/	/	/	/	/	/	/
C36	500	/	53,6	0,2	/	5,9	**8,4**	2,1	**1,0**	**2,0**	**0,2**	/	13,7	**2,5**	1,4	10,0	/	100	/	/	/	/	/	/	/
C38	500	/	43,0	0,4	/	1,0	**9,4**	2,6	/	**1,8**	**0,2**	/	21,6	**2,0**		17,8	0,2	100	/	/	/	/	/	/	/
C39	500	/	45,0	/	/	2,2	**20,8**	0,8	/	**1,4**	**0,4**	/	16,2	**2,4**	0,8	10,0	/	100	/	/	/	/	/	/	/
C40	500	/	48,8	1,2	/	5,6	**10,4**	1,8	1,0	**2,2**	/	/	18,0	**1,4**		10,0	/	100	/	/	/	/	1,0	/	/
C41	500	0,2	35,5	1,0	/	5,2	**7,4**	1,8	2,8	**2,2**	**0,4**	/	25,3	**4,4**	1,0	12,8	/	100	/	/	/	/	1,0	/	/
C42	500	/	32,4	/	/	3,5	**37,5**	2,0	2,2	**3,0**	/	/	7,2	**2,8**	1,9	7,5	/	100	/	/	/	/	1,0	/	/
C43	500	/	40,2	/	/	4,6	**27,4**	1,8	/	**0,8**	/	/	8,0	/	0,6	16,6	/	100	/	/	/	/	/	/	/
C44	500	0,2	46,8	/	/	2,2	**28,2**	3,2	1,0	**5,4**	**0,4**	/	2,4	**1,6**	0,6	8,2	/	100	/	/	/	/	/	/	/
C45	500	1,0	34,6	/	/	8,6	**18,2**	2,6	1,0	**5,0**	/	/	15,4	**2,0**	1,4	8,2	0,2	100	/	/	/	/	2,0	/	/
C46	500	/	31,8	0,2	/	2,0	**33,0**	4,6	1,0	**4,6**	/	/	13,2	**0,8**	1,2	7,6	/	100	/	/	/	**2,0**	4,0	1,0	/
C47	500	0,2	13,2	/	/	7,2	**38,5**	4,4	1,0	**2,4**	/	/	5,0	**1,8**	0,8	26,3	/	100	/	/	/	**2,0**	1,0	3,0	/
C48	500	/	35,8	/	/	2,6	**29,0**	4,4	1,0	**4,2**	/	/	14,0	**1,0**	0,4	8,0	/	100	/	/	/	**1,0**	2,0	3,0	/
C51	500	1,0	54,6	/	/	0,8	/	/	3,2	**8,8**	/	**0,2**	27,4	/	0,8	3,2	/	100	/	/	2,0	/	2,0	3,0	/
C52	500	0,2	32,6	/	/	0,2	/	0,6	/	**3,4**	/	**0,2**	52,0	/	0,6	10,0	0,2	100	/	/	2,0	/	/	2,0	**2,0**
C54	500	/	50,0	/	/	0,8	/	/	/	**4,0**	/	/	18,4	/	3,0	22,6	1,2	100	/	/	2,0	/	1,0	1,0	**2,0**

MNP 25a
MNP 24
MNP 23
MNP 22
MNP 21
MNP 20
/
MNP 19
MNP 18
/
MNP 17
MNP 15

Marmoreto
Fiumalbo

Barren
Covered Interval
Fiumalbo Shale
Marmoreto Marl
Modino Sandstone (thin bedded)
Modino Sandstone (thick bedded)

Fig. 4 - Mt. Cisa section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.

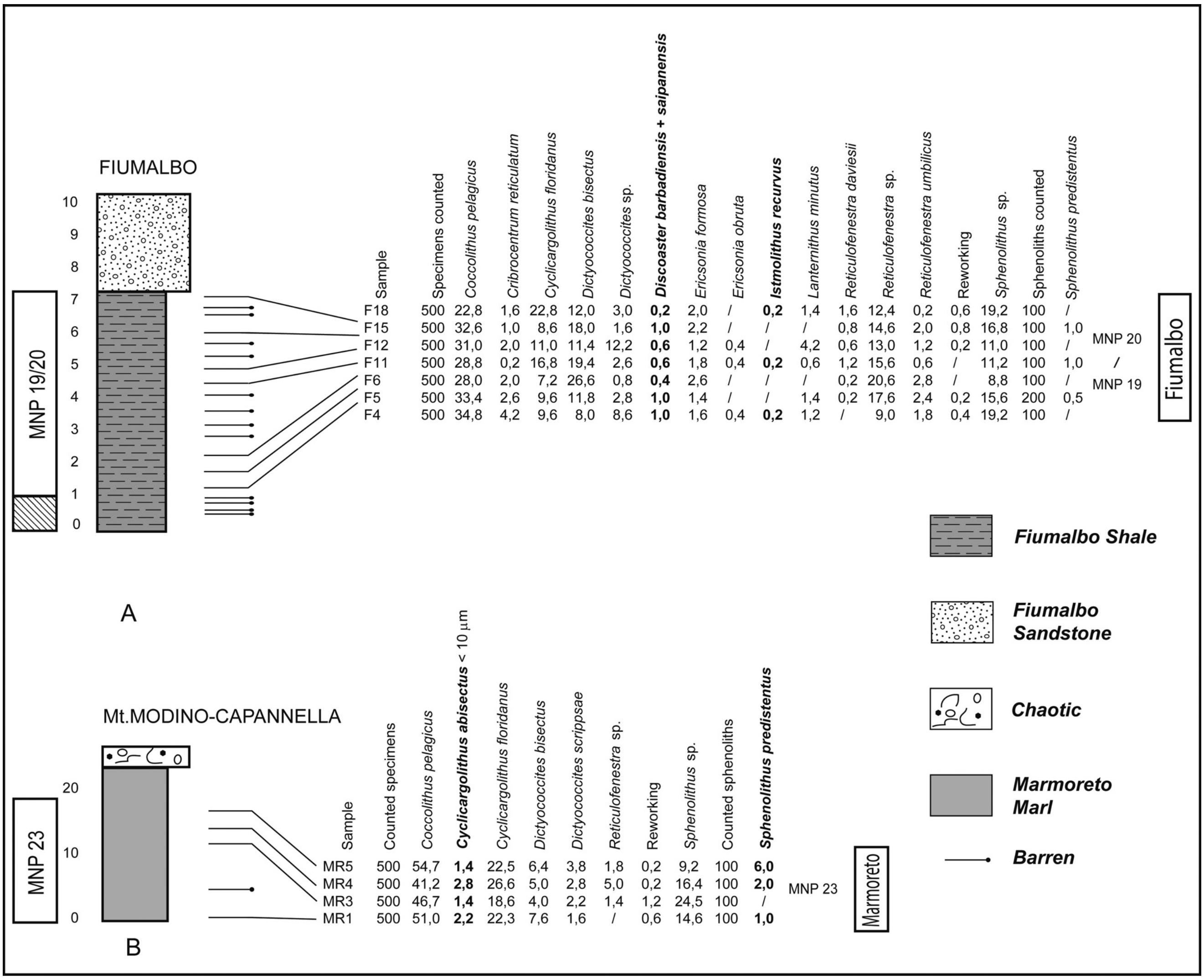


Fig. 5 - A) Fiumalbo section and B) Mt. Modino-Capannella section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.

rare specimens of C. *reticulatum* and *S. predistentus* (Fig. 4).

The biozones MNP19 and MNP20 are also combined. First, because the FO of *Sphenolithus pseudoradians* proposed as basal marker for the NP20 Zone is unreliable according to Perch-Nielsen (1985) and because the LO of *C. reticulatum*, proposed by Catanzariti (1993) to identify the MNP19/MNP20 Zone boundary, is also unreliable, as this species is very rare. The MNP19/20 combined Zone covers the interval from the FO of *I. recurvus* to the LO of *D. barbadiensis* and *D. saipanensis* (Figs. 4, 5, 8).

The MNP21 Zone spans the interval from the LOs of *D. barbadiensis* and *D. saipanensis* to the LCO (Last Common Occurrence) of *E. formosa,* which is defined by the abundance drop of this taxon below 1%. This biozone is therefore characterized by the presence of *E. formosa, R. umbilicus, D. bisectus*, *D. scrippsae* and *S. predistentus* (Fig. 4). *E. formosa* is considered reworked above this zone, due to its discontinuous occurrence and low abundance (<1%).

The MNP22 Zone is characterized by the scattered presence of *R. umbilicus* (Figs. 4, 8).

The LO of *R. umbilicus* is unreliable to identify the MNP23 Zone lower boundary, as this species is very rare and discontinuously present in its final range. Also unreliable is the FO of *H. recta* proposed by Catanzariti et al. (1997) to identify the MNP22/MNP23 Zone boundary, due to the rare and discontinuous presence of this taxon. We propose to recognize the MNP22/MNP23 Zone boundary using the FO of *C. abisectus* with specimens smaller than 10µm (Figs. 4, 8, 10A). The FO of *C. abisectus* is approximately concomitant with the FO of *H. recta* (Catanzariti 1993; de Kaenel & Villa 1996) and the LO of *R. umbilicus* (Wei 1991, 1992; Madile & Monechi 1991; Catanzariti 1993; de Kaenel & Villa 1996; Marino & Flores 2002). In the sampled sections, the MNP23 Zone is therefore characterized by the oc-

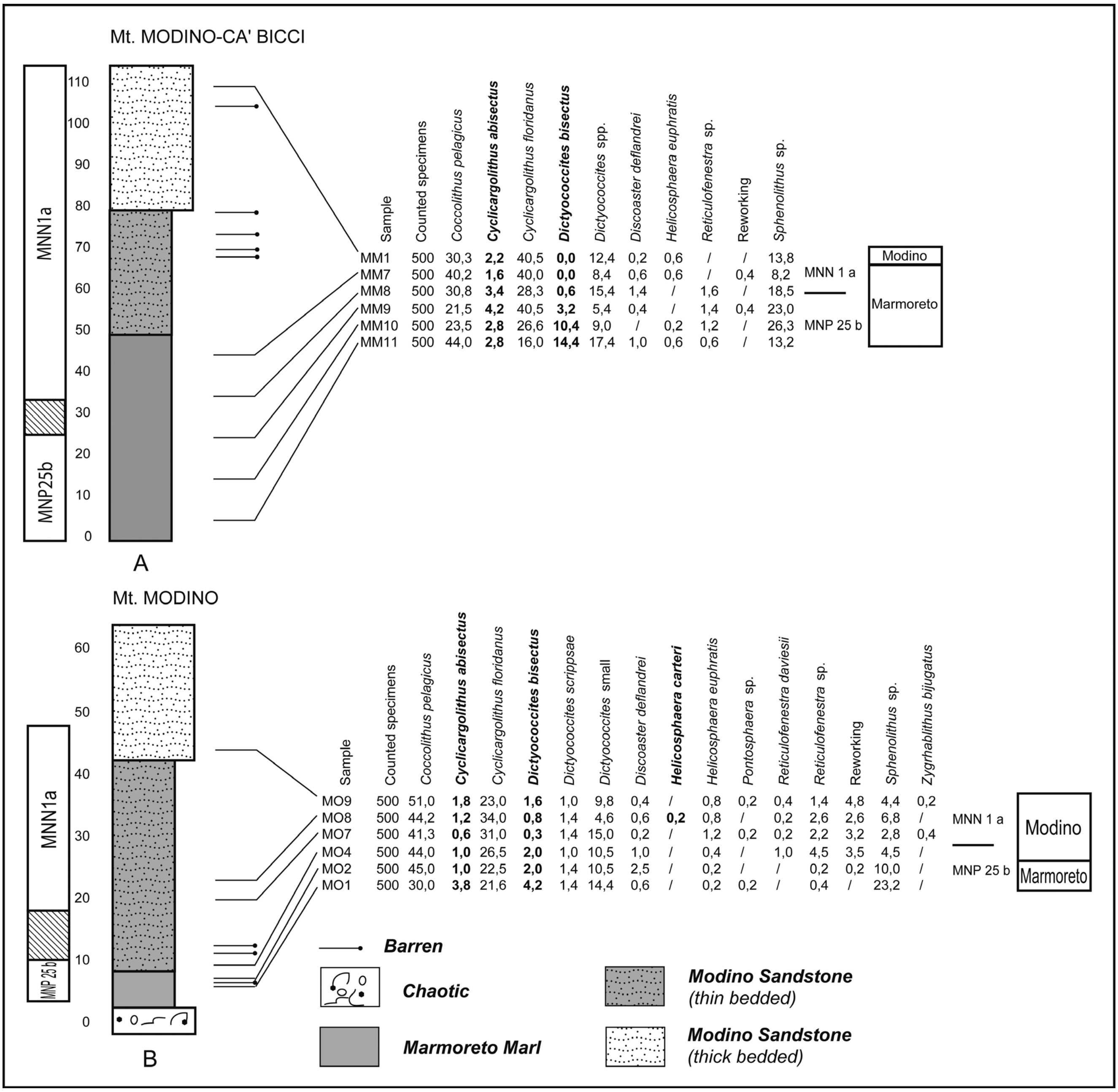


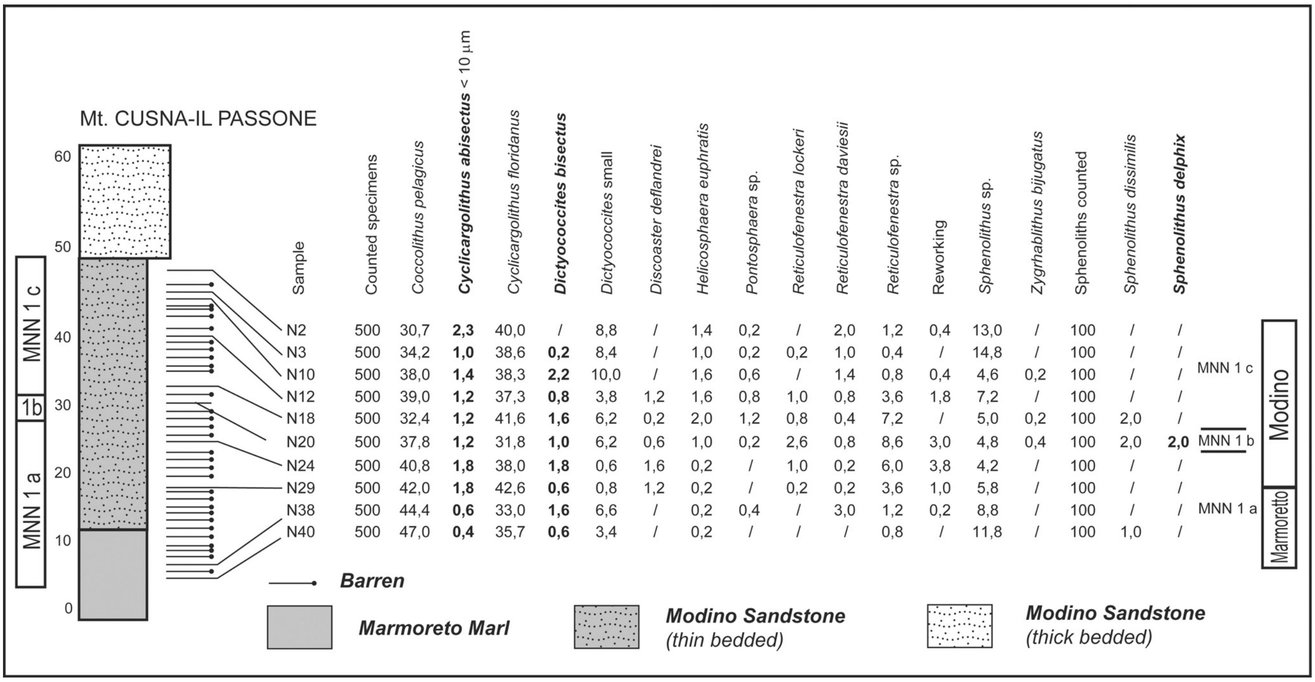
Fig. 6 - A) Mt. Modino-Ca' Bicci section and B) Mt. Modino section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.

currence of *C. abisectus* (< 10 μm), *S. predistentus* and rare specimens of *S. distentus* (Figs. 4, 5, 8, 10A, 11A).

The presence of *D. bisectus* and *C. abisectus* with specimens larger than 10 μm together with *S. distentus* and *S. ciperoensis* allows us to recognize the MNP24 Zone (Figs. 4, 10A-B).

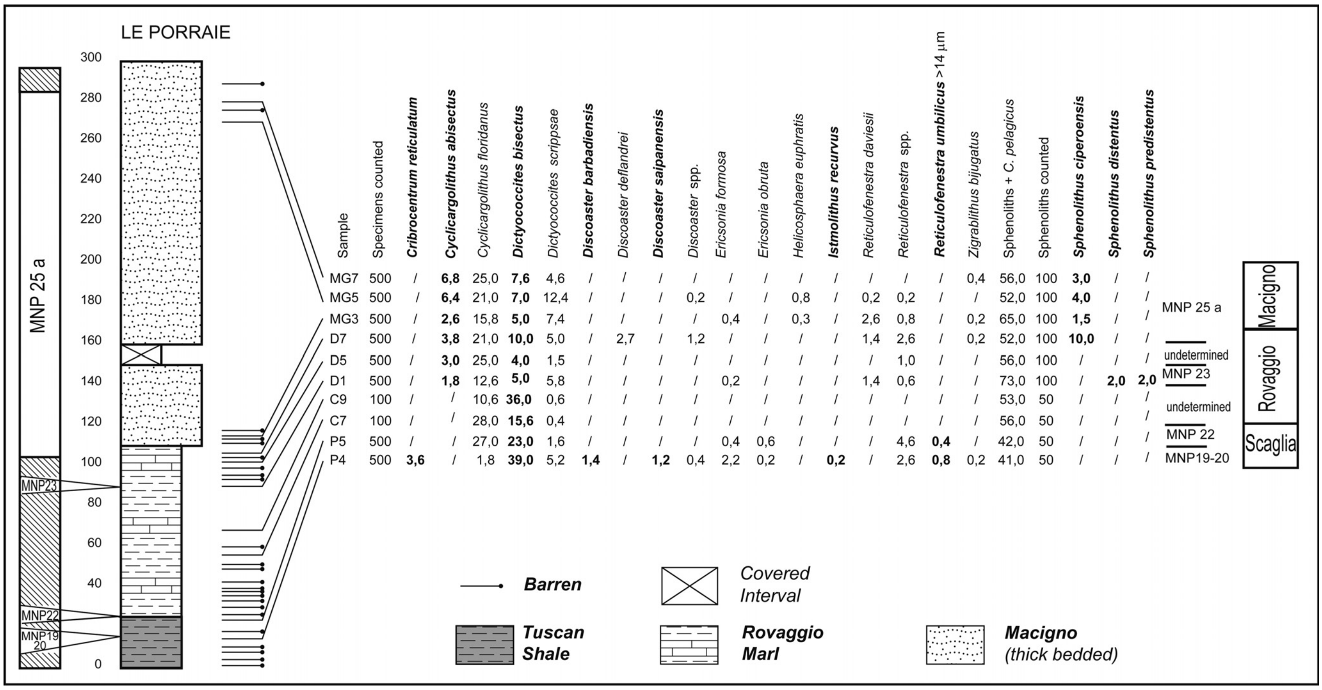
The MNP25a Subzone is characterized by the presence of *D. bisectus, C. abisectus* (> 10 μm) and *S. ciperoensis* (Figs. 4, 8, 10B). According to Fornaciari & Rio (1996), the presence of *D. bisectus* and *C. abisectus* (> 10 μm) allows us to recognize the MNP25b Subzone (Figs. 4, 6A-B, 10B, 11B-C, 12A), and the decrease in abundance of *D. bisectus* below 1% allow us to recognize the MNP25b/MNN1a Subzone boundary (Figs. 6A-B, 10B, 11C, 12A).

The interval from the MNN1a Subzone to the MNN1c Subzone is recognized by the continuous occurrence of *C. abisectus* (< 10 μm) along with scattered and rare specimens of *D. bisectus* and *D. scrippsae* (Figs. 7, 9A-B, 10B, 12B). Within the MNN1a Subzone rare specimens of *H. carteri* occur (Fig. 6B). The presence of *S. delphix* allows us to recognize the MNN1b Subzone (Figs. 7, 9B, 10B, 12B). The assemblages, characterized by the presence of *C. abisectus* (< 10 μm) and the common and continuous presence of small *Dictyococcites*, belong to the MNN1c Subzone (Figs. 7, 9B).



Sample	Counted specimens	*Coccolithus pelagicus*	***Cyclicargolithus abisectus*** < 10 µm	*Cyclicargolithus floridanus*	***Dictyococcites bisectus***	*Dictyococcites* small	*Discoaster deflandrei*	*Helicosphaera euphratis*	*Pontosphaera* sp.	*Reticulofenestra lockeri*	*Reticulofenestra daviesii*	*Reticulofenestra* sp.	Reworking	*Sphenolithus* sp.	*Zygrhablithus bijugatus*	Sphenoliths counted	*Sphenolithus dissimilis*	***Sphenolithus delphix***
N2	500	30,7	2,3	40,0	/	8,8	/	1,4	0,2	/	2,0	1,2	0,4	13,0	/	100	/	/
N3	500	34,2	1,0	38,6	0,2	8,4	/	1,0	0,2	0,2	1,0	0,4	/	14,8	/	100	/	/
N10	500	38,0	1,4	38,3	2,2	10,0	/	1,6	0,6	/	1,4	0,8	0,4	4,6	0,2	100	/	/
N12	500	39,0	1,2	37,3	0,8	3,8	1,2	1,6	0,8	1,0	0,8	3,6	1,8	7,2	/	100	/	/
N18	500	32,4	1,2	41,6	1,6	6,2	0,2	2,0	1,2	0,8	0,4	7,2	/	5,0	0,2	100	2,0	/
N20	500	37,8	1,2	31,8	1,0	6,2	0,6	1,0	0,2	2,6	0,8	8,6	3,0	4,8	0,4	100	2,0	2,0
N24	500	40,8	1,8	38,0	1,8	0,6	1,6	0,2	/	1,0	0,2	6,0	3,8	4,2	/	100	/	/
N29	500	42,0	1,8	42,6	0,6	0,8	1,2	0,2	/	0,2	0,2	3,6	1,0	5,8	/	100	/	/
N38	500	44,4	0,6	33,0	1,6	6,6	/	0,2	0,4	/	3,0	1,2	0,2	8,8	/	100	/	/
N40	500	47,0	0,4	35,7	0,6	3,4	/	0,2	/	/	/	0,8	/	11,8	/	100	1,0	/

Fig. 7 - Mt. Cusna-Il Passone section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.



Sample	Specimens counted	***Cribrocentrum reticulatum***	***Cyclicargolithus abisectus***	*Cyclicargolithus floridanus*	***Dictyococcites bisectus***	*Dictyococcites scrippsae*	***Discoaster barbadiensis***	*Discoaster deflandrei*	***Discoaster saipanensis***	*Discoaster* spp.	*Ericsonia formosa*	*Ericsonia obruta*	*Helicosphaera euphratis*	***Istmolithus recurvus***	*Reticulofenestra daviesii*	*Reticulofenestra* spp.	***Reticulofenestra umbilicus*** >14 µm	*Zigrablithus bijugatus*	Sphenoliths + *C. pelagicus*	Sphenoliths counted	***Sphenolithus ciperoensis***	***Sphenolithus distentus***	***Sphenolithus predistentus***
MG7	500	/	6,8	25,0	7,6	4,6	/	/	/	/	/	/	/	/	/	/	/	0,4	56,0	100	3,0	/	/
MG5	500	/	6,4	21,0	7,0	12,4	/	/	/	0,2	/	/	0,8	/	0,2	0,2	/	/	52,0	100	4,0	/	/
MG3	500	/	2,6	15,8	5,0	7,4	/	/	/	/	0,4	/	0,3	/	2,6	0,8	/	0,2	65,0	100	1,5	/	/
D7	500	/	3,8	21,0	10,0	5,0	/	2,7	/	1,2	/	/	/	/	1,4	2,6	/	0,2	52,0	100	10,0	/	/
D5	500	/	3,0	25,0	4,0	1,5	/	/	/	/	/	/	/	/	/	1,0	/	/	56,0	100	/	/	/
D1	500	/	1,8	12,6	5,0	5,8	/	/	/	/	0,2	/	/	/	1,4	0,6	/	/	73,0	100	/	2,0	2,0
C9	100	/	/	10,6	36,0	0,6	/	/	/	/	/	/	/	/	/	/	/	/	53,0	50	/	/	/
C7	100	/	/	28,0	15,6	0,4	/	/	/	/	/	/	/	/	/	/	/	/	56,0	50	/	/	/
P5	500	/	/	27,0	23,0	1,6	/	/	/	/	0,4	0,6	/	/	/	4,6	0,4	/	42,0	50	/	/	/
P4	500	3,6	/	1,8	39,0	5,2	1,4	/	1,2	0,4	2,2	0,2	/	0,2	/	2,6	0,8	0,2	41,0	50	/	/	/

Fig. 8 - Mt. Le Porraie section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.

Dating of the sampled successions

In the Mt. Le Porraie section (Fig. 8), the Tuscan Shale uppermost part contains assemblages assigned to the biozones MNP19/MNP20 and MNP22 (Priabonian-Rupelian), the Rovaggio Marl ranges from the MNP23 to the MNP25a (Rupelian-uppermost Chattian) and the Macigno furnishes assemblages referable to the MNP25a (uppermost Chattian). Assemblages belonging to the MNN1a (uppermost Chattian) in the Rio Re section (Fig. 9A) and spanning the interval from the MNN1a to the MNN1c (uppermost Chattian-lowermost Aquitanian) in the Val di Lima section (Fig. 9B) have been also recovered from the Macigno. In the Val

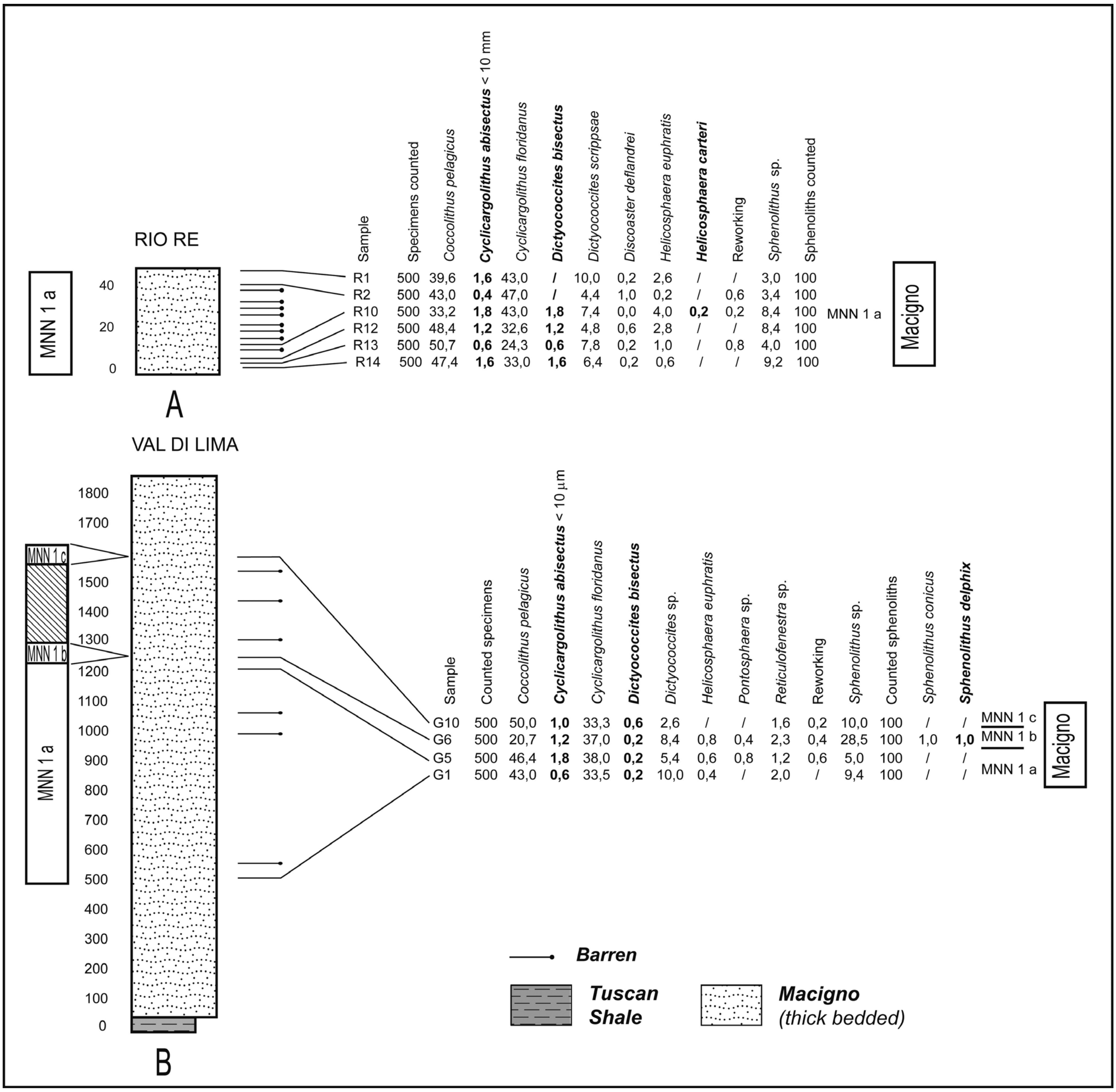
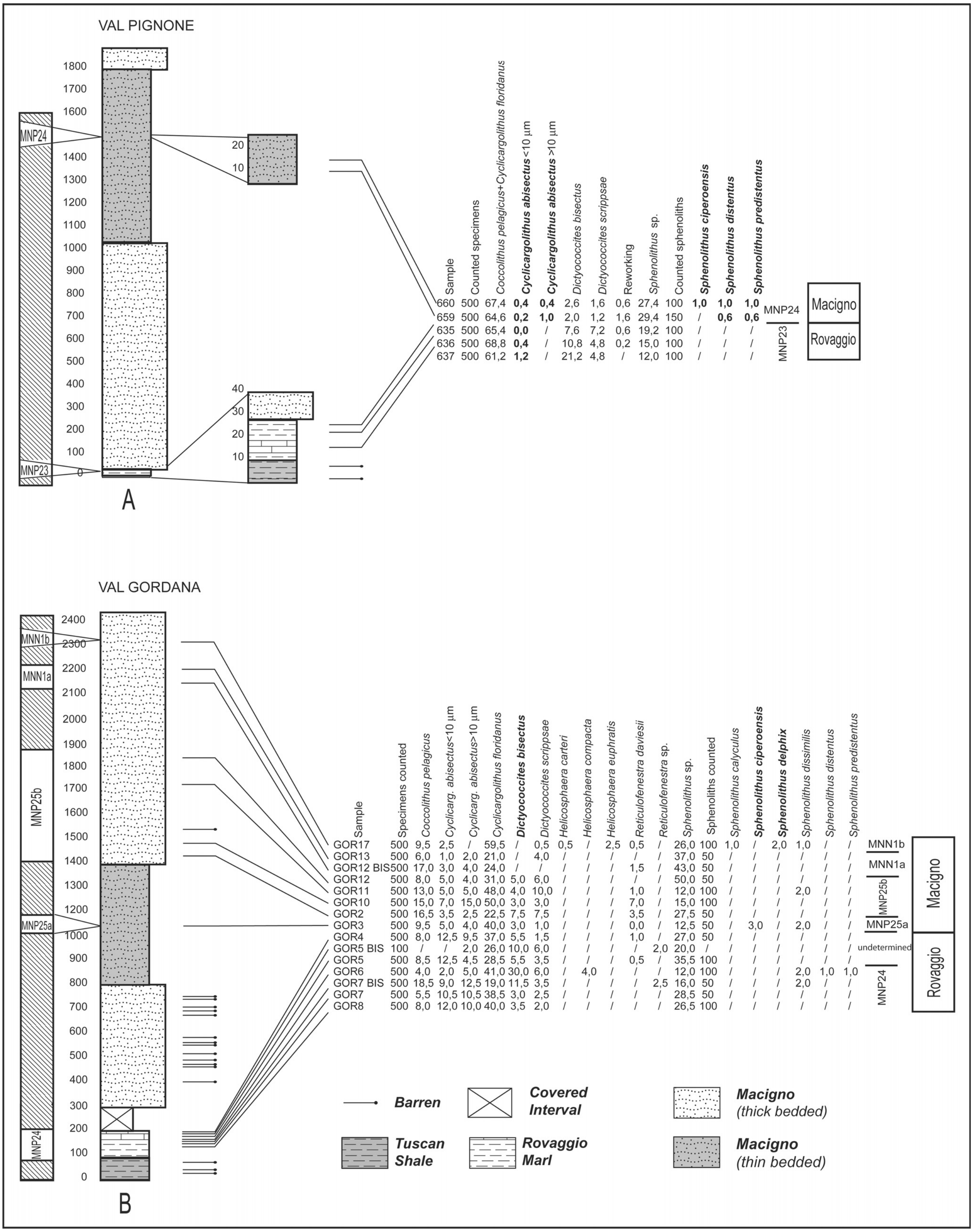


Fig. 9 - A) Rio Re section (Tuscan-Emilian Apennines) and B) Val di Lima section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and calcareous biozones recognized.

Gordana section (Fig. 10B), the assemblages from the Rovaggio Marl are referred to the MNP24 (Rupelian-Chattian) and those recovered from the Macigno range from the MNP25a to the MNN1b (uppermost Chattian-lowermost Aquitanian). Hence in the Tuscan-Emilian Apennines, the Tuscan Shale-Rovaggio Marl boundary should be placed between the MNP22 and the MNP23, the Rovaggio Marl-Macigno boundary lies within the MNP25a, and the Macigno spans the interval from the MNP25a to the MNN1c (Fig. 13A).

Though in the La Spezia and Carrara areas the investigated sedimentary record is fragmented and the outcrops scattered, the selected sections are helpful. The assemblages recovered from the Rovaggio Marl in the Val Pignone (Fig. 10A) and Maestà di Castelpoggio (Fig. 11A) sections are referable to the MNP23 (Rupelian). The assemblages from the Macigno allow us to recognize the MNP24 (Rupelian-Chattian) in the Val Pignone (Fig. 10A), the MNP25b (uppermost Chattian) in the Percorso Salute (Fig. 11B), Vallecchia (Fig. 11C) and Mt. Olivero (Fig. 12A) sections, and the MNN1a (uppermost Chattian) in the topmost part of these latter two sections. The MNN1a has been also recognized in the Ponteccio Marl exposed in the Mt. Olivero and Rizieri sections (Fig. 12A-B). In this last section, the Ponteccio Marl reaches the MNN1b (lowermost Aqui-



Sample	Counted specimens	*Coccolithus pelagicus+Cyclicargolithus floridanus*	***Cyclicargolithus abisectus*<10 µm**	***Cyclicargolithus abisectus* >10 µm**	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	Reworking	*Sphenolithus* sp.	Counted sphenoliths	***Sphenolithus ciperoensis***	***Sphenolithus distentus***	***Sphenolithus predistentus***		
660	500	67,4	**0,4**	**0,4**	2,6	1,6	0,6	27,4	100	**1,0**	**1,0**	**1,0**	MNP24	Macigno
659	500	64,6	**0,2**	**1,0**	2,0	1,2	1,6	29,4	150	/	**0,6**	**0,6**		
635	500	65,4	**0,0**	/	7,6	7,2	0,6	19,2	100	/	/	/	MNP23	Rovaggio
636	500	68,8	**0,4**	/	10,8	4,8	0,2	15,0	100	/	/	/		
637	500	61,2	**1,2**	/	21,2	4,8	/	12,0	100	/	/	/		

Sample	Specimens counted	*Coccolithus pelagicus*	*Cyclicarg. abisectus*<10 µm	*Cyclicarg. abisectus*>10 µm	*Cyclicargolithus floridanus*	***Dictyococcites bisectus***	*Dictyococcites scrippsae*	*Helicosphaera carteri*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Reticulofenestra daviesii*	*Reticulofenestra* sp.	*Sphenolithus* sp.	Sphenoliths counted	*Sphenolithus calyculus*	***Sphenolithus ciperoensis***	***Sphenolithus delphix***	*Sphenolithus dissimilis*	*Sphenolithus distentus*	*Sphenolithus predistentus*		
GOR17	500	9,5	2,5	/	59,5	/	0,5	0,5	/	2,5	0,5	/	26,0	100	1,0	/	2,0	1,0	/	/	MNN1b	Macigno
GOR13	500	6,0	1,0	2,0	21,0	/	4,0	/	/	/	/	/	37,0	50	/	/	/	/	/	/	MNN1a	
GOR12 BIS	500	17,0	3,0	4,0	24,0	/	/	/	/	/	1,5	/	43,0	50	/	/	/	/	/	/		
GOR12	500	8,0	5,0	4,0	31,0	5,0	6,0	/	/	/	/	/	50,0	50	/	/	/	/	/	/	MNP25b	
GOR11	500	13,0	5,0	5,0	48,0	4,0	10,0	/	/	/	1,0	/	12,0	100	/	/	/	2,0	/	/		
GOR10	500	15,0	7,0	15,0	50,0	3,0	3,0	/	/	/	7,0	/	15,0	100	/	/	/	/	/	/		
GOR2	500	16,5	3,5	2,5	22,5	7,5	7,5	/	/	/	3,5	/	27,5	50	/	/	/	/	/	/		
GOR3	500	9,5	5,0	4,0	40,0	3,0	1,0	/	/	/	0,0	/	12,5	50	/	3,0	/	2,0	/	/	MNP25a	
GOR4	500	8,0	12,5	9,5	37,0	5,5	1,5	/	/	/	1,0	/	27,0	50	/	/	/	/	/	/		Rovaggio
GOR5 BIS	100	/	/	2,0	26,0	10,0	6,0	/	/	/	/	2,0	20,0	/	/	/	/	/	/	/	undetermined	
GOR5	500	8,5	12,5	4,5	28,5	5,5	3,5	/	/	/	0,5	/	35,5	100	/	/	/	/	/	/		
GOR6	500	4,0	2,0	5,0	41,0	30,0	6,0	/	4,0	/	/	/	12,0	100	/	/	/	2,0	1,0	1,0	MNP24	
GOR7 BIS	500	18,5	9,0	12,5	19,0	11,5	3,5	/	/	/	/	2,5	16,0	50	/	/	/	2,0	/	/		
GOR7	500	5,5	10,5	10,5	38,5	3,0	2,5	/	/	/	/	/	28,5	50	/	/	/	/	/	/		
GOR8	500	8,0	12,0	10,0	40,0	3,5	2,0	/	/	/	/	/	26,5	100	/	/	/	/	/	/		

Fig. 10 - A) Val Pignone section (La Spezia area); B) Val Gordana section (Tuscan-Emilian Apennines). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.

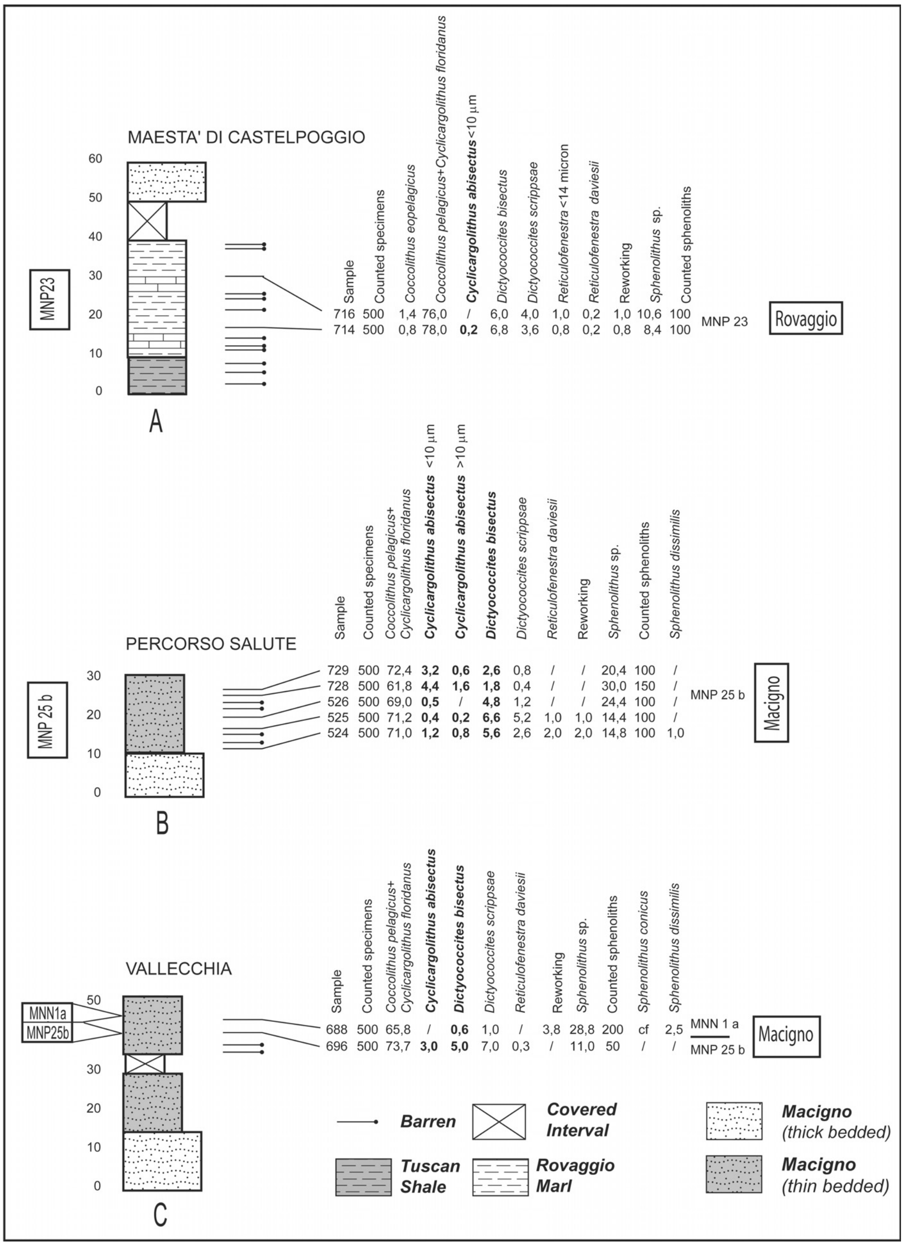


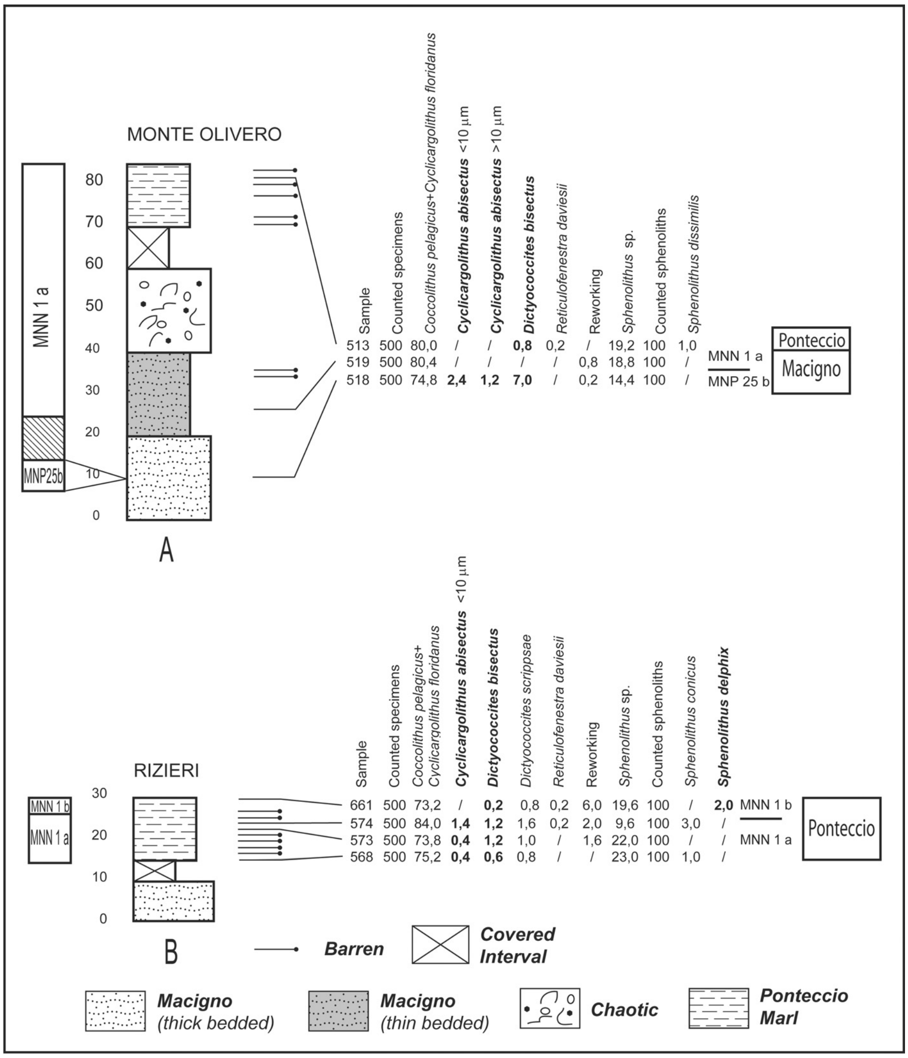
Fig. 11 - A) Maestà di Castelpoggio section, B) Percorso Salute section and C) Vallecchia section (Carrara area). Lithostratigraphy, abundance patterns of calcareous nannofossil species and calcareous nannofossil biostratigraphy.

tanian). Consequently, in the La Spezia and Carrara areas the Rovaggio Marl is referable to the MNP23, the Macigno uppermost part ranges from the MNP25b to the MNN1a and the Ponteccio Marl from the MNN1a to the MNN1b (Fig. 13B).

In the Mt. Cisa area (Fig. 4), the Fiumalbo Shale spans the interval from the MNP15 to the MNP23 (Lutetian-Rupelian) and the Marmoreto Marl ranges from the MNP23 to the MNP25b (Rupelian-upper Chattian). This last subzone has also been recognized in the overlying Mt. Modino Sandstone. In the Mt. Modino-Fiumalbo area, the combined biozone MNP19/MNP20 (Priabonian) has been recognized in the Fiumalbo Shale (Fig. 5A) and the MNP23, MNP25b and MNN1a (Rupelian-Chattian) in the Marmoreto Marl (Figs. 5B, 6A). The assemblages belonging to the MNN1a have been recovered from the overlying Mt. Modino Sandstone (Figs. 6A-B). In the Mt. Cusna-Il Passone section (Fig. 7), the Marmoreto Marl-Mt. Modino Sandstone boundary lies in the MNN1a (uppermost Chattian) and the Mt. Modino Sandstone reaches the MNN1c (lowermost Aquitanian). Therefore, the Fiumalbo Shale-Marmoreto Marl boundary lies within the MNP23 and the Marmoreto Marl-Mt. Modino Sandstone boundary lies within the MNP25b in the Mt. Cisa area and the MNN1a in the Mt. Modino area (Fig. 14A).

Summarizing, the achieved results allow us to refine the dating of two distinctive and continuous lithostratigraphic records: the Tuscan Shale-Macigno and the Fiumalbo Shale-Marmoreto Marl-Mt. Modino Sandstone spanning the upper Eocene-lower Miocene (MNP19/MNP20-MNN1c) and the middle Eocene-

Fig. 12 - A) Mt. Olivero section; B) Rizieri section (Carrara area). Lithostratigraphy, abundance patterns of calcareous nannofossil species and biozones recognized.



lower Miocene (MNP15-MNN1c), respectively. The superposition of the Priabonian-uppermost Chattian succession of the Mt. Modino Unit (Figs. 5, 6) onto the Chattian-lowermost Aquitanian Macigno of the Val di Lima (Fig. 9A-B) is well exposed in the Val di Lima-Abetone-Mt. Modino area. Furthermore, the inception and the end of the Macigno sedimentation seem to be younger in the La Spezia and Carrara areas than in the Tuscan Emilian Apennines (Fig. 13A-B). The inception and the end of the Mt. Modino Sandstone sedimentation are also younger at Mt. Cisa than at Mt. Cusna and Mt. Modino areas (Fig. 14A).

Comparison between previous findings and our results

Dating of the Mt. Modino Unit can be found only in Plesi et al. (1998, 2000). Based on a discontinuous sampling in the Pracchiola-Mt. Orsaro area (Fig. 14B), the Fiumalbo Shale and the Marmoreto Marl range from the MNP20 to the MNP25b (Plesi et al. 1998). Though not supported by range charts, the Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone of Mt. Cisa area span the interval from the MNP17 to the MNN1d (Plesi et al. 2000). Hence, with respect to previous findings, for the first time, our paper has refined the age of these formations and of their stratigraphic boundaries.

More data are available for the uppermost part of the Tuscan Shale and the Macigno though they are based on scattered samplings and discontinuous biostratigraphic signals (Fig. 15). In the La Spezia and Pontremoli areas, Costa et al. (1992) recognized the MNP25b in the Rovaggio Marl and assemblages referable to the MNP25b and MNN1c/d from the Macigno (Fig. 15A). Consequently, the age of the Rovaggio Marl topmost part, inferred by Costa et al. (1992), is younger than the age assigned to the Rovaggio-Macigno boundary and to the lowermost part of the Macigno in the Tuscan-Emilian Apennines and in the La Spezia area (Fig. 13A-B). The age assigned by Costa et al. (1992) to the uppermost part of the Macigno is also younger than the

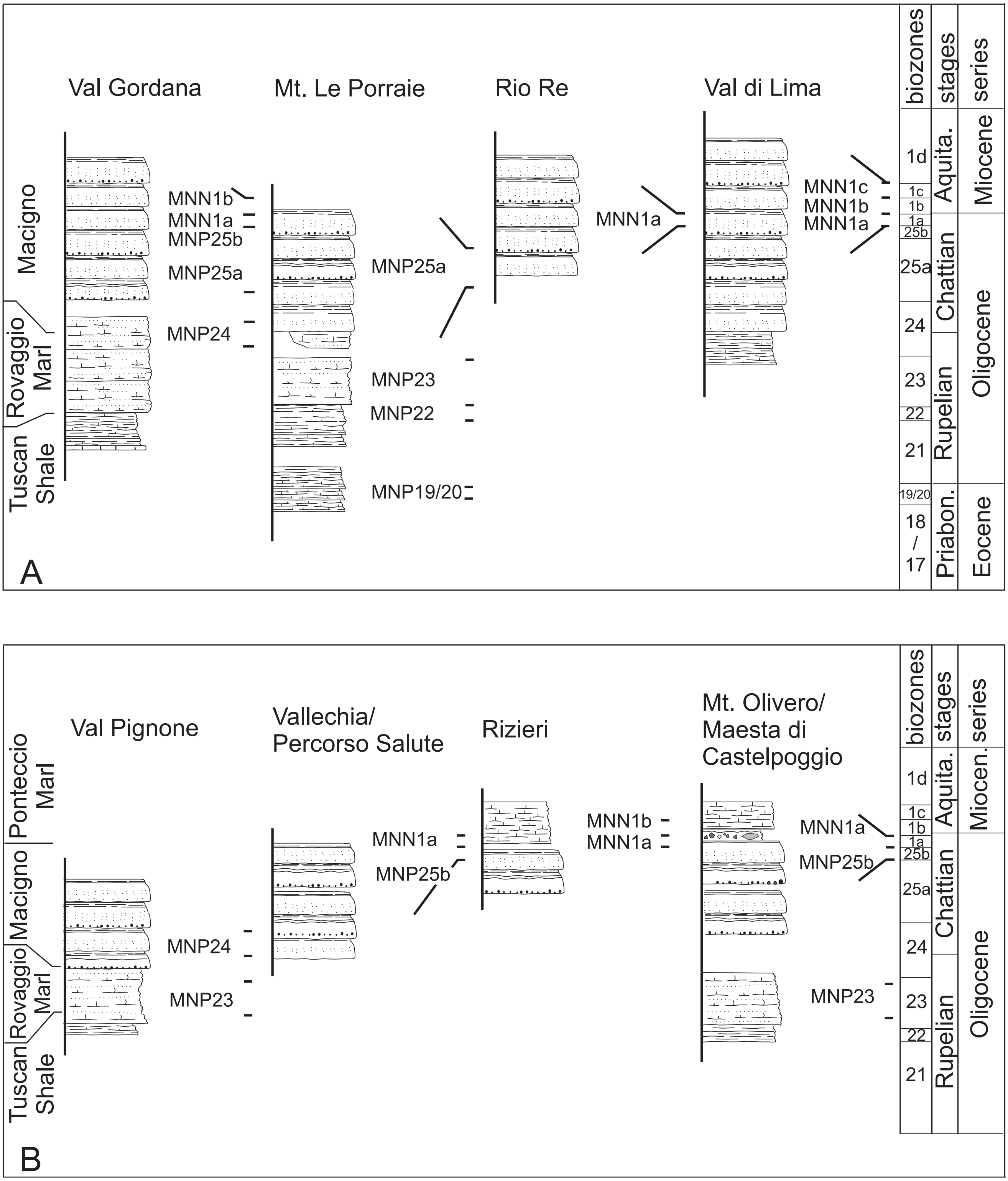


Fig. 13 - Ages and calcareous nannofossil biostratigraphy of the uppermost Tuscan Nappe in: A) Tuscan-Emilian Apennines (Val Gordana, Mt. Le Porraie, Rio Re, Val di Lima) and B) the areas of La Spezia (Val Pignone) and Carrara (Vallechia, Percorso salute, Rizieri, Maesta di Castelpoggio and Mt. Olivero). Priabon. = Priabonian; Aquita. = Aquitanian; Miocen. = Miocene.

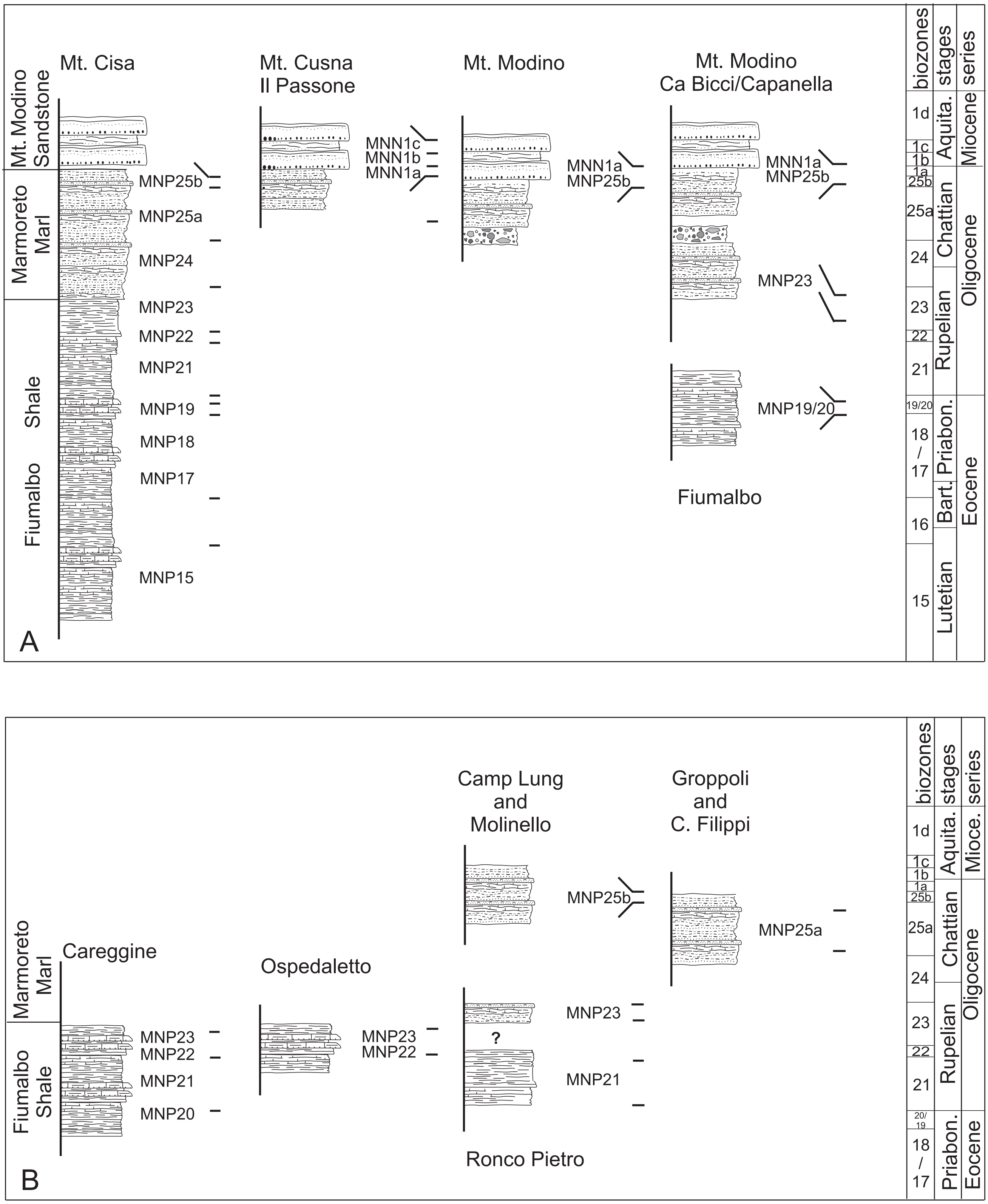


Fig. 14 - Ages and calcareous nannofossil biostratigraphy of the Mt. Modino Unit in: A) Mt. Cisa, Mt. Cusna-Il Passone, Mt. Modino and Fiumalbo areas (this paper) and B) Pracchiola-Mt Orsaro area according to Plesi et al. (1998). Bart. = Bartonian; Priabon. = Priabonian; Aquita. = Aquitanian; Miocen. = Miocene.

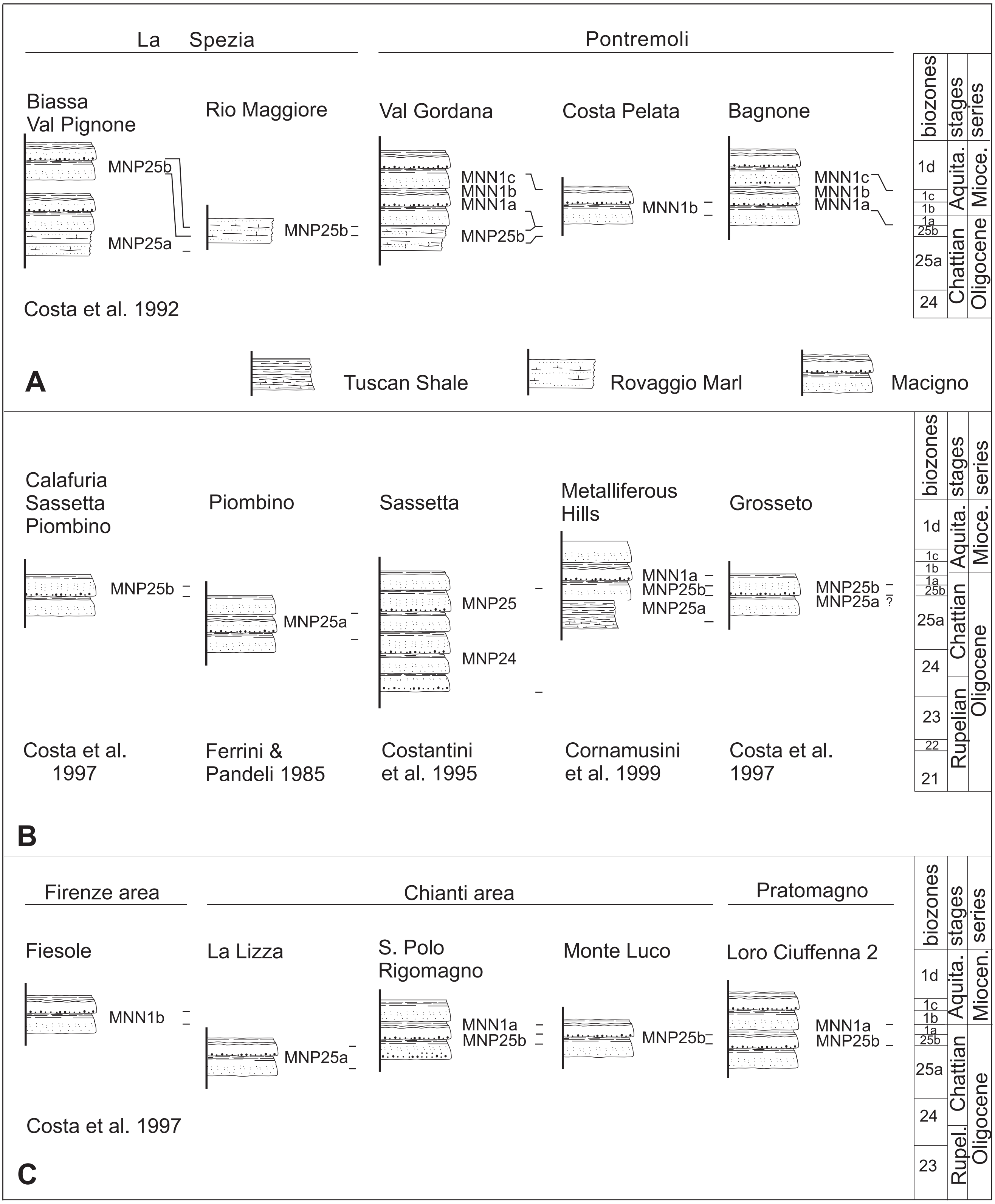


Fig. 15 - Ages and calcareous nannofossil biostratigraphy of the Macigno in: A) La Spezia and Pontremoli areas; B) Tuscan Tyrrhenian border between Livorno and Grosseto; C) Firenze, Chianti and Pratomagno areas. Rupel. = Rupelian; Aquita. = Aquitanian; Miocen. = Miocene.

age of the topmost part of the Macigno sampled in the Carrara area and in the Tuscan-Emilian Apennines (Fig. 13A-B).

In Cornamusini et al. (1999), the topmost part of the Nummulitico auctt. (belonging to the Tuscan Shale) and the overlying Macigno spans the interval from the MNP25a to the MNN1a, and the Macigno sampled by Costantini et al. (1993), Ferrini & Pandeli (1985) and Costa et al. (1997) ranges from the MNP24 to the MNP25b (Fig. 15B). Therefore, though based on few fossiliferous samples, also in the Metalliferous Hills the onset of the Macigno lies within the MNP25a, and the datings of the Macigno exposed along the Tyrrhenian coast are consistent with our data. From the Macigno cropping out from Firenze to Pratomagno, Costa et al. (1997) recovered scattered assemblages referable to the MNP25a, MNP25b, MNN1a and MNN1b (Fig. 15C). Hence also in this sector of the Northern Apennines, the Macigno spans the interval from the MNP25a to the MNN1b as noticed in the Tuscan-Emilian Apennines (Fig. 13A).

In summary, though some discrepancies still survive between our data and the previous findings, the uppermost part of the Tuscan Shale and the overlying Macigno are upper Priabonian-lowermost Aquitanian in age, whilst the stratigraphic succession including the Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone span the Lutetian-lowermost Aquitanian.

Conclusions

To highlight the relationship between the Macigno and the Mt. Modino Sandstone, which represents a cornerstone to unraveling the tectono-sedimentary evolution of a key sector of the Northern Apennines, in this paper we: 1) reconstructed the distribution patterns of calcareous nannofossil taxa recovered from the slope and foredeep deposits; 2) discussed the markers and assemblages helpful to recognize the biozones spanning in age from the middle Eocene to the early Miocene and 3) dated the boundaries between the selected units. The achieved results allow us to recognize two continuous assemblage successions useful to date two different sedimentary successions. The Tuscan Shale (including the Rovaggio Marl) and the Macigno (including the Ponteccio Marl) span the upper Eocene-lowermost Miocene (MNP19/MNP20-MNN1c). The Fiumalbo Shale, the Marmoreto Marl and the Mt. Modino Sandstone encompass the middle Eocene-lowermost Miocene (MNP15-MNN1c). Consequently these two successions sedimented in two distinct basins, and later the Mt. Modino Unit thrusted onto the Macigno of the Tuscan Nappe. In summary, this paper evidences the power of the calcareous nannofossil biostratigraphy to prove the tectonic relations between the Macigno and the Mt. Modino Sandstone and to constrain, between the latest Oligocene-earliest Miocene, the diachronous evolution of the Northern Apennine foredeep. The progressive NE-overthrusting of the Ligurian and Subligurian units deactivated the siliciclastic turbiditic sedimentation of the Macigno and the Mt. Modino Sandstone during the early Miocene.

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