CHRONOSTRATIGRAPHIC FRAMEWORK OF THE EXTERNAL LIGURIAN UNITS (LATE CRETACEOUS, NORTHERN APENNINES, ITALY) BASED ON CALCAREOUS NANNOFOSSILS

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ABSTRACT

The study of calcareous nannofossil assemblages recovered from the External Ligurian Units allows us (1) to reconstruct the distribution patterns of selected Late Cretaceous taxa, (2) to identify the biohorizons helpful in recognizing and characterizing the standard zones of Sissingh (1977), some of which have been grouped, and (3) to propose a synthesis of the ages achieved until now for the External Ligurian Units. According to the available dataset, rooted on published and unpublished data, the here proposed biostratigraphic scheme is based on 24 age-indicative taxa and 16 first occurrences, and its biostratigraphic resolution is comparable with the resolution of the scheme of Sissingh (1977), only considering FOs. Calcareous nannofossils are hence a fossil group useful to furnish a new and more complete chronostratigraphic framework of the main External Ligurian Units, helpful to better constrain the tectono-sedimentary and the geodynamic evolution of the Western Tethys Domain.

INTRODUCTION

In the last decades the study of calcareous nannofossils has allowed the data improvement of the Meso-Cenozoic successions of the Northern Apennines. This fossil group is very useful for biostratigraphy, because calcareous nannofossils are present in a wide spectrum of lithologies containing small amounts of calcium carbonate (e.g. hemipelagic calcareous clays, turbiditic silty marls), and in a wide range of environments (from platform to deep sea basin, also below the CCD). Therefore, in the last decades, calcareous nannofossils have been a key fossil group for dating and refining previous ages of the Ligurian lithostratigraphic units, and calcareous nannofossil biostratigraphy has allowed constraints to the tectono-sedimentary evolution of the Ligurian Domain. The first attempt to correlate the successions belonging to the Ligurian Units using calcareous nannofossils was done by Marroni et al. (1992). These authors dated the beginning of the Cretaceous "flysch sedimentation" in the Northern Apennines and provided some age constraints on the orogenesis-controlled sedimentation. The following is a list of the papers based on calcareous nannofossils recovered from successions belonging to the Ligurian Units that have been published to date: the lithostratigraphic units (e.g. Rio and Villa, 1983; Manivit and Proud'Homme, 1990; Ghiselli et al., 1991; Villa, 1992); the inception of the turbiditic sedimentation into the Ligurian Domain (e.g. Marroni and Perilli, 1990a; 1990b; 1992; Vescovi et al., 1999; Catanzariti et al., 2007); the onset of the Helminthoid Flysch sedimentation (e.g. Rio et al., 1983; Marino and Monechi, 1994; Perilli, 1995; Catanzariti and Perilli, 2006). Aims of this work are: (1) to reconstruct the distribution patterns of the common and age indicative calcareous nannofossil taxa recovered from the Late Cretaceous successions belonging to the External Ligurian Units, (2) to identify the nannobiohorizons useful in recognizing and characterizing the standard biozones, and (3) to propose a synthesis of the ages achieved until now for the External Ligurian successions. Our dataset is based on literature and unpublished analytical data that include all the results achieved by the authors of this paper during the realization of several sheets of the Geological Map of Italy at 1:50,000 scale (CARG Project), which cover a wide area of the Northern Apennines, extending between Bobbio and Pistoia.

GEOLOGICAL SETTING OF EXTERNAL LIGURIAN UNITS

The Northern Apennines thrust-fold belt developed during the Oligo-Miocene deformation of several units (Fig. 1) derived from oceanic and continental domains. This orogenic belt is characterized by the superposition of the Subligurian Units onto the Tuscan Nappe and the Umbria-Marche Units, in turn overthrust by the Ligurian Units. The thrust-top basin deposits of the Tertiary Piedmontese and Epiligurian Units seal the Northern Apennines nappe pile. The Ligurian Units include the Internal Ligurian Units (Marroni and Pandolfi, 2007; Meneghini et al., 2007, cum bibl.) and the External Ligurian Units (Elter et al., 1966; Elter, 1975; Marroni et al., 2001 *cum bibl*.). The External Ligurian Units (hereafter External Ligurids) may be divided into *western* and *eastern successions* (Fig. 2), on the basis of the lithostratigraphic features of their basal complexes, which are overlaid by the very thick, marly calcareous deposits of the Helminthoid Flysch *Auctt*. (Marroni et al., 2001). The basal complexes of the *western successions* are characterized by Campanian ophiolitic-rich mélanges (Casanova Complex), consisting of coarse grained, mass-gravity deposits and sandstones (Casanova Sandstone). These basal complexes show a clear transition to the Campanian-Maastrichtian turbiditic and hemipelagic deposits of the Ottone and Caio Flysch (Puccinelli et al., in press a; in press b). Ophiolitic-bearing mass-gravity deposits (e.g. Mt. Veri Complex) are also intercalated within the lower portion of the Ottone and Caio Flysch (Catanzariti and

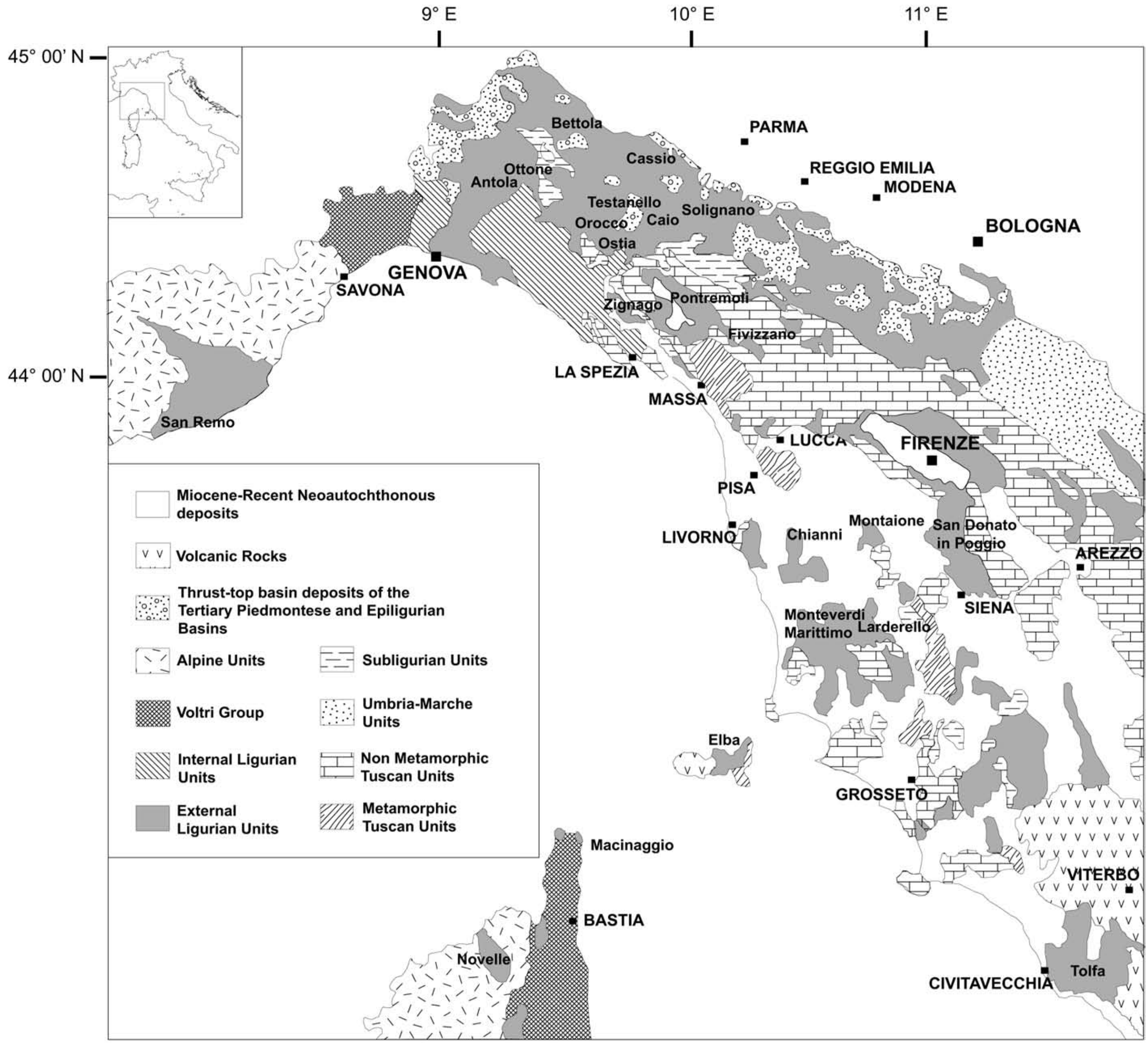

Fig. 1 - Outcropping areas (dark grey) of the External Ligurian Units in the Northern Apennines, Southern Tuscany, Elba Island, Corsica and Ligurian Alps.

Perilli, 2006). The lithostratigraphic features of the *western successions* (cfr. internal units of Daniele and Plesi, 2000) suggest a paleogeographic setting close to the transition area between the Ligure-Piedmontese Ocean and the Adria continental margin (Marroni et al., 2001; Marroni and Pandolfi, 2007; Bracciali et al., 2007). The basal complexes of the *eastern successions* consist of Cenomanian-Campanian monotonous carbonate-free shaly successions (i.e. Montoggio Shale and Cassio Varicoloured Shale), with intercalations of siliciclastic turbidites (i.e. Case Baruzzo Sandstons, Scabiazza Sandstone, Ostia Sandstone and Gorreto Sandstone), and coarse or very coarse grained clastic deposits (i.e. basal complex and Salti del Diavolo Conglomerates). The overlying marly calcareous turbiditic and hemipelagic deposits are the Campanian-Paleocene Antola and Cassio Flysch. The stratigraphic transition between the basal complex and the Antola Flysch is locally exposed (Catanzariti et al., 2007). Also the contact between the Cassio Flysch and its basal complex is considered stratigraphic though, up to now, it is not yet supported by biostratigraphic data. The lithostratigraphic features of the *eastern successions* (cfr. external units of Daniele and Plesi, 2000) are indicative of basins located at the distal edge of the Adria continental margin (Marroni et al., 2001). The Late Cretaceous-Paleocene Helminthoid Flysches *Auctt*. also crop out in the Ligurian Alps, Corsica, and Southern Tuscany. They are represented by the San Remo Flysch (Manivit and Proud'Homme, 1990), the Corsica Flysch, i.e. the Macinaggio Flysch or the Calcareous Flysch of Balagne (Marino et al., 1995), the Elba Flysch (Voisenet et al., 1983, cfr. Marina di Campo Formation, Bortolotti et al., 2001) and the Helminthoid Flysch (hereafter HF) cropping out in Southern Tuscany; which includes the Chianni HF, the Montaione HF, the St. Donato in Poggio HF, the Monteverdi Marittimo HF and the Larderello HF (Marino and Monechi, 1994).

PREVIOUS CRETACEOUS BIOSTRATIGRAPHIC SCHEMES

The first to propose a Cretaceous biozonation was Stradner (1963), but the first useful schemes were those of Thierstein (1976), which was based on a worldwide dataset, using both land sections and DSDP sites, and of Martini (1976), which was based on calcareous nannofossil markers from some Central Pacific Ocean sites. These schemes were immediately superseded by the more detailed biozonations of Sissingh (1977) and Roth (1978) which have become the most used schemes until now. Sissingh (1977) proposed a scheme based on 26 biozones using data from low paleolatitude land sections of Western Europe and Tunisia, including stage-stratotypes and subsurface data from North Sea wells. In his scheme, 11 zones were defined for the first time, 10 were amended from previous authors (Bukry and Bramlette, 1969; Cepeck and Hay, 1969; 1970; Thierstein, 1971; 1973; Martini, 1976; Manivit et al., 1977) and 2 zones were previously defined by Thierstein (1971) and Cepeck and Hay (1969). Based on material recovered in DSDP sites, Roth (1978) distinguished 23 biozones, and pointed out the potential of nannofossil biostratigraphy to correlate onshore and oceanic successions. Verbeek (1976a and b; 1977) in turn proposed a biostratigraphic scheme for Tunisia and Europe (Spain and France). In the following years, Perch-Nielsen (1979; 1983; 1985), slightly modified the scheme of Sissingh (1977), proposing a cosmopolitan calcareous nannofossil scheme and a succession of biohorizons helpful to date Cretaceous sedimentary successions. Bralower et al. (1995) produced a combined scheme for the entire Late Cretaceous, and Burnett (1998) proposed zones and subzones referable to different palaeobiogeographic nannofloral provinces, established on well-known and new events. These authors propose overviews and/or correlations with the main previous schemes.

MATERIAL AND METHODS

This paper is based on published and unpublished analytical data coming from the External Ligurids. The published data derive from papers spanning a long time interval: Iaccarino and Rio (1972); Rio et al. (1983); Rio and Villa (1983; 1987); Marroni and Perilli (1989; 1990a and b; 1992); Manivit and Proud'Homme (1990); Ghiselli et al. (1991);

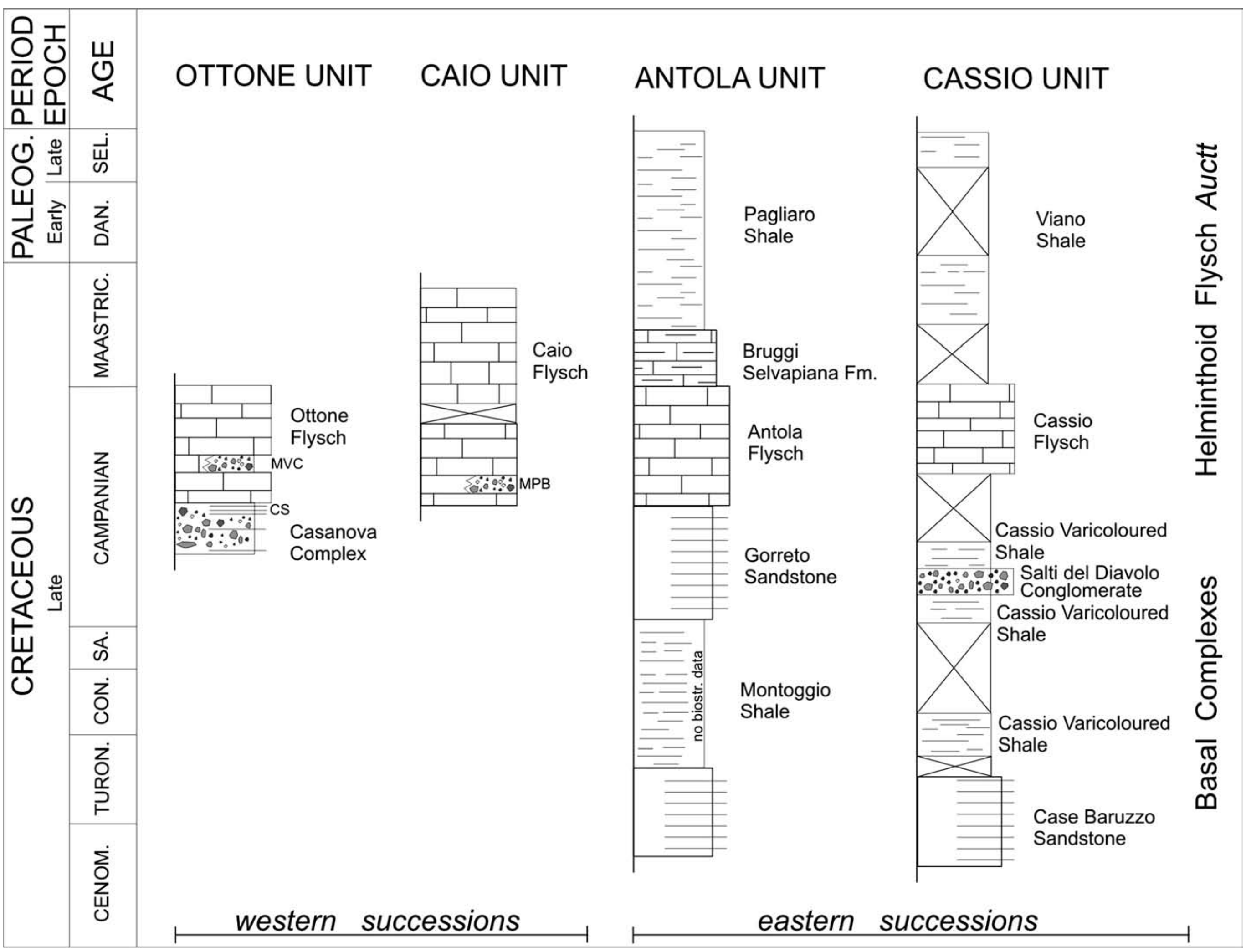

Fig. 2 - Lithostratigraphy of the main External Ligurids: Ottone Unit (Catanzariti and Perilli, 2006), Caio Unit (Puccinelli et al., in press a and b), Antola Unit (Catanzariti et al. 2007; Elter et al., in press) and Cassio Unit (Iaccarino and Rio, 1972; Rio and Villa, 1987; Vescovi et al., 1999). CS = Casanova Sandstones; MVC = Mt. Veri Complex; MPB = Mt. Palerà Breccias; PALEOG. = Paleogene; CENOM. = Cenomanian; TURON. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTRIC. = Maastrichtian; DAN. = Danian; SEL. = Selandian.

Villa (1991); Marroni et al. (1992); Cerrina Feroni et al. (1994); Cobianchi et al. (1994); Marino and Monechi (1994); Perilli (1995); Vescovi et al. (1999); Plesi et al. (2000); Catanzariti and Perilli (2006); Catanzariti et al. (2007). The unpublished results have been achieved by the authors of this paper during the realization of the following geological sheets: 196 - Cabella Ligure, 197 - Bobbio, 213 - Genova, 214 - Bargagli, 215 - Bedonia, 217 - Neviano degli Arduini, 233 - Pontremoli, 234 - Fivizzano, 250 - Castelnuovo Garfagnana, 262 - Pistoia, of the new Geological Map of Italy (CARG Project), mapped at scale 1:50,000 (CARG Project, http//www.isors.ambiente.gov.it/Media/carg/index/.html). Most of the samples have been collected from marly calcareous, low-density turbidites and marly to clayey marly hemipelagites of the Helminthoid Flysch *Auctt*., and from silty marls intercalated within the siliciclastic turbidites of the shaly succession of the basal complexes. In Fig. 3 the reconstructed distribution patterns of the calcareous nannofossil taxa have been reported. These patterns are based on assemblages identified by the different authors in simple smear slides, analyzed with a light polarizing microscope at 1000 to 1500 magnifications. These routine analyses allow the recognition of all the here-mentioned or listed species (Appendix I). Most of them are easily recognizable, whereas others need more attention during the analysis of scarce and poorly preserved assemblages. Considering the different type of analyses and range charts produced, data are not comparable because: (1) in qualitative analysis only the presence of taxa is estimated; (2) in semi-quantitative analysis the abundance of classes is evaluated using the number of specimens present with respect to a number of fields of view; and (3) in quantitative analysis the frequency of taxa is calculated taking into account 300-500 specimens (see material and methods in the quoted literature). Consequently, the classes of abundance utilized in Fig. 3 (i.e. Abundant to Common, Few to Rare, and Very Rare) are an effort to summarize all the different types of data present in previous literature. We have also identified two more categories: Continuous and Discontinuous. Continuous refers to taxa observable in a large number of samples; Discontinuous appoints taxa that are present in a very limited number of samples. Consequently, their occurrence should be carefully checked, even in moderate to well-preserved assemblages. In the next paragraphs we will adopt the following abbreviations: FO = First Occurrence, LO = Last Occurrence, FCO = First Common Occurrence.

RESULTS

Though the assemblages recovered from the External Ligurids are depleted by thaphonomic processes, including dissolution and overgrowth, the Late Cretaceous age-indicative taxa are present (Fig. 3). They can be divided into three groups. The first group includes: *Quadrum gartneri*, *Micula decussata*, *Calculites obscurus*, *Broinsonia parca*, *Ceratolithoides aculeus, Uniplanarius trifidus* and *Arkhangelskiella* spp. These useful and solution resistant taxa are usually present even in impoverished assemblages. The second group comprises: *Eiffellithus eximius*, *Reinhardtites anthophorus*, *Lucianorhabdus cayeuxii* and *Uniplanarius gothicus*. The presence of these species should be carefully checked, particularly in poorly preserved assemblages. The third group includes: *Reinhardtites levis, Lithraphidites quadratus*, *Micula murus, Ceratolithoides kamptneri, Nephrolithus frequens* and *Micula prinsii*. These species are also frequently rare or extremely rare in moderate to well-preserved assemblages, but they are helpful for dating the Maastrichtian successions. The third group also includes *Corollithion kennedyi, Lithraphidites acutus* and *Helenea chiastia*, which are useful for dating the Cenomanian successions. In summary, the successions of the proposed FOs are helpful in recognizing zones, or grouped zones (Fig. 4), of the standard scheme of Sissingh (1977). The Cenomanian-Maastrichtian age-indicative species recognized in the External Ligurids are listed in Table I. The other taxa recognized in External Ligurids are reported in Table II, and in Table III the selected lithostratigraphic units with cropping out areas and ages are listed. The age-indicative species chosen or discarded to define the zone boundaries have been discussed in Appendix II.

Zones and zone boundaries

- CC9. The lowermost portion of the Late Cretaceous is covered by the upper part of the CC9 Zone, which spans the time interval from the FO of *Eiffellithus turriseiffelii* (late Albian) to the FO of *L. acutus*. This zone is characterized by the presence of the zonal marker *E. turriseiffelii* along with *Tranolithus orionatus*, *Cribrosphaerella ehrembergii*, *C. kennedyi*, *H. chiastia* and *Lithraphidites alatus*. This latter species disappears at the CC9/CC10 boundary.
- CC10. In the studied successions, the FO of *Microrhabdulus decoratus* being useless, the lower limit of the CC10 Zone could be recognized using the FO of *L. acutus*. This latter taxon disappears in the uppermost part of the zone together with *C. kennedyi, H. chiastia* and *Rhagodiscus asper*.
- CC11. Both lower and upper limits are easily placed with the FO of *Q. gartneri* and the FO of *E. eximius* respectively. The latter event is more helpful than the FO of *Lucianorhabdus maleformis* as this species is extremely rare.
- CC12-CC13. The zones CC12 and CC13 are, instead, difficult to separate because the CC12/CC13 boundary is hard to place with the FO of *Marthasterites furcatus*. This grouped zone hence spans the time interval from the FO of *E. eximius* to the FO of *M. decussata*, two easily recognizable and cosmopolitan biohorizons.
- CC14. This zone is well detectable because the FOs of *M. decussata* and *Reinhardtites anthophorus* are two useful worldwide events, though in poor assemblages the presence of *R. anthophorus* should be carefully checked.
- CC15-CC16. The zones CC15 and CC16 have been assembled as the identification of their boundary is subordinated to the recognition of *L. cayeuxii* FO. This combined zone is defined by the FO of *M. decussata*, at the bottom and the FO of *C. obscurus* at the top.
- CC17. The CC17 Zone is well recognizable because the FOs of *C. obscurus* and of *B. parca* are easily detectable. Both taxa are two main components of the Campanian assemblages also in impoverished assemblages.
- CC18-CC19. We also propose to gather the CC18 and CC19 zones being impossible to place the CC18/CC19 boundary with the LO of *M. furcatus*. This long time interval corresponds to the NC18 Zone of Roth (1978) which spans the interval from the FO of *B. parca* to the FO of *C. aculeus*, two easily recognizable and cosmopolitan biohorizons.
- CC20. The CC20 Zone is well identifiable on the base of the FO of *C. aculeus*.

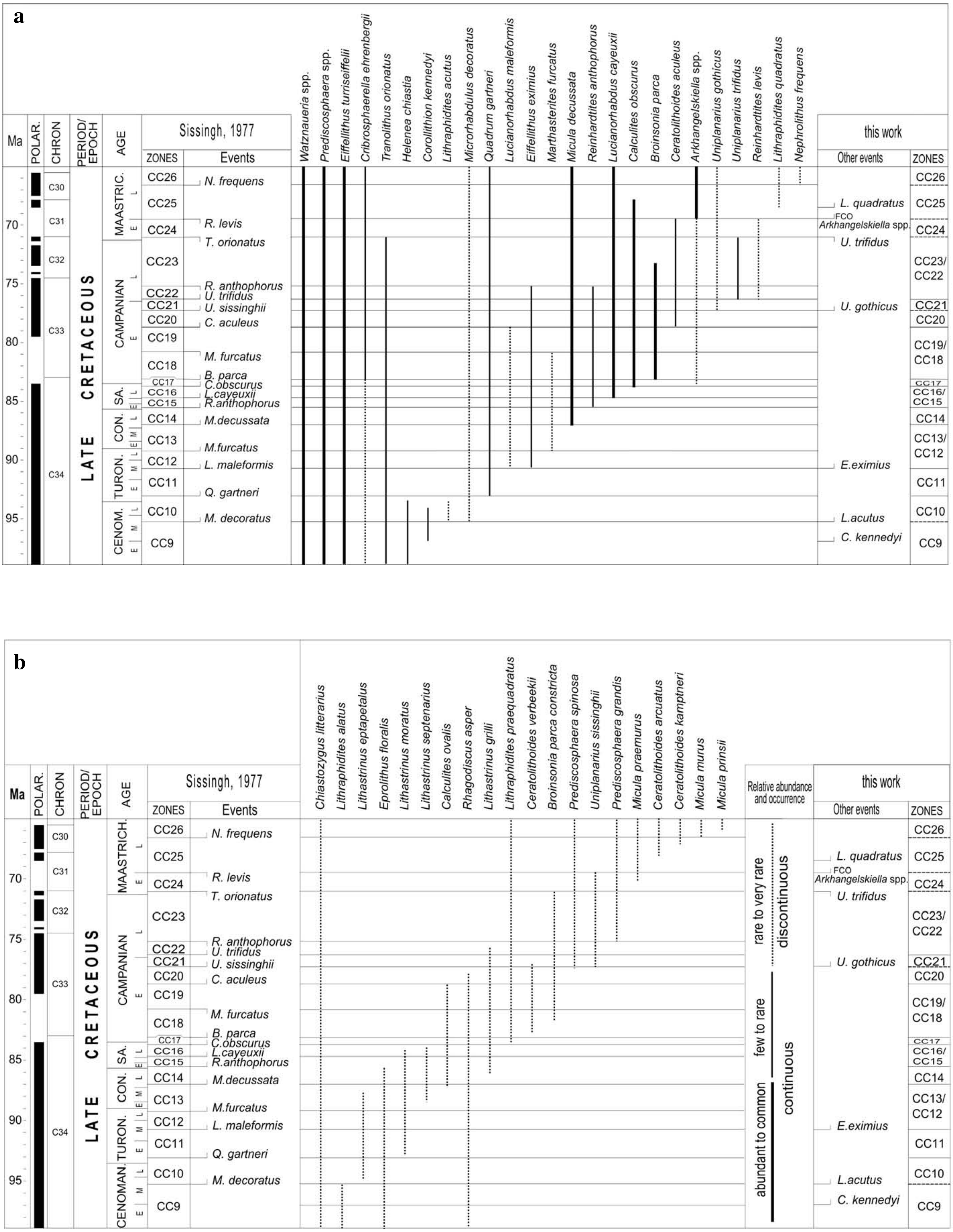

Fig. 3 - a) Stratigraphic range of selected taxa from the Late Cretaceous successions belonging to the External Ligurids. Chronostratigraphy after Gradstein et al. (2004), biochronology after Erba et al. (1995a; 1995b). POLAR. = Polarity; CENOM. = Cenomanian; TURON. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTRIC. = Maastrichtian. b) Continuation of 3a.

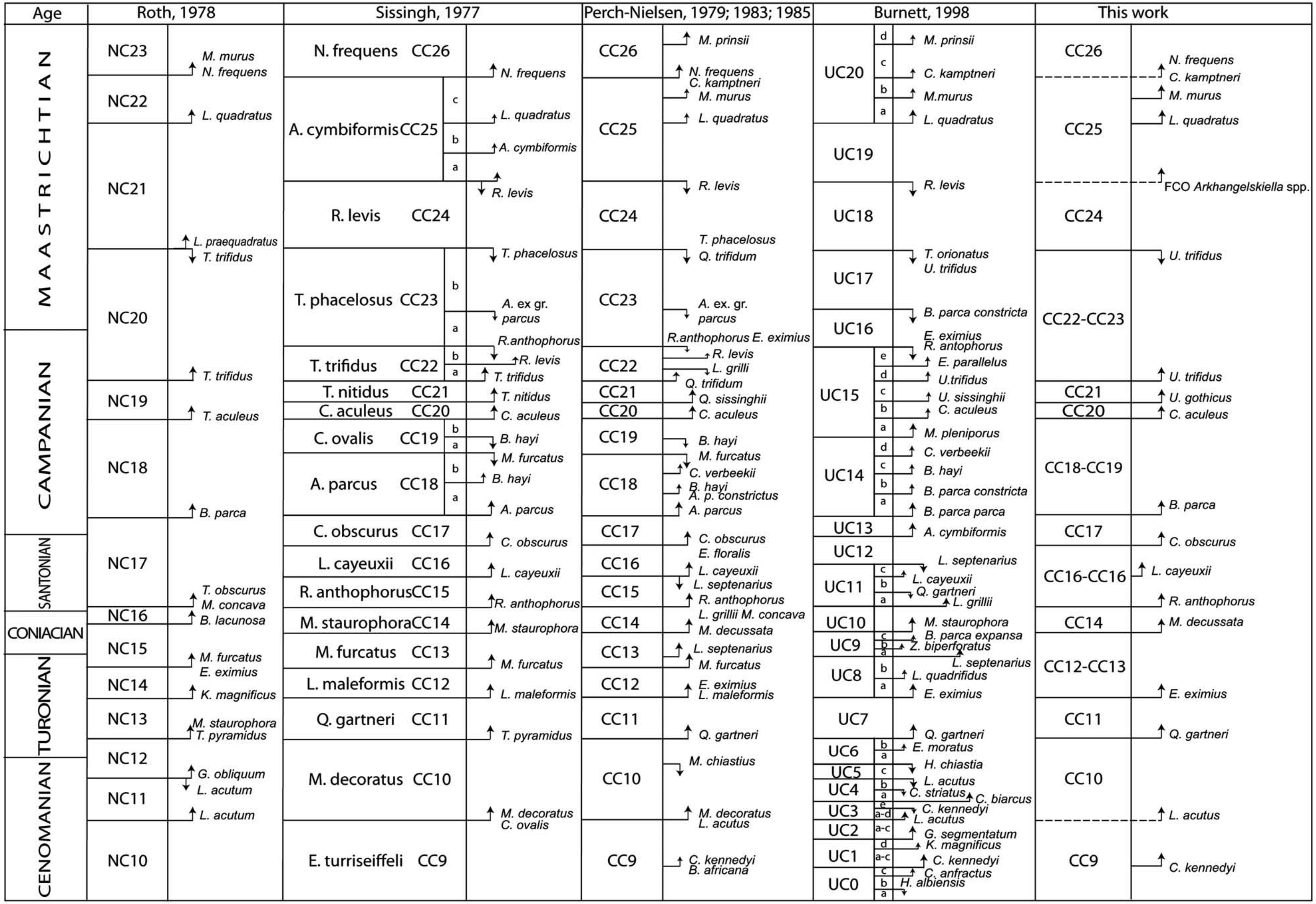

Fig. 4 - Late Cretaceous calcareous nannofossil biostratigraphic zonation proposed for the External Ligurids, compared to previous biostratigraphic schemes.

Table 1 - Age-indicative species recognized in the sedimentary successions belonging to the External Ligurids and reliability of both biohorizons and occurrences.

Age-indicative species recognized in the External Ligurian Units	Ottone Unit	Caio Unit	Antola Unit	Cassio Unit	Solignano Flysch	Southern Tuscany HF	Biohorizons			Occurrence	
Arkhangelskiella spp.			X	X	X	X	FCO	lower limit CC25	good	CC25-CC26	useful
Broinsonia parca	X	X	X	X	X	X	LO	within CC23	useless	CC18-CC23 p.p.	useful
							FO	lower limit CC18	very good		
Calculites obscurus	X	X	X	X	X	X	FO	lower limit CC17	very good	CC17-CC25 p.p.	useful
Calculites ovalis			X	X			FO	lower limit CC14	useless	CC14-CC19	indicative
Ceratolithoides aculeus	X	X	X	X	X	X	FO	lower limit CC20	very good	CC20-CC26	useful
Corollithion kennedyi				X		X	LO	within CC10	potentially good	CC9 p.p.-CC10 p.p.	useful
				X		X	FO	within CC9	potentially good		
Eiffelithus eximius	X	X	X	X	X		LO	upper limit CC22	potentially good	CC12-CC22	useful
							FO	lower limit CC12	good		
Eiffellithus turriseiffelii	X	X	X	X	X	X	FO	lower limit CC9	very good	CC9-CC26	useful
Helenea chiastia			X			X	LO	within CC10	potentially good	U. Jurassic-CC10p.p.	useful
Lithraphidites acutus	X					X	FO	lower limit CC10	potentially good	within CC10	useful
Lithraphidites quadratus		X	X			X	FO	within CC25	potentially good	CC25 p.p.-CC26	useful
Lucianorhabdus cayeuxii		X	X	X	X	X	FO	lower limit CC16	very good	CC16-CC26	useful
Lucianorhabdus maleformis		X		X	X		FO	lower limit CC12	useless	CC12-CC19	indicative
Marthasterites furcatus	X		X				LO	upper limit CC18	useless	CC13-CC18	useful
							FO	lower limit CC13	useless		
Microrhabdulus decoratus	X	X	X	X	X	X	FO	lower limit CC10	useless	CC10-CC26	indicative
Micula murus		X	X			X	FO	within CC25	potentially good	CC25 p.p.-CC26	useful
Micula prinsii		X	X				FO	within CC26	potentially good	CC26 p.p.	useful
Micula decussata	X	X		X	X	X	FO	lower limit CC14	very good	CC14-CC26	useful
Nephrolithus frequens		X	X			X	FO	lower limit CC26	potentially good	CC26	useful
Quadrum gartneri	X		X	X		X	FO	lower limit CC11	very good	CC11-CC26	useful
Reinhardtites anthophorus	X	X	X	X	X	X	LO	upper limit CC22	useless	CC15-CC22	useful
							FO	lower limit CC15	good		
Reinhardtites levis		X	X			X	LO	upper limit CC24	useless	CC22 p.p.-CC24	useful
							FO	within CC22	useless		
Tranolithus orionatus	X		X	X		X	LO	upper limit CC23	useless	CC8-CC23	indicative
Uniplanarius gothicus	X	X	X	X	X	X	FO	lower limit CC21	good	CC21-CC23	useful
Uniplanarius sissinghii			X			X	FO	lower limit CC21	useless	CC21-CC23	indicative
Uniplanarius trifidus	X	X	X		X	X	LO	upper limit CC23	good	CC22-CC23	useful
							FO	lower limit CC22	very good		

E. = Early, M.= Middle, L. = Late. For bibliography see Table 3.

Table 2 - Other taxa present in the successions belonging to the External Ligurids outcropping in the Northern Apennines, Western Alps and Southern Tuscany.

Other taxa recognized in the External Ligurian Units	Ottone Unit	Caio Unit	San Remo Flysch	Antola Unit	Cassio Unit	Solignano Flysch	Southern Tuscany HF	Occurrence	
Ahmuellerella octoradiata				X			X	CC20-CC26	indicative
Arkhangelskiella cymbiformis		X	X	X	X	X	X	CC20-CC26	indicative
Biscutum spp.				X		X	X		
Braarudosphaera africana							X	CC7-CC10	useful
Braarudosphaera bigelowii			X	X	X	X	X	CC10-CC26	
Braarudosphaera regularis							X	L. Jurassic-M. Cretaceous	
Braarudosphaera turbinea							X	CC25-CC26	indicative
Broinsonia enormis	X				X	X	X	Albian-Maastrichtian	indicative
Broinsonia parca constricta				X			X	CC18-CC23	useful
Ceratolithoides kampteri		X	X		X		X	CC25 p.p.-CC26	useful
Ceratolithoides verbeekii				X				CC18-CC21	useful
Chiastozygus amphiphons							X	Santonian-Maastrichtian	indicative
Chiastozygus litterarius	X		X		X		X	CC7-CC26	indicative
Corollithion exiguum	X				X			Turonian-Maastrichtian	indicative
Cretarhabdus conicus						X		L. Jurassic-Cretaceous	
Cretarhabdus crenulatus	X		X	X	X	X	X	Berriasian-Maastrichtian	
Cribrosphaerella ehrenbergii	X		X	X	X	X	X	CC8 p.p.-CC26	indicative
Cyclagelosphaera deflandrei							X	L. Jurassic-Cretaceous	
Cyclagelosphaera margerelii							X	L. Jurassic-Cretaceous	
Cyclagelosphaera reinhardtii							X	U. Jurassic-Cretaceous	
Cylindralithus serratus							X	Cenomanian-Maastrichtian	indicative
Diazomatolithus lehmanii							X	L. Jurassic-Cretaceous	
Eiffellithus gorkae	X			X	X		X	Albian-Maastrichtian	indicative
Eiffellithus trabeculatus							X	Albian-Maastrichtian	indicative
Eprolithus floralis		X		X	X		X	CC7-CC14 p.p.	indicative
Eprolithus rarus	X							Turonian-Campanian	indicative
Flabellites oblongus	X							late Barremian-Santonian	
Gartnerago obliquum							X	Cenomanian-Coniacian	indicative
Kamptnerius magnificus	X			X		X		CC11-CC26	indicative
Lithastrinus eptapetalus		X			X			CC10-CC13	useful
Lithastrinus grilli	X						X	CC14-CC22	indicative
Lithastrinus moratus					X			CC11-CC16	useful
Lithraphidites alatus	X				X		X	CC8-CC10	useful
Lithraphidites carniolensis	X				X	X	X	Berriasian-Maastrichtian	
Lithraphidites praequadratus				X			X	CC17-CC26	indicative
Lucianorhabdus quadrifidus				X				CC12-CC19	indicative

Table 2 (*continued*)

Other taxa recognized in the External Ligurian Units	Ottone Unit	Caio Unit	San Remo Flysch	Antola Unit	Cassio Unit	Solignano Flysch	Southern Tuscany HF	Occurrence	
Manivitella pemmatoidea							X	Tithonian-Maastrichtian	
Microrhabdulus attenuatus							X	CC16-CC26	indicative
Microrhabdulus undosus			X				X	CC25-CC26	indicative
Micula praemurus				X			X	CC24-CC26	useful
Placozygus fibuliformis							X	Turonian-Maastrichtian	indicative
Prediscosphaera columnata	X			X	X			CC8-CC9 p.p.	useful
Prediscosphaera cretacea	X	X	X	X	X	X	X	CC8-CC26	useful
Prediscosphaera grandis							X	CC23-CC26	useful
Prediscosphaera spinosa						X		CC9-CC26	useful
Prediscosphaera stoveri				X				CC21-CC26	useful
Rhagodiscus achylostaurion							X	CC7 p.p.-CC10 p.p.	indicative
Rhagodiscus angustus	X			X	X		X	CC7-CC26	indicative
Rhagodiscus asper	X			X	X	X	X	Tithonian-Cenomanian	indicative
Rhagodiscus splendens	X				X			Aptian-Maastrichtian	indicative
Rotellapillus laffittei							X	L. Jurassic-Turonian	
Rucinolithus irregularis							X	CC7-CC9 p.p.	indicative
Rucinolithus magnus							X	Campanian-Maastrichtian	indicative
Stoverius achylosus							X	CC7-CC11	indicative
Tegumentum stradneri							X	Valanginian-Maastrichtian	
Thoracosphaera saxea				X			X	L. Cretaceous	indicative
Thoracosphaera spp.		X	X	X	X		X	L. Cretaceous	indicative
Tranolithus exiguus	X			X	X	X		Albian-Maastrichtian	indicative
Tranolithus orionatus	X			X	X	X		Albian-Maastrichtian	indicative
Vagalapilla matalosa							X	Jurassic-Cretaceous	
Watznaueria barnesae			X	X	X	X	X	M. Jurassic-Cretaceous	
Watznaueria biporta							X	M. Jurassic-Cretaceous	
Watznaueria britannica							X	M. Jurassic-Cenomanian	
Zeugrhabdotus acanthus							X	Cenomanian-Campanian	
Zeughrabdotus bicrescenticus					X			Jurassic-Cretaceous	
Zeughrabdotus diplogrammus	X			X	X		X	Valanginian-Campanian	
Zeugrhabdotus embergeri	X			X		X	X	L. Jurassic-L- Cretaceous	
Zeugrhabdotus erectus							X	E. Jurassic-Cretaceous	
Zeugrhabdotus spiralis				X		X	X	Coniacian-Maastrichtian	

Table 3 - Synthesis of ages and calcareous nannofossils zones documented for the lithostratigraphic units belonging to the External Ligurids.

Formation	Areas/Localities	Ages	Previous Zones	Adopted Zones	Authors
Ottone-S. Stefano Flysch = Ottone Flysch	Caranza area Vara Valley	Campanian	C. aculeus/U. gothicus* B. parca	CC20/CC21* CC18/CC19	Marroni & Perilli, 1989; 1992
Mt. Penna/Casanova Complex = Casanova Complex	Zignago area Vara Valley	Campanian	C. aculeus B. parca	CC20 CC18/CC19	Marroni & Perilli, 1990b; 1992
Ottone Flysch	Vara Valley	Maastrichtian Campanian	U. gothicus C. aculeus	CC21 CC20	Catanzariti & Perilli, 2006
Casanova Complex	Vara Valley	Campanian	C. aculeus B. parca/C. ovalis	CC29 CC18/CC19	Catanzariti & Perilli, 2006
Ottone Flysch	Vara Valley Magra Valley	Maastrichtian Campanian	U. trifidus U. gothicus C. aculeus	CC22/CC23 CC21 CC20	F 233 Pontremoli (Puccinelli et al., in press a) F 234 Fivizzano (Puccinelli et al., b in press)
Casanova Complex	Vara Valley Magra Valley	Campanian	C. aculeus B. parca	CC20 CC18/CC19	F 233 Pontremoli (Puccinelli et al., in press a) F 234 Fivizzano (Puccinelli et al., in press b)
Ottone Flysch	Serchio Valley	Maastrichtian Campanian	U. gothicus C. aculeus	CC20 CC18/CC19	F 250 Castelnuovo Garfagnana (Puccinelli et al., in press c)
Casanova Complex	Serchio Valley	Campanian	C. aculeus B. parca	CC21 CC20 CC18/CC19	F 250 Castelnuovo Garfagnana (Puccinelli et al., in press c)
Ottone Flysch	Pistoia area	Maastrichtian Campanian	U. gothicus C. aculeus	CC21 CC20	F 262 Pistoia (Puccinelli et al., in press d)
Casanova Complex	Cabella Ligure Traschio Santa Maria	Campanian	B. parca	CC18/CC19	F 196 Cabella Ligure (Marroni et al., in press)
Mt. Very Complex	Cabella Ligure Traschio	Campanian	B. parca	CC20 CC18/CC19	F 196 Cabella Ligure (Marroni et al., in press)
Mt. Ragola Complex	Bobbio	Campanian	NC18 NC17 p.p.	CC18/CC19 CC17*	F 198 Bobbio (Elter et al., 1997)
Mt. Ragola Complex	Cabella Ligure Traschio, Santa Maria	Campanian	NC18 NC17 p.p.	CC18/CC19* CC17 p.p.*	F 215 Bedonia (Elter et al., 2005)
Caio Flysch	Baganza Valley Parma Valley Tizzano area	early Paleocene Maastrichtian Campanian	B. sparsus (1) M. prinsii (2) M. murus (3) L. quadratus (3) A. cymbiformis (3) U. trifidus (3)	NP1 CC26* CC25p.p./CC26 p.p.* CC24p.p./CC25 p.p.* CC22/CC23*	Rio et al., 1983
Basal Complex of Caio Flysch	M. Cavallo Baganza Valley	Campanian		CC21*	Rio et al., 1983
Caio Flysch	Pracchiola area	Maastrichtian Campanian	CC22	CC22/CC23	Plesi et al., 2000 F 235 Pievepelago (Plesi, 2002)
Caio Flysch	Magra Valley	Maastrichtian Campanian	U. trifidus U. gothicus	CC22/CC23 CC21	F 234 Fivizzano (Puccinelli et al., in press b)
Orocco Flysch	Orocco area	Maastrichtian Campanian	U. trifidus U. gothicus	CC22/CC23 CC21	Marroni et al., 1992
Orocco Flysch	Bobbio area	Maastrichtian Campanian	NC20-NC21	CC24/CC25 p.p. CC22/CC23	F 197 Bobbio (Elter et al., 1997)
Orocco Flysch	Bedonia area Aveto Valley Alpepiana	Maastrichtian Campanian	NC20-NC21	CC24/CC25 p.p. CC22/CC23	F 215 Bedonia (Elter et al., 2005)

Fm. = Formation; * re-interpreted data; ? = questionable data. (1) Romein, 1979; (2) Perch-Nielsen, 1979; (3) Martini, 1976; (4) Verbeek, 1977; (5) Rio and Villa, 1987.

Table 3 (*continued*)

Formation	Areas/Localities	Ages	Previous Zones	Adopted Zones	Authors
M. Bettola Flysch	Nure Valley	Maastrichtian Campanian	M. murus 3) U. trifidus (3)	CC25 p.p./CC26 CC22/CC23	Cerrina Feroni et al., 1994
M. Bettola Flysch	Luretta Valley	early Paleocene Maastrichtian	NP2 M. murus (4)	NP2 CC25 p.p./CC26	Cobianchi et al., 1994
M. Bettola Flysch	Bardi area	Campanian Maastrichtian	NP2/NP3 NC23	NP2/NP3 CC25 p.p.-CC26	F 198 Bardi (Martini & Zanzucchi, 2000)
Solignano Flysch	Taro Valley	Maastrichtian Campanian	A. cymbiformis (3) U. trifidus (3)	CC24 CC22/CC23	Rio & Villa, 1983
Pagliaro Shale	Cabella Ligure	early Paleocene Maastrichtian	NP2-NP5 UC20	NP2-NP5 CC26 p.p. CC25 p.p.	Catanzariti et al., 2007 F 196 Cabella Ligure (Marroni et al., in press)
Bruggi/Selvapiana Fm.	Cabella Ligure	Maastrichtian	UC19 UC18	CC25 p.p. CC24 p.p.	Catanzariti et al., 2007 F 196 Cabella Ligure (Marroni et al., in press)
Antola Flysch	Cabella Ligure	Maastrichtian Campanian	UC17 UC16 UC15 p.p.	CC22/CC23 CC21 CC20	Catanzariti et al., 2007 F 196 Cabella Ligure (Marroni et al., in press)
Basal Complex of Antola Flysch: Flysch Gorreto Sandstone	Cabella Ligure	Campanian	UC15 p.p. UC14 p.p.	CC20 CC18/CC19	Catanzariti et al., 2007 F 196 Cabella Ligure (Marroni et al., in press)
Basal Complex of Antola Flysch: Montoggio Shale (lowermost part)	Cabella Ligure	Turonian Cenomanian	UC7 UC6 UC5	CC11 CC10	Catanzariti et al., 2007 F 196 Cabella Ligure (Marroni et al., in press)
Antola Flysch	Bargagli area	Maastrichtian Campanian	U. trifidus U. gothicus	CC22/CC23 CC21	F 214 Bargagli (Elter et al., in press)
Antola Flysch	Genova area	Maastrichtian Campanian	U. trifidus U. gothicus	CC22/CC23 CC21	F 213 Genova (Capponi & Crispini, 2008)
S. Remo Flysch	Marittimes Alps	Maastrichtian Campanian	M. murus A. cymbiformis U. trifidus	CC26 CC24/CC25 CC22/CC23	Manivit & Proud'Homme, 1990
Basal Complex of S. Remo Flysch	Marittimes Alps	Maastrichtian Campanian	C. aculeus	CC20*/CC21*	Manivit & Proud'Homme, 1990
Testanello Flysch	Taro Valley	Maastrichtian Campanian	NC19-NC23	CC20-CC26	F 216 Borgo Val di Taro (Vescovi, 2002)
Arenarie di Campi	Bedonia	Campanian			F 215 Bedonia (Elter et al., 2005)
Arenarie di Campi	Taro Valley	Maastrichtian	NC18-NC19	CC21-CC21 CC18/CC19	F 216 Borgo Val di Taro (Vescovi, 2002)

- CC21. The identification of the CC21 Zone is related to the recognition of *Uniplanarius sissinghii*. In the studied successions this species is rare and discontinuously present, on the contrary *U. gothicus* is more frequent and its FO can be useful to recognize the lower boundary of the CC21 Zone (see Appendix II).
- CC22-CC23. These two zones are indistinguishable, as it is difficult to locate the CC22/CC23 boundary using the LO of *R. anthophorus*. Furthermore, the LO of *T. orionatus* being useless (see Appendix II), it is helpful to

Table 3 (*continued*)

Formation	Areas/Localities	Ages	Previous Zones	Adopted Zones	Authors
Cassio Flysch	Baganza Valley Parma Valley Tizzano area	Maastrichtian Campanian	U. trifidus	CC22/CC23	Rio et al., 1983
Basal Complex of Cassio Flysch: Varicoloured Shale	Baganza Valley Runniano	Campanian	C. ovalis (5)	CC18/CC19*	Rio & Villa, 1987
Basal Complex of Cassio Flysch: Conglomerati Salti del Diavolo	Baganza Valley Chiastre	Campanian	A. parcus (5)	CC18/CC19*	Rio & Villa, 1987
Basal Complex of Cassio Flysch: Varicoloured Shale	Baganza Valley	? Campanian ? Santonian	M. furcatus (5)	CC15*/CC16* CC14*	Rio & Villa, 1987
Basal Complex of Cassio Flysch: Varicoloured Shale	Pessola Valley Baganza Valley Tresinaro Valley	Coniacian		CC15* p.p. CC14 *p.p.	Vescovi et al., 1999
Basal Complex of Cassio Flysch: Case Baruzzo Sandstone	Pessola Valley Baganza Valley Tresinaro Valley	Turonian Cenomanian		CC11* CC9* p.p./CC10* p.p.	Vescovi et al., 1999
Cassio Flysch	Bardi area	Maastrichtian Campanian	NC20	CC22/CC23	F 198 Bardi (Martini & Zanzucchi, 2000)
Cassio Flysch	Neviano Arduini area	Maastrichtian Campanian	CC22/CC23	CC22/CC23	F 217 Neviano delgi Arduini (Cerrina Feroni et al., 2002)
Cassio Flysch	Cabella Ligure area	Maastrichtian Campanian	CC22/CC23 CC21	CC22/CC23 CC21	F 196 Cabella Ligure (Marroni et al., in press)
Signano Shale	Neviano Arduini area	early Paleocene Maastrichtian	NP1/NP2 CC25-CC26	NP1/NP2 CC25 p.p.-CC26	F 217 Neviano delgi Arduini (Cerrina Feroni et al., 2002)
Viano Shale	Val Tresinaro	early Paleocene	F. tympaniformis	NP5*	Iaccarino & Rio, 1972
Ostia Sandstone	Taro Valley Baganza Valley	Santonian Coniacian	CC15 CC14	CC15 CC14	Villa, 1991
Ostia Sandstone	Cedra Valley	Santonian Coniacian	M.furcatus (5)	CC16* CC14/-CC15*	Cerrina Feroni et al., 1991
Scabiazza Sandstone	Trebbia Valley	late Turonian/Santonian late Turonian	M. furcatus E. eximius	? CC17 CC15/CC16* CC14* CC12/ ? CC13?*	Ghiselli et al., 1991
Scabiazza Sandstone	Cabella Ligure area	late Turonian/Santonian late Turonian	M. furcatus E. eximius	CC11 CC10 CC9	F 196 Cabella Ligure (Marroni et al., in press)

group the CC22 and CC23 zones. This combined zone corresponds to the NC20 Zone of Roth (1978), which spans the time interval from the FO to the LO of *U. trifidus*. Both are cosmopolitan events. Within a continuous succession of well-preserved assemblages, the CC22/CC23 boundary could be approached by the LO of *E. eximius*; moreover, the first specimens of *R. levis* occur in this zone.

- CC24-CC26. The Maastricthian time interval is covered by the zones CC24, CC25 and CC26. The CC24 Zone can be recognized using the presence of *R. levis* (see Appendix II); the lower part of the CC25 Zone can be characterized by the lower range of the common occurrence of *Arkhangelskiella* spp.; the lower range of *L. quadratus* and/or *M. murus* is helpful in recognizing the upper part of the CC25 Zone; the findings of *N. frequens* and/or *C. kamptneri* are helpful in identifying the CC26 Zone; the presence of *M. prinsii* allow the identification of the uppermost part of this latter zone.

DISCUSSION

Based on literature and our unpublished analytical data, the nannofossil diversity of the assemblages recovered from the Late Cretaceous External Ligurids is low if compared with that of open oceans (Lees, 2002; Lees and Bown, 2005) and other Western Tethys successions (Verbeek, 1977; Tantawy, 2008), and the number of specimens is generally reduced, in particular for the Coniacian-Santonian time interval. In the studied successions, both the reduced number of species and specimens should be mainly related to diagenesis, as the poor assemblages make the use of all the standard markers difficult. This difficulty is enhanced by dissolution which depletes the assemblages, as well as by overgrowth that modifies the morphological features of taxa, leading to incorrectly identify species that are slightly different and underestimated in their occurrence, i.e. *L. cayeuxii* and *L. maleformis* (Marino and Monechi, 1994) or *R. anthophorus* and *R. levis* (Catanzariti et al., 2007).

Table 3 (*continued*)

Formation	Areas/Localities	Ages	Previous Zones	Adopted Zones	Authors
Chianni Flysch	Chianni area Ponte Muscoso-Pastina Prunicce	Maastrichtian Campanian	U. gothicus-U. trifidus U. gothicus	CC21-CC22/CC23 CC21	Marino & Monechi, 1994
Montaione Flysch	Montaione area Costa S. Vettore T. Egola	Campanian	C. aculeus-U. gothicus C. aculeus	CC20-CC21 CC20	Marino & Monechi, 1994
San Donato in Poggio Flysch	San Donato in Poggio Prummiano Casa Ticciana	Maastrichtian Campanian ? Santonian	U. trifidus C.aculeus C. obscurus	CC22/CC23 CC20 ? CC17	Marino & Monechi, 1994
Basal Complex of San Donato in Poggio Flysch	San Donato in Poggio Casa Ticciana A2 Casa Ticciana A1	Turonian Cenomanian	E. eximius L. acutus? E. eximius	CC 12/CC13* ? CC10 CC12/CC13*	Marino & Monechi, 1994
Basal Complex of Monteverdi Marittimo Flysch	Monteverdi Marittimo T. Massera	Cenomanian	E. turriseiffelii	CC10 CC9	Marino & Monechi, 1994
Basal Complex of Monteverdi Marittimo Flysch	Monteverdi Marittimo Frassine	Turonian Cenomanian	Q. gartneri L. acutus E. turriseiffelii	? CC11* ? CC10* ? CC9*	Marino & Monechi, 1994
Monteverdi Marittimo Flysch	Monteverdi Marittimo Frassine	Maastrichtian Campanian	L. quadratum U. trifidus U. gothicus C.aculeus B. parca C. obscurus	CC25/CC26* CC22/CC23 CC21 CC20 ? CC18/CC19* ? CC17*	Marino & Monechi, 1994
Monteverdi Flysch	Monteverdi Marittimo Monteverdi-Sassetta Monteverdello	Maastrichtian Campanian	U. trifidus	CC22/CC23	Marino & Monechi, 1994
Larderello Flysch	Larderello Podere Tanelle Coste Solaio	E. Paleocene Maastrichtian	E.macellus C. danicus M. murus	NP4 NP3 CC25 p.p.-CC26	Marino & Monechi, 1994
Larderello Flysch	Larderello Podere Pescine Podere Croci	Maastrichtian	M. murus L. quadratus	CC25 p.p./CC26 p.p. CC25 p.p.	Marino & Monechi, 1994
Larderello Flysch	Larderello Podere Nuovo Torrente Pavone	Maastrichtian	M. murus L. quadratus	CC25 p.p./CC26 p.p. CC25 p.p.	Marino & Monechi, 1994
Basal Complex of Larderello Flysch	Larderello Poggio Scarpenata	Turonian Cenomanian	E. eximius L. acutus E. turriseiffelii	CC12/CC13* CC10 CC9	Marino & Monechi, 1994
Elba Flysch	Lacona bay	Campanian	U. gothicus C.aculeus	NC18-NC19 (CC18-CC21)	Voisnet et al., 1983
Macinaggio Flysch	Macinaccio bay	Santonian		CC14-CC17*	Marino et al., 1995
Calcareous Flysch of Balagne	Ostriconi-Ozzari area	? Campanian ? Coniacian ? Cenomanian		? CC21 CC14-CC17*	Marino et al., 1995
Gare de Novelle Sandstone	Novella train Station	Cenomanian-Turonian			Marino et al., 1995

Furthermore, though the reworking of older taxa is limited (extremely rare and scattered Early Cretaceous taxa, e.g. *Conusphaera mexicana*, *Tubodiscus verenae*), the presence of some Late Cretaceous markers (e.g. *E. eximius*, *B. parca, T. orionatus, R anthophorus*) above their range (Rio and Villa, 1983; Marroni et al., 1992; Marino and Monechi, 1994) makes the FOs more reliable than the LOs. Therefore not all the standard markers are present and utilizable, and consequently the biostratigraphic scheme of Sissingh (1977) is not completely applicable to the sediments settled in the External Ligurian Domain. Nevertheless, the succession of the proposed biohorizons, based only on FOs, has proved to be robust for recognizing the following time intervals.

- The Cenomanian-earliest Turonian time interval has been documented for the lowermost portion of the Cassio and Antola Units (Figs. 5, 6), and for the shaly succession assigned to the basal complex of San Donato HF (Fig. 7a).

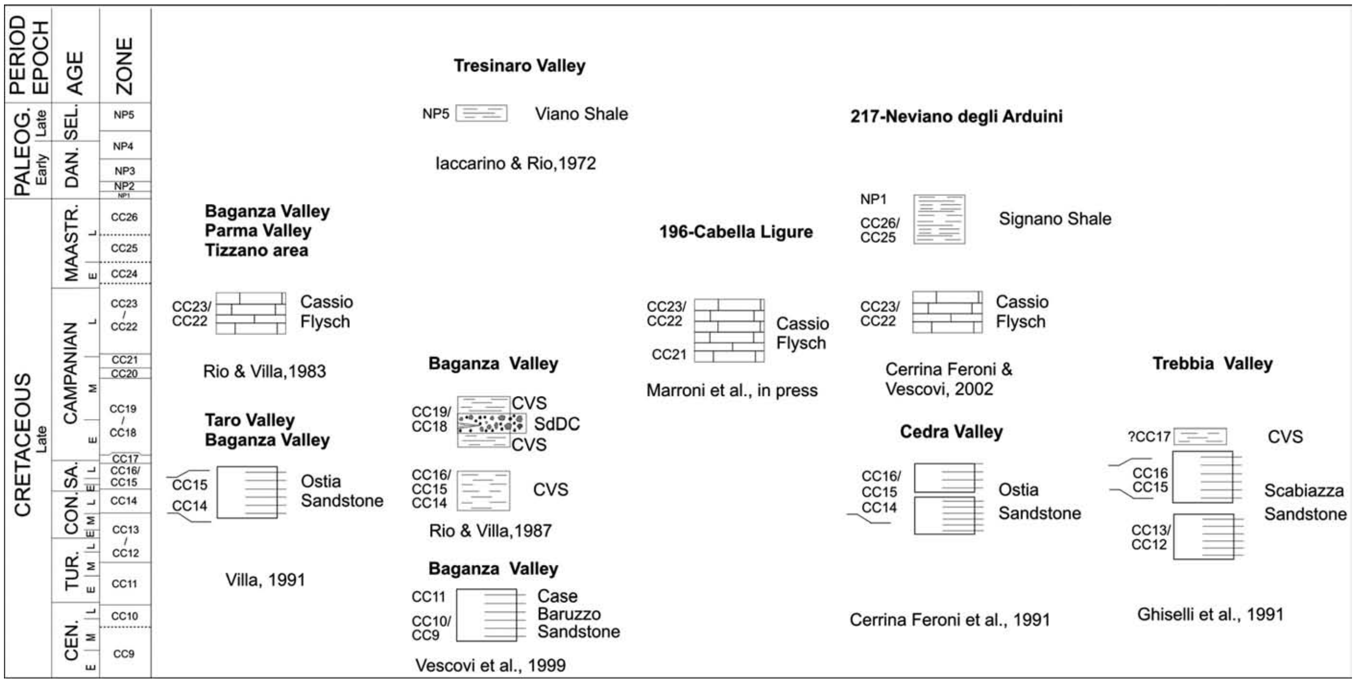

Fig. 5 - Ages of Case Baruzzo Sandstone (Pessola, Baganza and Tresinaro Valleys); (CVS) Cassio Varicoulored Shale (Baganza area and TrebbiaValleys), Ostia Sandstone (Taro, Baganza and Cedra Valleys); Scabiazza Sandstone (Trebbia, Valley and Cabella areas); (SdDC) Salti del Diavolo Conglomerate (Baganza Valleys); Cassio Flysch (Baganza and Parma Valleys, Tizzano, Cabella Ligure and Neviano degli Arduini areas); Signano Shale (Neviano degli Arduini area) and Viano Shale (Tresinaro Valley). CEN. = Cenomanian; TUR. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTR. = Maastrichtian; DAN. = Danian; SEL. = Selandian. Cretaceous chronostratigraphy and biochronology according to Fig. 3.

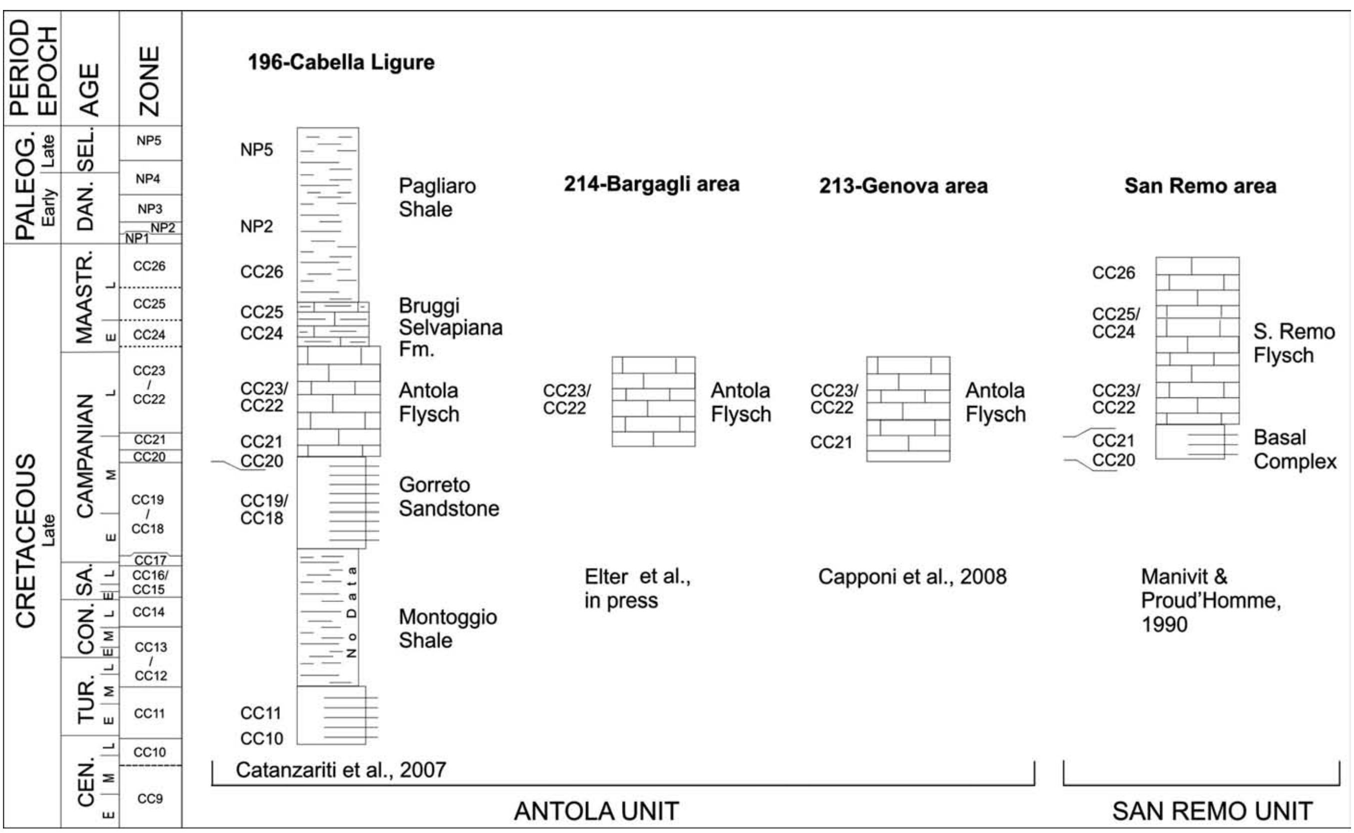

Fig. 6 - Ages of Antola Unit (Cabella Ligure, Bargagli and Genova areas) and San Remo Unit (San Remo area). CEN. = Cenomanian; TUR. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTR. = Maastrichtian; DAN. = Danian; SEL. = Selandian. Cretaceous chronostratigraphy and biochrology according to Fig. 3.

The assemblages recovered from these successions are characterized by the co-occurrence of *C. kennedyi* and *H. chiastia*.

- The Turonian-late Coniacian assemblages are characterized by the presence of *Q. gartneri*. In the studied successions, the presence of *E. eximius* is helpful in distinguish between the CC11 and the CC12-CC13 zones, the FOs of *L. maleformis* and *M. furcatus* being useless (see Appendix II). This zone has been documented for the lower portion of the Scabiazza Sandstone (Fig. 5) and for the shaly successions, assigned to the basal complexes of the Helminthoid Flysch of Southern Tuscan (Fig. 7a).
- In the late Coniacian-latest Santonian time interval, the assemblages characterized by the occurrence of *M decussata* and the co-occurrence of *M. decussata* and *R. anthophorus*, permit us to recognize the CC14 and CC15-CC16 zones respectively (see Appendix II). In poorly preserved assemblages, when dissolution and/or overgrowth could make the identification of *R. anthophorus* difficult, the sole presence of the genus *Reinhardtites* is crucial in recognizing the CC15-CC16 zone. Dissolution and overgrowth also make the discrimination between *L. cayeuxii* and *L. maleformis* difficult (Marino and Monechi, 1994). In the External Ligurids, the Santonian fossil record (CC15-CC16) is better represented than that of the latest Coniacian (CC14). Both zones have been documented for the Cassio Unit (Fig. 5).
- The latest Santonian-early Campanian time interval, CC17 and CC18-CC19 zones, is well document in almost all the External Ligurids, and assemblages that refer to

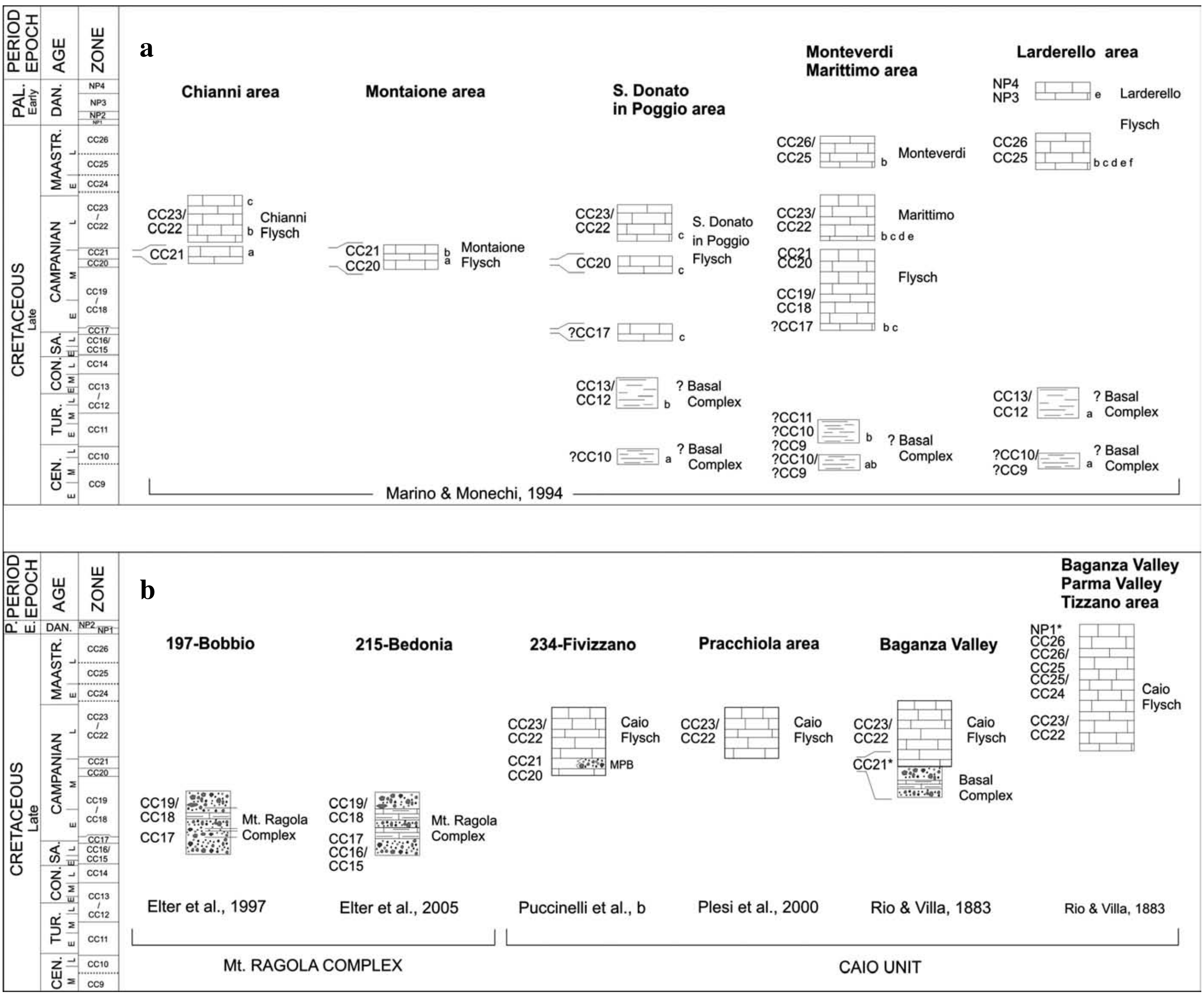

Fig. 7 - a) Ages of the Helminthoid Flysch of Southern Tuscany and relative Basal Complexes: Chianni HF (a- Prunicce, b- Ponte Muscoso and c- Pastina areas), Montaione HF (a- Costa S. Vettore, b- T. Egola areas), Basal Complex of San Donato in Poggio HF (a- Casa Ticciana1 and Casa Ticciana2 areas), San Donato in Poggio HF (c- Casa Ticciana, San Donato in Poggio, c- Prummiano), Basal Complex of Monteverdi HF (a- T. Massera, b- Frassine); Monteverdi HF (b- Frassine, c- Monteverdi, d- Sassetta and e- Monteverdello areas); Basal Complex of Larderello HF (a- Poggio Scarpenata); Larderello HF (b- Podere Nuovo, c- Torrente Pavone, d- Podere Tanelle, e- Coste Solaio, f- Podere Pescine-Podere Croci). CEN. = Cenomanian; TUR. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTR. = Maastrichtian; DAN. = Danian. Cretaceous chronostratigraphy and biochronology according to Fig. 3. b) Ages of Mt. Ragola Complex (Bobbio and Bedonia areas) and Caio Unit (Fivizzano and Pracchiola areas; Baganza and Parma Valleys; Tizzano area). P. = Paleocene; E. = Early; CEN. = Cenomanian; TUR. = Turonian; CON. = Coniacian; SA. = Santonian; MAASTR. = Maastrichtian; DAN. = Danian. * Reinterpreted data. Cretaceous chronostratigraphy and biochronology according to Fig. 3.

the latter combined zone are more abundant and diversified than previous zones. The CC17 Zone has been documented in the Caio (Fig. 7b) and Cassio Units (Fig. 5) and in the Helminthoid Flysch of Southern Tuscany (Fig. 7a). The CC18-CC19 zone has been identified in the Cassio (Fig. 5), Ottone (Fig. 8a) and Antola (Fig. 6) Units, as well as in the Monteverdi Marittimo HF (Fig. 7a).

- The overlying (late) early Campanian-earliest Maastrichtian zones have been documented for all the units (Figs. 5-8b) because the widespread and thick lower portion of the marly calcareous turbidites spans from the CC20 to the CC22-CC23 zones (Catanzariti and Perilli, 2006). However, the short time interval covered by the CC20 to CC21 zones could be missing in impoverished assemblages or in widely spaced samples (Catanzariti and Perilli, 2006). It is hence more easily recognizable in expanded successions or in closely spaced sampling. In the late Campanian assemblages, the presence of *R. levis* should be carefully checked because this species can be confused with *R. anthophorus* (see Appendix II). According to the literature, the LOs of *E. eximius* and *B. parca* have been placed within the CC22-CC23 zone, though very rare specimens of both taxa are found above their range (Rio and Villa, 1983; Marino and Monechi, 1994).
- The Maastrichtian time interval is easy to identify because the assemblages are characterized by the common occurrence of *Arkhangelskiella* spp. The identification of the Maastrichtian zones, instead, is more difficult, being related to the identification of *R. levis* (see above), and the presence of *N. frequens* which is usually rare or extremely rare (Marino and Monechi, 1994; Catanzariti et al., 2007). In the literature, the Maastrichtian zones of Caio (Fig. 7b), Orocco, Bettola Solignano (Fig. 8b), Antola (Fig. 6) and Cassio (Fig. 5) Units, and of both Monteverdi Marittimo and Larderello HF (Fig. 7a) have been identified using the occurrence of *L. quadratus*, *C. kamptneri*, *M. murus* and *M. prinsii* (see Appendix II).

CONCLUSIVE REMARKS

The study of calcareous nannofossil assemblages from the Late Cretaceous External Ligurids confirms the biostratigraphical potential of calcareous nannofossils and permits us (1) to reconstruct the distribution patterns of the age-indicative species and (2) to identify the biohorizons useful in identifying and characterizing the Late Cretaceous zones of Sissingh (1977), some of which have been grouped. The age-indicative species are divided into three groups. The first group includes: *Q gartneri*, *M. decussata*, *C. obscurus*, *B. parca*, *C. aculeus* and *U. trifidus*; their FO, along with the FCO of *Arkhangelskiella* spp., and the LO of *U. trifidus*, allows us to easily identify 8 zone boundaries. The second

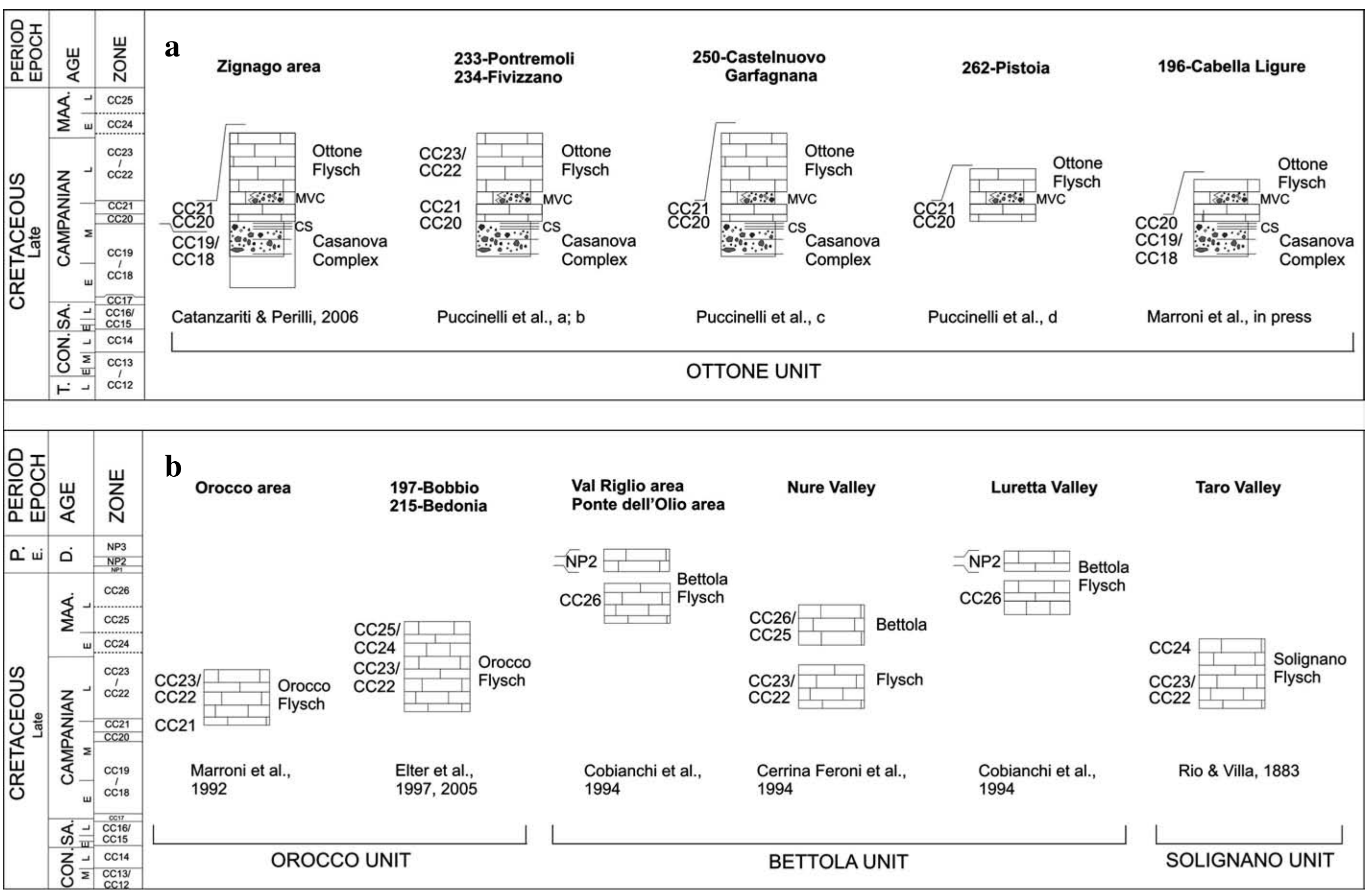

Fig. 8 - a) Ages of Ottone Unit (Zignago, Pontremoli, Fivizzano, Castelnuovo Garfagnana, Pistoia and Cabella Ligure areas). T. = Turonian; CON. = Coniacian; SA. = Santonian; MAA. = Maastrichtian. Chronostratigraphy and biochronology according to Fig. 3. b) Ages of Orocco Unit (Orocco, Bobbio and Bedonia areas), Bettola Unit (Val Riglio and Ponte dell'Olio areas, Nure and Luretta Valleys) and Solignano Unit (Taro Valley). P. = Paleocene; E. = Early; CON. = Coniacian; SA. = Santonian; MAA. = Maastrichtian; D. = Danian. Cretaceous chronostratigraphy and biochronology according to Fig. 3.

group includes: *E. eximius*, *R. anthophorus*, *L cayeuxii* and *U. gothicus*; their FO is helpful in refining the time resolution of our biostratigraphic scheme. The third group includes species characterized by short range and rare or very rare occurrences, even in moderately to well preserved and diversified assemblages. They are useful in improving the biostratigraphic resolution of Cenomanian (i.e. *C. kennedyi*, *L. acutus*) and Maastrichtian (i.e. *R. levis*, *L. quadratus*, *M. murus*, *C. kamptneri*, *N. frequens*) time intervals. Consequently, some zones or grouped zones of Sissingh (1977) are recognizable while some others can be recognized only with a closely spaced sampling and a careful analysis of moderate to well preserved assemblages. In particular:

- the zones CC11, CC14 and CC17 are easily identifiable;
- the CC11/CC12 boundary is more easily recognizable using the FO of *E. eximius* (Verbeek, 1977; Perch-Nielsen, 1979; 1983; 1985, Burnett, 1998);
- the CC12-CC13 and CC18-CC19 are grouped zones because the FO (Perch-Nielsen, 1979; 1983; 1985) and LO (Roth, 1978; Perch-Nielsen, 1979; 1983; 1985) of *M. furcatus* are useless;
- the CC15-CC16 are grouped zones because the FO of *L. cayeuxii* (Perch-Nielsen, 1979; 1983; 1985; Burnett, 1998) could be overlooked;
- the CC 20/CC21 boundary is recognizable using the FO of *U. gothicus*;
- the CC22-CC23 are assembled zones as the LO of *R. anthophorus* (Perch-Nielsen, 1979; 1983; 1985; Burnett, 1998) is useless;
- the CC23-CC24 boundary is recognizable using the LO of *U. trifidus* (Roth, 1978, Perch-Nielsen, 1979; 1983; 1985; Burnett, 1998);
- it could also be prudent to assemble the zones CC9 and CC10 because the FO of *M. decoratus* (Perch-Nielsen, 1979; 1983; 1985) is useless and the FO of *L. acutus* (Roth, 1978) is difficult to place;
- all the Maastrichtian assemblages are characterized by common *Arkhangelskiella* spp. specimens and the FCO of this group is helpful in identifying the CC24/CC25 boundary;
- the presence of *R. levis*, *L. quadratus*, *M. murus* and *N. frequens* (Thierstein, 1971; Verbeek, 1977; Roth, 1978; Perch-Nielsen, 1979; 1983; 1985; Burnett, 1998), as well as the occurrence of *C. kamptneri* and *M. prinsii* (Perch-Nielsen, 1979; 1983; 1985; Burnett, 1998) are helpful in identifying the Maastrichtian zones.

In summary, our work points out that calcareous nannofossils represent a powerful tool which provide a detailed chronostratigraphy of the External Ligurids, useful to better constrain the Late Cretaceous tectono-sedimentary and geodynamic evolution of large sectors of the Northern Apennines thrust-fold belt.

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APPENDIX I - Taxonomic nomenclature

Bibliographic references can be found in Perch-Nielsen (1985) and Bown (1998).

Ahmuellerella octoradiata (Górka, 1957) Reinhardt, 1966; *Arkhangelskiella* Vekshina, 1959; *Arkhangelskiella cymbiformis* Vekshina, 1959; *Biscutum* Black in Black and Barnes, 1959; *Braarudosphaera africana* Stradner, 1961; *Braarudosphaera bigelowii* (Gran and Braarud, 1935) Deflandre, 1947; *Braarudosphaera regularis* Black, 1973; *Braarudosphaera turbinea* Stradner, 1963; *Broinsonia enormis* (Shumenko, 1968) Manivit, 1971; *Broinsonia parca* (= *Aspidolithus parcus*) (Stradner, 1963) Bukry, 1969; *Broinsonia parca* (= *Aspidolithus parcus constrictus*) (Stradner, 1963) Bukry, 1969, ssp. *constricta* Hattner et al., 1980; *Broinsonia parca parca* (= *Aspidolithus parcus parcus*) (Stradner, 1963) Bukry, 1969; *Calculites obscurus* (Deflandre, 1959) Prins and Sissingh in Sissingh, 1977; *Calculites ovalis* (Stradner, 1963) Prins and Sissingh in Sissingh, 1977; *Ceratolithoides aculeus* (Stradner, 1961) Prins and Sissingh in Sissingh, 1977; *Ceratolithoides arcuatus* Prins and Sissingh in Sissingh, 1977; *Ceratolithoides kamptneri* Bramlette and Martini, 1964; *Ceratolithoides verbeekii* Perch-Nielsen, 1979; *Chiastozygus amphipons* (Bramlette and Martini, 1964) Gartner, 1968; *Chiastozygus litterarius* (Górka, 1957) Manivit, 1971; *Corollithion exiguum* Stradner, 1961; *Corollithion kennedyi* Crux, 1981; *Cretarhabdus conicus* Bramlette and Martini, 1964; *Cretarhabdus crenulatus* Bramlette and Martini, 1964; *Cribrosphaerella ehrenbergii* (Arkhangelsky, 1912) Deflandre in Piveteau, 1952; *Cyclagelosphaera deflandrei* (Manivit, 1966) Roth, 1973; *Cyclagelosphaera margerelii* Noël, 1965; *Cyclagelosphaera reinhardtii* (Perch-Nielsen, 1968) Romein, 1977; *Cylindralithus serratus* Bramlette and Martini, 1964; *Diazomatolithus lehmanii* Noël, 1965; *Eiffellithus* Reinhardt, 1965; *Eiffellithus eximius* (Stover, 1966) Perch-Nielsen, 1968; *Eiffellithus gorkae* Reinhardt, 1965; *Eiffellithus trabeculatus* (Gorka, 1957) Reinhardt and Gorka, 1967; *Eiffellithus turriseiffelii* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965; *Eprolithus floralis* (Stradner, 1962) Stover, 1966; *Eprolithus rarus* Varol, 1992; *Eprolithus eptapetalus* (= *Lithastrinus eptapetalus*) Varol, 1992; *Flabellites oblongus* (Bukry, 1969) Crux in Crux et al., 1982; *Gartnerago obliquum* (Stradner, 1963) Noël, 1970; *Helenea chiastia* (= *Microstaurus chiastius*) Worsley, 1971; *Kamptnerius magnificus* Deflandre, 1959; *Lithastrinus eptapetalus* (= *Eprolithus eptapetalus*) Varol, 1992; *Lithastrinus grillii* Stradner, 1962; *Lithastrinus moratus* Stover, 1966; *Lithraphidites acutus* Verbeek and Manivit in Manivit et al., 1977; *Lithraphidites alatus* Thierstein in Roth and Thierstein, 1972; *Lithraphidites carniolensis* Deflandre, 1963; *Lithraphidites praequadratus* Roth, 1978; *Lithraphidites quadratus* Bramlette and Martini, 1964; *Lucianorhabdus cayeuxii* Deflandre, 1959; *Lucianorhabdus maleformis* Reinhardt, 1966; *Lucianorhabdus quadrifidus* Forchheimer, 1972; *Manivitella pemmatoidea* (Deflandre in Manivit, 1965) Thierstein, 1971;

Markalius inversus (Deflandre in Deflandre and Fert, 1954) Bramlette and Martini, 1964; *Marthasterites furcatus* (Deflandre in Deflandre and Fert, 1954) Deflandre, 1959; *Microrhabdulus attenuatus* (Deflandre, 1959) Deflandre, 1963; *Microrhabdulus decoratus* Deflandre, 1959; *Microrhabdulus undosus* Perch-Nielsen, 1973; *Micula decussata* (= *Micula staurophora*) Vekshina, 1959; *Micula murus* (Martini, 1961) Bukry, 1973; *Micula praemurus* (Bukry, 1973) Stradner and Steinmetz, 1984; *Micula prinsii* Perch-Nielsen, 1979; *Micula staurophora* (=*Micula decussata*) (Gardet, 1955) Stradner, 1963; *Nephrolithus frequens* Górka, 1957; *Placozygus fibuliformis* (Reinhardt, 1964) Hoffmann, 1970; *Prediscosphaera columnata* (Stover, 1966) Perch-Nielsen, 1984; *Prediscosphaera cretacea* (Arkhangelsky, 1912) Gartner, 1968; *Prediscosphaera grandis* Perch-Nielsen, 1979; *Prediscosphaera spinosa* (Bramlette and Martini, 1964) Gartner, 1968; *Prediscosphaera stoveri* (Perch-Nielsen, 1968) Shafik and Stradner, 1971; *Quadrum gartneri* Prins and Perch-Nielsen in Manivit et al., 1977; *Reinhardtites anthophorus* (Deflandre, 1959) Perch-Nielsen, 1968; *Reinhardtites levis* Prins and Sissingh in Sissingh, 1977; *Rhagodiscus achlyostaurion* (Hill, 1976) Doeven, 1983; *Rhagodiscus angustus* (Stradner, 1963) Reinhardt, 1971; *Rhagodiscus asper* (Stradner, 1963) Reinhardt, 1967; *Rhagodiscus splendens* (Deflandre, 1953) Verbeek, 1977; *Rotelapillus laffittei* (Noël, 1957) Noël, 1973; *Rucinolithus irregularis* Thierstein in Roth and Thierstein, 1972; *Rucinolithus magnus* Bukry, 1975; *Stoverius achylosus* (Stover, 1966) Perch-Nielsen, 1986; *Tegumentum stradneri* Thierstein in Roth and Thierstein, 1972; *Thoracosphaera* Ostenfeld, 1910; *Thoracosphaera saxea* Stradner, 1961; *Tranolithus orionatus* (= *Tranolithus phacelosus*) (Reinhardt, 1966) Reinhardt, 1966; *Uniplanarius gothicus* (= *Quadrum gothicum*) (Deflandre, 1959) Hattner and Wise, 1980; *Uniplanarius sissinghii* (= *Quadrum sissinghii*) Perch-Nielsen, 1986; *Uniplanarius trifidus* (= *Quadrum trifidum*) (Stradner in Stradner and Papp, 1961) Hattner and Wise, 1980; *Vagalapilla matalosa* (Stover, 1966) Thierstein, 1973; *Watznaueria barnesae* (Black, 1959) Perch-Nielsen, 1968; *Watznaueria biporta* Bukry, 1969; *Watznaueria britannica* (Stradner, 1963) Reinhardt, 1964; *Zeugrhabdotus acanthus* Reinhardt, 1965; *Zeugrhabdotus bicrescenticus* (Stover, 1966) Burnett in Gale et al., 1996; *Zeugrhabdotus diplogrammus* (Deflandre in Deflandre and Fert, 1954) Burnett in Gale et al., 1996; *Zeugrhabdotus embergeri* (Noël, 1958) Perch-Nielsen, 1984; *Zeugrhabdotus erectus* (Deflandre in Deflandre and Fert, 1954) Reinhardt, 1965; *Zeugrhabdotus spiralis* (Bramlette and Martini, 1964) Burnett, 1997.

Appendix II - Age-indicative species

Cenomanian

- *Helenea chiastia* is present in the Cenomanian assemblages (up to the CC10) of Antola and Cassio Units, and in the succession assigned to the basal complexes of San Donato in Poggio and Monteverdi Marittimo HF. Its LO is a useful event because the species occurs also in poor preserved and depleted assemblages.
- *Corollithion kennedyi* is an easily recognizable species that occurs in the Cassio Unit and in the succession assigned to the basal complexes of San Donato in Poggio, Monteverdi Marittimo and Larderello HF. Its presence permits the identification of the middle-late Cenomanian (CC9 *p.p.*-CC10 *p.p.*), and both its FO and LO are useful to improve the biostratigraphic resolution of the CC9 and CC10 zones respectively.
- *Lithraphidites acutus* is only present in a few samples of the succession assigned to the basal complexes of Larderello HF, and specimens of *Lithraphidites* (cfr.) *L. acutus* have been found in the Cassio Unit.
- *Microrhabdulus decoratus* is rare and discontinuous, so that its FO is not reproducible. This taxon is more frequent in well preserved Campanian-Maastrichtian assemblages.

Turonian

- *Quadrum gartneri* is a rare to few species recognizable also in poorly preserved assemblages; hence, its FO is a good event indicating the lower limit of the CC11 Zone (Antola Unit, Scabiazza Sandstone, basal complex of Monteverdi Marittimo HF).
- *Lucianorhabdus maleformis* is extremely rare in the middle Turonian-early Campanian assemblages (Caio and Cassio Units, Solignano Flysch), so that its FO is useless in identifying the CC11/CC12 boundary. In the late Santonian-early Campanian poorly preserved assemblages of Caio, Cassio and Solignano Units it could be mistaken with *L. cayeuxii*.
- *Eiffellithus eximius* is usually present in the middle Turonian-early Campanian assemblages, hence its FO is helpful in indicating the lower limit of the CC12 Zone (Cassio Unit, basal complexes of the San Donato in Poggio and Larderello HF). Its LO (CC22/CC23), instead, should be carefully checked because specimens of *E. eximius* have been found in some late Campanian-Maastrichtian assemblages (e.g. Larderello HF).

Coniacian

- *Marthasterites furcatus* is an extremely rare species, so its FO and LO are useless in identifying the CC12/CC13 and CC18/CC19 boundaries respectively. *M. furcatus* is generally more frequent in the Coniancian-Santonian assemblages of the siliciclastic successions (Cassio Unit, Ostia Sandstones and Scabiazza Sandstone).
- *Micula decussata* is a common species present in the late Coniacian-Maastrichtian assemblages. The FO of *M. decussata* is a sharp and easily reproducible event, useful in identifying the lower limit of the CC14 Zone (Ostia Sandstone and Scabiazza Sandstone).

Santonian

- *Reinhardtites anthophorus* is usually present in the Santonian-Campanian assemblages, hence its FO is a good event to identify the CC15 Zone lower boundary (Cassio Unit). The LO of *R. anthophorus* (CC22/CC23) is, instead, difficult to detect because this taxon is rare in its final range. Furthermore, specimens of *R. anthophorus* are present above its stratigraphic range, and in poor preserved assemblages are indistinguishable from the younger *R. levis*.
- *Lucianorhabdus cayeuxii* is usually present in the Santonian-Maastrichtian assemblages (Caio, Antola, and Cassio Units). However, in poor preserved assemblages a careful investigation is required in order to distinguish *L. cayeuxii* from *L. maleformis,* consequently the FO of *L. cayeuxii* is not always helpful in identifying the CC15/CC16 boundary. From the late Santonian, the *Lucianorhabdus* population is dominated by *L. cayeuxii*.
- *Calculites obscurus* is a common species, easily recognizable in the Santonian-Maastrichtian assemblages.

Thus, the FO of *C. obscurus* is a good event allowing the determination of the CC17/CC18 boundary (e.g. Monteverdi Marittimo HF).

Campanian

- *Broinsonia parca* is a characteristic taxon of the Campanian assemblages. The FO of *B. parca* is a good event in placing the CC18 Zone lower boundary (Monteverdi Marittimo HF), whilst the LO of *B. parca* (CC23) is useless because the taxon is rare to very rare in its final range, and is sometimes present above its range (e.g. Caio Unit).
- *Ceratolithoides aculeus* is a rare to few species, always present in the Campanian-Maastrichtian assemblages. The FO of *C. aculeus* is a good event to identify the CC19/CC20 boundary (e.g. Ottone, Caio, Antola Units, San Donato in Poggio and Larderello HF).
- *Uniplanarius gothicus* though with a low percentages, it is frequently present in different units (e.g. Ottone, Caio, Antola and Cassio Units; Solignano Flysch; Monteverdi HF). In many investigated successions, the FO of *U. gothicus* appears to be a good event to identify the lower limit of CC21 Zone.
- *Uniplanarius sissinghii* is very rare and discontinuous, so its FO is useless.
- *Uniplanarius trifidus* is usually present in the late Campanian assemblages of the External Ligurids (Ottone, Caio, Antola and Cassio Units; Solignano Flysch; Chianni, San Donato in Poggio and Monteverdi Marittimo HF), and its FO is useful to identify the lower limit of the CC22 Zone, even if, it can be sometimes rare in its initial range. *U. trifidus* becomes rare and discontinuous in the upper part of its range, so its LO (CC223/CC24) should be carefully checked.
- *Tranolithus orionatus* is frequently present in the Cenomanian-Campanian assemblages, but its LO is not useful in identifying the CC24 lower boundary, because specimens of this species are also found above its range, in Maastrichtian assemblages of Antola Unit and Larderello HF.
- *Reinhardtites levis* can be confused with *R. anthophorus*, so that the FO of *R. levis* proves to be useless (Caio and Antola Units; San Donato in Poggio and Monteverdi Marittimo HF). The LO of *R. levis* is also difficult to recognize because of few specimens of this taxon have been recorded above its stratigraphic range (e.g. Antola and Caio Units, Larderello HF). However the presence of *R. levis,* with the absence of *U. trifidus*, is helpful in recognizing the CC24 Zone.

Maastrichtian

- *Arkhangelskiella* spp. is frequently present in the Maastrichtian assemblages and, in some successions (i.e. Antola Unit and San Remo Flysch), we recognize a significant increase of the taxon. This common occurrence can be correlated with the increase of large *Arkhangelskiella* placed by Sissingh (1977) slightly before the LO of *R. levis*. Consequently we propose the use of the FCO of *Arkhangelskiella* spp. as a biostratigraphical signal helpful in defining the lower boundary of the CC25 Zone.
- *Lithraphidites quadratus* usually occurs in low percentages (Caio and Antola Units; Monteverdi Marittimo and Larderello HF), however its presence is helpful in recognizing the upper part of the CC25 Zone and the CC26 Zone.
- *Micula murus* is present, though with a low number of specimens, in many successions (e.g. Antola and Caio Units; Larderello HF). The FO of *M. murus* is detectable in continuous successions of well preserved assemblages allowing the subdivision of the CC25 Zone.
- *Nephrolithus frequens* is very rare and discontinuously present (Caio and Antola Units; Larderello HF). Nevertheless, the FO of *N. frequens* is useful in defining the CC26 lower boundary, and its presence allows the recognition of the latest Maastrichtian CC26 Zone.
- *Ceratolithoides kamptneri* is present with extremely rare specimens in several sections (Caio, Cassio and Antola Units; San Remo Flysch), and its presence can help to define the CC26 Zone.
- *Micula prinsii* is extremely rare in the assemblages of Antola and Caio Units; however its presence allows the identification of the latest Maastrichtian (upper part of CC26 Zone).

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