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THE MIDDLE EOCENE IN THE ALPINE RETROFORELAND BASIN (NORTHERN ITALY): SEDIMENTARY RECORD OF A "MESO-ALPINE" ARC-TRENCH SYSTEM IN THE ALPS

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Abstract. The middle Eocene Cibrone Formation of Brianza (central-western Lombardy) represents an important stratigraphic record to understand a key step of the tectonic evolution of the Alpine range poorly recorded elsewhere. Quantitative petrographic analysis of turbidite arenites, well-constrained in age by the biostratigraphy of interlayered marlstones based on calcareous foraminifera and nannoplankton, allowed us to identify a possible vertical compositional trend within the Cibrone Fm. and to document the NP17 nannofossil Zone (Bartonian) in central Lombardy exposures, east of the Ternate Formation outcrop area. Variable arenite compositions are interpreted to reflect contributions from different source areas, i.e., recycled orogen, island arc, and starved continental shelf. In a paleogeographic scenario still open to different interpretations, the proposed reconstruction supports a classical plate tectonics model for arc-trench systems. The stratigraphic gap, recorded everywhere in Lombardy, between the Eocene succession and the base of the Gonfolite Lombarda Group (upper NP24 nannofossil Zone, early Chattian), corresponds to the earliest stage of continental collision, uplift and erosion that climaxed in the Neo-Alpine Phase.

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time

T.S. Eliot, Four Quartets

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Introduction

Relative to other stratigraphic series, the Eocene is poorly represented in the sedimentary successions of the central and western Southern Alps despite being characterized invariably by marine facies, because of sedimentation at relatively low rates that was shortly followed by Alpine collision, uplift and erosion, and due to its structural behaviour as

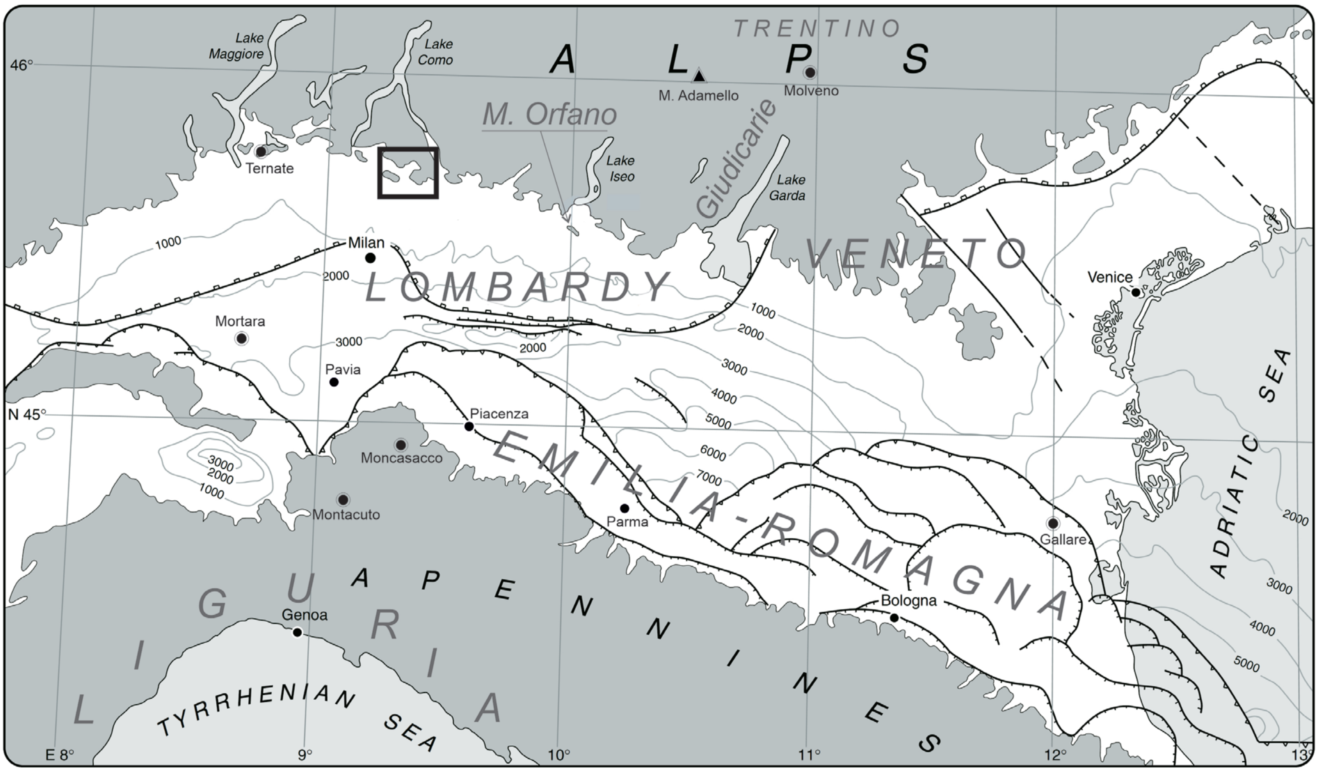


Fig. 1 - Regional location map for the study area. The main structures associated to the Alpine and Apennine fronts, buried below the Po Plain basin fill, are displayed: the isobaths (m) of the Messinian unconformity (Pieri & Groppi 1981; Bigi et al. 1990) are also shown. The investigated area, pictured in detail in Fig. 2, is framed while major cities and relevant localities are located.

a preferential *décollement* horizon during the outward propagation of the Alpine thrusts (Fantoni et al. 2004). In the central Southern Alps (Fig. 1), limited exposures are commonly restricted to the core of synclines and such a fragmentary sedimentary record has probably contributed to the prolonged underrating of the Eocene as a turning point in the Alpine Orogeny; during this epoch not only the metamorphic peak of HP/LT metamorphism in the Western Alps was recorded (Frey et al. 1999), but also the oldest plutonic products, now fringing the Periadriatic Fault System, were emplaced (Callegari & Brack 2002; Lu et al. 2019). According to plate tectonic models, at that time the episutural sedimentary basins should have accommodated detritus from both the growing accretionary prism, formed by tectonic erosion of the Adriatic continental margin (Polino et al. 1990), and the magmatic arc in a hinterland position.

New evidence about the Eocene of central-western Lombardy (central Southern Alps) was acquired during the field mapping of CARG Sheets 096 "Seregno" (Bini et al. 2014) and 097 "Vimercate" (Bersezio et al. 2014). In those sheets, the Eocene is represented by limited outcrops (Fig. 2), not restricted to the classical Tabiago (Premoli Silva & Luterbacher 1966; Kleboth 1982) and Paderno d'Adda (Premoli Silva & Luterbacher 1966; Cita et al. 1968) sections, but also found in the countryside of the small towns of Nibionno, Veduggio con Colzano, Missaglia, and Montevecchia (central and eastern Brianza), where younger sediments are also represented relative to the Tabiago and Paderno sections.

The present paper aims to frame the sedimentary record of those newly found Eocene exposures in the broader scenario of the Alpine Orogeny, cor-

Fig. 2 - Topographic map and close-ups (the latter all the same scale, square grid = 1 km) of the investigated outcrop areas. The near-vertical dotted line crossing the map marks the boundary between the 096 "Seregno" (to the west) and 097 "Vimercate" (to the east) sheets.

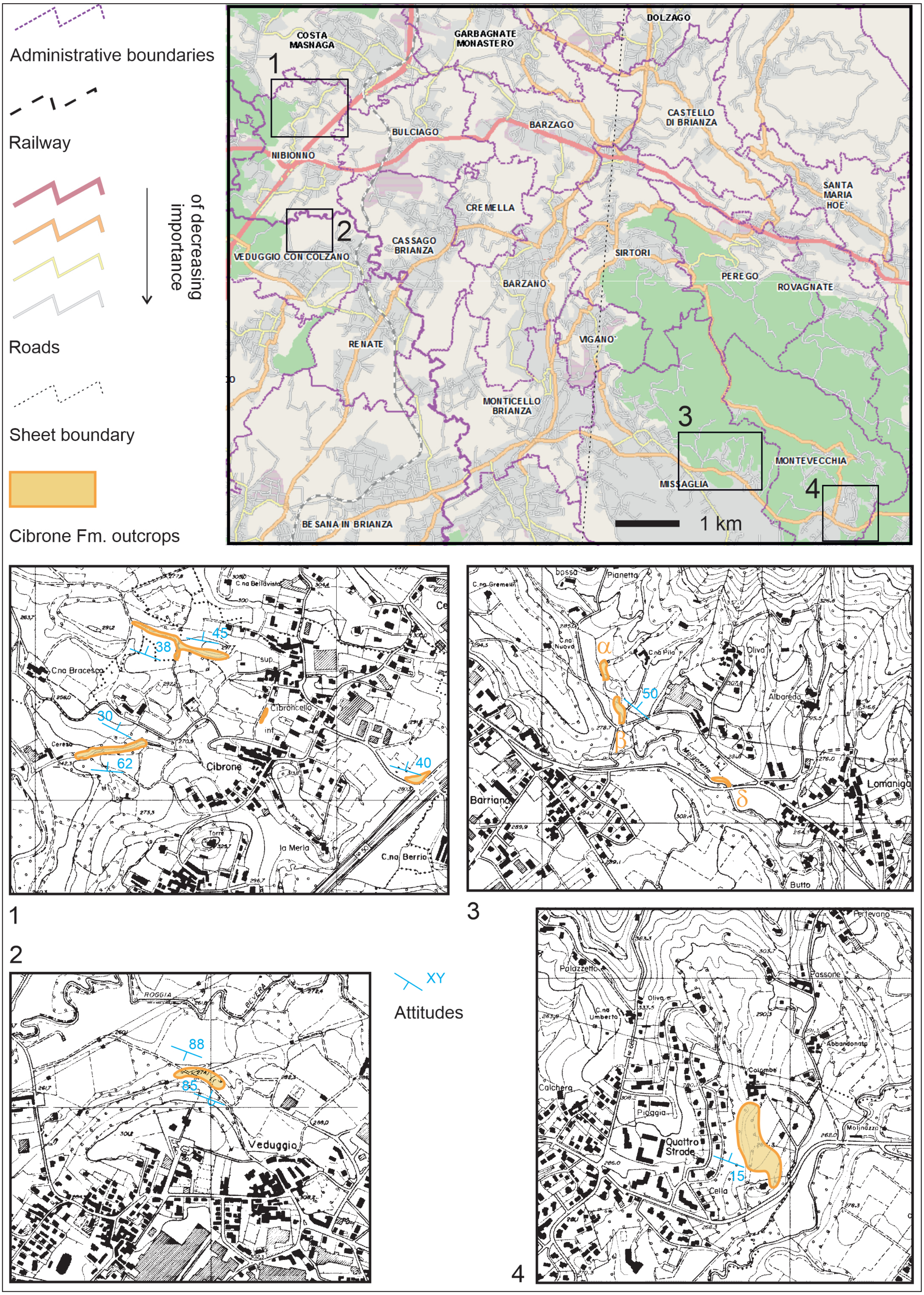

Administrative boundaries
Railway
Roads
of decreasing importance
Sheet boundary
Cibrone Fm. outcrops
COSTA MASNAGA
GARBAGNATE MONASTERO
DOLZAGO
BULCIAGO
BARZAGO
CASTELLO DI BRIANZA
NIBIONNO
SANTA MARIA HOE'
CREMELLA
CASSAGO BRIANZA
SIRTORI
VEDUGGIO CON COLZANO
PEREGO
ROVAGNATE
BARZANO'
VIGANO'
RENATE
MONTICELLO BRIANZA
MONTEVECCHIA
MISSAGLIA
BESANA IN BRIANZA
1 km
1
2
3
4
Cibrone
Veduggio
Attitudes
XY

FIGURE 2

relating such evidence with the more widely studied areas of Ternate (western Southern Alps: Coletti et al. 2016 and references therein) to the west, of the Epiligurian succession of Northern Apennines to the south (Cibin et al. 2001) and of the Trentino-Giudicarie area to the east (e.g., Luciani 1989; Sciunnach & Borsato 1994; Mair et al. 1996; Martin & Macera 2014; Lu et al. 2019). To do this, in the present paper the middle Eocene Cibrone Fm. is characterised in terms of stratigraphy, lithofacies, biostratigraphy, petrography, and single-mineral geochemistry.

Geological setting

After Jurassic to Early Cretaceous structuring of the continental passive margin at the northern border of Adria (Bertotti et al. 1993; Schumacher et al. 1996), a phase of convergence commenced since the Aptian (Arthur & Premoli Silva 1982) and lasted up to the early Maastrichtian, resulting in deposition of up to over 2000 m of flysch in the Lombardian Basin (Bersezio et al. 1993). This tectonic phase, seemingly resulting in a subduction complex limited to the Central and Eastern Alps (Doglioni & Bosellini 1987), and still controversial as to geodynamic interpretation, is often referred to as “pre-Gosau Phase” from the name of a shallow-water clastic unit suturing Cretaceous structures in the eastern Southern Alps. Late Cretaceous tectonics was characterised by HP/LT metamorphism, negligible volcanic activity (Bernoulli et al. 2004), thrusting in the Southern Alps Variscan basement and Permo-Mesozoic sedimentary cover (D’Adda 2010), and by local evidence of emerging land because of incipient orogenesis (Gnaccolini 1971; “eo-Alpine Orogen” of Handy et al. 2010).

From Maastrichtian to earliest Lutetian times, pelagic sedimentation resumed, at low accumulation rates (Tremolada et al. 2008), with little (Maastrichtian) or no (Paleocene-early Eocene) siliciclastic input. Since middle Eocene, marly hemipelagites started to be deposited at higher rates (Premoli Silva et al. 2010), embedding sparse volcaniclastic turbidites.

During the middle to late Eocene, hemipelagic sedimentation is also recorded in adjoining sectors of the Giudicarie Valleys (Ponte Pià Fm., Nago Limestone, Ponte Arche Clayey Marls), while in the western Southern Alps downslope mass movements were triggered by topographic instability of the shelf (upper Eocene Ternate Fm.; Bernoulli et al. 1988; Mancin et al. 2001; Coletti et al. 2016). Early Oligocene sediments seem to record a relative quiescence (Linfano Limestone of the Giudicarie Valleys) during a time interval only documented in ENI subsurface drillings in Lombardy (Pieri & Groppi 1981; Di Giulio et al. 2001), where monotonous silty-marls successions predominate. Such facies, with only occasional clastic intercalations, seem to continue up to the late Oligocene (NP24; Tremolada et al. 2010), when they were truncated by a regional unconformity recognised from Lombardy (Chiasso Fm./Gonfolite Lombarda Group boundary) to Trentino (Linfano Lmst./Mt. Brione Fm. boundary) and Veneto-Friuli regions (base of the *Molassa Veneta* boundary; Stefani et al. 2007), corresponding to the onset of paroxysmal uplift and widespread emergence of the Alpine range. Coarse clastic sedimentation was continuous for most of the Miocene, producing the huge siliciclastic wedges of the Gonfolite Lombarda Group (Tremolada et al. 2010), the Monte Orfano Conglomerate (Sciunnach et al. 2009), the Molassa Veneta (Stefani et al. 2007) and, in the Apennines, the Macigno-Modino (Di Giulio 1999), Cervarola and Marnoso-Arenacea turbidite supersystems (Cibin et al. 2004; Di Giulio et al. 2013).

This evolution (Fig. 3) can be easily framed into the classical tripartition of the Alpine orogenic “phases” (Eoalpine, Mesoalpine, and Neoalpine), that has been challenged by structural studies fo-

Fig. 3 - Ideal stratigraphic column for the Cenozoic succession of central and western Lombardy, compiled after Tremolada et al. (2008; 2010); Premoli Silva et al. (2010); Bini et al. (2014). Standard chronostratigraphy and related biozonation after Gradstein et al. (2020). Faded strata indicate lack of exposure: in such cases, lithology is inferred after drillings or indirect geological evidence. MSC = Messinian Salinity Crisis; PLIOC. TR. = Pliocene transgression. While in central (Tabiago) and western (Montorfano) Brianza the resedimented bodies within the Tabiago Fm. are confined to the Tanethian, in eastern Brianza (Paderno d’Adda) they form a continuum with the overlying, so-called “Paderno Nummulitic breccias”, which extend into the NP12 Zone (Ypresian) and, reportedly, reach the Lutetian (Bersezio et al. 2014; Bini et al. 2014; F. Tremolada, own unpublished data).

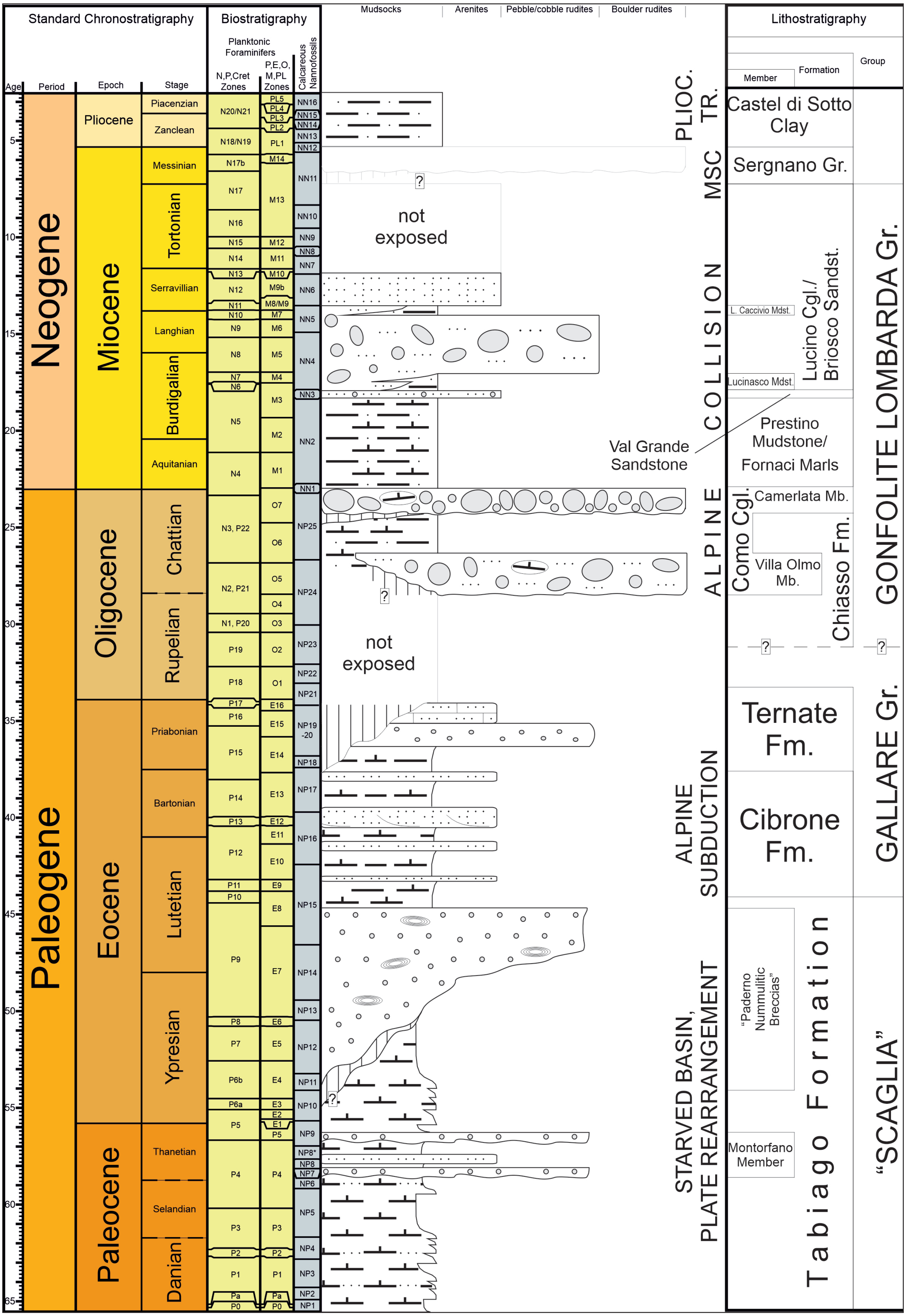

Standard Chronostratigraphy
Biostratigraphy
Lithostratigraphy
Age
Period
Epoch
Stage
Planktonic Foraminifers
N,P,Cret Zones
P,E,O, M,PL Zones
Calcareous Nannofossils
Mudsocks
Arenites
Pebble/cobble rudites
Boulder rudites
Member
Formation
Group
Neogene
Paleogene
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Piacenzian
Zanclean
Messinian
Tortonian
Serravillian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
not exposed
not exposed
Val Grande Sandstone
PLIOC. TR.
MSC
ALPINE COLLISION
ALPINE SUBDUCTION
STARVED BASIN, PLATE REARRANGEMENT
Castel di Sotto Clay
Sergnano Gr.
L. Caccivio Mdst.
Lucinasco Mdst.
Lucino Cgl./ Briosco Sandst.
Prestino Mudstone/ Fornaci Marls
Camerlata Mb.
Como Cgl.
Villa Olmo Mb.
Chiasso Fm.
GONFOLITE LOMBARDA Gr.
Ternate Fm.
Cibrone Fm.
GALLARE Gr.
"Paderno Nummulitic Breccias"
Montorfano Member
Tabiago Formation
"SCAGLIA"

FIGURE 3

Fig. 4 - Typical facies of the studied Pl-arenite beds and the intercalated marlstones. A = Cibrone Fm., Cibrone SS36 exit. Decimetric arenite beds displaying sharp base, with flute casts and other countermarks, and cross- to parallel lamination, can be interpreted as T_{cde}, T_{de} Bouma sequences. B = Marne di Monte Piano, Rio Roncale, Montacuto. Sharp-based, massive arenite beds grade upwards to the intercalated marlstone.

cused on the brittle kinematics of the Southalpine retro-wedge (e.g., Schönborn 1992). According to this model, Alpine evolution can be reduced merely to "pre-Adamello" and "post-Adamello" steps, based on the analysis of mutual geometric relationships of brittle horses within thrust stacks and on balanced palynspastic reconstructions. While the "Eoalpine" Cretaceous flysch deposition is obviously pre-Adamello, the latest Oligocene to Late Miocene deformation coincides with the post-Adamello "phase": yet, Eocene volcanism presumably is one of the few sources of evidence for a "syn-Adamello" (Mesoalpine?) tectonic activity, that reportedly did not result in thrust stacking in the Southern Alps, but is coeval with HP/LT metamorphism in the Western Alps (Frey et al. 1999) and arc magmatism along the Periadriatic Lineament (Callegari & Brack 2002; D'Adda et al. 2010).

Previous studies and stratigraphic nomenclature

The available literature on the Eocene of central and eastern Brianza can be subdivided into four main types: 1) local studies, generally aiming at a detailed biostratigraphic frame, 2) district studies related to geological mapping, 3) regional studies, mostly addressed to oil potential assessment and commonly relying on subsurface data, and 4) provenance studies, focused on petrography, geochemistry, and fission-track (FT) analysis of clastic sediments to reconstruct the regional paleotectonic evolution. The studies by Franchino (1958), Bolli & Cita (1960a, 1960b), Cita (1965), Premoli Silva & Luterbacher (1966), Cita et al. (1968), Kleboth (1982), Franchino & Cairo (1984), Tremolada et al. (2008), Premoli Silva et al. (2010) belong to the first group. The second group includes the explanatory memories by Venzo (1954), Galbiati (1969), Bersezio et al. (1990, 2014), Bini et al. (2014). The third group consists of studies mostly performed by ENI geologists, such as Rizzini & Dondi (1979), Dondi et al. (1982) and, more recently, Di Giulio et al. (2001). In the fourth group the studies by Di Giulio et al. (2005), Malusà et al. (2011), Martin & Macera (2014), Sciunnach (2014), and Di Capua et al. (2021a, b) can be included.

While the lower Eocene of Brianza is composed by marls and marly limestones ("Scaglia" facies, Tabiago Fm.; Tremolada et al. 2008 and references therein), a major lithostratigraphic boundary occurs within the Lutetian, where the "Scaglia" facies are replaced upwards by monotonous hemipelagic marlstones, with rare and thin veneers of arenites and volcaniclastics. The most comprehensive lithostratigraphic term introduced for these rocks all over western and central Northern Italy is the "Marne di Gallare" Group, a unit defined by AGIP geologists in the Emilia-Romagna subsurface (Rizzini & Dondi 1979; Dondi et al. 1982) and including middle Eocene to Miocene hemipelagic sediments across the Po and Venetian plains subsurface, as well as several formations from dif-

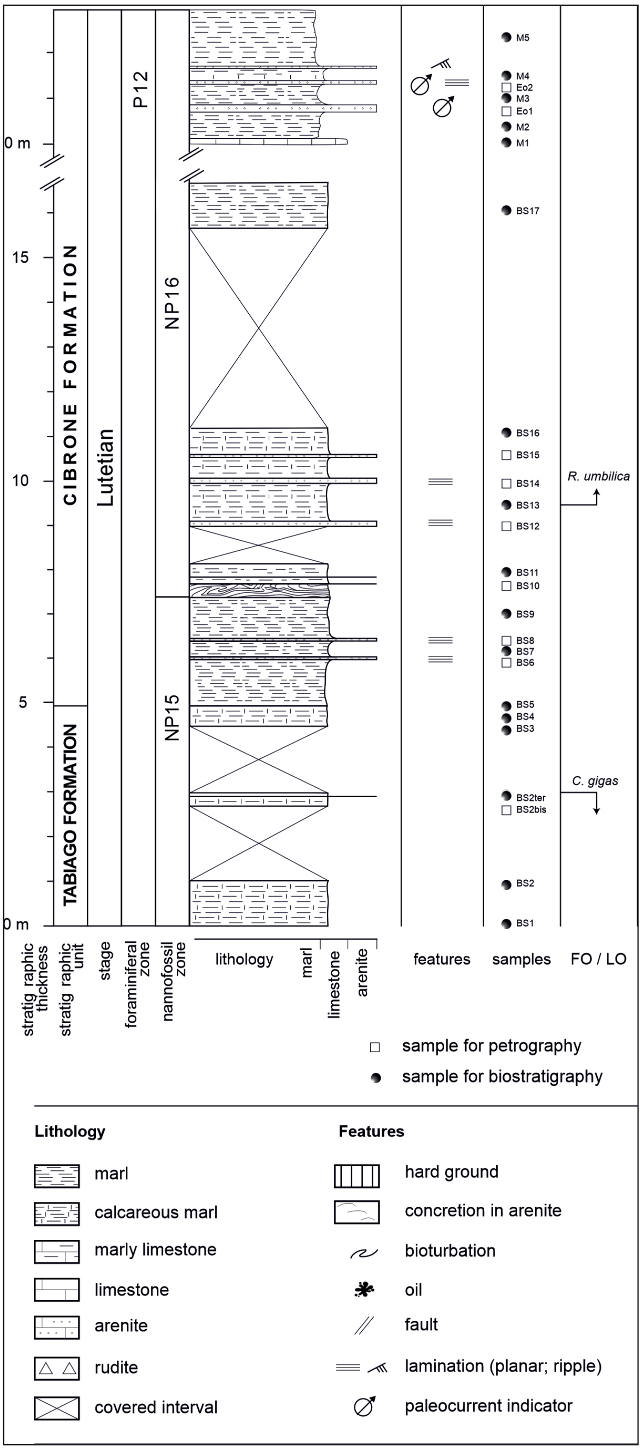


Fig. 5 - Stratigraphy of the Cibrone Fm. in the Cibrone composite section. The lower part, where the boundary with the underlying Tabiago Fm. is exposed, is ideally topped by the outcrop at the SS36 exit (see Fig. 4A). Modified from Bini et al. (2014).

ferent structural units of the Apennines, where the traditional terms "Scaglia Variegata", "Scaglia Cinerea" (Petti & Falorni 2005a) and "Bisciaro" (Petti & Falorni 2005b) are also rooted in the literature. The apparently subtle shift in sedimentation patterns between "Scaglia" facies and "Marne di Gallare" is regarded as a major turning point in Alpine evolution (Di Giulio et al. 2001), as we will highlight further in the paper.

More recently, the prevailingly marly sediments of middle Eocene age of central and eastern Brianza have been classified as Cibrone Fm. (Premoli Silva et al. 2010; Bini et al. 2014), a lithostratigraphic unit hierarchically subordinate to the Marne di Gallare Group. Although the Italian stratigraphic nomenclature is biased by redundant local names, introduction of a new lithostratigraphic unit has been recommended in this case to identify a distinctive marly unit, exposed in natural and artificial outcrops, conformably overlying Paleocene to earliest Lutetian marlstones and marly limestones in "Scaglia" facies that, in the Brianza area, take the formal name of Tabiago Fm. (Bini et al. 2014).

Eocene chronostratigraphy and geochronology: a necessary premise

The Eocene global timescale is currently under review, due to the uncertain definition of the Bartonian Stage. In the traditional literature, the Eocene has been subdivided into a lower part, coinciding with the Ypresian Stage; a middle part, including the Lutetian and Bartonian Stages; and an upper part, coinciding with the Priabonian Stage. In the recent contribution by Agnini et al. (2021) defining the GSSP for the base of the Priabonian Stage (late Eocene), such informal subdivision was abandoned, recommending the proper use of Eocene stages. Nonetheless, for the sake of simplicity and for coherence with most of the cited literature, in the present paper we still adopt the early/middle/late tripartition of the Eocene, regarding the Bartonian Stage as the later part of the middle Eocene.

Field data

With few notable exceptions, outcrop conditions of the Eocene Cibrone Fm. are very poor; even scarcer than for the underlying Tabiago Fm., that has been quarried to produce cement and that, with the more resistant Montorfano Mb., finds some remarkable natural exposures (Kleboth

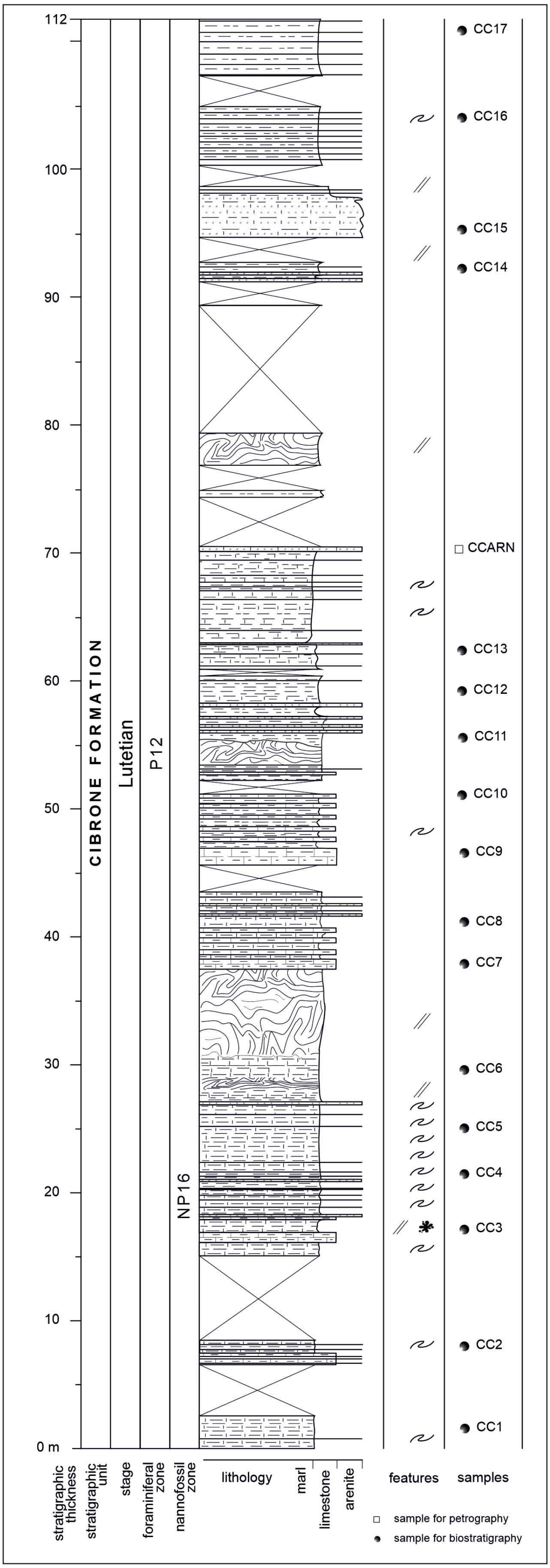


Fig. 6 - Stratigraphy of the Cibrone Fm. in the Rio di Ceresa section. Symbols as in Fig. 5.

1982). After careful field work carried out during the first decade of 2000 for the geological mapping of the Sheets 096 "Seregno" and 097 "Vimercate", four main outcrop areas of the Cibrone Fm. (Fig. 2) have been identified, west to east:

1) the town of Nibionno and its surroundings, where the type-locality of Cibrone Fm. occurs. At Cibrone, both artificial and natural outcrops are found: the former include the SS36 exit (Figs. 4A and 5) and Cibroncello outcrops, while the latter are best represented by the Cibrone Cemetery section, where the boundary with the underlying Tabiago Fm. is exposed (Fig. 5), and by the thickest measured section of Rio di Ceresa (Fig. 6). The SS36 exit outcrop, where the samples RL/A1 and RL/A2 studied by Malusà et al. (2011) were taken, is remarkable also due to the basal countermarks in sandstone beds indicating westward paleocurrents (Bini et al. 2014).

2) the hillock north of the San Martino Church, Veduggio, where massive or poorly bedded marlstones are exposed, and a single sandstone bed was sampled. The outcrop lies just about 1.5 km apart from the Renate outcrop belonging to the Gonfolite Lombarda Group (sample GLGB1 of Tremolada et al. 2010: nannofossil Zone NN1), with the Quaternary deposits in between masking a major tectonic boundary between the tightly folded Cretaceous to Eocene succession to the north-east and the gently buckled homocline of the GLG to the south-west (Bini et al. 2014).

3) the Rio Molgoretta section, Missaglia. Three natural outcrops, labelled as alpha, beta, and delta in ascending stratigraphic order (Fig. 7; Tab. 2), are characterized by thicker beds of coarse-grained bioclastic arenites, pebbly arenites, and fine-grained rudites, locally with nodular concretions and deeply recrystallized surfaces, particularly stiff at hammering (hard grounds); only the topmost "delta" outcrop consists of monotonous marlstones. In earlier maps by Galbiati (1969) and Bersezio et al. (1990) all these outcrops were interpreted as belonging to the Cretaceous Bergamo Flysch, whereas in the Sheet 097 Vimercate they have been included into the Cibrone Fm. (Bersezio et al. 2014) despite coarser arenite grain size and a more abundant, coarse-grained bioclastic fraction relative to the Cibrone type-locality.

4) the woods between Quattro Strade and Cascina Colombé, Montevecchia. Sparse outcrops of prevailing marlstones and up to coarse-grained arenites had been studied for foraminiferal content by previous authors (Franchino & Cairo 1984) and

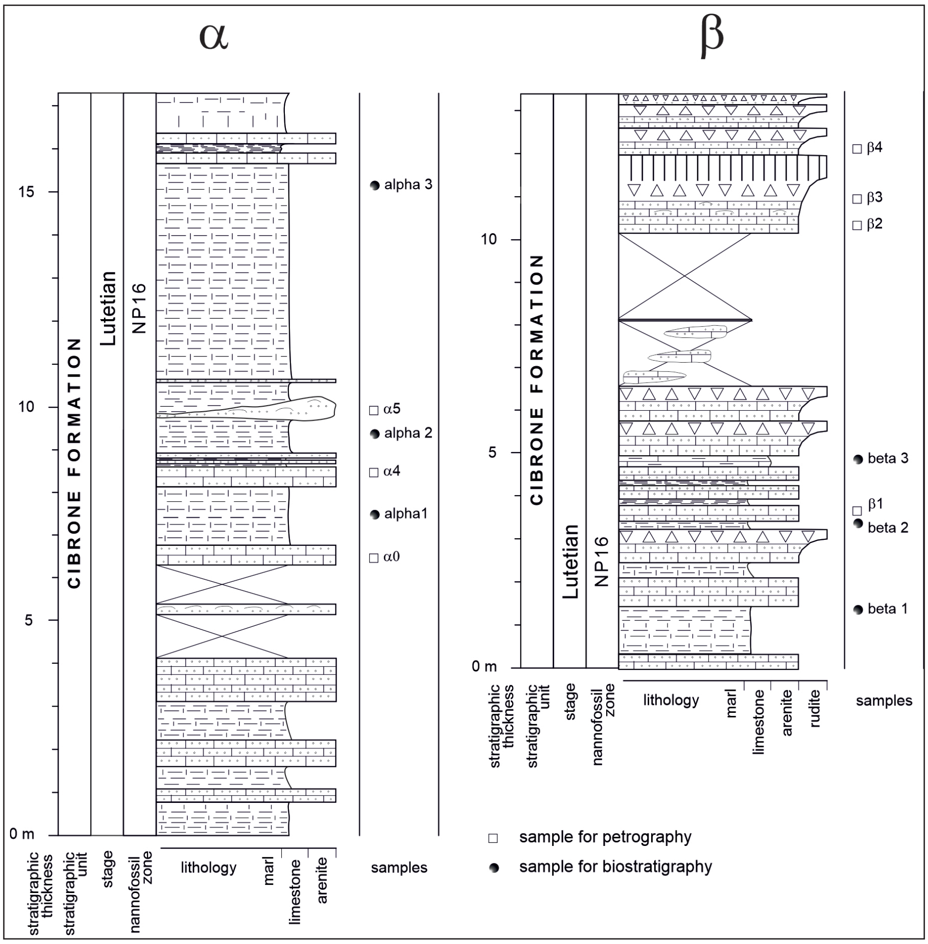
Section/Outcrop	Age	Formation	Foraminifera Zone	Sample	Abundance	Preservation	Other components	*Acarinina bullbrooki*	*Acarinina* sp.	*Catapsydrax unicavus*	*Globigerinatheka index*	*Globigerinatheka subconglobata*	*Globigerinatheka* cf. *korotkovi*	*Globigerinatheka* sp.	*Globorotaloides eovariabilis*	*Globoturborotalita martini*	*Guembelitrioides nuttalli*	*Hantkenina dumblei*	*Morozovelloides bandyi*	*Morozovelloides crassatus*	*Morozovelloides* cf. *bandyi*	*Morozovelloides* sp.	*Parasubbotina pseudowilsoni*	*Parasubbotina varianta*	*Parasubbotina* sp.	*Planorotalites* sp.	*Planorotalites* ?	*Pseudohastigerina micra*	*Pseudohastigerina* sp.	*Pseudohastigerina* ?	*Subbotina corpulenta*	*Subbotina eocaena*	*Subbotina linaperta*	*Subbotina senni*	*Subbotina yeguaensis*	*Subbotina* cf. *corpulenta*	*Subbotina* cf. *crociapertura*	*Subbotina* sp.	*Turborotalita carcosellensis*	*Turborotalia frontosa*	*Turborotalia pomeroli*	*Turborotalia possagnoensis*	*Turborotalia* cf. *pomeroli*	*Turborotalia* cf. *possagnoensis*	*Turborotalia* sp.	*Turborotalia* ?	*Turborotalita* ?	***Pearsonites broedermanni***
Rio di Ceresa	middle Eocene (Lutetian)	Cibrone	P12	CC17	F	P	b,r	x	x	x				x	x											x							x					x		x								
				CC16	R	P-M		x	x	x												x																x		x								**rw**
				CC15	VR	P	b,o	x												x										x						x		x										
				CC14	VR	P	b	x		x																x					x							x								x		
				CC13	C	P-M	b,o	x		x				x				x									x	x			x	x					x			x								
				CC12	F	M	b		x	x				x				x						x				x					x			x		x		x								
				CC11	R	M	b	x		x				x										x						x				x				x						x				
				CC10	R	M	b,o,r	x		x				x							x				x			x				x				x		x		x								
				CC9	R	P	b	x	x	x				x														x						x			x	x		x					x			
				CC8	R	VP-P	b,o,r	x		x	x			x														x								x		x									x	
				CC7	F	M	b,o	x		x		x		x	x		x								x						x			x				x		x								
				CC6	A	M-G	b	x	x	x	x	x		x																	x	x						x		x								
				CC5	A	M	b	x		x	x	x	x	x																						x		x		x			x					
				CC4	C	M	b,o	x	x			x		x						x						x					x							x		x								
				CC3	C	P-M	b	x	x			x		x						x								x			x	x		x				x		x			x					
				CC2	A	P-M	b,o	x		x														x				x			x									x				x				
				CC1	C	P	b,o	x		x												x						x	x							x		x										
Cibrone SS36 exit				M5	R	P	b	x		x								x	x					x							x	x		x				x		x								**rw**
				M4	C	M	b,e	x		x		x		x		x		x						x				x			x				x			x		x								
				M3	R	M	b	x		x				x				x										x			x	x		x				x		x	x							
				M2	R	P-M	b	x									x		x																			x	x	x		x						
				M1	C	P	b	x		x	x	x		x			x	x					x					x			x	x		x				x		x								

Tab. 1 - Stratigraphic distribution of planktonic Foraminifera and their abundance from the Rio di Ceresa section (samples CC) and Cibrone SS36 exit (samples M). Foraminifera Zone, after Berggren and Pearson (2005), equated to E 10-E11 of Pearson et al. (2006). Abundance: VR = very rare, R = rare, F = few, C = common, A = abundant; Preservation: VP = very poor, P = poor, M = moderate, G = good; rw = reworked; b = benthic foraminifera, e = echinoid spines, o=ostracods, r = radiolarians.

Tab. 2 - Range chart for the recognized calcareous nannofossil species. Preservation: P = poor, M = moderate, G = good. Abundance/occurrence: R = rare (1-4 specimens/100 Field of View), F = few (5-15 specimens/100 Field of View), C = common (16-30 specimens/100 Field of View), A = abundant (>31 specimens/100 Field of View). The gray pattern indicates first or last occurrences relevant for the calcareous nannofossil zonation.

Section/Outcrop	Cibrone cemetery (boundary section)												Cibron-cello		Quattro Strade	Missaglia Rio Molgoretta									Cibrone SS36 exit					Rio di Ceresa							Veduggio		
Age	middle Eocene (Lutetian)												m. Eocene (Lutetian)		m. Eocene (Lutetian)	middle Eocene (Lutetian)									middle Eocene (Lutetian)					middle Eocene (Lutetian)							Bartonian		
Formation	Tabiago						Cibrone						Cibrone		Cibrone	Cibrone									Cibrone					Cibrone							Cibrone		
Nannofossil Zone (Martini, 1971)	NP15b			NP15c					NP16				NP16		NP16	NP16									NP16					NP16							NP 17		
Sample	BS1	BS2	BS2ter	BS3	BS4	BS5	BS7	BS9	BS11	BS13	BS16	BS17	CM5	CM4	QS2	alpha 1	alpha 2	alpha 3	beta 1	beta 2	beta 3	δ 1	δ 2	δ 3	M1	M2	M3	M4	M5	CC1	CC2	CC3	CC4	CC5	CC6	CC7	Ve1	Ve2	Ve4
Abundance	A	A	A	A	A	A	A	A	A	A	A	F	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Preservation	M	G	M	G	M	M	M	M	M	M	M	M	P	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Calcidiscus? protoannulus											R												R	R				R					R		R	R			
Campylosphaera dela	R	R	R					R	R		R		R	R				R		R					R			R		R		R	R						
Chiasmolithus consuetus	R		R				R	R		R	R	R	R	R	R	R			R	R				R	R		R	R	R		R	R		R	R	R	R	R	
Chiasmolithus grandis													R	R	R					R																	R	R	R
Chiasmolithus modestus																		R?																					
Chiasmolithus solitus	R	R	R				F	R	R	R	R		R	R	R	R	R	R		R					R			R		R		R		R	R				
Chiasmolithus spp.	R	R			R	R			R		R			R	R			R		R				R		R		R		R	R		R		R		R	R	
Clausicoccus fenestratus									R		R		R	R		R	R	R	R	R	R	R	R	R	R	R		R		R	R		R		R				
Coccolithus eopelagicus																																					R	R	R
Coccolithus pelagicus	A	A	A	A	A	A	A	A	A	A	A	A	C	A	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	C	C	F
Coronocyclus nitescens	R	R	R				R	R	R	R	R	R	R	R	R	R	F	R	R	R	R	R	R	R	R	R		R	R		R	R	R		R	R	R		
Cribrocentrum reticulatum									**R**		R		R	R	R	R	R		R		R			R	R		R	R	R	R	R		R	R	R	R	R	R	
Cyclicargolithus floridanus	R	R	F	R	R	F	R	R	F	R	R	R	C	C	C	C	C	C	C	C	C	C	C	C	R	F	F	F	R	F	F	R	F	R	F	R	A	A	A
Discoaster barbadiensis	R	R	R		R		R	R	R	R	R			R	R	R	R	R	R	R	F	R	R	R	R	R		R	R	R	R	R	R	R	R	R	R		R
Discoaster bifax										R	R													R				R			R			R	R				
Discoaster distinctus																																		R		R			
Discoaster deflandrei	R		R				R		R	R	R		R						R	R		R		R	R	R	R	R	R		R	R	R	R	R	R	R	R	
Discoaster saipanensis									R	R	R					R	R		R	R	R	R		R		R	R	R	R	R	R	R	R	R	R	R			
Discoaster spp	R	R	R				R	R			R		R	R	R	R	R		R	R		R		R	R			R			R	R			R		R	R	R
Discoaster spp. (6 ray)															R																								
Ericsonia formosa		R	R				R	F	F	R	R		F	F	R	R	R	F	F	R	F	F	R	R	F	F	R	R	F	F	R	F	F	R	R	F	C	F	R
Ericsonia obruta																								R?															
Helicosphaera bramlettei										R	R	R		R										R			R	R	R			R		R	R	R			
Helicosphaera compacta																																					R		
Helicosphaera lophota							R		R		R				R				R												R		R		R		R		
Helicosphaera seminulum							R													R																			
Lanternithus minutus													R		R	F	F	F	F	R	F	F	F	R															
Markalius apertus													R																										
Markalius inversus													R																										
Nannotetrina quadrata			R		R						R																												
Neococcolithes dubius							R			R				R	R			R				R		R							R						R		
Pedinocyclus larvalis		R							R		R								R		R					R					R		R		R				
Pletolithus gigas	R	R	**R**																																				
Pontosphaera spp.			R				R	R	R		R							R	R		R	R	R		R	R	R	R			R		R		R				
Reticulofenestra bisecta				R				R	R	R	R	R	F	F	F	A	A	A	A	A	A	A	A	A	F	F	F	F	F	R	F	F	F	F	R	F	F	C	R
Reticulofenestra dictyoda	A	A	A	A	A	A	A	A	A	A	A	A	C	C	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A			
Reticulofenestra hillae								R											R			R																	
Reticulofenestra lockeri																																					R	R	
Reticulofenestra minuta group	F	F	F	F	F	F	F	F	F	F	F	F	F	F	C	C	A	C	C	C	A	C	C	C	F	F	F	F	F	F	C	F	F	F	C	F	C	C	F
Reticulofenestra umbilicus										**R**	R	R	F	F	F							**R**	R	R	R		R	R	R	R	R		R	R	R	R	F	F	R
Rhabdosphaera pinguis			R													R																							
Sphenolithus furcatolithoides	R	R		R	R	R	R	R	R	R	R	R	R	R	R		R			R	R	R		R	R	R	R	R	R	R	R	R	R	R	R	R			
Sphenolithus moriformis	F	F	F	F	F	F	F	F	F	F	R	F	C	C	C	F	F	F	C	F	F	F	F	R	F	C	F	R	F	R	F	R	F	F	R	F	C	C	R
Sphenolithus predistentus														R	R																						R	R	
Sphenolithus pseudoradians	R	R	R	R	R	R	R	R	R	R	R	R	R						R		R	R		R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Sphenolithus radians	R		R								R?						R		R						R			R		R	R	R	F	R	R	R	R		
Sphenolithus spiniger	R			R	R			R						R		R	R	R	R	R																			
Toweius? gammation	R	F	R	R	R	F	R	R		F	R		R			R	R	R	R	R	R		R	R	R	F	F	R	R	F	R	R	R	F	R	R			
Transversopontis spp.								R			R							R		R					R	R		R			R	R			R				
Zygrhablithus bijugatus	R	R	R	F	R	R	R	R	R	R	R	R	R	F		R	F	F	F	F	F	R	R	R	R	R	R	R	R	R	F	R	R	R	R	R	R		
Reworked Cretaceous													R																								R		R

Fig. 7 - Stratigraphy of the Cibrone Fm. in the Rio Molgoretta section, Missaglia. Subsections "alpha" and "beta" as in Fig. 2; symbols as in Fig. 5. Redrawn from Bersezio et al. (2014).



then referred to the *Hantkenina aragonensis* and *Globigerinatheka subconglobata* zones (middle Eocene); they have thus been interpreted as belonging to the Cibrone Fm. in the Sheet 097 Vimercate (Bersezio et al. 2014) based on lithofacies and age. Northwards, sparse outcrops of variegated marlstones have been mapped as Tabiago Fm. (Bersezio et al. 2014). New sampling for arenites and calcareous marlstones carried out in the present work confirmed the occurrence of both formations.

In all the four outcrop areas, the Cibrone Fm. occurs on the limbs or at the cores of tight folds involving all the underlying stratigraphic units down to the Cretaceous Flysch units at least, being the Bruntino Marl a possible *décollement* horizon relative to the underlying Maiolica-Selcifero-Medolo succession (Fantoni et al. 2004).

Similar outcrops of the Cibrone Fm. are found as eastward as the Adda River, at Sabbione di Imbersago and Paderno d'Adda, where the NP15c nannofossil Zone has been identified in a few samples from sparse outcrops (Scardia and Tremolada, unpubl. data).

Materials and methods

For the study of planktonic foraminifera 22 total marlstone samples were analyzed, 5 of which collected in the Cibrone SS36 exit outcrop and 17 sampled in the Rio di Ceresa section.

Samples have been crushed and treated with diluted hydrogen peroxide; disaggregation resulted to be fair. Three grain size fractions (>250 μm, >150 μm and >40 μm) have been separated by water sieving.

Planktonic foraminifera have been qualitatively analysed to identify bioevents useful for the zonal attribution of the section(s). Foraminiferal taxonomy adopted in this study follows Berggren and Pearson (2005) and Pearson et al. (2006) (see also Wade et al. 2011).

For the study of calcareous nannofossils 42 total productive rock samples have been processed by using the standard technique described in Bown & Young (1998) and investigated to provide a detailed biostratigraphic framework. A total of 17 samples were collected in the Cibrone composite

(Cemetery + SS36 exit) section, 9 from the Rio Molgoretta section near Missaglia, 7 from the Rio di Ceresa section (corresponding to the seven older samples studied for foraminifera), 3 from the Veduggio outcrop, 3 from the Paderno d'Adda section, 2 from the Cibroncello outcrop and one from the Quattro Strade outcrop. In this study, we have adopted the nannofossil biozonations of Martini (NP biozonation, 1971) with modifications (and subzones) proposed by Perch-Nielsen (1985), Aubry (1991) and Michelsen et al. (1998), and the GTS 2020 timescale (Gradstein et al. 2020). Since primary zonal markers are often absent, some nannofossil zones were obtained by combining the stratigraphic ranges of secondary markers as documented in Nannotax (https://www.mikrotax.org/Nannotax3/).

From 21 arenite samples, obtained from all the main investigated sections as well as from sparse outcrops, standard 25 x 40 mm thin sections have been obtained. Those (n = 6) yielding abundant, fresh euhedral plagioclase or detrital chromian spinel have been polished for microprobe analysis; the remaining have been stained with red alizarine and covered with a coverslip. On the coarsest samples, all from the Missaglia outcrops, qualitative observations on the fossil content (mostly large benthic foraminifera) have been carried out; on all the 21 thin sections, point-countings (300 points counted per section according to the Glagolev-Chayes method described in Carver, 1971) have been performed with a James Swift & Son automatic table: results are shown in Fig. 8. Arenite grain size (at $\Phi/4$ scale intervals) and sorting were semiquantitatively assessed following the Garzanti method described in Sciunnach (1996).

Cr-spinels and fresh plagioclase crystals have been analyzed in polished thin section through SEM-EDS microprobe (kV = 20.00, livetime = 50 sec for each analysis, metallic cobalt for standard) and the results are displayed in Figs. 9 and 10.

Arenite fossil content

From the six coarsest-grained arenite samples, all from the Rio Molgoretta section (Missaglia), a rich benthic foraminiferal fauna was detected in thin section, including common *Nummulites*, *Operculina*, *Assilina*, *Discocyclina*, *Asterocyclina*, and rare *Gypsina, Chapmanina*, *Fabiania*; other benthic foraminifera include miliolids, *Victoriella*, and rare agglutinated forms. Among planktonic foraminifera, *Acarinina* gr. *bullbrooki, Globigerinatheka* (both indicating a middle Eocene age) and *Turborotalia* are recognized.

Other bioclasts include common red algae, echinoid plates and spines, and bryozoans, as well as less common mollusks (*Dentalium*, ostreids), corals, vertebrate phosphate bones and fish scales. Tintinnids (some of them questionable, due to their exceedingly large dimensions) are found only in clasts of Maiolica-like calcilutite, and also deeply recrystallized single radiolarians are probably recycled from Jurassic radiolarites.

Planktonic foraminiferal biostratigraphy

Stratigraphic distribution, abundance, and preservation of the planktonic foraminifera, along with the occurrence of other biogenic components, have been revised and updated relative to Premoli Silva et al. (2010) and Bini et al. (2014) and here fully reported in Table 1.

In the SS36 exit outcrop (Fig. 4A, Fig. 5), the biogenic component includes planktonic (from sparse to frequent) and benthic (from rare to very rare) foraminifera. All foraminifera are moderately to poorly preserved; in some samples foraminiferal tests are frequently deformed, less frequently heavily encrusted. In sample M2 a fish tooth was found, whereas in sample M4 very rare echinoid spines occur.

Age-diagnostic associations are homogeneous for all samples. Especially *Hantkenina dumblei, Globigerinatheka subconglobata, Turborotalia pomeroli*, *Turborotalita carcoselleensis* etc. indicate Zone P12 (middle Eocene), equated to E10-11 Zones.

Still in the Cibrone area, the Rio di Ceresa section (Fig. 6) biogenic component includes planktonic foraminifera in highly variable abundance (from very rare to abundant), less common benthic foraminifera (from very rare to scarce); in some samples very rare ostracods, possible echinoid spines and tubular structures that can be ascribed to marine invertebrates (Polychaetes?), also occur. The inorganic fraction includes peculiar spherules (microtektites?), in the topmost sample CC16. Foraminifera, commonly moderately to poorly preserved and heavily encrusted, are well-preserved only in samples CC4, CC6.

The association is in all monotonous and similar to the one from the SS36 exit outcrop. The steady, locally conspicuous, occurrence of Globigerinathekids in samples where *Morozovella aragonensis* is lacking indicates Zone P12, as also confirmed by the occurrence of *Hantkenina dumblei* and *Morozovelloides crassatus*. Furthermore, the occurrence of *Guembelitriodes nuttalli* in sample CC7, that marks the top of Zone E 10 with its LAD, would point to a lower Zone P12 at least up to that level. Such dating is consistent with the identification of the calcareous nannofossil Zone NP16.

Rare *Pearsonites broedermanni* (Soldan et al. 2014) need to be regarded as reworked from the lower Eocene or from the lower part of the middle Eocene.

Age of the section is therefore middle Eocene (late Lutetian).

Calcareous nannofossil biostratigraphy

In the Cibrone Cemetery section (Fig. 5), straddling the stratigraphic boundary between the Tabiago and Cibrone Fms., all the 11 marl samples contain abundant calcareous nannofossils with a preservation ranging from poor to moderate. Reworked Mesozoic taxa such as *Watznaueria barnesae*, *Cretarhabdus* spp., *Nannoconus* spp., *Zeughrabdothus* spp., and *Micula staurophora* are present in this section. The "in situ" nannofossil assemblages are mainly composed of taxa with a very long stratigraphic range such as *Reticulofenestra dictyoda*, *Coccolithus pelagicus*, *Ericsonia* spp., *Chiasmolithus* spp. (especially *C. consuetus* and *C. solitus*), *Sphenolithus moriformis*, and *Sphenolithus radians*. The bottom of the section has been dated as NP15 nannofossil Zone owing to the presence of the zonal markers *Pletolithus gigas*, *Sphenolithus furcatolithoides*, and *Nannotetrina fulgens*. The LO of *P. gigas* lies in sample BS2ter and defines the base of NP15c nannofossil (sub)Zone. The base of NP16 nannofossil Zone has been placed in the sample BS11 due to the First Occurrence (FO) of *Cribrocentrum reticulatum*. This age assignment is supported by the FO of *Reticulofenestra umbilicus* (>14 mm) and the presence of the secondary marker *Discoaster bifax* in the sample BS13. However, the latter taxon was found to occur in hemipelagic and neritic environments of Paris Basin and London Basin dated as NP14 nannofossil Zone (Aubry 1983) and, thus, it is unlikely a reliable marker. The stratigraphic interval from the sample BS11 to the top of the section (sample BS17) is assigned to the NP16 nannofossil Zone owing to the continuous occurrence of taxa such as *Chiasmolithus solitus* (stratigraphic range = NP10-NP16), *Cribrocentrum reticulatum* (stratigraphic range = NP16-NP19/20), and *Sphenolithus furcatolithoides* (stratigraphic range = NP15-NP16). The species *Blackites gladius,* whose LO (Last Occurrence) once defined the base of the NP16, is absent in this section.

The SS36 exit outcrop (5 samples, the same analyzed also for foraminifera) yielded less conclusive assemblages due to rare and poorly preserved calcareous nannofossils. However, the fairly continuous co-occurrence of taxa such as *Cribrocentrum reticulatum* (stratigraphic range = NP16-NP19/20), *Chiasmolithus solitus* (stratigraphic range = NP10-NP16) and *Sphenolithus furcatolithoides* (stratigraphic range = NP15-NP16) clearly suggests the NP16 nannofossil Zone. The nannofloral assemblage of this section is generally dominated by *Reticulofenestra* spp., *Sphenolithus* spp., and *Coccolithus pelagicus.*

The Rio di Ceresa section (Fig. 6) records a nannofloral assemblage similar to that of the SS336 exit outcrop. However, calcareous nannofossils are fairly more abundant and moderately preserved with remarkable reworking of Cretaceous to lower Eocene units. A middle Eocene age (NP16) is suggested through the presence of taxa such as *Cribrocentrum reticulatum*, *Chiasmolithus solitus*, *Sphenolithus furcatolithoides*, and their combined ranges.

The small sections of Cibroncello and Quatto Strade and the thicker Rio Molgoretta section are also assigned to the middle Eocene NP16 nannofossil Zone owing to the co-occurrence of *Cribrocentrum reticulatum*, *Chiasmolithus solitus*, and *Sphenolithus furcatolithoides*. Nannofloral assemblages show high abundances of the taxa *Reticulofenestra* spp., *Sphenolithus* spp., *Ericsonia formosa*, and *Coccolithus pelagicus.*

The Veduggio section records a completely different nannofloral association. Important components of the NP16 nannofossil Zone such as *Reticulofenestra dictyoda*, *Sphenolithus furcatolithoides*, *Toweius*? *gammation* (*Girgisia gammation* for some authors), and *Chiasmolithus solitus* are absent, whilst the taxon *Cyclicargolithus floridanus* shows higher abundances.

Area	Section/ outcrop	Unit	Sample	Qs	Qb	Qp	Pl ut,uz	Pl tw	Pl n-oz	Pl oz	Pl Pltot	Af	VRF F+V	VRF Micr	HRF	MRF	SRF CE	SRF Chert	SRF TRF	Bt	HM	PhPs	OpPs	Psix	NCI	CI	Epim	Matr	Cem	Aut	TOT	GSZ	SRT	Qt	F	L	C/Q	P/F	V/L	NCE	CE	NCI	CI
Central Brianza (Sheet 096 Seregno)	Cibrone cemetery (boundary section)	Tabiago	BS 2bis	18,0	-	0,7	8,3	4,7	0,7		13,7	2,3	3,7	-	0,3	0,7	10,3	6,0	-	1,0	0,7	0,3	0,3	-	tr.	12,7	-	4,7	0,3	24,3	100	VFS	M/P	41	35	24	0,04	0,85	0,37	66	15	0	19
		Formazione di Cibrone	BS 6	7,0	-	0,3	16,7	8,3	1,0		26,0	1,0	3,7	2,0	0,3	-	7,3	1,3	-	-	1,7	1,7	-	-	1,3	10,0	-	2,7	-	33,7	100	FS	M	19	66	15	0,04	0,96	0,79	69	12	2	17
			BS 8	4,7	-	-	14,0	5,3	1,0		20,3	0,7	13,3	4,7	-	-	6,7	tr.	-	0,7	tr.	1,3	0,3	2,3	3,3	15,3	-	2,0	-	24,3	100	FS	P	12	51	37	0	0,97	1	63	10	5	22
			BS 10	0,7	-	-	15,7	5,3	4,3		25,3	1,0	10,3	1,3	-	-	3,3	0,7	-	1,7	3,0	8,3	-	-	0,3	8,7	-	0,7	0,3	34,3	100	FS	P	2	69	29	0	0,96	0,94	76	6	1	17
			BS 12	0,7	-	-	25,7	8,7	1,7		36,0	0,7	13,3	0,3	0,3	-	5,0	0,7	-	0,7	7,0	6,0	-	-	-	1,7	1,0	-	-	26,7	100	FS	P	1	71	28	0	0,98	0,95	89	8	0	3
			BS 14	1,3	-	-	16,7	8,3	4,7		29,7	1,7	14,3	2,3	-	-	1,0	0,7	-	1,7	1,0	2,0	-	1,3	tr.	10,0	-		-	33,0	100	FS	M/P	3	65	32	0	0,95	0,96	82	2	0	16
			BS 15	3,3	-	-	21,0	11,3	1,3		33,7	0,3	6,7	1,7	0,7	-	3,7	0,7	-	2,0	1,3	-	0,7	2,3	1,0	5,3	2,0		-	34,7	100	FS	P	7	73	20	0	0,99	0,93	83	6	2	9
	Cibrone SS 36 exit		Eo1	1,0	-	-	14,0	6,0	4,0		24,0	0,3	5,0	0,3	0,7	-	-	-	-	4,3	1,3	3,3	0,3	-	-	28,0	18,3		-	13,0	100	VFS	P	3	76	21	0	0,99	1	53	0	0	47
			Eo2	-	0,3	-	11,3	12,7	6,0		30,0	0,3	7,0	-	-	-	-	-	-	1,7	1,3	4,0	-	1,0	-	16,0	12,0		23,3	3,0	100	FS	P	1	82	17	0	0,99	1	70	0	0	30
	Rio di Ceresa		CC ARN	1,3	-	-	26,3	4,0	3,7		34,0	2,0	6,0	1,0	-	-	4,3	1,0	-	1,0	3,3	1,3	0,3	-	tr.	11,0	0,7	-	-	32,7	100	VFS	VP	3	79	18	0	0,94	0,88	75	7	0	18
	Cimarosa		CIM	tr.	-	-	2,3	0,3	0,3		3,0	-	2,0	1,0	-	-	59,0	5,0	-	0,3	0,7	0,3	1,7	-	-	4,3	-	2,3	-	20,3	100	MS	M/W	0	27	73	-	1	0,37	15	79	0	6
			CIRO	8,7	-	7,3	1,0	0,3	-		1,3	0,3	5,0	-	-	14,0	26,3	1,3	-	-	0,3	-	0,3	1,0	0,3	8,3	0,3	0,3	-	24,7	100	MS	P	43	4	53	0,47	0,80	0,23	52	36	1	11
	Veduggio		Eo3	14,7	-	6,7	4,0	-	-		4,0	-	10,0	0,3	0,7	3,7	24,7	2,7	-	0,3	tr.	4,3	0,7	-	-	2,3	3,3	-	1,0	20,7	100	MS	P	50	9	41	0,31	1	0,60	61	36	0	3
Eastern Brianza (Sheet 097 Vimercate)	Quattro Strade		Eo4	0,7	-	-	13,7	6,0	4,0		23,7	0,3	17,3	6,0	2,7	-	1,3	tr.	-	-	7,7	-	-	7,7	-	2,7	19,7	-	-	10,3	100	CS	P	2	53	45	0	0,99	1	93	2	0	5
	Missaglia Rio Molgoretta		α0	2,7	-	0,7	5,3	4,0	2,0		11,3	-	13,3	4,0	-	-	12,0	5,0	-	tr.	0,3	-	-	1,0	1,0	25,0	-	0,3	-	23,3	100	CS	P	9	32	59	0,20	1	0,77	49	16	1	34
			α4	2,3	0,7	0,3	1,0	7,7	5,0		13,7	0,3	14,7	9,3	0,3	-	14,3	3,3	-	0,7	0,3	-	2,0	-	2,0	15,0	-	3,3	-	17,3	100	CS	M/P	8	33	59	0,09	0,98	0,87	59	19	3	19
			α5	3,7	0,3	1,0	5,7	7,3	1,7		14,7	-	8,0	10,0	-	-	14,0	3,3	0,3	0,7	tr.	-	-	4,3	-	10,3	-		-	29,3	100	CS	P	12	38	50	0,20	1	0,82	59	20	6	15
			β1	3,0	-	-	10,3	3,3	1,3		15,0	-	14,0	3,7	1,7	-	8,3	2,7	-	1,3	tr.	-	1,7	8,3	0,7	2,7	11,7		-	25,3	100	FS	VP	8	38	54	0	1	0,88	67	14	15	4
			β2	2,3	-	0,3	5,3	9,3	3,7		18,3	2,0	8,3	13,7	-	-	2,0	4,3	0,3	0,3	0,7	-	0,3	4,0	3,0	23,0	-	1,0	0,3	15,7	100	CS	M/P	6	42	52	0,12	0,90	0,82	64	3	4	29
			β3	1,7	0,3	-	2,3	4,3	5,7		12,3	0,3	3,7	8,7	-	-	7,0	1,3	-	0,7	-	2,0	-	0,3	1,7	35,3	-	1,7	-	23,0	100	CS	P	7	48	45	0	0,98	0,89	39	10	2	49
			β4	1,7	1,3	0,3	2,0	5,0	3,7		10,7	-	4,0	5,7	-	-	11,7	4,7	-	0,3	-	2,0	-	0,7	0,7	29,0	0,7		1,0	25,7	100	CS	P	13	39	48	0,09	1	0,66	41	17	1	41
Northern Apennines	Montacuto	Marne di Monte Piano	MTU	5,0	-	-			42,9			0,5	12,1		-	0,2	-	-	-	19,0	10,9	-	-	-	-	0,2	6,2	1,0	2,1	-	100	FS	M/W	8	72	20	0	0,99	0,98	99	0	0	1
	Moncasacco		MOA	tr.	-	-	10,3	32,0	11,7		54,0	-	5,0	0,3	0,7	-	-	-	-	4,0	-	-	0,3	4,0	-	tr.	22,0	-	-	9,7	100	MS	W	0	85	15	-	1	1	100	0	0	0
			MOB	0,7	-	-	15,0	21,0	16,7		52,7	1,3	7,3	-	0,3	0,3	-	-	-	1,3	0,7	-	-	3,0	-	4,0	9,3	-	1,3	17,7	100	MS	W	1	86	13	0	0,98	0,96	94	0	0	6
			MOC	0,7	-	-	19,7	15,7	11,3		46,7	-	7,0	1,0	-	-	-	-	-	1,0	-	0,3	0,3	6,3	-	5,7	17,0	-	0,3	13,7	100	MS	W	1	84	15	0	1	1	91	0	0	9
Trentino	Molveno	Formazione di Ponte Pià	ABE 3	0,6	-	-	7,2	11,6	21,4	8,4	48,6	-	3,2	0,2	1,0	-	-	-	-	1,0	tr.	8,2	0,6	0,2	-	0,4	25,2	-	0,4	10,6	100	FS	W	1	91	8	0	1	1	99	0	0	1
			E 16	-	-	-	4,4	12,0	13,0	18,0	47,4	-	0,2	-	-	-	-	-	-	-	-	8,2	2,6	-	-	1,0	0,2	12,2	-	28,2	100	MS	M/P	0	99	1	-	1	1	98	0	0	2
			EB 2	0,4	-	-	2,6	13,8	9,0	4,8	30,2	-	0,2	0,4	0,4	-	-	-	-	0,8	tr.	8,4	1,4	0,8	-	tr.	0,4	15,8	-	40,8	100	MS	P	1	96	3	0	1	1	100	0	0	0
			EB 3	-	0,2	-	6,0	11,4	12,6	16,2	46,2	-	1,0	-	0,6	-	-	-	-	tr.	tr.	5,4	0,8	-	-	tr.	0,4	3,8	-	41,6	100	MS	M	1	96	3	0	1	1	100	0	0	0
			EB 4	1,2	0,6	-	6,6	12,0	25,2	6,4	50,2	-	5,6	-	1,0	-	-	-	-	4,0	tr.	5,4	tr.	2,0	-	tr.	23,2	-	-	34,0	100	MS	W	3	86	11	0	1	1	100	0	0	0
			EB 5	-	-	-	12,2	18,6	17,2	3,0	51,0	-	6,0	0,6	1,6	-	-	-	-	2,0	0,4	7,6	tr.	1,6	-	2,2	19,8	-	0,4	6,6	100	MS	M/W	0	86	14	-	1	1	96	0	0	4
			EB 6	-	-	-	8,2	12,6	18,6	5,6	45,0	-	4,8	0,6	0,2	-	-	-	-	2,4	tr.	10,0	0,8	2,4	-	0,2	28,0	-	-	5,6	100	MS	W	0	89	11	-	1	1	99	0	0	1

Tab. 3 - Complete data set for the modal analyses carried out on Eocene arenites from Brianza, the Trentino area (samples ABE3 to EB6: Sciunnach & Borsato 1994) and the Northern Apennines (samples MTU to MOC: Di Giulio et al. 2005). The data set includes textural parameters and recalculated detrital modes. Qs = monocrystalline quartz, Qb = with resorption embayments; Qp = polycrystalline quartz. Pl = plagioclase, including untwinned & unzoned (ut, uz), twinned (tw), non-oscillatorily (n-oz) and oscillatorily zoned (oz) crystals: Pltot = total plagioclase; Af = alkalifeldspar. VRF = volcanic rock fragments, displaying felsitic, vitric and undetermined (F + V) and microlithic structures (Micr). HRF = hypabyssal rock fragments, MRF = metamorphic rock fragments, SRF = sedimentary rock fragments, including carbonate extrabasinal grains (CE), chert and terrigenous rock fragments (TRF). Biotite (Bt) is distinguished from the other heavy minerals (HM). Pseudomorphs, replaced by phyllosilicates (PhPs) or opaques (OpPs) are distinguished by deformed pseudomatrix (Psix). NCI = noncarbonate, CI = carbonate intrabasinal grains; Epim = epimatrix, Matr = protomatrix, Cem = cement, Aut = authigenic minerals, TOT = total. GSZ = grain size (VFS = very fine-grained sand, FS = fine-grained sand, MS = medium-grained sand, CS = coarse-grained sand), SRT = sorting (W = well, M = moderate, P = poor, VP = very poor); QtFL modes and C/Q, P/F, V/L ratios after Dickinson (1970); NCE-CE-NCI-CI modes after Zuffa (1980; 1987).

In addition, all samples contain *Chiasmolithus grandis* (stratigraphic range= NP14-NP17) whilst *Sphenolithus predistentus* (NP17-NP24) is present in the samples Ve1 and Ve2 and a single specimen of *Helicosphaera compacta* (NP17-NP24) is observed in the sample Ve1. These findings suggest that the Veduggio section may be assigned to the Bartonian NP17 nannofossil Zone.

Arenite petrography

The analyzed arenites consist of variable amounts of Non-Carbonate Extrabasinal grains (NCE: Zuffa 1980), Carbonate Extrabasinal grains (CE), Non-Carbonate Intrabasinal grains (NCI) and Carbonate Intrabasinal grains (CI). NCE grains include *quartz*, both monocrystalline (commonly with "fast" extinction, pseudo-hexagonal outlines and less commonly with resorption embayments, all indicating a volcanic origin) and polycrystalline; *feldspars*, represented mostly by euhedral and relatively fresh plagioclase, commonly twinned and/or zoned, and less frequently by alkalifelspar; and *rock fragments*, including volcanic lithics, chert, hypabyssal rock fragments and locally metamorphic rock fragments. CE grains include limestone and dolostone lithoclasts, easily distinguished in thin sections stained with red alizarine. NCI grains (Garzanti 1991) include clayey mudclasts, glauconite pellets, phosphate nodules and bioclasts. CI grains include carbonate bioclasts (benthic foraminifera, coralline algae, echinoids, bryozoans, planktonic foraminifera) and marly mudclasts. Heavy minerals include opaques, brown and white mica flakes, locally abundant hornblende and augite, apatite, zircon, monazite, red chromian spinel (Sciunnach 2014), garnet, tourmaline, rutile, titanite, and epidote. The interstitial fraction includes matrix, both detrital (micrite/microsparite) and recrystallized (epimatrix sensu Dickinson 1970); rare syntaxial cement occurs as grain overgrowths, while authigenic calcite and opaques precipitated in secondary pores (Schmidt & McDonald 1979). Incidentally, in the studied arenites all the main ambiguities commonly affecting grain identification - i.e., quartz vs. feldspar; chert vs. volcanic glass (Dutta 1990); carbonate lithics vs. intraclasts (Zuffa 1987) are represented.

Based on 21 modal analyses, detrital modes (QtFL of Dickinson 1970) and NCE-CE-NCI-CI parameters of Zuffa (1980) were obtained; the results are presented in Tab. 3 and Fig. 8.

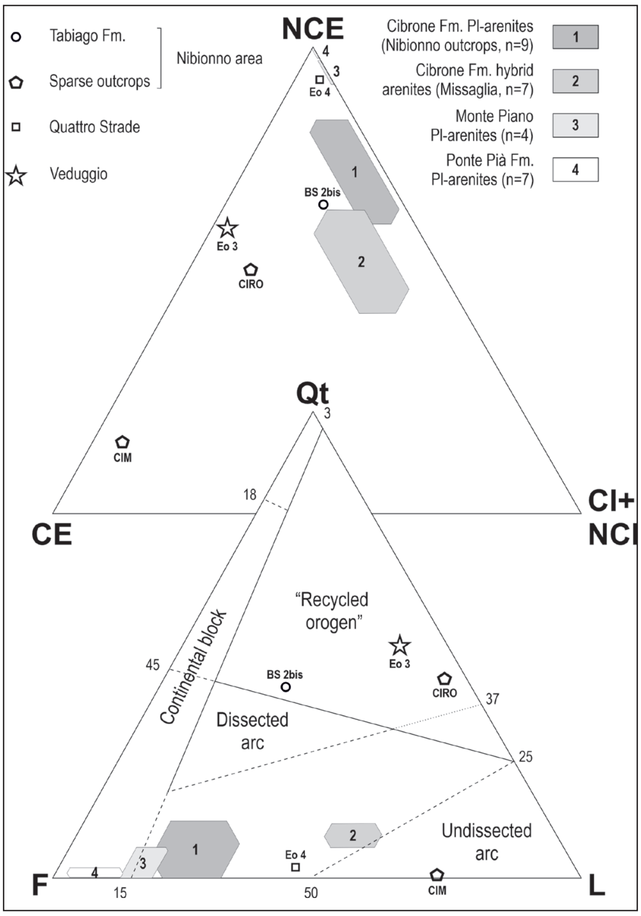


Fig. 8 - Detrital QtFL modes (Dickinson 1985) and NCE-CE-NCI-CI triangular plots (Zuffa 1985) for the 21 analyzed arenite samples from central Brianza, compared to 11 samples previously described by Sciunnach & Borsato (1994) and Di Giulio et al. (2005). Polygons are one standard deviation each side of the mean.

Geochemistry of single detrital minerals

SEM-EDS microprobe analysis on detrital plagioclase from the Cibrone Fm. (Di Giulio et al. 2005; Fig. 9) has revealed a calcic composition (labradorite/bytownite: An_{55-85}), recently confirmed also by analyses on different samples from the same localities (Di Capua et al. 2021a).

In nine sandstone samples from the Cibrone Fm., rare transparent detrital Cr-spinel occurs as angular to subangular, fragmentary to octahedral grains, averaging 100 μm in size, with a colour ranging in thin section from deep amber-red to coffee-brown. Cr-spinel, due to remarkable chem-

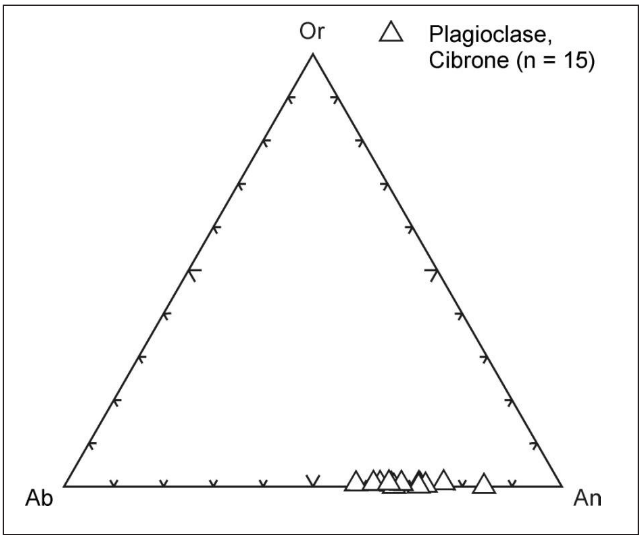


Fig. 9 - Standard Ab-An-Or compositional triangle for plagioclase crystals analyzed from samples Eo1, Eo2 (SS 36 exit, Cibrone).

ical stability under diagenetic conditions, preserves reliable information on petrogenetic environments. SEM-EDS microanalysis on 9 grains has revealed a Cr_2O_3 content of 34÷48%, corresponding to a Cr# (Cr/Cr + Al ratio) between 0.41 e 0.61 (Fig. 10). Upon normalization of microprobe data, the analyzed Cr-spinels can be classified as solid solutions of the end-members magnetite, chromite, Mg-ferrite, and Mg-chromite, with subordinate spinel and hercynite. The provenance of such detrital Cr-spinels has been discussed in detail in Sciunnach (2014): possible recycling from the Permo-Mesozoic sedimentary successions of the Southern Alps (where Cr-spinels have been found in Ladinian-Carnian units; Garzanti & Sciunnach 1997) is not supported by invariably lower #Cr ratio in the Cibrone Cr-spinels, that also displays only partial overlap with values of Cr# recorded in the Val Nozza basaltic flow. Further clues militating against the recycling of Cr-spinel from older sedimentary units are the extremely poor content of Cr-spinel even in the Ladinian-Carnian units, and the relatively poor content, in most of the Cibrone Fm. samples yielding detrital Cr-spinel, of those carbonate lithics (CE, DE) that should derive from the associated Triassic succession. Rather, the composition of the studied Cr-spinel is consistent with provenance from a wide range of mafic and ultramafic magmatic rocks probably occurring as xenoliths in the volcanic successions that represented the *Source V* of the Cibrone Fm. (see below).

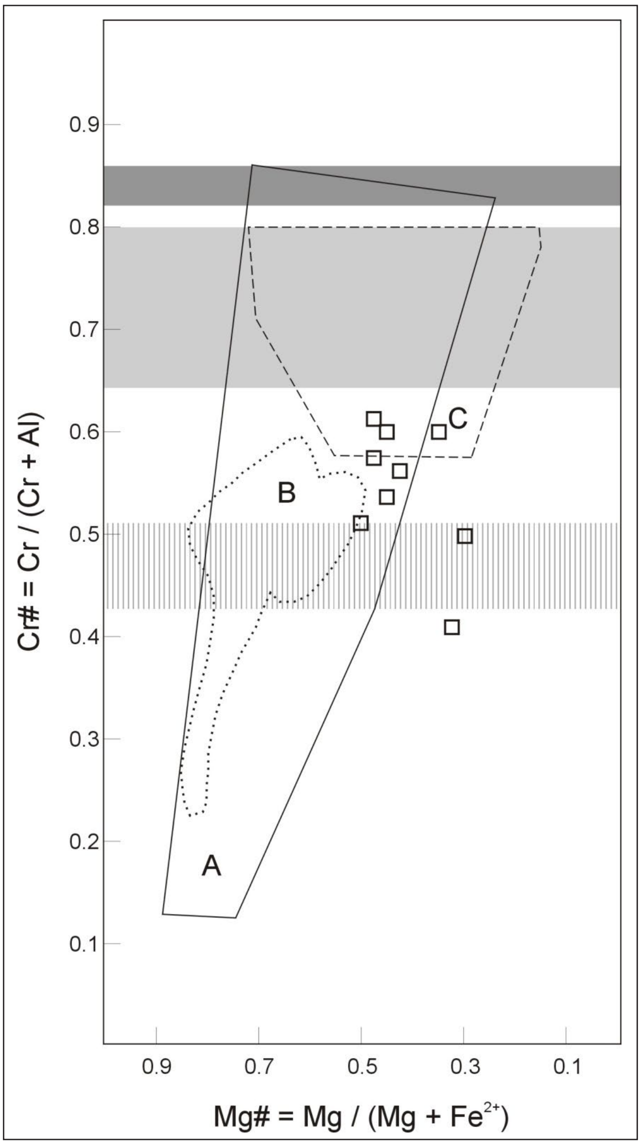


Fig. 10 - Mg# vs. Cr# plot for the analyzed detrital chromian spinels. A) (solid line) = field of spinels from alpine-type ophiolite complexes after Hamlyn & Bonatti (1980); B) (dotted line) = field of spinel from Atlantic MORB after Sigurdsson & Schilling (1976) and Jaques (1981); C) (dashed line) = field of spinels from stratiform intrusions after Hamlyn & Bonatti (1980). Shaded areas indicate the Cr# ranges for spinels from the Ladinian-Carnian succession of the Southern Alps after Garzanti & Sciunnach (1997): dark grey = Carnian S. Giovanni Bianco Fm., light grey = Ladinian Wengen Fm., vertically striped = Carnian Val Nozza basaltic flow.

Discussion

Arenite provenance vs. texture

Provenance analysis of the middle-late Eocene turbidites of the Cibrone Fm. allowed us to identify at least three distinct source areas, from which diagnostic debris was derived; most of the studied samples did not derive their detritus from a single source, but rather a continuum of combinations of variable amounts of detritus from the three sources is observed.

Source S corresponds to a Mesozoic sedimentary succession, eroded mostly in its upper levels ("undissected stage of continental block provenance" according to Garzanti et al. 2006), and only eventually as deep as into the metamorphic basement; samples mostly derived from this source (CIM, CIRO, Eo3) consist of medium-grained calclithites, containing subordinate NCE and sparse bioclasts. Monocrystalline quartz prevails over polycrystalline quartz, whereas limestone and dolostone fragments prevail over chert lithics, with a Chert/(Chert + CE) ratio ranging from 5 to 10%. The abundance of dolostone fragments (DE), expressed as DE/(CE + DE), ranges from 26.6 to 27.8% in the two samples where (CE + DE) > 25% of rock volume. Metamorphic rock fragments also occur.

Source V can be interpreted as a volcanic succession eroded soon after deposition (facies V_{2a} of Zuffa 1985) or, more likely if the poor alteration of unstable Mg-Fe minerals and the fresh, euhedral habit of plagioclase are considered, direct pyroclastic debris into the basin (facies V_{2b} of Zuffa 1985). Both models are consistent with an active volcanic district in the source area, such as an island arc with intermediate to basic chemistry; chromian spinel is interpreted as an accessory mineral in harzburgite xenoliths dragged to the surface by basalt/andesite magmas (Sciunnach 2014). Samples mostly derived from this source are classified as very fine to fine-grained, moderately to poorly sorted Pl-arenites ("Feldspat-Areniten" of Kleboth 1982). Fresh and euhedral plagioclase crystals, commonly twinned and/or zoned, make up to 36% of the rock volume; volcanic quartz (0-7%) and lithics (3-18%) are subordinate, sedimentary lithics can be as abundant as 10%, whereas Mg-Fe accessories (amphibole, biotite, pyroxene, Cr-spinel and opaques) and other heavy minerals (mostly zircon and apatite) occur in variable abundance (1-8%). Intrabasinal grains consist of oversized mudclasts and planktonic foraminifera, that on the average represent about 12% of rock volume.

Source I corresponds to a starved continental platform, from which mostly intrabasinal detritus was derived. Hybrid arenites dominated by this source are mostly coarse-grained, poorly-sorted feldspathic litharenites with abundant CI (see section "Arenite fossil content") and occasional intraclasts. Sparse glauconite and coarse-grained recrystallized calcite locally make the rock comparable to a poorly developed *hard ground*.

The resulting scenario sees the Brianza sector of the Lombardian Basin receiving, since the mid-Lutetian (nannofossil Zone NP15), sand-sized detritus from three distinct sources: 1) a newly-uplifted Mesozoic sedimentary succession eroded in its topmost units, that could be consistent with an accretionary prism related to the Alpine subduction; 2) basalt/andesite "neovolcanic" (sensu Zuffa 1985) debris reworked by turbidity currents, consistent with the structuring of a juvenile island arc; 3) a starved continental shelf, shedding mostly intrabasinal clasts (CI, NCI sensu Zuffa 1980), possibly developed on the distal ramp of the forearc (Adriatic hinterland). The arenites documenting these three sources (being the source S located at North-Northwest, the source V located at Northeast and the source I likely at South-Southeast) alternate to prevailing hemipelagic marls rich in planktonic foraminifera and calcareous nannofossils, that allowed us a precise dating of the succession.

The proposed reconstruction might fit a classical plate tectonics model for arc-trench systems, with the Mesozoic passive margin of Adria already evolved into a hinterland basin as an effect of the subduction of the Alpine Tethys.

As most samples belong to the same few biozones, we assume that the observed spatial variability in composition mostly reflects variable contribution from different source areas in the same time interval; only in the case of the Veduggio outcrop, a peculiar arenite composition, richer in polycrystalline quartz, metamorphic rock fragments and white mica, is associated to a younger age and therefore might reflect a vertical compositional trend, possibly related to deeper dissection of source S.

Arenite texture needs to be considered to correctly interpreting provenance signals (e.g., Garzanti et al. 2004 and references therein). The Cibrone Fm. arenites from the Cibrone Cemetery section display similar grain size, clustering in just four Φ/4 classes (2.75 to 2.00). Therefore, the observed vertical compositional trends of the Q and F parameters (with Q decreasing from 12-19 to 1-7, F increasing from 51-66 to 71-73 base to top) cannot be determined by grain size variations, commonly affecting feldspar content (Odom et al. 1976). On the other hand, in the Missaglia section, the coarsest arenites

(Φ = 0.50 to 0.25) display the same feldspar content (F = 38 to 39) of the finest (Φ= 2.25). Independence of feldspar content from grain size seemingly reflects ineffective hydraulic sorting in these texturally immature arenites.

A possible explanation for the higher rock fragments content of the Missaglia arenites, compared to the coeval ones from the Cibrone Cemetery section (BS 6 to BS 11), might be their coarser grain size: but this cannot account for their higher content also of fine-grained lithics (limestone, dolostone, chert), indicating a higher contribution from the Mesozoic sedimentary succession.

Local correlation

If the base of the Cibrone Fm. is clearly exposed in the Cibrone Cemetery section, the mutual stratigraphic position of the SS36 exit and of the Rio di Ceresa sections are uncertain as they both belong to the NP16 nannofossil Zone. Thin and rare arenite layers (sample CCARN) in the Rio di Ceresa section militate against a lateral equivalence of two sections that are so closely spaced in the field; moreover, despite overall comparable detrital modes, the only arenite sample from Rio di Ceresa displays CE lithics that are absent in the studied samples from the SS36 exit. Therefore, the Rio di Ceresa section might overlie the SS36 exit section, documenting a stage of prevailing hemipelagic sedimentation after a series of volcanic episodes documented both in the Cibrone Cemetery and in the SS36 exit sections; alternatively, it might document a period of relative quiescence in volcanic activity between the two. Whatever the solution, it seems that at least 115 m of the Cibrone Fm. were deposited during part of Zone NP16, allowing to calculate a sediment accumulation rate of at least 29 m/Myr - about three times as much as in the underlying Tabiago Fm. (Tremolada et al. 2008; Premoli Silva et al. 2010).

The boundary between the Tabiago and Cibrone Fms., exposed only on the southern slope of the hillock just north of the Cibrone Cemetery (Fig. 5), is found also in the Po Plain subsurface where it is dated as early Lutetian (Di Giulio et al. 2001). To explain the decrease of carbonate content in the marlstones below (80%) and above (50%) the boundary, Di Giulio et al. (2001) consider two alternative explanations, 1) a reduction in carbonate productivity, and 2) an increase in siliciclastic input, choosing the latter as the most likely. In our view, the increase in the sedimentation rate recorded across the boundary clearly indicates silicilastic input as the main cause for the decrease of carbonate content in the Cibrone Fm.; if the alternative explanation is considered, a decrease in sedimentation rate would be expected instead. We suggest, however, that the explanation given by Di Giulio et al. (2001) for the increase of siliciclastic input (i.e., increased rainfall) should be complemented by volcanic activity, shedding pyroclastic detritus in the basin, and tectonic uplift and erosion of the subduction complex.

Different composition of texturally immature arenites that belong to the same nannofossil zone (samples BS6-14 and α0-β4: Tab. 3) and are exposed less than 10 km apart seems to indicate a complex drainage pattern, characterized by limited dispersal and rapid burial of detritus derived from local source areas. Therefore, in this case petrofacies results to be unreliable as a tool for correlation, in the terms proposed by Dickinson & Rich (1972).

Instead, the Veduggio outcrop represents for sure the topmost part of the Cibrone Fm., as documented by the NP17 age of the intercalated marls. The remarkable shift in arenite composition recorded by this outcrop, and likewise by the very similar CIRO sample (Fig. 8; Tab. 3), relative to the underlying succession (with Q passing from < 10% to 40-50%, C/Q passing from 0% to 30-40%, F dropping from 70-80% to 5-10% and L increasing from 20-30% to 40-50%, also due to the appearance of common metamorphic rock fragments) might thus be interpreted as the effect of a vertical compositional trend, possibly explained by active thrusting and/or unroofing of deeper crustal levels in the subduction complex. Unfortunately, this tempting interpretation relies only on the composition of sample Eo3, because the sample of nearly identical petrography CIRO is not biostratigraphically constrained.

On two arenite beds (corresponding to samples Eo1, Eo2) from the Cibrone SS36 exit, FT ages on detrital apatites were obtained (Malusà et al. 2011). Apatites obtained from the Cibrone Fm. arenites display euhedral crystal shape and homogeneous FT distribution, representing a single crystal population and indicating a clear volcanic origin (Malusà, pers. comm.); however, their FT ages of 30.1 ± 2.5 and 30.2 ± 2.7 Ma are at least 10 Ma younger than biostratigraphic ages (Zones P12-NP16 range 40-44 Ma according to standard timescales) and therefore can be interpreted only as exhumation ages. At a normal gradient, this would require a 4-5 km burial depth to achieve total annealing of the original fission tracks, which seems to be way too much according to the observed accumulation rates. An alternative explanation would be a very high geothermal gradient in the Early Oligocene, possibly linked to the regional magmatic activity (e.g., Bergell Pluton, ca. 31 Ma; Tiepolo et al. 2014). This would also fit diagenetic paths recorded by Carnian sandstones in the Orobic Prealps as interpreted in Garzanti (1985). The issue exceeds the scope of the present paper but definitely requires further investigation, e.g. fission track analysis and U/Pb datings on detrital zircon or U/Th/He on apatite from the same samples.

Regional correlation and tectonic setting

The neovolcanic detritus characterizing the Cibrone Fm. arenites fed by source V is common also to correlatable stratigraphic intervals exposed both in the Trentino area and in the Epiligurian Units of the Northern Appennines (Fig. 1).

Trentino. In the Trentino-Alto Adige region, stratigraphic evidence of intermediate volcanism during the Eocene has been reported by several authors (Piccoli 1966; Bars & Grigoriadis 1969; Mair et al. 1996). Plagioclase-arenites similar to those from the Cibrone Fm. (although they completely lack sedimentary rock fragments: Tab. 3), occur in the upper part of the Ponte Pià Fm., on the eastern side of the Molveno Lake (Trento Province; Sciunnach & Borsato 1994), in various localities from the Giudicarie fault zone where the so-called "Sarca di Campiglio Member" is exposed (Martin & Macera 2014), and in general in the area of the 1:50,000 geological sheet 059 "Tione di Trento" (Castellarin et al. 2005a). "Pyroclastic arenite" intervals in the Ponte Pià Fm. are mentioned also in the explanatory notes of the 1:50,000 geological sheet 080 "Riva del Garda" (Castellarin et al. 2005b), where however are not described in detail.

Northern Apennines. Mostly medium-grained and well-sorted plagioclase-arenites occur in the lower part of the Marne di Monte Piano (Di Giulio et al. 2005), at Montacuto di Ponte Nizza (Pavia Province) and at Moncasacco (Piacenza Province) in the area of the 1:50,000 geological sheet 178 "Voghera" (Vercesi et al. 2014). The sample from Montacuto records a very high abundance of heavy minerals, mostly biotite and opaques, representing 30% of rock volume (Tab. 3). These peculiar characters, coupled with rare carbonate intraclasts and bioclasts (less than 6% of rock volume), suggest that these arenites, rather than turbidites fed by the reworking of an original crystal tuff (facies V_{2a} of Zuffa 1985), might represent a crystal tuff itself (facies V_{2b} or V_3 of Zuffa 1985). In both areas, medium-grained plagioclase-arenites occur as decimetric layers in prevailing marlstones (Fig. 4B) and cannot be represented at mapping scale; the 178 "Voghera" Sheet explanatory notes even fail to mention them.

Further evidence for Eocene volcanic activity in adjoining areas is represented by the buried Mortara volcano (Falletti et al. 1994, Fantoni et al. 2004), which still preserves the shape and dimensions of a volcanic edifice whose outer slopes are mantled by hemipelagic sediments as old as the Eocene, and by the Peri-Adriatic plutons, especially the Adamello Batholith (Callegari & Brack 2002), whose oldest cooling ages range from 43.47 ± 0.16 to 39.1 ± 0.3 Ma (U/Pb on zircon: Schaltegger et al. 2019).

In the Orobic Alps, the Gandino and the Presolana dyke swarms revealed U-Pb zircon ages bracketed to the middle-late Eocene (D'Adda et al. 2010), suggesting close time relationships between the earliest Adamello intrusion stages and the Alpine dyke magmatism widespread all-over central Lombardy.

The Eocene Lombardian Basin, seemingly bracketed between a subduction complex (accretionary prism) at NW and a volcanic arc stretching from SW to NE in the present geographic setting (Fig. 11), finds actualistic models in many arc-trench systems worldwide and supports the most recent palaeotectonic and paleogeographic reconstructions available in the literature for the considered time slice (Ji et al. 2019; Lu et al. 2019), which recognize slab steepening, rather than slab break-off, as a source of magma generation and admit the occurrence of an emerged subduction complex northwest of the study area. The alternative model of a cordilleran, Andean-type magmatism is at odds with persisting hemipelagic sedimentation in the Lombardian Basin from Paleocene to middle Eocene times and the missing evidence for thrust stacking in the Southern Alps during the Mesoalpine "phase" (Schönborn, 1992)

Over a wider area, stretching from the Jura-Helvetic Nappes (i.e., Haute-Savoie, Alpe de Taveyanne, Glarus) to the Parma Northern Apennines, sandstones fed by "andesitic" detritus can be found

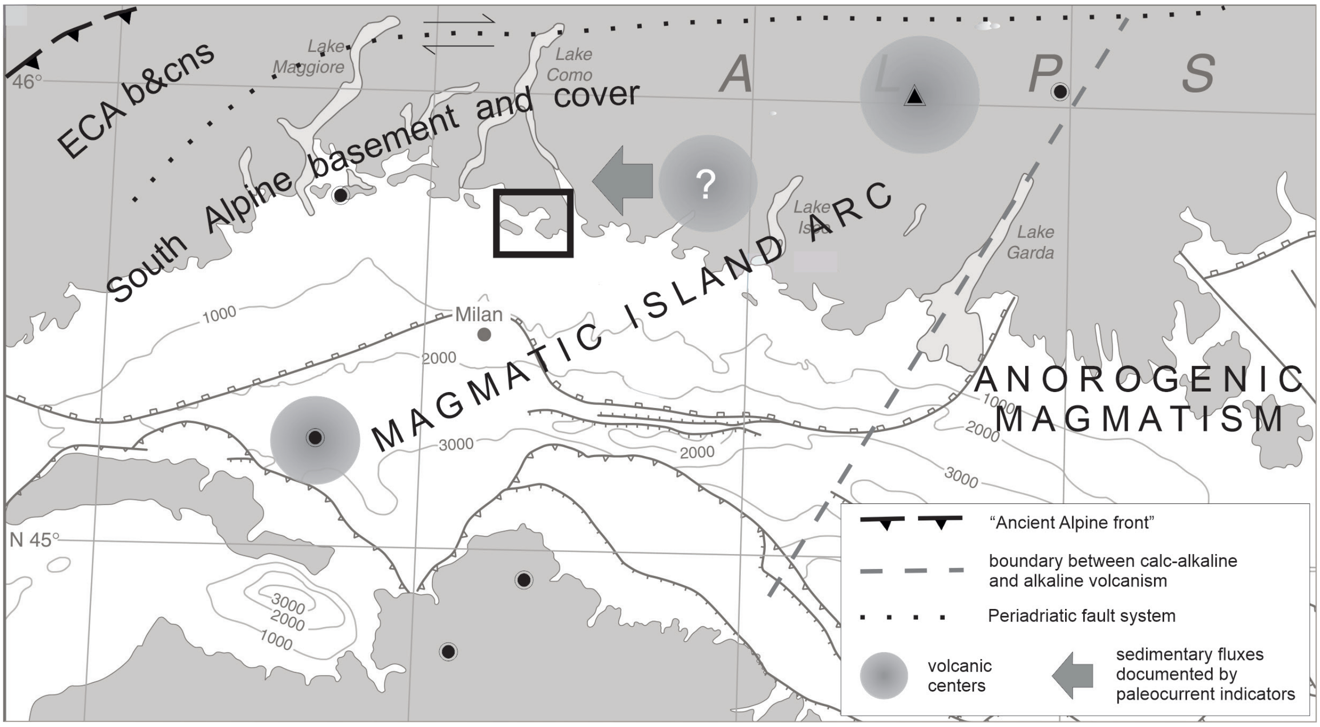


Fig. 11 - Ideal cartoon showing a non-palinspastic reconstruction of some structural elements of the Lombardian basin in the Eocene (location map as a close-up of Fig. 1). A question mark is placed on the possible Bergamasc Valleys volcano(es), documented only by dyke swarms. "Ancient Alpine front" for the Lutetian-Priabonian after Lu et al. (2019); boundary between areas of calc-alkaline (west) and alkaline/anorogenic (east) volcanism according to Martin & Macera (2014). ECA b&cns = "Early Central Alpine basement and cover nappe stack" of Lu et al. (2019).

as upwards in the stratigraphic columns as in the Lower Oligocene (i.e., Taveyannaz Fm. or Taveyanne Sandstones of Vuagnat 1985 and Ruffini et al. 1997; Val d'Aveto-Petrignacola Sandstones of Elter et al. 1999 and Mattioli et al. 2012). Relationships between the sediment sources and sinks for these units have been discussed in detail by Lu et al. (2019) and Di Capua et al. (2021a) and go far beyond the scope of the present paper. However, geochemical signatures of single diagnostic minerals support detailed provenance analyses documenting the prevailing influence of the Biella Pluton and the Bergell Tonalite as source rocks for the Helvetic basins during the Oligocene (Lu et al. 2019), while a "south-western" (Ligurian-Provençale) origin for the Val d'Aveto-Petrignacola clastics is indicated (Di Capua et al. 2021a).

The middle to late Eocene magmatic activity recorded in Trentino, in Brianza and in the Pavia-Piacenza Northern Apennines displays a calc-alkaline signature and therefore is clearly distinct, not only spatially but also geochemically, from the roughly contemporaneous anorogenic magmatism in the Veneto Province (Martin & Macera 2014).

Conclusions

At the close of the Paleocene, starting from Zone NP7, hemipelagic sedimentation in *Scaglia* facies in the Lombardian Basin was episodically replaced by mass sedimentation including up to coarse-grained bioclasts and intraclasts reworked from a shelf (Montorfano Mb. of the Tabiago Fm. in Bini et al. 2014). Since Lutetian times, peculiar arenites, consisting of prevailing fresh and euhedral plagioclase, along with variable amounts of quartz, volcanic rock fragments, ferromagnesian minerals (essentially amphibole and biotite), opaques and intrabasinal bioclasts, as well as minor zircon, apatite and chromian spinel, were deposited over a wide area in Northern Italy, stretching from Brianza as southwards as the Northern Apennines (Pavia and Piacenza Provinces) and as eastwards as to the Giudicarie belt (Trento Province). Such arenites can be interpreted as volcaniclastic sandstones or reworked crystal tuffs (V_2 to V_3 of Zuffa 1985) depending on local conditions. The few available paleocurrent data, all indicating westward sediment flows, support the paleogeographic reconstructions proposed by Martin & Macera (2014) and Di Capua et al. (2021a).

In the study area, these peculiar plagioclase-arenites are concentrated in middle Eocene (Lutetian to Bartonian) sediments. Dating of the arenites is particularly precise and reliable where they are intercalated to hemipelagic marlstones rich in planktonic foraminifera and calcareous nannofossils, both offering good biostratigraphic age constraints. The typical plagioclase-arenites from the Cibrone Fm. are invariably confined to the NP15c - NP17 nannofossil Zones, with a remarkable cluster in the P12/NP16 Zones.

Neovolcanic products, resedimented in hemipelagic basins locally receiving negligible or no sand supplies from continental areas, coherently point to a magmatic island arc as the most likely source area. This arc, which was active somewhere in the Adriatic hinterland during subduction of oceanic remnants of the Alpine Tethys underneath Adria, was eventually abandoned since the Oligocene, possibly due to slab break-off (Handy et al. 2010). The "pre-collisional" stage of island arc magmatism is poorly documented in outcrop because of generalised uplift and erosion of the Palaeogene succession starting from the collisional stage: this is accounted for by limited preservation of the plagioclase-arenites, commonly at the core of synclines (Molveno and Cibrone areas). A remarkable exception is represented by the Mortara volcano, still buried in the Po Plain subsurface.

The prevailing island arc provenance can be locally mixed with contributions from two more main sources, i.e., recycled orogen and starved continental shelf. Recycled orogen provenance, documented by sedimentary clasts distinctly derived from the Jurassic-Early Cretaceous succession of the Alpine Tethys (and probably reaching down into the Triassic when dolostone clasts appear), can be referred to a subduction complex which is expected to match a volcanic island arc according to plate tectonic models. A few arenite beds, sampled near Cibrone and at Veduggio, display a drastic change in composition relative to the prevailing, plagioclase-rich arenites, as quartz (especially polycrystalline quartz) and metamorphic rock fragments, negligible in all the other arenite samples, become frequent; since the Veduggio sample can be referred to the NP17 Zone, this shift possibly indicates the unroofing of deeper crustal levels within the subduction complex.

In the Brianza succession, no evidence for the NP18 to NP23 Zones (late Eocene to Early Oligocene) has ever been recorded to date; the youngest sediments from the Cibrone Fm. belong to the NP17 Zone, while the oldest Oligocene sediments belong to the Chattian nannofossil Zone NP24b (Tremolada et al. 2010). This indicates a ≈ 9 Ma hiatus, from about 37 to 28 Ma, consistent with the apatite ages of Malusà et al. (2011), and during which the Mesozoic to Paleogene succession could have been deformed and exhumed within the uprising, south-verging Alpine thrust-and-fold belt that was to feed with detritus the GLG clastic wedges. Such ages are also consistent with the ≈ 35 Ma age of the transition from Alpine Tethys subduction and Alpine collision indicated by Handy et al. (2010), possibly associated to slab break-off in the Alpine Tethys.

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