TAXONOMIC LIST OF FORAMINIFERA FROM THE VAL MIRADOLO CALCAREOUS FACIES OF THE SAN COLOMBANO FORMATION (PLEISTOCENE, LOMBARDY)

Dario Marcello SOLDAN[1], Vittorio PIERONI[2]

Key words - San Colombano formation, Foraminifera, calcareous facies, Early Pleistocene, Val Miradolo.

Abstract - The San Colombano Hill, located in the central Po Plain, represents a significant geological site due to its rich fossil deposits. This study focuses on the calcareous facies of the San Colombano formation exposed in Val Miradolo, a locality within the San Colombano Hill, attributed to the Early Pleistocene. A detailed analysis of the samples identified 126 foraminiferal species, including 117 benthic and 9 planktonic taxa, recording the highest biodiversity reported for the Calabrian in the Lombardy region. Common species include *Elphidium crispum* and *Amphistegina lessonii*. Comparisons with other Calabrian successions, such as the Stirone River, Castenedolo, and the Torrente Tiepido Pleistocene sediments reveal significant paleoenvironmental variations. The associations from San Colombano indicate warmer, coastal depositional environments, while Castenedolo suggests more restricted coastal conditions, and the Torrente Tiepido reflects deeper and colder settings. The findings enhance understanding of Early Pleistocene paleoenvironmental and climatic changes in the region, establishing San Colombano as a crucial site for biodiversity studies in the Po Valley.

Parole chiave - formazione di San Colombano, Foraminiferi, facies calcarea, Pleistocene Inferiore, Val Miradolo.

Riassunto - *Lista tassonomica dei Foraminiferi della facies calcarea di Val Miradolo della formazione di San Colombano (Pleistocene, Lombardia)* - La collina di San Colombano, situata nella Pianura Padana centrale, rappresenta un sito geologico di rilievo grazie ai suoi ricchi depositi fossiliferi. Questo studio si concentra sulle facies calcaree della formazione di San Colombano esposta in Val Miradolo, attribuita al Pleistocene Inferiore. L'analisi dettagliata dei campioni ha permesso di identificare 126 specie di foraminiferi, di cui 117 bentonici e 9 planctonici, registrando la maggiore biodiversità segnalata per il Calabriano nella regione Lombarda. Tra le specie più abbondanti si trovano *Elphidium crispum* e *Amphistegina lessonii.* Il confronto con altre successioni calabriane, come il Torrente Stirone, Castenedolo e il Torrente Tiepido, evidenzia significative variazioni paleoambientali. Le associazioni di San Colombano indicano ambienti deposizionali costieri e più caldi, mentre Castenedolo suggerisce condizioni costiere più ristrette, e il Torrente Tiepido riflette ambienti marini più profondi e freddi. I risultati arricchiscono la comprensione dei cambiamenti paleoambientali e climatici del Pleistocene Inferiore nella Pianura Padana, confermando l'importanza di San Colombano come sito cruciale per studi sulla biodiversità.

INTRODUCTION

The San Colombano Hill in the central Po Plain (Lombardy region) rises approximately 70 meters above the surrounding level. This hill is renowned for its rich fossil fauna, which has attracted the attention of geologists and paleontologists since the 18th century. In 1785, Amoretti published the "*Osservazioni sulla collina di S. Colombano nel territorio lodigiano*". Later, Stoppani (1857) provided a stratigraphic framework of the hill and described the fossiliferous localities of the Miradolo limestone facies (pp. 43–46). Subsequently Sartorio (1879) and Airaghi (1897a) expanded the list of identified fossil *taxa* from the hill through further studies. Among the numerous investigations of the Pleistocene marine fauna of this locality, noteworthy contributions include studies on mollusks (Patrini, 1930; Anfossi & Brambilla, 1981; Guioli & Brambilla, 2003) and echinoderms (Airaghi, 1897b).
The first study on foraminifera from the limestone facies of the hill dates back to Sartorio (1879), who reported about a dozen species. Later, Mariani (1888) identified 42 species, although the exact provenance of the samples analyzed was not specified. A more detailed analysis, focusing on paleoenvironmental reconstruction, was carried out by Coggi & Di Napoli (1950), who investigated the foraminiferal assemblages in various facies of the San Colombano formation. Farioli (1954) described microfaunas from the clays of Val Magna, located near the village of San Colombano al Lambro, listing 27 species. In agreement with Coggi & Di Napoli (1950), these marine sediments were attributed to the Early Pleistocene (Calabrian).
The aim of this study is to provide a comprehensive list of the foraminiferal *taxa* identified from the calcareous facies outcrop of the San Colombano formation, exposed in Val Miradolo (Fig. 1).

GEOLOGICAL SETTING

The hill of San Colombano, a solitary rise in southern Lombardy, develops over one of the buried frontal sectors of the northern Apennine thrust belt in the Po Plain. Although it is predominantly covered by Quaternary fluvial deposits, the base of the hill is made up of marine sediments (Zuffetti *et al.*, 2018). The oldest sediments emerging from the hill of San Colombano consist of greyish marls and clays, alternating with thin fine-grained sandstones (Miocene, Langhian-Tortonian), attributed to the formation of the Marne di Sant'Agata Fossili

[1]Società Italiana di Scienze Naturali, Corso Venezia 55, 20121 Milano, Italy. ✉ dario.soldan@yahoo.it
[2]Museo di Storia Naturale "A. Stoppani", Seminario Arcivescovile "Pio XI", Via Papa Pio XI 32, 21040 Venegono Inferiore (Varese), Italy.

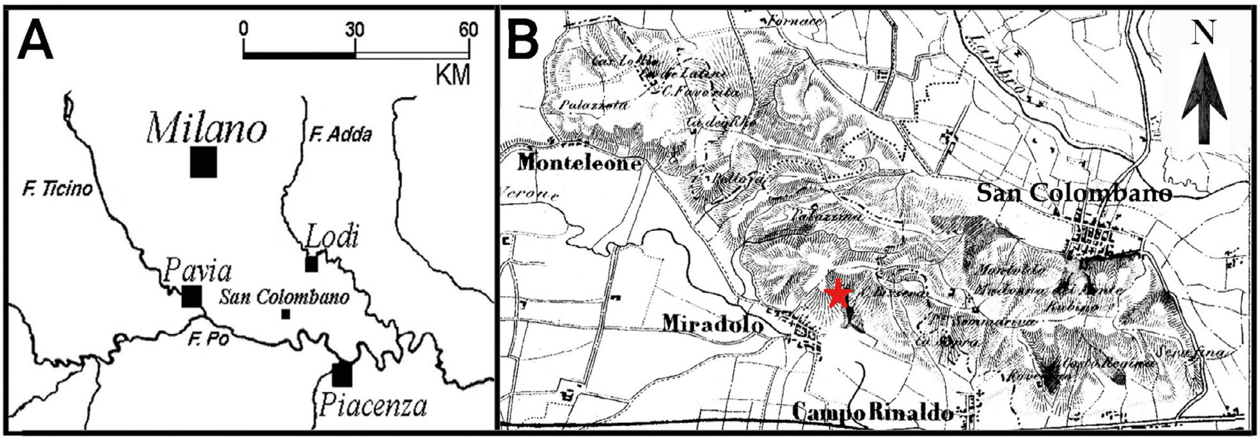

Fig. 1 - **A**. Geographic location of the study area. **B**. Sampling point (indicated by a star) within the calcareous facies of Val Miradolo, where sediments were collected for foraminiferal analysis. **A**. After SOLDAN (2007). **B**. Modified from SARTORIO (1879).

(BONI, 1967; ANFOSSI *et al.*, 1971; ZUFFETTI *et al.*, 2018). Above these Miocene marls, which constitute the discordant substrate of the entire hill, lies the San Colombano formation, attributed to the Lower Pleistocene (Calabrian; BONI, 1967). This formation is composed of different facies. Directly above the Tortonian marls, we find an organogenic limestone, in which conglomerate with pebbles of Alpine origin are occasionally found in the northern and eastern part of the hill (ANFOSSI & BRAMBILLA, 1981; SOLDAN, 2007), while in the southern part fine detrital materials predominate, with banks of coralline algae (MASTRORILLI, 1950). Based on its faunal content, the detrital/conglomeratic limestone with coralline algae has been deposited in a temperate or warm temperate water reef environment (BONI, 1967; ANFOSSI *et al.*, 1971). Sometimes the limestone is dominated by the coral genus *Cladocora*, becoming a madreporic conglomeratic limestone (BONI, 1967; ANFOSSI *et al.*, 1971). Above the limestone, a second sedimentary facies is observed, consisting of bluish-grey clays, coarsely stratified, with a thickness that can exceed ten meters (ZUFFETTI *et al.*, 2018). This facies represents a phase of marine transgression, which occurred in a context of climatic cooling, as attested by the studies of COGGI & DI NAPOLI (1950) and ZUFFETTI *et al.* (2018). In the upper part, the clays alternate with fine sands, indicating a coastal environment in a phase of transgression that gradually transforms into a shallow continental shelf, characterized by a transition from circalittoral to infralittoral settings, as evidenced by the research of ANFOSSI & BRAMBILLA (1981) and ZUFFETTI *et al.* (2018).

MATERIALS AND METHODS

For this study, three samples were collected approximately 50 centimeters apart horizontally from the very small outcrop of the calcareous facies exposed in a valley near the village of Miradolo Terme, mentioned by BONI (1967) as Val Miradolo (Fig. 2). The detrital limestone is visible on the right side of a small lateral valley with a southwest-northeast direction that rejoins the bottom of the Val Miradolo. Starting from an altitude of about 90 meters, one meter of marl belonging to the formation of the Marne di Sant'Agata Fossili, partially covered by Quaternary sediments, was observed. Continuing upwards along the small valley, a layer of recent sediments was encountered, above which the outcrop of the limestones was found (Fig. 2). This outcrop is composed of about 3.5 meters of detrital organogenic limestones without evident stratification, characterized at the base by well-rounded pebbles, from which the samples were collected. Due to the limited extension of the outcrop, it was not possible to perform a wider sampling, and the number of samples was therefore restricted to three.

Generally, the samples consist of loose sediment and, in the case of fragments of more compact limestone, they were crushed. The samples were washed, dried, and sieved to obtain two size-fractions of 450 µm and 150 µm. The washed residues, of about 45 grams each one, were subsequently examined under a stereomicroscope to observe and identify the foraminifera.

The predominant mineralogical component is quartz, mica, and other silicates of Alpine origin, as already observed by previous authors (FARIOLI, 1954; ZUFFETTI *et al.*, 2018).

Foraminifera were abundant and generally well preserved, usually presenting a whitish or yellowish coloration (Fig. 3). From the analysis, it was possible to isolate more than 400 specimens, which were studied and classified. In addition to foraminifera, the examined size-fractions contain numerous fragments of bivalves, gastropods, bryozoans, anthozoans, porifers, and echinoderm echinoid radioles. Ostracods are less frequent, while fish teeth are rare. Small brachiopods, mainly belonging to the genus *Megathyris*, have also been observed.

Bivalves and gastropods are strongly eroded, whereas brachiopods are well preserved with articulated shells, suggesting two times of deposition: the first one made by allochthonous material, the second one containing autochthonous or parautochthonous shells.

Classification of the observed foraminifera at generic and specific levels follows the Atlas Foraminiferi Padani (AGIP, 1982), updating with World Register of Marine Species (WoRMS, 2024) and FORAMINIFERA.EU (2024).

DISCUSSION ON THE FORAMINIFERAL FAUNA

In the analyzed samples, approximately 117 benthic foraminiferal species and 9 planktonic species were identified (Tab. 1). Additionally, for each *taxon* , Table 1 reports the typical depth range based on MURRAY (2006) and the references cited therein for the Mediterranean area, integrated with additional

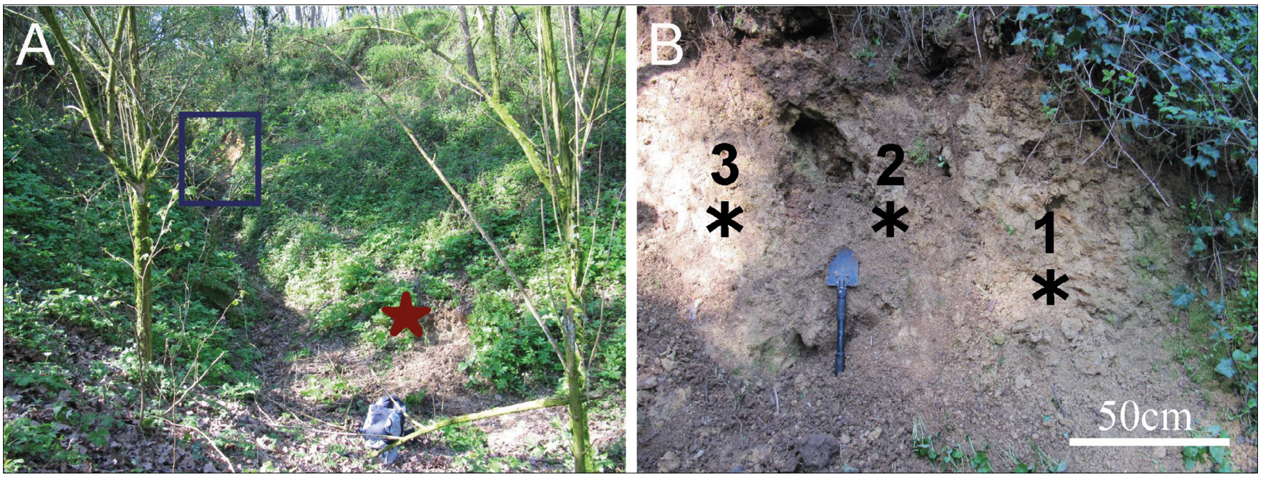

Fig. 2 - **A**. Location in Val Miradolo with the San Colombano formation outcrop (highlighted by a rectangle) directly upon the formation of the Marne di Sant'Agata Fossili (red star; coordinates: 45°10'35.37''N, 9°26'58.81''E). **B**. Outcrop of the organic-detrital limestone (calcareous facies of San Colombano formation). The numbered asterisks indicate the points where the samples were collected.

data from the Mikrotax database (Mikrotax.org, 2024). The most abundant and generally larger species are *Elphidium crispum* (Fig. 3, 11), *Lenticulina costata* (Fig. 3, 6-7), *L. rotulata*, *Amphistegina lessonii* (Fig. 3, 12), consistently found in all analyzed samples. Rare specimens of *Planularia cassis* (Fig. 3, 10) were recovered from samples 2 and 3. In the finer fraction, the most common *taxa* are *Heterolepa praecinta* (Fig. 3, 4) and *H. dutemplei* (Fig. 3, 5) which are present in all analyzed samples. Species belonging to the genera *Cibicides* and *Cibicidoides* are also common but less frequent than *Heterolepa*. *Cibicides refulgens* (Fig. 3, 2) is frequent and present in all three studied samples. Taxa of the Textularidae family are significantly represented, with large specimens of *Textularia*, while the Hauerinidae are rare. Rare specimens of the Vaginulinidae family, including large individuals of *Vaginulina* and *Marginulina*, were also identified. One specimen of *Ammonia* was found in sample 2 and another in sample 3 (Tab. 1). No significant differences in faunal composition were observed among the three analyzed samples. The co-occurrence of shallow infralittoral and circalittoral species and *taxa* typical of deeper, even bathyal, environments likely reflects reworking and transport of material within a high-energy coastal cliff setting. These dynamic conditions may have favored the accumulation of foraminiferal tests from different source areas within the same depositional context.

Additionally, we observed the presence of *Amphicoryna tenuicostata* (Fig. 3, 18) and *Marginulina hirsuta* (Fig. 3, 17) in sample 1 (Tab. 1), *taxa* that are not longer recorded in Pleistocene assemblages and whose occurrence may result from the reworking of older deposits. The scarcity of planktonic foraminifera compared to the benthic foraminifera in these samples indicates that the deposition environment was coastal, as also highlighted in a study on the bivalves from this facies (Anfossi & Brambilla, 1981).

A comparison with the current distribution of benthic foraminifera in the modern Mediterranean Sea (Sgarella & Moncharmont Zei, 1993; Milker & Schmiedl, 2012) reveals that the most abundant extant species (Tab. 1) predominantly are distributed within infralittoral and circalittoral environments. The absence of *Hyalinea balthica* (Schröter, 1783) a species typical of colder waters, is consistent with observations from previous studies (Coggi & Di Napoli, 1950; Zuffetti *et al.*, 2018). As noted by Coggi & Di Napoli (1950), the absence of *Hyalinea balthica* may suggest that marine conditions during the deposition of the calcareous facies at San Colombano Hill were characterized by higher temperatures compared to the clayey facies from where this *taxon* was reported. Moreover, the presence of *Amphistegina lessonii* (Fig. 3, 12), a large benthic foraminifer typical of warm, shallow infralittoral environments, provides useful paleoenvironmental information. This species is not only well preserved but also widely distributed throughout the studied samples (Tab. 1), suggesting it is probably not reworked. Its abundance could indicate a depositional interval characterized by warm climatic conditions, as similarly documented by Baio & Violanti (2021).

Farioli (1954) noted that the foraminiferal fauna associated with the calcareous facies is oligotypic, thus characterized by a limited number of species. However, the results of the present analysis suggest that the limited number of species identified in earlier studies is primarily due to factors such as sampling methodologies and outcrop characteristics, rather than restrictive environmental conditions. Indeed, compared to previous research, a total of 126 foraminiferal species were identified at the site examined in this study. The number is significantly higher than those reported in earlier works: for instance, Mariani (1888) described 42 species, Coggi & Di Napoli (1950) 30 species, and Farioli (1954) 27 species. Thus, the Val Miradolo outcrop stands out as the site with the highest foraminiferal species diversity within the Calabrian of San Colombano formation, offering a more detailed view of the fossil fauna contained in this formation.

From a taxonomic diversity perspective, the comparison between the San Colombano Hill succession and the Calabrian deposits of the Stirone River reveals differing quantitative data. Approximately 83 hyaline benthic species, 7 genera of miliolids, and 4 genera of agglutinated foraminifera have been recorded at the Stirone River (Mariani *et al.*, 2022). The genus *Lenticulina* is not reported at the Stirone River, whereas miliolids are rare at San Colombano Hill. However, both

Fig. 3 - Benthic Foraminifera from the calcareous facies of the San Colombano formation in the studied outcrop of Val Miradolo.
1. *Planulina ariminensis* D'ORBIGNY, 1826 (a-c, lateral view; b, apertural view); **2**. *Cibicides refulgens* MONTFORT, 1808 (a-c, lateral view; b, apertural view); **3**. *Bolivina catanensis* SEGUENZA, 1862; **4**. *Heterolepa praecincta* (KARRER, 1868) (a-c, lateral view; b, apertural view); **5.** *Heterolepa dutemplei* (D'ORBIGNY, 1846) (a-c, lateral view; b, apertural view); **6, 7**. *Lenticulina costata* (FICHTEL & MOLL, 1798) (a, lateral view; b, apertural view); **8**. *Textularia pseudorugosa* LACROIX, 1931 (a, lateral view; b, apertural view); **9**. *Karreriella bradyi* (CUSHMAN, 1911) (a, lateral view; b, apertural view); **10**. *Planularia cassis* (FICHTEL & MOLL, 1798); **11**. *Elphidium crispum* (LINNAEUS, 1758) (a, lateral view; b, apertural view); **12**. *Amphistegina lessonii* D'ORBIGNY in DESHAYES, 1830; **13**. *Textularia pala* CZJZEK, 1848 (a, lateral view; b, apertural view); **14**. *Pyramidulina raphanistrum* (LINNAEUS, 1758); **15**. *Marginulina filicostata* FORNASINI, 1891; **16**. *Marginulinopsis costata* (BATSCH, 1791); **17.** *Marginulina hirsuta* D'ORBIGNY, 1826; **18**. *Amphicoryna tenuicostata* (COSTA, 1853); **19**. *Vaginulina americana* CUSHMAN, 1923; **20**. *Lingulina seminuda* HANTKEN, 1875.

localities share similarities in their faunal composition, with abundant species belonging to the most common genera, such as *Elphidium* and *Cibicides*.

The presence of deeper-water *taxa* in the San Colombano formation, such as *Cibicidoides robertsonianus*, *Melonis pompilioides*, and *Lingulina seminuda* (Fig. 3, 20), in a predominantly infralittoral-circalittoral assemblage (Tab. 1) can be explained by two complementary factors: the active transport of material from the deeper platform to the coastal environment, and the probable reworking of older Pliocene deposits. This indicates a complex depositional setting characterized by the mixing of faunas from different *habitat*s.

Bini *et al.* (2016) analyzed core samples from a hole in the locality Orio Litta, in the Po Valley located near San Colombano al Lambro. In the C7a4-S007 core, they identified a foraminiferal assemblage dominated by few infralittoral species such as *Ammonia beccarii* and *Elphidium crispum*, along with circalittoral *taxa* including *Bolivina marginata*, *Cancris auriculus*, *Cassidulina carinata*, and *Valvulineria bradyana*. Based on the presence of *Bulimina marginata* and *Neogloboquadrina pachyderma*, the deposits have been dated to the Gelasian (Lower Pleistocene). The species reported at Orio Litta indicate an infralittoral and circalittoral environment similar to that of San Colombano Hill, which, however, exhibits greater diversity in benthic foraminifera.

The foraminiferal assemblage recorded at San Colombano Hill was also compared with that of other Pleistocene successions in the Po Valley, such as the Castenedolo (Brescia) and the Torrente Tiepido succession located near Modena. Compared to San Colombano Hill, the foraminiferal assemblage at Castenedolo is more sparse, with predominant forms such as *Ammonia* and *Elphidium* adapted to brackish or coastal environments (Brambilla *et al.*, 1988). This evidence highlights different paleoenvironmental influences: while San Colombano Hill preserves both coastal and deeper water species, the assemblage at Castenedolo seems to indicate proximity to a coastal environment with limited connection to the open sea (Brambilla *et al.*, 1988).

In the Torrente Tiepido succession, significant differences emerge in the foraminiferal assemblages. In the basal sediments of the Torrente Tiepido succession, dated to the Early Pleistocene (Calabrian), the assemblage is dominated by benthic foraminifera such as *Bolivina catanensis*, *Bulimina elegans* and *Cassidulina laevigata*, with planktonic species constituting only 8% of the total and mainly represented by *Globigerina* and rare species of *Globorotalia* (Annovi *et al.*, 1979). This suggests a deeper depositional environment compared to that of San Colombano Hill, where the scarcity of planktonic foraminifera is consistent with a coastal setting. Furthermore, the presence of species such as *Hyalinea balthica* in the Torrente Tiepido succession indicates colder climatic conditions, contrasting with those of San Colombano Hill, where the absence of *Hyalinea balthica* and the faunal composition suggest relatively warmer waters. These differences confirm distinct paleoenvironmental conditions between the two marine deposits during the Early Pleistocene, with Torrente Tiepido reflecting a progressively colder climate and indicating a neritic infralittoral environment.

Family	**Genera and species**	**Sample**			**Strat. Distr.**			**Depth Environment**
		1	**2**	**3**	**Pli**	**Ple**	**Hol**	
Acervulinidae	*Sphaerogypsina globulus* (Reuss, 1848)	R	VR	VR	X	X	X	**I**
Alabaminidae	*Oridorsalis umbonatus* (Reuss, 1851)	C	C	C	X	X	X	**CL-B**
Ammoniidae	*Ammonia beccarii* (Linnaeus, 1758)		VR		X	X	X	**I**
	Ammonia inflata (Seguenza, 1862)			VR	X	X		**I**
Amphisteginidae	*Amphistegina lessonii* D'Orbigny in Deshayes, 1830	C	C	C	X	X	X	**I**
Asterigerinatidae	*Biasterigerina planorbis* (D'Orbigny, 1846)	C	C	R	X	X	X	**I**
Bolivinitidae	*Bolivina alata* (Seguenza, 1862)		VR	VR	X	X	X	**B**
	Bolivina catanensis Seguenza, 1862	R	VR		X	X		**CL-B**
	Bolivina dilatata Reuss, 1850	VR	VR		X	X	X	**CL-B**
Buliminidae	*Bulimina elegans* D'Orbigny in Parker, Jones & Brady, 1865	VR	VR	VR	X	X	X	**B**
	Bulimina elongata D'Orbigny, 1846	VR		VR	X	X	X	**I-CL**
	Bulimina inflata Seguenza, 1862	VR	VR		X	X	X	**CL-B**
	Bulimina lappa Cushman & Parker, 1937	VR		VR	X	X	X	**B**
	Bulimina marginata D'Orbigny, 1826	VR	VR		X	X	X	**CL-B**
	Bulimina striata D'Orbigny in Guérin Méneville, 1832		VR	VR	X	X	X	**B**
	Protoglobobulimina pupoides (D'Orbigny, 1846)		VR		X	X	X	**CL-B**
Cassidulinidae	*Reissia hystrix* (Brady, 1881)	VR	VR	VR	X	X	X	**B**
	Globocassidulina crassa (D'Orbigny, 1839)	R	R	VR	X	X	X	**CL-B**
Chilostomellidae	*Chilostomella oolina* Schwager, 1878			VR	X	X	X	**B**
Cibicididae	*Cibicides floridanus* (Cushman, 1918)	VR		VR	X	X	X	**CL-B**
	Cibicides refulgens Montfort, 1808	C	C	C	X	X	X	**CL-B**
	Cibicidoides ornatus (Costa, 1856)		VR	VR	X	X		**CL-B**
	Cibicidoides pseudoungerianus (Cushman, 1922)	R	R	VR	X	X	X	**CL-B**
	Cibicidoides mundulus (Brady, Parker & Jones, 1888)	R	VR		X	X	X	**B**
	Cibicidoides robertsonianus (Brady, 1881)			VR	X	X	X	**B**

Family	Genera and species	Sample			Strat. Distr.			Depth Environment
		1	2	3	Pli	Ple	Hol	
	Heterolepa bradyi (TRAUTH, 1918)		VR	VR	X	X	X	**B**
	Heterolepa dutemplei (D'ORBIGNY, 1846)	A	C	A	X	X		**CL-B**
	Heterolepa praecincta (KARRER, 1868)	A	A	A	X	X	X	**CL-B**
	Lobatula lobatula (WALKER JACOB in KANMACHER, 1798)	C	R	C	X	X	X	**I-CL**
	Lobatula ungeriana (D'ORBIGNY, 1846)	R	VR	R	X	X	X	**CL-B**
Cornuspiridae	*Cornuspira carinata* (COSTA, 1856)	VR			X	X	X	**I-CL**
	Cornuspira involvens (REUSS, 1850)	VR	VR		X	X	X	**I-CL-B**
Discorbinellidae	*Discorbinella bertheloti* (D'ORBIGNY, 1839)		VR	VR	X	X	X	**CL-B**
	Hanzawaia boueana (D'ORBIGNY, 1846)	VR		VR	X	X	X	**CL-B**
Eggerellidae	*Bannerella gibbosa* (D'ORBIGNY, 1826)	VR	VR		X	X	X	**I-CL**
	Martinotella communis (D'ORBIGNY, 1846)	R	VR	R	X	X	X	**B**
	Karreriella bradyi (CUSHMAN, 1911)	R	R	VR	X	X	X	**CL-B**
Ellipsolagenidae	*Geminiella gibbera* (BUCHNER, 1940)		VR	VR	X	X	X	**CL-B**
	Favulina foveolata (SEGUENZA, 1862)	VR			X	X	X	**I-CL**
Elphidiidae	*Elphidium complanatum* (D'ORBIGNY, 1839)		VR		X	X	X	**I-CL**
	Elphidium crispum (LINNAEUS, 1758)	A	A	A	X	X	X	**I-CL**
	Elphidium macellum (FICHTEL & MOLL, 1798)	R	R	R	X	X	X	**I-CL**
Eponididae	*Eponides repandus* (FICHTEL & MOLL, 1798)	C	C	C	X	X	X	**CL**
Gavelinellidae	*Hansenisca soldanii* (D'ORBIGNY, 1826)	VR	VR	VR	X	X	X	**B**
Glandulinidae	*Glandulina glans* (D'ORBIGNY in JONES & PARKER, 1860)	VR			X	X		**CL-B**
Globobuliminidae	*Globobulimina ovata* (D'ORBIGNY, 1846)			VR	X	X	X	**CL-B**
	Globobulimina pyrula (D'ORBIGNY, 1846)	VR	VR		X	X	X	**B**
Haynesinidae	*Haynesina depressula* (WALKER & JACOB in KANMACHER, 1798)		VR	VR	X	X	X	**I**
Hauerinidae	*Pyrgo bulloides* (D'ORBIGNY, 1826)	VR			X	X	X	**CL**
	Pyrgo depressa (D'ORBIGNY, 1826)		VR		X	X	X	**CL-B**
	Quinqueloculina vulgaris D'ORBIGNY, 1826		VR		X	X	X	**I-CL**
	Sigmoilopsis schlumbergeri (SILVESTRI, 1904)	VR		VR	X	X	X	**CL-B**
Melonidae	*Melonis padanus* (PERCONIG, 1954)	VR	VR	VR	X	X	X	**B**
	Melonis pompilioides (FICHTEL & MOLL, 1798)	R	R	VR	X	X	X	**B**
Nodosariidae	*Laevidentalina inflexa* (REUSS, 1866)			VR	X	X	X	**CL-B**
	Laevidentalina leguminiformis (BATSCH, 1791)	VR		VR	X	X	X	**CL-B**
	Lingulina seminuda HANTKEN, 1875		VR	VR	X	X	X	**B**
	Pandaglandulina dinapolii LOEBLICH & TAPPAN, 1955	VR	VR		X	X		**CL-B**
	Pyramidulina raphanistrum (LINNAEUS, 1758)	VR	VR	VR	X	X		**CL-B**
	Pyramidulina raphanus (LINNAEUS, 1758)		VR		X	X	X	**CL-B**
Nonionidae	*Nonion boueanum* (D'ORBIGNY, 1846)	VR	VR		X	X		**I-CL**
	Nonionoides turgidus (WILLIAMSON, 1858)		VR		X	X	X	**I-CL**
Planulinidae	*Planulina ariminensis* D'ORBIGNY, 1826	R	VR	R	X	X	X	**CL-B**
Plectofrondiculariidae	*Mucronina compressa* (COSTA, 1855)	VR			X	X	X	**B**
Polymorphinidae	*Globulina gibba* (D'ORBIGNY in DESHAYES, 1832)		VR	VR	X	X	X	**I**
	Guttulina communis (D'ORBIGNY, 1826)	R	R	R	X	X	X	**CL-B**
Pulleniidae	*Pullenia bulloides* (D'ORBIGNY, 1846)	R	R	R	X	X	X	**CL-B**
	Pullenia quadriloba REUSS, 1867	VR	R	R	X	X		**B**
	Pullenia quinqueloba (REUSS, 1851)	R	R	VR	X	X	X	**CL-B**
Reussellidae	*Reussella spinulosa* (REUSS, 1850)	VR	VR	VR	X	X	X	**I-CL**
Rosalinidae	*Neoconorbina terquemi* (RZEHAK, 1888)		VR	VR	X	X	X	**CL-B**
	Rosalina globularis D'ORBIGNY, 1826			VR	X	X	X	**I-CL**
Sphaeroidinidae	*Sphaeroidina bulloides* D'ORBIGNY in DESHAYES, 1832	C	C	C	X	X	X	**CL-B**
Spiroloculinidae	*Spiroloculina excavata* D'ORBIGNY, 1846			VR	X	X	X	**I-CL**
Spiroplectamminidae	*Spiroplectinella wrightii* (SILVESTRI, 1903)		VR		X	X	X	**CL-B**
Stainforthiidae	*Stainforthia fusiformis* (WILLIAMSON, 1858)		VR	VR	X	X	X	**I-CL**
Textulariidae	*Bigenerina nodosaria* D'ORBIGNY, 1826	VR	VR		X	X	X	**B**
	Sahulia conica (D'ORBIGNY, 1839)	C	C	C		X	X	**I-CL**

Family	**Genera and species**	**Sample**			**Strat. Distr.**			**Depth Environment**
		1	**2**	**3**	**Pli**	**Ple**	**Hol**	
	Textularia agglutinans D'Orbigny, 1839	C	C	C	X	X	X	**I-CL**
	Textularia gramen D'Orbigny, 1846	R	VR	R	X	X	X	**I-CL**
	Textularia pseudorugosa Lacroix, 1931	C	C	C	X	X	X	**CL-B**
	Textularia pala Czjzek, 1848	R	C	C	X	X	X	**I-CL**
	Textularia sagittula Defrance, 1824	VR	VR	VR	X	X	X	**I-CL**
	Textularia soldanii Fornasini, 1883	VR	VR	R	X	X	X	**I-CL**
Uvigerinidae	*Trifarina angulosa* (Williamson, 1858)	VR	VR	VR	X	X	X	**CL-B**
	Trifarina bradyi Cushman, 1923	VR	R	R	X	X	X	**B**
	Trifarina fornasinii (Selli, 1948)	R	VR	R	X	X	X	**B**
	Uvigerina flintii Cushman, 1923	R	VR	R	X	X	X	**B**
	Uvigerina canariensis D'Orbigny, 1839	VR	VR	VR	X	X	X	**B**
	Uvigerina mediterranea Hofker, 1932			VR	X	X	X	**B**
	Uvigerina peregrina Cushman, 1923		VR	VR	X	X	X	**B**
Vaginulinidae	*Cribrorobulina serpens* (Seguenza, 1880)	VR			X	X	X	**B**
	Amphicoryna hirsuta (D'Orbigny, 1826)		VR		X	X	X	**CL-B**
	Amphicoryna proxima (Silvestri, 1872)	VR		VR	X	X	X	**B**
	Amphicoryna scalaris (Batsch, 1791)	R	VR		X	X	X	**CL-B**
	Amphicoryna tenuicostata (Costa, 1853)	VR			X			**B**
	Dentalina aciculata (D'Orbigny, 1826)		VR		X	X		**B**
	Dimorphina tuberosa D'Orbigny, 1826	VR		VR	X	X		**B**
	Lenticulina calcar (Linnaeus, 1767)	VR	VR		X	X	X	**CL-B**
	Lenticulina costata (Fichtel & Moll, 1798)	C	C	R	X	X	X	**CL-B**
	Lenticulina cultrata (Montfort, 1808)	R	R	VR	X	X	X	**B**
	Lenticulina gibba (D'Orbigny, 1839)		VR	VR	X	X	X	**B**
	Lenticulina inornata (D'Orbigny, 1846)	R	VR	R	X	X	X	**B**
	Lenticulina orbicularis (D'Orbigny, 1826)	R	R	R	X	X	X	**B**
	Lenticulina rotulata (Lamarck, 1804)	C	C	C	X	X	X	**CL**
	Lenticulina stellata (Seguenza, 1880)	VR			X	X		**B**
	Lenticulina vortex (Fichtel & Moll, 1798)	R	R	VR	X	X	X	**B**
	Marginulina filicostata (Fornasini, 1891)	R	VR	R	X	X		**B**
	Marginulina advena (Cushman, 1923)	VR		VR		X	X	**CL-B**
	Marginulina cherensis Tedeschi & Zanmatti, 1957		VR		X	X		**B**
	Marginulina hirsuta D'Orbigny, 1826	VR			X			**B**
	Marginulina similis D'Orbigny, 1846	VR	VR	VR	X	X	X	**CL-B**
	Marginulinopsis costata (Batsch, 1791)	VR	VR	VR	X	X	X	**CL-B**
	Planularia cassis (Fichtel & Moll, 1798)		VR	VR	X	X	X	**B**
	Saracenaria italica Defrance, 1824			VR	X	X	X	**CL-B**
	Vaginulina americana Cushman, 1923	VR	VR	VR		X	X	**B**
	Vaginulina bradyi Cushman, 1917		VR		X	X	X	**CL-B**
Globigerinidae	*Globigerina bulloides* D'Orbigny, 1826	VR	VR	R	X	X	X	**P**
	Globigerina falconensis Blow, 1959			VR	X	X	X	**P**
	Globigerinella siphonifera (D'Orbigny, 1839)			VR	X	X	X	**P**
	Globigerinoides extremus Bolli & Bermúdez, 1965	VR		VR	X	X		**P**
	Globigerinoides obliquus Bolli, 1957		VR	VR	X	X		**P**
	Globigerinoides ruber (D'Orbigny, 1839)	R	R	VR	X	X	X	**P**
	Globorotalia crassaformis (Galloway & Wissler, 1927)		VR		X	X	X	**P**
	Orbulina universa D'Orbigny, 1839	C	C	R	X	X	X	**P**
	Trilobatus trilobus (Reuss, 1850)	R	C	C	X	X	X	**P**

Tab. 1 - List of foraminifera species identified in the limestone of the San Colombano formation at Val Miradolo. The abundance of each species is represented by the following codes: **A**=Abundant (more than 20 specimens were found); **C**=Common (10-20 specimens were found); **R**=Rare (5-10 specimens were found); **VR**=Very rare (1-5 specimens were found). Stratigraphic Distribution: **Pli**=Pliocene; **Ple**=Pleistocene; **Hol**=Holocene. Depth Environment: **I**=Infralittoral (0-50 meters); **CL**=Circalittoral (50-200 meters); **B**=Bathyal (200-2000 meters); **P** = Planktic (pelagic species). Bibliographic references for the species authors are available from the online databases Foraminifera.eu (2024), Mikrotax.org (2024) and WoRMS (2024).

The comparison of these localities reveals significant paleoenvironmental and climatic variations in the Po Valley during the Early Pleistocene. San Colombano Hill and Stirone River localities display high biodiversity and a prevalence of species adapted to coastal waters, and a similar paleoenvironmental conditions are recorded at Orio Litta section. On the contrary the marine deposit of Castenedolo suggests more isolated coastal conditions, and that of Torrente Tiepido indicates deeper waters and colder climates. These findings contribute to a better understanding of the paleoenvironmental changes in the Po Valley during the Early Pleistocene, offering a more detailed scenario of faunal and climatic variations.

CONCLUSION

The herein described fauna from Val Miradolo, belonging to the calcareous facies of the San Colombano formation, represents one of the highest levels of biodiversity in the Po Valley, with the identification of 126 foraminiferal species, including 117 benthic and 9 planktonic. This result represents the highest number of species reported for the Calabrian in the region. The lower number of foraminiferal species reported in earlier studies (e.g., COGGI & DI NAPOLI, 1950; FARIOLI, 1954) is likely due to the smaller volume of sediment sampled or analyzed in these works. Additionally, variations in outcrop conditions may have contributed to this discrepancy.

Analysis reveals a predominance of shallow-water benthic *taxa*, mainly infralittoral and circalittoral, with deeper-water species comparatively rare. The coexistence of deeper-water *taxa* likely reflects the transport of material within a high-energy depositional environment, with some species potentially originating from reworked older deposits. A considerable proportion of the identified *taxa* displays a broad temporal range, with many species already present in the Pliocene and continuing into the Holocene.

In comparison, the Stirone River locality exhibited similar faunal composition characterized by common genera such as *Elphidium* and *Cibicides*. Compared to other successions in the Po Valley, such as the Castenedolo and Torrente Tiepido outcrops, San Colombano Hill clearly emerges as the most representative site to analyze the benthic foraminiferal diversity. These results underscore the significance of the San Colombano formation, not only for its faunal richness but also for its contribution to the understanding of the taxonomic distribution and Foraminifera biodiversity of the Early Pleistocene formations of the Po Plain useful to a reconstruction of its marine palaeoenvironments.

TAXONOMIC NOTES

Bulimina lappa

Bulimina elongata var. *lappa* CUSHMAN & PARKER, 1937, has been assigned to the genus *Caucasina* by WoRMS (2024) as a result of their recent taxonomic revisions suggesting a closer affinity with this genus. However, based on the morphological characteristics observed in the analyzed morphotypes, which are consistent with the traditional descriptions of *Bulimina*, and following the classifications proposed by the FORAMINIFERA.EU (2024) and the Atlas of Foraminiferi Padani (AGIP, 1982), we have decided to maintain this species in the genus *Bulimina*.

Cibicidoides ornatus

Originally described as *Nonionina ornata* COSTA, 1856, this species was subsequently included in the genus *Anomalinoides* by AGIP (1982). However, the website WoRMS (2024) in agreement with SPROVIERI & HASEGAWA (1990) includes this form in the genus *Cibicidoides*. On the other hand, the name *Cibicidoides ornatus* CICHA & ZAPLETALOVÁ (1960) has been used for another *taxon*. If *Cibicidoides ornatus* (COSTA, 1856) is considered valid, then *Cibicidoides ornatus* CICHA & ZAPLETALOVÁ (1960) would be a junior homonimy and would have to be renamed.

Lenticulina costata

Numerous specimens showing the typical taxonomic features of specimens from the Vienna Basin illustrated by PAPP & SCHMIDT (1985) have been observed in the samples. These medium to large morphotypes show a characteristic keel with spines and ribs in planispiral view (Fig. 3, 6-7).

Marginulina similis

We have observed specimens that fall well within the characteristics of *Marginulina glabra* (D'ORBIGNY in PARKER, JONES & BRADY, 1865). However, observing the taxonomic characters of the morphotypes in accordance with WoRMS (2024), we believe that this *taxon* can be included in *Marginulina similis* D'ORBIGNY, 1846.

Vaginulina americana

This species is characterized by an elongated shell with a smooth or slightly ornamented external surface (Fig. 3, 19). We have included in this *taxon* rare large specimens that correspond well to the morphotypes figured by CUSHMAN (1923).

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