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INTEGRATED STRATIGRAPHY OF MIDDLE-LATE MIOCENE SYNOROGENIC DEPOSITS OF THE EASTERN SOUTHERN APENNINE CHAIN: THE SAN BARTOLOMEO FLYSCH

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Abstract. The present paper deals with the stratigraphic and biostratigraphic study of the middle-late Miocene thrust-top basin deposits of the San Bartolomeo Flysch, exposed north of Matese mountains and analysed during the geological survey of the sheet N° 405 Campobasso of the new Geological Map of Italy, 1:50.000 scale. The integrated study of calcareous nannofossils and planktonic foraminifera, based on the semi-quantitative distribution range of index species, revealed the presence of age-diagnostic assemblages which are comparable with those of different middle-late Miocene deep-marine sedimentary settings of the Mediterranean Basin. The biostratigraphic dataset suggests an early Serravallian – early middle Tortonian age. In terms of calcareous nannofossil biostratigraphy, the studied succession falls between the Last Occurrences of *Sphenolithus heteromorphus* and the First Occurrence of *Discoaster bellus* gr., corresponding to the MNN6 – MNN8 zone interval. In terms of planktonic foraminiferal biostratigraphy the studied sediments fall between the Last Occurrence of *Globorotalia peripheroronda* and the First Regular Occurrence of *Neogloboquadrina acostaensis*, corresponding to the MM6 p.p. – MMi10 p.p. zone interval. This study documents the applicability of the recent Mediterranean middle–late Miocene biozonations for the biostratigraphic study of siliciclastic synorogenic sediments, and challenges the most recent studies that dated the San Bartolomeo Flysch to the late Tortonian-early Messinian.

Riassunto. Vengono presentati i risultati dello studio stratigrafico e biostratigrafico effettuato sui depositi silicoclastici del Miocene medio-superiore, attribuiti al flysch San Bartolomeo, che affiorano a Nord dei monti del Matese, nel Foglio N° 405 Campobasso della Carta Geologica d'Italia alla scala 1: 50.000. L'analisi semiquantitativa integrata dei foraminiferi planctonici e dei nannofossili calcarei, basata sulla identificazione di significative variazioni di abbondanza delle specie marker, ha permesso di identificare una successione di bioeventi confrontabile con quella riconosciuta in diverse successioni sedimentarie di stessa età e di mare profondo del Bacino Mediterraneo. I sedimenti studiati hanno un'età compresa tra il Serravalliano inferiore e il Tortoniano inferiore-medio. In termini di biostratigrafia a nannofossili calcarei, la successione investigata è compresa tra la Last Occurrence di *Sphenolithus heteromorphus* e la First Occurrence di *Discoaster bellus* gr., ovvero tra le biozone MNN6 e MNN8. Per quanto riguarda i foraminiferi planctonici, essa ricade tra la Last Occurrence di *Globorotalia peripheroronda* e la First Regular Occurrence di *Neogloboquadrina acostaensis*, ossia tra le biozone MM6 p.p. and MMi10 p.p. Questo studio, in accordo con altri studi eseguiti sui flysch s.l. dell'Appennino meridionale, dimostra l'applicabilità degli schemi biozonali validi per il Miocene medio e superiore del Bacino del Mediterraneo, sviluppati su successioni non torbiditiche di mare profondo.

Introduction

The Miocene palaeogeographic evolution of the Southern Apennines mountain chain, is recorded by the siliciclastic and calcareous "turbidite systems *s.l.*" which represent the sedimentary filling of the basins formed during its structural evolution (fore-deep, piggy-back, thrust-sheet-top basins). The age of the beginning of siliciclastic and calcareous sedimentation de-

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fines the chronological boundaries of the deformation of the thrust sheets and provides data to reconstruct the synsedimentary tectonic settings.

The scarcity or absence of fossil remains and the diffuse reworking of microfossils which affect the "flysch s.l." sediments of Southern Apennines (e.g., the Albidona, Gorgoglione, Castelvetere, and San Bartolomeo flysch) have discouraged several Authors (i.e., Amore et al. 1988, 2005, 2010; Sgrosso 1998) to use the entire set of marker bioevents, by selecting only the appearance level of the species that are more reliable.

Nevertheless biostratigraphic studies based on calcareous nannofossils, or on both planktonic foraminifera and calcareous nannofossils, carried out on some fore-deep and thrust-sheet top deposits of the Southern Apennines (Maiorano 1998; Gallicchio & Maiorano 1999; Lentini et al. 2002; Lirer et al. 2007) showed that a higher resolution can be achieved by taking into consideration additional and auxiliary bioevents from Mediterranean Miocene schemes recently proposed by Fornaciari et al. (1996), Hilgen et al. (2000), Sprovieri et al. (2002), Iaccarino et al. (2007), and Di Stefano et al. (2008). These schemes, based on close-spaced samplings, quantitative analyses, abundance fluctuations of index species and astronomical tuning, provide finer subdivisions than the standard zonations (Martini 1971; Okada & Bukry 1980; Iaccarino & Salvatorini 1982; Iaccarino 1985), thus enabling precise dating of the Mediterranean Miocene sediments.

The present paper deals with the stratigraphic and biostratigraphic study of the thrust-top basin siliciclastic deposits of the San Bartolomeo Flysch (Crostella & Vezzani 1964) (SBF hereafter), that are exposed to the north of the Matese mountains (Fig. 1) and were analysed during the geological survey of the sheet N° 405 Campobasso of the new Geological Map of Italy (1:50.000 scale). The main goal of this study, based on stratigraphic analysis and integrated calcareous plankton biostratigraphy (nannofossils and foraminifera) is to test the applicability of the aforesaid recent biozonations, to define the age and improve the stratigraphic resolution of this siliciclastic succession.

Geological and stratigraphical framework

The studied area is situated within the junction zone between the southern and the central- northern

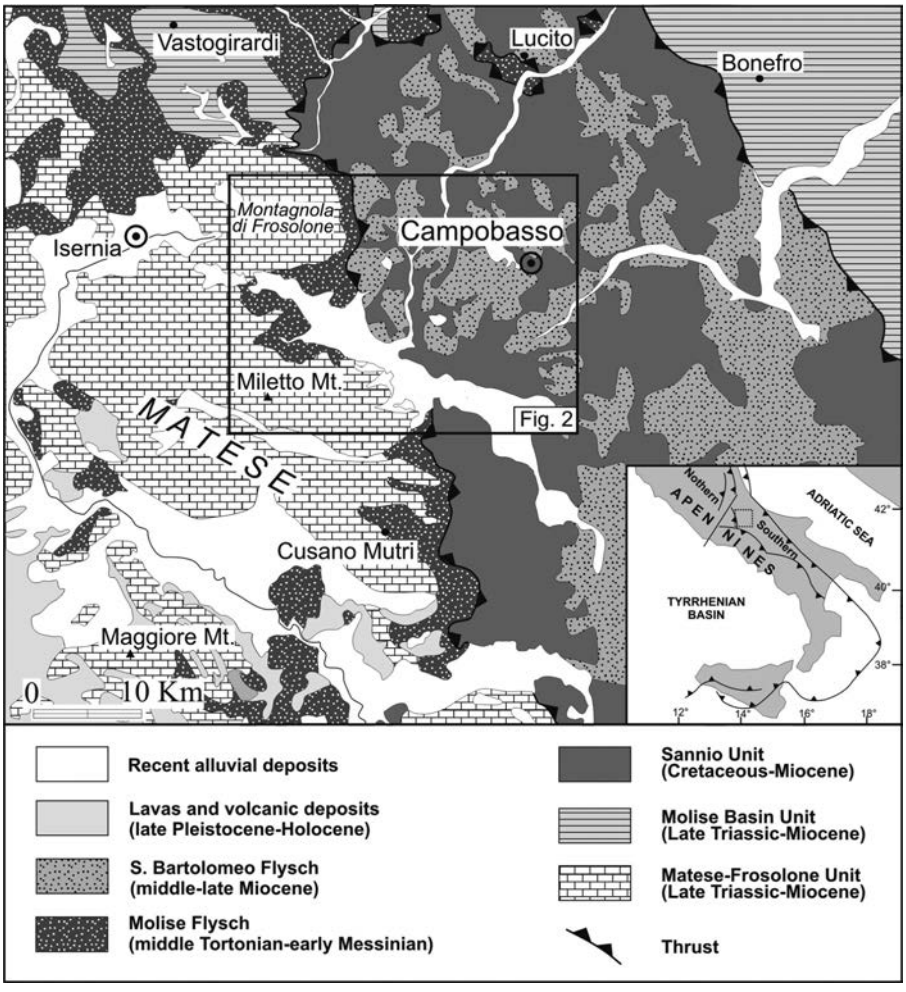

Fig. 1 - Geological sketch map of the eastern portion of the Southern Apennines with the location of the studied area, modified after Vezzani et al. (2004).

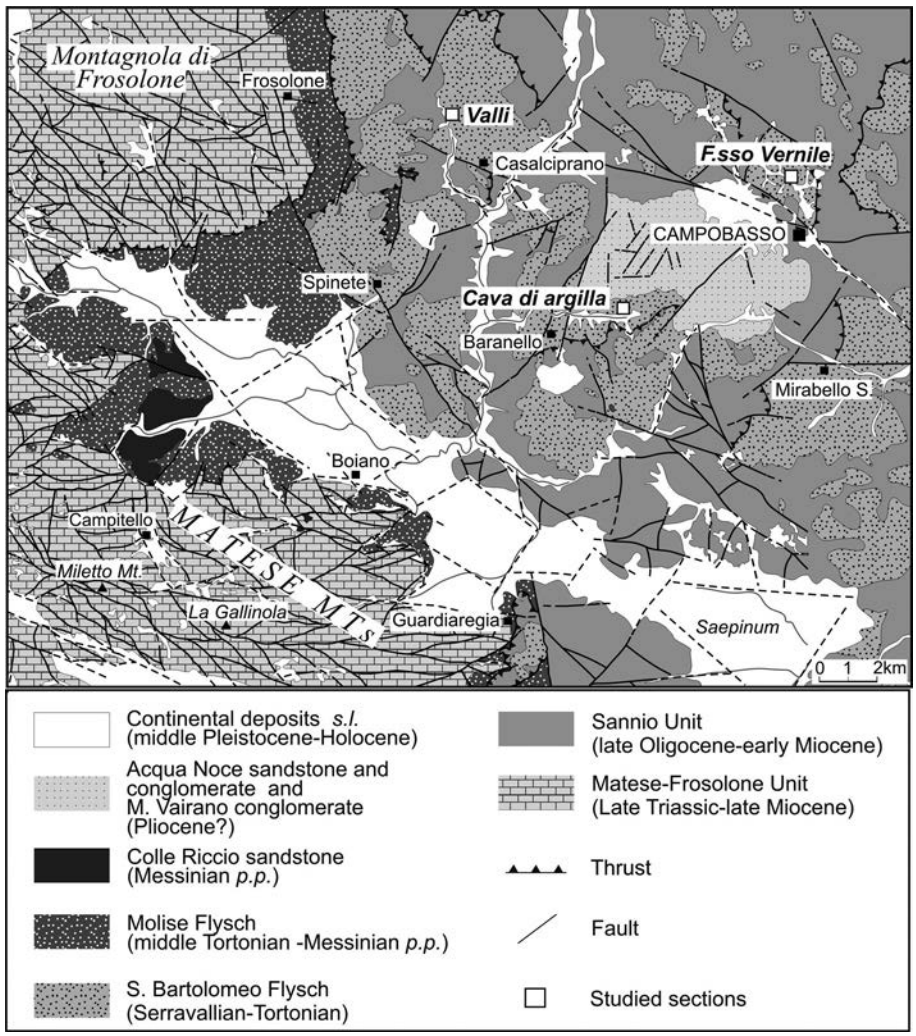

Fig. 2 - Tectonic sketch of the studied area and location of the studied sections, modified after Pappone et al. (2012) and Sgrosso & Naso (2011).

arcs of the Apennine chain (Patacca et al. 1992) (Fig. 1). In this area several tectonic units can be distinguished, which were stacked during eastward migration of the Apennine orogenic system and the coeval spreading of the Central Mediterranean back arc basins (Channell et al. 1979; Malinverno & Ryan 1986; Patacca et al. 1990; Mazzoli et al. 2000; Rosenbaum & Lister 2002; Patacca & Scandone 2007). The southern and western sectors of the study area are characterized by Mesozoic to Miocene carbonate platform and slope-to-basin successions of the Matese – Frosolone Unit (Fig. 2), whereas the sector north of Boiano and the Sepino plain, and south of Campobasso and Casalciprano, is characterized by basinal clays, marls and limestones of the Sannio Unit (sensu Patacca et al. 1992; Cesarano et al. 2011; Pappone et al. 2012; Sgrosso & Naso 2011), unconformably covered by thrust-top siliciclastic deposits of the SBF (Fig. 2).

Since the paper of Crostella & Vezzani (1964), who first described the SBF in the surroundings of the San Bartolomeo in Galdo village (Benevento), this formation has been the object of specific stratigraphic and regional geologic studies, mainly focussed on the "type" area and its surroundings (Tab. 1). Most part of previous studies did not report any biostratigraphic data, proposed different sedimentary settings, and showed some differences in the description of the sedimentary succession as well.

At present, the SBF is regarded as a synorogenic turbidite sequence of late Miocene age, which widely crops out in the eastern sector of the Southern Apennines (Patacca & Scandone 2007; Di Nocera et al. 2011 (Fig. 1). It unconformably overlies allochtonous basin successions, which were allocated as the Sannio Unit (Patacca et al. 1992; Patacca & Scandone 2007), Sicilide Units or "Argille Varicolori Auct." (Tortorici 1975; Vezzani et al. 2004; Festa et al. 2006) and Fortore Unit (Dazzaro et al. 1988; Pescatore et al. 1996; Pescatore et al. 2000), according to their geographic location or palaeogeographic modeling (Fig. 3).

The most useful biostratigraphic data regarding the siliciclastic deposits of the present study, are those of Cestari et al. (1975), Tortorici (1975), and Lanzafame & Tortorici (1976). Cestari et al. (1975), in the geological sheet N° 162 "Campobasso" (Geological Map of Italy 1:100.000 scale), mapped a sandy-arenaceous stra-

Author	Area	Age	Biostratigraphy	Sedimentary setting
Crostella & Vezzani (1964)	San Bartolomeo in Galdo (Bn)	Elvetian (Serravallian)-Tortonian	not reported data	foredeep basin
Iacobacci et al. (1967)	San Bartolomeo in Galdo (Bn)	late Miocene	(f) (not specified assemblages)	foredeep basin
Di Nocera et al. (1988)	Celenza Valfortore	Langhian - Serravallian	(f) *G . siakenis* Zone of Iaccarino (1985)	piggy-back basin
Patacca et al. (1990, 1992)	San Bartolomeo in Galdo (Bn) ?	latest Tortonian - early Messinian	not reported data	piggy-back basin
Pescatore et al. (2000)	San Bartolomeo in Galdo (Bn)	late Tortonian - Messinian	according to previous literature data	wedge-top tardorogenic basin
Di Nocera et al. (2006, 2011)	Irpinia - Daunia	middle late Tortonian - Messinian	(n) CN9a-CN9b Zones of Okada & Bukry (1980)	wedge-top synorogenic basin
Patacca & Scandone (2007)	San Bartolomeo in Galdo (Bn) ?	latest Tortonian ? - early Messinian	not reported data	thrust-sheet top basin
Pescatore et al. (2008)	Sannio Mounts	not older than late Serravallian	(n) (not specified assemblages)	wedge-top synorogenic basin
Pieri et al. (2011)	San Bartolomeo in Galdo (Bn)	Langhian ? - Tortonian	(n) (not specified assemblages)	
Cestari et alii (1975)	Campobasso	Langhian - Tortonian	(f)	foredeep basin
Tortorici (1975)	Campobasso, San Bartolomeo in Galdo (Bn)	Elvezian (Serravallian)	(f)	foredeep basin
Vezzani et alii (2004)	Campobasso	late Messinian	not reported data	

Tab. 1 - San Bartolomeo Flysch: state of the art – previous ages assigned to the S. Bartolomeo Flysch based on planktonic foraminifera (f) and calcareous nannofossils (n).

tigraphic unit dated to the Langhian- Tortonian for the presence of the planktonic foraminifera *Globigerina nepenthes*, *Globigerinoides obliquus*, *Orbulina suturalis*. In particular, Tortorici (1975) studied the SBF between the Trigno River and Benevento separating two members: a lower mostly pelitic member ("Membro del Vallone Castelluccio"), which gradually passes upward to an arenaceous one ("Membro Valli"). The Author dated the SBF to the Helvetian (i.e. Serravallian) on the basis of the occurrence of *O. universa*, *O. suturalis*, *Globorotalia mayeri* and *G. acostaensis*; moreover he assigned the SBF to the "Tardorogenic Flysch Complex", deposited in the inner portion of a foredeep, and correlated it with similar flysch deposits of the Gorgoglione Flysch.

To conclude, in the Geological Map of Molise Region (Vezzani et al. 2004; Festa et al. 2006) the flysch deposits, identifiable as SBF, have a late Messinian age (no biostratigraphic data are provided) and are represented by the "Sabbie di Valli Formation", which lies uncomformably on the Sicilide Unit. This formation coincides with the "Membro di Valli" of Tortorici (1975) and represents part of our studied succession.

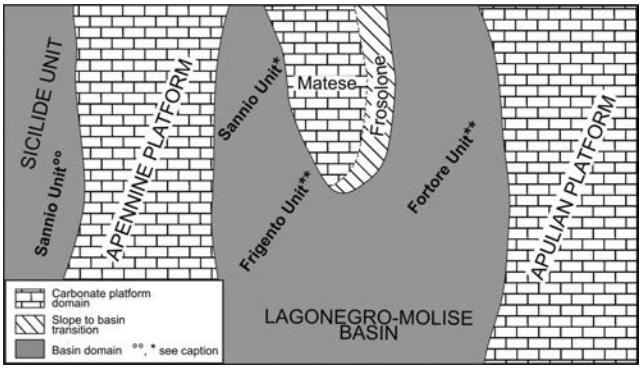

Fig. 3 - Simplified pre-orogenic palaeogeographic scheme of the Southern Apennines, with the inferred position of the basin tectonic units hosting the SBF. °°: Patacca at al. 1992; *: Patacca & Scandone 2007; Vezzani et al. 2010; ** Di Nocera et al. 2002, 2006; Pescatore et al. 2000, 2008. (Not to scale).

Studied sections and methods

Studied sections

The SBF was surveyed to the west and north-west of Campobasso (Figs. 1, 2), three main sections were logged and sampled (Fig. 4), allowing the reconstruction of a lithostratigraphic succession which reaches a thickness of 400 m (Fig. 5). Four partially interfingering lithostratigraphic members were distinguished (Fig. 5).

A **lower arenaceous-pelitic member** was observed to north-west of Casalciprano, composed of alternate feldspathic sandstones (beds from 50 cm to 1 m thick) and yellowish silty marls, with very rare reddish siltites.

An **arenaceous-conglomeratic member** is widely exposed in the surroundings of Casalciprano village and to the north and north-west of Spinete. This member consists generally of coarse-grained feldspathic massive

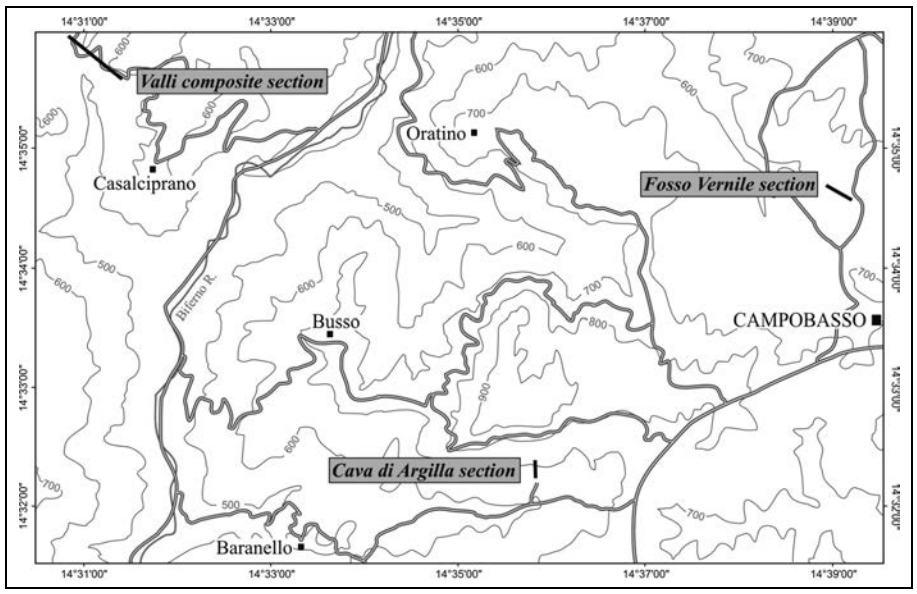

Fig. 4 - Detailed location map of the studied sections. GPS coordinates: Valli composite section (N 41°35'99"- E 14°30'82,9") (E 4°59'483"E - N 46°05'542"), Fosso Vernile section (N 41°32'23,8"- E 14°35'83,2") (E 4°66'399"E - N 45°98'565"), Cava di Argilla section (N 41°34'55,2"- E 14°39'28,9") (E 4°71'222"E - N 46°02'825").

sandstones, forming beds 1-2 meter thick. Channel casts and gravel beds are well developed. Typical diagenetic structures (represented by the bed parallel concretions – locally named *costole*, and the irregularly distributed spheroid concretions - *cogoli*) and thick intercalations of grey silty marls and thin beds of fine-grained sandstones are also present. This member corresponds to the "Membro di Valli" of Tortorici (1975), and to the "Sabbie di Valli Fm." of Vezzani et al. (2004).

The upper **arenaceous-pelitic member** crops out close to the localities of Campobasso, Casalciprano, and Spinete. This unit consists of alternations of yellowish medium to fine grained calcareous sandstones (somewhere coarse), graded and laminated silty marls and silty shales. Rare thin beds of white calcilutites also occur. In the upper part the unit becomes more marly and shaly, with rare intercalations of calcisiltites. This member corresponds to part of the "Membro del Vallone Castelluccio" of Tortorici (1975), and part to the"-Sabbie di Valli Fm." of Vezzani et al. (2004).

The **pelitic member**, is found exclusively to the south of Vairano Mount, between Baranello village and Fornace hamlet. Good exposures are located in Cava di Argilla and along the eastern hillside of Colle Calicare, east of Baranello. The lithology of this unit consists of grey-blue silty-marly shales with some intercalations of thin beds of yellowish laminated sandstones (Fig. 5). Thin dark levels rich in organic matter are present at different stratigraphic levels. This member corresponds to the Argille del Fiume Fortore Fm. of Vezzani et al. (2004).

Valli section

The Valli section is composed of three sub-sections, namely Cava di Valli, Ponte S. Cristoforo and Strada di Valli, logged and sampled in the nearby of the Valli hamlet (Figs 4, 6). The section is about 150 m thick, and includes the lower arenaceous-pelitic, the arenaceous-conglomeratic members of the SBF, and the upper part of the Argille Policrome Fm of the Sannio Unit (APS) (Fig. 7). The unconformable boundary between the two formations is exposed in the Cava di Valli subsection (Fig. 6).

Fosso Vernile section

This section was sampled just north of Campobasso, along the Fosso Vernile rill (Fig. 4), it is 140 m thick, and representative of the upper arenaceous-pelitic member (Figs 6, 8).

Cava d'Argilla section

The Cava di Argilla section is exposed in a quarry located north-west of Baranello village (Fig. 4), where we logged and sampled a succession of about 80 m belonging to the pelitic member of the SBF (Figs 6, 9). The succession is truncated by yellow sands, through an unconformable boundary marked by a lens of gravel (Fig. 9).

Methods

Sampling

Samples were collected with an overall average spacing of 2 m. Sometimes samples were collected at more closely spaced intervals to obtain a better resolution for the base of the succession (Valli composite section), or to define accurately the fossil content just below a covered/barren interval (central part of the Fosso Vernile section).

In total, 55 samples were collected in the Valli composite, 48 samples in the Fosso Vernile and 40 samples in the Cava di Argilla (Figs 7-9).

Calcareous plankton

The low abundance of the index species, the occurrence of reworking, and the siliciclastic characteristic of the sedimentary succession, led us to perform a semi-

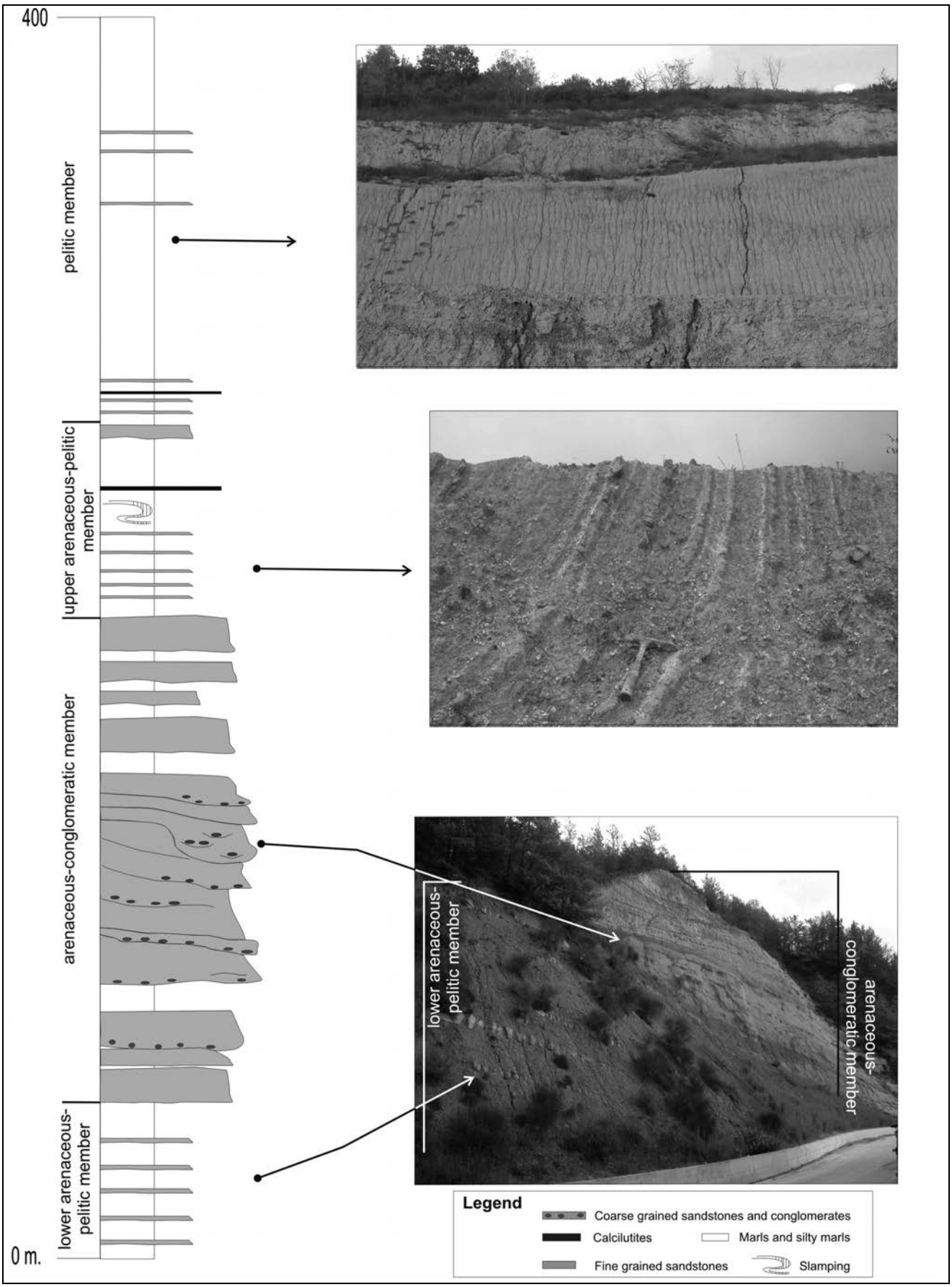

Fig. 5 - Synthetic lithostratigraphic log of the studied succession and sedimentary features of lithologic members. Outcrop pictures, from the bottom: Strada di Valli, Fosso Vernile, and Cava di Argilla.

Cava di Argilla section

Fosso Vernile section

Valli composite section

Fig. 6 - Panoramic views and tracks of the studied sections. The arrow on the left of the Valli composite section picture, indicates the boundary between the Argille Policrome Fm and the SBF.

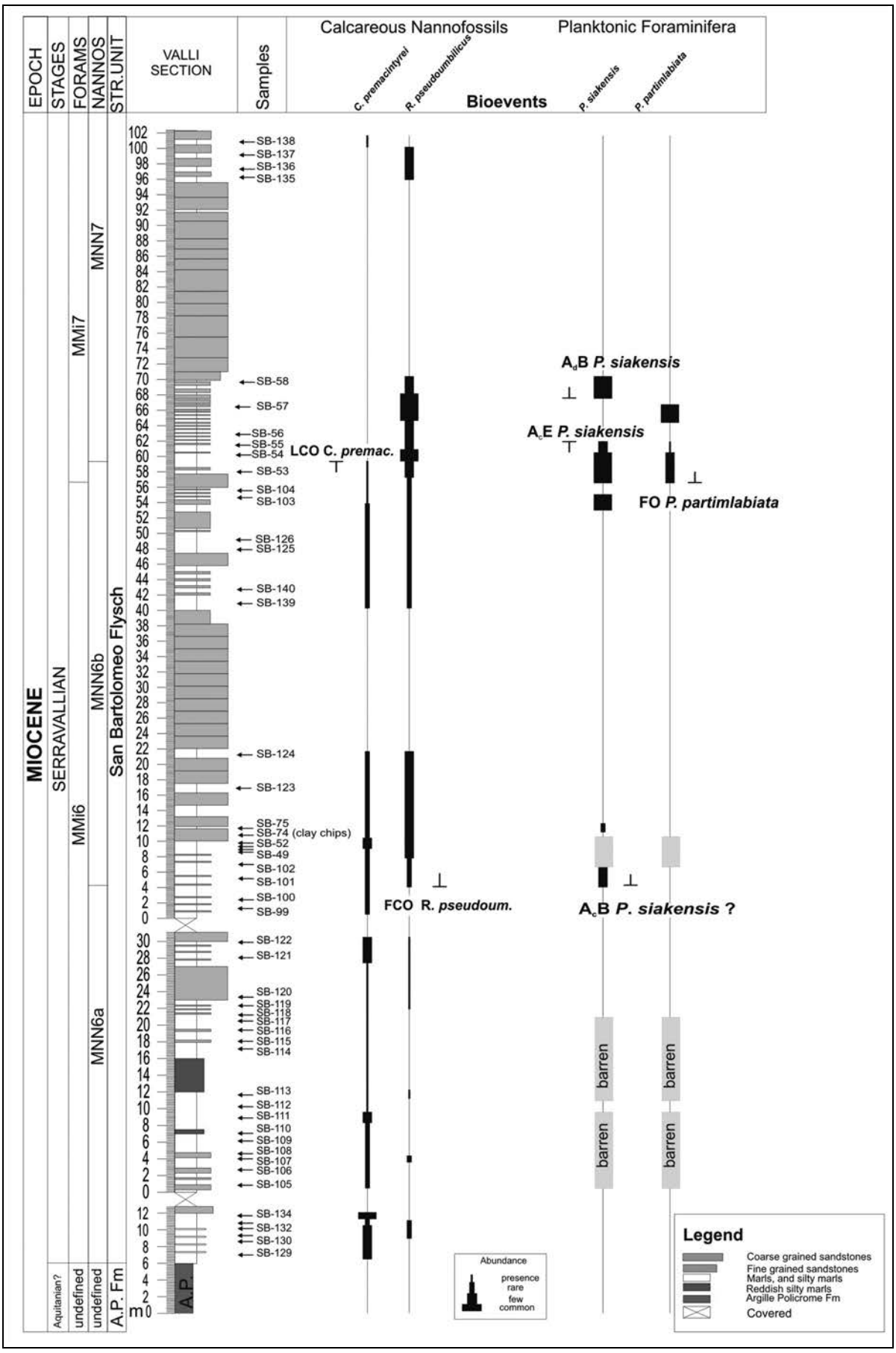

Fig. 7 - Lithologic log of the Valli composite section and estimated semi-quantitative abundance distribution of selected planktonic foraminifera and calcareous nannofossils. The grey bands represent the barren intervals. For symbols see text.

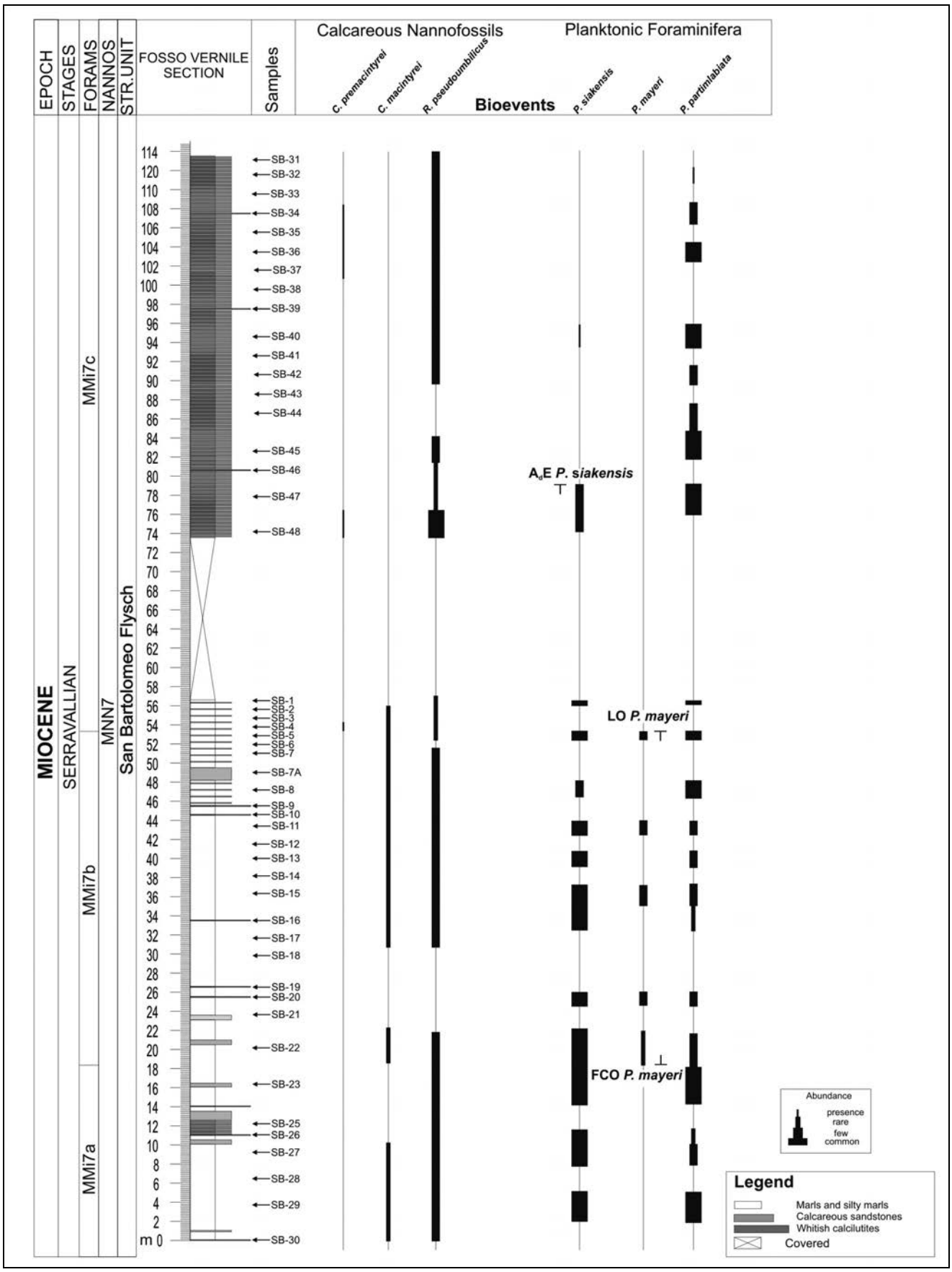

Fig. 8 - Lithologic log of the Fosso Vernile section and estimated semi-quantitative abundance distribution of selected planktonic foraminifera and calcareous nannofossils. For symbols see text.

quantitative analysis of the calcareous plankton. This analytic method has been widely used for the study of the planktonic foraminifera in deep marine records, where the microfossils content is not well preserved and where abundant fragments of poorly disaggregated sediment are present. It resulted more adequate for checking a number of microfossils larger than the standard counting methods, and for drawing the distribution patterns of the more rare species (Hilgen et al. 2003, 2009; Turco et al. 2011).

The semi-quantitative analysis of planktonic foraminifera was performed on the >125μ fraction, and was based on surveying a standard number of fields (27 out of 45) in a rectangular picking tray while distinguishing the following abundance categories (Hilgen et al. 2003): Presence (<3 specimens in 9 fields), Rare (3-10 specimens), Few (10-30 specimens), and Common (>30 specimens). The biostratigraphic scheme adopted (MMi zones) is that of Sprovieri et al. (2002), emended by Iaccarino et al. (2007) (Fig. 10).

The analysis of calcareous nannofossils was carried out on standard smear slides (Bown 1998), and analysed using a light microscope (transmitted light and crossed nicols) at a magnification of 1250X. The abundance of selected calcareous nannofossils was estimated as number of specimens for field of view of at least four traverses (i.e. about 800 fields of view) of each slide. Moreover, two additional traverses were scanned in order to recognize the presence of very rare species. The following abundance categories were distinguished: Presence (1 specimen/ > 100 fields), Rare (1 specimen/ 10-100 fields), Few (1 specimen/2-10 fields), and Common (> 1 specimen/field). The calcareous nannofossil biozones (MNN zones) of Fornaciari et al. (1996) emended by Sprovieri et al. (2002) and by Di Stefano et al. (2008) have been used (Fig 10). We refer to Perch-Nielsen (1985), Fornaciari et al. (1996) and Bown (1998) for the description of the nannofossils recorded.

The acronyms FO, LO, FCO, FRO, LCO have been used for: First Occurrence, Last Occurrence, First Common Occurrence, First Regular Occurrence, and Last Common Occurrence, respectively.

Distribution of selected calcareous nannofossil and planktonic foraminifera marker species are reported in figures 7 to 9.

Results

Planktonic foraminifera

The planktonic foraminifera are abundant and well preserved. Only in the lower part of Valli section (Ponte San Cristoforo subsection) and in the arenaceous-conglomeratic member (Valli section) the planktonic foraminifera content is very scarce or absent. We were not able to document plain reworking evidence, however, it cannot be foreclosed due to the turbiditic nature of the deposits studied.

The taxa *Dentoglobigerina altispira* gr. (this group includes *D. altispira altispira*, *D. altispira globosa* and *D. baromoenensis*), *Globigerina bulloides* gr. (this group includes *G. bulloides*, *G. parabulloides* and *G. praebulloides*), *Globoturborotalita druryi-nepenthes*, *Globigerinita glutinata*, *Globigerinoides quadrilobatus* gr. (this group includes *G. trilobus* and *G. quadrilobatus*), *Turborotalita quinqueloba* gr. (this group includes *T. quinqueloba* and *T. angustiumbilicata*), *Globorotalia scitula*, and *Paragloborotalia siakensis* (sensu Foresi et al. 2001, 2002a) are continuously present and show abundance fluctuations throughout the studied sections.

The taxa showing a discontinuous distribution such as: *Globoquadrina dehiscens dehiscens*, *Orbulina* spp., *Globigerinoides subquadratus*, *G. obliquus obliquus*, *Globigerinella obesa* gr. (this group includes *G. obesa* and *G. praesiphoniphera*), and *Globorotalia praemenardii- menardii* gr., *Paragloborotalia mayeri* (sensu Foresi et al. 2002a), *Neogloboquadrina atlantica praeatlantica*, and *N. atlantica atlantica*, only occasionally reach significant percentages.

In this study the distribution of marker species and the abundance pattern of *Paragloborotalia siakensis*, *P. mayeri*, *P. partimlabiata* and of *Neogloboquadrina atlantica atlantica* (sensu Foresi et al. 2002b) have been considered for the biostratigraphic reconstruction (Figs 7-11).

Calcareous nannofossils

The observed calcareous nannofossils assemblages consist mostly of common to abundant specimens of the genera *Coccolithus*, *Dictyococcites*, and *Reticulofenestra*. Also specimens of the genera *Helicosphaera* and *Calcidiscus* are consistently present, whereas specimens belonging to the genus *Discoaster* are rare. Among the helicolits, *Helicosphaera carteri* is abundant (about 90%), *H. walbersdorfensis* and *H. stalis* are resulted few to rare. *Discoasters*, generally poorly preserved, mainly consist of *D. variabilis*. Common reworked Upper Cretaceous and Palaeogene specimens are also present.

Integrated calcareous plankton biostratigraphy of the San Bartolomeo Flysch

The lower portion of the SBF (Valli composite section) contains common and diversified calcareous nannofossil assemblages, which can be attributed to the interval MNN6a p.p. - MNN7a p.p., early Serravallian in age, on the bases of the absence of *Sphenolithus heteromorphus*, the presence of the FCO of *Reticulofenestra pseudoumbilicus* (> 7μm), and the *Calcidiscus premacintyrei* LCO.

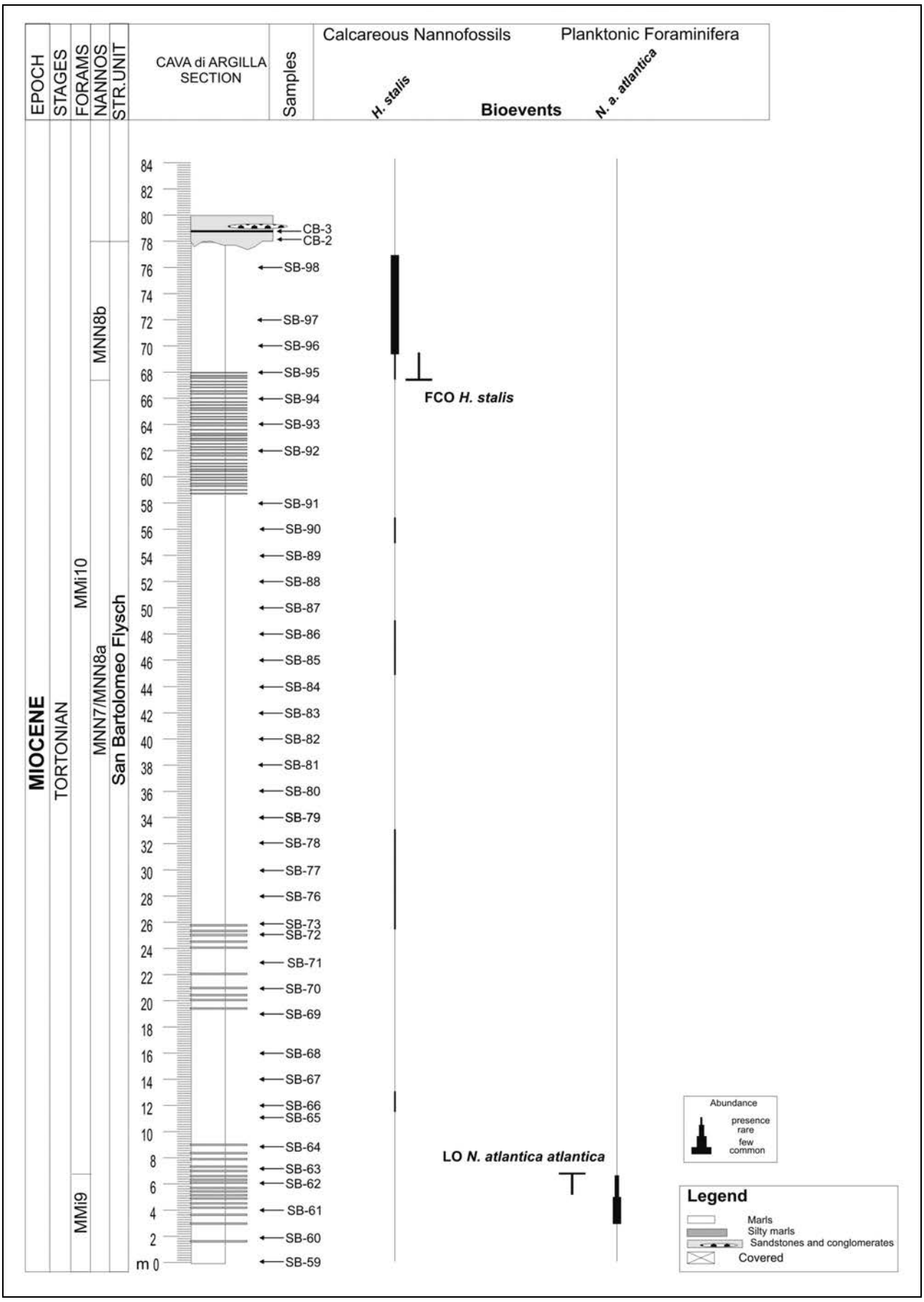

Fig. 9 - Lithologic log of the Cava di Argilla section and estimated semi-quantitative abundance distribution of selected planktonic foraminifera and calcareous nannofossils. For symbols see text.

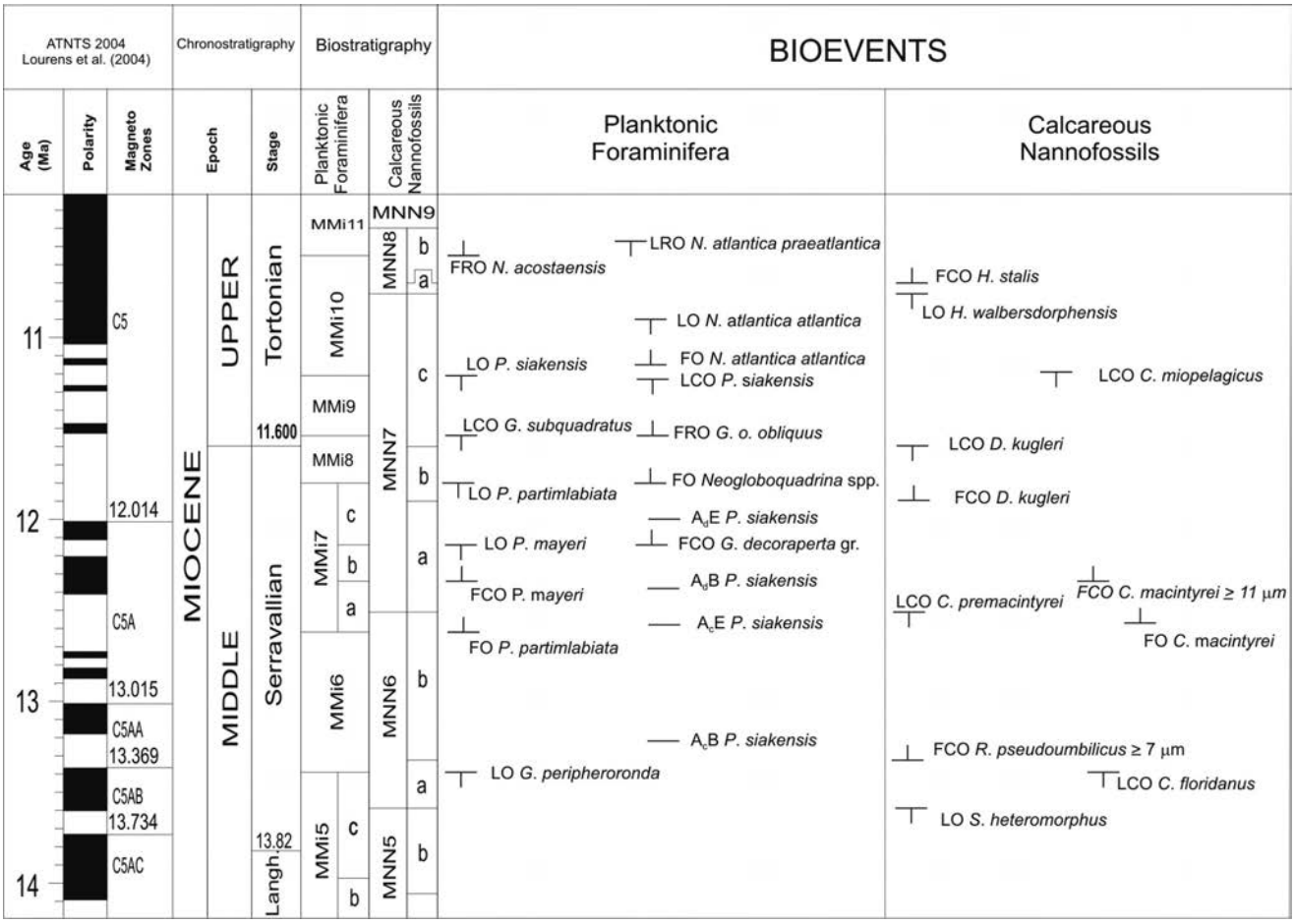

Fig. 10 - Mediterranean integrated calcareous plankton biostratigraphic scheme adopted in this work. Planktonic foraminifera: Sprovieri et al. (2002), revisited by Iaccarino et al. (2007). Calcareous nannofossils: Fornaciari et al. (1996) emended in Sprovieri et al., (2002). For symbols see text.

Fornaciari et al. (1996) used the FCO of *R. pseudoumbilicus* (> 7µm) and the *C. premacintyrei* LCO as subzonal boundary events for the top of the MNN6a and MNN6b subzones, respectively. Following these Authors we identified the FCO of *R. pseudoumbilicus* (> 7µm) in the lower-middle part of the Valli section (Fig. 7). Above this level the species becomes more commonly and continuously present. While the *C. premacintyrei* LCO was identified, about 50 m higher, in the upper-middle part of the section, above this level the species virtually disappears, or is very rare and present in few samples (Fig. 7).

Calcareous nannofossil biostratigraphy is also supported by planktonic foraminiferal bioevents as the Acme Base (A_cB) of *P. siakensis* and the FO of *P. partimlabiata* (Fig. 7), that marks the base of the MMi7 Zone (Fig. 10). In addition, the Acme End (A_cE) and the Acme Base (A_dB) of *P. siakensis* are recorded in the upper part of Valli section and fall in the lower part of MMi7 Zone (Fig. 7).

The middle and upper portions of the studied stratigraphic record, represented by the Fosso Vernile section (Fig. 8) and most part of the Cava di Argilla section (Fig. 9), falls in the interval MNN7 - MNN8a, between the *C. premacintyrei* LCO (this event occurs before the FCO of planktonic foraminifera *P. mayeri*, recorded in the lower part of Fosso Vernile section, see Fig. 10) and the *H. stalis* FCO (Fig. 9), suggesting a middle Serravallian - early Tortonian age.

Helicosphaera stalis is very rare and only occurs in very few samples of the aforesaid interval, whereas in the uppermost part of the succession (Cava di Argilla section) the species becomes more common and shows a continuous distribution, allowing the identification of its FCO which marks the base of the MNN8b Subzone (Figs 9, 10).

Planktonic foraminiferal assemblages from Fosso Vernile and from Cava di Argilla sections allowed us to attribute these records to the upper Serravallian – lower Tortonian interval. In particular, in the Fosso Vernile section the total distribution of *P. mayeri* is recorded, indentifying the MMi7b Subzone (Fig. 8). Finally, the Acme End (A_dE) of *P. siakensis,* which falls in the lower part of the MMi7c Subzone (Fig. 10) is registered in the middle upper part of Fosso Vernile section (Fig. 8). The Tortonian interval is well documented in

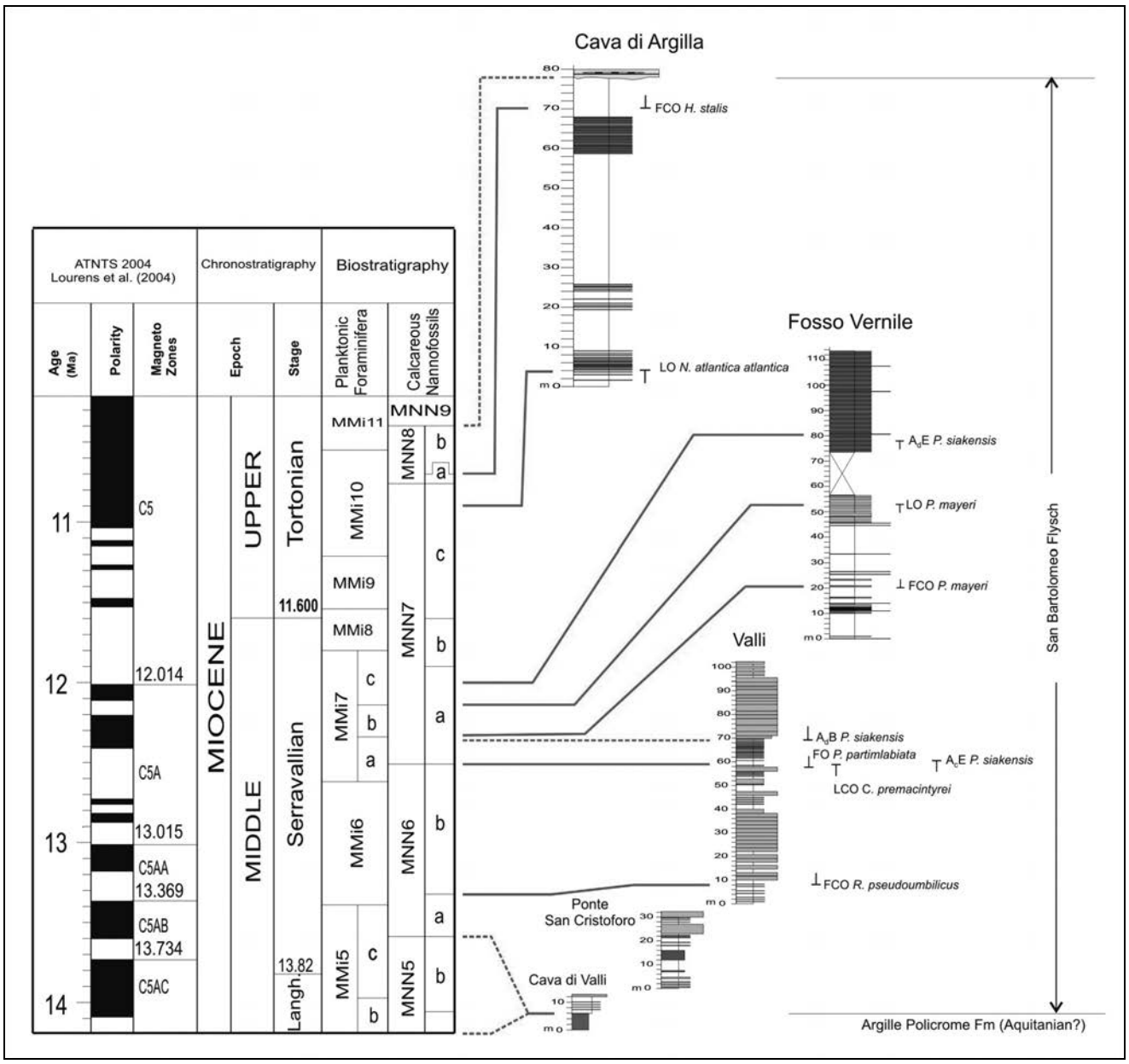

Fig. 11 - Integrated biostratigraphic correlation of the studied sections to the standard Mediterranean biostratigraphic scheme. For symbols see text.

the Cava di Argilla section where the temporary LO of *N. atlantica atlantica* in the Miocene (Hilgen et al. 2000) occurs in the lowermost part of the section (Fig. 9). This planktonic foraminiferal bioevent, corresponding to the LO of *N. atlantica atlantica* (see Foresi et al. 2002b, for a complete discussion) and dated at 10.832 Ma by Hilgen et al. (2002), falls in the lower part of MMi10 Biozone (Fig. 10). Moreover the continuous presence of *N. atlantica praeatlantica* (*N. atlantica* small size of Hilgen et al. 2000, 2003) along the whole sedimentary record, suggests that the top of Cava di Argilla section is younger than the LRO of this subspecies, dated at 10.473 Ma by Hilgen et al. (2003). This stratigraphic interpretation fits well with the FCO of the nannofossil *H. stalis,* dated at 10.717 Ma by Hilgen et al. (2000) and recorded at the top of the section.

Discussion

Biostratigraphy of turbiditic sediments of Southern Apennines, has been usually considered difficult to be accomplished with confidence for the paucity of the fossil remains, and diffuse reworking of microfossils. Nevertheless, we obtained detailed and reliable biostratigraphic data by performing an integrated study of calcareous nannofossils and planktonic foraminifera, based

on the semi-quantitative record of abundance fluctuations of index species. This analytic methodology assures the cross-control of the biostratigraphic data, and provides the possibility to correlate our data set with those of deep and astronomically dated marine sediments.

The integrated study of calcareous nannofossils and planktonic foraminifera revealed a consistent biostratigraphic scenario, comparable with those reported from different middle-late Miocene deep-marine sedimentary settings of the Mediterranean Basin (Hilgen et al. 2000, 2003; Foresi et al. 2002a; Di Stefano et al. 2008). These biostratigraphic similarities make unlikely that the ordered succession of bioevents identified is the fortuitous result of reworking events, as some Authors proposed in their studies on turbiditic deposits of the Southern Apennines (i.e., Amore et al. 1988; Sgrosso 1998). In particular, the biostratigraphic dataset suggests an early Serravallian – early middle Tortonian age (Fig. 11) for the SBF cropping out in the Campobasso area, in agreement with the previous studies carried out in this area by Cestari et al. (1975), Tortorici (1975), and Lanzafame & Tortorici (1976).

The detailed biostratigraphic study documented a stratigraphic gap (not recovered interval) between the upper part of the Fosso Vernile section and the lower portion of the Cava di Argilla section (Fig. 11). The estimated stratigraphic gap of ca 1myr spans the Serravallian/Tortonian boundary, between the Acme End (A_dE) of *P. siakensis* and the *N. atlantica atlantica* LO. Unfortunately, the absence of age-diagnostic planktonic assemblages, in the upper portion of Fosso Vernile section (Fig. 8), prevented the documentation of other bioevents to improve the stratigraphic resolution of this part of sampled succession.

As far as the correlation with the San Bartolomeo in Galdo area, the new dating is in agreement with the data of Pieri et al. (2011; Notes of the Sheet N°407 "San Bartolomeo in Galdo", Geological Map of Italy, 1:50.000 scale), who dated the SBF to the Langhian (?) – Tortonian, whereas it is quite different from the late Tortonian – early Messinian age attributed to the SBF by other Authors (Di Nocera et al. 2006; Patacca & Scandone 2007). Moreover, in the Campobasso area the lithostratigraphic successions starts with arenaceous-pelitic deposits, while in the type area (Benevento zone) the base of the succession is constituted by coarse grained deposits. We speculate that the finer-grained deposits of the Valli section could represent the distal portion of the coarse deposits of the type area. In fact, Boiano (2000) documented a material transport toward ENE-wards sedimentary transport during the deposition of the first turbiditic system of SBF.

Conclusions

The integrated calcareous plankton biostratigraphic study carried out on the SBF, that is exposed to the north of the Matese mountains, provided a micropaleontological data set correlatable directly to the quantitative calcareous plankton data of the Mediterranean middle-late Miocene deep marine records. It also confirms the possibility to use the complete sequence of marker and/or auxiliary events (FO, LO, LRO, LCO, Acme and Paracme) recently adopted in the standard Mediterranean biostratigraphic schemes [Sprovieri et al. 2002 (emended by Iaccarino et al. (2007); Fornaciari et al. 1996 (emended by Sprovieri et al. 2002, and Di Stefano et al. 2008]

The studied succession encompasses a stratigraphic interval of about 3 myr, which in terms of calcareous nannofossil biostratigraphy, falls between the LO of *Sphenoilthus heteromorphus* and the FO of *Discoaster bellus* gr., corresponding to the zone interval MNN6 – MNN8 of Fornaciari et al. (1996) (Fig. 11). In terms of plankton foraminiferal biostratigraphy the studied succession falls between the LO of *Globorotalia peripheroronda* and the FRO of *Neogloboquadrina acostaensis*, corresponding to the zone interval MM6 p.p. - MMi10 p.p. of Sprovieri et al. (2002) (Fig.11).

Open questions remain, however, regarding the lithostratigraphic and biostratigraphic correlations with different areas of exposure. It would be useful that forthcoming biostratigraphic studies will follow the methodology adopted herein, to improve the stratigraphic resolution in reconstructing the tectonic evolution of the Southern Apennines.

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