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# MICROPALEONTOLOGICAL STUDY ON THE MIOCENE CALCAREOUS TURBIDITE DEPOSITS OF FAETO AND TUFILLO FORMATIONS (EASTERN SECTOR OF THE SOUTHERN APENNINE CHAIN)

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*Key words*: Calcareous plankton biostratigraphy, Early and Middle Miocene, Mediterranean, Faeto Formation, Tufillo Formation, Southern Apennines.

*Abstract*. A biostratigraphic study was carried out on four sections of the Miocene Tufillo and Faeto Formations (Southern Apennines). The sediments analyzed were referred to the late Burdigalian – early Tortonian on the basis of planktonic foraminifers (MMi2b Subzone through the MMi8 Zone) and calcareous nannofossils (MNN3b Zone through the MNN7 Zone). Almost the majority of the bioevents of the recently published Miocene biozonal schemes of Mediterranean area were identified. Particularly, the marked changes in the abundance pattern of *Paragloborotalia siakensis* resulted very useful to correlate the sediments. A new acme abundance of the letter species has been recorded in the uppermost part of the Burdigalian planktonic foraminiferal MMi2b Subzone. Moreover, the integrated calcareous plankton biostratigraphy revealed that the First Common Occurrence (FCO) of *Sphenolithus heteromorphus* occurs before the Last Occurrence (LO) of *Catapsidrax dissimilis*, in the upper part of Burdigalian record.

This study indicates that the lower Langhian portion of the Tufillo Formation is characterized by arkose sandstones which pass upwards into calcarenites and/or calcirudites and marly deposits. Field data suggest that these sandstones directly overly the "Numidian Sandstones". The Faeto Formation starts with calcarenites and calcareous marls, in the calcareous nannofossil MNN3b Zone (Burdigalian), and lies on the "Numidian Sandstones" as well.

High-resolution sampling and biostratigraphy reveal that the deposition of the "Numidian Sandstones" ends in the late Burdigalian stage, just below the FCO of *S. heteromorphus* (MNN3b Zone) and the LO of *C. dissimilis* (MMi2b Subzone).

*Riassunto*. Uno studio biostratigrafico integrato (foraminiferi planctonici e nannofossili calcarei) ed un'accurata analisi di campagna sono stati condotti su quattro sezioni delle Formazioni Tufillo e Faeto (Appennino meridionale). Le successioni studiate sono state attribuite ad un intervallo cronostratigrafico compreso tra il Burdigaliano superiore e il Tortoniano inferiore (tra la subzona MMi2b e la zona MMi8 dei foraminiferi planctonici; tra la zona MNN3b e la zona MNN7 dei nannofossili calcarei). Questo studio ha permesso di stabilire l'applicabilità, anche in questi sedimenti, dei più recenti schemi biostratigrafici, validi per l'area mediterranea. Tra gli eventi biozonali secondari riconosciuti vanno sottolineati quelli basati sulle variazioni d'abbondanza di *Paragloborotalia siakensis*. In particolare, un nuovo acme di abbondanza di questa specie è stato registrato, nel Burdigaliano, all'interno della Subzona a foraminiferi planctonici MMi2b. Inoltre, è stato riscontrato che la First Common Occurrence (FCO) di *Sphenolithus heteromorphus* precede la Last Occurrence (LO) di *Catapsidrax dissimilis*.

È stata studiata anche la porzione superiore del Numidian Sand Event ed è stato riconosciuto che la sedimentazione di questo evento termina prima della FCO di *S. heteromorphus* (bioevento che definisce il top della Zona a nannofossili calcarei MNN3b) e della LO di *C. dissimilis* (bioevento che segna il top della Subzona a foraminiferi planctonici MMi2b).

## Introduction

The Faeto (Crostella & Vezzani 1964) and the Tufillo Formations (Selli 1962) consist of calcareous turbiditic deposits widely exposed along the eastern sector of the Southern Apennines. These deposits settled into the Molise depositional domain, consisting in a basinal area situated between the Apennine and the Apulian carbonate platforms (Patacca et al. 1992b). The Late Miocene Apennine orogeny dismembered the Molise domain into east-verging trust sheets, grouped into four

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regional tectonic units by Patacca et al. (1992b), these were as follows: Frosolone, Agnone, Tufillo-Serra Palazzo and Daunia units. The Tufillo and Faeto Formations belong to the two easternmost tectonic units, the Tufillo-Serra Palazzo and Daunia units, respectively. The latter formations lay stratigraphically on the Burdigalian Numidian quartzarenites (Patacca et al. 1992a; Pagliaro et al. 1999; Patacca & Scandone 2005). However, no Numidian quartzarenites have been found in the Agnone and Frosolone tectonic units (Patacca et al. 1992b).

The Tufillo and Faeto Formations were referred to the Early - Late Miocene mostly on the basis of planktonic foraminifer biostratigraphy and a few calcareous nannofossil studies; integrated biostratigraphy is lacking (Santo & Senatore 1988; Patacca et al. 1992b; Maiorano 1998; Sgrosso 1998; Pescatore et al. 2000; Vezzani et al. 2004; Patacca & Scandone 2004, 2005). Santo & Senatore (1988) carried out a sedimentological and biostratigraphic research on an almost complete succession of the Daunia unit, exposed in the Monte Sidone area. The latter Authors subdivided the Faeto Formation into three lithostratigraphic intervals dating the formation as upper Burdigalian - upper Tortonian (NN4 through NN11 calcareous nannofossil Zones of Martini 1971). The paper of Maiorano (1998), based on calcareous nannofossils, represents the most complete biostratigraphic study of the Tufillo and Faeto Formations. Maiorano (1998) dated the Tufillo Formation as Langhian to Tortonian, (MNN4b through MNN9 Zones of Fornaciari et al. 1996) and the Faeto Formation as Burdigalian to Serravallian (MNN4a through MNN7 Zones). Maiorano (1998) emphasised the difficulty to compare her results with the past ones (see references therein), in terms of inappropriate biostratigraphic and chronostratigraphic terminologies, and absence of a clear correlation between the schemes used and the relevant foraminiferal biostratigraphy of the area.

Recent studies on planktonic foraminifera and calcareous nannofossils improved the chrono-biostratigraphy of the Miocene in the Mediterranean region (Hilgen et al. 2000; Sprovieri et al. 2002; Iaccarino et al. 2004a, b). These works, based on close-spaced samplings, quantitative analyses, abundance fluctuations of index species and astronomical tuning, provide zonal schemes with finer subdivisions than the ones defining the standard zonations; thus enabling precise dating of the Mediterranean Middle-Late Miocene sediments. The aim of this study is to test the applicability of these recent biozonations into the calcareous and siliciclastic foredeep sediments, in order to improve the chronostratigraphy of the Faeto and Tufillo Formations for a better understanding and modelling of the tectono-sedimentary evolution of the Southern Apennines.

## The studied sections

The deposits investigated were studied along the following four sections (Fig. 1): the Volturino section, located north of the Faeto village and the Colle Amare-

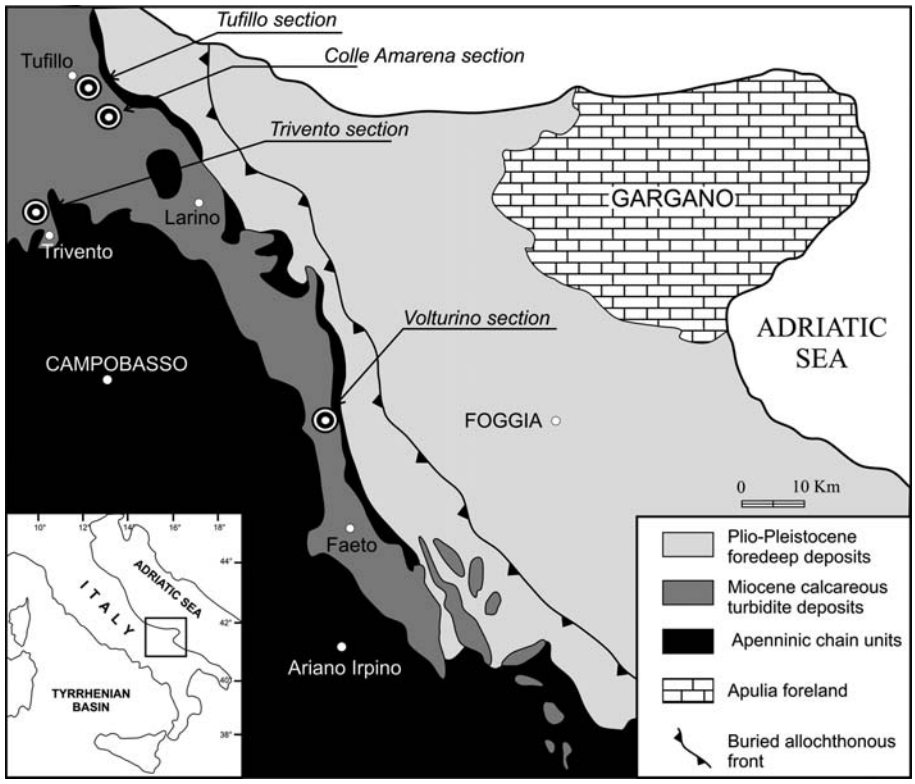


Fig. 1 - Geological sketch map of the eastern portion of the Southern Apennines with the location of the studied sections.

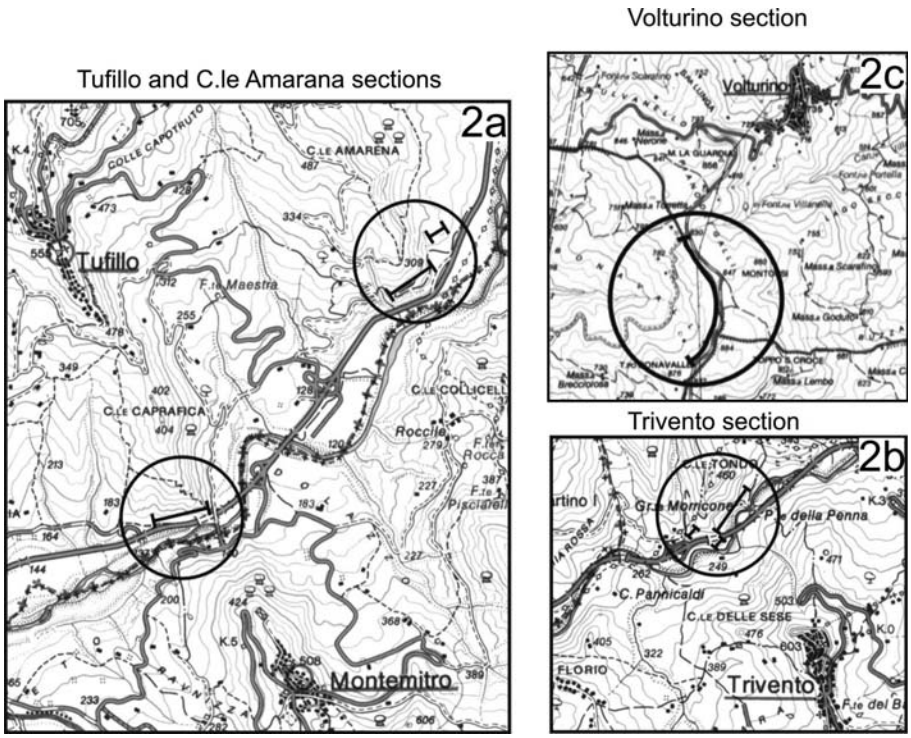


Fig. 2 - Detailed location maps of the studied sections of Miocene calcareous turbidite deposits: Fig. 2a: location of the Tufillo and Colle Amarena sections; Fig. 2b: location of the Trivento section; Fig. 2c: location of the Volturino section.

na, Tufillo and Trivento sections exposed along the Trigno river near the Tufillo and Trivento villages. Following Patacca & Scandone (2004, 2005) and Vezzani et al. (2004), the Volturino and the Colle Amarena sections belong to the Daunia tectonic unit, and thus assignable to the Faeto Formation. The Tufillo and Trivento sections are referred to the Tufillo-Serra Palazzo unit (Patacca & Scandone 2004, 2005) and belong to the Tufillo Formation. At the base of the Colle Amarena section, the Numidian quartzarenites were sampled as well. Unfortunately, the top of the letter formation was not observed below the Tufillo Fm., being that interval is not suitable for sampling along the Tufillo section.

All sections were sampled and logged along different trajectories, due to the presence of small faults and to minimise the extent of covered intervals. Samples were collected with a spacing between 50 cm and 3 m.

**Tufillo section**

The Tufillo section belongs to the Tufillo Formation and is exposed south of Tufillo village (Fig. 2a). The sampled sequence is 140 m thick and mainly consists of alternating fine-grained calcarenites and calcareous marls, in which four distinct lime-breccia events are interlayered (Fig. 3). A thick interval of yellowish sandstones occurs from 7 to 23 m. Two major slumped intervals were observed from 41 to 56 m and between 100 and 127 m. Along this section 30 samples were collected for planktonic foraminifera analyses, and 27 samples for calcareous nannofossil analyses.

**Trivento section**

This section is exposed along the Trigno valley, north of the Trivento village (Fig. 2b), and belongs to the Tufillo Formation. The sampled interval is 178.5 m in thickness and is mainly composed of bioclastic calcarenites, calcilutites, marls and massive sandstones. The bioclastic calcarenites show a coarsening-thickening upward trend, while the amount of calcareous and marly intervals progressively decrease upsection (Fig. 4).

The first 18 m show alternations of light-grey marls to clayey marls, calcareous marls and thin yellowish, medium to fine, bioclastic calcarenites. In the uppermost part of this interval, yellowish fine-grained sandstones replaced the bioclastic calcarenites. The subsequent interval, 18 to 98 m, is principally dominated by the presence of yellow massive sandstones. Thickness of beds increases upwards as well as the grain-size of bioclastic calcarenites which pass to calcirudites. A slumped sandy interval is observed between 141 m and 153 m (Fig. 4). Eight-two samples were analysed in this section for planktonic foraminifera and calcareous nannofossils.

**Colle Amarena section**

The Colle Amarena section is located along the Trigno valley, east of the Tufillo village (Fig. 2a). The sampled sequence consists of 36.5 m of quartzarenites representing Numidian Sand Event (*sensu* Patacca et al. 1992a) which pass stratigrafically to the overlying sediments of the Faeto Formation (212.5 m in thickness) (Fig. 5).

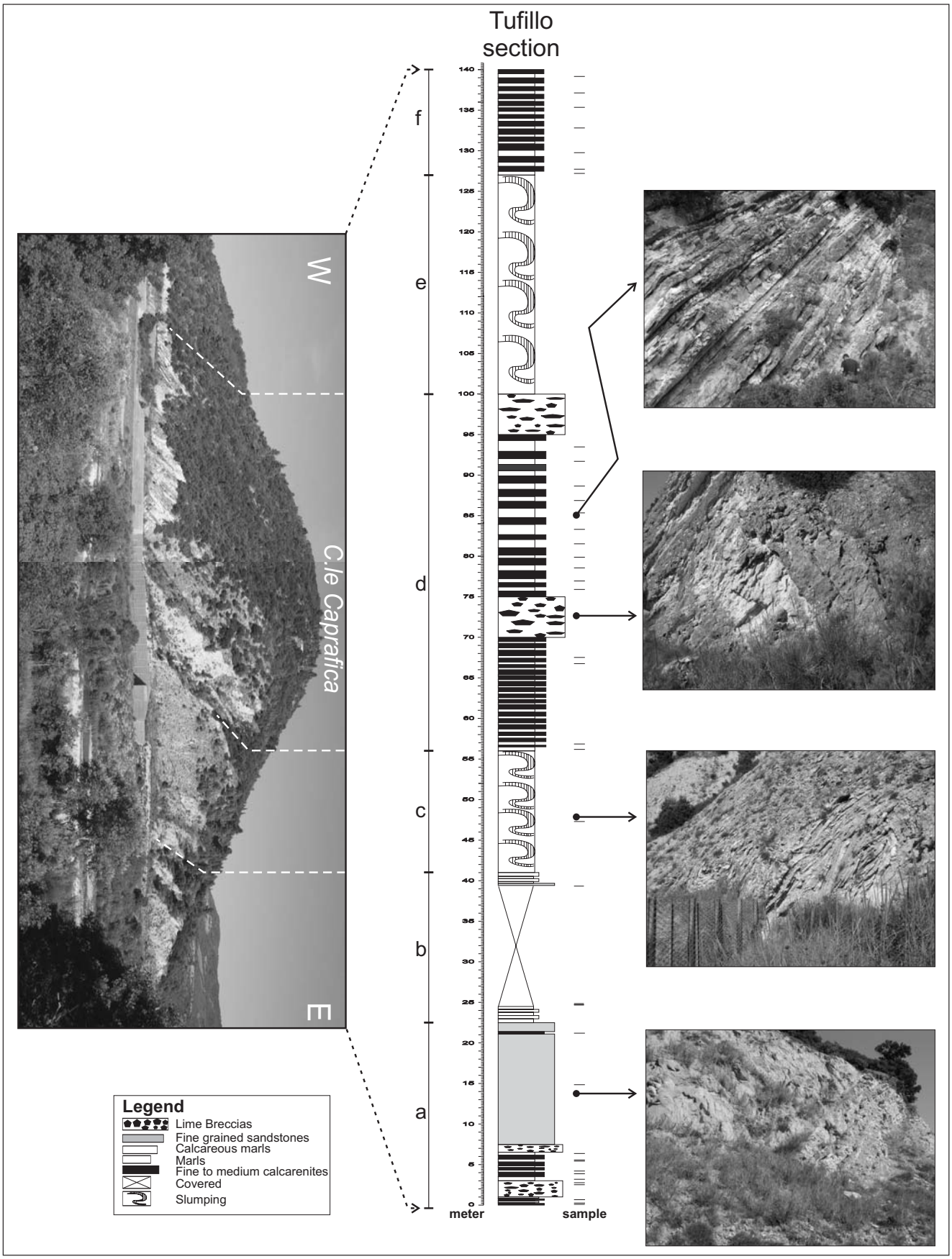


Fig. 3 - Lithologic log of the Tufillo section with selected views of the sampled sedimentary record.

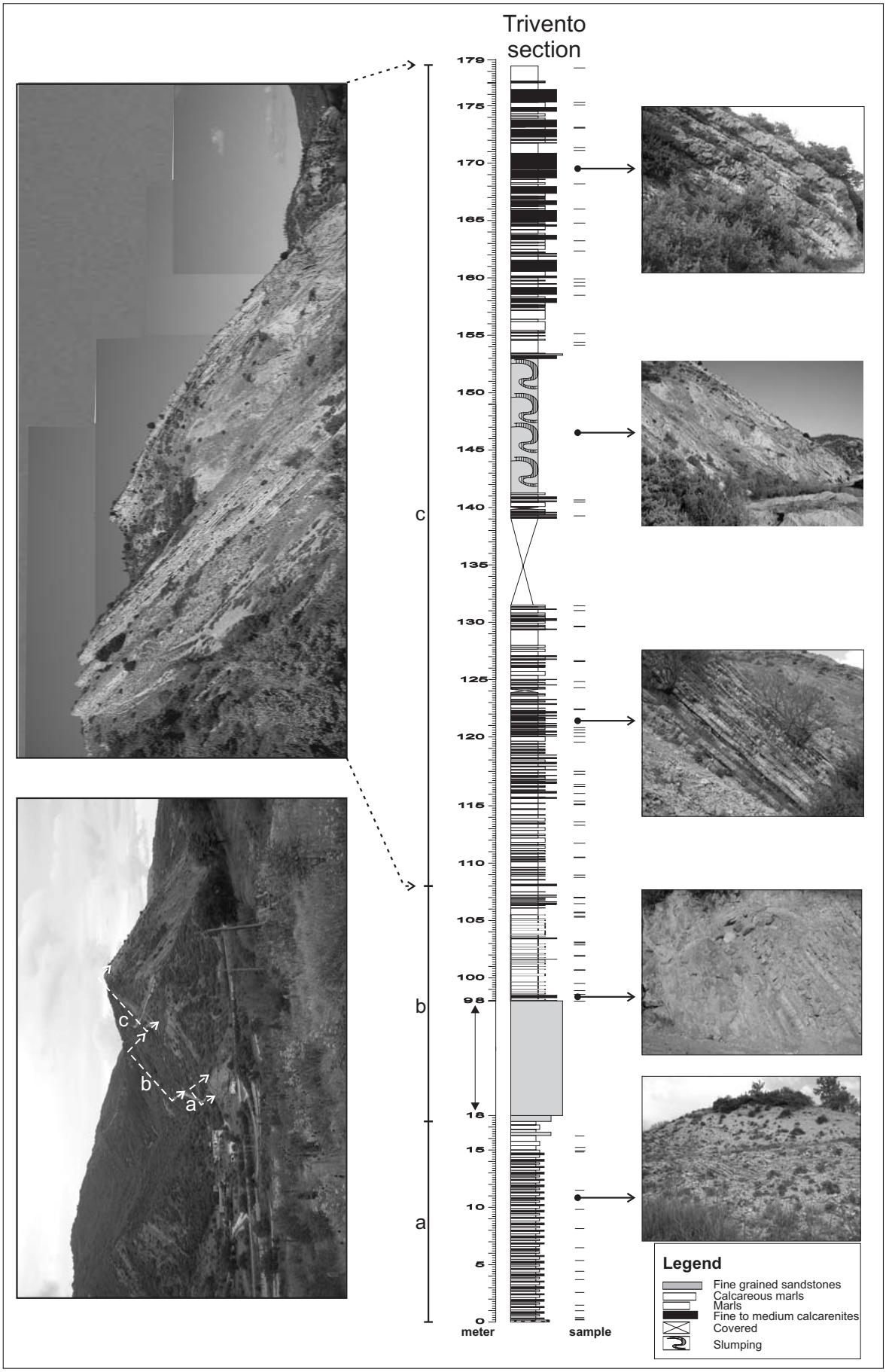


Fig. 4 - Lithologic log and panoramic view of the Trivento section.

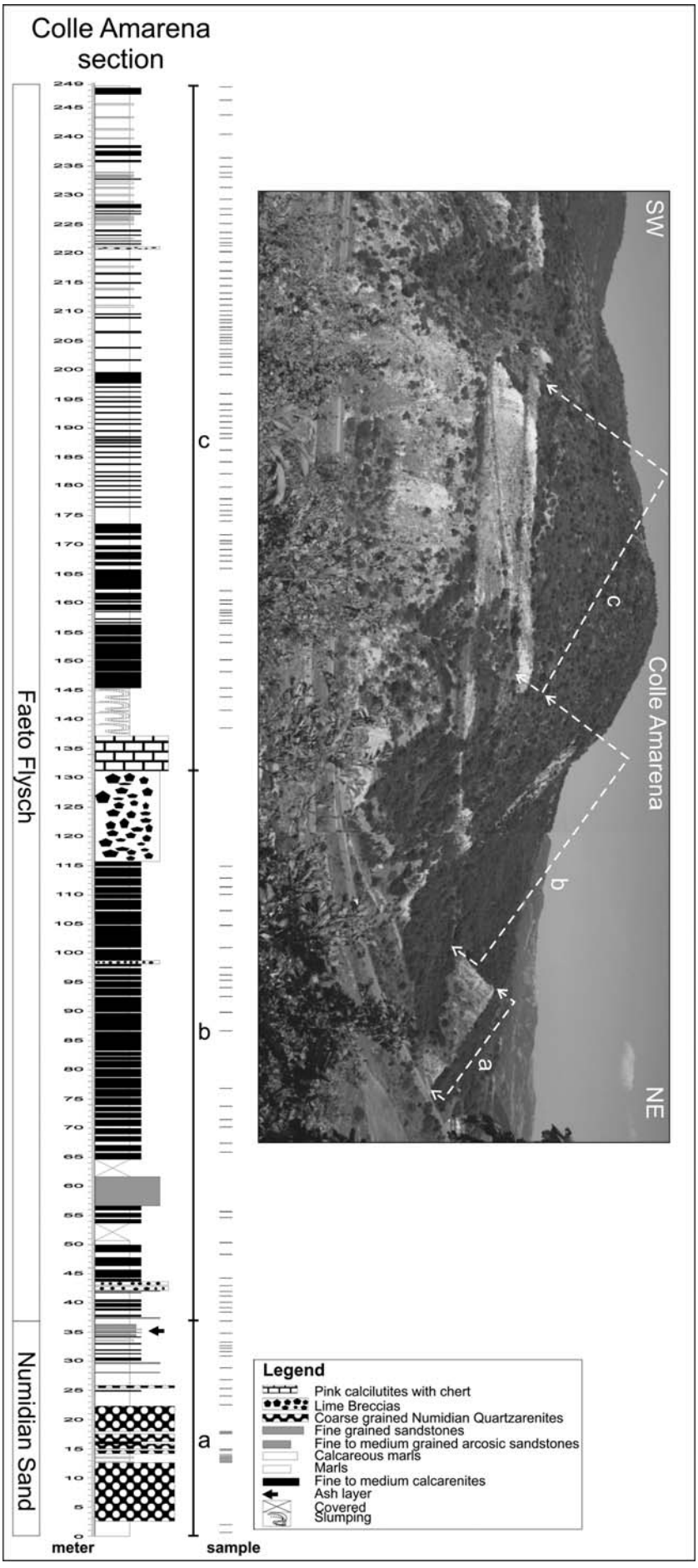


Fig. 5 - Lithologic log of the Colle Amarena section and selected views of the sampled sedimentary record.

The lower and middle portions of the "Numidian Sand" reveal alternations of yellowish quartzarenite beds and thin greenish shaly intervals. The gradual increase of shaly intervals marks the passage to the upper portion, formed by marls, light-grey biocalcarenites, white foraminiferal-rich layers and thin arkose sandstones. Two volcanic layers are observed at about 35 m.

The overlying sedimentary sequence belongs to the Faeto Formation (Fig. 5). It is characterized by alternations of coarse to medium-grained bioclastic calcarenites and thin marly layers, in which a few lime-breccias intercalate. A thick sandy bed is observed from 56.6 to 61.6 m. A level of pink calcilutites with chert nodules is sandwiched between a lime-breccia and a mega-slump from 131.2 m to 137.2 m (Fig. 5). From 173.6 m to the top of the section, the sedimentary sequence is characterized by fine-grained calcarenites (decreasing in amount upward) alternating with greyish marls; the uppermost portion of the section bears white foraminifer-rich calcareous marls. Along this section 130 samples were collected for planktonic foraminifera and calcareous nannofossil analyses.

**Volturino section**

The Volturino section is exposed near the Volturino village (Fig. 2c), close to the section studied by Santo & Senatore (1988). The stratigraphic interval attains a maximum thickness of 84 m and belongs to the Faeto Formation. It is composed of interbedded yellowish to brownish bioclastic calcarenites, greenish-grey marls and white calcareous marls rich in foraminifera (Fig. 6). The bioclastic calcarenites are fining and thinning

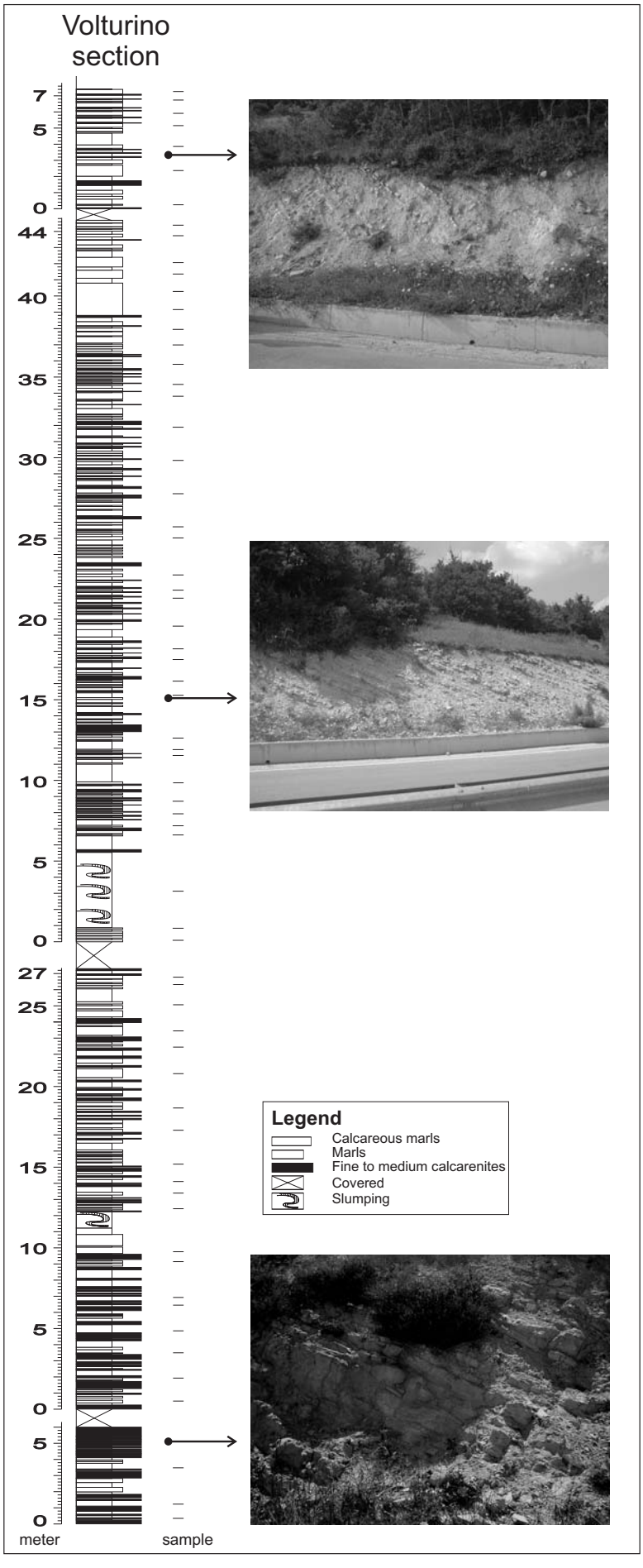


Fig. 6 - Lithologic log of the Volturino section and selected views of the sampled sedimentary record.

upward; the Bauma-intervals **a**, **b** and **e** are observed in the lower part of the section, while only the Bauma-intervals **d** and **e** occur in the upper part (Fig. 6). The amount of calcareous marls and marls increases upward. Furthermore, two distinct slumped intervals were recognised in the lower and middle part of the section (Fig. 6). Along the Volturino section 111 samples were collected for the analyses of planktonic foraminifers and calcareous nannofossils.

## Material and methods

Strongly lithified lime samples for foraminiferal analyses were treated by "cold acetolise", a processing method proposed by Lirer (2000). Samples were first broken into small fragments, approximately 5 mm in size, they were subsequently disaggregated in acetic acid for 6 hours and then washed using a 63 μm sieve. Only the samples from the fine-grained calcarenites were disaggregated in acetic acid for 10 hours in order to remove all the incrustation and obtain a clean washed residue.

The semi-quantitative analysis of the >125 μm fraction 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): Present (<3 specimens in 9 fields), Rare (3-10 specimens), Few (10-30 specimens), and Common (>30 specimens).

For the calcareous nannofossil the samples were prepared as smear slides (Bown 1998) and analysed using a light microscope (transmitted light and crossed nicols) at about 1250X magnification. Abundance data were collected using the methodology described by Backman & Shackleton (1983) and Rio et al. (1990), which is extensively used in Mediterranean and extra-Mediterranean quantitative biostratigraphic studies of Neogene marine records (Raffi & Flores 1995; Raffi et al. 1995; Fornaciari et al. 1996; Backman & Raffi 1997; Di Stefano 1998; Hilgen et al. 2000).

Following this method, the abundance patterns of selected key taxa was estimated: *Sphenolithus heteromorphus* abundance within 100 sphenoliths, *Discoaster deflandrei* and *D. variabilis* gr. within 50 discoasterids, the *Helicosphaera* species were counted in 50 helicolits,

*Calcidiscus premacintyrei* in 10-50 *Calcidiscus*, *Cyclicargolithus floridanus* and *Reticulofenestra pseudoumbilicus* in 100 reticulofenestrids. We refer to Perch-Nielsen (1985), to Fornaciari et al. (1996) and to Bown (1998) for the description of the nannofossils recorded.

## Biostratigraphy

During the last decade several biostratigraphic schemes, based on quantitative analyses of calcareous nannofossils (Fornaciari & Rio 1996; Fornaciari et al. 1996; Hilgen et al. 2000), and more recently on planktonic foraminifera (Sprovieri et al. 2002; Iaccarino et al. 2004a, b), have been proposed for the Mediterranean Miocene to improve the biostratigraphic resolution of standard zonations (Martini 1971; Okada & Bukry 1980; Iaccarino 1985; Foresi et al. 1998). These zonal schemes are based not only on the FO and the LO, but also on further biohorizons identified by the abundance fluctuations of index species, such as: first common and regular occurrence (FCO, FRO), last common and regular occurrence (LCO, LRO), interval of temporary absence (Paracme), interval of particularly abundance (Acme). For example, the distribution of the *Paragloborotalia siakensis*, which is characterised by several acme and paracme intervals, represents a very useful tool to improve the biostratigraphic resolution of the Middle Miocene (Hilgen et al. 2003; Iaccarino et al. 2004a). Following the abundance patterns of index taxa and their chronology, as proposed in the adopted biostratigraphic scheme by Sprovieri et al. (2002) and Iaccarino et al. (2004a, b) (Fig. 7), it was possible to date the studied sections with different degrees of accuracy.

At present, a detailed integrated high-resolution calcareous plankton biostratigraphy for the Burdigalian stage of the Mediterranean area is lacking, thus being unable to adopt a precise criterium concerning the relationship between the LO of *Catapsydrax dissimilis* and the FCO of *S. heteromorphus*.

Distribution of selected taxa (planktonic foraminifera and calcareous nannofossils) and correlation of the sections studied are reported in Figures 8 to 12.

## Planktonic foraminifera

The planktonic foraminifera herein studied are abundant and well preserved.

The *Dentoglobigerina altispira* gr. (including *D. altispira altispira*, *D. altispira globosa* and *D. baromoenensis*), *Globigerina bulloides* gr. (including *G. bulloides*, *G. parabulloides* and *G. praebulloides*), *Globoturborotalita druryi-nepenthes*, *Globigerinita glutinata*, *Globigerinoides quadrilobatus* gr. (including *G. trilobus*, *G. quadrilobatus* and *G. parawoodii*), *Turborotalita quinqueloba* gr. (including *T. quinqueloba* and *G. angustiumbilicata* of Kennet & Srinivasan 1983 according to Turco et al. 2001), *Globorotalia scitula* gr. (including *G. scitula and G. praescitula)*, and *Paragloborotalia siakensis* are continuously present and show abundance fluctuations throughout the sections studied.

The species *Globoquadrina dehiscens dehiscens*, *Orbulina* spp., *Praeorbulina* spp., *G. subquadratus*, *G. obliquus obliquus*, *Globigerinella obesa* gr. (this group includes *G. obesa* and *G. praesiphoniphera*), and *Globorotalia praemenardii- menardii* gr., show a discontinuous distribution and occasionally attaining significant abundance.

The majority of the bioevents used for the Mediterranean biostratigraphic correlations, generally recognised by quantitative analyses, were detected notwithstanding of the semi-quantitative analysis performed.

In this study, the distribution of marker species and the abundance pattern of *P. siakensis* were considered for biostratigraphic reconstruction.

*Tufillo Formation*. The sections studied (Trivento and Tufillo) span the interval from the lower Langhian to the upper Serravallian, from the AcmeEnd ($A_aE$) of *P. siakensis*, where the taxon shows a random coiling direction (left and right), up to the FO of *P. partimlabiata* (Figs 8 and 9). The two sections overlap from the $A_bB$ up to the $A_cB$ of *P. siakensis*.

*P. siakensis* is a long ranging species but its distribution pattern reveals marked changes of biostratigraphic significance (Foresi et al. 2002; Iaccarino et al. 2004b). Unfortunately, the acme intervals of *P. siakensis* are partly recorded in the two sections studied, owing to the presence of thick sandstones, slumps and lime breccias (Figs. 8 and 9).

*Praeorbulina-Orbulina* evolutionary lineage is incomplete in the Tufillo section (FOs of *P. sicana* and *P. glomerosa* are absent), whereas in the Trivento section only the FO of *P. glomerosa* is recorded, below the thick sandstone interval (Figs. 8 and 9).

In the Mediterranean area *G. praemenardii* and *G. peripheronda* are rare and have a discontinuous distribution (Foresi et al. 2001, 2002). In the studied records, the FO of *G. praemenardii* is recorded in the Tufillo section, while the LO of *G. peripheronda*, which generally shows an increase in abundance close to its LO (Foresi et al. 2002), is recorded in both sections (Figs 8 and 9). The FO of *P. partimlabiata* were recorded in the uppermost part of the Trivento section (Fig. 9).

*Faeto Formation*. The planktonic foraminifera of the Colle Amarena and the Volturino sections are abundant and well preserved in all the samples studied. Biostratigraphic analyses indicate that the two sections spanned the interval from the upper Burdigalian (below

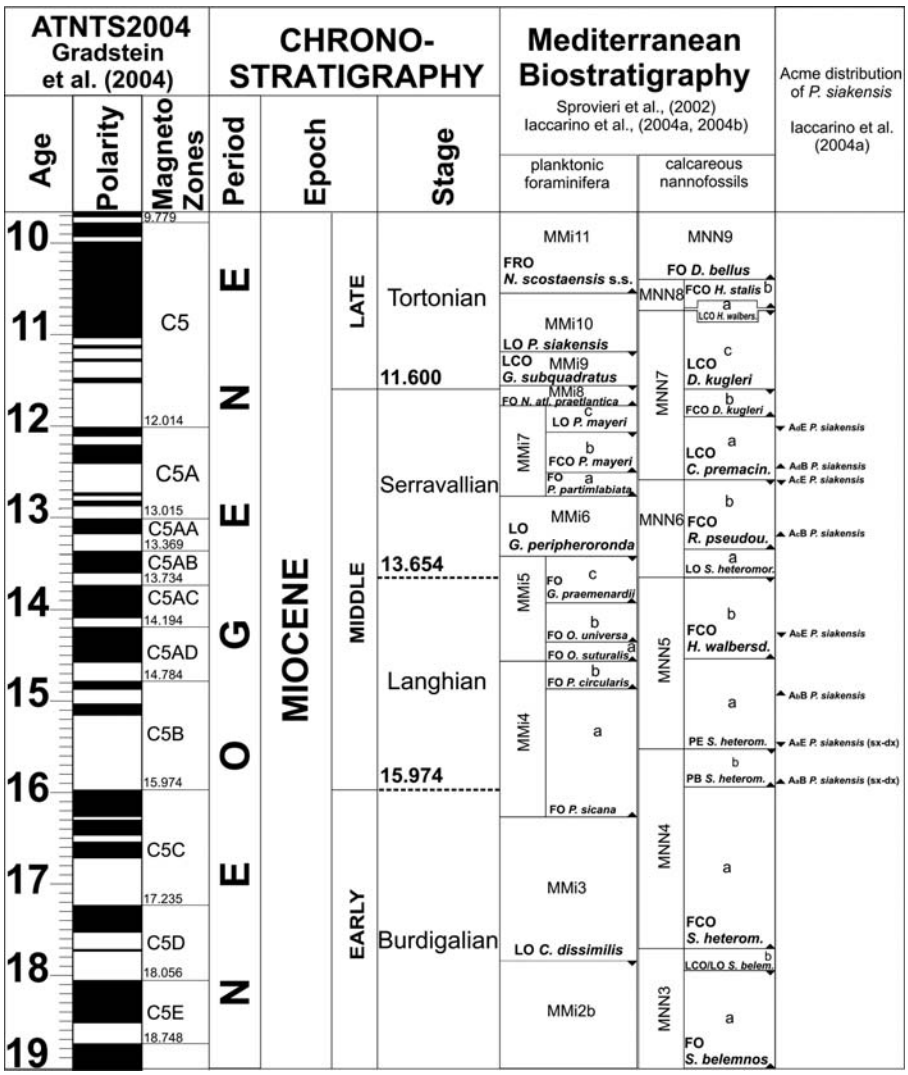


Fig. 7 - Integrated calcareous plankton biostratigraphy scheme of Sprovieri et al. (2002), revisited by Iaccarino et al. (2004a, b). The position of the Acme intervals of *P. siakensis* according to Iaccarino et al. (2004a, b).

the LO of *C. dissimilis*) up to the lower Tortonian (LCO of *G. subquadratus*).

In the Colle Amarena section the upper portion of the Numidian Sand Event is well represented. Abundant and well preserved planktonic foraminifer assemblages characterised the marly layers interbedded to the quartzarenites. The assemblages are dominated by *P. acrostoma*, *G. bulloides* gr., *G. quadrilobatus* gr., *D. altispira* gr. and *T. quinqueloba* gr.; these species show abundance fluctuations throughout the interval studied, whereas *G. subquadratus* occasionally reaches high abundance values (Fig. 10). In this interval left coiling *P. siakensis* has its acme distribution, herein labelled AB-AE *P. siakensis* **, from 12.6 up to 40.6 m; at 40.6 meter the LO of *C. dissimilis* also occurs (Fig. 10).

The Colle Amarena and Volturino sections overlap from the $A_aB$ up to the $A_bE$ of *P. siakensis* (Fig. 12).

The complete *Praeorbulina-Orbulina* evolutive lineage is recorded in the Colle Amarena section (Fig. 10), while in the Volturino section the FOs of *P. sicana* and *P. glomerosa* are absent (Figs. 11 and 12).

The well-exposed and continuous record of the Colle Amarena section allowed us to detect the FO of *G. praemenardii*, the LO of *G. peripheroronda* and the FO of *P. partimlabiata*.

Just above the acme of *P. siakensis* ($A_cB$-$A_cE$) a fault cuts the uppermost part of the Serravallian record (Figs 10, 12). Especially noteworthy is the absence of the last acme interval of *P. siakensis* ($A_dB$-$A_dE$ acme interval) and the complete distribution range of *P. partimlabiata* and *P. mayeri*. (Figs 10, 12).

The occurrence of *Neogloboquadrina atlantica praeatlantica* is recorded 6 m above the FO of *P. partimlabiata*. In the uppermost part of the Colle Amarena section the LCO of *G. subquadratus* and the FCO of *G. obliquus obliquus* are observed (Fig. 10). The LCO of *G. subquadratus* represents the planktonic foraminifera bioevent which best approximates the Serravallian/Tortonian boundary (dated at 11.606 Ma by Hilgen et al. 2003) and is well dated at 11.54 Ma (Hilgen et al. 2003; Lirer et al. 2002).

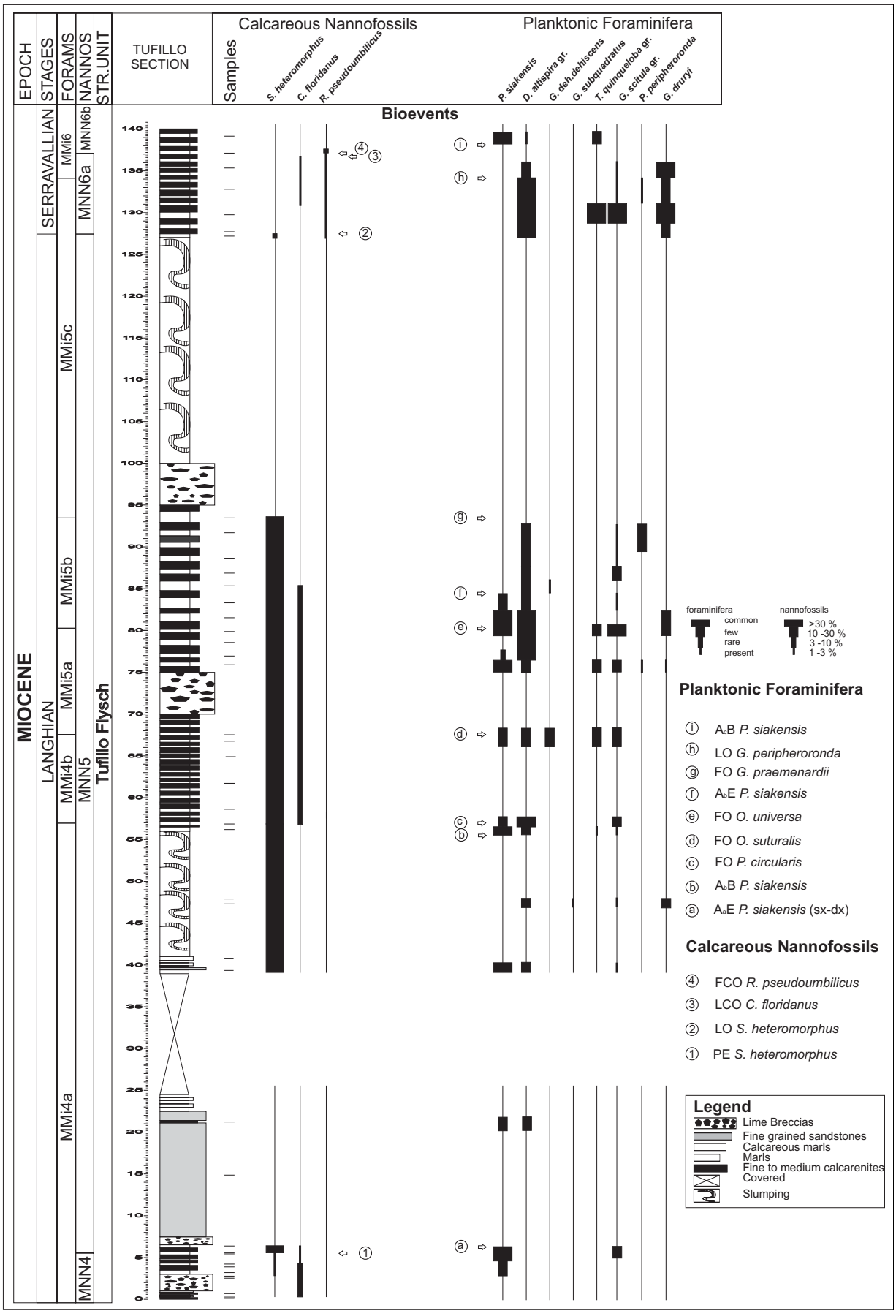


Fig. 8 - Lithologic log of the Tufillo section plotted together with the range charts of selected planktonic foraminifera and calcareous nannofossils and their estimated abundance.

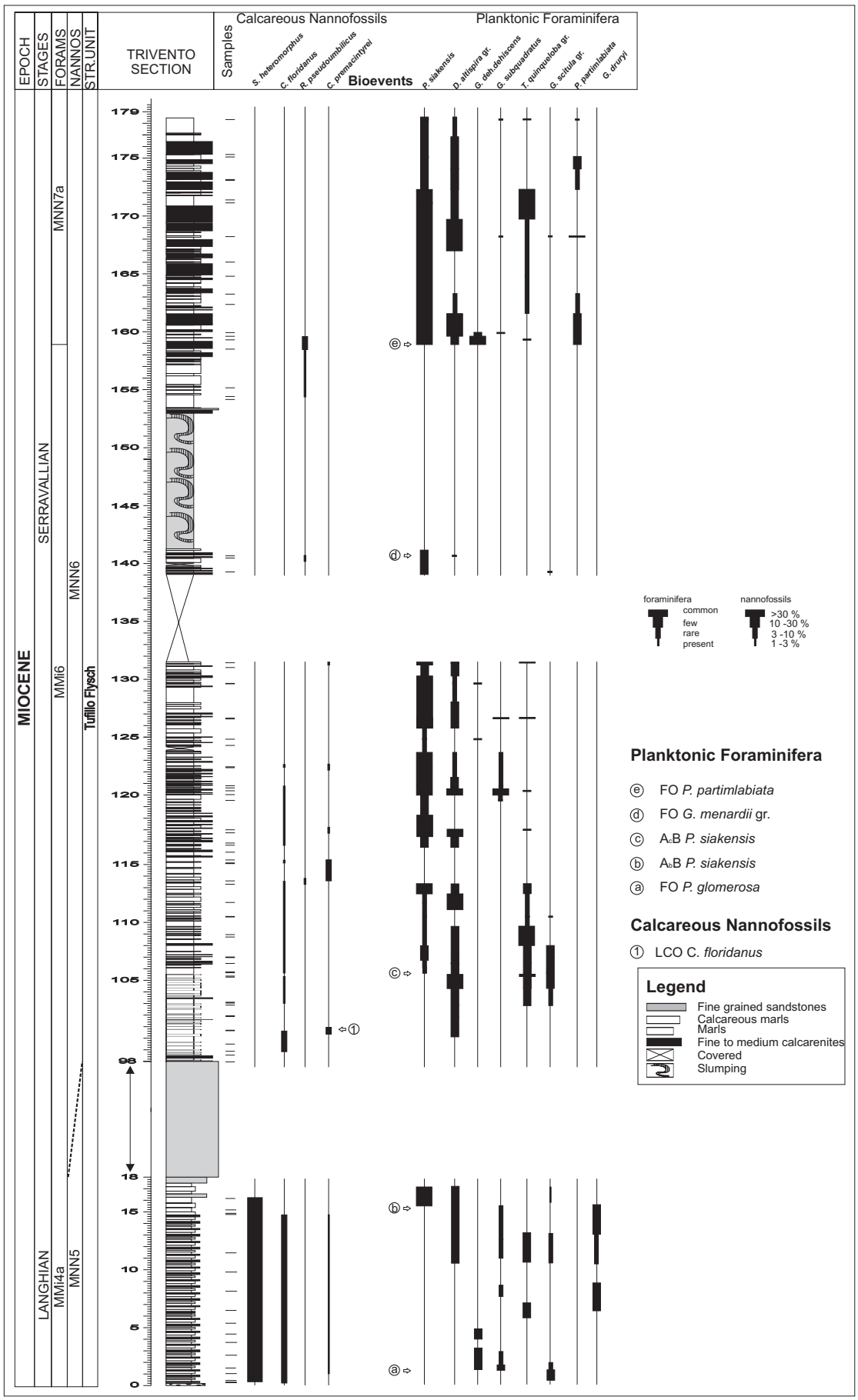


Fig. 9 - Lithologic log of the Trivento section plotted together with the range charts of selected planktonic foraminifera and calcareous nannofossils and their estimated abundance. The grey band represents the barren interval.

**Calcareous nannofossils**

The calcareous nannofossils are generally from few to common and show a moderate to poor preservation. The assemblages are specially characterized by *Dictyococcites* spp., *C. pelagicus*, associated to *C. miopelagicus* and *C. floridanus*. Other constituents, albeit less frequent, are *Discoaster deflandrei*, *Discoaster variabilis* gr., *Helicosphaera carteri*, *Reticulofenestra* spp., *R. pseudoumbilicus*, *Sphenolithus* spp., *S. heteromorphus*, *C. leptoporus*, *C. premacintyrei, H. ampliaperta*, *H. walbersdorfensis*. Cretaceous and Paleogene reworked taxa occur as well. The quantitative analyses enable to recognize almost all the bioevents of the adopted biostratigraphical scheme and to ascribe the sections studied to the biostratigraphical interval between the MNN3b and the MNN7 Zones, late Burdigalian – early Tortonian in age.

*Tufillo Formation.* The two sections studied span the early Langhian to early Serravallian stratigraphic interval, from the MNN4b through MNN6b Zones of Fornaciari et al. (1996).

In the Tufillo section (Fig. 8) the distribution pattern of *S. heteromorphus* indicates the MNN4b Zone, from the base of the section to 5,5 m, and the MNN5 Zone from 5,5 m to 127,4 m. The FCO of *R. pseudoumbilicus*, recorded at 137 m, clearly shows the presence of the following Subzones: the MNN6a from 127,4 m to 137 m, the MNN6b from 137 m to the top of the section.

The first 18 meters of the Trivento section belong to the MNN5 Zone; its top boundary, i.e. LO of *S. heteromorphus*, was not identified owing to the presence of massive sandstones between 18 and 98 meters. The subsequent sediments can be referred to the MNN6 Zone (Fig. 9). On the basis of discontinuous occurrences of *R. pseudoumbilicus*, its FCO cannot be precisely detected. However, this bioevent could be replaced by the LCO of *C. floridanus* (see Fornaciari et al. 1996), which occurs at 100,4 m.

*Faeto Formation*. The Colle Amarena and Volturino sections (Figs 10, 11) extend across the MNN3b and MNN7 Zones, from the late Burdigalian to the early Tortonian.

The Colle Amarena section (Fig. 10) spans the stratigraphic interval from the MNN3b through MNN7 Zones of Fornaciari et al. (1996). The MNN3b Zone is identified from the base of the section up to 41.0 m, on the evidence of very rare and discontinuous *S. belemnos*, *S. heteromorphus* and *H. ampliaperta*. Following the distribution of *S. heteromorphus*, the MNN4a to MNN5 Zones were identified from 41.0 m up to 211.0 m. The MNN6 Zone was recognized between the *S. heteromorphus* LO and the LCO of *C. premacintyrei* at 234,3 m. The MNN7 Zone is recorded from 234,3 m up to the top of the section (Fig. 10).

The Volturino section (Fig. 11) falls within the *S. heteromorphus* distribution range above its FCO. Quantitative analyses identified the MNN4a to the MNN5a Zones of the scheme proposed by Fornaciari at al. (1996). Furthermore, the distribution pattern of *D. deflandrei* vs. *D. variabilis* gr. (Fig. 11) shows a drastic change in abundance right in the *S. heteromorphus* paracme interval in good agreement with Fornaciari et al. (1996). It is worth noting that the assemblages of some green clayey levels contain numerous discoasterids and lack in Sphenoliths. This is likely to the dissolution action to which discoasterids are more resistant than Sphenoliths.

**Calcareous Nannofossils Remarks**

The bioevents based on the *S. heteromorphus* distribution (FCO, ParaAcme and LO) provide a good biostratigraphic resolution and are very useful for the correlation between the sections studied. The FCO of *R. pseudoumbilicus* is not easily detectable, contrarily to what previously indicated by Maiorano (1998). The LCO or the LO of *H. ampliaperta*, the FCO of *H. walbersdorfensis* are also less useful, since these taxa are very rare and scattered in the sediments studied. The LCO of *C. premacintyrei* is fairly good; but, the distribution of *Calcidiscus* species has a more valuable biostratigraphic importance. In the sections studied, below the LO of *S. heteromorphus*, the genus *Calcidiscus* is represented mainly by small and elliptical specimens with a closed central area, referable to *C. fuscus*, *C. pataecus* and *C. radiatus* (see de Kaenel & Villa 1996). These specimens become progressively rare and then disappear above the LO of *S. heteromorphus*, in the MNN6 Zone. *C. leptoporus* with an open central area (wide 7-10 m), referable to *C. tropicus* of de Kaenel & Villa (1996), makes its appearance slightly before the LO of *S. heteromorphus* and becomes increasingly common in MNN6 Zone. This pattern is clear in the sections studied and can be used to identify stratigraphic levels above the LO *S. heteromorphus*, referable to Zones MNN6/MNN7. Finally, the change in abundance between *D. deflandrei* and *D. variabilis* is of limited applicability in the sections studied, owing to preservation problems precluding its clear recognition.

## Conclusions

Detailed fieldwork from four sections of the Faeto and Tufillo formations, characterized by similar lithologic and depositional features, reveals differences in sediment supply and basin-floor morphology. New biostratigraphic data, from planktonic foraminifera and

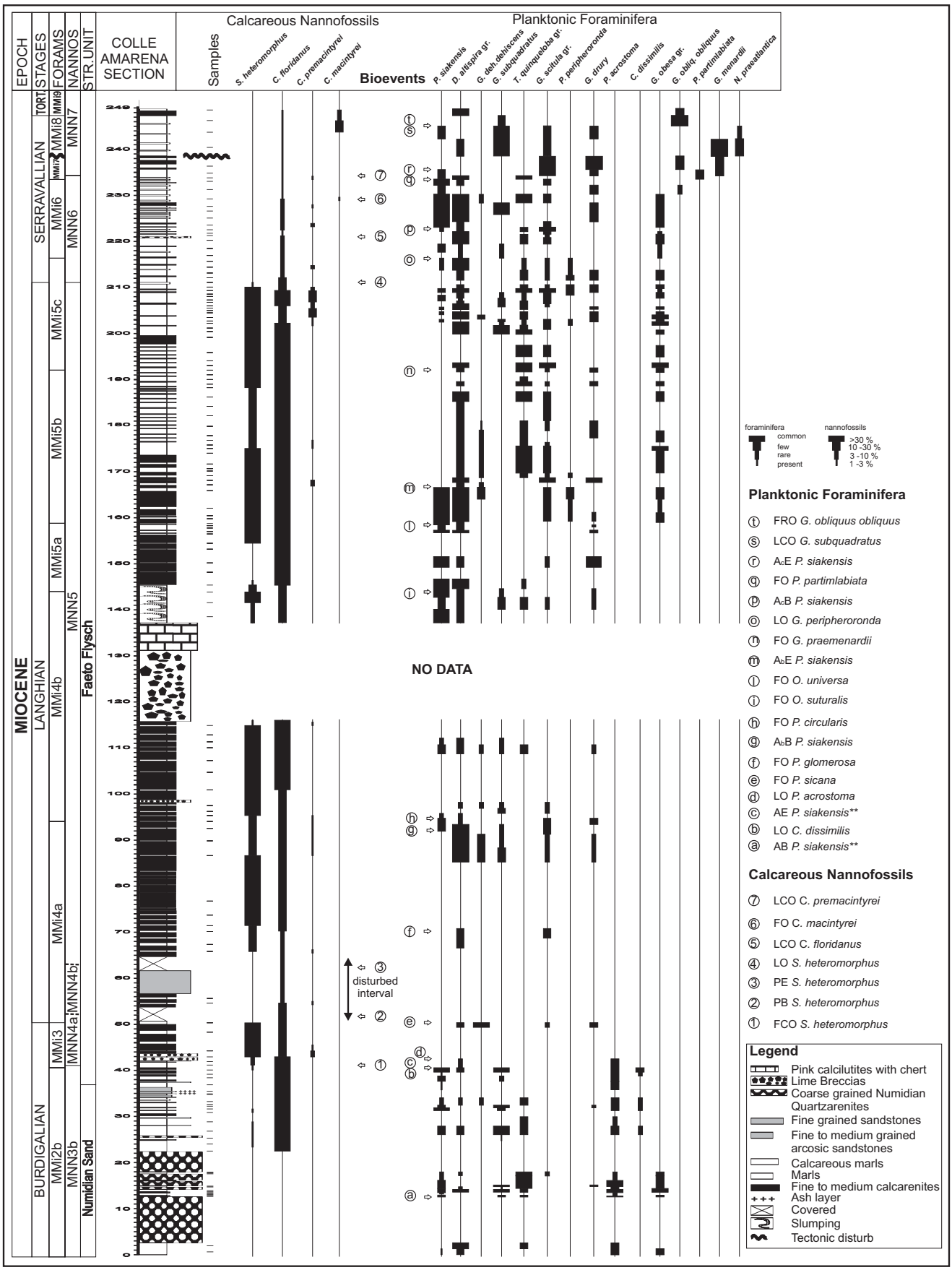


Fig. 10 - Lithologic log of the Colle Amarena section plotted together with the range charts of selected planktonic foraminifera and calcareous nannofossils and their estimated abundance. The grey bands represent the barren intervals.

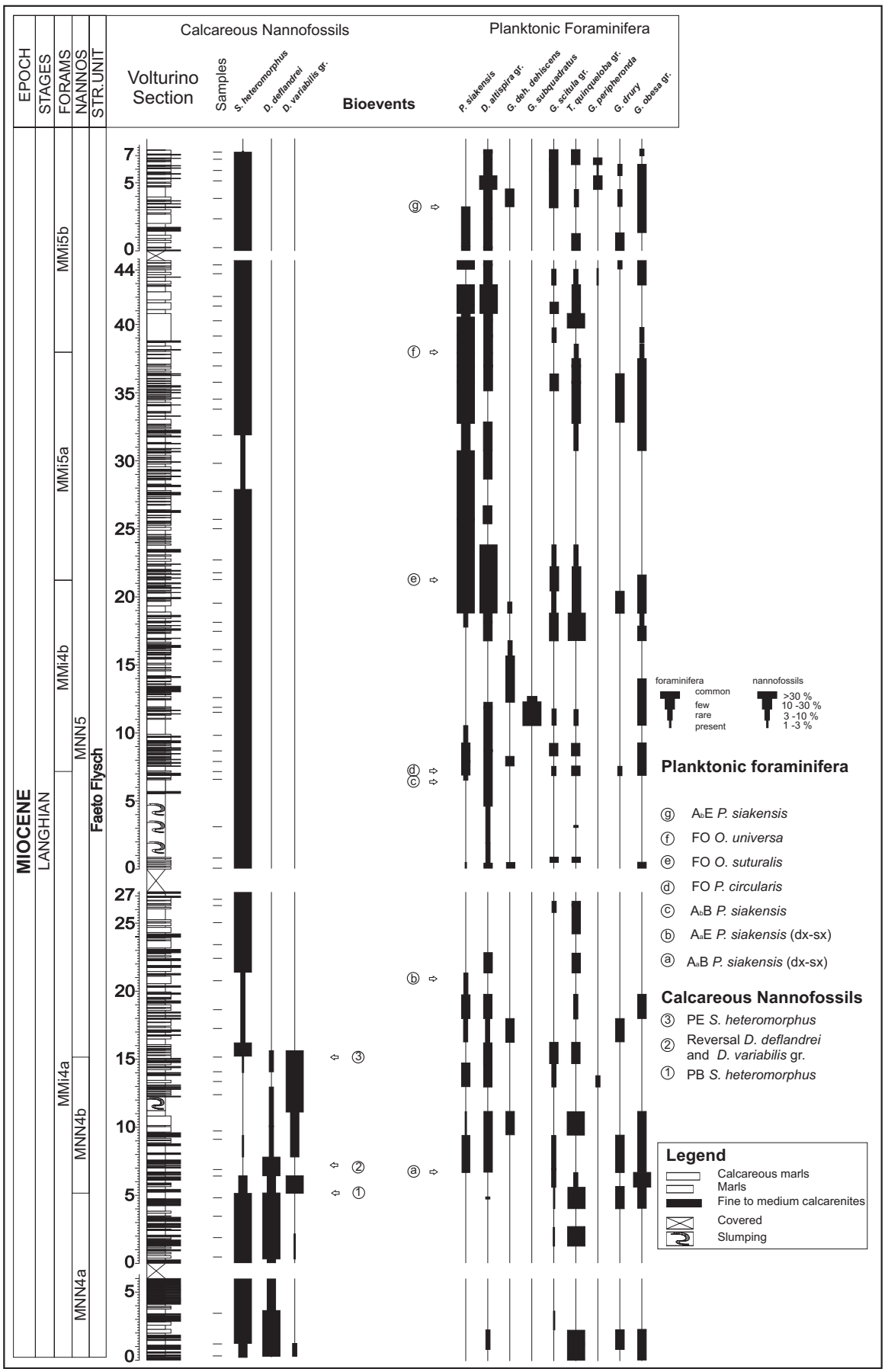


Fig. 11 - Lithologic log of the Volturino section plotted together with the range charts of selected planktonic foraminifera and calcareous nannofossils and their estimated abundance. The grey bands represent the barren intervals.

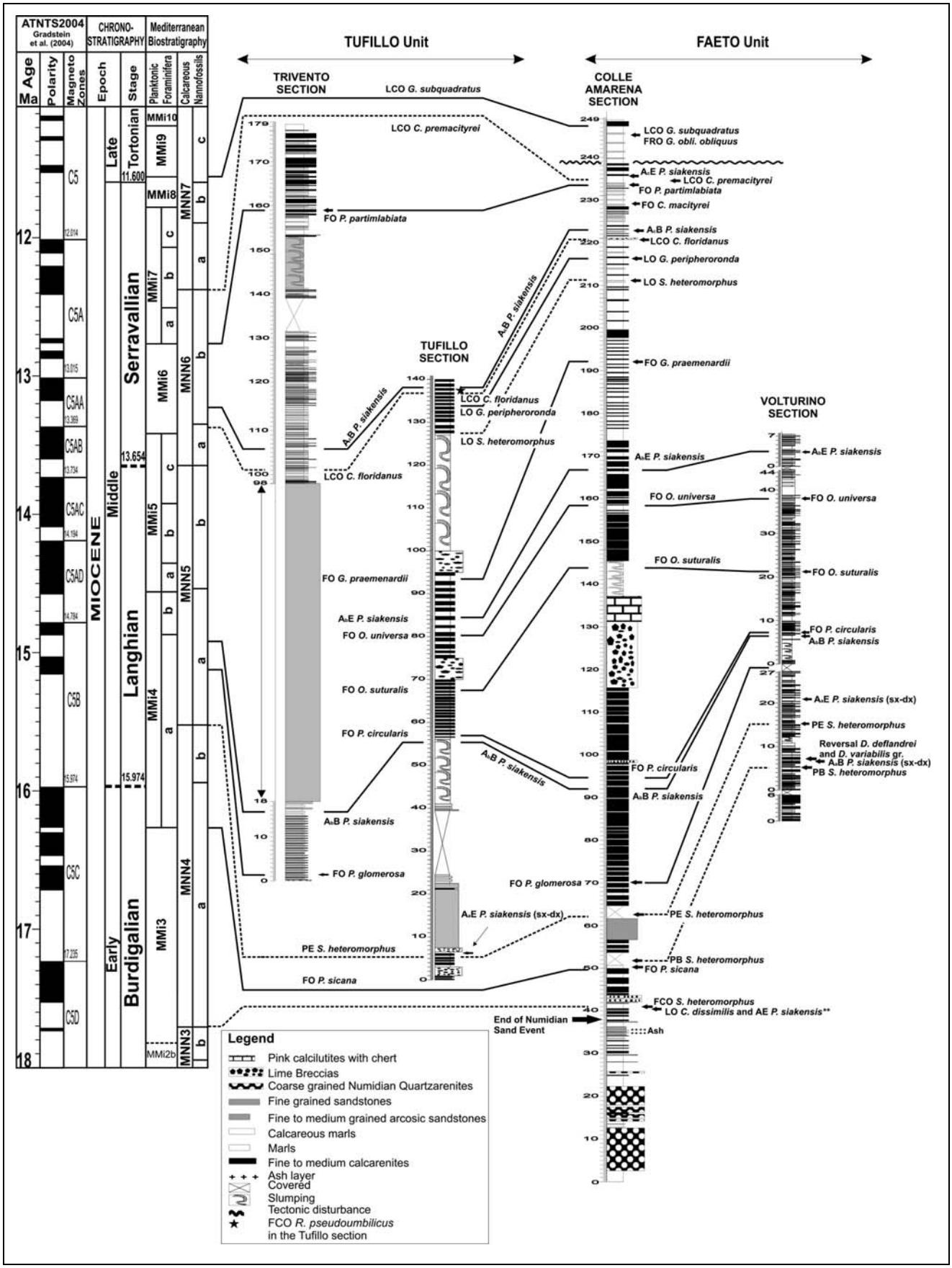


Fig. 12 - Biostratigraphic correlation of the studied sections. The position of the bioevents are indicated by the following acronyms: PB (ParaAcme Base), PE (ParaAcme End), AB (Acme Base), AE (Acme End), FO (First Occurrence), FCO (First Common Occurrence), FRO (First Regular Occurrence), LO (Last Occurrence), LCO (Last Common Occurrence). Continuous and dotted lines indicate, respectively, the correlation of bioevents for planktonic foraminifera and for calcareous nannofossils.

calcareous nannofossils provide a refinement of their biostratigraphy and also of the Numidian Sand Event.

Data from the Faeto and Tufillo formations can be directly correlated to the Mediterranean Middle-Late Miocene schemes of Sprovieri et al. (2002) and Iaccarino et al. (2004a, b) (Fig. 12).

A new acme interval of left coiling *P. siakensis* occurs in the uppermost part of Burdigalian planktonic foraminiferal Subzone MMi2b; this acme starts after the LO of *Sphenolitus belemnos* (dated at 17.95 Ma, Lourens et al. 2004) and ends with the LCO of *C. dissimilis* (17.54 Ma, Lourens et al. 2004). *P. siakensis* abundance intervals are useful in correlating the study sediments (Fig. 12), as recently observed by Foresi et al. (2002), Hilgen et al. (2003) and Lirer et al. (2004) in Middle Miocene Mediterranean marine records. Furthermore, the integrated calcareous plankton biostratigraphy reveals the FCO of *S. heteromorphus* occurs below the LO of *C. dissimilis*, in agreement with Deino et al. (1997).

This investigation evinces that the end of the Numidian Sand Event and the onset of the Faeto Formation occur below the FCO of *S. heteromorphus*, MNN3b Zone, and the LO of *C. dissimilis*, Mi2b Subzone (Fig. 12). The top of the Numidian Sandstones was not observed below the Tufillo Fm., although following Maiorano (1998) it can be referred to the MNN3b Zone.

More complete successions are under detailed investigation to provide a comprehensive up-to-dated stratigraphic framework of the Tufillo, the Faeto formations and the Numidian Sand Event on the basis of the most recent bio-chronostratigraphy.

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