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Integrated calcareous plankton biostratigraphy of selected Miocene successions in the Northern Calabria (Italy)

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KEY WORDS - Planktonic foraminifera, Calcareous nannofossils, Biostratigraphy, Late Miocene, Northern Calabria, Italy.

ABSTRACT - An integrated calcareous plankton biostratigraphic approach on six sections cropping out in Northern Calabria allowed to define a revised chronostratigraphic framework for Tortonian-Messinian deposits. Four sections have been investigated in the Amantea Basin (Timpone Napoli, Vallone Salina, Case Vespano, and Cozzo Salice) and two in the Rossano Basin (Vallone Casino and Cozzo Sant'Isidoro). Biostratigraphic analyses have been based on quantitative counting of planktonic foraminifers and semiquantitative counting of nannofossils.

The Timpone Napoli and Vallone Salina sections are Late Tortonian in age and referable to the Globorotalia suterae *Zone. In terms of nannofossils zonal scheme these sections fall within the* Coccolithus pelagicus - Amaurolithus primus *Zones. The Case Vespano and Cozzo Salice sections can be ascribed to the Messinian. The Case Vespano section is wholly characterized by the common occurrence of* Globorotalia miotumida *group. The co-occurrence of* Amarolithus delicatus*, A. cf.* amplificus,. *and* Reticulofenestra rotaria *confirms a Messinian age. The lower part of the Cozzo Salice section is rich of* Gt. conomiozea*, while its middle and the upper part is barren in planktonic foraminifers. In the Vallone Casino and Cozzo Sant'Isidoro sections the Tortonian-Messinian boundary corresponds to the first occurrence (FO) of* Gt. miotumida *group (*sensu *Hilgen et al., 2000), just above the first occurrence of* A. delicatus.

Biostratigraphic data allowed to correlate the Messinian silty layers of Amantea Basin with the coeval diatomitic beds of Rossano Basin indicating that the two areas, during the Messinian, had different paleogeographic and palaeoecological evolution.

RIASSUNTO - [Biostratigrafia integrata a plancton calcareo di alcune successioni mioceniche affioranti in Calabria settentrionale (Italia)] - *Uno studio biostratigrafico integrato a foraminiferi planctonici e nannofossili calcarei è stato effettuato su sei sezioni rappresentative dei depositi del Miocene superiore della Calabria settentrionale: quattro sezioni affiorano nel bacino di Amantea (Timpone Napoli, Vallone Salina, Case Vespano, and Cozzo Salice) e due sezioni nel bacino di Rossano (Vallone Casino and Cozzo Sant'Isidoro). L'indagine biostratigrafica è stata sviluppata per mezzo d'analisi quantitative (foraminiferi planctonici) e semiquantitative (nannofossili calcarei).*

Bacino di Amantea - Foraminiferi planctonici: Neogloboquadrina acostaensis *e* Globorotalia scitula *sono presenti in tutte le sezioni con predominanza di esemplari ad avvolgimento sinistro*. Gt. suterae *è comune nelle sezioni Timpone Napoli e Vallone Salina, mentre è assente nelle sezioni Case Vespano e Cozzo Salice*. Gt. saheliana *è stata rinvenuta nelle sezioni Vallone Salina I, II e nei primi campioni della sezione Case Vespano. Esemplari di* Gt. menardii *con avvolgimento sinistro sono stati osservati nella sezione Timpone Napoli; forme con entrambi gli avvolgimenti sono presenti invece nella sezione Vallone Salina III, ove prevalgono quelle ad avvolgimento destro. Globorotalie carenate appartenenti al gruppo* Gt. miotumida*, sono presenti dalla base della sezione Case Vespano; mentre morfotipi conici riferibili a* Gt. conomiozea *s.s. compaiono dal campione CV14. Tali forme sono presenti anche nei campioni CS1-CS8 della sezione Cozzo Salice.*

Nannofossili calcarei: I generi Amaurolithus *e* Reticulofenestra *hanno fornito gli eventi più significativi per l'aggiornamento del quadro biostratigrafico dei bacini studiati. La comparsa (FO) di* Amaurolithus primus *è stata registrata nel campione VS19 della sezione Vallone Salina I. Questo bioevento predata il limite Tortoniano/Messiniano*. R. rotaria *compare nel campione VL7 ed è rara o assente nei campioni sovrastanti (Vallone Salina II and III). Essa è presente con continuità nelle sezioni Case Vespano e Cozzo Salice e scompare nel campione CS13*. A. delicatus *è molto raro nella parte superiore della sezione Vallone Salina III ed è presente, anche se con discontinuità, nelle sezioni Case Vespano e Cozzo Salice*. A. *cf.* amplificus *è stato rinvenuto nelle sezioni Case Vespano e Cozzo Salice.*

I dati ottenuti permettono di attribuire le sezioni Timpone Napoli, Vallone Salina e la parte inferiore della Sezione Case Vespano alla Zona a Globorotalia suterae (*Tortoniano superiore - Messiniano inferiore*). *La parte superiore della sezione Case Vespano e la parte inferiore della sezione Cozzo Salice sono attribuibili alla Zona a* Globorotalia conomiozea (*Messiniano inferiore*).

I dati a nannofossili calcarei confermano il quadro cronostratigrafico ottenuto con i foraminiferi planctonici. In particolare sono state riconosciute le Zone a Coccolithus pelagicus *e* Amaurolithus primus *nelle sezioni Timpone Napoli e Vallone Salina, la Zona a* Reticulofenestra rotaria *nella sezione Case Vespano e nella parte inferiore di Cozzo Salice e la Zona a* Calcidiscus leptoporus *nella parte superiore di Cozzo Salice*.

Bacino di Rossano - Foraminiferi planctonici: Gt. menardii *sx e dx è presente nella parte inferiore di Vallone Casino. Esemplari con solo avvolgimento destro sono stati rinvenuti a Cozzo Sant'Isidoro I e II. Il gruppo* Gt. miotumida *è presente dal campione CR2 e SS2 della sezione Vallone Casino della sezione Cozzo Sant'Isidoro II; in corrispondenza dei campioni SS3 e CR6 compaiono inoltre forme riferibili a* Gt. conomiozea.

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Nannofossili calcarei: *Una ricca associazione a nannofossili calcarei, caratterizzata dall'assenza di* R. rotaria, *è stata osservata nelle marne (campioni CR23 e SD2) intercalate ai livelli carbonatici del Calcare di Base. Il limite Tortoniano/Messiniano è stato individuato in entrambe le sezioni del bacino di Rossano, rispettivamente nei campioni CR2 e SS2. Nella sezione Vallone Casino il limite è posizionabile circa 10 m sotto la formazione del Tripoli. L'associazione a nannofossili calcarei negli strati marnosi della formazione del Tripoli è caratterizzata da una bassa diversità specifica e da pochi esemplari appartenenti ai generi* Sphenolithus, Helicosphaera *e* Reticulofenestra. *Gli strati diatomitici che si alternano ai livelli marnosi della stessa sono sterili.* A. primus *è comune in tutti i campioni.* R. rotaria *compare nel campione CR4 e diventa relativamente abbondante nel campione CR6 della sezione Vallone Casino e nel campione SI3 della sezione Cozzo Sant'Isidoro I.* A. delicatus *è presente con discontinuità in entrambe le sezioni.*

Durante il Messiniano l'evoluzione sedimentaria del bacino di Amantea registra un aumento della componente siltitica, con fauna a foraminiferi planctonici di dimensioni ridotte e di difficile determinazione; ciò sembra indicare un ambiente deposizionale stressato ma ancora di mare aperto. Nel bacino di Rossano le alternanze marne-diatomiti (Formazione di Tripoli), coeve alle siltiti del bacino di Amantea e sterili in foraminiferi planctonici, suggerirebbero un ambiente deposizionale stressato, meso/eutrofico relativamente ristretto. Il confronto tra gli strati siltitici del bacino di Amantea e quelli coevi diatomitici del bacino di Rossano suggerisce che le due aree durante il Messiniano inferiore subirono una evoluzione paleoecologica e paleogeografica differente.

INTRODUCTION

High-resolution biostratigraphic, magnetostratigraphic and cyclostratigraphic studies of marine sections in the central and eastern Mediterranean provided in the last decade an excellent chronostratigraphic framework for the late Neogene time interval (Lourens et al., 2004). During the Messinian particular environmental conditions of the Mediterranean caused a widespread deposition of evaporites generally preceded by cyclic alternations of diatomites and marls (Tripoli formation of Sicily; Sierro et al., 2001). This succession of facies reflects the progressive closure of the Mediterranean gateways, which first resulted in salinity increase and later in the complete isolation of the Mediterranean (Hsü et al., 1973; Nesteroff, 1979; Cita & Corselli, 1993). Recently four new scenarios were proposed for the Mediterranean Messinian Salinity Crisis (Butler et al., 1995; Clauzon et al., 1996; Riding et al., 1998; Krijgsman et al., 1999). In general these scenarios are in good agreement with the key-points of the previous models. The authors maintain that the isolation has been controlled predominantly by tectonic processes, but changes of the world sea level and regional climate variation have been also considered to explain the complex development of the evaporitic crisis (Rouchy et al., 2006).

Several attempts have been made, mainly in the Mediterranean region, to establish a detailed biostratigraphic framework for the Late Miocene (Colalongo et al., 1979; Langereis et al., 1984; Krijgsman et al., 1994, 1995, 1997; Sprovieri et al., 1996; Hilgen et al., 1995, 2000; Negri et al., 1999; Negri & Villa, 2000; Raffi et al., 2003). The proposal for defining the Messinian Global Boundary Stratotype Section and Point (GSSP) at the base of the reddish layer in the Oued Akrech section (Marocco) has been officially accepted by International Commission on Stratigraphy (ICS) and ratified by the Executive Committee of the International Union Geological Sciences. The GSSP coincides closely with the First Regular Occurrence (FRO) *Gt. miotumida* group (Hilgen et al., 2000). The calcareous nannofossil genus *Amaurolithus* provides a series of useful events to improve the biostratigraphic resolution across the boundary.

In this paper we present the results of a biostratigraphic research on six sections cropping out in the Amantea and Rossano basins (Northern Calabria) (Figs. 1-3). The data, based on foraminifers and nannofossils bioevents (Fig. 4), provide an updating of the existing chronostratigraphic framework and a better understanding of the evolution of the two basins during the Tortonian-Messinian time interval.

GEOLOGICAL SETTING

The Neogenic successions of Northern Calabria record the sedimentary response to the tectonic evolution of the Calabrian-Arc orogenic system that experienced abrupt uplift and rapid migration towards south-east (Fig. 1). This caused general accretionary

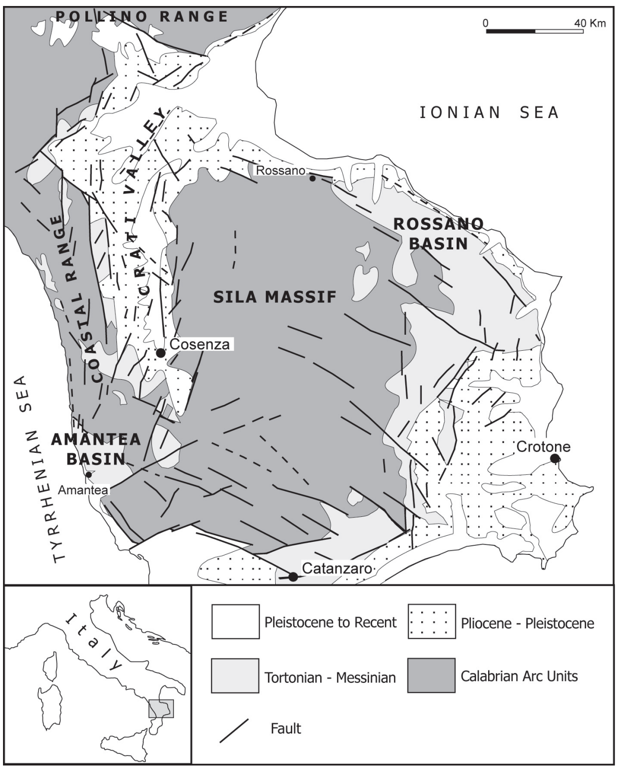

Fig. 1 - Schematic geological map of the study areas: Amantea and Rossano basins.

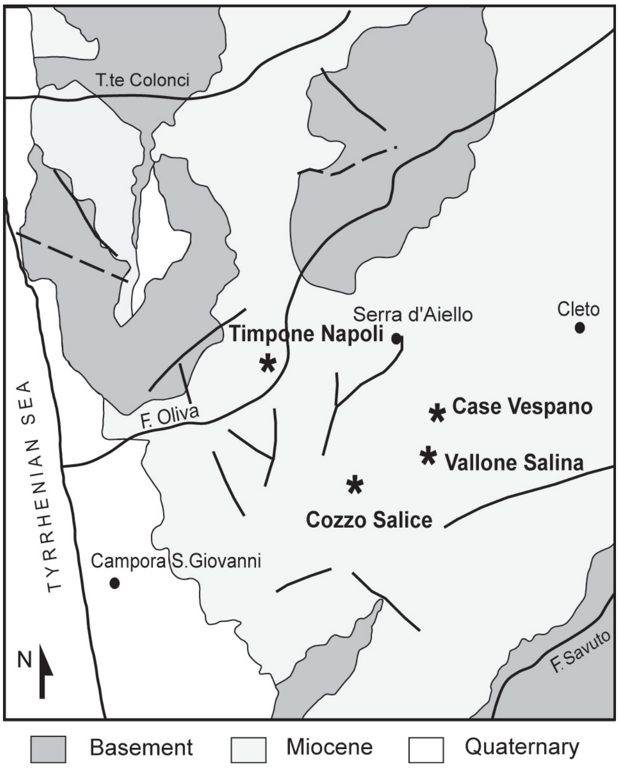

Fig. 2 - Location map of the sampled sections in the Amantea Basin.

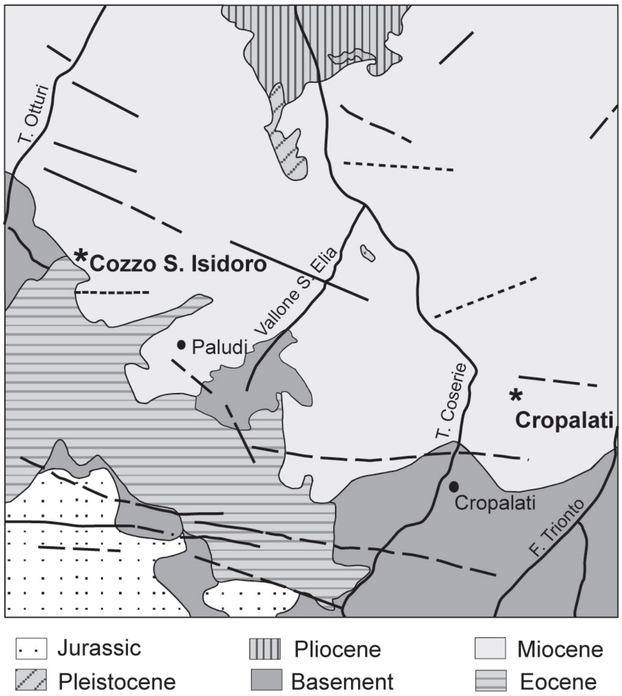

Fig. 3 - Location map of the sampled sections in the Rossano Basin.

tectonics, along the Ionian border, and extensional tectonics in the incipient Tyrrhenian Sea back-arc region. According to this regional tectonic view, the Amantea Basin (Fig. 2), located along the Tyrrhenian coast, is interpreted as a portion of a syn-rift basin, related to the nascent Tyrrhenian back-arc basin. The Rossano, Cirò and Crotone basins, along the onshore Ionian side of Calabrian Arc, are interpreted as forearc basins (Malinverno & Ryan, 1986; Patacca & Scandone, 1989; Patacca et al., 1990; Sartori, 1990; Cavazza & De Celles, 1993; Critelli & Le Pera, 1995, 1998; Cavazza et al., 1997; Funiciello et al., 1997; Critelli, 1999; Van Dijk et al., 2000; Bonardi et al., 2001; Mattei et al., 2002; Zecchin et al., 2004).

Neogene sedimentary basins of the Eastern Calabria are filled by Tortonian to Pleistocene mainly clastic sediments, including the Messinian evaporite cycles.

Several previous studies (Di Nocera et al., 1979; Ortolani et al., 1979; Colella, 1995; Muto & Perri, 2002) show that the Amantea Basin (Fig. 2) can be subdivided into five main depositional units (Miocene to Pleistocene), separated by stratigraphic discontinuities:

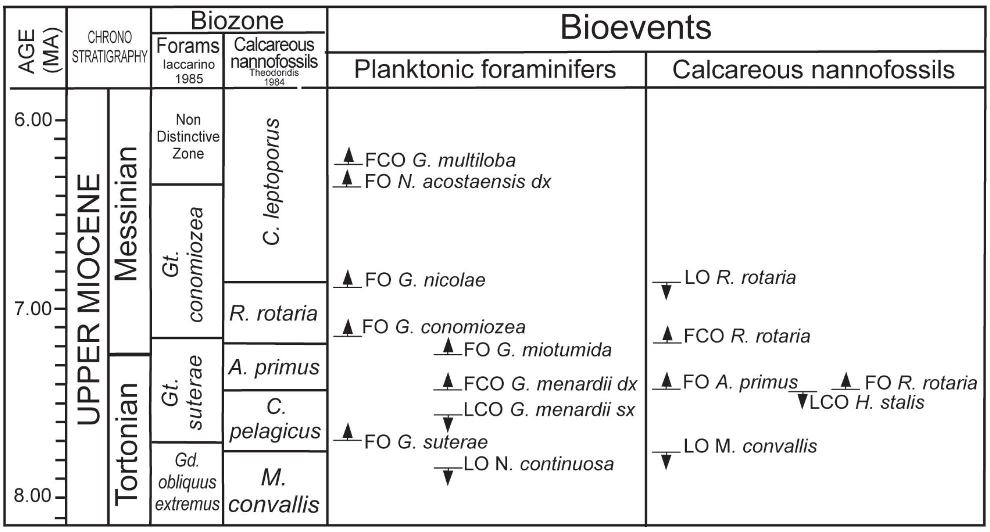

Fig. 4 - Chronostratigraphy and calcareous plankton bioevents of the Upper Miocene (modified from Sprovieri et al., 1996).

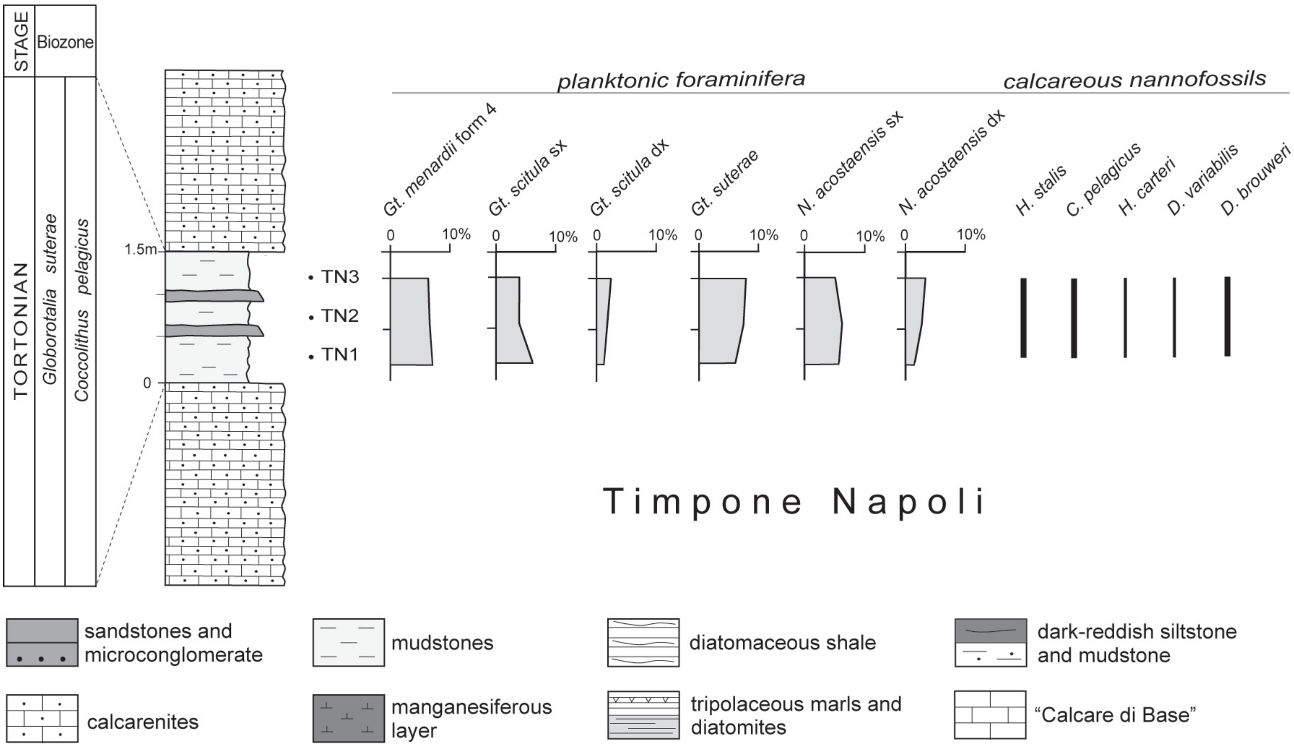

Fig. 5 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in the Timpone Napoli section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

1. coarse-grained alluvial fans passing to fan-deltas deposits;

2. small alluvial-marine conoids passing to a widespread mixed siliciclastic-carbonate platform recording shallow to deep marine depositional environments;

3. small coarse-grained marine conoids abruptly passing to pelagic pelite and sandstone turbidites and then diatomaceous shales;

4. evaporitic sulphate deposits covering with angular unconformity the previous sequences or directly the metamorphic basement;

5. sands and conglomerates.

According to Roda (1964) the Neogenic Rossano Basin infill consists of a continental-marine-paralic succession. The first depositional unit, Tortonian-early Messinian in age, unconformably cover the relative substratum and it is composed of a transgressive system, rapidly evolving from continental (alluvial conglomerate) to deep marine (turbiditic sandstones and pelagic clays) sedimentation. Following there are marls and diatomaceous shales (Tripoli fm) and fine grained carbonates (Calcare di Base fm) that cap the unit. The Messinian evaporite unit (Gessoso-Solfifera fm) composed of gypsum, halite, marls and detrital evaporites, unconformable covers the previous deposits. In the Early Pliocene the deep-marine sedimentation, represented by marls and turbiditic sandstones, record the restoration of normal marine condition (Zecchin et al., 2004).

LITOSTRATIGRAPHY

Amantea Basin

In the Amantea Basin four stratigraphic sections have been sampled: Timpone Napoli, Vallone Salina (I, II, III), Case Vespano, and Cozzo Salice.

EXPLANATION OF PLATE 1

fig. 1 - *Neogloboquadrina acostaensis* sx Blow. a - spiral, b - umbilical and c - lateral view. Vallone Salina section, sample VS30, x 160.

fig. 2 - *Neogloboquadrina acostaensis* dx Blow. a - spiral, b - umbilical and c - lateral view. Vallone Salina section, sample VL21, x 160.

fig. 3 - *Globigerinoides obliquus obliquus* Bolli. a - spiral, b - umbilical and c - lateral view. Case Vespano section, sample CV23, x 110.

fig. 4 - *Globigerinoides trilobus immaturus* Le Roy. a - spiral, b - umbilical and c - lateral view. Vallone Salina section, sample VL11, x 120.

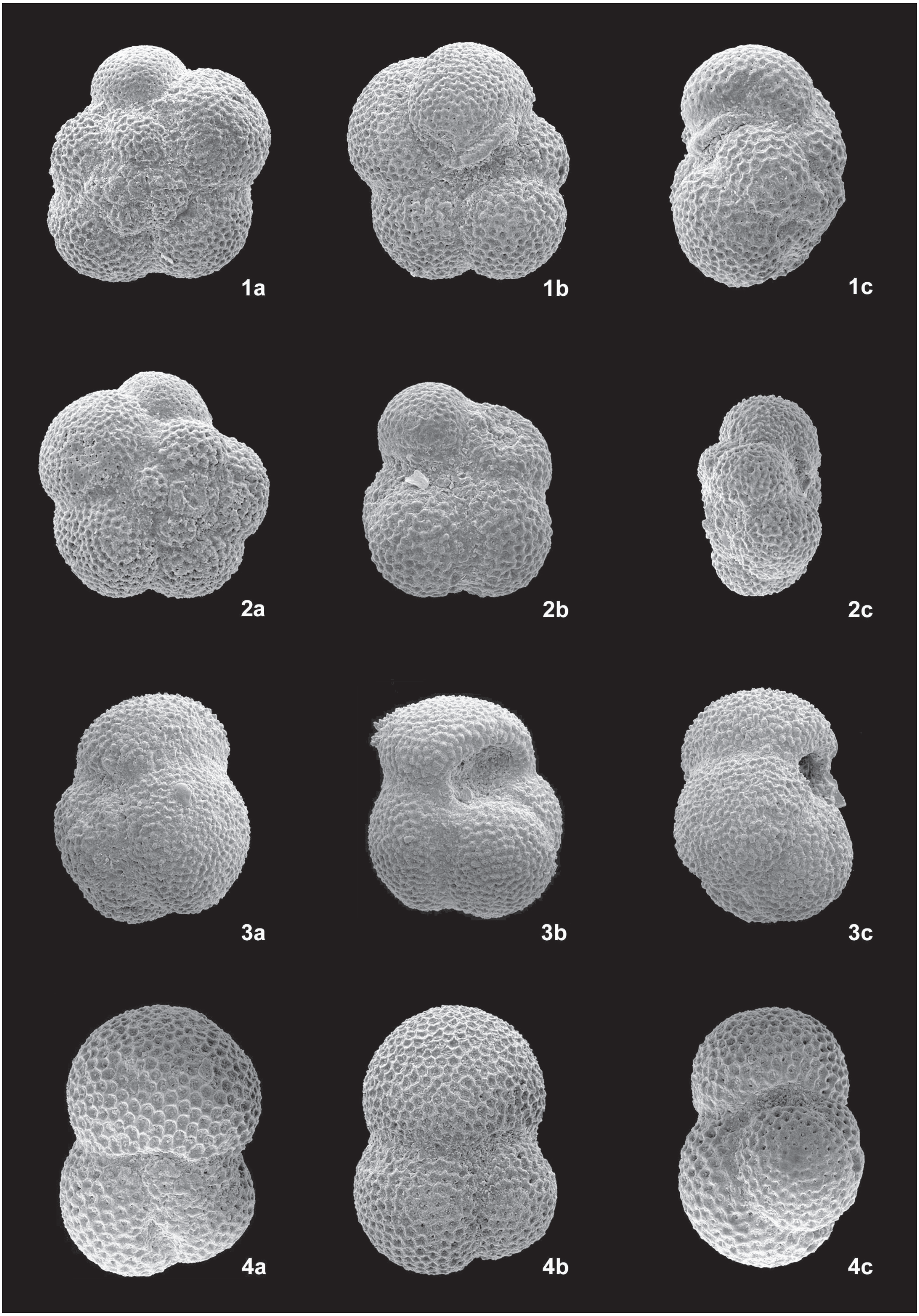
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Fig. 6 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in Vallone Salina section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

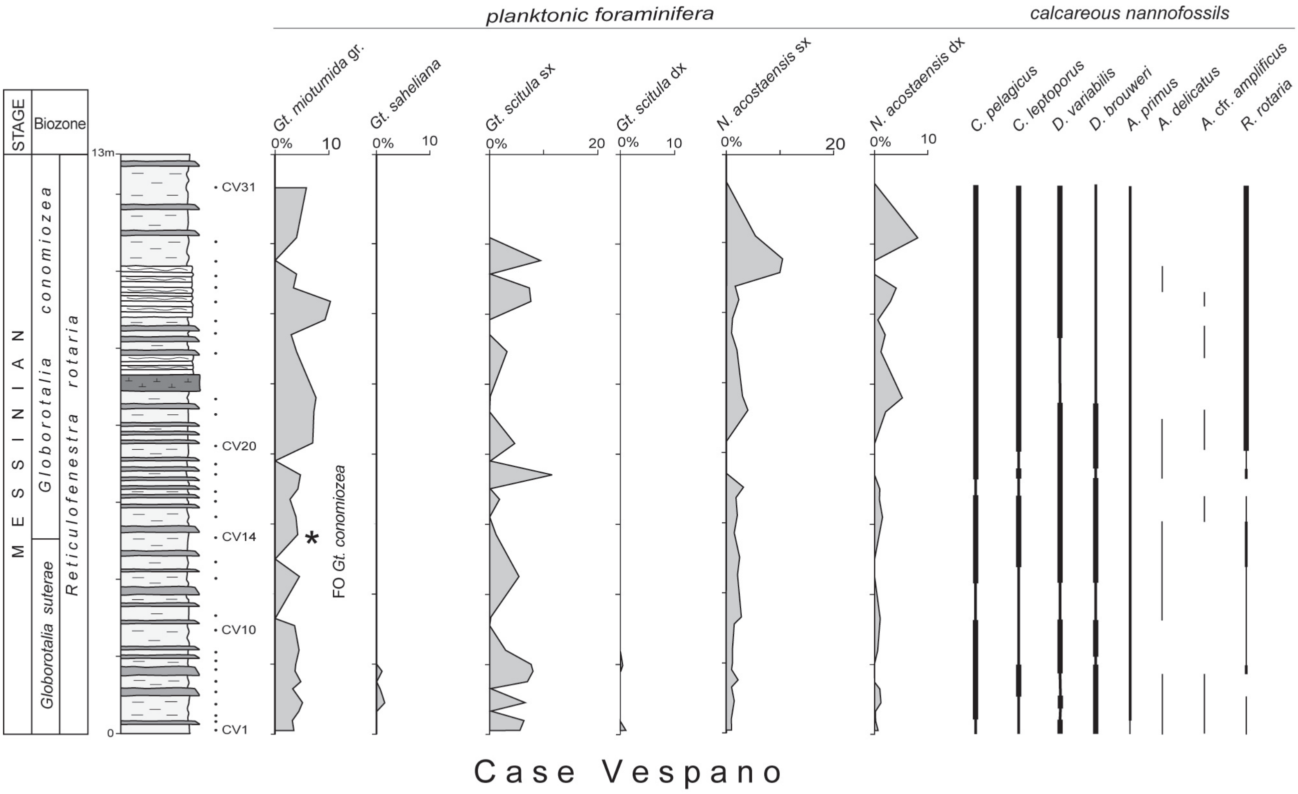


Fig. 7 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in the Case Vespano section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

Timpone Napoli Section - The Timpone Napoli section (TN), about six meters in thickness, consists of bioclastic calcarenites (2.5 m), interbedded with mudstones (1.5 m), and followed by centimetric strata of calcarenites and sandstones (2.5 m). Three samples were collected in the mudstones for micropaleontologic analyses (Fig. 5).

Vallone Salina section - The Vallone Salina is a composite section made up by three distinct segments: Vallone Salina I (VS, 59 m thick, 38 samples), II (VL, 55 m thick, 53 samples), III (VN, 20 m thick, 17 samples) (Fig. 6). The composite section is mainly characterized by grey mudstones, sampled for the biostratigraphic analyses, interbedded with centimetric/decimetric thick turbiditic sandstones.

Case Vespano section - The Case Vespano section (CV) is about 13 m in thickness (Fig. 7) and, in the lower part, it consists of grey-brown mudstones, interbedded with centimetric-thick graded and laminated gray sandstones and marls. Upwards laminated yellow sandstones increase in frequence, and a decimetric bed of manganesiferous silty clays crops out. These strata are overlain by silty shales capped by siltstones and centimetric thick yellow-brown sandstones (Fig. 7).

Cozzo Salice section - The Cozzo Salice section (CS) shows the transition from clayey to silty beds. In particular the section, 9.5 m in thickness, in the lower part is constituted by an alternation of mudstones and siltstones. Upwards follow siltstones, manganesiferous mudstones and centimeter-thick graded red microconglomerate. The upper portion of the section consists of a centimetric-millimetric alternation of dark-reddish siltstones and mudstones (Fig. 8).

Rossano Basin

In the Rossano Basin, two sections have been sampled (Vallone Casino and Cozzo Sant' Isidoro).

Vallone Casino section - The section is located near Cropalati Village (Cosenza) and it is 39 m in thickness. The lower portion is made up by finely stratified dark-grey mudstones and it is overlain by 15 m of an alternation of brown-green marls and diatomitic beds (Tripoli formation). The upper part of the section consists of whitish limestones, interbedded with a decimetric layer of marls (Calcare di Base formation). Twenty-three samples were collected, CR1 to CR8 in the mudstones, CR9 to CR20 in the Tripoli formation, CR22 in the marly bed (Fig. 9).

Cozzo Sant'Isidoro section - The section, 27 meters thick, crops out northeast of Paludi Village. Three distinct stratigraphic segments, I (SI), II (SS) and III (SD) have been measured. The lower and middle portion is constituted by dark grey mudstones, while the upper portion consists of whitish limestones interbedded with decimetric-thick marls (Calcare di Base formation). Eleven samples (SI and SS) have been collected in the

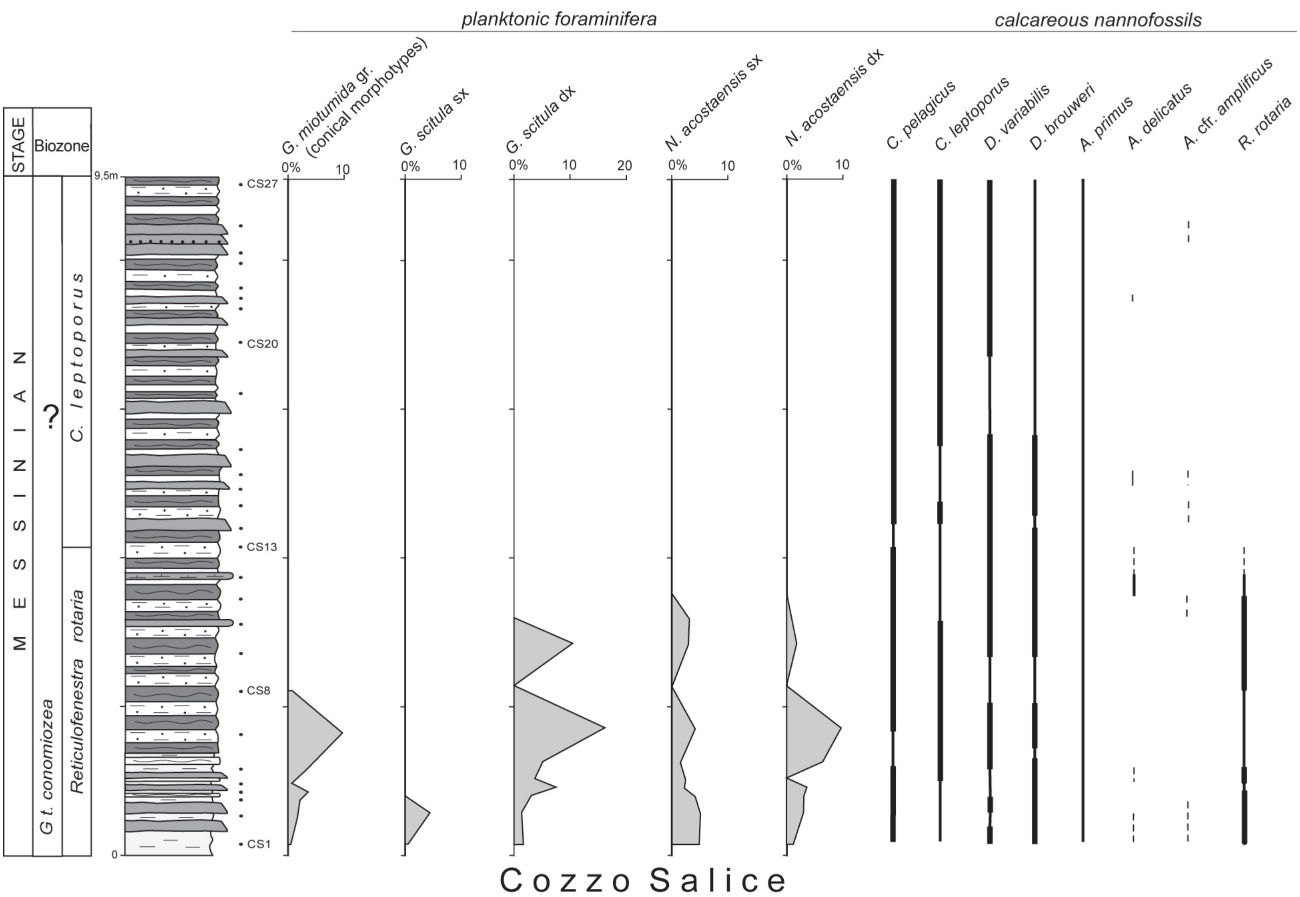


Fig. 8 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in the Cozzo Salice section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

mudstones and one (SD2) in the marly whitin the limestones (Fig. 10).

METHODOLOGY AND ADOPTED BIOSTRATIGRAPHIC SCHEMES

The residues for planktonic foraminifers analyses were obtained from 200 g of dry sediment disaggregated in normal water and washed in 63 µm sieve. All the residue was observed, but only the fraction larger than 125 µm was considered for quantitative counting (300 specimens).

Calcareous nannofossils were studied on smear slides with light microscope at about 1000 x magnifications. Semiquantitative analyses have been performed and the frequencies of the most important taxa have been roughly estimated by observation of 50-100 fields of view.

Taxa frequency has been labelled as rare, common and very common. The number of counted forms for field of view is variable and depends on the relative abundance of the species in the sample. For *Calcidiscus leptoporus, Coccolithus pelagicus, Helicosphaera carteri, H. stalis,* Reticulofenestrids, *Discoaster brouweri, D. variabilis* we labelled: rare <10 specimens per field (spf); common = 10-20 spf ; very common >20 spf. For *Amaurolithus primus:* rare <5 spf; common = 5-10 spf; very common >10 spf. For *Reticulofenestra rotaria, Amaurolithus delicatus, A.* cf. *amplificus*: rare <3 spf; common = 3-6 spf; very common >6 spf.

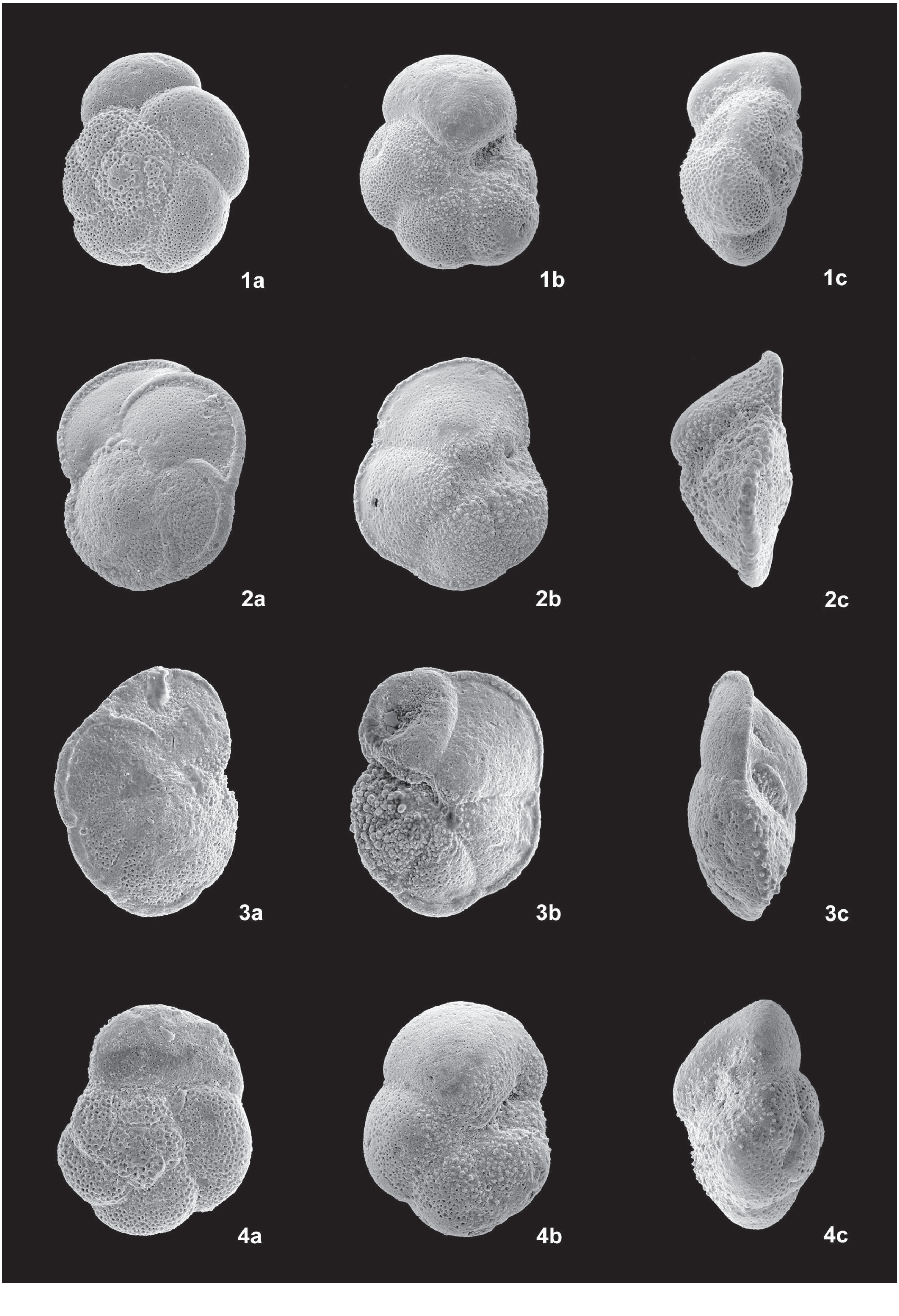
EXPLANATION OF PLATE 2

fig. 1 - *Globorotalia suterae* Catalano & Sprovieri. a - spiral, b - umbilical and c - lateral view.. Vallone Salina section, sample VL33, x 110.

fig. 2 - *Globorotalia menardii* sx Parker, Jones & Brady. a - spiral, b - umbilical and c - lateral view. Timpone Napoli section, sample TN2, x 120.

fig. 3 - *Globorotalia menardii* dx Parker, Jones & Brady. a - spiral, b - umbilical and c - lateral view. Vallone Salina section, sample VN7, x 140.

fig. 4 - *Globorotalia scitula* sx Brady. a - spiral, b - umbilical and c - lateral view. Vallone Salina section, sample VL5, x 140.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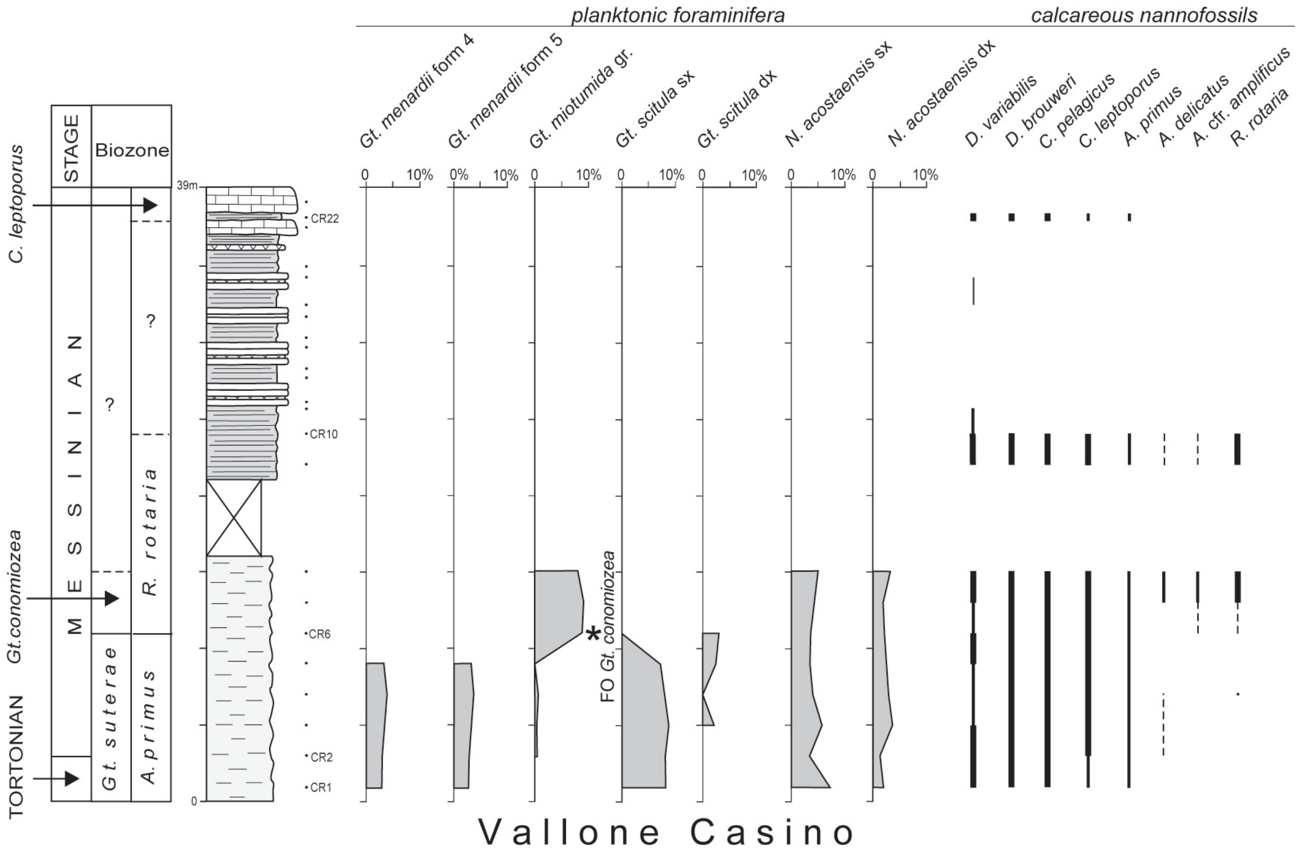


Fig. 9 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in the Vallone Casino section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

We adopted the planktonic foraminifera biostratigraphic zonation scheme of Iaccarino (1985), integrated by Sprovieri et al. (1996) (Fig. 4). Following the formal definition of GSSP, officially located in the Oued Akrech section (Morocco), the T/M boundary coincides with the first regular occurrence of *Globorotalia miotumida* gr., astronomically dated 7.251 Ma (Hilgen et al., 2000).

We followed the calcareous nannofossils biostratigraphy scheme proposed by Theodoridis (1984), later revised with quantitative methods by Negri et al. (1999) and Hilgen et al. (2000). On the base of semiquantitative counting we were able to distinguish some crucial bioevents like the FO of *Amaurolithus primus*, the FO and the FCO of *R. rotaria*, the FO of *A.* cf. *amplificus*, the FO of *A. delicatus*.

Recently Raffi et al. (2003), maintaining that FO and FCO of *R. rotaria* and FO of *A. delicatus* are not reliable, carried out an high resolution biostratigraphic study on Upper Miocene based on the following bioevents: *Discoaster hamatus, Discoaster pentaradiatus, Reticulofenestra pseudoumbilicus, Amaurolithus* spp. (*A. primus*), and *Nicklithus amplificus*. In our sections, because the events linked to *R. rotaria* and *A. delicatus* are clearly distinguishable and well represented, we followed the revised scheme of Theodoridis (1984).

BIOSTRATIGRAPHY

Amantea Basin

Planktonic foraminifera - Planktonic foraminiferal fauna appears to be in a quite good preservation state. The assemblage is constituted by *Dentoglobigerina altispira, Globigerina apertura, G. bulloides, G. nepenthes, G. falconensis, Globigerinoides bollii, Gld. bulloideus, Gld. conglobatus, Gld. trilobus immaturus* (Pl. 1, fig. 4)*, Gld. obliquus extremus, Gld. obliquus obliquus, Gld. trilobus, Gld. sacculifer, Globorotalia conomiozea, Gt. menardii* sx and dx (form 4 and form 5 of Tjalsma, 1971), *Gt. miotumida* group, *Gt. saheliana, Gt. scitula* (sx and dx)*, Gt. suterae, Hastigerina siphonifera, Neogloboquadrina acostaensis* (sx and dx), *N. humerosa* (sx and dx), *Orbulina universa, Turborotalita quinqueloba,*

The quantitative distributions of the most significant species are illustrated in Figs. 5-8. Both *N. acostaensis* (Pl. 1, figs. 1-2) and *Gt. scitula* (Pl. 2, fig. 4) are continuously present along all sections with a predominance of the left coiling specimens, except in the lower part of the Cozzo Salice, where right coiling specimens of *Gt. scitula* prevail. *Gt. suterae* (Pl. 2, fig. 1) is quite abundant in the Timpone Napoli and Vallone Salina sections (Figs. 5-6), while it is absent in the Case Vespano and Cozzo Salice (Figs. 7-8). *Gt.*

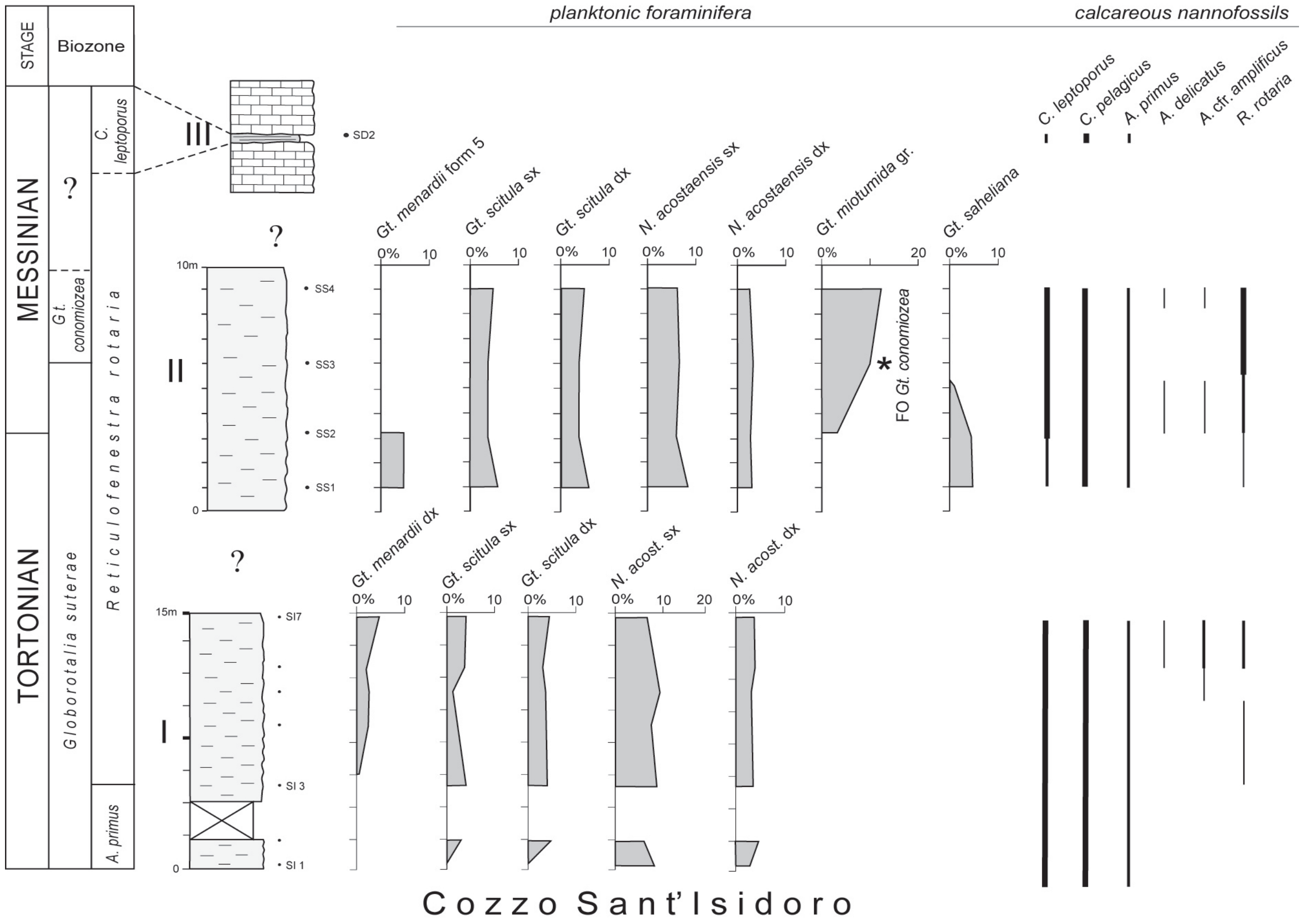
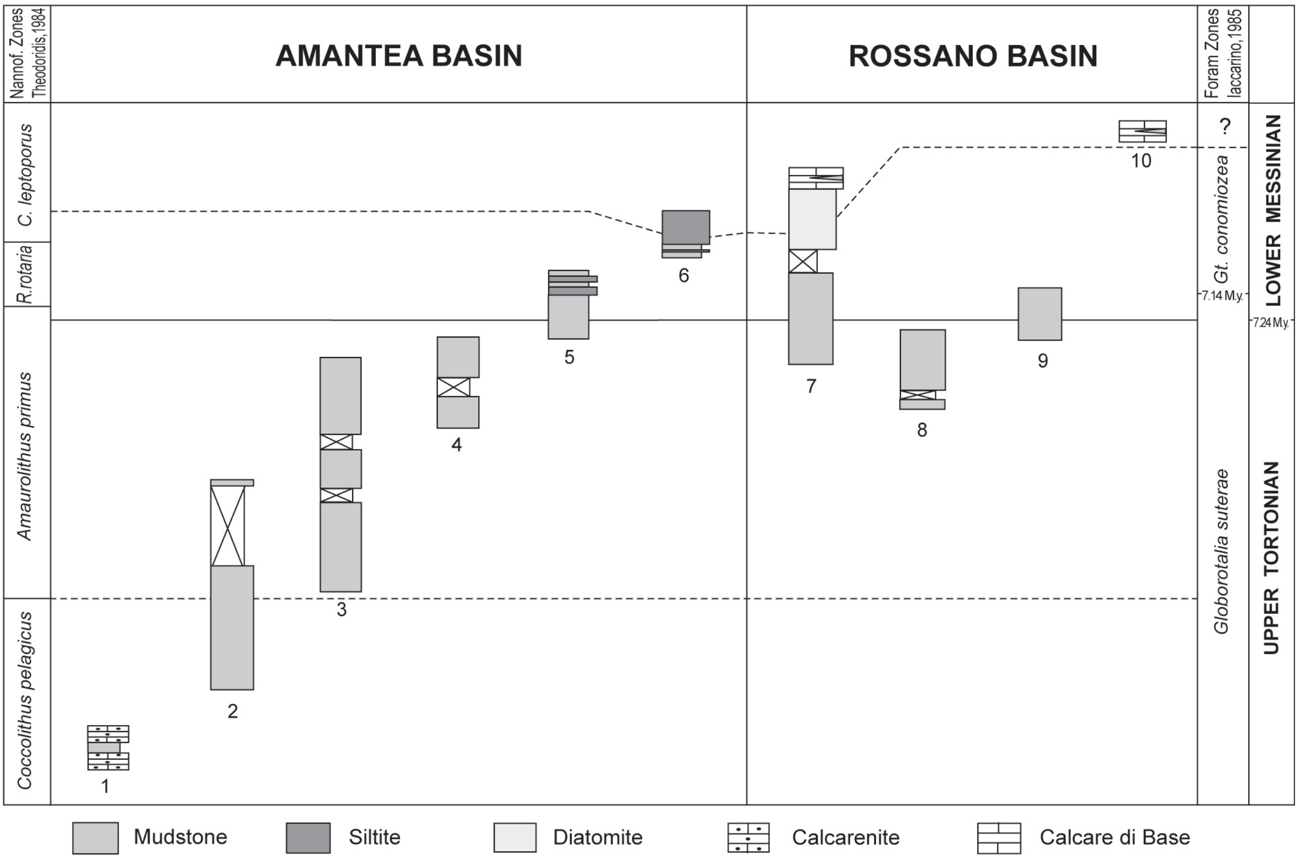


Fig. 10 - Quantitative (planktonic foraminifera) and semiquantitative (calcareous nannofossils) distributions of selected taxa in the Cozzo Sant'Isidoro section. Distribution line thickness of calcareous nannofossils qualitatively reflect the relative abundance of the taxa: rare, common, and very common.

saheliana is more or less continuously present in the Vallone Salina I and II and it occurs only in the first samples of the Case Vespano (Figs. 6-7). Only left coiling specimens of *Gt. menardii* have been found in the Timpone Napoli, while both *Gt. menardii* form 4 and 5 are present in the Vallone Salina III (Fig. 6), where the form 5 (Pl. 2, fig. 3) is predominant. Keeled globorotaliids, belonging to the *Gt. miotumida* (Pl. 3, fig. 2), occur from the base of the Case Vespano section (Fig. 7). Conical morphotypes of *Gt. miotumida* group, referable to *Gt. conomiozea* s.s., appear in the sample CV14 of the Case Vespano. In the Cozzo Salice they also occur in the samples CS1-CS8 (Fig. 8). In the Cozzo Salice section, with the beginning of the silty layers (sample CS5), the foraminifera fauna decreases in abundance and in specimen sizes, and it is missing from the sample CS11 (Fig. 8).

Calcareous nannofossils - Calcareous nannofossils are abundant and generally well preserved in the mudstone beds, while they are poor and strongly recrystallized in the silty layers of the Cozzo Salice section. The assemblage is mainly constituted by *Amaurolithus primus, A. delicatus, A.* cf. *amplificus, Calcidiscus leptoporus, Coccolithus pelagicus* (Pl. 4, fig. 13), *Helicosphaera carteri* (Pl. 4, fig. 15), *H. stalis, Reticulofenestra rotaria, Discoaster brouweri* (Pl. 4, fig. 7), *D. surculus*, *D. variabilis* (Pl. 2, fig. 18), *Sphenolithus abies*. Nannofossil flora is also characterized by the occurrence of "small reticulofenestrids", as already observed by several authors in the late Miocene (Backman, 1978; Flores & Sierro, 1987; Gartner, 1992; Flores et al., 1992; Sierro et al., 1993; Raffi et al., 2003).

The genera *Amaurolithus* and *Reticulofenestra* provide a series of events useful to assemble the biostratigraphic framework of the studied sections. The first occurrence (FO) of *Amaurolithus primus* is recorded in the sample VS19 of the Vallone Salina I (Fig. 6) and this species is common in all studied sections. According to several authors (Negri et al., 1999; Hilgen et al., 2000) the FO of *Amaurolithus primus* predates the Tortonian/Messinian boundary. *R. rotaria*, which appears in the sample VL7, is rare or absent in the overlying samples of the Vallone Salina II and III (Fig. 6). It is continuously present in the Case Vespano and Cozzo Salice (Figs. 7-8) and it disappears in the sample CS13 (Fig. 8). We did not record the FO of *R. rotaria* very close to the FO *A. primus*, like it was observed in the Monte del Casino by Negri et al. (1999) and in the Faneromani by Negri & Villa (2000).



1 = Timpone Napoli section; 2, 3, and 4 = Vallone Salina I, II, and III sections; 5 = Case Vespano section;
6 = Cozzo Salice section; 7 = Vallone Casino section; 8, 9, and 10 = Cozzo Sant' Isidoro I, II, and III sections.

Fig. 11 - Biostratigraphic correlation scheme among the studied sections.

A. delicatus is very rare in the uppermost part of the Vallone Salina III (Fig. 6) and it is discontinuously present in the Case Vespano and Cozzo Salice (Figs. 7-8). *A.* cf. *amplificus,* with specimens of small size (~ 8 µm), occurs only in the Case Vespano and Cozzo Salice (Figs. 7-8). The occurrence of these morphotypes have been previously reported from the Monte del Casino by Negri et al. (1999) and from Faneromeni by Negri & Villa (2000).

Age - The presence of *Gt. suterae* allows to attribute the Vallone Salina and the lower part of the Case Vespano sections to the *Globorotalia suterae* Zone (late Tortonian-early Messinian), and the Timpone Napoli section to the lower part of this biozone (late Tortonian), for the co-occurrence of *Gt. suterae* and *Gt. menardii* form 4. The upper part of the Case Vespano and the lower part of the Cozzo Salice can be ascribed to the *Globorotalia conomiozea* Zone for the presence of the index species (early Messinian).

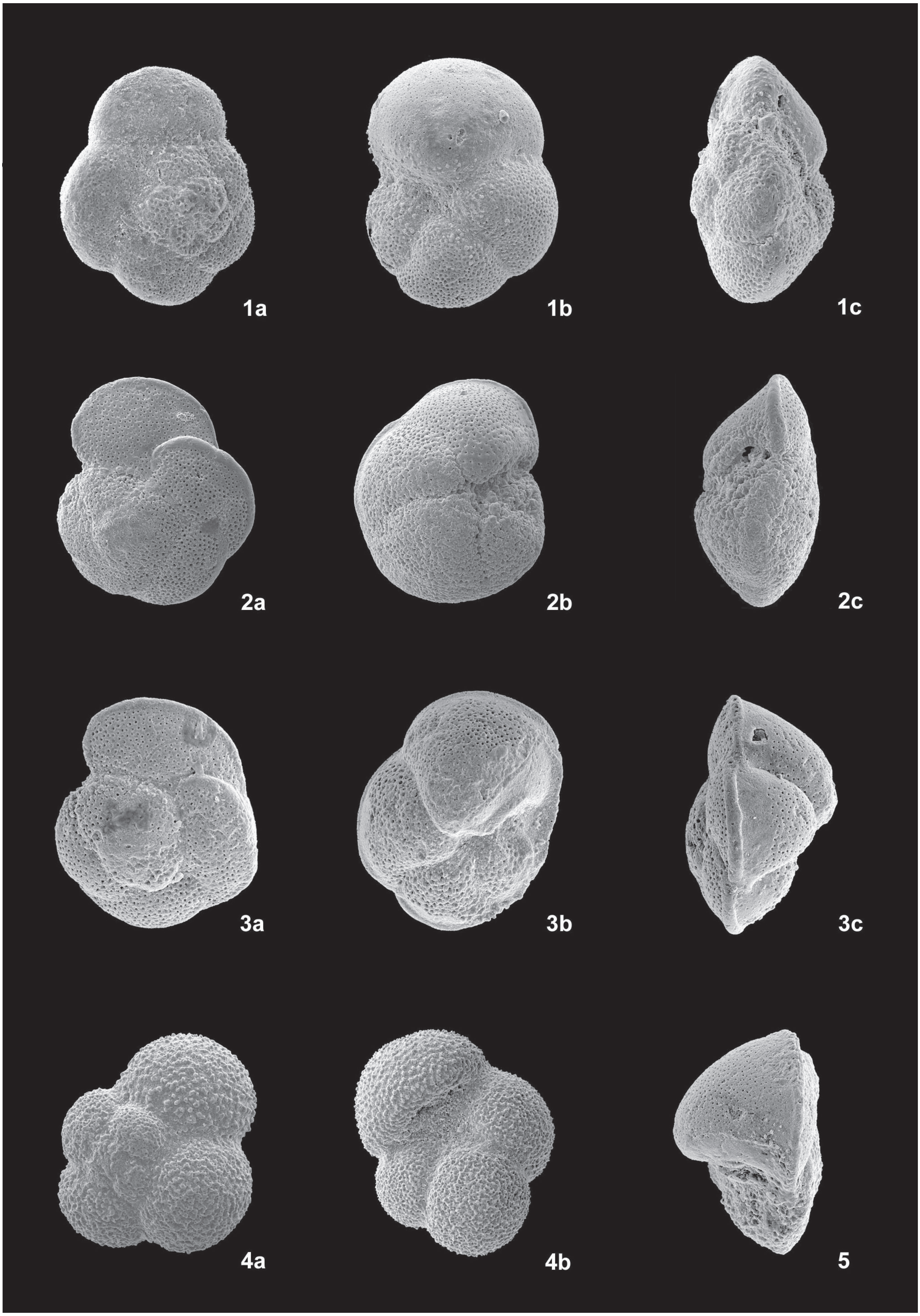
Di Nocera et al. (1974) and Ortolani et al. (1979) found, in the silty layers, some specimens of *Turborotalita multiloba,* attributing these strata to the Messinian (*Gt. conomiozea* Zone - *T. multiloba* Zone). In terms of calcareous nannofossil biostratigraphy the *Coccolithus pelagicus* and *Amaurolithus primus* Zones have been recognized in the the Timpone Napoli and Vallone Salina sections, *Reticulofenestra rotaria* Zone in the Case Vespano and the lower part of the Cozzo Salice sections, and *Calcidiscus leptoporus* Zone in upper part of the Cozzo Salice.

Rossano Basin

Planktonic foraminifera - The mudstones yielded a rich fauna of planktonic foraminifers while the

EXPLANATION OF PLATE 3

fig. 1 - *Globorotalia scitula* dx Brady. a - spiral, b - umbilical and c - lateral view.. Vallone Casino section, sample CR1, x 120.
fig. 2 - *Globorotalia miotumida* Jenkins. a - spiral, b - umbilical and c - lateral view. Case Vespano section, sample CV4, x 120.
figs. 3, 5 - *Globorotalia conomiozea* Kennett. 3a - spiral, b - umbilical and c - lateral view. Cozzo Sant'Isidoro section, sample SS3, x 120; 5 lateral view. Case Vespano section, sample CV30, x 120.
fig. 4 - *Globigerina bulloides* D'Orbigny. a - spiral and b - umbilical views. Vallone Casino section, sample CR2, x 120.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tripolaceous layers are barren. The sediments are characterized by the same planktonic foraminifer assemblage as that observed in the Amantea Basin.

In the lower part of the Vallone Casino section *Gt. menardii* form 4 and form 5 are present (Fig. 9). Only right coiling specimens of *Gt. menardii* occurs in the Cozzo Sant'Isidoro I and II (Fig. 10). *N. acostaensis* and *Gt. scitula* are represented by right and left coiling specimens (Pl. 3, fig. 1), the latter are more abundant. *Gt. miotumida* group appears in the sample CR2 of the Vallone Casino and SS2 of the Cozzo Sant'Isidoro II (Figs. 9-10). The occurrence of the *Gt. miotumida* group marks the turnover in the keeled globorotaliids from assemblages dominated by dextrally coiled *Gt. menardii* to those dominated by sinistrally coiled *Gt. miotumida,* corresponding to the *Gt. menardii*/*Gt. miotumida* replacement. According to Hilgen et al. (2000) this event slightly predates or coincides with the FO of conical morphotypes (*Gt. conomiozea*) (Pl. 3, fig. 3). The *Gt. miotumida* group shows an increase in abundance in the sample SS3 and CR6, due to the FO *Gt. conomiozea* (Figs. 9-10).

Calcareous nannofossils - The calcareous nannofossil assemblage is rich, diversified and well preserved in the mudstone beds, on the contrary in the marls (CR10 and CR11) it is badly preserved.

The nannoflora is mainly composed by the following assemblage: *Amaurolithus delicatus, A. primus* (Pl. 4, fig. 1), *A.* cf. *amplificus, Calcidiscus leptoporus, C. macintyrei*, *Coccolithus pelagicus*, *Discoaster brouweri* (Pl. 4, fig. 17), *D. pentaradiatus* (Pl. 4, fig. 4), *D. variabilis* (Pl. 4, figs. 5-6), *Helicosphaera carteri* (Pl. 4, fig. 10), *H. pacifica*, *Reticulofenestra rotaria* (Pl. 4, fig. 9), *Sphenolithus abies* (Pl. 4, fig. 12).

A. primus is common in all sections, *R. rotaria* occurs rarely in sample CR4 and becomes relatively abundant in the sample CR6 of the Vallone Casino (Fig. 9). It is present continuously from the sample SI3 and becomes very common in the sample SS3 of the Cozzo Sant'Isidoro section (Fig. 10). *A. delicatus* is scantily present in the Vallone Casino and Cozzo Sant'Isidoro (Figs. 9-10). The tripolaceous samples are characterized by an abrupt decrease in species diversity and few specimens are determinable. Samples CR10-CR19 contain only a few specimens of sphenoliths, helicoliths, reticulofenestrids and some fragments of discoasterids. The diatomitic layers, barren in calcareous nannofossils, are rich in diatom fragments, plant remains and fishes. A well preserved and diversified nannofossils assemblage, characterized by the absence of *R. rotaria*, occurs in the marls within the Calcare di Base (CR23 and SD2; Figs. 9-10).

Age - Both Vallone Casino and Cozzo Sant'Isidoro sections are late Tortonian-early Messinian in age. The Tortonian /Messinian boundary is located in the sample CR2 and SS2 (Figs. 9-10), about 10 m below the Tripoli formation, corresponding to the occurrence of *Gt. miotumida* group (*sensu* Hilgen et al., 2000). Our data are in good agreement with those of D'Onofrio et al. (1975) that recorded the Tortonian/Messinian boundary in the upper part of the clayey beds.

CONCLUSIONS

Quantitative biostratigraphic analyses on planktonic foraminifers integrated with semiquantitative data on calcareous nannofossils allowed to update the chronostratigraphic framework of the Tortonian-Messinian deposits of Northern Calabria.

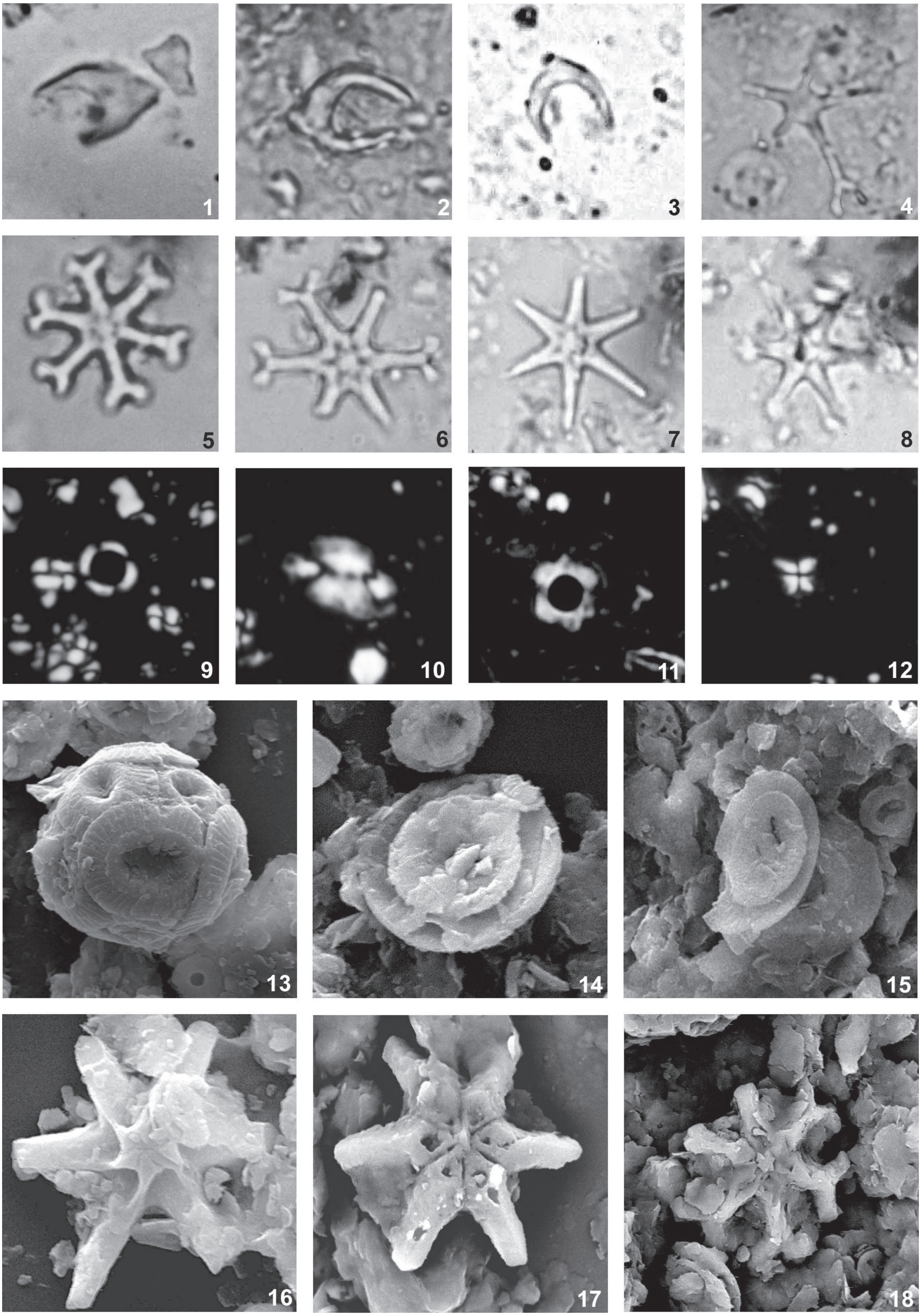
In particular the Timpone Napoli and Vallone Salina sections are Upper Tortonian in age being referable to the *Globorotalia suterae* Zone. In terms of calcareous nannofossils biozones these sections can be ascribed to the *Coccolithus pelagicus* and *Amaurolithus primus* Zones.

The Case Vespano and Cozzo Salice sections are Messinian in age as testified by the presence, from the base, of the *Gt. miotumida* group. They can be referred to the *Globorotalia suterae* and *Globorotalia*

EXPLANATION OF PLATE 4

fig. 1 - *Amarolithus primus* (Bukry & Percival). Cozzo Sant'Isidoro section, sample SI6.
figs. 2-3 - *Amarolithus delicatus* (Bukry & Percival). Cozzo Sant'Isidoro section, sample SS4.
fig. 4 - *Discoaster pentaradiatus* (Tan Sin Hok). Cozzo Sant'Isidoro section, sample SS2.
figs. 5-6 - *Discoaster variabilis* Martini & Bramlette. Cozzo Sant'Isidoro section, sample SS3.
fig. 7 - *Discoaster brouweri* Tan Sin Hok. Case Vespano section, sample CV38.
fig. 8 - *Discoaster surculus* Martini & Bramlette. Cozzo Salice section, sample CS16.
fig. 9 - *Reticulofenestra rotaria* Theodoridis. Cozzo Sant'Isidoro section, sample SS1.
fig. 10 - *Helicosphaera carteri* (Wallich). Cozzo Sant'Isidoro section, sample SI1.
fig. 11 - *Geminilithella rotula* Theodoridis. Cozzo Salice section, sample CS16.
fig. 12 - *Sphenolithus abies* Deflandre. Cozzo Sant'Isidoro section, sample SS3.
fig. 13 - Coccosphaera of *Coccolithus pelagicus* Case Vespano section, sample CV1, x 2500.
fig. 14 - *Calcidiscus leptoporus* (Murray & Blackman). Cozzo Salice section, sample CS2, x 6000.
fig. 15 - *Helicosphaera carteri* (Wallich). Case Vespano section, sample CV22, x 4000.
fig. 16 - *Discoaster* sp. Cozzo Salice section, sample CS2, x 5000.
fig. 17 - *Discoaster brouweri* Tan Sin Hok. Cozzo Sant'Isidoro section, sample SI1, x 4000.
fig. 18 - *Discoaster variabilis* Martini & Bramlette. Case Vespano section, sample CV1, x 3000.

figs. 1-12 optical microscope pictures, x 1000; figs. 13-18 SEM photos.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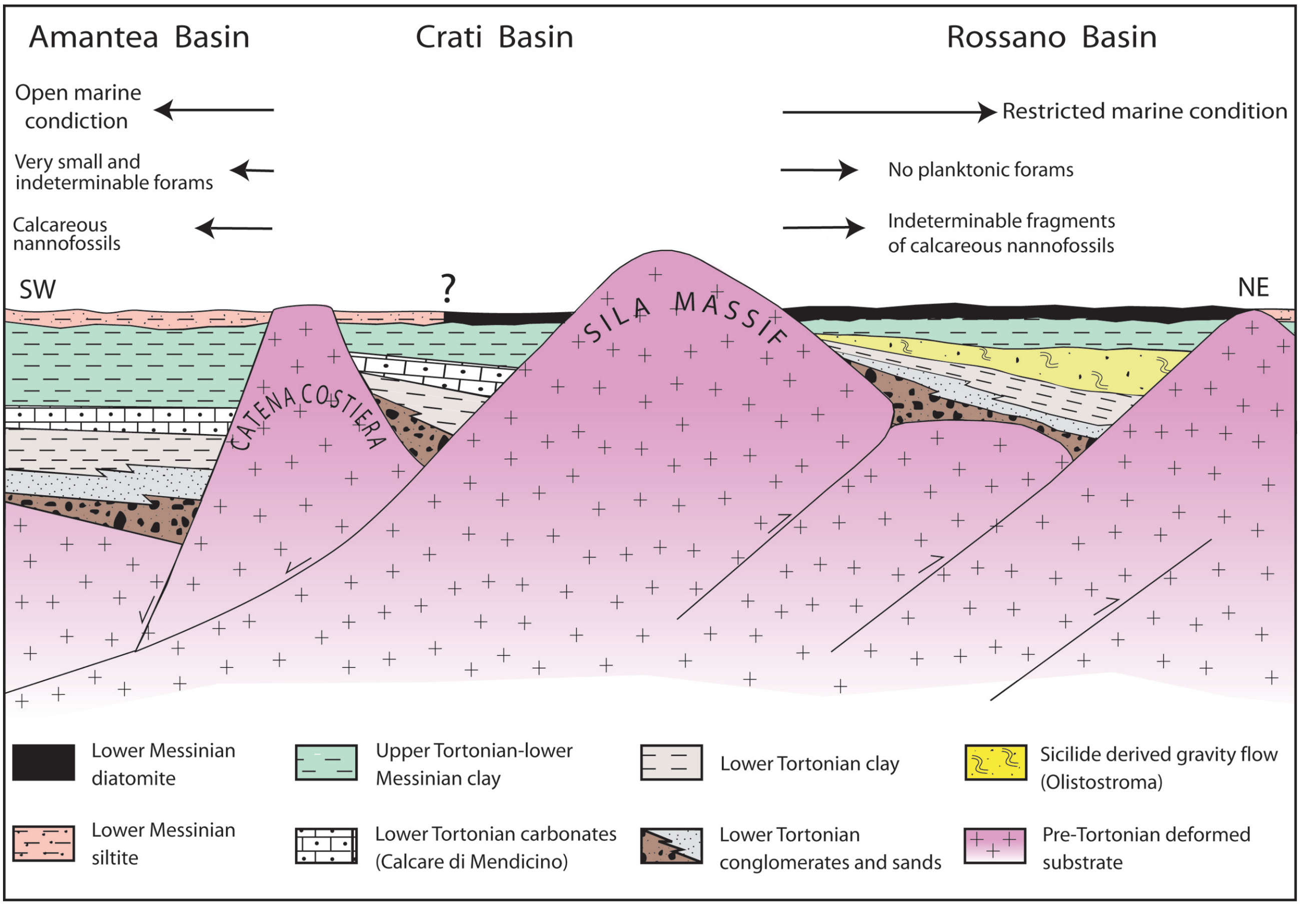

Fig. 12 - Simplified paleogeographic profile across Northern Calabrian Arc during the early Messinian time according to the regional tectonic framework and palaeontological data.

conomiozea Zones, that correspond to the *Reticulofenestra rotaria* and *Calcidiscus leptoporus* Zones.

The sequence of these biohorizons is coherent with recent schemes of calcareous plankton quantitative biostratigraphy on the Tortonian-Messinian deposits of the Mediterranean marine record (Hilgen et al., 2000; Negri & Villa, 1999, 2000; Sprovieri et al., 1996; Raffi et al., 2003).

The Tortonian-Messinian boundary has been identified in the Rossano Basin: in particular, in the Vallone Casino section, about 10 m below the Tripoli formation and, in the Cozzo Sant'Isidoro section, in the mudstone sample SS2.

The sampled sections represent the sedimentary transition from clay to silty/diatomitic deposits which reflect the environmental evolution of the Mediterranean at the onset of the salinity crisis.

During the early Messinian time, the sedimentary evolution of the Amantea Basin, in which we did not observe diatomitic beds as reported by Ortolani et al. (1979), shows the onset of silty layers characterized by a dwarf and indeterminable planktonic foraminifera fauna. These beds should record a stressed but still marine depositional environment. In the Rossano Basin, the same time interval, record the sedimentation of diatomitic layers, barren in foraminifera, suggesting a more restricted sedimentary environment characterized by general meso/euthrophic conditions. The comparison between the Amantea Basin silty layers and the coeval diatomitic beds of the Rossano Basin suggests that these two areas, during the Early Messinian, followed a different paleogeographic and palaeoecological evolution (Fig. 12).

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