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Evolution of the Miocene Carbonate Shelf of Monferrato (North-western Italy)

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KEY-WORDS - Carbonate shelf, Foramol, Rhodalgal, Foraminifera, Miocene, NW Italy.

ABSTRACT - A multidisciplinary study including sequence stratigraphy, biostratigraphy, paleoecology and paleoclimatology was performed on Lower Miocene carbonate sedimentary rocks, the "Pietra da Cantoni Group" within which two depositional sequences bound by discontinuity surfaces were recognized.

Sequence 1 consists of bioturbated inner-middle shelf packstones and wackestones (lower Burdigalian), resting unconformably on the silty slope facies sediments of the Marne di Antognola Fm. In this sequence the benthic foraminiferal assemblages, dominated by epifaunal and epiphytic taxa, indicate a well-oxygenated substratum within the photic zone. Climatic indices, among the planktonic foraminifera, suggest cool-temperate climate conditions. These sediments likely record the Burdigalian transgression at the beginning of the TB2 supercycle, as defined by Haq et al. (1987).

Sequence 2 includes two superimposed units. The lower unit (upper Burdigalian) consists of rhodalgal rudstones and packstones of shelf environment with a mobile substrate and well-oxygenated water, rich in benthic foraminifera and Corallinaceae, deposited in warm-temperate conditions. A drowning unconformity surface bounds this unit from the second and reflects a relative sea-level rise that could be correlated with the maximum flooding surface within the cycle TB2.2.

The upper unit (upper Burdigalian-lower Langhian) consists of foraminifera and glaucony-rich packstones ranging from inner shelf environment, characterized by epiphytic foraminifera and Miogypsinids, to outer shelf environment suggested by the increase of planktonic, of benthic deep-water taxa and rhodoliths, deposited in warm-temperate conditions.

This succession grades upward to upper Langhian-lower Serravallian planktonic foraminifer-rich marls of the Mincengo Fm. .

Deposition of the carbonate sediments of the Sequence 2 is linked to the combined effect of: (1) tectonic reorganization of the basin; (2) sea level oscillations; (3) upwelling of nutrient-rich waters; (4) increase of trophic resources connected to increasing erosion of uplifted alpine relieves, favoring the development of "temperate-type" rhodalgal-foramol facies, similar to the coeval carbonate deposits reported in many places of the Mediterranean area.

RIASSUNTO - [Evoluzione della Piattaforma Carbonatica miocenica del Monferrato (Italia nord-occidentale)] - *Una ben nota successione di rocce sedimentarie carbonatiche del Miocene inferiore ampiamente affiorante nel Monferrato orientale (Italia nord-occidentale), il "Gruppo della Pietra da Cantoni", è stato studiato con un approccio multidisciplinare che comprende la stratigrafia sequenziale, la biostratigrafia, la paleoecologia e la paleoclimatologia. All'interno del "Gruppo della Pietra da Cantoni", che comprende la facies classica citata in letteratura, sono state riconosciute due sequenze deposizionali, limitate da superfici di discontinuità. Vengono illustrate le due sezioni più complete (Colma e Rosignano Monferrato, Alessandria), in cui sono rappresentate tutte le litofacies caratteristiche, oltre alle unità litostratigrafiche sottostante (Formazione delle Marne di Antognola) e soprastante (Formazione delle Marne di Mincengo).*

La Sequenza 1 è stata riconosciuta unicamente nella sezione di Rosignano Monferrato ed è costituita da packstones *e* wackestones *bioturbate di piattaforma interna del Burdigaliano inferiore che poggiano talora in discordanza sui sedimenti siltosi della Formazione delle Marne di Antognola, deposti in ambiente di scarpata. Le associazioni a foraminiferi bentonici, dominate da taxa epifaunali ed epifitici, indicano un ambiente deposizionale ben ossigenato compreso nella zona fotica. I dati paleoclimatici sono basati su indici appartenenti ai foraminiferi planctonici ed evidenziano un clima temperato-fresco. È verosimile che questi sedimenti registrino la trasgressione burdigaliana all'inizio del superciclo TB2 definito da Haq et al. (1987).*

La Sequenza 2 è costituita da 2 unità sovrapposte. L'unità inferiore, del Burdigaliano superiore, è rappresentata da rudstones *e* packstones *deposti in ambiente di piattaforma su un substrato mobile e con acque ben ossigenate in cui prosperavano foraminiferi epifiti ed alghe corallinacee, in condizioni climatiche temperato-calde. Questa unità è separate dalla successiva da una superficie di "annegamento" paraconcordante (*drowning unconformity*) che testimonia un sollevamento relativo del livello marino e che può essere correlata con la superficie di massima trasgressione all'interno del ciclo TB2.2.*

L'unità superiore della Sequenza 2 (Burdigaliano superiore-Langhiano inferiore) è costituita da packstones *a foraminiferi e glauconite corrispondenti ad un ambiente deposizionale esteso tra la piattaforma interna, come indicano i foraminiferi epifiti e i macroforaminiferi, e la piattaforma esterna, come suggerisce l'incremento dei foraminiferi planctonici, di taxa bentonici indicatori di profondità maggiore e le rodoliti, deposte in condizioni climatiche temperato-calde.*

La successione passa alla Formazione delle Marne di Mincengo ricche di foraminiferi planctonici, riferite al Langhiano superiore-Serravalliano inferiore.

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*La biostratigrafia è basata sullo studio integrato di nannofossili calcarei, foraminiferi planctonici e macroforaminiferi (*Miogypsina *e* Lepidocyclina*). Le indicazioni paleoecologiche e paleoclimatiche si riferiscono soprattutto rispettivamente ai foraminiferi bentonici e ai foraminiferi planctonici.*

Sulla base dei dati di terreno, delle analisi micropaleontologiche e dello studio delle microbiofacies è stata interpretata la genesi e l'evoluzione della successione carbonatica, contribuendo così a completare il quadro dell'evoluzione tettonica dell'area. La deposizione dei sedimenti carbonatici del "Gruppo della Pietra da Cantoni" è messa in relazione all'effetto concomitante di vari fattori che hanno favorito lo sviluppo di facies di foramol-rhodalgal *di tipo temperato, simili ai depositi carbonatici coevi descritti in numerose successioni stratigrafiche dell'area mediterranea.*

Tra i fattori che hanno contribuito alla deposizione e all' evoluzione di questi sedimenti carbonatici alcuni sono stati attivi solo a scala locale, altri a scala globale: (1) eventi tettonici del bacino; (2) oscillazioni del livello marino legate all'eustatismo; (3) instaurazione di correnti di upwelling *ricche di nutrienti; (4) aumento delle risorse trofiche connesse con l'incremento dell'erosione dei rilievi alpini in via di sollevamento.*

INTRODUCTION

Interest in temperate shelf carbonates has significantly increased during the last decade (e.g. Nelson, 1988; James & Clarke, 1997). Many works have focused attention on the Mediterranean region, which is a key area for the study of this type of carbonate facies developed during the Tertiary and controlled by climatic changes, relative sea-level fluctuations, tectonics and evolution of fauna and flora. Lower Miocene carbonate deposits are largely spread around the Mediterranean and have been described from North Africa, Malta, Sicily, Sardinia, Central and Southern Apennines (Simone & Carannante, 1988; Carannante et al., 1988; Raymo, 1994; Carannante & Simone, 1996; Esteban, 1996; Pedley, 1996; Mutti et al., 1997; Cherchi et al., 2000; Murru et al., 2002). A few studies are published (Amorosi, 1997) or in progress on the Northern Apennines. In particular, temperate carbonate shelves of Early Miocene age are known from NW Italy; they crop out in the southern sector of the Tertiary Piedmont basin (Visone Fm., Franceschetti, 1967; d'Atri 1990a) and in the Monferrato domain, the focus of this study, where they are known as the Pietra da Cantoni (PdC).

Since the last century, the PdC has been the object of detailed paleontological studies (e.g. Sacco, 1890; Parona, 1916; Socin, 1954; Bonsignore et al., 1969). More recent works have been devoted to the paleogeographic interpretation of the PdC sediments (Schüttenhelm, 1976) and to their sequential organization (Falletti, 1994).

Further studies still in progress indicate an extremely heterogeneous succession of lithofacies with abundant lateral variations, more evident than in original description (Dela Pierre et al., 1998). The whole succession of lithofacies has therefore been informally defined as the "Pietra da Cantoni Group" (Polino et al., 1995), characterized by a highly complex depositional setting (Clari et al., 1995b) including some hiatuses, even of wide extension. The easternmost part of the Eastern Monferrato is characterized by carbonate sediments of the "PdC Gr." deposited on a structural high. Two sections in particular show good outcrops of this carbonate lithofacies: Rosignano and Colma (Fig. 1). These sections have already been described in recent papers, such as Bicchi (1998) and Bicchi et al. (1997, 1999, 2003), and the rhodolithic levels of Colma have been studied by Vannucci et al. (1996). In the present work the "PdC Gr." has been carefully reexamined with a multidisciplinary approach integrating from one hand biostratigraphy, paleoecology and paleoclimatology and from the other sedimentology and sequence stratigraphy.

The main purposes of this research are:

1. to correlate the various lithotypes of the carbonate succession, to establish the time interval involved, and to identify possible hiatuses by means of integrated biostratigraphy (calcareous nannofossils, planktonic and larger foraminifera);
2. to integrate the litho- and biostratigraphy with sequence stratigraphy analysis;
3. to evaluate paleoclimatic evolution using as climatic indices planktonic foraminifera and temperature-related benthic organisms.

The results of our integrated approach provide new data for the interpretation of the paleoenvironmental evolution of the Early Miocene carbonates of the Eastern Monferrato and allow to compare them with similar settings known in other areas of the Mediterranean.

GEOLOGICAL FRAMEWORK

The Monferrato is a part of the Tertiary Piedmont Basin and characterized by a mainly terrigenous Eocene-Miocene succession unconformably resting on Upper Cretaceous and Eocene Ligurian Flysch deposits (Clari et al., 1995b). The kilometer-wide Rio Freddo transpressional deformation zone (R.F.D.Z.) separates this area from the adjoining Torino Hill domain (Piana & Polino, 1995).

Some authors in recent stratigraphic and structural works on Monferrato (Clari et al., 1995a; Piana, 2000; Dela Pierre et al., 2003) distinguished two tectonostratigraphic units (Fig. 1):

1. Western Monferrato consisting of Oligocene to Miocene terrigenous sediments deposited both in strongly subsiding marine basins and on structural highs;
2. Eastern Monferrato consisting of Oligocene to Aquitanian deep water terrigenous sediments unconformably overlain by Early to Middle Miocene shelf carbonate sediments of the "Pietra da Cantoni Group". The basal unconformity of these deposits

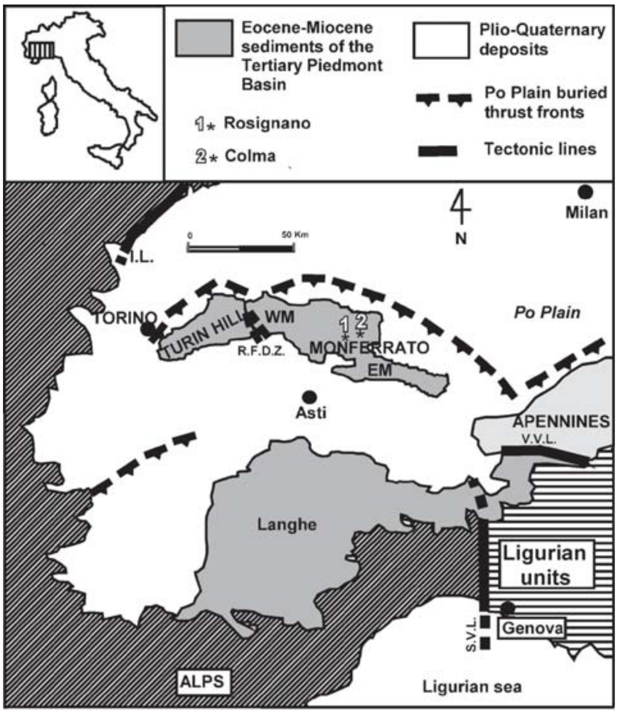

Fig. 1 - Structural sketch map of northwestern Italy.
I.L. - Insubric Line; S.V.L. - Sestri-Voltaggio Line; V.V.L. - Villalvernia-Varzi Line; WM - Western Monferrato; EM - Eastern Monferrato; R.F.D.Z. - Rio Freddo Deformation Zone; AM - Alto Monferrato; BG - Borbera Grue; (*) Location of the sections. (From Bigi et al., 1990, Structural model of Italy, modified).

reflects the Burdigalian tectonic phase that affected the whole Apenninic belt (e.g. Boccaletti et al., 1990; Falletti et al., 1995).

In Eastern Monferrato, the "PdC Gr." generally consists of rhodolith-rich packstones, rudstones and floatstones and of planktonic foraminifera and glaucony-rich packstones. Vertical and lateral relationships among the different lithofacies clearly depict a westward deepening of the depositional environment and a general deepening upward trend as indicated by more distal calcareous and siliceous marl deposits.

Both in the Eastern and Western Monferrato, the succession ends with Langhian to Serravallian deposits of the Marne di Mincengo Fm. (Clari et al., 1995b), followed by Tortonian slope sediments of the Marne di S.Agata Fossili Fm. and finally by Messinian chaotic complex including evaporites (Dela Pierre et al., 2003).

MATERIALS AND METHODS

Field observations on the lithologic and sedimentologic features of the depositional facies were carried on and numerous samples, collected from lithified and loose lithofacies, were analyzed. Detailed microfacies and paleontological analyses were carried out on 60 samples collected in the finer fraction of the various lithofacies. Thin section analysis was performed for numerous samples from lithified facies for describing the textures and biotic content.

Biostratigraphic data are based on nannofossils, planktonic and larger foraminifera assemblages of disaggregated samples. For calcareous nannofossil analyses, smear slides were mounted. No centrifugation was applied to concentrate the biogenic fraction in order to retain the original composition of the nannofossil assemblage. Semi-quantitative analyses were performed with a light microscope at 1250x magnification and counting at least 300 specimens per sample (Rio et al., 1990). Additional counts of at least 100 specimens were made for the genera *Helicosphaera* and *Discoaster*.

For the study of smaller foraminifera, 300 g of each sample were disaggregated with oxygen peroxide (120 vol.); fractions washed through 125 and 63 µm sieves were examined. When possible 150 specimens were counted both for benthic and planktonic foraminifera in the fraction coarser than 125 µm for quantitative analysis.

For paleoclimatic purposes, the planktonic foraminifera were subdivided into warm and warm-temperate, cool and cool-temperate taxa, according to Spezzaferri (1995), Novaretti & Bicchi (1996), Bicchi et al. (2000, 2003). Their relative abundance is represented in percentage curves.

Quantitative analyses on benthic foraminifera were performed for paleoenvironmental reconstructions (cfr. Murray, 1991; Sgarrella & Moncharmont, 1993; Violanti et al., 1999; Russo et al., 2002). The following parameters were considered: Fisher index (á, according to Murray, 1973), infaunal/epifaunal ratio (I/E); frequency curves of the most significant taxa and also planktonic foraminifera percentage (P%). Furthermore a Q-mode Cluster analysis, implemented using City-block (Manhattan) as the similarity coefficient and complete linkage as the clustering technique, was performed on benthic assemblages.

Larger foraminifera were separated from the coarser fraction (> 0.5 mm). The analysis focused on Miogypsinids and Lepidocyclinids. Each specimen was sectioned and studied in equatorial plane. Biometry of parameters pertinent to the embryo and to the nepionic protoconchal spirals was performed in order to define the taxonomy of each population, according to Drooger (1954, 1956), Matteucci & Schiavinotto (1977), Wildenborg (1991), Maia (1997). The determination, according to Maia (1996), was based on the comparison of the parameters of each population with the corresponding values for taxonomic units recorded in literature using Student's "t" test, on the analysis of variance and discriminant analyses.

RESULTS

Depositional sequences and microfacies analyses

The "PdC Gr." is subdivided into two sequences, defined as depositional units bounded by discontinuity surfaces, according to Clari et al. (1995a). The considered sedimentary succession consists of the uppermost part of the Marne di Antognola Fm., grey terrigenous marls, the overlying sediments of "PdC Gr." and the basal part of the following Marne di Mincengo Fm.. The Marne di Antognola Fm.- "PdC Gr." boundary is not visible both at Rosignano (Fig. 2) and Colma (Fig. 3) sections, but the distinct facies change between the fine-grained siliciclastic sediments and the overlying carbonatic sediments suggests an important discontinuity surface. The conctact with the sediments of the Marne di Mincengo Fm., exposed in the Colma section, is also covered.

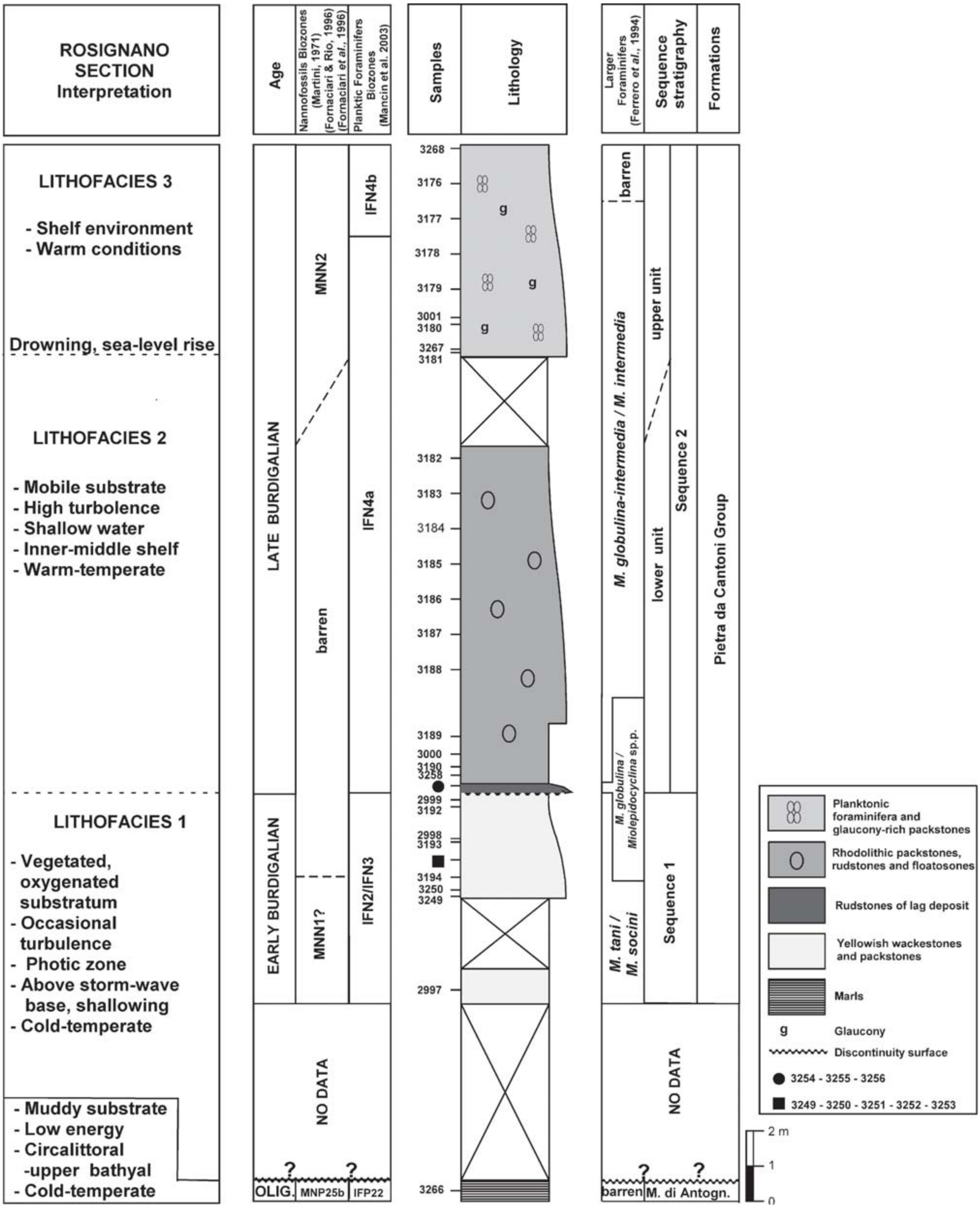

Fig. 2 - Schematic lithostratigraphic column of Rosignano section. Chronostratigraphic assessment based on planktonic and larger foraminifera.

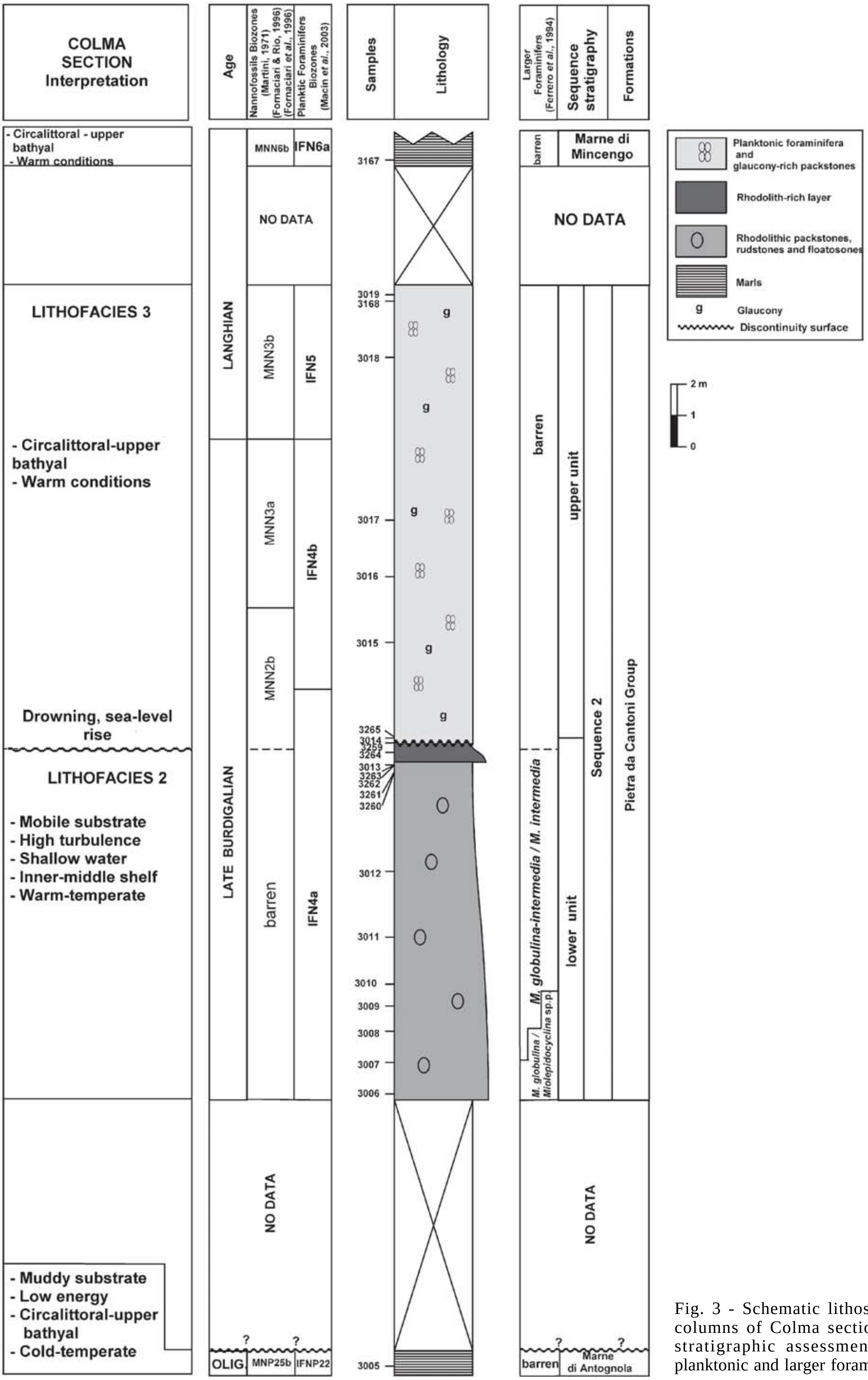

Fig. 3 - Schematic lithostratigraphic columns of Colma section. Chronostratigraphic assessment based on planktonic and larger foraminifera.

The two studied sections show the following sedimentary succession: in the Rosignano section (Fig. 2), about 28 m thick, a small outcrop of the upper part of the Marne di Antognola Fm. is followed, after 5 meters not exposed, by the "PdC Gr.", where three main lithofacies have been recognized: (1) burrowed, yellowish packstones and wackestones (Sequence 1); (2) whitish rhodolithic packstones, rudstones and floatstones and (3) planktonic foraminifera and glaucony-rich packstones (Sequence 2) (Bicchi et al., 1997, 1999; Bicchi, 1998). In the Colma section (Fig. 3), about 42 m thick, the "PdC Gr." consists only of the two lithofacies (2 and 3) of Sequence 2: the lithofacies 1 is not present and the rhodolithic sediments (lithofacies 2) pass upward to the planktonic foraminifera and glaucony-rich packstones (lithofacies 3) through a packed phosphatized layer. The whitish marls belonging to the Marne di Mincengo Fm. overlie the "PdC Gr." in this section.

Sequence 1 - This sequence is present only at Rosignano (Fig. 4A, Figs. 5A-C). It consists of at least 6 m of the yellowish wackestones and packstones with scattered rhodoliths (lithofacies 1). Large firm-ground burrows belonging to the ichnogenus *Thalassinoides* can be recognized. Fossil content (Figs. 6A-B) consists of larger foraminifera (*Miogypsina*, *Operculina*), Corallinaceae and bryozoans fragments, echinoid plates and spines, scattered planktonic foraminifera. A terrigenous fraction, consisting of quartz grains, fragments of metamorphic rocks and white mica flakes is also present, together with glauconitic and phosphatic grains. Thick lenticular bodies, observed in the uppermost part of this sequence, are considered as storm layers. They consist of mollusk-bearing rudstones with scattered rounded extrabasinal clasts of millimetric size (mainly serpentinites), grading to yellowish packstones with low angle cross stratification interpreted as hummocky cross stratification. The fossil content of samples 3251, 3252, 3253 (Fig. 6C) consists of abundant coralline algae, bryozoans and echinoid fragments, larger foraminifera (*Miogypsina*, *Operculina*), unidentified bivalve fragments and rare planktonic and benthic foraminifera.

The boundary between this sequence and Sequence 2 (lithofacies 2 and 3) is well exposed and consists of a flat, complex, polygenic discontinuity surface (ds) *sensu* Clari et al. (1995a). Under this surface a 30 cm thick cemented horizon, with the same paleontologic content as the underlying sediments (wackestones and packstones), is locally visible (Fig. 5A), sometimes cut by centimetric-wide neptunian dykes (Fig. 7) filled with whitish bioclastic sediments. The discontinuity surface is also underlined by a slight angular unconformity and cuts the topmost burrows and conjugate sets of fractures affecting the underlying sediments (Fig. 5B).

In the Colma section (Fig. 4B) the Sequence 1 is lacking; an angular unconformity between the Marne di Antognola Fm. and carbonates of Sequence 2 was observed in the past under more favorable conditions of exposure and actually is inferred on the basis of regional evidence (Ferrero, unpublished data). In this section the Marne di Antognola Fm. is Oligocene in age (see chapters Biostratigraphy and Interpretation of the data). The discontinuity and angular unconformity between "PdC Gr." and Marne di Antognola of Aquitanian age is also well documented in adjacent areas, such as the Terruggia section (Falletti, 1994; Bicchi et al., 2003), where the Sequence 1 is totally lacking.

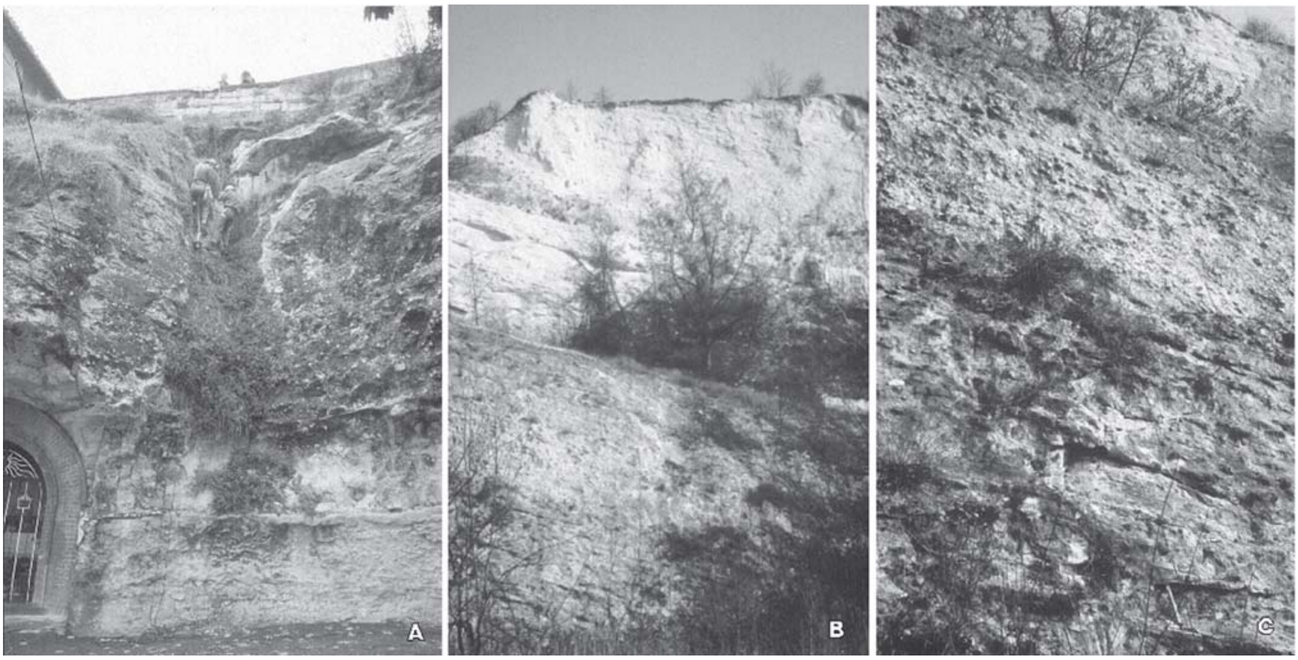

Fig. 4 - Outcrops of the studied sections and lithological details. A. Outcrop of the lower part of the Rosignano section; B. Outcrop of Colma section; C. Colma, lower unit, whitish bioclastic packstones and rudstones with large-scale stratification.

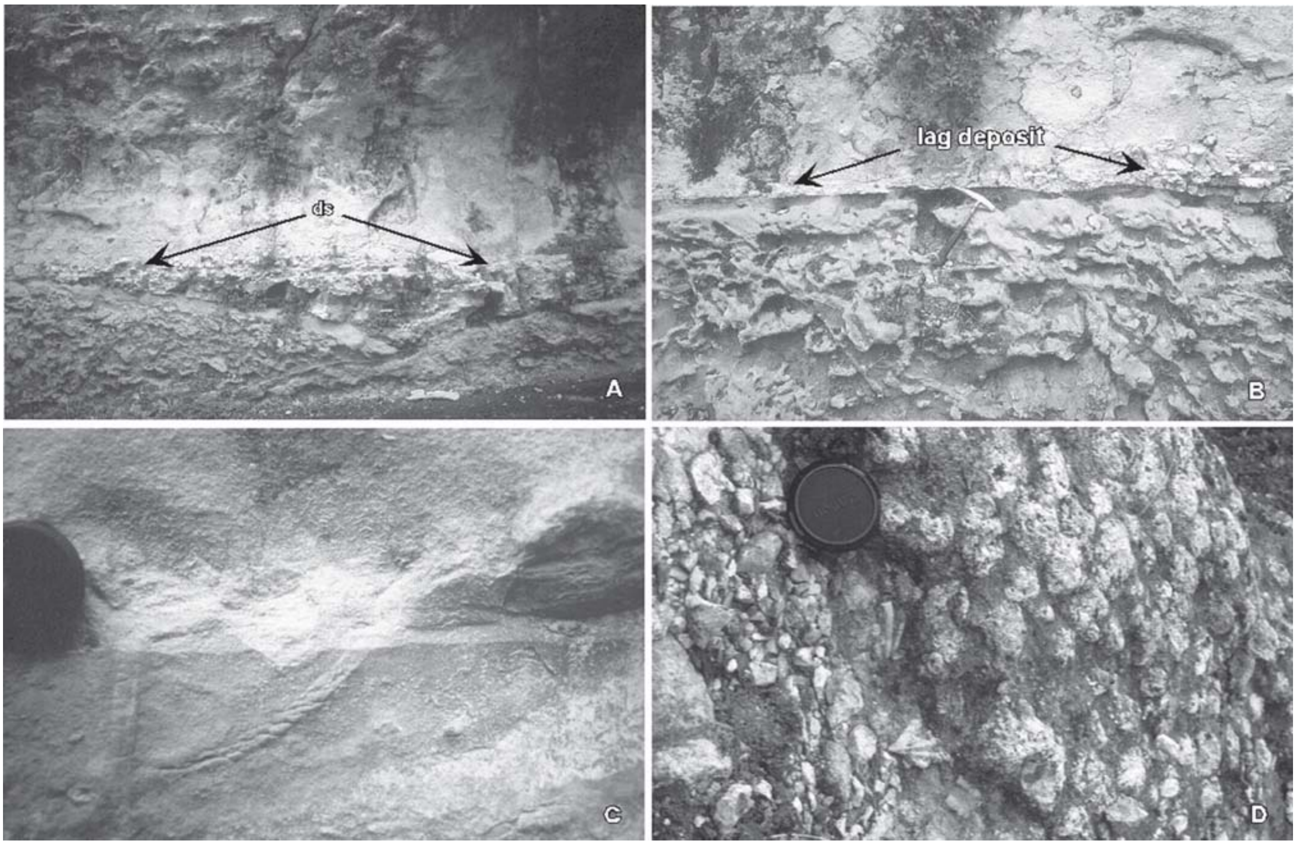

Fig. 5 - Lithological details of the studied sections. A. Rosignano, poligenic discontinuity surface (ds) between Sequence 1 and Sequence 2; B. Rosignano, Sequence 1, bioturbation structures sharply cut by the discontinuity surface; C. Rosignano, Sequence 1, yellowish packstones and wackestones with burrows and lag deposit at the base of Sequence 2. D. Colma, rhodolith-rich layer between lower and upper units.

Sequence 2 - Sequence 2 is thicker than Sequence 1 (at least 16-17 m at Rosignano, more than 25 m at Colma) and is subdivided into two units.

The lower unit is exposed for 12-16 meters and consists of whitish bioclastic packstones, rudstones and floatstones (Fig. 4C), locally showing large-scale cross stratifications and containing abundant Corallinaceae, larger foraminifera (*Miogypsina*, *Nephrolepidina*, *Operculina*), echinoid spines, fragments of bivalves, bryozoa, balanids and rare planktonic foraminifera (lithofacies 2), (Fig. 6D). The Corallinaceae form large rhodoliths that are scattered in the lower part and packed in the upper one. The inorganic fraction is subordinate and consists of quartz grains and mica flakes.

The base of the lower unit in the Rosignano section locally shows a lag deposit formed by rudstones with packed abraded and disarticulated bivalve tests (among which *Flabellipecten burdigalensis*), scattered large rhodoliths and rounded to angular clasts of older sediments (mainly Ligurian Flysch), as observed in sample 3263 (Fig. 5C). Large burrows filled by the overlying glaucony-rich packstones affect the lag deposit as well as the underlying sediments (samples 3260, 3261) of the Sequence 1. The matrix of this level (samples 3259, 3264) is sand-sized bioclastic debris of bivalves, larger foraminifera and bryozoa, with planktonic foraminifera. Glaucony and phosphates are present as single grains or as partial filling of the planktonic foraminifera and of the conceptacles of Corallinaceae (Fig. 6E).

The upper unit consists of completely bioturbated, glaucony-rich packstones (lithofacies 3). At Rosignano the transition between the lower and the upper unit is not exposed, neither the topmost part of the upper unit is present. At Colma a 10-30 cm thick rhodolith-rich layer separates the lower from the upper unit (Fig. 5D). Sediments of the upper unit contain also coralline algae, echinoid fragments, larger and planktonic foraminifera, these last increasing upwards in percentage (samples 3267, 3268). At Colma, the skeletal grains are only planktonic foraminifera, whose tests are frequently filled by glaucony (Fig. 6F). No clear sedimentary structure was observed in these sediments, with the exception of badly preserved parallel laminae in the Colma section.

The boundary with the overlying whitish Marne di Mincengo Fm. is poorly exposed only at Colma.

BIOSTRATIGRAPHY

The standard zonation scheme of Martini (1971) is adopted for calcareous nannofossils (CN) of the

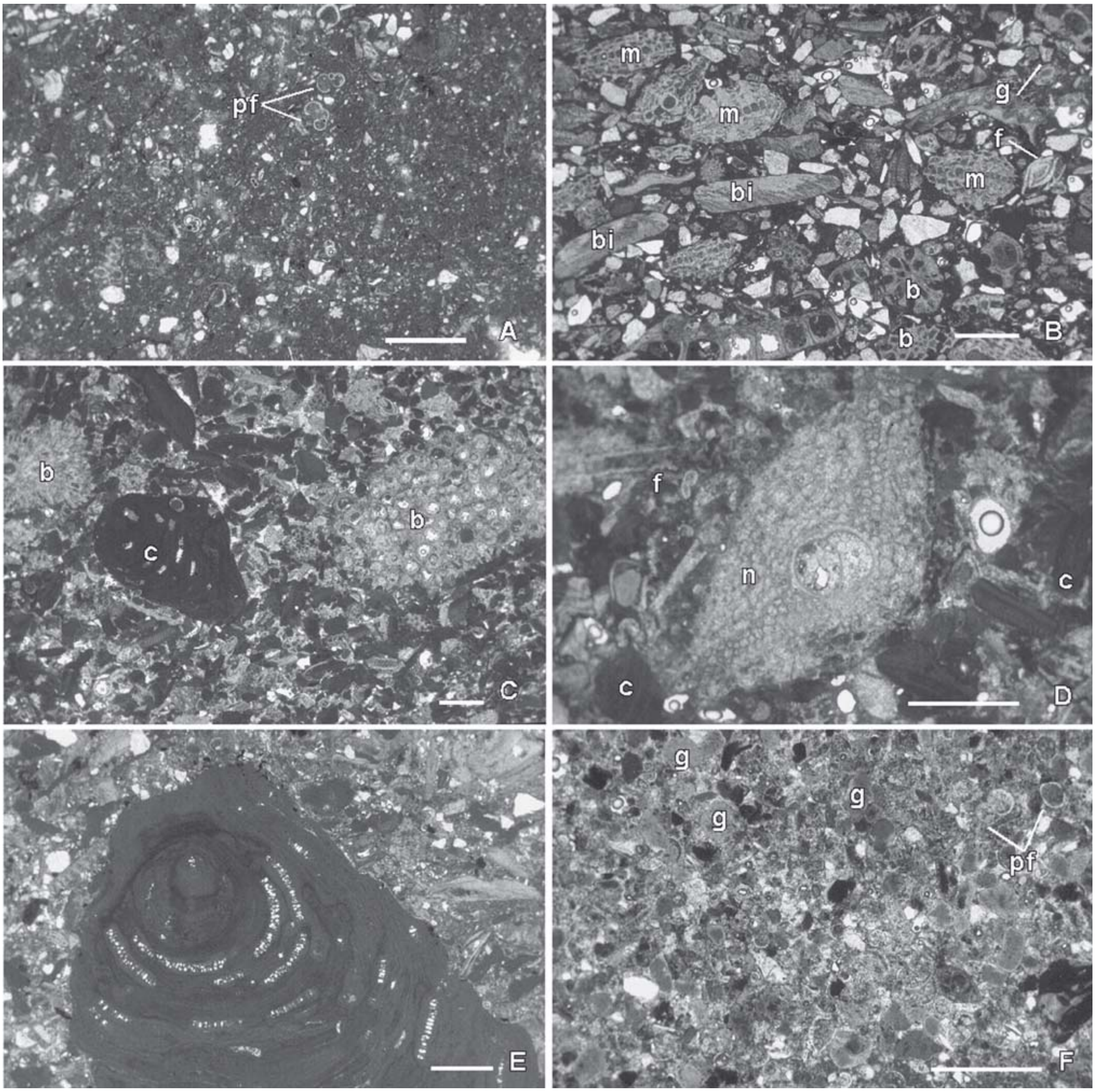

Fig. 6 - Microfacies of the sediments of the Pietra da Cantoni Group. Scale bar = 1 mm. A. Rosignano, Sequence 1, sample 3250: wackestone with scattered planktonic foraminifera (pf). An abundant terrigenous fraction is also recognizable; B. Rosignano, Sequence 1, sample 3249: bioclastic packstone with (m) larger foraminifera (*Miogypsina socini*), bivalves (bi), bryozoa (b) and scattered coralline algae (c). Some glaucony (g) grains are also recognizable; C. Rosignano, Sequence 1, sample 3253: bioclastic rudstone with abundant coralline algae (c), bryozoa fragments (b) and scattered benthic foraminifera; D. Rosignano, Sequence 2, lower unit, sample 3258: bioclastic rudstone with oblique section of *Nephrolepidina tournoueri* (n), coralline algae (c) and scattered smaller foraminifera (f); E. Colma, Sequence 2, rhodolith-rich layer at the top of the lower unit, sample 3259: bioclastic rudstone including a large algal nodule (*Sporolithon* sp.); F .Colma, Sequence 2, upper unit, sample 3265: planktonic foraminifera (pf) and glaucony (g) rich packstone. Rare quartz grains are visible.

Oligocene; the scheme proposed for Mediterranean area by Fornaciari & Rio (1996); Fornaciari et al. (1996, 1997) is adopted for the Miocene. (Fig. 8; Tabs. 1-2).

For planktonic foraminifera (PF), the zonal scheme of Mancin et al. (2003) has been used. It considers and partially modifies the regional schemes, proposed over the years for the Mediterranean area (Cati et al., 1968; Molina, 1979; Iaccarino & Salvatorini, 1982; Iaccarino, 1985; Iaccarino et al., 2001; Sprovieri et al., 2002). These are in fact scarcely applicable as a consequence of the marked bioprovinciality of the Monferrato area (Bicchi et al., 1994; Novaretti et al., 1995; Bicchi, 1998; Mancin et al., 2003).

For larger foraminifera the scheme of Maia (1997), based on the assemblages of the Torino Hill and Monferrato area (Ferrero et al., 1994), was adopted.

Fig. 7 - Centimetric-wide neptunian dyke of cutting the top of Sequence 1, filled with whitish sediments of Sequence 2, Rosignano. Similar structures were observed in thin section of sample 3254.

Four biozones were distinguished in this scheme:

1. *Miogypsina gunteri/M. gunteri-tani* Zone (late Aquitanian-early Burdigalian), defined by the FO of *M. gunteri* at the base and by the LO of *M. gunteri-tani* at the top.
2. *M. tani/M. socini* Zone (early Burdigalian-basal late Burdigalian), defined by the FO of *M. tani* or *M. socini* at the base and by the FO of at least one of the index species of the next biozone (*M. globulina, Miolepidocyclina burdigalensis* and /or *Ml. negrii*) at the top.
3. *M. globulina/Miolepidocyclina* spp. Zone (late Burdigalian p.p.), defined by the FO of at least one of the following species: *M. globulina, Ml. burdigalensis* or *Ml. negrii*; the top is represented by the FO of *M. globulina-intermedia.*
4. *M. globulina-intermedia/M. intermedia* Zone (late Burdigalian p.p.), defined by the FO of *M. globulina-intermedia* at the base and by the LO of *M. intermedia* at the top.

The integrated biostratigraphy (Fig. 8) compares calcareous nannofossils, planktonic foraminifera and larger foraminifera.

Biostratigraphic data based on planktonic foraminifera and larger foraminifera are often more reliable than calcareous nannofossil data because in the studied sections there are some intervals with assemblages barren or devoid of significant taxa of CN. Moreover biostratigraphic indications of PF and larger foraminifera are consistent both between themselves and with data from other stratigraphic successions, i.e NW Italy and Northern Apennines, (Bicchi et al., 1994; Novaretti et al., 1995; Bicchi, 1998; Mancin et al., 2003). For this reason the age of the successions, comprised in the time interval from latest Oligocene to Middle Miocene (Figs. 2-3; Tabs. 3-4), is in this study assigned on the basis of PF and larger foraminifera indications.

Significant data are provided for the Marne di Antognola Fm. by PF assemblage (Zone IFP22) and by CN assemblage (Subzone NP25b), both indicative of Late Oligocene.

CN assemblages of samples from Sequence 1 of "PdC Gr." are not significant, but could tentatively be referred to the Zone MNN1; the PF assemblages are clearly referable to the Zone IFN2/IFN3; larger foraminifera indicate the *Miogypsina tani/M. socini* Zone. These records are indicative of an early Burdigalian age (Fig. 8).

The sediments of the lower unit of Sequence 2, barren of CN, contain PF assemblages indicating the Subzone IFN4a. The larger foraminiferal populations identify the *Miogypsina globulina/Miolepidocyclina* spp. and *M. globulina-intermedia/M. intermedia* Zones. These data indicate a late Burdigalian age (Fig. 8).

In samples from the upper unit of Sequence 2 the CN assemblages at Colma indicate the Subzones MNN2b, MNN3a and MNN3b (Fig. 3). At Rosignano, the poor preservation of nannofossils prevents a further specification within the Zone MNN2, indicating a lower-middle part of Burdigalian. In both the Rosignano and Colma sections (Figs. 2-3) the PF assemblages point to Subzones IFN4a and IFN4b; the Zone IFN5 has been detected only at the top of the upper unit of Colma. Larger foraminifera, present at Rosignano up to sample 3177, indicate the *Miogypsina globulina-intermedia/ M. intermedia* Zone, whereas at Colma they are absent. On the basis of the foraminiferal assemblages, in contrast with the nannofossil assemblages indicating a lower-middle part of Burdigalian, the upper unit is referred to late Burdigalian-early Langhian.

At the base of the Marne di Mincengo Fm. (Fig. 3), the PF assemblage indicates the Subzone IFN6a, referable to the Late Langhian, while the CN assemblage indicates the biozone MNN6b, corresponding to a Serravallian age. (Fig. 8).

Biozones	Samples	Preservation	Abundance	*Dictyococcites bisectus*	*Ciclycargolithus abisectus*	*Helicosphaera perch-nielseniae*	*Helicosphaera recta*	*Zygrablithus bijugatus*	*Helicosphaera euphratis*	*Sphenolithus moriformis*	*Coccolithus pelagicus*	*Ciclycargolithus floridanus*	*Coronocyclus nitescens*	*Discoaster deflandrei*	*Reticulofenestra daviesi*	*Helicosphaera carteri*	*Reticulofenestra spp.*	Reworked (Cretaceous-Paleogene)
MNN2a	3176	VP	R								R					RR	F	
	3178	VP	R								R					RR	F	
	3179	VP	R								R					RR	R	
	3180	VP	R								RR	RR				RR		
barren	3182		B															
	3183		B															
	3184		B															
	3185		B															
	3186		B															
	3187		B															
	3188		B															
	3189		B															
	3190		SB															R
?	2999	VP	R	RR							RR	RR						RR
	3192	VP	R	RR							RR	RR						RR
MNN1	3194	M	R						R			RR				RR		RR
	2997	G	C	R					F			F		RR				A
MNP25b	3266	G	A	C	R	C	C	F	C	C	R		C	R	R			

Tab. 1 - Range chart of calcareous nannofossils of Rosignano section. VP - very poor; M - medium; G - good; B - barren; SB - semibarren; RR - very rare; R - rare; F - frequent; C - common; A - abundant.

Biozones	Samples	Preservation	Abundance	*Dictyococcites bisectus*	*Ciclycargolithus abisectus*	*Helicosphaera perch-nielseniae*	*Helicosphaera recta*	*Zygrablithus bijugatus*	*Helicosphaera euphratis*	*Sphenolithus moriformis*	*Coccolithus pelagicus*	*Ciclycargolithus floridanus*	*Coronocyclus nitescens*	*Discoaster deflandrei*	*Reticulofenestra daviesi*	*Sphenolithus* aff. *heteromorphus*	*Sphenolithus disbelemnos*	*Sphenolithus dissimilis*	*Helicosphaera ampliaperta*	*Helicosphaera mediterranea*	*Sphenolithus belemnos*	*Geminilithella rotula*	*Helicosphaera carteri*	*Helicosphaera walberdorfensis*	*Reticulofenestra* sp.p.	*Pontosphaera* sp.p.	*Discoaster exilis*	*Discoaster variabilis*	*Coccolithus miopelagicus*	*Calcidiscus leptoporus*	*Calcidiscus premacintyrei*	*Reticulofenestra pseudoumbilicus*	Reworked (Cretaceous-Paleogene)
MNN6b	3167	M	A							R	C											F	C	A	C	RR	RR	R	F	R	R	C	R
MNN3b	3019	M	A							R	A		C		F				A			RR	C	C	R			R	RR	RR			R
	3018	M	A							R	C	C	C	R	F		RR		C			RR	C		R				R	R			R
MNN3a	3017	M	A							R	R	F	C	R	R	F			C		A				A								R
	3016	G	A							RR	R	F	C	R		R			C	C	R	R	C	R	A								R
MNN2b	3015	M	A							C	R	F	C	RR			RR	F	C						C								R
	3014	M	R						RR	R	R	F			RR								F	RR									R
barren	3012		B																														
	3011		B																														
	3010		B																														
	3009		B																														
	3008		B																														
	3007		B																														
	3006		B																														
MNP25b	3005	M	C	F	F	F	F	R	C	R	F	R		R																			C

Tab. 2 - Range chart of calcareous nannofossils of Colma section. Abbreviations as in Tab. 1.

Comparing the nannofossil and the foraminiferal data some discrepancies arise. In the upper unit, in fact, the boundary between the Subzones IFN4a and IFN4b of planktonic foraminifera falls within an interval where the CN assemblages indicate the Zone MNN2 and more precisely, in the Colma section, the Subzone MNN2b (Figs. 2-3).

The poor preservation, the discontinuous and scarce occurrence of CN assemblages (Tab. 1), due to unfavorable depositional conditions, may explain that the upper unit age, based on CN assemblages, seems older than the age based on planktonic foraminifers (Fig. 8).

A more crucial discrepancy between the nannofossils and the foraminifera data is observed in the Marne di Mincengo Fm. On the basis of the PF assemblage the basal part of the formation, outcropping in the Colma section, has been referred to the Subzone IFN6a p. p., corresponding to a Langhian age. The CN assemblage on the contrary, on the basis of the presence of large (10-12 µm) *Reticulofenestra pseudoumbilicus*, concomitant with the noteworthy absence of *Sphenolithus heteromorphus,* indicates the subzone MNN6b (defined at the base by the LO of *Sphenolithus heteromorphus),* corresponding to a Serravallian age (cfr. Berggren et al., 1995; Rio et al., 1997). *Orbulina universa* FO, indicating the upper limit of IFN6a Subzone, occurs 5 meters over the last sample (3167, see Fig. 3) of Colma section analysed in the present work (Bicchi et al., 1999; 2003). It is here remarked a stratigraphic inversion of the two bioevents, *O. universa* FO and *S. heteromorphus* LO, generally recorded at base of Serravallian stratotype. This fact has already been noted in the Gargano and Tremiti Miocene sediments (Casolari et al., 2000 as well as Negri, unpublished data) and in the Middle Miocene turbiditic succession of the Umbria-Marche (Luchetti et al., 2002).

The Authors point out that the CN assemblages data, contradictory in respect to the foraminiferal assemblages data, can be a useful starting point in order to stimulate further researches and a revision of the integrated biostratigraphic correlation.

PALAEOECOLOGY

Smaller Foraminifera - In the Marne di Antognola, the smaller foraminifera assemblage is composed by

IFP22	IFN2/IFN3					IFN4a													IFN4b		Biozones
3266	2997	3194	3193	3192	2999	3190	3189	3188	3187	3186	3185	3184	3183	3182	3181	3180	3179	3178	3177	3176	**Samples**
		C	F			F	F		R		C	RR	R							RR	*Globigerina* cf. *bulloides*
			RR	RR	RR	C	RR	R				C								RR	*Globigerina ciperoensis*
RR		RR	RR													RR					*Globigerina euapertura*
															RR						*Globigerina nepenthes*
				R							RR		F								*Globigerina anguliofficinalis*
	R																				*Globigerina ouachitensis*
	R			F	C											RR					*Globigerina* aff. *praebulloides*
C	CC		CC	CC	C	CC	C	CC	CC	RR	C	C	F	RR	C	C	C	C	CC	CC	*Globigerina praebulloides*
R																					*Globigerina rorhi*
R																					*Globigerina tripartita*
RR	R	R	R	F	F	RR					R										*Globigerina venezuelana*
RR																					*Globigerinita* gr.
									R												*Globigerinita incrusta*
	R	F	R								RR	C	RR		R	F	F	R	R	RR	*Zeaglobigerina woodi brazieri*
													R								*Zeaglobigerina woodi connecta*
	C	CC	C	RR		R	RR	R	R		CC	CC	CC		CC	CC	CC	CC	CC	CC	*Zeaglobigerina woodi woodi*
																	RR				*Globigernoides altiaperturus*
																			R	RR	*Globigerinoides bisphericus*
	RR					RR	R														*Globigerinoides immaturus*
									RR												*Globigerinoides parawoodi*
	RR	RR	RR	RR	RR		F		RR								RR	RR			*Globigerinoides primordius*
	R			RR	RR	R	C	C	C		RR	R	R				RR	R	RR	RR	*Globigerinoides quadrilobatus*
							R														*Globigerinoides* sp.
					RR													R	R		*Globigerinoides subquadratus*
	RR			R	R	R	CC	C	C		F	F	F		F	RR	F	R	R		*Globigerinoides trilobus*
	RR	RR																RR			*Dentoglobigerina altispira altispira*
							RR	R			RR	F	C						RR		*Dentoglobigerina altispira globosa*
			RR	RR	R	R		R	R		RR	RR	R			RR			RR		*Dentoglobigerina baroemoenensis*
		RR																			*Dentoglobigerina* aff. *langhiana*
																		RR			*Dentoglobigerina langhiana*
RR	R	R	RR	R	RR	RR		R	RR												*Dentoglobigerina larmeui*
C																					*Globoquadrina binaiensis*
RR	R		RR	F		RR			RR								R				*Globoquadrina dehiscens praedehiscens*
	RR				RR												RR				*Globoquadrina dehiscens dehiscens*
RR		RR	RR	RR	RR							R									*Globorotaloides* sp.
RR	R	R	F	R	RR	R		R													*Catapsydrax unicavus*
C	R		RR	RR	RR																*Catapsydrax dissimilis*
RR	F	RR	R	R	RR	R	RR	R	RR	RR		RR	RR	RR				RR	RR	R	*Globigerinella obesa*
RR			RR		RR						RR		F		CC	C	C	CC	CC		*Paragloborotalia acrostoma*
RR		R																			*Paragloborotalia opima opima*
			R		R																*Paragloborotalia opima/continuosa*
	F	F		R	R				RR			RR									*Paragloborotalia pseudocontinuosa*
RR																					*Paragloborotalia pseudokugleri*
	R					RR	R		RR		F		R		R				RR	RR	*Paragloborotalia continuosa*
RR			RR			RR										RR	RR	RR			*Paragloborotalia mayeri*
RR																	RR				*Paragloborotalia siakensis*
					RR																*Globorotalia birnageae*
		RR									RR									RR	*Sphaeroidinellopsis* sp.
		RR	RR	R		RR	RR	R	R		C	F	F	R	RR		RR		RR	RR	*Tenuitellinata angustiumbilicata*

Tab. 3 - Range chart of planktonic foraminifera. Rosignano section. RR - very rare; R - rare; F - frequent; C - common; CC - very common.

over 70% planktonics. The benthic assemblage is characterized by a high value of Fisher index (FI = 16) at Rosignano, by a value of 7 at Colma and it includes about 42.9% of infaunal foraminifera (I/E = 0.75) at Rosignano and 36% (I/E = 0.56) at Colma (Figs. 9A-B; Tab. 5). The most common forms are *Uvigerina* spp., *Gyroidinoides* spp., *Heterolepa floridana*, *Brizalina* spp. and *Stilostomella* spp. (Figs. 10-11). The state of preservation of the tests is generally good.

The Sequence 1 of the "PdC Gr." (Tab. 5) shows a relatively high abundance of planktonic foraminifera (average value 43.2%); the benthic assemblage has a high value of FI (14.4) and an average I/E ratio = 0.76 (43% of infaunal forms). All these values show a

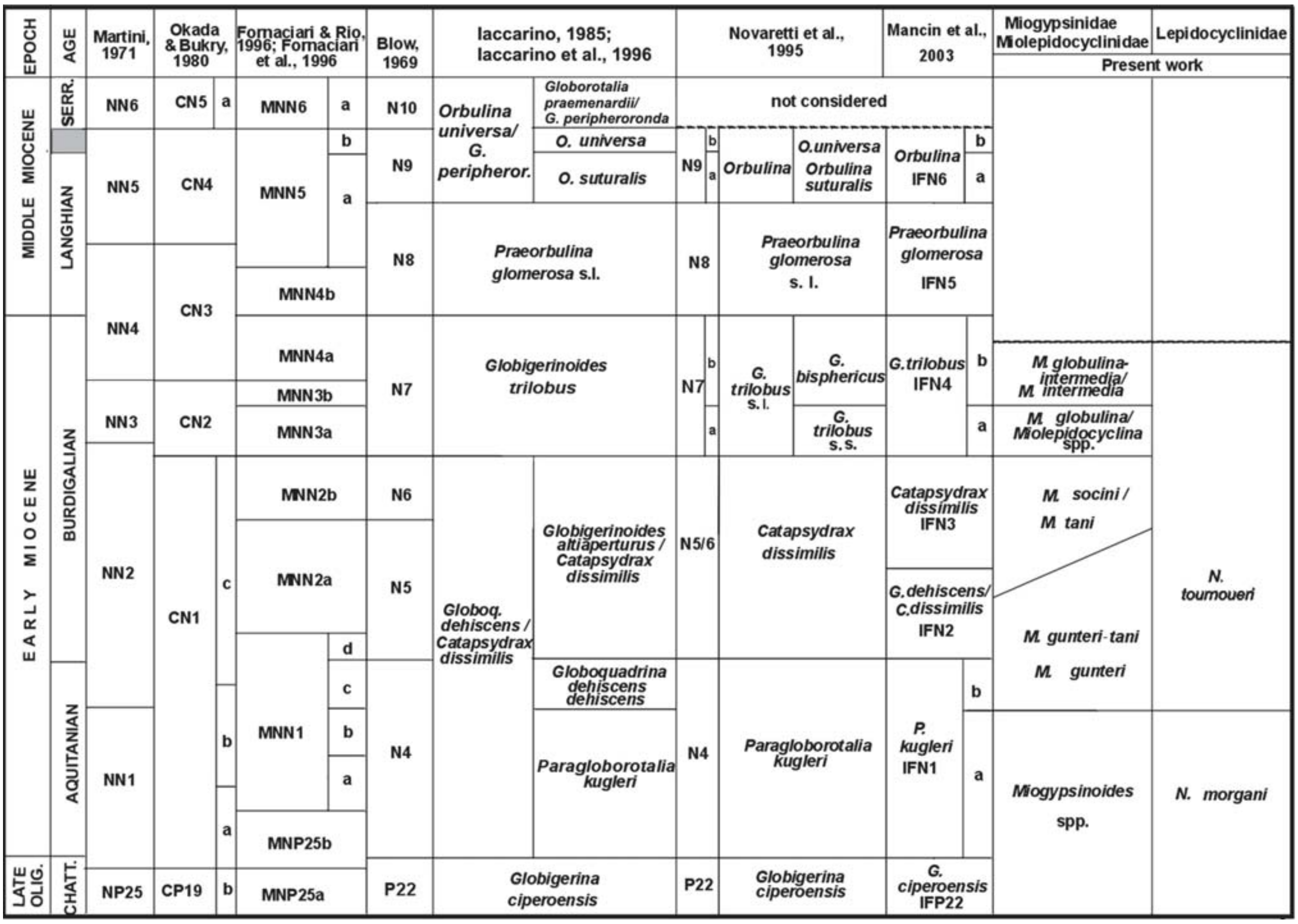

Fig. 8 - Uppermost Oligocene-middle Miocene biostratigraphic zonal scheme proposed for the Monferrato Area comparing standard zonations for nannofossils of Martini (1971), Okada & Bukry (1980), Fornaciari & Rio (1996), Fornaciari et al. (1996) with zonations for planktonic foraminifera of Blow (1969), Iaccarino (1985), Iaccarino et al. (1996), Novaretti et al. (1995), Mancin et al. (2003) and present work zonation for larger foraminifera.

decreasing trend (Fig. 9A). Frequent and significant species (Fig. 10) include *Asterigerinata planorbis*, *Lenticulina calcar* and the epiphytic *Lobatula lobatula*, whereas *Hanzawaia boueana* and *Heterolepa floridana* are less frequent. Among the others, sparse specimens of *Uvigerina* spp., *Melonis* spp., *Bolivina antiqua*, *B. miocenica*, *Brizalina arta*, *Elphidium crispum* and agglutinated foraminifera (*Martinottiella communis*) were recorded. The specimens as a rule are rather badly preserved.

In the lower unit of Sequence 2 (Tab. 5), at Rosignano the abundance of planktonic foraminifera clearly decrease (average 15%), compared with to the underlying sequence; at Colma the values are always low: 4.4% on average. The state of preservation of the tests is bad, both for planktonic and benthic forms. The benthic assemblages are characterized by a medium-low FI (around 7 at Rosignano and 6 at Colma) and are dominated by epifaunal taxa, ranging around 71% at Rosignano (I/E = 0.4) and 90% at Colma (I/E = 0.1).

The most common taxa at Rosignano section are the *Cibicidoides* group, *Asterigerinata planorbis* and abundant epiphytic forms such as *Lobatula lobatula*, *Rosalina bradyi* and *Elphidium crispum*; *Bolivina miocenica* is quite common, followed by *Hanzawaia boueana* and *Brizalina arta*. The most common taxa at Colma are the *Cibicidoides* group, *Elphidium crispum*, *Amphistegina lessonii* and *Asterigerinata planorbis*; moreover *Heterolepa mexicana*, *H. praecincta*, *Siphonina reticulata*, *Neoconorbina orbicularis*, *Eponides* spp., and *Stomatorbina torrei* are relatively frequent. Few species of agglutinated foraminifera occur, with very rare specimens.

In the upper unit of Sequence 2 (Tab. 5), planktonic foraminifera, whose state of preservation is generally good, become dominant at Colma section (85%) and increase to 24% at Rosignano. A high value of FI (14 at Rosignano and 16 at Colma) characterizses the benthic assemblages, within which the infaunal forms are respectively 52.4% and 46% (I/E = 1.1 and 0.85). Between the hyaline forms *Heterolepa (H. mexicana, H. floridana* and *H. praecincta*), *Elphidium crispum*, *Lenticulina calcar*, *Melonis (M. soldanii* and *M. pompilioides*) considerably increase at Rosignano section in comparison with the underlying unit (Fig. 10). Taxa such as *Heterolepa*, *Lenticulina* and *Melonis* also increase remarkably at Colma (Fig. 11), while *Asterigerinata* and *Elphidium* disappear completely. Both at Rosignano and Colma, *Siphonina reticulata*, *Sphaeroidina bulloides*, *Stilostomella* spp., *Uvigerina* (*U. barbatula*, *U. rutila* and *U. galloway*) appear. A few agglutinated forms are still present.

IFP22	IFN4a									IFN4b			IFN5			IFN6a	**Biozones**
3005	3006	3007	3008	3009	3010	3011	3012	3013	3014	3015	3016	3017	3018	3168	3019	3167	**Samples**
									R	R		RR	R			RR	*Globigerina* cf. *bulloides*
RR									RR		RR	R	RR	RR		R	*Globigerina ciperoensis*
		R	F	C	R	RR											*Globigerina ciperoensis* aff. *ottnangiensis*
R		R															*Globigerina euapertura*
R		RR				RR			F	C	C	F	F	R	RR	CC	*Globigerina praebulloides*
R		R	R	RR		F	F		RR								*Globigerina venezuelana*
							RR						RR				*Zeaglobigerina woodi brazieri*
							RR										*Zeaglobigerina* cf. *decoraperta*
RR		RR	RR	F		RR	F		C	RR			RR			RR	*Zeaglobigerina woodi woodi*
													RR		R		*Globigerinoides altiaperturus*
										R	RR	R	R	CC	F		*Globigerinoides bisphericus*
		RR								RR				R			*Globigerinoides immaturus*
												RR					*Globigerinoides parawoodi*
						RR			RR								*Globigerinoides primordius*
		RR							R	CC	R	F	R	F	R	R	*Globigerinoides quadrilobatus*
	RR													RR			*Globigerinoides subquadratus*
										RR		RR	R	RR	R	RR	*Globigerinoides subsacculifer*
	RR	R	RR		R	RR	R		R	C	RR	C	CC	CC	CC		*Globigerinoides trilobus*
													RR			CC	*Praeorbulina glomerosa curva*
																R	*Praeorbulina glomerosa glomerosa*
																F	*Praeorbulina glomerosa circularis*
													RR	RR	RR		*Praeorbulina sicana*
																RR	*Orbulina suturalis*
										RR		F	RR			R	*Dentoglobigerina altispira altispira*
RR						RR	R		RR								*Dentoglobigerina altispira globosa*
		R		R						F	R		R	RR	RR	RR	*Dentoglobigerina baroemoenensis*
									RR	R	F	F	RR	RR		R	*Dentoglobigerina langhiana*
RR		RR								RR	F	R		RR		F	*Dentoglobigerina larmeui*
											R	RR					*Dentoglobigerina* sp.
		RR			R	RR											*Globoquadrina* cf. *binaiensis*
RR	R	R	RR	F	R	C			RR		RR	RR					*Globoquadrina dehiscens praedehiscens*
			RR		RR	RR	R		C	C	CC	C					*Globoquadrina dehiscens dehiscens*
						RR											*Globoquadrina sellii*
F			R		RR			RR									*Globorotaloides suteri*
RR	RR	R	RR	R	R		R										*Globorotaloides* sp.
C	R	RR	R		RR	F	RR										*Catapsydrax unicavus*
C		R			RR	RR											*Catapsydrax dissimilis*
	RR								R	RR	RR		R			R	*Globigerinella obesa*
									R	R	R	F	F	F	R	RR	*Paragloborotalia acrostoma*
RR	RR									RR						RR	*Paragloborotalia* cf. *continuosa*
RR	RR								F	RR			RR		CC	R	*Paragloborotalia continuosa*
							RR		RR	RR		RR	F	F	CC	F	*Paragloborotalia mayeri*
R				RR			RR		RR	RR							*Paragloborotalia opima-continuosa*
RR	RR																*Paragloborotalia opima*
		RR							R	RR		RR	R	F	RR	R	*Paragloborotalia siakensis*
										R	F		RR	R	F	R	*Globorotalia birnageae*
																RR	*Globorotalia praemenardii*
																RR	*Globigerinita incrusta*
						RR											*Sphaeroidinellopsis disjuncta*
RR							RR										*Sphaeroidinellopsis seminulina*
		RR	RR		RR				R	R	RR		R		RR		*Tenuitellinata angustiumbilicata*

Tab. 4 - Range chart of planktonic foraminifera. Colma section. Abbreviations as in Tab. 3.

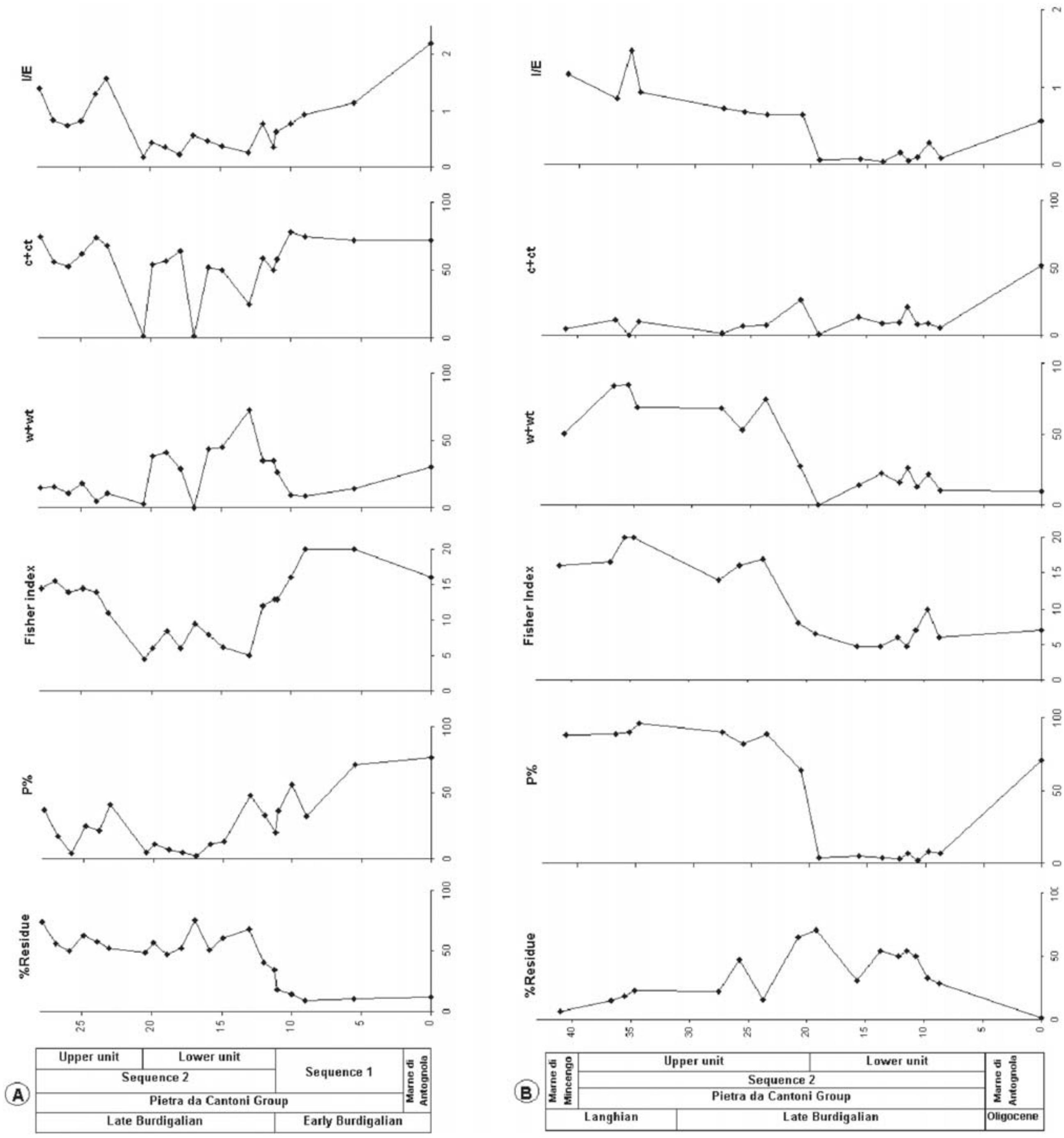

Fig. 9 - Curves of percentage of residue (% Residue); percentage of planktonic foraminifera (P%); Fisher index; planktonic foraminifera, warm and warm-temperate indices (w+wt); planktonic foraminifera, cool and cool-temperate indices (c+ct); ratio between infaunal and epifaunal benthic foraminifera (I/E). (A) Rosignano section. (B) Colma section.

The Marne di Mincengo Fm. (Tab. 5) shows a well-preserved assemblage dominated by planktonic foraminifera (88%). Among the benthic forms, with a rather high value of FI = 16, the infaunal types are dominant (54%, corresponding to I/E = 1.17). The most common taxa are *Uvigerina* spp., *Siphonina reticulata, Cibicidoides* spp., *Lenticulina* spp. which all increase significantly compared to the underlying upper unit of Sequence 2. Other species such as *Vulvulina pennatula, Stilostomella* spp. and *Brizalina arta* are relatively frequent.

The Q-mode analysis (Fig. 12) performed on the benthic assemblages of Colma splits the samples into two distinct clusters (I and II, within which only two samples are not included) corresponding to the lower and upper units of Sequence 2 respectively. At Rosignano the samples are grouped in five clusters (I-V) considering the linkage distance of 20. It is significant to observe that the cluster III includes only samples of the lower unit of Sequence 2, the cluster IV comprises samples of Sequence 1, while the cluster V groups the main part of samples of the upper unit of Sequence 2.

ROSIGNANO

Age	Formation			Preserv.	P%	WI	CI	FI	I/E
Late Burdigalian	Pietra da Cantoni Group	Sequence 2	Upper Unit	good	24	12.4	64.6	13.9	1.1
			Lower Unit	bad	15	34	33.9	7.3	0.4
Early Burdig.		Sequence 1		bad	43	18.6	66.6	14.4	0.76
Oligocene	Antognola Marls			good	77	30	72	16	0.75

COLMA

Age	Formation			Preserv.	P%	WI	CI	FI	I/E
Early Langhian	Mincengo Marls			good	88	50.5	4.7	16	1.2
Late Burdigalian	Pietra da Cantoni Group	Sequence 2	Upper Unit	good	85	66	8.5	15.9	0.85
			Lower Unit	bad	4.4	15.3	9.45	6.2	0.1
Early Burdig.	Antognola Marls			good	71	9.3	52	7	0.56

Tab. 5 - Average values for the different stratigraphic units of: degree of preservation; percentage of planktonic foraminifera (P%); warm and warm-temperate indices (w+wt); cool and cool-temperate indices (c+ct); Fisher index (FI); ratio between infaunal and epifaunal benthic foraminifera (I/E).

Larger Foraminifera - Miogypsinids (Fig. 13; Tab. 6) and Lepidocyclinids generally show a good state of preservation of the tests, except for specimens of samples 3256 and 3000 collected at the base of Sequence 2, that are commonly re-crystallized. The Miogypsinids diameter range between 0.7 mm and 2.0 mm, whereas Lepidocyclinids range between 1.0 mm and 2.6 mm.

In the Sequence 1 of the “PdC Gr.”, larger foraminifera consist of Miogypsinids only. Their abundance, compared with the total number of benthic foraminifera, decreases from the base of the sequence to the top.

In the lower unit of Sequence 2, also Lepidocyclinids are present. The total number of larger foraminifera shows an oscillating pattern along this sequence. The Lepidocyclinids are slightly more abundant than Miogypsinids; in Colma section they both disappear at the top of this unit.

In the upper unit of Sequence 2, Miogypsinids and Lepidocyclinids are present only in Rosignano section, where the lithofacies is coarser than in Colma, and they disappear after the sample 3177, near the top of the succession.

Coralline Algae - Rosignano and Colma sections contain two algal assemblages, each showing structures related to peculiar paleoecological conditions.

The first assemblage is present in the upper half of the lower unit of Sequence 2 in both sections. It is characterized by the dominance of the genus *Lithothamnion* with *Mesophyllum* in suborder and *Sporolithon, Spongites, Lithoporella* and *Lithophyllum* as accessories (Abate, 1991; Vannucci et al., 1996; Fortunato, 1997). Rhodoliths are elliptic to subspherical, with major axes ranging from 4 to 10 cm, and mainly show lamellar internal structures.

The second algal assemblage is included in the rhodolithic layer, observed only at Colma at the top of the same unit. This is similar to the previous assemblage, but shows a higher frequency of *Mesophyllum* (becoming dominant together with *Lithothamnion*) and a significant presence of *Sporolithon* and *Lithophyllum.* A decrease in lamellar internal structures has been observed (Abate, 1991; Vannucci et al., 1996; Fortunato, 1997).

Paleoclimatic Indices (Figs. 9A-B; Tabs. 5, 7) - In the assemblages of the Marne di Antognola Fm., cool/cool-temperate climatic indices (72% at Rosignano, 52% at Colma) clearly prevail over warm/warm-temperate indices. The cool/cool-temperate indices of Sequence 1 show an average value of 66.6% whereas the warm/warm-temperate values are on average 18.6%.

In the lower unit of Sequence 2 at Rosignano, the cool/cool-temperate indices decrease (medium value 33.9%); the warm/warm-temperate indices on the contrary increase (34% on average). The climatic indices at Colma show a different pattern: the cool/cool-temperate species are on average 9.5%, whereas the warm/warm-temperate indices reach a medium value of 15.3%. The cool/cool-temperate indices of the upper unit are 64.6% at Rosignano and attain much

ROSIGNANO

Age	Formation			Sample	N	X	γ	V	Species
Late Burdigalian	Pietra da Cantoni Group	Sequence 2	Upper Unit	3177	11	5.3	36.2	51.4	*M. intermedia*
				3178	12	5.6	42.6	46.4	*M. globulina-intermedia*
				3001	11	5.2	36.8	45.3	*M. globulina-intermedia*
			Lower Unit	3184	14	5.3	30.3	49.3	*M. globulina-intermedia*
				3000	7	5.4	37.5	42.2	*M. globulina-intermedia*
				3256	7	5.8	31.8	39.3	*M. globulina*
Early Burdigalian		Sequence 1		2999	15	7.4	-19.4	11	*M. tani*
				2998	34	8	-16.2	12.8	*M. tani*
				3249	19	8	-17.9	20.2	*M. socini*
				2997	39	8.5	-21.2	16.5	*M. socini*

COLMA

Age	Formation			Sample	N	X	γ	V	Species
Late Burdigalian	Pietra da Cantoni Group	Sequence 2	Lower Unit	3013	6	5.8	34.8	40	*M. globulina-intermedia*
				3012	35	5.5	32.3	52.1	*M. intermedia*
				3011	17	5.6	35.6	34.9	*M. globulina*
				3010	12	5.3	34.1	45.8	*M. globulina-intermedia*
				3009	17	5.6	40.3	41.8	*M. globulina-intermedia*
				3008	18	5.6	32.4	46.7	*M. globulina-intermedia*
				3007	16	5.8	36.7	37.9	*M. globulina*
				3006	5	6.0	31	37.1	*M. globulina*

Tab. 6 - Biometric data of *Miogypsina* populations.
N - number of examined specimens. V = 200 ˜/˜, degree of symmetry of protoconchal spirals. Parameters X, ˜, ˜, ˜ are illustrated in Fig. 13.

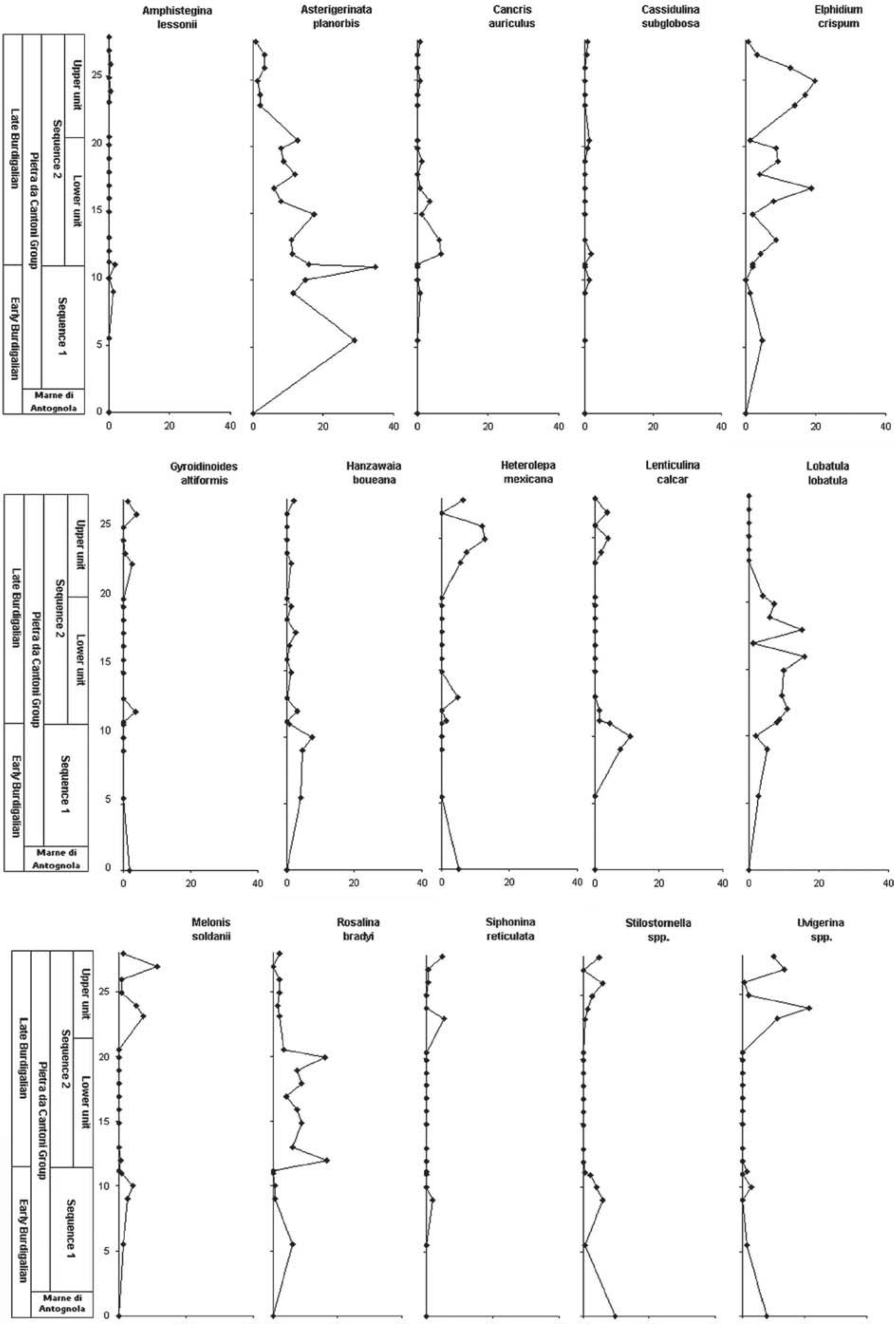

Fig. 10 - Frequency curves of selected benthic taxa from the Rosignano section.

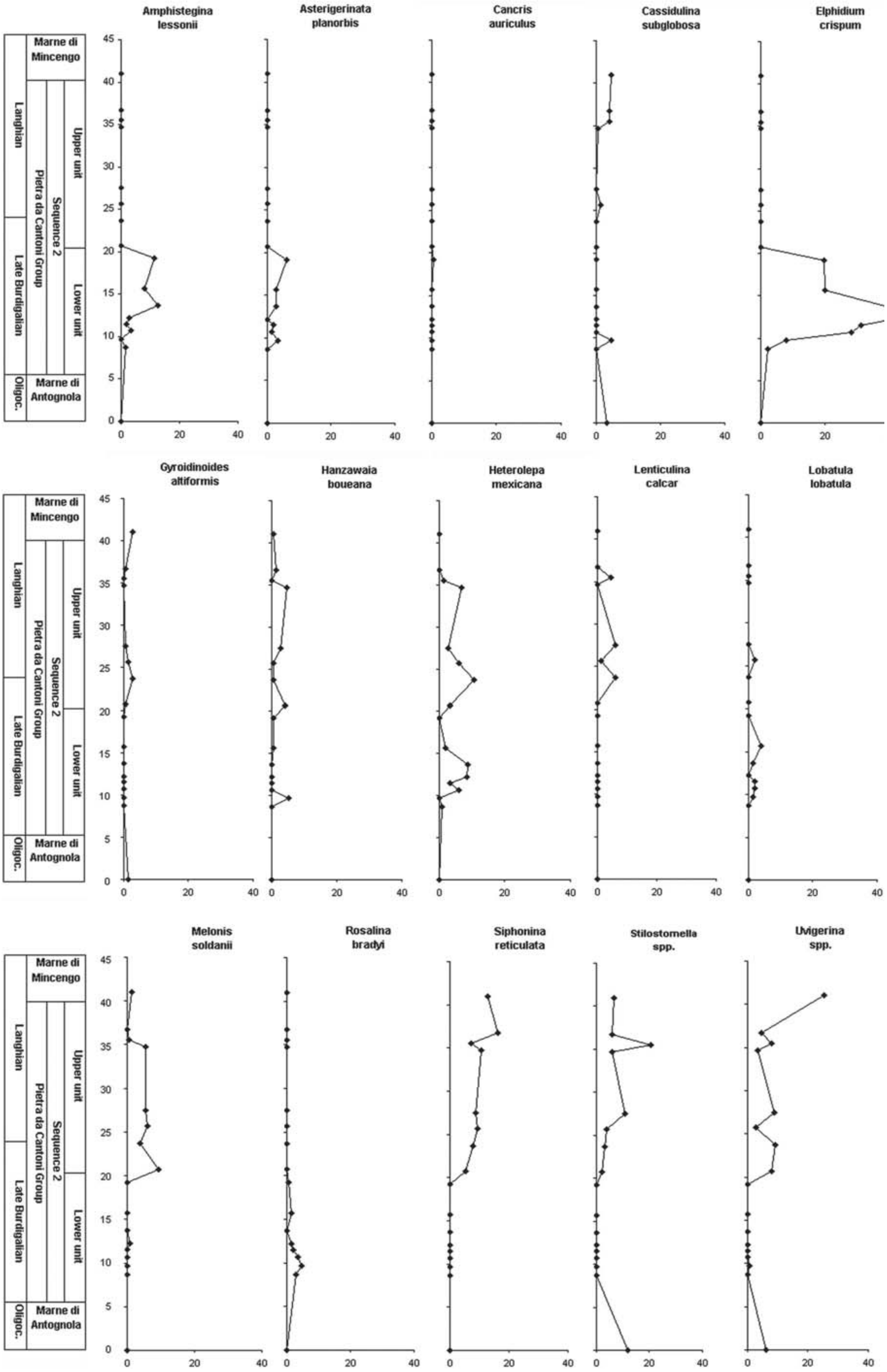

Fig. 11 - Frequency curves of selected benthic taxa from the Colma section.

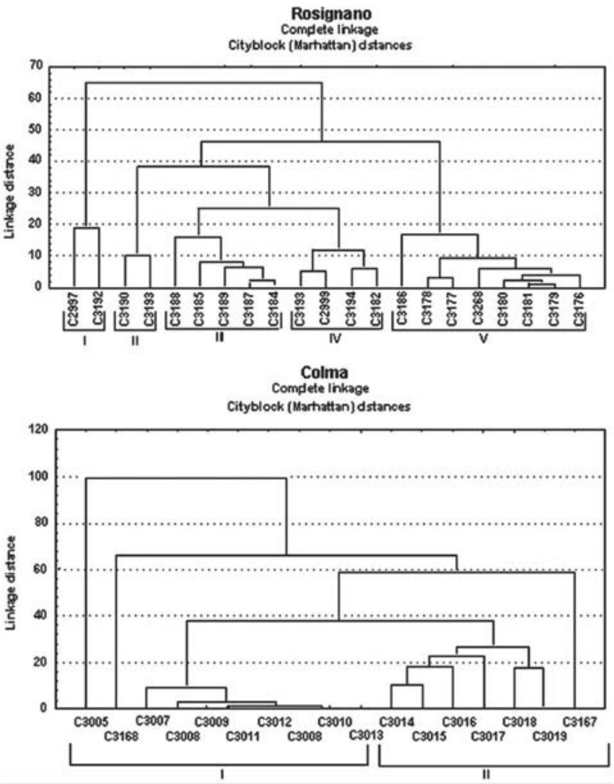

Fig. 12 - Cluster analysis dendrograms. Unweighted pair-groups average City-block (Manhattan) distance. Samples of Colma section are clearly split in two clusters, corresponding to the lower (I) and upper unit (II) of the Sequence 2. Samples of Rosignano section are mainly grouped in three clusters, corresponding respectively to the Sequence 1 (IV), to the lower (III) and upper unit (V) of the Sequence 2.

lower values (8.5%) at Colma. The warm/warm-temperate indices are 12.4% and 66% respectively.

In the Marne di Mincengo Fm. cool/cool-temperate indices are 4.7% and warm/warm-temperate indices 50.5%.

INTERPRETATION OF THE DATA

The Marne di Antognola Fm. (Upper Oligocene - Zone IFP22) contains benthic assemblages with common infaunal taxa, which are indicative of muddy substrata and low-energy circa-littoral to upper bathyal environments; the planktonic indices suggest cool-temperate waters and some benthic species are typical of deep waters (Tab. 8). All these data indicate deposition in an upper slope paleoenvironment, during a relatively cool interval.

A hiatus between the Marne di Antognola Fm. and Sequence 1 of "PdC Gr." has been detected on the basis of PF and larger foraminifera, including at least to the Zone IFN1 and the *M. gunteri/M. gunteri-tani* Zone (Aquitanian). This hiatus is marked by a discontinuity surface due to erosion, according to the regional framework (see also remarks in the Depositional Sequences and Microfacies Analyses chapters). However, poor outcrop conditions do not allow specifying if the discontinuity surface is the result of subaerial or submarine erosion.

Sequence 1 of the "PdC Gr." (lower Burdigalian, Zone IFN2-IFN3 and *M. tani/M. socini* Zone) is characterized by a relatively high percentage of planktonic foraminifera and by the prevalence of epifaunal forms in the benthic assemblages (Tab. 8). The abundance, among the latter, of epiphytic taxa indicates a vegetated and well-oxygenated substratum, whereas the abundance of forms belonging to the biconvex morphogroup indicates some bottom turbulence (Corliss & Chen, 1988). The high value of Fisher index á confirms good oxygenation. These data, together with the presence of *Thalassinoides* burrows (Frey et al., 1978) and larger foraminifera points to a shelf environment within the photic zone. Moreover, the occurrence of storm layers evidenced in the upper part of the sequence by hummocky structures (see chapter Results, Sequence 1), indicates deposition in a shelf environment above storm-wave base. Also the decreasing values of P%, FI and I/E (Figs. 9A-B; Tab. 5) indicate a gradual upward shallowing. The presence of some deep-water taxa is explained by "migration" of single specimens towards a shallower environment due to a persisting cool-temperate climate (as suggested by the climatic indices) and/or by shoreward transport.

Sediments of the lower unit of Sequence 2 (lower part of upper Burdigalian - Subzone IFN4a; *M. globulina/Miolepidocyclina* spp. and *M. globulina-intermedia/M. intermedia* Zones) correspond to rhodalgal deposits *sensu* Carannante et al. (1988). The

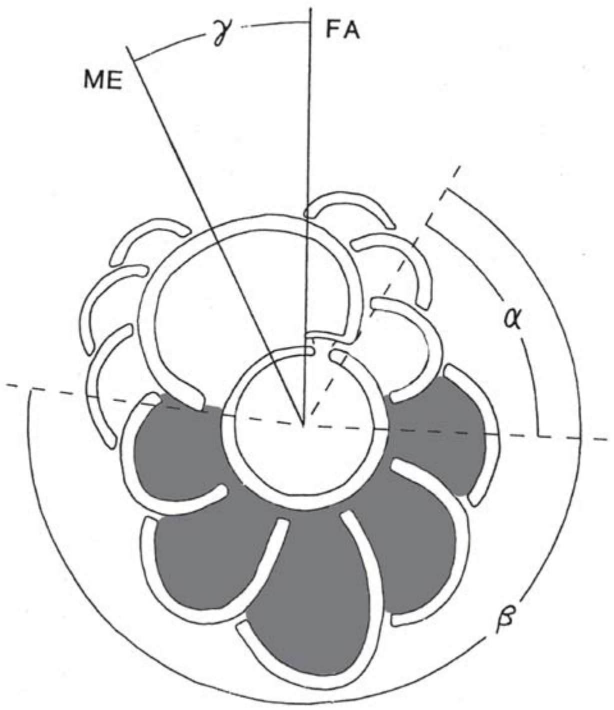

Fig. 13 - Scheme of embryonic-nepionic apparatus of *Miogypsina* s.l. X (in grey): principal protoconch spiral; ME: medium embryonic line; FA: frontal-apical line. For measurement and use of the angular parameters a,b,g see also Wildenborg (1991) and Maia (1996).

WARM INDICES	WARM-TEMPERATE INDICES	COOL-TEMPERATE INDICES	COOL INDICES
Globigerinoides spp. *Praeorbulina* spp. *Orbulina* spp. *Dentoglobigerina altispira* gr. *Globigerina ciperoensis*	*Tenuitellinata angustiumbilicata* *Dentoglobigerina baroemoenensis* *Globoquadrina tripartita* gr. *Globigerina venezuelana* gr. *Paragloborotalia siakensis* gr.	*Globigerina bulloides* *Paragloborotalia pseudocontinuosa* *Paragloborotalia continuosa* *Zeaglobigerina* spp.	*Globotaloides suteri* *Catapsydrax* spp. *Globigerina* gr.

Tab. 7 - Climatic indices. *Dentoglobigerina altispira* gr. includes *D. altispira altispira* and *D. altispira globosa*. *Globoquadrina tripartita* gr. includes *G. tripartita, G. binaiensis, G. sellii, G. dehiscens praedehiscens, G. dehiscens dehiscens*; *Paragloborotalia siakensis* gr. includes *P. siakensis, P. mayeri, P. acrostoma, P. continuosa, P. pseudocontinuosa*; *Globigerina venezuelana* gr. includes *G. venezuelana* and *G. euapertura*; *Globigerina* gr. includes *G. praebulloides, G. ouachitensis, G. anguliofficinalis*.

benthic forms are prevalent among the foraminifera. Epifaunal taxa, and in particular the epiphytic forms, clearly prevail, all suggesting a mobile substrate in a shallow water environment (Tab. 8) whereas lower values of FI could be related to high energy rather than to low oxygenation. An inner-middle shelf environment is suggested for these sediments, as also supported by:

1. the abundance of rhodoliths (Vannucci et al., 1996);
2. the disappearance and/or decrease of benthic smaller foraminifera indicative of deeper waters;
3. the abundance of larger foraminifera;
4. the scarcity and bad preservation of planktonic foraminifera;
5. the presence of sedimentary structures like large-scale cross stratification, connected with a high-energy depositional environment.

The climatic indices curves, based on the rare planktonic forms from the assemblage of this unit, are not considered significant; therefore larger foraminifera and coralline algae such as *Sporolithon* and *Lithoporella*, which are indicative of warm conditions, provide the best data for paleoclimatic interpretation.

The rhodolithic layer, marking the boundary between the lower and upper units, can be interpreted as a relict sediment (*sensu* Swift et al., 1971), that was exposed for a long time at the water-sediment interface, as also suggested by the occurrence of glaucony and phosphates. This layer is related to the drowning of the carbonate shelf, consequent to a relative sea-level rise, event that produced a drastic reduction in sedimentation rate, evidenced by the presence of condensed phosphatized levels and the demise of the carbonate shelf.

INNER SHELF	OUTER SHELF	OUTER SHELF - BATHYAL
Amphistegina lessonii *Asterigerina planorbis* *Cancris auriculus* *Elphidium crispum* *Hanzawaia boueana* *Lobatula lobatula* *Miogypsina sp.p.* *Miolepidocyclina sp.p.* *Nephrolepidina sp.p.* *Rosalina bradyi*	*Cancris auriculus* *Elphidium crispum* *Gyroidinoides altiformis* *Heterolepa mexicana* *Lenticulina calcar* *Melonis soldanii* *Siphonina reticulata* *Stilostomella sp.p.*	*Cassidulina subglobosa* *Uvigerina sp.p.*

Tab. 8 - Benthic foraminifera significant for palaeoenvironmental interpretation.

A hiatus between the rhodolith-rich layer and the upper unit in the Colma section is inferred, based on both an abrupt change of the lithofacies and the demise of larger foraminifera, but it is not evidenced by the planktonic foraminifera assemblages.

In the upper unit of Sequence 2 (upper Burdigalian to lower Langhian; Subzones IFN4a p.p., IFN4b and Zone IFN5; *M. globulina-intermedia/M. intermedia* Zone) the benthic assemblages are generally characterized by an increase of the infaunal genera (Figs. 9A-B). Only the older part of the upper unit outcrops at Rosignano, where the benthic assemblages are characterized by an abundance of taxa suggesting shallower waters in comparison with Colma assemblages. The abundance of epiphytic forms and the presence of Miogypsinids and rhodalgal remains indicate a shelf environment. In this section cool and cool-temperate planktonic climatic indices remarkably increase and apparently show a cooling trend. At Colma, benthic deep-water taxa reappear and the shallower ones abruptly disappear (Figs. 9B, 11; Tab. 8) as well as larger foraminifera and rhodalgal remains, indicating a circalittoral to bathyal environment, with temperate to cool deep waters (Murray, 1991). This fact also supports the hypothesis of a hiatus at the lower boundary, not evidenced by the stratigraphic markers, as said before, but clearly outlined by the lithostratigraphical evidence. In the same section the planktonic climatic indices suggest relatively warm surface conditions.

The discrepancy of the climatic data between the two sections could be explained by selective dissolution, which preferably removes the warm group represented by thin-walled taxa with large pores, scarcely solution resistant. This process might have affected the faunal composition and may be partly responsible for the decrease of the warm indices in Upper unit of Sequence 2 at Rosignano in comparison with the increase recorded at Colma.

Warm conditions continued with a positive trend during the early Langhian (IFN5 Zone) in the topmost part of Sequence 2 at Colma and in the overlying Marne di Mincengo Fm.

The sedimentological and paleoecological characteristics of the "PdC Gr." are indicative of a foramol *s.l.* shelf environment (Simone & Carannante, 1988; Carannante et al., 1988; Carannante & Simone, 1996; Cherchi et al., 2000; Murru et al., 2002), as already mentioned by Clari et al. (1994, 1995b); Vannucci et al. (1996); Bicchi (1998); Bicchi et al. (1997,1999). The sediments of the upper unit indicate the beginning of a progressive drowning of the carbonate shelf, culminating with the deposition of the marly sediments of the Marne di Mincengo Fm., rich in planktonic foraminifera.

DISCUSSION

The "PdC Gr." in the study area consists of carbonate deposits containing among the others rhodalgal grains. The depositional environment shows a deepening trend from a depositional environment of inner-middle shelf (Sequence 1 and the lower unit of Sequence 2) to a depositional environment of outer shelf-slope (the upper unit of Sequence 2 at Colma).

Paleoclimatic data indicate a warming trend, from cool-temperate conditions of Sequence 1 to warm/warm-temperate conditions of Sequence 2.

The hiatus between sediments of Sequence 1 and the underlying Marne di Antognola Fm. could be due to some uplift of the area correlated to a tectonic episode located between the Aquitanian and the very base of the Burdigalian. Deposition of Sequence 1, corresponding to the Zone IFN2/IFN3 of planktonic foraminifera, can be related to the early Burdigalian transgression reported by Haq et al. (1987) at the beginning of the TB2 supercycle. The prominent unconformity (Figs. 5A-B) at the top of Sequence 1 is related to a younger regional tectonic event (at the early-late Burdigalian boundary?), but not exactly referable to a precise age, because of the unsatisfactory biostratigraphic resolution of the sampled assemblages. This tectonic event is recorded in Monferrato (Sturani, 1973; Clari et al., 1995b; Falletti et al., 1995), in the Tertiary Piedmont Basin (Gelati, 1969; d'Atri, 1990a; d'Atri et al., 1997; Piana et al., 1997; Gelati & Gnaccolini, 1998) and in the Apenninic belt (Boccaletti et al., 1990). In the studied area, this unconformity is a polygenic discontinuity surface: corresponding to a span time during which the shelf sediments of Sequence 1 underwent a partial erosion and a successive lithification, as also suggested by the cm-wide neptunian dykes, occurring at the top. The above mentioned discontinuity surface in the Rosignano section consists in a flat erosional surface capping these sediments. It is interpreted as a ravinement surface (*sensu* Nummedal & Swift, 1987) that, according to Bicchi et al. (2003), is related to the late Burdigalian transgressive phase (base of the cycle TB2.2 of Haq et al., 1987) during which the rodhalgal carbonates composing the lower unit of Sequence 2 deposited.

In present-day environments, rhodalgal carbonates are commonly deposited at the boundary between tropical and temperate zones, but they also occur in tropical areas in deeper waters or in places where stressed conditions (i.e. Campeche bank, Logan et al., 1969), such as the upwelling of cold, nutrient-rich waters, prevent the growth of hermatypic corals and green algae (Carannante et al., 1988; Carannante & Simone, 1996; James, 1997).

A phosphate-rich level caps the rhodalgal sediments in outcrops close to the sections object of this study (i.e. Terruggia section, in Bicchi et al., 2003). This level, which correlates with the partly phosphatized rhodolith-rich layer bounding in the Colma section the upper unit from the lower unit, suggests that upwelling of nutrient-rich waters played an important role in deposition of "temperate type" carbonates. This interpretation is also in agreement with Esteban (1996), who links the development of temperate-type shelf carbonates to an estuarine type circulation in the Mediterranean basin, even under still subtropical climatic conditions. Coeval carbonate build-ups, comparable with the Monferrato rhodalgal sediments, are in fact reported in many areas of the Mediterranean region (Esteban, 1996; Pedley, 1996) with different structural settings (Grasso & Pedley, 1985; d'Atri, 1990b; Carannante & Simone, 1996; Mutti et al., 1997; Vecsei & Sanders, 1999; Casolari et al., 2000).

The abundance of nutrients may have been enhanced by an increase of weathering in continental areas, due to Alpine orogenesis (see also Raymo, 1994; Mutti et al., 1997). These conditions are documented by the abundant, sometimes coarse grained, terrigenous sediments deposited during the Burdigalian in the adjoining basins: Western Monferrato (i.e. Arenarie di Moransengo, Dela Pierre et al., 2003) and Torino Hill (i.e. Complesso di Termo Forà, Bonsignore et al., 1969) to the West, Langhe to the South (i.e. "Marne di Montechiaro d'Acqui", d'Atri, 1990a). These terrigenous sediments did not affect the carbonate shelf thanks to its geographic location, on a gentle westward dipping platform of an isolated submarine ridge that developed since early Burdigalian ("tectonic arc" *sensu* Falletti et al., 1995).

The physiographic position of the uplifted area certainly allowed the occasional presence of strong bottom currents favoring the production of rhodoliths and down-slope transport of bioclastic debris.

The rhodolith-rich layer marks the sharp transition from the inner shelf sediments to the planktonic foraminifera and glaucony-rich packestones of the upper unit of Sequence 2. This transition is likely due to the drowning of the shelf connected to a relative sea level rise resulting in the sudden demise of the carbonate shelf. In the Tertiary Piedmont Basin (Alto Monferrato domain) some authors (d'Atri, 1990a; Gelati & Gnaccolini, 1998) recognized a similar sequence of events. The age of this event, corresponding to a time span within the interval of Subzone IFN4a, is correlated with the maximum flooding surface reported by Haq et al. (1987) within cycle TB2.2.

Finally, the deposition of the Marne di Mincengo in an upper slope environment started in the late Langhian. This remarkable change in the sedimentation pattern reflects the deepening of the basin, probably due to an increase of subsidence (Dela Pierre et al., 2003).

CONCLUSIONS

A multidisciplinary study, integrating sequence stratigraphy, biostratigraphy, paleoecology and paleoclimatology, was carried out on Early Miocene carbonate deposits known as the “Pietra da Cantoni Group” in Eastern Monferrato (NW Italy). The shallow water carbonate deposits are interbedded between deep water marls and have been split into two depositional sequences bound by discontinuity surfaces. The results of the study made it possible to define the main factors (tectonics, sea-level fluctuations, oceanic-water mass circulation, climate changes) that affected the sedimentation and evolution of this carbonate succession.

The PdC Group is underlined by a wide discontinuity surface (i.e. at Rosignano). The contact shows also an angular unconformity with levels of the Marne di Antognola Fm., of Oligocene age at Colma, of Aquitanian age at Terruggia, (Falletti, 1994; Bicchi et al., 2003).

Sequence 1, of early Burdigalian age, is composed of inner shelf burrowed wackestones and packstones deposited in cool-temperate climatic conditions. Sequence 2 consists of upper Burdigalian rhodalgal facies, deposited in an inner-middle shelf environment and in warm-temperate conditions. It is followed by outer shelf planktonic foraminifera and glaucony-rich packstones, spanning the late Burdigalian-early Langhian interval. These deposits mark the beginning of a deepening-upward trend that culminates in the late Langhian, with the deposition of slope sediments of the Marne di Mincengo Fm.

The age of the discontinuity surface between the Marne di Antognola Fm. and Sequence 1, interpreted as an erosion surface, has been defined by means of integrated biostratigraphy and corresponds to a hiatus (planktonic and larger foraminifera data). On the contrary, at the boundary between Sequence 1 and Sequence 2, no hiatus was evidenced by the resolution of the biostratigraphic scale. Another hiatus has been inferred, on the basis of the absence of larger foraminifera concomitant with an abrupt change of the lithofacies, between lower and upper units of Sequence 2 and is related to the drowning of the carbonate shelf.

The development of shelf carbonates was extensive during early and late Burdigalian times, corresponding to global second-order highstands of supercycles of relative sea-level change. Sequence 1 reflects the Burdigalian transgression at the base of the TB2 supercycle (Haq et al., 1987), whereas the shelf sediments of the lower unit of Sequence 2, deposited after a phase of tectonic deformation, are related to the late Burdigalian sea-level rise at the base of the cycle TB2.2. The drowning of the shelf, evidenced by a rhodolith-rich layer, correlated with a phosphatizsed marker level cropping out close to the investigated area, is correlated to the maximum flooding surface reported by Haq et al. (1987) within cycle TB2.2.

This interpretation based on the analytical data supports the results of the literature cited and is in good agreement with similar and coeval situations described in the Mediterranean region. The investigated shelf carbonates reflect the global Miocene cooling trend of the waters all over the Mediterranean, combined with an evolving pattern of oceanic circulation (Carannante & Simone, 1996) which caused the change from chlorozoan (tropical to subtropical) assemblages to rhodalgal (warm-temperate) assemblages in Mediterranenan carbonate platforms (Esteban, 1996). According to this author, the increasing biogeographical isolation of the Mediterranean, due to the closure of Tethyan seaways and the widening of the Atlantic, allowed deep Atlantic nutrient-rich waters to enter the Mediterranean basin that, during the early Burdigalian, had an estuarine-type circulation. Upwelling phenomena along the shelves favoured the demise of coral reefs in the regions where they previously flourished and the deposition of warm-temperate rhodalgal carbonates, under climate conditions still subtropical (Esteban, 1996; Pedley, 1996).

The abundance of nutrients may have been enhanced by an increase of weathering from continental areas, whose total surface was increasing in this time interval, due to the Alpine orogenesis (Raymo, 1994; Mutti et al., 1997). The consequent production of huge quantities of terrigenous sediments affected the basins (Western Monferrato and Torino Hill; Langhe, Gelati & Gnaccolini, 1998) close to the study area, with the exclusion of the Eastern Monferrato, that, as an uplifted portion of an isolated submarine ridge, was a relatively protected sector, favourable to carbonate-shelf sedimentation (Falletti et al., 1995).

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REFERENCES

Abate C. (1991). Indagini paleoecologiche e biostratigrafiche in successioni a rodoliti della “Pietra da Cantoni” (Basso Monferrato). 137 pp., Unpubl. Thesis, University of Genova.

Amorosi A. (1997). Miocene shallow-water deposits of the northern Apennines: a stratigraphic marker across a dominantly turbidite foreland-basin succession. *Geologie en Mijnbouw*, 75: 295-307.

Berggren W.A., Kent D.V., Swisher C.C. III & Aubry M-P. (1995). A revised Cenozoic geochronology and chronostratigraphy. *In* Berggren W.A, Kent D.V., Aubry M-P. & Hardenbol J. (eds.), Geochronology, time scales and global stratigraphic correlation. *Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology) Special Publication*, 54: 129-212.

Bicchi E. (1998). Evoluzione biostratigrafica, paleoecologica e paleoclimatica del Monferrato orientale nel Miocene Inferiore e Medio. Studio delle associazioni a Foraminiferi planctonici e bentonici. 158 pp., Unpubl. Ph.D. Thesis, University of Torino.

Bicchi E., Dela Pierre F., Ferrero E., Maia F., Negri A., Pirini Radrizzani C., Tonon M. & Valleri G. (1999). Evolution of carbonate platforms in Eastern Monferrato (NW Italy). European Palaeontological Association Workshop, Lisboa: 15-20.

Bicchi E., Ferrero E., Novaretti A., Pirini C. & Valleri G. (1994). Biostratigrafia della successione Oligo-Miocenica della Collina di Torino e del Monferrato. *Atti Ticinensi di Scienze della Terra, Serie Speciale*, 1: 215-225.

Bicchi E., Ferrero E. & Gonera M. (2000). Planktonic Foraminifera approach to Middle Miocene Palaeoclimatic reconstruction of Tethys (Monferrato) and Paratethys (Silesia Basin). XI Congress of Regional Committee on Mediterranean Neogene Stratigraphy, Fez, Abstract Volume: 19.

Bicchi E., Ferrero E. & Gonera M. (2003). Palaeoclimatic interpretation based on Middle Miocene planktonic Foraminifera: the Silesia Basin (Paratethys) and Monferrato (Tethys) records. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 196: 265-303.

Bicchi E., Maia F., Ferrero E., Pirini Radrizzani C. & Valleri G. (1997). Carbonate platforms in the Lower-Middle Miocene succession of the Eastern Monferrato area: the biostratigraphic record. Interim Colloquium Regional Committee on Mediterranean Neogene Stratigraphy, Catania, Abstract volume: 31.

Bigi G., Castellarin A., Coli M., Dal Piaz G.V., Sartori R., Scandone P. & Vai G.B. (1990). Structural model of Italy, Sheet n. 1. *In* Bigi G., Cosentino D., Parotto M., Sartori R., & Scandone P. (eds.), Structural model of Italy, Geodynamic Project, C.N.R., SELCA, Firenze.

Blow W.H. (1969). Late Middle Eocene to recent planktonic foraminiferal biostratigraphy. Proceedings First International Conference on planktonic microfossils, Geneve 1967, 1: 199-422.

Boccaletti M., Calamita F., Deiana G., Gelati R., Massari F., Moratti G. & Ricci Lucchi F. (1990). Migrating foredeep-thrust belt system in the northern Apennines and southern Alps. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 7: 3-14.

Bonsignore G., Bortolami G., Elter G., Montrasio A., Petrucci F., Ragni U., Sacchi R., Sturani C. & Zanella E. (1969). Note illustrative della Carta Geologica d'Italia alla scala 1:100.000. Fogli 56 e 57, Torino/Vercelli. 96 pp. Libreria dello Stato, Roma.

Carannante G., Esteban M., Milliman J.D. & Simone L. (1988). Carbonate facies as palaeolatitude indicators: problems and limitations. *In* Nelson C.S. (ed.), Non-Tropical Shelf Carbonates - Modern and Ancient. *Sedimentary Geology*, 60: 333-346.

Carannante G. & Simone L. (1996). Rhodolith facies in the Central-Southern Apennines Mountains, Italy. *In* Franseen E.K., Esteban M., Ward W.C. & Rouchy J-M. (eds.), Models for Carbonate Stratigraphy. Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology), *Concepts in Sedimentology and Paleontology*, 5: 261-275, Tulsa.

Casolari E., Negri A., Picotti V. & Bertotti G. (2000). Neogene stratigraphy and Sedimentology of the Gargano Promontory (Southern Italy). *Eclogae Geologicae Helvetiae*, 93: 7-23.

Cati F., Colalongo M.L., Crescenti U., D'Onofrio S., Follador U., Pirini Radrizzani C., Pomesano Cherchi A., Salvatorini G., Sartoni S., Premoli Silva I., Forese Wezel, C., Bertolino V., Bizon G., Bolli H.M., Borsetti Cati A.M., Dondi L., Feinberg H., Jenkins G.D., Perconig E., Sampò M. & Sprovieri R. (1968). Biostratigrafia del Neogene Mediterraneo basata sui foraminiferi planctonici. *Bollettino della Società Geologica Italiana*, 87: 491-503.

Cherchi A., Murru M. & Simone L. (2000). Miocene carbonate factories in the Syn-rift Sardinia Graben Subbasins (Italy). *Facies*, 43: 223-240.

Clari P., Dela Pierre F. & Martire L. (1995a). Discontinuities in carbonate successions: identification, interpretation and classification of some Italian examples. *Sedimentary Geology*, 100: 97-121.

Clari P., Dela Pierre F., Novaretti A. & Timpanelli M. (1994). La successione oligo-miocenica del Monferrato occidentale: confronti e relazioni con il Monferrato orientale e la Collina di Torino. *Atti Ticinensi di Scienze della Terra, Serie Speciale*, 1: 191-203.

Clari P., Dela Pierre F., Novaretti A. & Timpanelli M. (1995b). Late Oligocene- Miocene sedimentary evolution of the critical Alps/Apennines junction: the Monferrato area, North-Western Italy. *Terra Nova*, 7: 144-152.

Corliss B.H. & Chen C. (1988). Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. *Geology*, 16: 716-719.

d'Atri A. (1990a). Facies e sequenze deposizionali nella Formazione di Visone (Miocene Inferiore, Bacino Terziario Ligure Piemontese). *Memorie della Società Geologica Italiana*, 45: 723-729.

d'Atri A. (1990b). Analisi sedimentologica, biostratigrafica e sequenziale della successione del Miocene Inferiore tra le valli Lemme e Bormida di Spigno (Margine sudorientale del Bacino Terziario Ligure-Piemontese). Unpubl. Ph.D. Thesis, 143 pp. University of Torino.

d'Atri A., Piana F., Tallone S., Bodrato G., & Roz Gastaldi M. (1997). Tettonica oligo-miocenica nell'Alto Monferrato (Bacino Terziario Piemontese) e nel settore nord-occidentale del Gruppo di Voltri (Acqui Terme – Cassinelle, AL). *Atti Ticinensi di Scienze della Terra, Serie Speciale*, 5: 85-100.

Dela Pierre F., Piana F., & Bicchi E. (1998). Rapporti tra tettonica e sedimentazione nella successione oligo-miocenica del Monferrato orientale. *Giornale di Geologia*, 60: 34-35.

Dela Pierre F., Piana F., Fioraso G., Boano P., Bicchi E., Forno M.G., Violanti D., Clari P. & Polino R. (2003). Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 157, Trino.147 pp. Litografia Geda, Torino.

Drooger C.W. (1954). Miogypsina in Northern Italy. *Proceedings Koninklijke Nederlandse Akademie van Wetenschappen*, ser.B, 57: 227-249.

Drooger C.W. (1956). Parallel Evolutionary Trends in Larger Foraminifera. *Proceedings Koninklijke Nederlandse Akademie van Wetenschappen*, ser. B, 59: 458-469.

Esteban M. (1996). An overview of Miocene reefs from Mediterranean areas: general trends and facies models. *In* Franseen E.K., Esteban M., Ward W.C. & Rouchy J-M. (eds.), Models for Carbonate Stratigraphy. Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology). *Concepts in Sedimentology and Paleontology*, 5: 3-53, Tulsa.

Falletti P. (1994). Caratteri stratigrafici della successione oligo-miocenica nel settore orientale del Monferrato. *Atti Ticinensi di Scienze della Terra, Serie Speciale*, 1: 269-282.

Falletti P., Gelati R. & Rogledi S. (1995). Oligo-Miocene evolution of Monferrato and Langhe, related to deep structures, Atti del Convegno "Rapporti tra Alpi e Appennino" - Peveragno (CN), *Accademia Nazionale delle Scienze detta dei XL, Collana Scritti e Documenti*, 14: 1-19.

Ferrero E., Maia F. & Tonon M. (1994). Biostratigrafia dei livelli bioclastici del Miocene inferiore del Monferrato. *Atti Ticinensi di Scienze della Terra, Serie Speciale*, 1: 227-230.

Fornaciari E. & Rio D. (1996). Latest Oligocene to early middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 1-36.

Fornaciari E., Di Stefano A., Rio D. & Negri A. (1996). Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. *Micropaleontology*, 42: 37-63.

Fornaciari E., Iaccarino S., Mazzei R., Rio D., Salvatorini G., Bossio A. & Monteforti B. (1997). Calcareous plankton biostratigraphy of the Langhian historical stratotype. *In* Montanari A., Odin G.S. & Coccioni R. (eds.), Miocene Stratigraphy. An Integrated Approach: 88-96, Elsevier Science B.V., Amsterdam.

Fornaciari E., Raffi I., Rio D., Villa G., Backman J. & Olafsson G. (1990). Quantitative distribution patterns of Oligocene and Miocene calcareous nannofossils from the Western Equatorial Indian Ocean. *In* Duncan R.A., Backman J. & Peterson L.C. (eds.), *Proceedings of the O.D.P., Scientific Results*, 115: 237-254.

Fortunato A. (1997). Studio biostratigrafico e paleontologico di alcune sequenze affioranti nel Monferrato orientale. Unpubl. Thesis, University of Genova.

Franceschetti B. (1967). Studi geologici sulla regione ad ovest di Ovada (Provincia di Alessandria). *Memorie della Società Geologica Italiana*, 6: 379-420.

Frey R.W., Howard J.D., & Pryor W.A. (1978). *Ophiomorpha*: its morphologic, taxonomic and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 23: 199-229.

Gelati R. (1969). Il calcare di Acqui. *Rivista Italiana di Paleontologia e Stratigrafia*, 75: 761-830.

Gelati R. & Gnaccolini M. [con contributo di Petrizzo M.R.] (1998). Synsedimentary tectonics and sedimentation in the Tertiary Piedmont Basin, Northwestern Italy. *Rivista Italiana di Paleontologia e Stratigrafia*, 104: 193-214.

Grasso M. & Pedley H.M. (1985). The Pelagian Islands: a new geological interpretation from sedimentological and tectonic studies and its bearing on the evolution of the central Mediterranean Sea (Pelagian Block). *Geologica Romana*, 24: 13-34.

Haq B.U., Hardenbol J. & Vail P.R. (1987). Chronology of fluctuating Sea Level since the Triassic. *Science*, 35: 1156-1167.

Iaccarino S. (1985). Mediterranean Miocene and Pliocene Planktonic Foraminifera. *In* Bolli H.M., Saunders J.B. & Perch-Nielsen K. (eds), Plankton Stratigraphy: 283-314, Cambridge University Press, Cambridge.

Iaccarino S. & Salvatorini G. (1982). A framework of planktonic foraminiferal biostratigraphy for early Miocene to late Pliocene Mediterranean area. *Paleontologia, Stratigrafia ed Evoluzione*, 2: 115-125.

Iaccarino S., Borsetti A. M. & Rögl F. (1996). Planktonic foraminifera of the Neogene Lemme-Carrosio GSSP Section (Piedmont, Northern Italy. *In* Steininger F.F., Iaccarino S. & Cati F. (eds.), In search of the Paleogene/Neogene boundary. Part III: The Global stratotype section and point the GSSP for the base of the Neogene (The Paleogene/Neogene boundary). *Giornale di Geologia*, 58 (1-2): 35-49.

Iaccarino S., Foresi L. M., Mazzei R. & Salvatorini G. (2001). Calcareous plankton stratigraphy of the Miocene sediments of the Tremiti Islands (Southern Italy). *Revista Espanola de Micropaleontologia*, 33: 237-248.

James N.P. (1997). The cool-water carbonate depositional realm. *In* James N.P. & Clarke J.A.D. (eds.), Cool-water carbonates. *Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology), Special Publication*, 56: 1-20, Tulsa.

James N.P. & Clarke J.A.D., eds. (1997). Cool-water carbonates. *Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology), Special Publication*, 56. 440 pp., Tulsa.

Logan B.W., Harding J.L., Ahr W.M., William J.D., & Snead R.G. (1969). Carbonate sediments and reefs, Yucatan Shelf, Mexico. *American Association of Petroleum Geologists Memoir*, 11: 5-198.

Luchetti L., Brozzetti F., Nini C., Nocchi M. & Rettori R. (2002). Lithostratigraphy, integrated biostratigraphy and paleoenvironmental analysis of the Miocene Monte Santa Maria Tiberina succession (Umbria-central Italy). *Bollettino della Società Geologica Italiana, Volume speciale*, 1: 589-602.

Maia F. (1996). Comparison between cladistic and phenetic methods in larger Foraminifera analysis, Atti del 6° Simposio Palaeobenthos, Alghero (SS). *Rivista Italiana di Paleontologia e Stratigrafia*, 102: 367-374.

Maia F. (1997). Studio biostratigrafico dei depositi oligo-miocenici del Monferrato e della Collina di Torino. Analisi dei macroforaminiferi. Unpubl. Ph.D. Thesis, 182 pp. University of Torino.

Mancin N., Pirini C., Bicchi E., Ferrero E. & Valleri G. (2003). Middle Eocene to Middle Miocene planktonic foraminiferal biostratigraphy for internal basins (Monferrato and northern Appennines, Italy). *Micropaleontology*, 49 (4): 341-358.

Martini E. (1971). Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci A. (ed.), Proceedings of the II Planktonic Conference, Roma, 1970, 2: 738 -785.

Matteucci R. & Schiavinotto F. (1977). Studio biometrico di *Nephrolepidina, Eulepidina* e *Cycloclypeus* in due campioni dell'Oligocene di Monte la Rocca, L'Aquila (Italia Centrale). *Geologica Romana*, 16: 141-171.

Molina E. (1979). Oligoceno-Mioceno inferior por medio de foraminiferos planctonicos en el sector central de las Cordilleras Beticas (Espana). 804-880, Ph.D. Thesis. Pubblication Universidades de Granada y Zaragoza, Deposito Legal Z.

Murray J.W. (1973). Distribution and ecology of living benthic foraminiferids. 274 pp. Heinemann Educational Books Limited, London.

Murray J.W. (1991). Ecology and Palaeoecology of Benthic Foraminifera. 397 pp. Longman Scientific & Technical, New York.

Murru M., Simone L. & Vigorito M. (2002). Lower Miocene Isili carbonate factories (South-eastern Sardinia, Italy). *In* Cherchi A., Corradini C. & Putzu M.T. (eds.), Sardinia field Trip – Palaeontology and Stratigraphy. *Rendiconti Società Paleontologica Italiana*, 1: 335-342.

Mutti M., Bernoulli D. & Stille P. (1997). Temperate carbonate platform drowning linked to Miocene oceanographic events: Maiella platform margin, Italy. *Terra Nova*, 9: 122-125.

Nelson C.S., ed. (1988). Non-Tropical Shelf Carbonates - Modern and Ancient. *Sedimentary Geology*, 60: 333-346

Novaretti A. & Bicchi E. (1996). Planktonic foraminifera as paleoclimatic indicators of the Upper Oligocene-Middle Miocene interval in the Monferrato area (NW Italy). *Palaeopelagos*, 6: 299-309.

Novaretti A., Bicchi E., Condello A., Ferrero E., Maia F., Tonon M., & Torta D. (1995). La successione oligo-miocenica del Monferrato (Italia NW): Sintesi dei dati biostratigrafica. Convegno " Rapporti tra Alpi e Appennino", Peveragno (CN), giugno 1994. *Collana scritti e documenti. Accademia Nazionale delle Scienze detta dei XL*, 14: 39-59.

Nummedal D. & Swift D.J.P. (1987). Transgressive stratigraphy at sequence-bounding unconformities: some principles derived from Holocene and Cretaceous examples. *In* Nummedal D., Pilkey O.H. & Howard J.D. (eds.), Sea-level fluctuation and coastal evolution. *Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology), Special Publication*, 41: 242-260, Tulsa.

Okada H. & Bukry D. (1980). Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Marine Micropaleontology*, 5: 321-325.

Parona C.F. (1916). Nuovi fossili del Miocene di Rosignano Piemonte. *Atti Regia Accademia delle Scienze di Torino*, 51: 963-968.

Pedley M. (1996). Miocene reefs distribution and their associations in the Central Mediterranean region: an overview. *In* Franseen E.K., Esteban M., Ward W.C. & Rouchy J-M. (eds.), Models for Carbonate Stratigraphy. *Society for Economic Paleontology and Mineralogy (Society for Sedimentary Geology), Concepts in Sedimentology and Paleontology*, 5: 73-87, Tulsa.

Piana F. (2000). Structural features of Western Monferrato (Alps-Apennines junction zone, NW Italy). *Tectonics*, 19: 943-960.

Piana F. & Polino R. (1995). Transpressive tertiary tectonics at the Alps/Apennines junction zone (Northwestern Italy). *Terra Nova*, 7: 138-143.

Piana F., d'Atri A. & Orione P. (1997). The Visone Formation: a marker of the Early Miocene tectonics in the Alto Monferrato domain (Tertiary Piedmont Basin, NW Italy). *Memorie di Scienze Geologiche dell'Università di Padova*, 49: 145-162.

Polino R., Clari P., Crispini L., d'Atri A., Dela Pierre F., Novaretti A., Piana F., Ruffini R., & Timpanelli M. (1995). Convegno sul tema: "Rapporti tra Alpi e Appennino", Peveragno, giugno 1994. Guida all'escursione post convegno: Monferrato e zona Sestri-Voltaggio. *Collana scritti e documenti, Accademia Nazionale delle Scienze detta dei XL*, 14: 531-593.

Raymo M. E. (1994). The Himalayas, organic carbon burial, and climate in the Miocene. *Paleoceanography*, 9; 399-404.

Rio D., Cita M.B., Iaccarino S., Gelati R. & Gnaccolini M. (1997). Langhian, Serravallian, and Tortonian historical stratotypes. *In* Montanari A., Odin G.S. & Coccioni R. (eds.), Miocene Stratigraphy. An Integrated Approch: 57-87. Elsevier Science B.V., Amsterdam.

Rio D., Raffi I. & Villa G. (1990). Pliocene-Pleistocene calcareous nannofossil distribution patterns in the Western Mediterranean. *Proceedings of the O.D.P., Scientific Results*, 107: 513-533.

Russo B., Sgarrella F. & Gaboardi S. (2002). Benthic foraminifera as indicators of paleoecological bottom conditions in the middle Serravallian-basal Tortonian Tremiti sections/eastern Mediterranean, Italy). *In* Iaccarino S.M (ed.), Integrated stratigraphy and Paleoceanography of the Mediterranean Middle Miocene. *Rivista Italiana di Paleontologia e Stratigrafia*, 108: 275-287.

Sacco A. (1890). Il Bacino Terziario e Quaternario del Piemonte. Bibliografia, Geologia pura, Paleontologia, Geologia applicata. 634 pp. Tipografia Bernadoni di C. Rebeschini, Milano.

Schüttenhelm R.T.E. (1976). History and modes of Miocene carbonate deposition in the interior of the Piedmont Basins, NW Italy. *Utrecht Micropaleontological Bulletins*, 14: 1-207.

Sgarrella F. & Moncharmont Zei M. (1993). Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology. *Bollettino della Società Paleontologica Italiana*, 32: 145-264.

Simone L. & Carannante G. (1988). The fate of foramol ("temperate-type") carbonate shelfs. *In* Nelson C.S. (ed.), Non-Tropical Shelf Carbonates - Modern and Ancient. *Sedimentary Geology*, 60: 347-354.

Socin C. (1954). Microfaune terziarie del Monferrato. Pubblicazioni dell'Istituto di Geologia, Università di Torino, 3: 25-50.

Spezzaferri S. (1995). Planktonic foraminiferal palaeoclimatic implications across the Oligocene-Miocene transition in the oceanic record (Atlantic, Indian and South Pacific). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 114: 43-74.

Sprovieri R., Bonomo S., Caruso A., Di Stefano A., Di Stefano E., Foresi L. M., Iaccarino S. M., Lirer F., Mazzei R. & Salvatorini G. (2002). An integrated calcareous plankton biostratigraphic scheme and biochronology for the Mediterranean Middle Miocene. *Rivista Italiana di Paleontologia e Stratigrafia*, 108: 337-353.

Sturani C. (1973). Considerazioni sui rapporti tra Appennino settentrionale ed Alpi occidentali. Atti Conv. Moderne vedute sulla geologia dell'Appennino. *Accademia Nazionale dei Lincei, Quaderni*, 183: 119-142.

Swift D.J.P., Stanley D.J. & Curray J.R. (1971). Relict sediments, a reconsideration. *Journal of Geology*, 79: 322-346.

Vannucci G., Piazza M., Fravega P. & Abate C. (1996). Litostratigrafia e Paleoecologia di successioni a rodoliti della "Pietra da Cantoni" (Monferrato Orientale, Italia Nord-Occidentale). *Atti Società Toscana Scienze Naturali, Memorie, Serie a*, 103: 69-86.

Vecsei A. & Saunders D.G.K. (1999). Facies analysis and sequence stratigraphy of a Miocene warm-temperate carbonate ramp, Montagna della Maiella, Italy. *Sedimentary Geology*, 123: 103-127.

Violanti D., Ippolito G. & Matassa L. (1999). Foraminiferal assemblages as palaeoenvironmental indices in the middle Miocene of the Southeastern Piedmont (Val Lemme, Northern Italy). *Revista Española de Micropaleontologia*, 31: 411-417.

Wildenborg A.F.B. (1991). Evolutionary aspects of the Miogypsinids in the Oligo-Miocene carbonates near Mineo (Sicily). *Utrecht Micropaleontological Bulletins*, 41:1-139.

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