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Acervulinid macroid and rhodolith facies in the Eocene Nummulitic Limestone of the Dauphinois Domain (Maritime Alps, Liguria, Italy)

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Key words: acervulinid macroids, rhodoliths, Eocene, Alpine foreland basin, Nummulitic Limestone, carbonate ramp facies

ABSTRACT

The Eocene Nummulitic Limestone of the Dauphinois domain in the Argentina Valley (Maritime Alps, Liguria, Italy) is characterized by the local presence of carbonate ramp facies rich in acervulinid macroids, rhodoliths and larger foraminifera. The development of these particular facies is mainly controlled by palaeomorphology of the substratum, tectonics, type and amount of terrigenous supply and global sea level changes.

The Upper Cretaceous to Eocene succession outcropping in the Argentina Valley shows differences in facies and age if compared to the typical succession of the Maritime Alps:

- the Cretaceous substratum is younger (early Maastrichtian) and is followed by an unconformity that is interpreted as a submarine discontinuity surface;
- the first Eocene carbonate deposits are older (late Lutetian);
- the Nummulitic Limestone is characterized by the development of carbonate facies deposited in a deep infralittoral-circalittoral setting of a carbonate ramp, sheltered from terrigenous input; in these facies encrusting foraminifera (*Solenomeris*) replace calcareous red algae in nodules similar to rhodoliths (acervulinid macroids);
- the Nummulitic Limestone is thicker than usual, reaching 110–160 m of thickness.

The Eocene tectonostratigraphic evolution can be summarized as follow: (1) synsedimentary tectonic activity that causes the development of a carbonate ramp with an adjacent structural trough where ramp-derived bioclastic material is deposited (late Lutetian); (2) interruption of the tectonic activity and uniform deposition of deep circalittoral sediments, characterized by deepening upward trend (late Lutetian?); (3) regression indicated by an abrupt shallowing of the depositional setting (Bartonian); and (4) deepening of the depositional setting, ending with the drowning of the carbonate ramp (late Bartonian).

The evolution of the Eocene Argentina Valley succession is strongly influenced by tectonics related to the Alpine foreland basin development, but locally, and during definite time intervals, the global sea level changes could be recorded by the sediments during periods of stasis in tectonic activity. The regressive events recognized in the studied succession could be related to the sea level fall reported in the global sea level curve during the Bartonian.

RIASSUNTO

I Calcari a Nummuliti (Eocene) del dominio Delfinese, affioranti in Val Argentina (Alpi Marittime, Liguria, Italia), sono localmente caratterizzati da tipiche facies di rampa carbonatica ricche in macroidi ad acervulinidi, rodoliti e macroforaminiferi, che non sono presenti in altri settori delle Alpi Marittime. In questo lavoro sono descritte e interpretate queste facies particolari, collegando il loro sviluppo alla paleomorfologia del substrato, alla tettonica, alla tipologia e quantità di apporti terrigeni e alle variazioni del livello marino a scala globale.

L'analisi di facies e biostratigrafica ha messo in evidenza le principali differenze tra le facies affioranti in Val Argentina e la classica successione cretacico-eocenica delle Alpi Marittime:

- il substrato pre-eocenico è più giovane (Maastrichtiano inferiore) ed è seguito da una superficie di discontinuità sottomarina maastrichtiano-eocenica;
- i primi depositi carbonatici eocenici sono più vecchi (Luteziano superiore);
- i Calcari a Nummuliti sono caratterizzati dalla presenza di facies carbonatiche ricche di foraminiferi incrostanti (acervulinidi), rodoliti e macroforaminiferi, riferibili ad un ambiente deposizionale infralitorale inferiore circalitorale in cui gli apporti silicoclastici sono molto scarsi. In queste facies sono presenti noduli simili alle rodoliti (macroidi), ma in cui le alghe corallinacee sono sostituite da foraminiferi incrostanti (*Solenomeris*);
- la potenza complessiva della successione è superiore ed è compresa tra 110 e 160 m.

L'evoluzione tettonostratigrafica dell'area studiata è la seguente: (1) attività tettonica sinsedimentaria che causa la formazione di un settore di rampa carbonatica con adiacente un basso strutturale in cui viene risedimentato il materiale bioclastico proveniente dalla rampa (Luteziano superiore); (2) interruzione dell'attività tettonica e deposizione uniforme di sedimenti di ambiente circalitorale inferiore, caratterizzati da un trend di approfondimento (Luteziano superiore?); (3) regressione indicata da una marcata diminuzione di profondità nell'ambiente deposizionale (Bartoniano); (4) nuovo approfondimento che si conclude con l'annegamento della rampa carbonatica (Bartoniano superiore).

La successione studiata in Val Argentina è fortemente condizionata dalla tettonica connessa allo sviluppo del bacino di avanfossa alpino. Tuttavia, all'interno della successione eocenica è riconoscibile una regressione; questa può essere ricollegata alla caduta del livello marino riportata nelle curve di variazione del livello marino nel Bartoniano e registrata nei sedimenti in un momento in cui l'attività tettonica era meno influente.

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Introduction

This paper reports a peculiar carbonate succession characterized by a fossil assemblage rich in encrusting foraminifera, larger foraminifera and calcareous red algae, occurring in the Eocene Nummulitic Limestone (NL) of the Dauphinois Domain in the Argentina Valley area (Maritime Alps, Liguria).

In the Maritime Alps, the NL is Middle Eocene in age (Lanteaume 1990) and represents the first marine deposit of the SE sector of the Alpine foreland basin (Ford et al. 1999). The NL is up to 100 m thick and unconformably overlies Upper Cretaceous (Santonian-Campanian, Sturani 1969; Varrone 2004) pelagic marly limestones. It consists of mixed siliciclastic-carbonate sediments deposited in a ramp environment (Sinclair 1998) with dominant siliciclastic content. These Eocene sediments are well known for their rich well preserved larger foraminiferal (*Nummulites*) fauna.

Detailed studies of the Middle Eocene succession in the Argentina Valley have shown that in this area the sedimentological features of the NL are quite different from those sketched above for the Maritime Alps. Here the Nummulitic Limestone is represented by a thick (120 to 160 m) carbonate succession rich in encrusting foraminifera and calcareous red algae (D'Atri & Varrone 2001). These facies were reported in previous papers (Boussac 1911; Lanteaume 1968; Campredon 1972), but detailed microfacies analyses and a palaeoenvironmental reconstruction are still lacking. Moreover, the presence of encrusting foraminifera in these facies has never been reported.

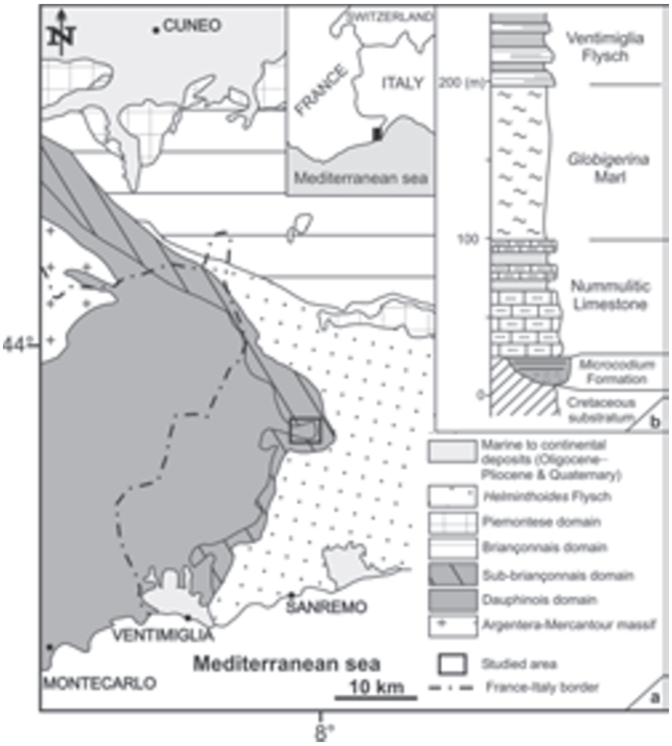

Fig. 1. a) Structural sketch map of the southern most part of the Western Alps, with location of the studied area. b) Eocene succession of the Maritime Alps.

The facies described in this work are distributed in a restricted area, but their importance is not strictly local. In fact, similar facies were described in other sectors of the Alpine foreland basin: in Haute Savoie (Sinclair et al. 1998), in the Subalpines Chains of Switzerland (Viard 1998), and in Upper Austria (Rasser 2000).

Geological setting

The studied area is located in the Maritime Alps and comprises the southeasternmost outcrops of the Dauphinois domain (Fig. 1a). In this domain, the Mesozoic succession was deposited on the European margin between the opening and the beginning of the closure of the Tethyan Ocean. During the Late Cretaceous convergence, the Tethyan oceanic crust, together with its sedimentary cover, was involved in the Alpine accretionary wedge that overthrusted the European margin. The lithospheric flexure resulting from collision acted upon a previously stretched continental margin and produced the Alpine foreland basin (Ford et al. 1999). The Paleogene sediments of the Dauphinois domain were deposited during the early stages of subsidence of the underfilled Alpine foreland basin (Allen et al. 1991). A basal unconformity separates the Mesozoic sediments (Santonian to Campanian in age) from the Paleogene foreland basin fill. This discontinuity surface is characterized by evidence for subaerial exposure and can be related to a period of significant uplift, emersion and erosion of the substratum in which some hundreds of metres of Upper Cretaceous strata were removed. This uplift can be due to the development of a forebulge ahead of the foreland basin (Crampton & Allen 1995).

In the Maritime Alps, the Paleogene sediments consist of four lithostratigraphic units (Fig. 1b): the *Microcodium* Formation, MF (Faure-Muret & Fallot 1954; Bodelle & Campredon 1968; Sturani 1969), the Nummulitic Limestone, NL (Boussac 1911), the *Globigerina* Marl, GM, and the Ventimiglia Flysch, VF (Vanossi 1991).

The MF (Lutetian?) is locally developed between the Upper Cretaceous marly limestones and the NL. It consists of up to 100 m thick lenticular bodies that can be traced laterally for 4 to 5 km. The basal discontinuity surface is characterized by the presence of *Microcodium* and paleosols indicating subaerial exposure. The main facies are nodular marls with paleosols, conglomerates and bitumen-rich mudstones (Varrone 2004). These deposits have been interpreted as incised-valley fills (Gupta 1999; Varrone & Clari 2003).

The NL (Bartonian) unconformably overlies the Upper Cretaceous marly limestones or the MF where present. The basal discontinuity surface is mantled by a lag deposit containing extrabasinal clasts and *Microcodium* fragments. This formation is 20–100 m thick and consists of arenaceous limestones, limestones rich in larger foraminifera and bioclastic quartzarenites deposited on a moderate energy, mixed siliciclastic-carbonate ramp (Sinclair et al. 1998).

The GM (Priabonian) is 10 to 80 m thick and drapes the

Table 1. Comparison between the Argentina Valley succession (Loreto-Realdo) and the typical Eocene succession of the Maritime Alps.

	Loreto-Realdo succession	**Maritime Alps Eocene succession**
Substratum age	Campanian–Maastrichtian	Upper Santonian
Cretaceous-Paleogene discontinuity	erosional surface with no evidences of subaerial exposure	erosional surface with evidence of subaerial exposure (*Microcodium*)
First Paleogene deposits	marine deposits	continental to lagoonal deposits (*Microcodium* Formation)
Lag deposits at the base of Nummulitic Limestone	substratum clasts	substratum clasts + volcanic rocks + black cherts
Terrigenous contents in Nummulitic Limestone	absent or very poor	highest of 20 to 30%, locally over 50%
Environmental energy	high	moderate to high
Package trend	two deepening upward successions	a deepening upward successions
Depositional environment	inner-middle ramp	inner-middle ramp
Dominant fossil group	encrusting foraminifera, calcareous red algae, larger foraminifera	larger foraminifera
Nummulitic Limestone thickness	120 to 160 m	ca. 20–100 m

NL. This unit consists of bioturbated hemipelagic marls rich in planktonic foraminifera, deposited in a deep water setting (Allen et al. 1991). Various bathymetric indicators demonstrate that the top of the GM represents the time of maximum water depths in the Eocene succession (Sinclair 1997).

The Ventimiglia Flysch (lateral equivalent of the Grès d'Annot, Stanley 1961, Priabonian–Lower Oligocene) consists of a thick turbidite succession. It represents the end of sedimentation in this sector of the Alpine foreland basin (Ford et al. 1999).

Argentina Valley succession

The Argentina Valley succession shows significant differences with the typical succession of the Maritime Alps (Table 1).

In the Argentina Valley, a well developed Eocene transgressive succession crops out resting over a Cretaceous substratum made up of hemipelagic deep-water marly limestones in cm to dm-thick beds. The discontinuity surface separating the Cretaceous substratum from the overlaying units is a slight angular unconformity represented by a sharp and slightly undulating surface without evidence of subaerial exposure, such as *Microcodium*, paleosols and/or karstification evidence. The presence of a submarine discontinuity surface differentiates the Argentina Valley succession from the common Dauphinois succession of the Maritime Alps where the Cretaceous–Eocene discontinuity surface always corresponds to an emersion, as indicated by the presence of *Microcodium* and/or paleosols, in place or in fragments (Varrone 2004).

The Eocene succession consists of NL passing upwards to the hemipelagic GM. The NL of the Argentina Valley is made up of 120–160 m thick limestones rich in encrusting foraminifera and calcareous red algae that, in some intervals, became the dominant fossil groups. These facies, that are the object of the present paper, crop out in the Realdo and Loreto areas (Fig. 2); the same facies are also present in southernmost areas (Colle Melosa).

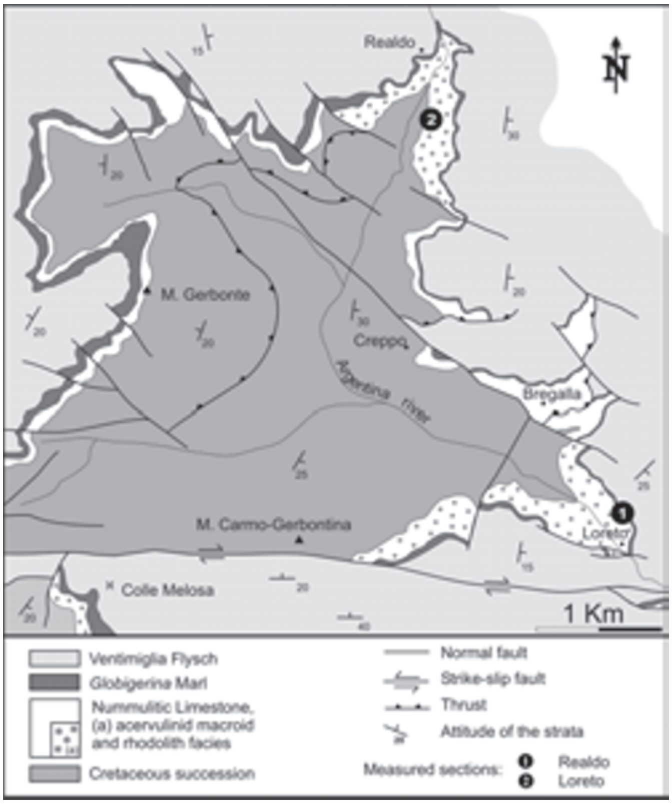

Fig. 2. Simplified geological map of the studied area with location of the stratigraphical sections.

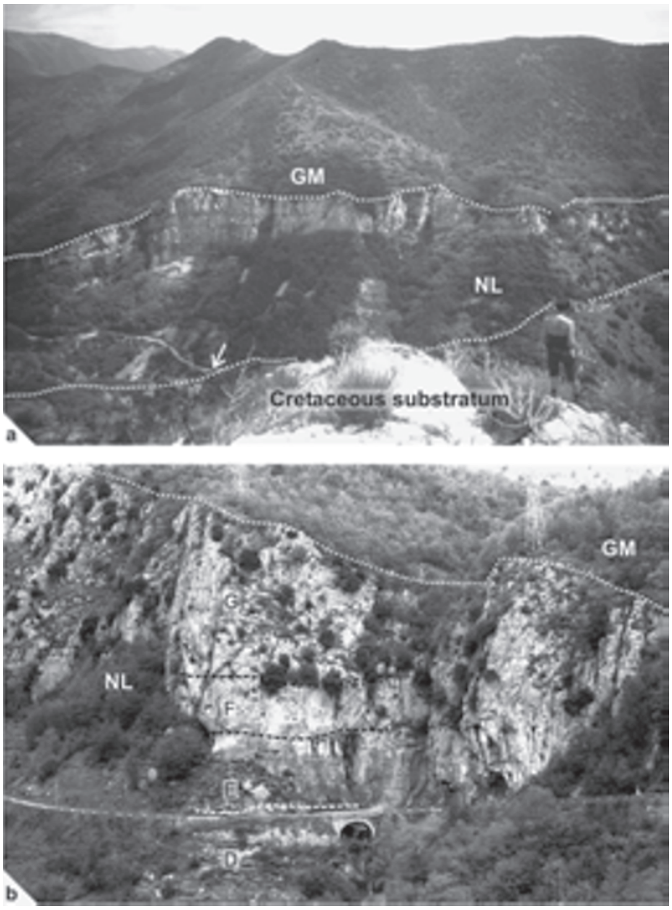

Fig. 3. Panoramic view of the studied sections. a) Realdo section; the arrow indicates the base of the section. b) Loreto section. Letters D to G indicate facies and facies associations. Abbreviations: GM, *Globigerina* Marl; NL, Nummulitic Limestone.

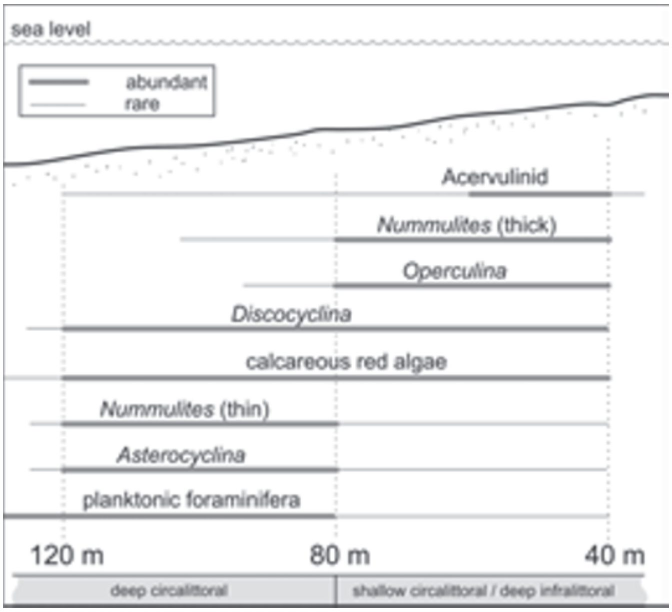

Fig. 4. Palaeobathymetrical distribution of the main Eocene fossil groups used in the present work.

Methods

The studied succession, cropping out in an area of about 30 km^2, was mapped at a 1:10.000 scale (Fig. 2). Two sections (Realdo and Loreto) were measured and sampled (Fig. 3). Fossil content, diagenetic characteristics and petrography of the siliciclastic fraction were observed in 73 acetate peels, 132 polished slabs, 35 thin sections and 10 smear slides obtained from 74 samples. Biostratigraphic analyses were carried out on larger foraminifera (microscope observation of oriented sections on polished surfaces and thin sections), planktonic foraminifera (thin sections) and calcareous nannofossils (smear slides). The Cretaceous–Paleocene biostratigraphy is based on the schemes of Premoli Silva & Sliter (1995) for Cretaceous planktonic foraminifera, Serra-Kiel et al. (1998) for larger foraminifera, and Martini (1971) for calcareous nannofossils.

Due to the lack of diagnostic sedimentary structures, the palaeoenvironmental interpretation of the described facies is mainly based on the palaeoecological significance of the fossil assemblage. Sorting and shell morphology of the larger foraminifera (Nummulitidae and encrusting foraminifera), abundance of planktonic foraminifera and characteristics and distribution of the macrofossil association (mainly larger foraminifera, encrusting foraminifera and calcareous red algae) have been evaluated. A synthesis of the palaeobathymetric distribution of the macro- and microfauna described in this work is reported in Figure 4.

According to Hottinger (1983a, 1997), during the Middle Eocene the larger foraminifera living between 20 and 120 m depth are characterized by depth-controlled shell morphologies. The shell morphology shows a flattening from shallow to deep environments with the following distribution:

a) conical/discoidal foraminifera such as *Fabiania* (high water energy and/or hard substrate) or *Orbitolites* (low water energy and/or soft substrate) (< 40 m);
b) thick lenticular foraminifera such as *Nummulites*, associated with *Operculina* and *Discocyclina* (ca. 40 to 80 m);
c) thin lenticular *Nummulites* and flat lenticular/discoidal foraminifera such as *Discocyclina* and *Asterocyclina* (ca. 80 to 120 m).

Brasier (1980) indicates that the planktonic foraminifera are usually abundant at water depths greater than 80–100 m. At water depth greater than 120 m, where larger foraminifera do not live, planktonic foraminifera represent the dominant group in the fossil association (Fig. 4).

The sediments characterized by assemblages rich in larger foraminifera, encrusting foraminifera and calcareous red algae (rhodalgal assemblages *sensu* Carannante et al. 1988; heterozoan associations, facies rhodalgal sensu James 1997) can be interpreted with the aid of the classic zonation of Mediterranean benthonic assemblages of Pérès and Picard (1964). This distinguishes biocenoses distributed in discontinuous belt parallel to the coast line. The deep infralittoral/shallow circalittoral bottoms (at depths of 40–80 m) are mantled by bioclastic material characterized by low sedimentation rate (*détritique côtier* sediments, DC). DC sediments consist of bioeroded and fragmented tests of macrofossils derived from bioerosion and mechanical break down of local and neighbouring biocenoses accumulated in lowered sectors of the ramp. Bioclastic sediments rich in rhodoliths are abundant in areas exposed to strong currents (*faciès à pralines* of the DC biocenosis), while locally facies consisting of encrusting forms (mainly red algae and bryozoans) characterize sectors of hard bottoms (*coralligène de plateau* biocenosis). In circalittoral environments deeper than 120 m (deep circalittoral) and characterized by an abundant terrigenous supply, the sediments consist of marls and/or siltstones interbedded to storm layers consisting of resedimented bioclastic material derived from inner sector of the shelf.

Locally the fossil association of the studied succession is dominated by encrusting foraminifera. The encrusting foraminifera represent a poorly known group. Some encrusting foraminifera (Acervulinidae) form cm-dm nodules similar to rhodoliths (foraminiferal macroids sensu Hottinger 1983b; acervulinid macroids sensu Rasser 1994). In some present-day examples (Hottinger 1983b), they are the main encrusting forms in competition with calcareous red algae and bryozoans on the hard bottoms and in high energy conditions. In these cases the foraminiferal macroids are supported by a matrix consisting of bioclastic sand without a pelitic fraction and form discontinuous belts at depths of 40 and 60 m (Hottinger 1983b).

The acervulinid macroids present in the studied facies are mainly formed by the encrusting foraminifera *Solenomeris*. *Solenomeris*, in the past considered a calcareous red algae or *incertae sedis*, is now considered an acervulinid foraminifera (Plaziat & Perrin 1992; Perrin 1994). Acervulinidae are opportunistic encrusting foraminifera that seem to live in hydrodynamic and water depth conditions similar to that in which coralline algae flourish, replacing them when low light levels (due to major depth or increase of water turbidity) are unfavourable to the growth of coralline algae (Perrin 1992; Rasser 1994). Acervulinid macroids could thus be formed in high energy conditions (Perrin 1994), in environments similar to that of the "*faciès à pralines*" (sensu Pérès & Picard 1964) and of the rhodalgal facies (sensu Carannante et al. 1988).

Facies analysis

In the Eocene succession of the Argentina Valley different facies and facies associations have been recognized and grouped in 3 main depositional intervals indicating important changes in the depositional framework (Fig. 5). For each facies and facies association, macro- and microscopic characteristics are described and a palaeoenvironmental interpretation is proposed.

The facies and facies associations are characterized by fossil assemblages (dominated by larger foraminifera, encrusting foraminifera and calcareous red algae), that can be ascribed to a heterozoan association (sensu James 1997) and to a rhodalgal assemblage (sensu Carannante et al. 1988).

Depositional interval 1

The base of the depositional interval 1 is a poorly evident submarine discontinuity followed, in the two studied sections, by different facies and facies associations.

(A) Lag deposit

It consists of clast-supported conglomerates overlying an irregular discontinuity surface characterized by firm ground bioturbations. It contains cm-sized rounded clasts of Cretaceous marly limestones and subordinately of foraminiferal-algal limestones (facies C), in a matrix consisting of foraminiferal grainstones to packstones with scarce quartz grain content. The fossil content is represented by larger foraminifera (*Nummulites*, *Discocyclina*), pyritized biserial benthonic foraminifera, planktonic foraminifera (*Morozovella*) and micritized calcareous red algae. The lag deposit, present in the Realdo section (Fig. 5), is connected to an offshore marine erosion surface (sensu Nummedal & Swift 1987).

(B) Paraconglomerates and pelitic marls

This facies association consists of chaotic sediments composed of heterometric, poorly sorted paraconglomerates with rounded clasts from pebble- to boulder-size in a pelitic matrix (Fig. 6a), followed by some metres of poorly exposed thin-bedded pelitic marls. The paraconglomerate bodies, up to 3 m thick, have a lenticular geometry. The clasts are represented by Cretaceous marly limestones and subordinate Eocene foraminiferal-algal limestones (facies C). The matrix contains a planktonic foraminifera assemblage represented by *Turborotalia*, *Subbotina* and *Acarinina.* A rich content in reworked bio- and lithoclasts is also present, among which:

- cm-sized fragments of larger foraminifera (*Operculina*, *Nummulites*, *Discocyclina*, *Actinocyclina*, *Asterocyclina, Rotalia*), encrusting foraminifera (*Chapmanina*, *Miscellanea*), echinoids, calcareous red algae, bryozoa, serpulids, *Dentalium* and *Inoceramus* prisms;
- mm-sized clasts of Cretaceous mudstones containing *Globotruncana arca*, *G.* sp. (Fig. 6b) and biserial benthonic foraminifera;
- Cretaceous reworked planktonic foraminifera;
- mm-sized clasts of packstones (foraminiferal algal limestone, facies C);
- scarce mm-sized well rounded quartz grains.

The sedimentological characteristics of the facies and its scarce lateral continuity, suggest that facies association B cropping out in the Loreto section (Fig. 5) can be interpreted as debris flow deposits.

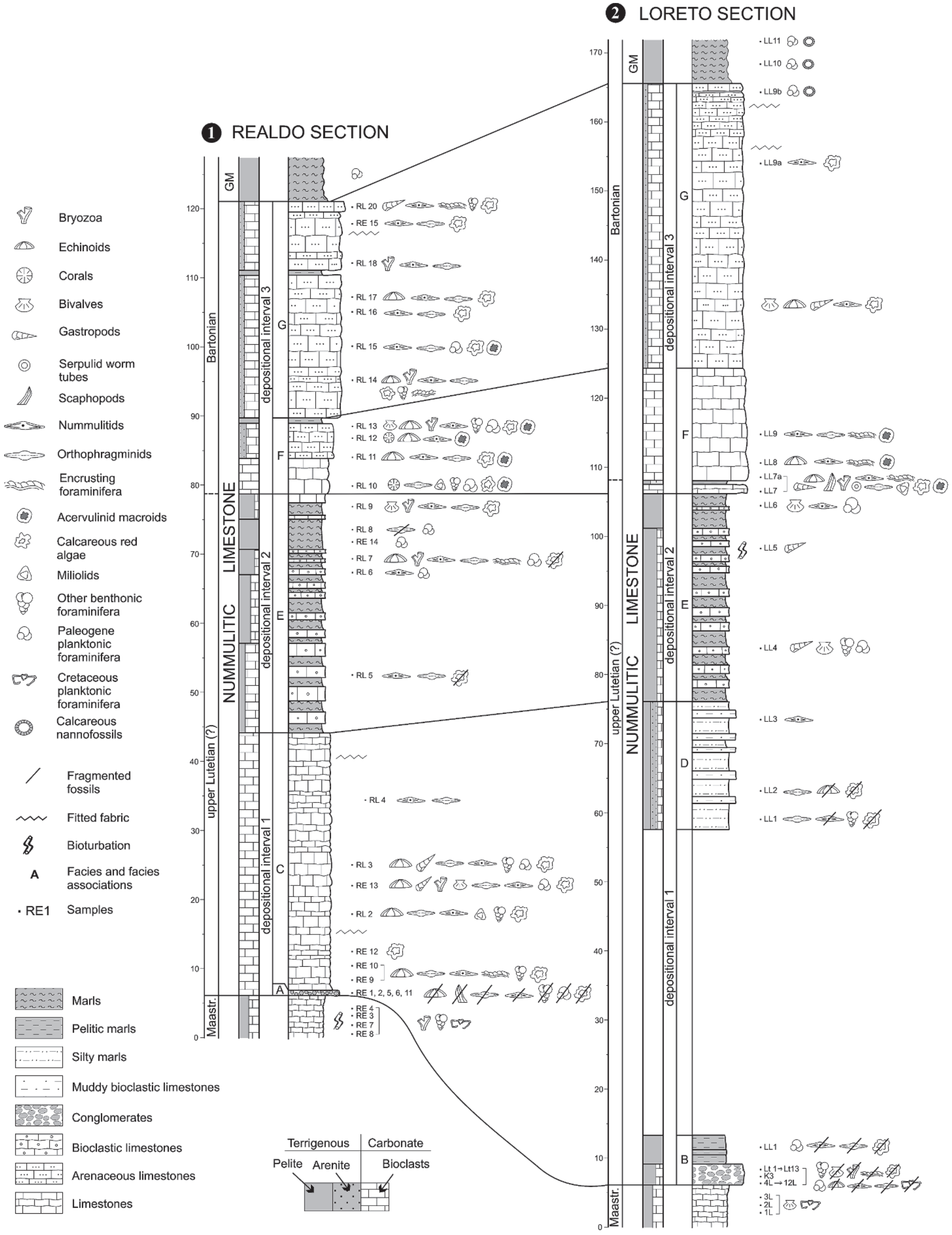

Fig. 5. Stratigraphical logs of the Realdo and Loreto sections, showing lithological features, facies, facies associations, depositional intervals, fossil assemblages and position of the studied samples.

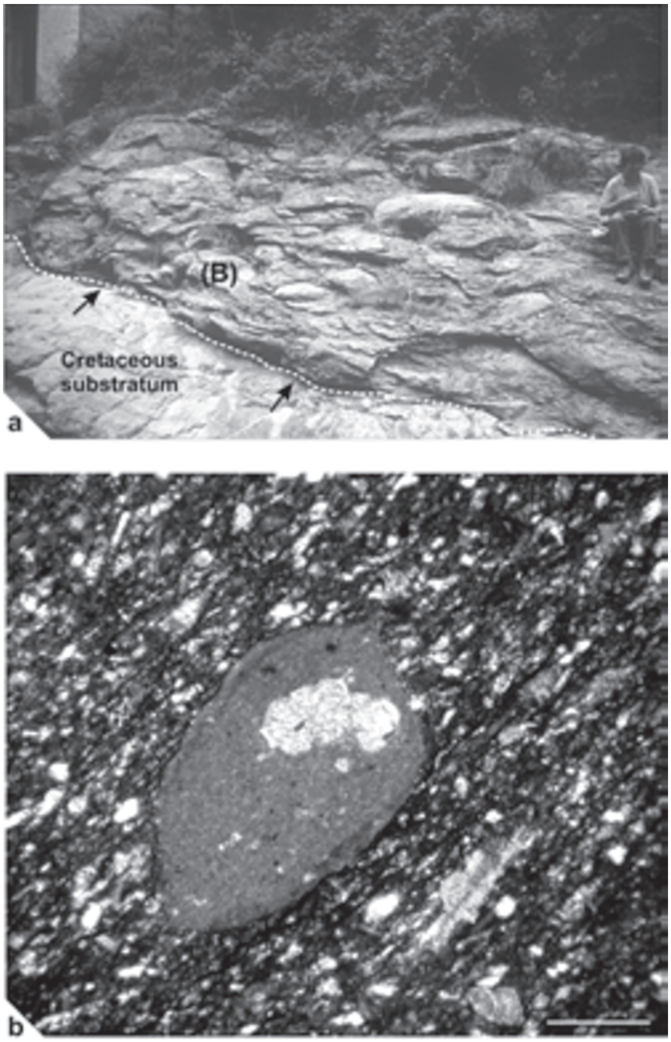

Fig. 6. Facies association B, Loreto section. a) Paraconglomerates containing metre-sized blocs in a pelitic matrix resting over the Cretaceous substratum; the arrows indicate the discontinuity surface. b) Paraconglomerate pelitic matrix containing a clast of Cretaceous mudstone with *Globotruncana*, larger foraminifera fragments and quartz-grains. Scale bar: 0.2 mm (b)

(C) Foraminiferal-algal limestones

Homogeneous limestones characterized by a well-defined, dm-thick bedding (Fig. 7a). Some beds are marked, at the base, by an evident concentration of coarse and abraded bioclasts. A siliciclastic sand-sized content less than 5% is present, consisting of quartz single grains.

In thin section they are grainstones to packstones characterized by scarce early cementation and an evident fitted fabric (Fig. 7b). The fossil assemblage consists of: *Nummulites* gr. *perforatus* (probably *Nummulites aturicus)*, *Nummulites* sp., Rotaliidae, *Discocyclina*, *Gypsina*, *Orbitolites*, encrusting foraminifera, bivalves, echinoid spines, fragments of calcareous red algae, small gastropods, bryozoans, benthonic (Miliolidae, arenaceous and hyaline forms) and rare planktonic foraminifera (*Subbotina*?). Most of the bioclasts are abraded and fragmented.

The larger foraminiferal assemblage, dominated by thick lenticular forms (*Nummulites*) indicates a deep infralittoral/shallow circalittoral setting (ca. 40 to 80 m). The presence of shallow water foraminifera (as *Orbitolites* and Miliolidae), indicates a transport from the inner sector of the ramp. These limestones can be interpreted as bioclastic deposits referable to *détritique côtier* sediments (DC, sensu Pérès & Picard 1964). Facies C follows facies A in the Realdo section.

(D) Muddy bioclastic limestones alternating with bioclastic silty marls

This facies association consists of dm-thick, well-stratified bioclastic limestones with abundant pelitic matrix separated by dm-thick bioclastic silty marls (Fig. 5). The muddy bioclastic limestone layers are characterized by an evident normal grading and by a preferred orientation of the bioclasts.

In thin section (Fig. 7c), the fossil assemblage of both muddy bioclastic limestones and bioclastic silty marls consists of larger foraminifera (*Asterocyclina*, *Discocyclina, Gypsina* and scarce *Nummulites*), echinoid spines, fragments of calcareous red algae, gastropods and benthonic foraminifera. The larger foraminifera assemblage of the bioclastic silty marls, dominated by forms with flat lenticular to discoidal shell morphology (*Operculina*, *Discocyclina*), indicates a deep circalittoral setting (ca. 80–120 m). The biocalcarenite layers can be interpreted as sediments derived from inner areas and transported offshore by storm currents. Facies association D follows facies association B in the Loreto section.

Depositional interval 2

A single facies association present in both sections characterizes the depositional interval 2.

(E) Bioclastic limestones alternating with marls

This facies association consists of dm-thick bioclastic limestones with regularly interbedded cm-thick bioturbated marly layers (Fig. 7d). The pelitic content appears lesser than in facies association B. The bioclastic limestones decrease in thickness and frequency upward.

In thin section (Fig. 7e), the calcareous layers are well-sorted grainstones and floatstones in a microbioclastic matrix. The bioclasts are represented by larger foraminifera (thin *Nummulites*, *Actinocyclina* and *Discocyclina*), echinoid spines, fragments of calcareous red algae, encrusting foraminifera (*Miniacina* and *Placopsilina*), gastropods, bryozoa, serpulid worm tubes, benthonic and planktonic foraminifera.

In the marly layers the fossil content is represented by planktonic (*Turborotalia*, *Acarinina pseudobullbrooki*, *Globigerinatheka senni*) and rare benthonic foraminifera. The

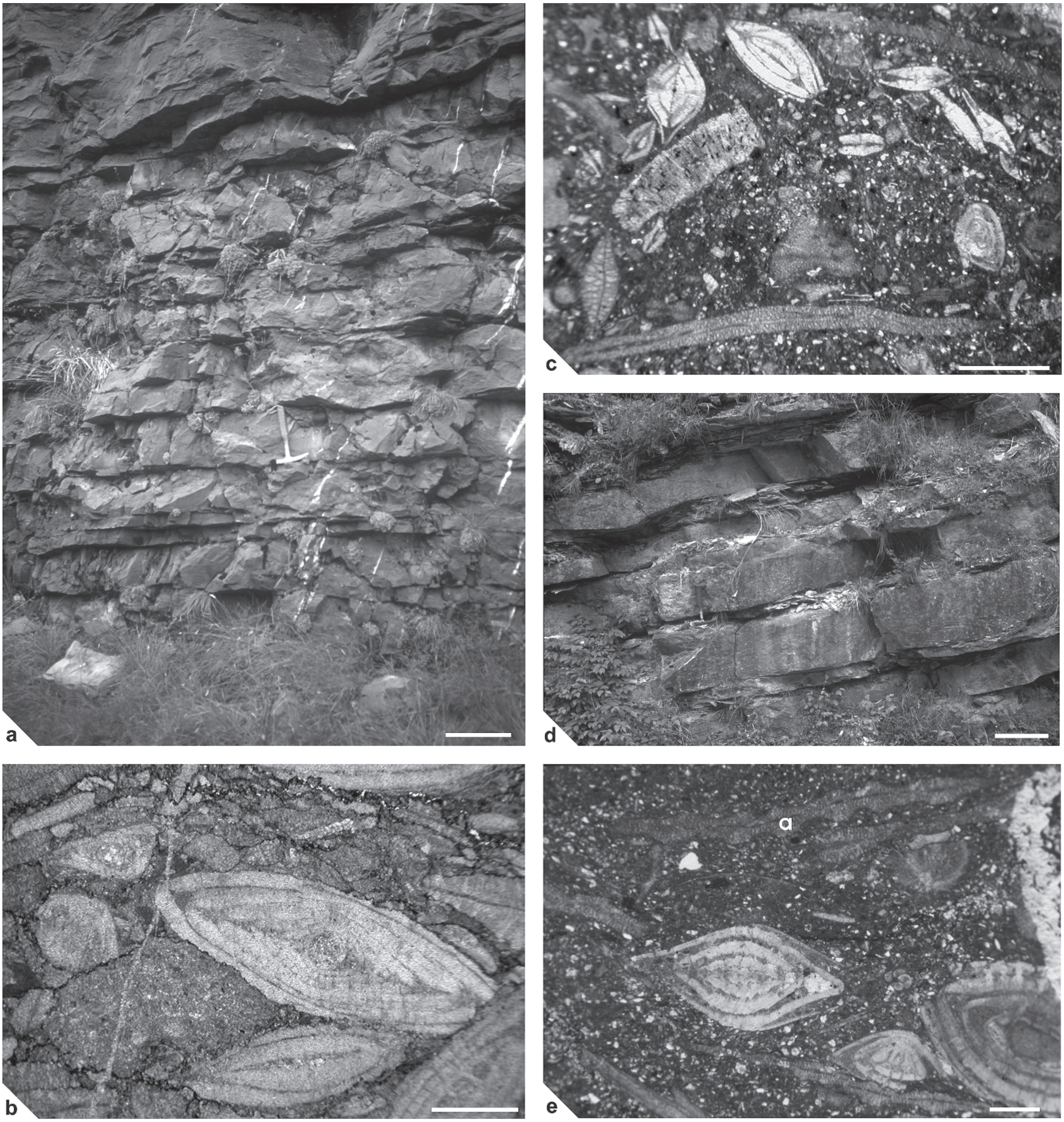

Fig. 7. a) Foraminiferal algal limestones (facies C) with dm-thick bedding, Realdo section. b) Nummulite-rich limestones characterized by fitted fabric, Realdo section, facies C. c) Floatstones rich in larger foraminifera (orthophragminids and *Nummulites)* with pelitic matrix, Loreto section, facies association D. d) Bioclastic limestones alternating with marls, Realdo section, facies association E. e) Floatstones in a microbioclastic matrix (facies association E), Realdo section; the bioclasts consist of *Actinocyclina* ("a") and *Nummulites*. Scale bars: 0.5 mm (b); 1 mm (c, e); 30 cm (a, d).

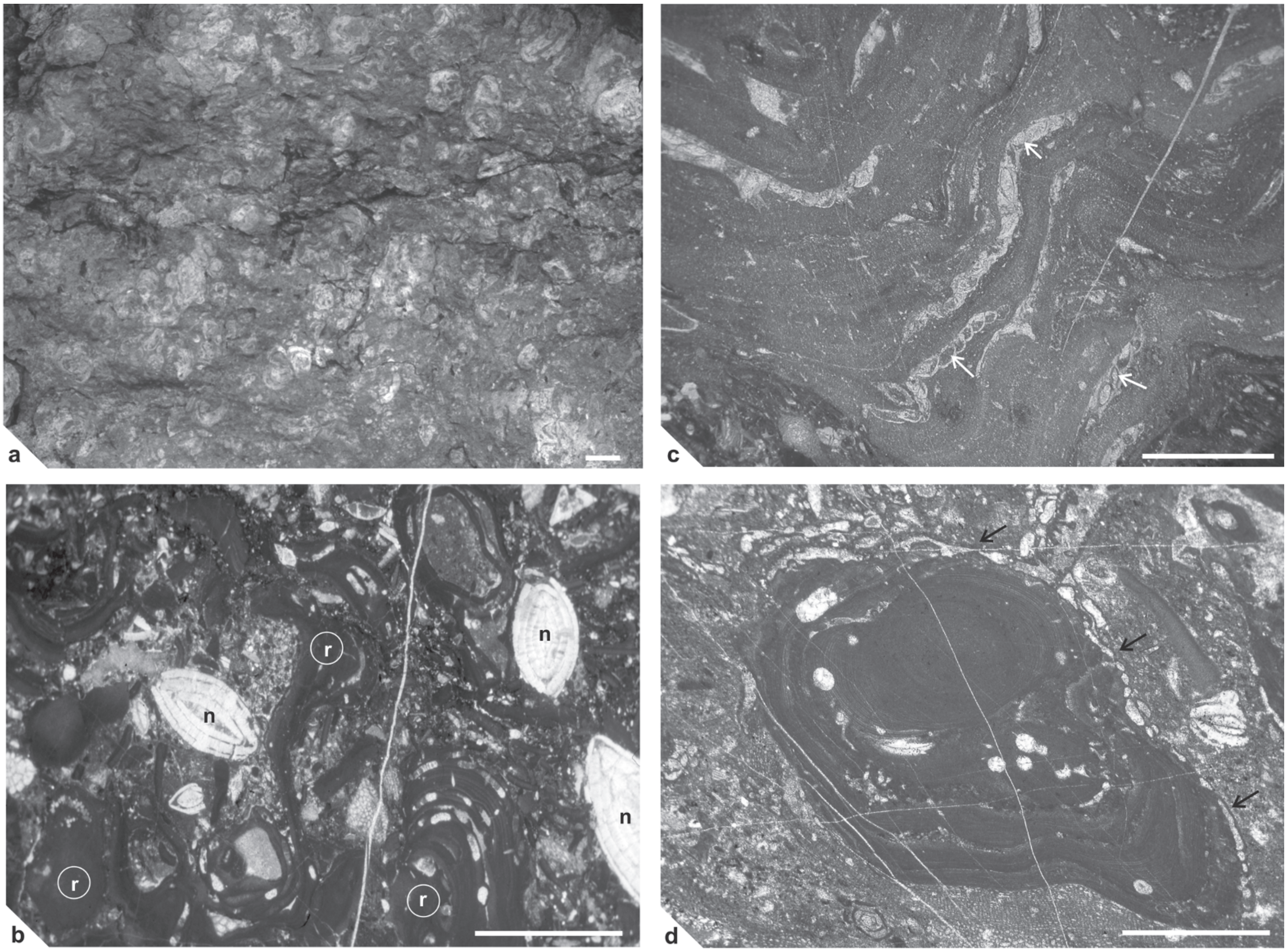

Fig. 8. Encrusting foraminifera-algal limestones (facies F), Loreto section. a) Acervulinid macroids and rhodolith rudstones with a scarce matrix. b) Facies F in thin section: calcareous red algae ("r") and *Nummulites* ("n"). c) Detail of an acervulinid macroid, consisting of *Solenomeris* alternated with the encrusting foraminifera *Placopsilina* (arrows). d) Encrusting foraminifera (arrows) growing on a rhodolith. Scale bars: 0.5 cm (b–d); 3 cm (a).

presence, however, of planktonic foraminifera, more abundant than in A, B and C, indicates a deeper environment.

The facies association E is referable to deep circalittoral settings (ca. 80–120 m). The bioclastic layers could represent sediment produced in inner sectors of the carbonate ramp and resedimented by storm currents. The lesser pelitic content than in underlying deposits (B and D) indicates a decrease of siliciclastic input probably due to the deeper depositional setting and/or to a change in the sediment distribution pattern of coastal currents.

Depositional interval 3

Depositional interval 3 is separated from interval 2 by a sharp discontinuity surface. Above the discontinuity surface a 10–15 cm thick layer of coarse grained abraded and fragmented bioclasts is present. The depositional interval 3 groups two facies, observed in both sections.

(F) Encrusting foraminifera-algal limestones

This facies consists of thick-bedded rudstones rich in acervulinid macroids and rhodoliths (Fig. 8a). The rudstone matrix consists of scarce bioclastic material; locally in the matrix a siliciclastic silty and arenitic fraction is present (Realdo section). The fossil association (Fig. 8b) consists of encrusting foraminifera, larger foraminifera (*Nummulites perforatus*, *N. striatus*, *N.* gr. *brongniarti, N. dufrenoyi?*, *Discocyclina*, *Actinocyclina*, *Asterocyclina, Asterigerina*, *Rotalia*, *Sphaerogypsina)*, calcareous red algae, solitary corals, miliolides, gastropods, echinoid spines, fragments of bryozoans, sponge spicules, *Dentalium* and serpulids.

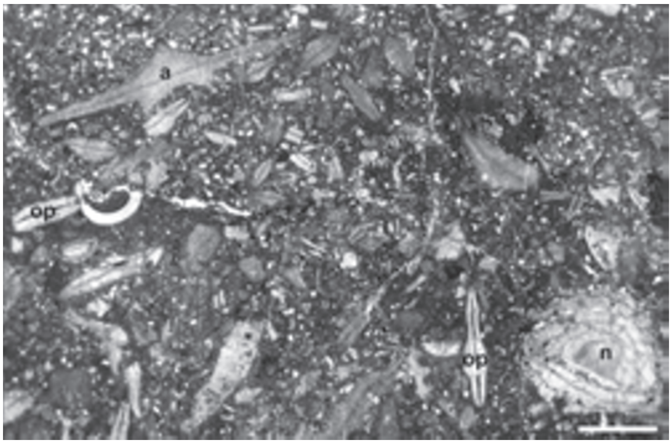

Fig. 9. Foraminifera-mollusc arenaceous limestones in thin section (facies G), Realdo section. Floatstones to rudstones with a fossil assemblage rich in *Asterocyclina* ("a"), *Nummulites* ("n"), *Operculina* ("op"), orthophragminids and benthonic foraminifera. Scale bar: 1 mm.

This facies is characterized by the abundance of encrusting foraminifera (*Solenomeris, Placopsilina*, *Miniacina*, *Silvestriella*, Figs. 8c, d). *Solenomeris* forms macroids characterized by columnar morphology (sensu Bosence 1983). In some macroids, layers of coralline algae are alternated with *Solenomeris*. Locally *Placopsilina*, *Miniacina* or *Silvestriella* are intercalated to *Solenomeris* or encrusting coralline algae.

The algal association (Figs. 8b, d) is dominated by nongeniculate coralline algae, in particular *Mesophyllum*, *Sporolithon* and rare *Lithoporella*, in fragments or as rare rhodoliths. The rhodoliths are multispecific and have a predominant laminar-columnar morphology (sensu Bosence 1983). The presence of *Sporolithon* indicates a moderately deep environment and sciaphilic conditions (Fravega et al. 1989; Rasser 1994).

The presence of *Nummulites*, rhodoliths and the abundance of acervulinid macroids indicate deep infralittoral/shallow circalittoral settings (ca. 40–80 m).

(G) Foraminifera-mollusc arenaceous limestones

This facies consists of rudstones and floatstones containing a siliciclastic arenite fraction (10–15%) with more than 5% of quartz composite grains. The matrix is represented by very fine bioclastic material and siliciclastic silt. This facies is organized into m-thick massive beds. The fossil assemblage (Fig. 9) consists of larger foraminifera (*Nummulites perforatus*, *N. striatus*, *N.* sp., *Discocyclina*, *Asterocyclina*, *Operculina*, *Sphaerogypsina globulus*, *Rotalia* sp.), encrusting foraminifera (*Miniacina*, *Placopsilina*, *Haddonia*), calcareous red algae, bryozoa, *Ostrea*, gastropods, echinoid fragments and benthonic foraminifera.

These sediments show compositional characteristics similar to facies C and can be interpreted as deposits of the *detritique côtier* – type. The absence of acervulinid macroids in facies G indicates a deeper environment than facies F.

Some metres of whitish grainstones to rudstones with well-sorted, abraded skeletal debris (larger foraminifera, calcareous red algae and gastropods) are locally present at the top of facies G. These deposits, characterized by absence of fine matrix, high fragmentation of the skeletal remains and high granulometric sorting of the sediment, indicate intensive winnowing processes and a reduction of the carbonate production, probably connected to rapid relative sea level rise.

Biostratigraphical data

The planktonic foraminifera association recognized in the upper part of the Cretaceous succession is represented by *Globotruncanita* sp., *G. stuarti*, *Globigerinelloides* sp., *Globotruncana lapparenti*, *G. linneana*, *Marginotruncana* (?), *Planomalina buxtorfi*. This association is referable to the *Ganserrina ganserri* p.p. and *Contusotruncana contusa-R. fructicosa* Zones of Premoli Silva & Sliter (1995), early Maastrichtian in age, in accordance with previous data (Campredon & Portault 1971). The top of the Cretaceous succession in the Argentina Valley is thus younger than in other sectors of the Maritimes Alps, where it is Santonian to Campanian (Sturani 1969; Varrone 2004).

The NL succession of the Maritime Alps is generally referred to Middle–Upper Eocene (Blondeau et al. 1968; Lanteaume 1990). The biostratigraphical data presented here allow a more precise attribution.

In the depositional interval 1, a low number of *Nummulites* tests (*N. aturicus* ?) recognized only in facies C seems to indicate the SBZ 16 Zone of Serra Kiel et al. (1998) (late Lutetian). Depositional interval 2 cannot be dated because biostratigraphically significant forms are not present. Depositional interval 3 is referable to the SBZ 17-SBZ 18 Zones of Serra Kiel et al. (1998) (Bartonian) due to the occurrence of *Nummulites perforatus* and *N. striatus*. The larger foraminifera biostratigraphic data indicates that in the Argentina Valley shallow water carbonate sedimentation begins earlier (late Lutetian) than in other sectors of the Maritime Alps.

In the GM, the fossil content is composed by *Globigerina*, Rotaliacea and calcareous nannofossils. The calcareous nannofossil content is very poor and characterized by rare *Cribrocentrum reticulatum*, *Lanternithus minutus*, *Dictyococcites hesslandi* and *D. bisectus*. This association is not diagnostic, but indicates the NP17-NP18 Zones (Martini 1971), late Bartonian-early Priabonian in age (Berggren et al. 1995).

Discussion

The classical Eocene succession of the Maritime Alps rests on the Cretaceous substratum over a subaerial discontinuity surface corresponding to a hiatus of about 40 My (upper Santonian–Lutetian). The formation of this discontinuity surface is due to important deformation and emersion of the Cretaceous substratum related to the development of the Alpine foreland basin forebulge (Crampton & Allen 1995).

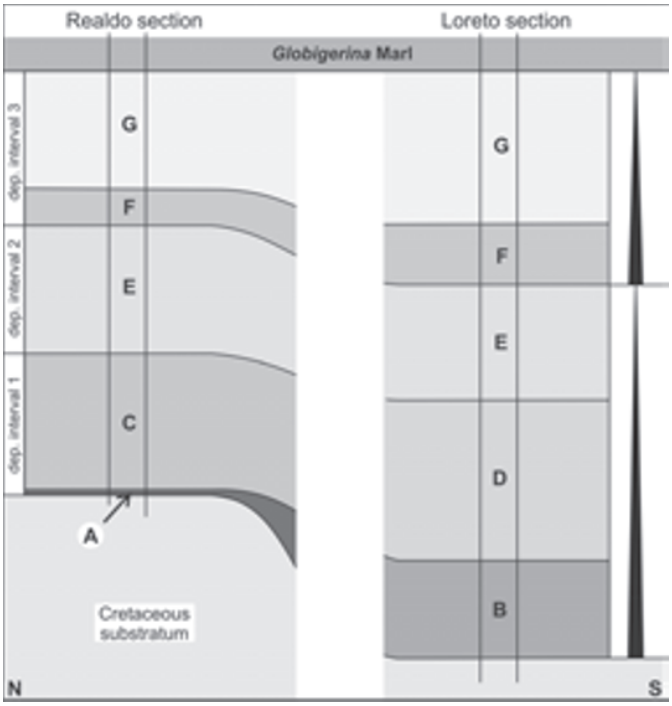

Fig. 10. Scheme of the stratigraphical relationships between the studied sections. Letters A to G indicate facies and facies association. On the right, the two recognized deepening upward successions are indicated.

Conversely, in the Argentina Valley (Loreto and Realdo sectors), the Mesozoic–Cenozoic succession is characterized by a stratigraphic gap of about 22 My, separating the early Maastrichtian pelagic succession from the late Lutetian carbonate sediments. This gap is revealed by an unconformity that shows no evidence of subaerial exposure, related to the deformation (without emersion) of the Cretaceous succession. It can be inferred that in the Argentina Valley, emersion was opposed by extensional faulting probably located in the frontal bulge zone that could be also responsible for the observed thickness and facies variations.

In the Argentina Valley, the basal discontinuity surface is followed by carbonate ramp deposits that have been grouped in 3 depositional intervals. These intervals consist of different facies and facies association showing a different vertical distribution in the two studied sections (Fig. 10). Interval 1 is characterized by facies associations A and C, in the Realdo section, and by facies association B and D, in the Loreto section. Depositional intervals 2 and 3 consist of facies and facies associations present in both sections, although with different thickness, indicating a relative consistency of the depositional setting.

In the Loreto area, the basal submarine discontinuity surface is followed by debris flow deposits (B) involving reworked clasts of Upper Cretaceous marly limestones and Middle Eocene carbonate ramp sediments. The presence of these Eocene clasts in the debris flow deposits indicates the previous development of a carbonate ramp in adjacent areas. The debris flow deposits are followed by a succession characterized by an alternation of resedimented muddy bioclastic limestones with shallow water bioclasts and bioclastic silty marls deposited in deep circalittoral settings (D), probably late Lutetian in age. In the same time interval, the Realdo area was located on a structural high. Here the basal discontinuity surface (also in this case without evidence of subaerial exposure) is mantled by a submarine lag deposit (A), followed by foraminiferal-algal limestones (C). These latter are referable to the loose bioclastic bottoms of the deep infralittoral/shallow circalittoral stage (DC sediments, sensu Pérès & Picard 1964), and indicates an environment sheltered from terrigenous input. The differences between C and D indicate that, while in the Realdo sector a carbonate ramp was developing, the Loreto area was situated in deeper water conditions, where storm-related resedimentation of bioclastic material from adjacent high areas took place. The presence of the Loreto trough can be related to the activity of synsedimentary faults.

A more uniform depositional setting may be inferred for the facies and facies associations pertaining to the depositional interval 2, occurring in both Loreto and Realdo sections. Facies association E consists of alternating bioclastic limestones and marls deposited in the deep circalittoral stage. The composition of the fossil assemblage indicates a deep environment exceeding the depositional setting of the reworked deposits of D. On the when the vertical trend of the succession indicates a deepening upward of the depositional setting.

Deposits of the interval 2 are abruptly interrupted by a carbonate succession tens of metres thick represented by depositional interval 3, Bartonian in age. These sediments were deposited in the shallow circalittoral stage, indicating a rapid decrease in water depth. In fact, facies F (*faciès a praline*) and G (DC sediments) document a more proximal setting than depositional interval 2. The appearance of a scarce arenitic siliciclastic content in G, absent in the underlying E and F, is probably due to the migration of fluvial mouths and/or to a change in the sediment distribution pattern of coastal currents. The change of the extrabasinal fraction could be related to a modification of the source areas.

The facies F, characterized by acervulinid macroids and rhodoliths, is referable to higher water energy and a lower depth than facies G. The facies succession in the depositional interval 3 indicates a deepening of the depositional setting. The deepening upward trend ends with the drowning of the carbonate ramp (corresponding to the condensed deposits at the top of depositional interval 3) and the rapid transition to the basin deposits of the GM. These events are related to a rapid increase of the basin subsidence.

The typical NL of the Maritime Alps is characterized by a continuous deepening trend, from shallow to deep circalittoral environments (Table 1). This trend has a geodynamic origin, being related to the continuous flexural subsidence of the foreland basin (Sinclair 1997). On the contrary, in the Argentina Valley, a deepening trend interrupted by a regressive phase, not evident in the other sectors, is observed (Fig. 10). This regression can be produced by a local tectonic uplift or by a global sea level fall. During the deposition of the lower part of the succession (depositional interval 1), tectonic activity is evident (presence of the Loreto trough); from depositional interval 2 (Bartonian in age), consistency of the depositional setting indicates scarce synsedimentary tectonics. Therefore, it cannot be excluded that during this period a global sea level fall could have been recorded in the Eocene succession of the Argentina Valley. In the sea level change curves of Haq et al. (1987), an important sea level fall (about 200 m) is reported during the Bartonian; the regression recognizable in the Argentina Valley succession can be considered as the registration of this sea level fall.

As in the other sectors of the Maritime Alps, the studied succession ends with a deepening of the depositional setting, culminating with the drowning of the carbonate ramp; this final phase, always recognizable at the top of the NL, can be related to an increment of the flexural subsidence of the Alpine foreland basin.

Conclusions

In the Argentina Valley (Maritime Alps, Liguria) the Eocene Nummulitic Limestone (NL) of the Dauphinois Domain is characterized by a thick carbonate succession (110–160 m), consisting of limestones rich in encrusting foraminifera and calcareous red algae. These local and particular deposits, not yet described in previous works, have been mapped and studied from a sedimentological, micropalaeontological and biostratigraphical point of view.

In this sector, the NL rests on a lower Maastrichtian marly succession with a slight angular unconformity. This basal surface is a submarine discontinuity surface followed by lag (Realdo) or debris flow (Loreto) deposits reworking Cretaceous marly limestones and Middle Eocene carbonate platform sediments. These deposits are Middle Eocene in age.

The NL of the Realdo-Loreto area is characterized by acervulinid macroids, rhodoliths and larger foraminiferal facies (heterozoan association, sensu James 1997; rhodalgal assemblage sensu Carannante et al. 1988) deposited on a carbonate ramp. These facies indicate a deposition in a circalittoral environment sheltered from terrigenous input.

The tectono-stratigraphic evolution of the studied area can be summarized as follows:

1) Synsedimentary tectonic activity (late Lutetian?) producing the differentiation of a carbonate ramp (Realdo, A and C) and an adjacent trough (Loreto, B and D), where bioclastic material derived from the ramp is resedimented.
2) End of tectonic activity and uniform deposition of deep circalittoral sediments (depositional interval 2), with a deepening upward trend (late Lutetian?).
3) Regression (Bartonian) indicated by an evident and abrupt shallowing of the depositional setting. The previous deep circalittoral sediments are followed by shallow circalittoral facies characterized by fossil associations dominated by *Nummulites*, encrusting foraminifera and calcareous red algae (F).
4) Deepening of the depositional setting (G) ending with the drowning of the carbonate ramp and the rapid transition to the deep water GM (Bartonian). During this period, the appearance of scarce arenitic siliciclastic content is probably due to the migration of fluvial mouths and/or a change in the sediment distribution pattern of coastal currents.

The general upward deepening trend of the Eocene succession and in particular the drowning of the carbonate ramp has a tectonic origin and is related to the continuous increase of the foreland basin flexural subsidence. On the contrary, in the Argentina Valley, the regression recognisable in the NL could be related to the important sea level fall known during the Bartonian.

The geological complexity of the studied area suggests that, during the Cretaceous–Eocene interval, the palaeogeography is very complex and the tectonic activity is the major control on the palaeoenvironmental evolution. Nevertheless, it is possible that locally and during specific time intervals, the sediments can have recorded sea level fluctuations at periods of stasis in tectonic activity.

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