RECONSTRUCTION OF A LOST CARBONATE FACTORY BASED ON ITS BIOGENIC DETRITUS (TERNATE-TRAVEDONA FORMATION AND GONFOLITE LOMBARDA GROUP - NORTHERN ITALY)

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Abstract. This work reconstructs a now completely eroded late Eocene to earliest Oligocene carbonate factory of Northern Italy, through the analysis of a carbonate deep-water-fan sequence (Ternate-Travedona Formation) and the limestone detritus dispersed into the late Oligocene clastic-wedge of the Gonfolite Lombarda Group. Textural characteristics and skeletal assemblages of the Gonfolite pebbles were studied and compared to those of the Ternate-Travedona Formation. The same skeletal assemblage and the same taxa were found in samples from both areas, suggesting their common origin. Whereas the Ternate-Travedona Formation skeletal grains were reworked during transport, the Gonfolite Lombarda Group pure-limestone pebbles are pristine fragments of the carbonate platform, that was uplifted and eroded from the late Eocene to the early Oligocene. Using both these sources of information it was possible to reconstruct the late Eocene environment and its facies distribution. The areas undergoing high hydrodynamic energy were dominated by free-living coralline-algal branches, rhodoliths and larger thick-tested benthic foraminifera. A coralline framework, associated with thin-tested benthic foraminifera and boxwork rhodoliths, was present in slightly deeper and sheltered environments. Episodic debris flows, mainly triggered by river floods, supplied the sub-marine fan of the Ternate-Travedona Formation. These events were able to down-cut through the narrow platform and rip off large fragments of the substrate. River runoff probably also supplied large quantities of organic matter, leading to local oxygen-depletion and preservation of organic matter. The combined stressful effects of bottom instability and riverine discharge probably excluded corals from the association. The integrated study of the Ternate-Travedona Formation, and of the limestone pebbles in the Gonfolite Group, have enabled the reconstruction of this otherwise lost Eocene carbonate factory.

INTRODUCTION

Limestone pebbles and bioclasts within siliciclastic units are a powerful tool to assess the age of the successions and to study the provenance of the detrital flux to the basin (e.g., Ulrich 1927; Bradshaw 1973; Palmer et al. 1984; Ueno et al. 1994; Armstrong et al. 2000; Kobayashi 2003; Pirkenseer et al. 2011; Fabbi et al. 2013; Fabbi & Rossi 2014). The same detrital elements are also very useful for paleoecological reconstruction whenever the source area is lost or unobservable (e.g. Giammarino et al. 1970). Shallow-water skeletal elements transported basinward are also a potential tool in reconstructing the lost carbonate factories since they might provide information on the environment where they were produced (Nebelsick et al. 2001; Rasser & Ne-

belsick 2003; Basso et al. 2012; Leszczyński et al. 2012; Coletti et al. 2015). This is especially useful in active, compressional tectonic settings, where short-lived small carbonate platforms develop on topographically high areas over thrust sheets and where resedimentation is frequent (Carannante et al. 1996; Bosence, 2005).

Using both limestone pebbles and transported skeletal-grains this study aims to unravel the paleoecological characteristics and the depositional history of a completely eroded late Eocene to earliest Oligocene carbonate factory that developed in front of the Southalpine Cretaceous belt (Zanchetta et al. 2012). The study of limestone pebbles and cobbles of Eocene age, included in the Alpine Foredeep clastic sequences of the Como Conglomerate Formation (lower part of the Gonfolite Lombarda Group; Bernoulli et al. 1989; Di Giulio et al. 2001; Di Capua et al. 2015), was complemented with the analysis of
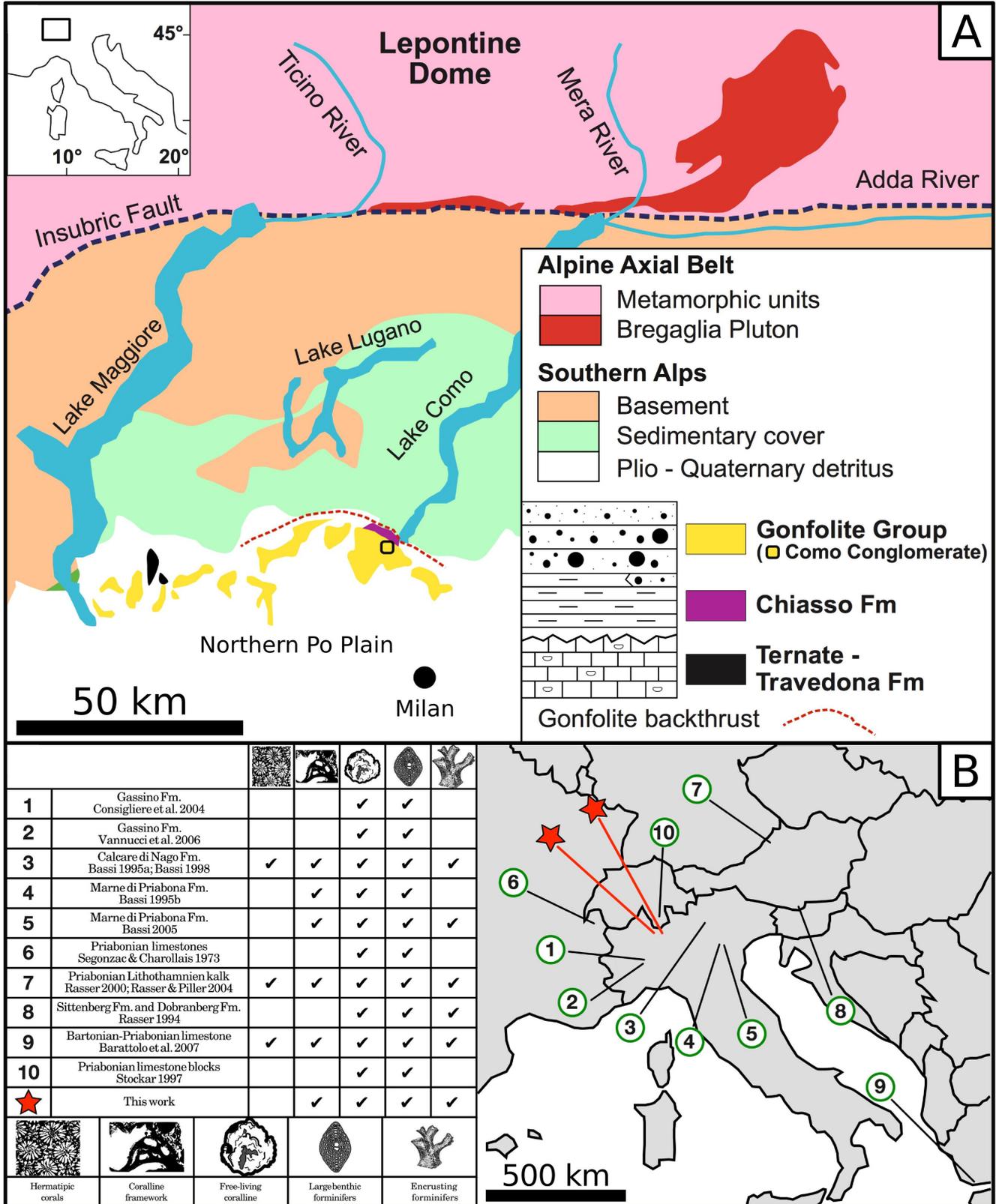
Fig. 1 - A) Schematic map of the Central Alps with Bregaglia-Gonfolite system and Ternate - Travedona Fm. after Gelati et al. (1988) and Ma-lusà et al. (2011a). B) General composition of the skeletal assemblages of the most thoroughly studied late Eocene carbonate-factories of the area; coordinates of the investigated outcrops, Ternate quarry 45°47'25"N 8°41'28"E, Como Conglomerate Camerlata Member 45°47'38"N 9°5'18"E, Como Conglomerate Villa Olmo Member 45°48'45"N 9°3'34"E.

the Ternate-Travedona Formation deep water fan (Braghieri & Montanari 1976; Bernoulli 1980; Man-

cin et al. 2001). The latter was probably supplied by the same shallow-water carbonate factories that

Fig. 2 - Characteristic facies of the Ternate Travedona Fm. and Como Conglomerate. A) Stratigraphic column of the Ternate-Travedona Fm. B) Fine grained redeposited, stratified, bioclastic limestone. C) Detail of a large rock fragment within a bed of coarse-grained, massive, bioclastic limestone. D) Coarse-grained, massive bioclastic limestone with abundant rock-fragments and rip-up clasts. E) Stratigraphic column of the Como Conglomerate Formation. It consists of >2 km-thick conglomerates and pebbly sandstones of Chattian/Aquitanian age divided into Villa Olmo and Camerlata members. F) Villa Olmo Member; upper Eocene limestone cobble. G) Villa Olmo Member; upper Eocene limestone pebble in the center of the panel. H) Camerlata Member.
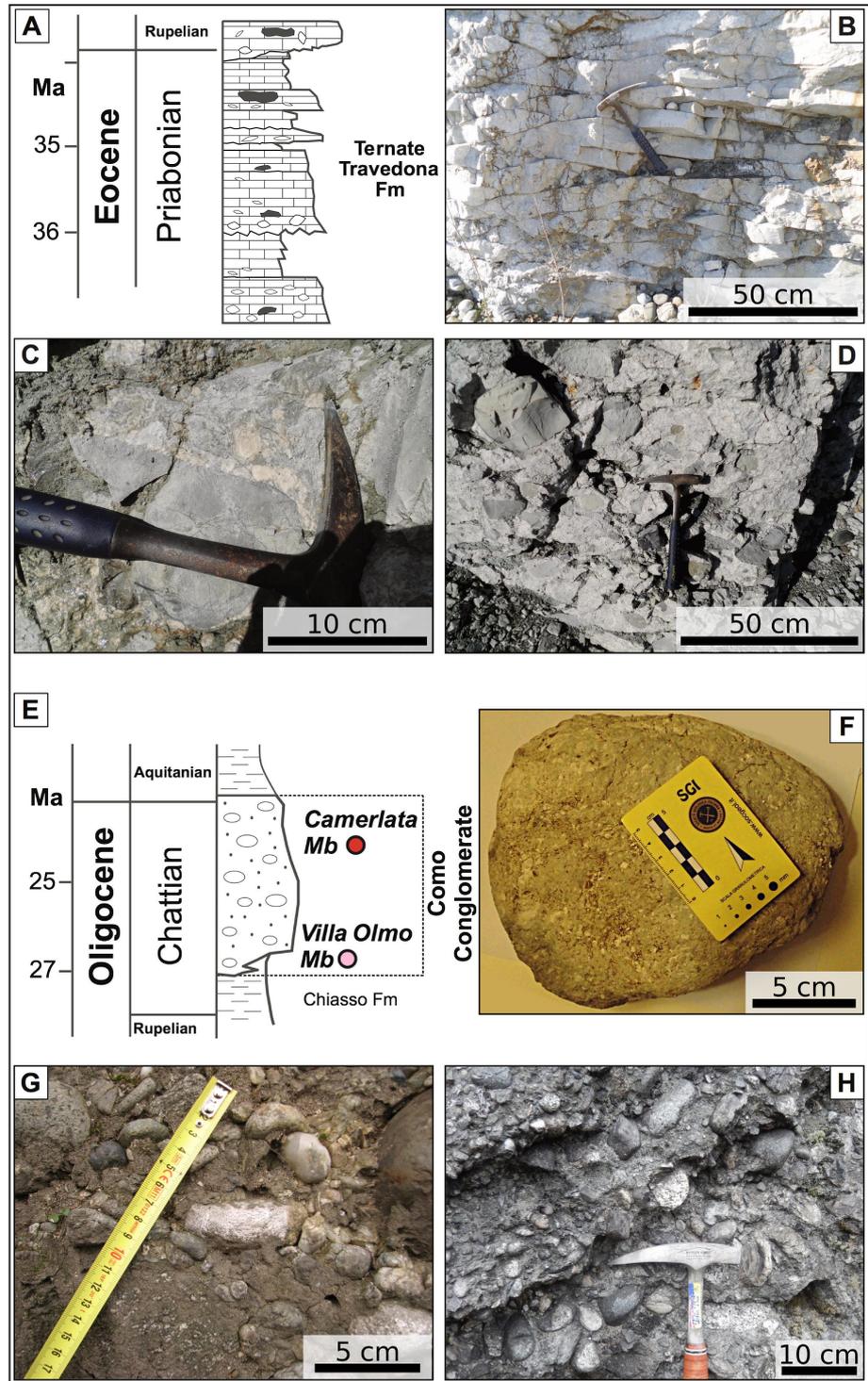
produced the skeletal limestones whose remnants are preserved within the Como Conglomerate Formation (Bernoulli et al. 1987; Stockar 1997, 1999).

GEOLOGICAL OUTLINE

The Ternate-Travedona Formation, exposed northwestern of Milan (Fig. 1A), consists of 150 m of redeposited bioclastic limestones, channelized conglomerates (Fig. 2A-D), and subordinate hemipelagic marls with a late Eocene - earliest Oligocene fauna of planktonic foraminifera (Braghieri & Montanari 1976; Herb 1976; Bernoulli 1980; Mancin et al. 2001). Facies association indicates turbidite and mass gravity-flow sedimentation within a channel-interchannel environment at upper bathyal depth (Bernoulli et al. 1988). The most abundant
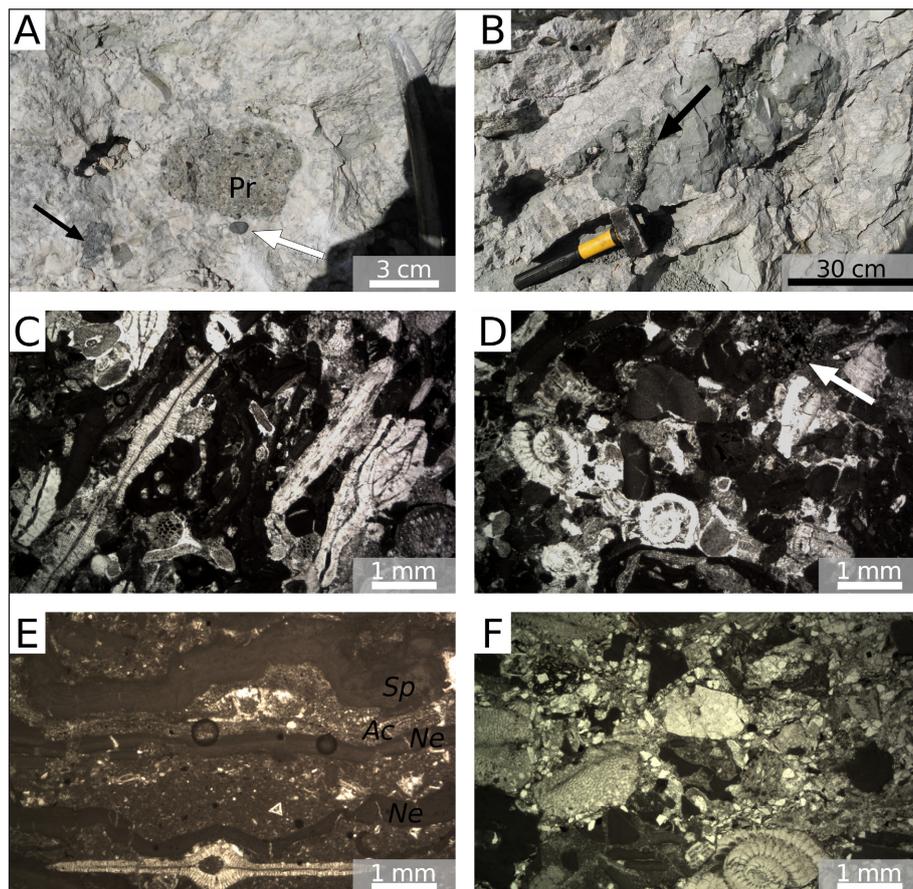
Fig. 3 - Field pictures and microphotographs of the studied successions. A) Ternate quarry, coarse bed; pr = pebble issued from the Prella Conglomerate; white arrow = slightly rounded chert pebble; black arrow = lump of hydrocarbon-rich limestone. B) Ternate quarry, large and burrowed intraclast rich in hydrocarbon and pyrite; black arrow = burrow filled by skeletal limestone. C) Ternate-Travedona Fm., coarse grainstone with common orientation of the grains, large benthic foraminifers, coralline algae, echinoids and bryozoans. D) Ternate-Travedona Fm., coarse grainstone with large benthic foraminifers, coralline algae and echinoids; white arrow = lithic fragment. E) Villa Olmo Member, Gonfolite Group, coralline algae framework; *Ne* = *Neogoniolithon* crust; *Ac* = *Acervulina linearis*; *Sp* = *Sporolithon* crust. F) Camerlata Member, Gonfolite Group, impure-limestone pebble, abraded large benthic foraminifers and skeletal-limestone fragments in a siliciclastic matrix.

rock fragments are limestones and marls of Liassic, late Cretaceous and middle Eocene age (Fig. 2C, D). The redeposited bioclastic limestones, which constitute the bulk of the succession, contain coralline algae, larger foraminifera (e.g., nummulitids, orthophragminids), bryozoans, echinoderms and other shallow water skeletal grains (Fig. 1B; Mancin et al. 2001). Similar associations are widely distributed in the late Eocene shallow-water carbonate sequences of the region (Fig. 1B) and they indicate the existence in the studied area of a carbonate platform that is now completely eroded (Bernoulli 1980; Bernoulli et al. 1987).

The coarse-grained Gonfolite Lombarda Group, discontinuously exposed north of Milan, extends ~ 40 km N–S and ~ 200 km E–W in the subsurface of the northern Po Plain (Fig. 1A; Pieri & Groppi 1981; Di Giulio et al. 2001). Its lower formation, named the Como Conglomerate Formation, consists of >2 km-thick conglomerates and pebbly sandstones of Chattian/Aquitanian age (Fig. 2E-H; 27.3 – 23 Ma; Tremolada et al. 2010), lying over mid-Oligocene marls (Chiasso Formation), and comprises the Villa Olmo Member and the Camerlata Member (Cita 1957; Rögl et al. 1975; Gelati et

al. 1988). These clastic units are interpreted as fandeltas fed from the North and passing southward to a deep-sea fan (Gelati et al. 1988). They are both characterized by the presence of metamorphic, sedimentary, plutonic and volcanic pebbles (Fig. 2F-H; Bernoulli et al. 1993; Carrapa & Di Giulio 2001; Malusà et al. 2011a; Di Capua et al. 2015).

MATERIAL AND METHODS

The Ternate-Travedona succession has been studied in the Ternate quarry, where a total of 25 samples were collected. In the area of Como, ten limestone clasts have been collected in the conglomerate deposits of the Villa Olmo and Camerlata members. From the samples, 45 thin sections were prepared for paleontological analyses of the bioclastic components and the benthic foraminiferal and coralline-algal assemblages. The relative abundance of the different skeletal components of the major groups of larger benthic foraminifera, and of the orders of coralline algae, have been expressed through a semi-quantitative scale (Sancetta 1979), organized as follows: Very rare (RR; <5%); Rare (R; 5-10%); Common (C; 10-25%); Very common (CC; 25-50%); Frequent (F; 50-75%); Very frequent (FF; >75%).

The texture, composition and bioclastic assemblage of the samples were quantified by point counting (Flügel 2009) on digital photomicrographs of thin sections. A 150x150 µm grid was used and over 400 points were counted in each analyzed section. The recognized categories were: coralline algae, larger benthic foraminifera,

small benthic foraminifera, planktonic foraminifera, mollusks, bryozoans, echinoids, serpulids, ostracods, corals, brachiopods, micrite, sparite and silicates. The results of bioclastic composition, derived from point-counting, were statistically treated by hierarchical cluster analysis and non-metric multidimensional scaling ordination (MDS) based on the Bray-Curtis similarity with PRIMER 6 (Kruskal 1977; Field et al. 1982; Clarke & Gorley 2006).

Benthic foraminiferal assemblages were evaluated with the area counting technique (Flügel 2009). The thickness/diameter ratio (T/D) of larger benthic foraminifera was measured along the axial section, cutting the embryonic chambers. The suprageneric classification adopted for benthic foraminifera follows Loeblich and Tappan (1987).

The rhodoliths were described following Molinier (1956), Bosence (1976, 1983), Basso (1998) and Basso et al. 2009. Thin sections of coralline-algal samples were observed under a light microscope to study and measure their anatomical features. Growth-forms terminology follows Woelkerling et al. (1993). Coralline algae vegetative anatomy was described along longitudinal radial sections (Quaranta et al. 2007; Vannucci et al. 2008). The diameter of the cells was measured including the cell wall; cell length was measured as the distance between two primary pit connections and includes the cell wall (Basso et al. 1996). Conceptacles were measured along their axial section (i.e. the longitudinal section that cuts a conceptacle medially, resulting in the pore canal being completely visible; Afonso-Carillo et al. 1984), in agreement with Quaranta et al. (2007) and Vannucci et al. (2008).

Coralline taxonomy at higher ranks follows Braga et al. (1993); Harvey et al. (2003); Le Gall et al. (2009); Kato et al. (2011) and Nelson et al. (2015).

High-resolution petrographic analysis was carried out on eight sandstone samples collected from the Como Conglomerate Formation (four for each of the two members). In each sample 400 points were counted by the QFL Gazzi-Dickinson method (Ingersoll et al. 1984). Metamorphic grains were classified according to the protolith composition and the metamorphic rank. Average rank for each sample was

	Ternate Fm.	Ternate Fm. (rhodoliths)	Villa Olmo member	Camerlata member (pure limestone)	Camerlata member (impure limestone)
Skeletal components					
Coralline algae	F	–	F	F	F
LBF	C	–	C	C	CC
Small benthic foram.	R	–	R	RR	RR
Planktonic foram.	RR	–	RR	RR	RR
Bryozoans	R	–	R	C	R
Mollusks	RR	–	RR	R	RR
Echinoids	R	–	RR	R	RR
Others	RR	–	RR	RR	//
Foraminifers					
Nummulitids	CC	–	C	CC	CC
Orthophragminids	C	–	C	CC	F
Victoriellidae	RR	–	R	RR	RR
Small rotalids	C	–	CC	CC	R
Textulariina	RR	–	RR	RR	–
Miliolida	RR	–	–	–	RR
Globigerinina	RR	–	C	R	RR
Acervulina linearis	✔	✔	✔	✔	✔
T/D ratio					
T/D Nummulitids	0.43 ± 0.1	–	0.29 ± 0.9	0.42 ± 0.12	0.5
T/D Orthophragminids	0.39 ± 0.08	–	0.31 ± 0.15	0.46 ± 0.11	0.5
Coralline algae					
Hapalidiales	FF	CC	CC	FF	FF
Corallinales	R	CC	CC	R	RR
Sporolithales	R	CC	CC	R	C
Coralline species					
Lithothamnion valens	✔	–	–	✔	✔
Lithothamnion marianae	✔	✔	–	–	✔
?Lithothamnion sp. A	✔	✔	✔	✔	–
Lithothamnion sp. 1	✔	–	✔	✔	✔
Lithoporella melobesioides	✔	✔	✔	✔	✔
Sporolithon aschersonii	✔	✔	✔	✔	✔

Tab.1 - Summary of the results of the paleontological analyses on the different groups of samples.

expressed by the Metamorphic Index (MI, sensu Garzanti & Vezzoli 2003), which varies from 0 in detritus from sedimentary and volcanic cover rocks to 500 in detritus from high-grade basement rocks. Sands were classified according to their main components exceeding 10% QFL (e.g., in a lithofeldspathoquartzose sandstone Q > F > L > 10% QFL; Dickinson 1970).
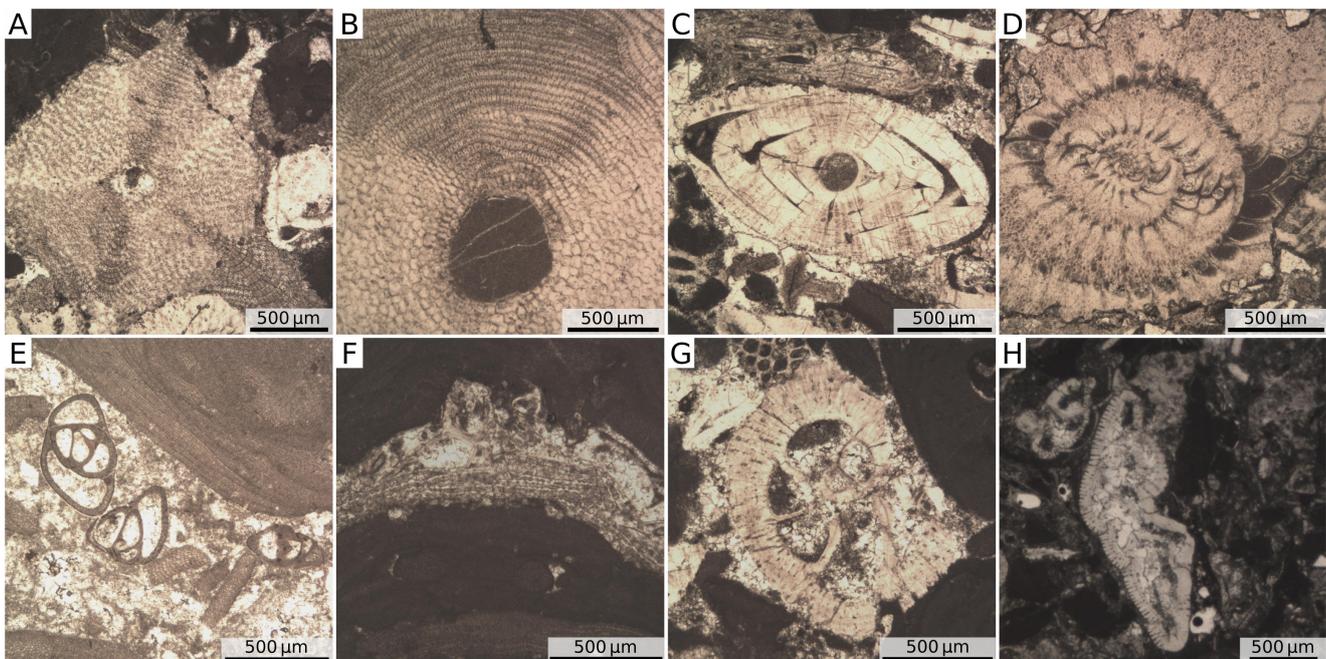
Fig. 4 - Microphotographs benthic foraminifers common in the studied successions. A) Ternate-Travedona Fm., *Asterocyclina*. B) Camerlata Member, Gonfolite Group, impure limeston pebble, *Orbitoclypeus*. C) Ternate-Travedona Fm. *Nummulites*. D) Camerlata Member, Gonfolite Group, impure limestone pebble, *Heterostegina*. E) Ternate-Travedona Fm., miliolids trapped inside a rhodolith. F) Ternate-Travedona Fm., *Acervulina linearis* between coralline algal crusts. G) Ternate-Travedona Fm., victoriellidae. H) Camerlata Member, Gonfolite Group, *Victoriella*.
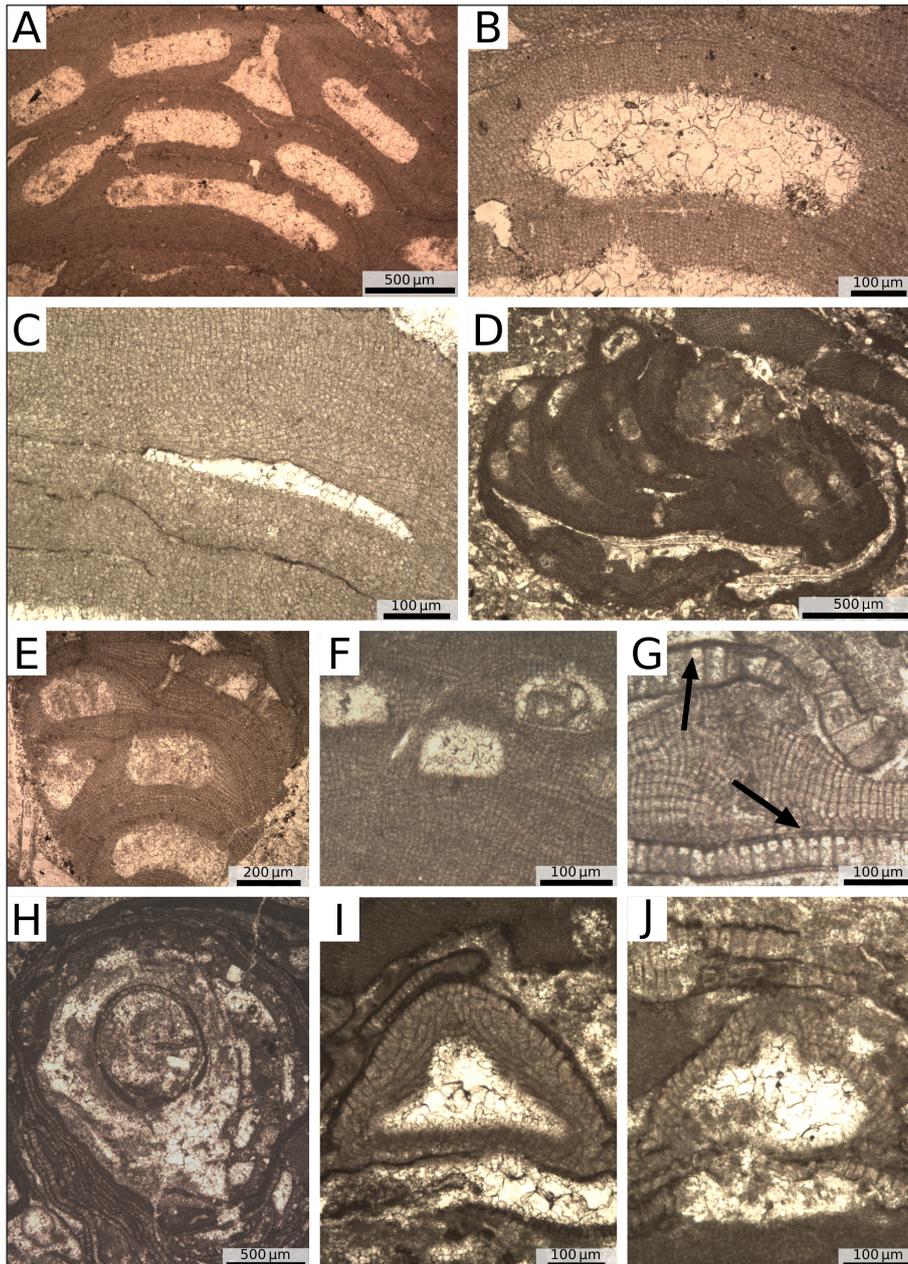
Fig. 5 - Common coralline algae. A) Camerlata Member, Gonfolite Group, impure limestone pebble, *Lithothamnion marianae*. B) Camerlata Member, Gonfolite Group, impure limestone pebble, *Lithothamnion marianae*, detail of a multiporated conceptacle. C) Ternate Fm., *Lithothamnion marianae*, detail of the ventral core. D) Villa Olmo Member, Gonfolite Group, *Lithothamnion* sp. 1. E) Ternate-Travedona Fm., *Lithothamnion* sp. 1. F) Camerlata Member, Gonfolite Group, pure limestone pebble, *Lithothamnion* sp. 1, detail of a multiporated conceptacle. G) Ternate-Travedona Fm., *Lithoporella melobesioides*; black arrow = detail of epitallial cells. H) Ternate-Travedona Fm., *Lithoporella melobesioides* at the core of a rhodolith. I) Ternate-Travedona Fm., *Lithoporella melobesioides,* detail of a uniporate conceptacle. J) Ternate-Travedona Fm., *Lithoporella melobesioides,* detail of a uniporate conceptacle.

RESULTS

Four different kinds of samples have been distinguished in the analyses, on the basis of their provenance and petrological composition: 1) samples from the Ternate-Travedona Formation, 2) pebbles from the Villa Olmo Member, samples from the Camerlata Member, subdivided into 3) pure limestone pebbles and 4) pebbles composed of bioclastic fragments packed in a siliciclastic matrix (impure-limestone pebbles).

Ternate-Travedona Formation
The outcrop of the Ternate quarry consists principally of a highly irregular alternation of co-arse and massive bioclastic limestone interbedded with beds of more fine-grained and regularly-bedded bioclastic limestone. The upper part of the sequence is characterized by the widespread presence of marly, often plurimetric, rip-up clasts. A 5-meter-thick slump deposit closes the sequence.

Coarse beds are massive rhodolith rudstones and floatstones with common rip-up clasts (Figs 2C, D; 3A), 20 to 60 cm thick and with sharp undulatory contacts. Pebbles, cobbles and some rare boulders of Mesozoic rocks (limestones, cherts, cherty limestones and conglomerates) are locally abundant (Figs 2C, D; 3A). The observed clasts are angular to sub-angular, with the exception of some slightly rounded chert pebbles (Fig. 3A). The size of rip-up

clasts is highly variable, ranging from less than 1 cm to several meters in length. The overwhelming majority of rip-up clasts are light brown in color and marly in composition; they are seldom dark or dark green, glaucony rich and highly bioturbated (Fig. 3A, B). Coralline-algal nodules of various shapes and sizes are tightly packed together and the space in between is occupied by benthic foraminifera, bryozoans and unattached coralline-algal branches. Echinoid and mollusk fragments are also present (Tab. 1). Rhodoliths are small to medium sized (2 to 5 cm in diameter). Rhodolith shape is generally ellipsoidal, although sub-spheroidal and discoidal specimens also occur. Coralline algal growth-form is mainly encrusting and warty, with rare lumpy and fruticose specimens. Erosional surfaces cutting the protuberances are a common feature of the observed rhodoliths. The internal structure of rhodoliths is more or less compact, but large nodules may also have a loose internal arrangement and large voids created by borers. Thick-tested nummulitids and orthophragminids are the most common benthic foraminifera outside the rhodoliths (Tab. 1; Fig. 4A-D), while small miliolids are common in the sediment trapped in the voids inside the rhodoliths (Fig. 4E). Within the slump deposit at the top of the succession, small pralines rhodoliths (sensu Molinier 1956; Basso et al. 2009) can also be found. These small pralines rhodoliths can be either laminar or branched (protuberance degree group II and III; Bosence 1976; Basso et al. 2009) and have a very compact internal structure.

Rhodolith-forming coralline algae are represented by members of the order Sporolithales, Corallinales and Hapalidiales, roughly in the same proportion (Tab. 1). Rhodoliths are generally multispecific. Their core is generally composed of encrusting laminar thalli of *Lithoporella melobesioides* growing over skeletal grains, while the outer layers are characterized by warty crusts of *Sporolithon* or *Lithothamnion* (Tab 1; Figs 5-6). *Sporolithon* sometimes occurs also in the core of pralines rhodoliths, together with *Lithoporella*. ?*Lithothamnion* sp. A, *Spongites*, *Mesophyllum* and *Polystrata* are minor components of
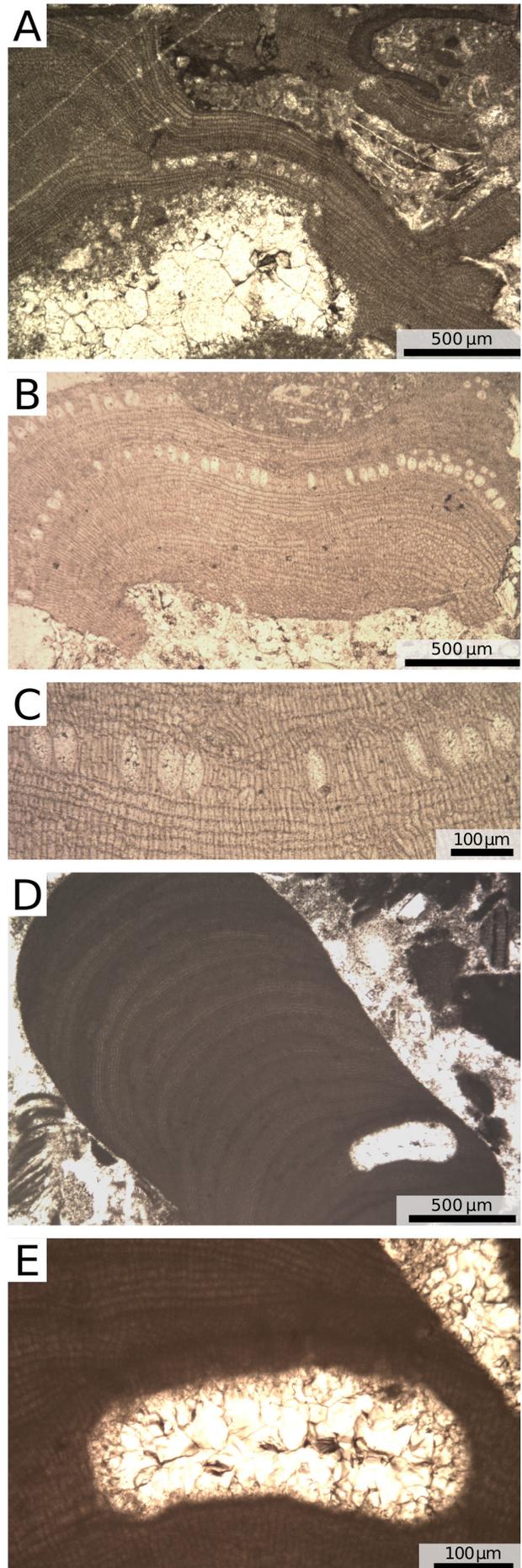
Fig. 6 - Other common coralline algae. A) Ternate-Travedona Fm., *Sporolithon aschersonii*. B) Camerlata member, impure limestone pebble, *Sporolithon aschersonii*. C) Camerlata member, impure limestone pebble, S*porolithon aschersonii*, detail of the sporangial cavities. D) Ternate Fm. *Lithothamnion valens*. E) Ternate-Travedona Fm., *Lithothamnion valens*, detail of a multiporated conceptacle.
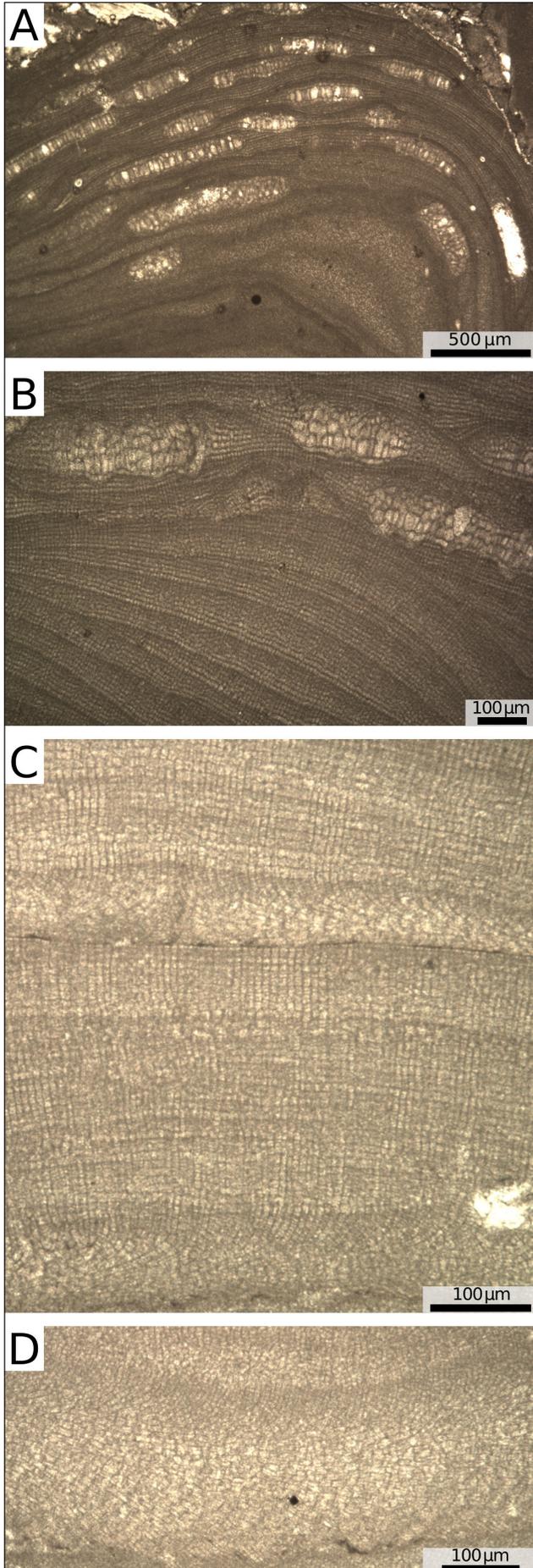
rhodoliths (Tab. 1; Fig 7). Encrusting foraminifers and bryozoans significantly contribute to the nodule structure and among them, the encrusting foraminiferal species *Acervulina linearis* is the most important (Fig. 4F).

The thick and coarse skeletal limestones, rich in rock fragments and rip-up clasts, are irregularly interbedded with thinner layers of packstones, grainstones and floatstones with iso-oriented grains (Figs 2B; 3C, D). The degree of sorting in these beds is variable and ranges from good to poor. Gravel-sized elements are mainly bioclasts, but in some layers rip-up clasts are exceedingly common. The skeletal assemblage is similar to that observed in the coarse beds between the rhodoliths, and is dominated by coralline algae, benthic foraminifera, bryozoans, echinoids and mollusks (Tab. 1). Unattached branches and fragments of coralline algal crusts are abundant, rhodoliths are small and rare. Most of the coralline algal crust fragments lack the taxonomic elements necessary for their identification, nevertheless it has been observed that they are generally characterized by a coaxial ventral-core and cell fusions. The unattached branches are thin and simple (protuberance degree group I and II). Hapalidiales dominate the recognizable association, Sporolithales and Corallinales are less abundant (Tab. 1). *Lithothamnion* sp. 1 (sensu Vannucci et al. 2006), *Lithothamnion valens*, ?*Lithothamnion* sp. A, and *Sporolithon aschersonii* form unattached branches (Tab. 1; Figs 5-7). The rare rhodoliths are composed of species of Hapalidiales and *Lithoporella melobesioides*. The benthic foraminiferal association is dominated by nummulitids (*Assilina, Nummulites, Operculina, Heterostegina*). Orthophragminds (*Discocyclina, Orbitoclypeus, Asterocyclina*) are also common but less frequent (Tab. 1), and both groups are characterized by thick-tested specimens with a T/D ratio of 0.43 for nummulitids and 0.39 for orthophragminids (Tab. 1). *Amphistegina, Asterigerina, Victoriella* (Fig. 4G, H) and agglutinated foraminifera rarely occur (Tab. 1). Small rotalids are common, especially in very fine-grained layers, where they are even more abundant than orthophragminids and are accompanied by frequent planktonic foraminifera (Tab. 1).

Fig. 7 - ?*Lithothamnion* sp. A. A) Villa Olmo Member, Gonfolite Group, overeview of ?*Lithothamnion* sp. A thallus. B) Ternate-Travedona Fm., ?*Lithothamnion* sp. A, detail of the reproductive anatomy. C) Ternate-Travedona Fm., ?*Lithothamnion* sp. A, detail of the secondary ventral-core and of the peripheral zone. D) Ternate-Travedona Fm., ?*Lithothamnion* sp. A, detail of the ventral-core.
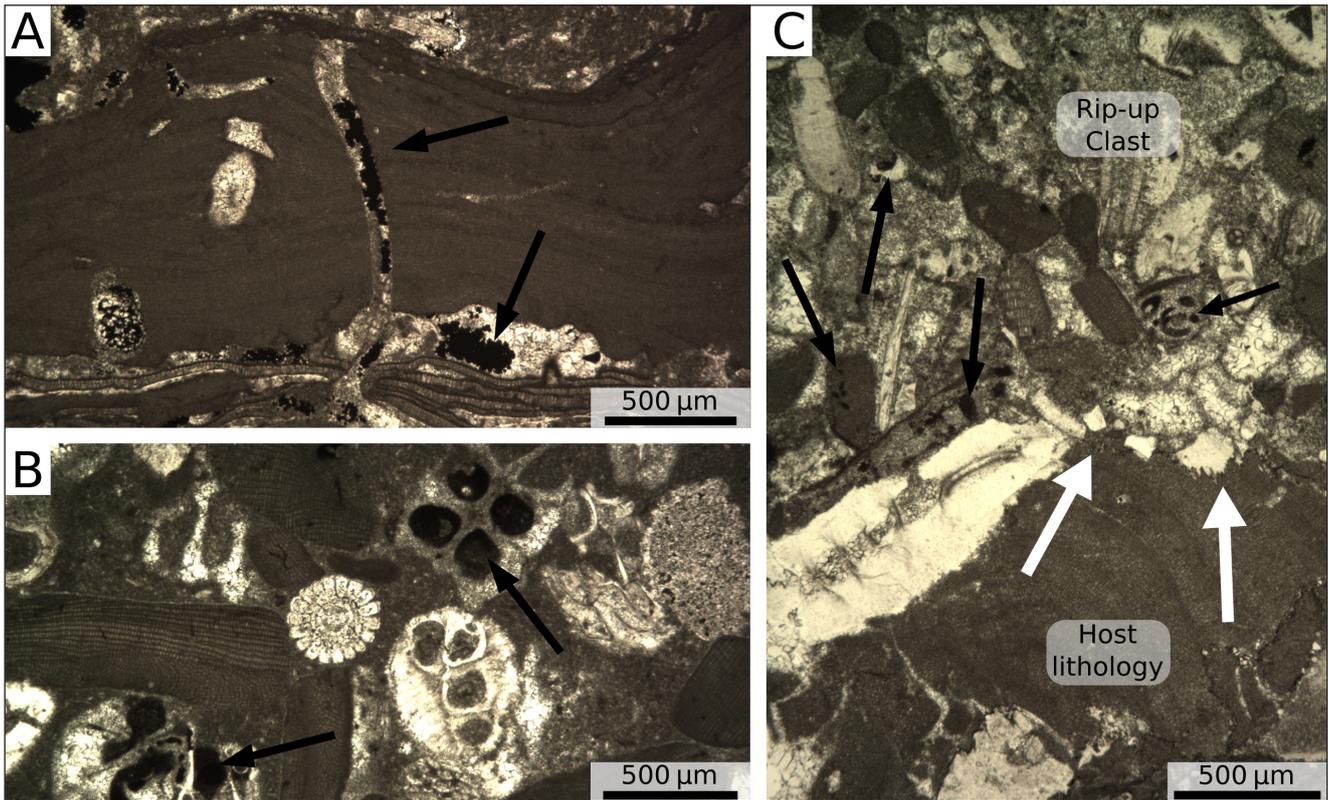
Fig. 8 - Hydrocarbons in the Ternate-Travedona Fm. A) Bore hole within a rhodolith filled by hydrocarbon droplets; black arrows = hydrocarbon fillings. B) Lump of sediment rich in hydrocarbons; black arrows = hydrocarbon fillings. C) Sharp erosive boundary between a lump of hyrocarbon-rich limestone and the "usual" Ternate-Travedona Fm. limestone; black arrows = hydrocarbon fillings; white arrows = boundary.

Throughout the succession of the Ternate quarry, rhodoliths and rip-up clasts (both coarse-grained, Fig. 3A, and fine-grained, Fig. 3B), with a remarkably dark color, have been observed. These elements are rich in iron sulfide and hydrocarbons. In the rhodoliths the hydrocarbon is generally confined in the borings of the outer coating (Fig. 8A). In the rip-up clasts composed of coarse-grained (coarse sand to gravel) bioclasts, the hydrocarbons fill both the interparticle and intraparticle porosity (Fig. 8B, C). The skeletal assemblage of these coarse-grained rip-up clasts is the same as that of the host lithology. It is noteworthy that these rip-up clasts have remarkable sharp and erosive boundaries with the host lithology (Fig. 8C), suggesting at least partial lithification before entering the gravity flow. The skeletal grains inside the rip-up clasts are also remarkably better preserved than those of the host rock, showing little or no fragmentation (Fig. 8B, C). The rip-up clasts composed of fine-grained (very fine silty sand) bioclasts, are mainly composed of planktonic foraminifera and they are heavily burrowed (Fig. 3B). These burrows are not filled by hydrocarbons (Fig. 3B), suggesting that the rip-up clasts were moved by gravity-flows after organic matter filling, when they were still soft.

Como Conglomerate Formation

The lower members of the Como Conglomerate Formation are polygenic conglomerates with a sandstone matrix. The matrix of the Villa Olmo Member includes dominant monocrystalline quartz, feldspars (plagioclase and microcline) and minor acidic to intermediate volcanic rock fragments and limestone grains (Fig. 9). The Camerlata Member is characterized by quartz and feldspars grains (microcline to perthitic alkali feldspars, twinned and sericitized plagioclase; Fig. 9). Detrital modes of the sandy matrix in the Como Conglomerate Fm. suggest provenance from the metamorphic units of the Alpine belt for the Villa Olmo Member (Fig. 1, 9; "*Axial Belt provenance*" by Garzanti et al. 2010) and a contribution also from the exhumed Bregaglia Pluton for the Camerlata Member.

In both members, limestone clasts rich in coralline algae and larger benthic foraminifera occur.
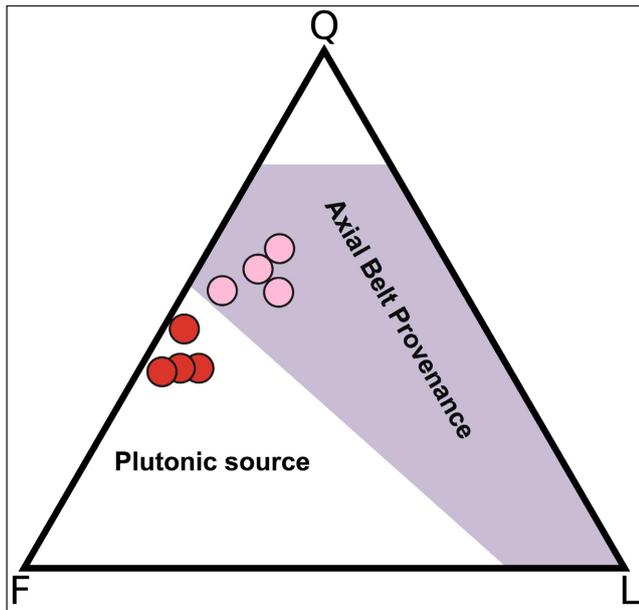
Fig. 9 - QFL plot of the lower members of the Gonfolite Lombarda Group; pink circles = Villa Olmo Member; red circles = Camerlata Member. The matrix composition of the Villa Olmo Member includes monocrystalline quartz (Q), feldspars (F) and minor acidic to intermediate volcanic rock fragments and limestone grains (L). The matrix of the Camerlata Member is dominated by quartz and feldspar grains (microcline to perthitic alkali feldspars, twinned-sericitized plagioclase). Provenance areas mirror the present-day catchments of the Lepontine rivers, whose drainage remained fixed since Oligocene times (Garzanti & Malusà 2008).

These limestone elements were separated according to their origin and their petrological characteristics.

Pebbles and cobbles from the Villa Olmo Member - Limestone clasts in the Villa Olmo Member are of various sizes, ranging from small pebbles to large cobbles (Fig. 2F). They are very scarce at the base of the member and more common at the top of it, especially near the boundary with the overlaying Camerlata Member. Limestone pebbles and cobbles are classified as wackestones, packstones and floatstones. They are composed of coralline-algae, benthic foraminifera, bryozoans, mollusks and echinoids in a micrite matrix (Tab. 1; Fig. 3E). The skeletal grains are generally not abraded nor fragmented.

Coralline-algae occur as thin crusts organized in bindstones, crusts fragments, small rhodoliths and unattached branches (protuberance degree group I and II). The fragments of algal crusts lack the taxonomic elements essential for their identification but they are generally characterized by a coaxial ventral-core and cell fusions. The bindstone crusts

also have a coaxial ventral core, cell fusions and large uniporate conceptacles, therefore they have been included in the genus *Neogoniolithon*. *Sporolithon aschersonii* is another important crust-forming species in the bindstone (Tab. 1; Figs 3E, 6A-C). Rhodoliths are mainly ellipsoidal and boxwork (sensu Bosence 1983; Basso et al. 2009), they are formed by thin laminar crusts of coralline algae, their structure is loose and binds a considerable amount of micrite. *Sporolithon aschersonii*, *Lithoporella melobesioides*, ?*Lithothamnion* sp. A, and *Lithothamnion* spp. are common rhodolith-forming species (Tab. 1; Figs 5-7). Unattached branches are formed by *Lithothamnion* sp. 1 and ?*Lithothamnion* sp. A (Tab. 1; Figs 5, 7). The coralline-algal association is dominated by species of the order Sporolithales, while Corallinales and Hapalidiales, albeit common, are less abundant (Tab. 1). The benthic foraminiferal assemblage is dominated by small benthic foraminifera (Tab. 1). Orthophragminds (*Discocyclina*, *Orbitoclypeus*, *Asterocyclina*) are frequent, nummulitids (*Assilina*, *Nummulites*, *Operculina*, *Heterostegina*) are abundant but less important (Tab. 1). Larger benthic foraminiferal tests are thin, with a T/D ratio of 0.3 for nummulitids and 0.29 for orthophragminids; victoriellidae are rare and agglutinated foraminifera are very rare; planktonic foraminifera are common (Tab. 1).

Pebbles from the Camerlata Member - Two different kinds of pebbles have been recognized: pure-limestone pebbles and impure-limestone pebbles.

The pure-limestone pebbles are wackestones, packstones and floatstones, composed of well preserved coralline-algae, benthic foraminifera, bryozoans, mollusks, echinoids and rare brachiopods (Tab. 1), in a micrite matrix. Coralline algae occur as rare small rhodoliths, free-living branches (group I and II) and thin crusts. The crusts lack the taxonomic elements essential for their identification but they are generally characterized by a coaxial ventral-core and cell fusions. The recognizable assemblage is dominated by Hapalidiales while Corallinales and Sporolithales are rare (Tab. 1). *Lithothamnion valens*; *Lithothamnion* sp. 1 and ?*Lithothamnion* sp. A commonly compose the unattached branches (Tab. 1). *Sporolithon aschersonii* is present both as unattached branches and as small nodular rhodoliths, while *Lithoporella melobesioides* is present exclusively in the small rhodoliths, where the encrusting foraminiferal species *Acervulina linearis* is also common (Tab. 1).
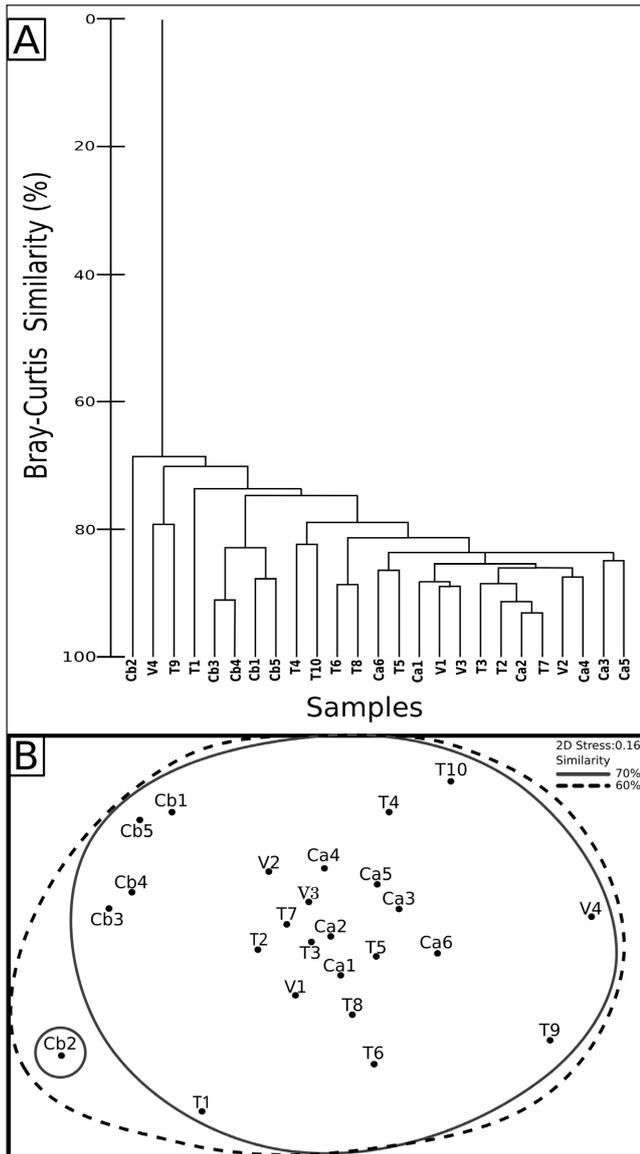
Fig. 10 - Multivariate statistical analyses, based on Bray-Curtis similarity, of the bioclastic composition of the samples. Point counts of bioclastic composition were standardized and then analyzed for Bray-Curtis similarity; T = Ternate-Travedona Fm.; V = Villa Olmo Member, Gonfolite Group; Ca = Camerlata Member, Gonfolite Group, pure-limestone pebble; Cb = Camerlata Member, Gonfolite Group, impure-limestone pebble. A) Hierarchical agglomerative dendrogram. Most of the samples are grouped in a large cluster at 70% of Bray-Curtis similarity. B) MDS (2D) ordination of the samples, based on the same Bray-Curtis similarity as in 8A; 2D stress indicates the displacement of the sample in the representation from its actual position in the multidimensional space.

Orthophragminids (*Discocyclina*, *Orbitoclypeus*, *Asterocyclina*), nummulitids (*Nummulites*, *Assilina*, *Operculina*, *Heterostegina*) and small benthic rotalids dominate the benthic foraminiferal assemblage (Tab. 1). Orthophragminid and nummulitid tests are thick, with a T/D ratio of 0.46 for the former and 0.42

for the latter (Tab. 1). *Victoriella* is present but not common; agglutinated and planktonic foraminifera are rare (Tab. 1).

Impure-limestone pebbles are composed of highly fragmented and abraded skeletal grains embedded in a sandy siliciclastic matrix (Fig. 3F). Common grains are: broken larger benthic foraminiferal tests, coralline algal branches, fragments of rhodoliths, sub-angular clasts of mudstone with planktonic foraminifera and thin coralline-algal crusts. The siciliclastic matrix is composed of angular rock-fragments and mineral grains. Coralline algae and benthic foraminifera dominate the skeletal assemblage; bryozoans are common, mollusks scarce (Tab. 1). Coralline algae are present as unattached branches (protuberance degree group I and II), fragments of small rhodoliths and crust fragments. The crust fragments lack the taxonomic elements essential for their identification but they are generally characterized by a coaxial ventral-core and cell fusions. Hapalidiales dominate the recognizable flora, Sporolithales and Corallinales are rare (Tab. 1). *Lithothamnion valens*, *Lithothamnion marianae*, *Lithothamnion* sp. 1 and *Sporolithon aschersonii* occur commonly (Tab. 1). *Lithoporella melobesioides* is recognized in the small rhodolith fragments, together with incrustations of *Acervulina linearis* (Tab. 1). The benthic foraminiferal assemblage is dominated by thick-tested orthophragminids (*Orbitoclypeus*, *Asterocyclina*, *Discocyclina*), (T/D ratio of 0.5; Tab. 1). Nummulitids (*Nummulites*, *Heterostegina*, *Operculina*, *Assilina*) are also thick-tested (T/D of 0.5; Tab. 1) and they are more frequent than orthophragminids (Tab. 1). Small benthic rotalids are common whereas planktonic foraminifera are rare and agglutinated foraminifera are absent (Tab. 1).

Statistical analysis

The results of point-counting analysis of the bioclastic components were classified by a hierarchical cluster analysis and ordered by MDS. This system allows easily comparison of the differences and similarities of the skeletal assemblages of the samples. The procedure identifies one large group at 70% of Bray-Curtis similarity, encompassing samples from all the studied localities (Fig. 10). Only at very high Bray-Curtis similarity (>80%), do the samples from the impure-limestone pebbles of the Como Conglomerate Formation form their own separate cluster (Fig. 10). The other recogniza-

ble clusters, that separate at >80% of Bray-Curtis similarity, include samples from two or more of the four recognized groups of samples (Fig. 10).

Discussion

Origin of the carbonate detritus

The Ternate-Travedona Formation and the pebbles of the Como Conglomerate Formation show remarkable similarities in their skeletal assemblages, their coralline-algal flora and their benthic foraminiferal associations.

As shown by multivariate statistical analyses (Fig. 10), samples do not separate into various clusters according to their area of provenance but rather gather in a large cluster, thus suggesting a common composition. Samples of the impure-limestone pebbles are slightly different from most of the others since they almost all lack echinoids fragments. Fragments of echinoids occur in the other samples, but they are never a major component of the skeletal assemblage. The presence of small quantities of echinoids is not particularly significant from an ecological point of view, since echinoids are common in almost any marine environment and they are absent only in hypersaline and hyposaline waters (Flügel 2009). Therefore, their absence in the impure-limestone pebbles is unlikely to be related to different environmental conditions in the source area of the bioclasts and was probably caused by other processes, like reworking of the skeletal grains.

Remarkable similarities can be observed in the coralline-algal flora. *Sporolithon aschersonii*, *Lithoporella melobesioides*, *Lithothamnion valens*, *Lithothamnion marianae*, *Lithothamnion* sp. 1 and ?*Lithothamnion* sp. A, commonly occur in most of the samples (Figs 5, 6, 7; Tab. 1). ?*Lithothamnion* sp. A (Fig. 7) is a species of particular importance. While the other species are also known from different other Eocene coralline-bearing limestones (Fig. 1B; Barattolo et al. 2007; Bassi 1995a, 1995b, 1998, 2005; Consigliere et al. 2004; Rasser 1994, 2000; Rasser & Piller 2004; Segonzac & Charrolais 1974; Vannucci et al. 2006), ?*Lithothamnion* sp. A is peculiar to the study area. The diagnostic features of this species include species a plumose ventral core (=hypothallus) and large and low multiporate conceptacles filled by more or less elongated, irregular adventitious cells which represent the latest stages of conceptacles develop-

ment, after spore release (Cardinal et al. 1979; Wilks & Woelkerling 1994; Basso et al. 1997; Fig. 7). This feature is very distinctive and has been used as diagnostic character at the species level within several genera of Hapalidiales (Aguirre et al. 1996; Basso et al. 1997; Hrabovský et al. 2015). In the Eocene of the Alpine area, this feature so far has been reported only in coralline species collected in the Ternate-Travedona Formation (Braghieri & Montanari 1976; Stockar 1997). Therefore ?*Lithothamnion* sp. A is quite a distinctive representative of late Eocene coralline-algal association of this area of Northern Italy and a useful provenance marker.

Orthophragminids and nummulitids always dominate the benthic foraminiferal assemblage (Tab. 1). Ternate-Travedona Formation samples are generally dominated by nummulitids while Como Conglomerate Formation samples are generally dominated by orthophragminids (Tab. 1). *Orbitoclypeus*, *Asterocyclina*, *Heterostegina* and *Victoriella* are commonly present in most of the samples (Tab. 1). This association points to a late Eocene age for all the studied samples according to larger foraminifera biostratigraphy (Racey 1992; Sierra-Kiel et al. 1998; Nebelsick et al. 2005), and in agreement with previous works on the Ternate-Travedona Formation (Bernoulli 1980; Bernoulli et al. 1987; Mancin et al. 2001; Stockar 1997, 1999).

The studied samples have the same age, they are characterized by the same skeletal assemblage, the same fossil species and even the same endemic species (Tab. 1). Thus, it is reasonable to assume that they formed under similar environmental conditions in the same area.

Differences in texture exist between the samples. In the Ternate-Travedona Formation the rock is rich in rip-up clasts, and the skeletal grains show common orientation, diffuse abrasion and fragmentation (Fig. 11A-C). On the contrary, the pure-limestone pebbles of the Como Conglomerate Formation have well preserved, randomly oriented skeletal grains and no rip-up clasts. (Fig. 11D). These textural features suggest reworking during transport for the Ternate-Travedona Formation samples. The Gonfolite Lombarda Group pure-limestone pebbles, on the other hand, are probably fragments eroded directly from the lost outcrops of the original carbonate platform and, therefore, they represent important and pristine witnesses of that late Eocene environment. The impure-limestone peb-
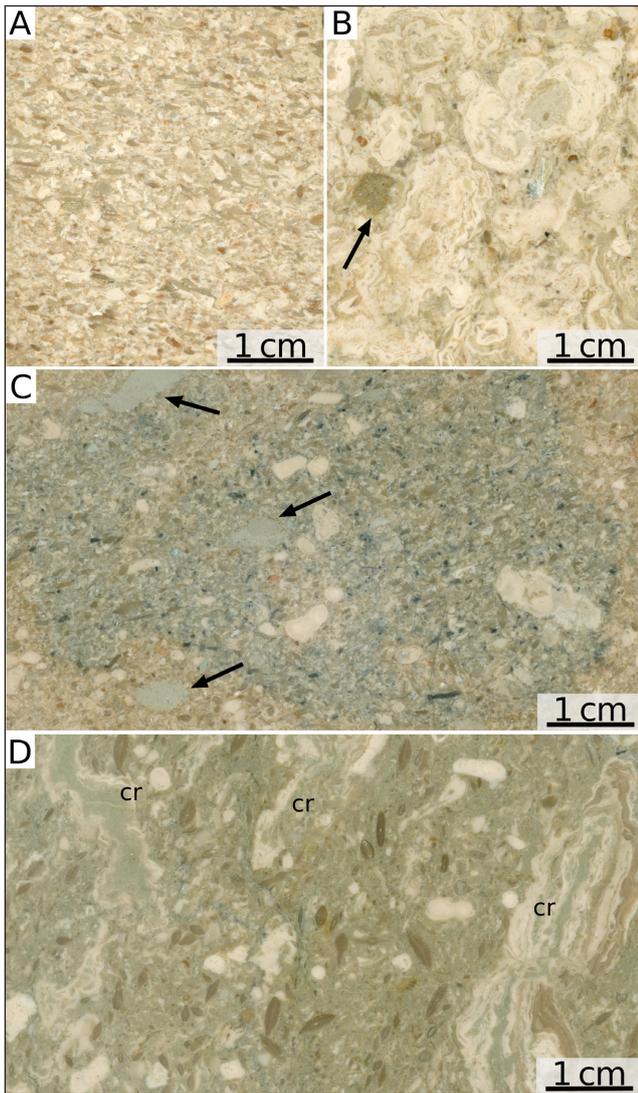
Fig. 11 - Polished surface of Ternate-Travedona Fm. and Gonfolite Group samples. A) Ternate-Travedona Fm., coarse grainstone with common orientation of the skeletal elements. B) Ternate-Travedona Fm., rhodolith rudstone; black arrow = intraclast. C) Ternate-Travedona Fm., floatstone with coralline-algal branches, intraclasts and common orientation of the skeletal elements; black arrows = intraclasts. D) Villa Olmo Member, Gonfolite Group, floatstone with thin coralline-algal crusts and large benthic foraminifers; cr = coralline-algal crusts.

bles suggest a different and more complex story. They are actually composed of bioclastic elements that were probably eroded from already exposed outcrops of the original late Eocene carbonate platform. These fragments sedimented and lithified together with siliciclastic detritus originating from the rising mountain chain. Eventually, this newly formed rocks were uplifted, eroded, and recycled as pebbles in the Gonfolite basin. This testifies that lithified and reworked skeletal-elements, originated from the late Eocene platform like the present-day

Ternate-Travedona Formation, were already undergoing erosion during the deposition of the Como Conglomerate Formation in the Oligocene.

Paleoecological reconstruction

Environmental conditions - Warm water species (e.g. larger benthic foraminifera, *Sporolithon*, *L. melobesioides*) dominate flora and fauna, suggesting a tropical climate with average annual temperatures at least above 20° (Adey 1979; Fravega et al. 1989; Vannucci et al. 1996; Aguirre et al. 2000; Geel 2000; Langer & Hottinger 2000; Beavington-Penney & Racey 2004). This is in line with the general climatic reconstructions for the late Eocene (e.g. Zachos et al. 2001) and the widespread presence of tropical carbonate factories in the region (N Italy, Giammarino et al. 1970; N Italy, Bassi 1995a; N Italy, Bassi 1998; NW Italy Consigliere et al. 2004; NW Italy, Vannucci et al. 2006; NE Italy, Bassi 1995b; NE Italy Bassi 2005; C Italy, Vecsei & Moussavian 1997; SW Italy, Parente 1994; SW Italy, Bosellini et al. 1999; S Italy, Benedetti 2010; W Spain, Morsili et al. 2012; W France, Segonzac & Charrolais 1974; Austria, Rasser 2000; Austria, Rasser & Piller 2004; Greece, Barattolo et al. 2007; Alpine region, Nebelsick et al. 2005).

Much of the sediment produced by the carbonate factory on the platform was moved basinward by sediment gravity-flows, feeding the Ternate-Travedona sub-marine fan (Fig. 12). Major events, represented by the massive bioclastic limestone beds, are characterized by abundant rock fragments, including rounded chert pebbles. It seems reasonable to suppose that these large events were triggered by episodic river floods, eroding the platform and transporting into the basin carbonate sediments and river-eroded rock-fragments (Fig. 12). In narrow carbonate platforms, like those developing over active thrusts and thrust and fold belts (Bosence 2005), mass transport events, triggered by river hyperpycnal flows, are common (e.g. Brandano & Ronca 2014). The reconstruction of plate movements suggests that convergence was active during middle-late Eocene time in this sector of the Alps (Malusà et al. 2011b), supporting a compressive tectonic setting. It is also noteworthy that many other late Eocene carbonate factories of the circum-alpine area, are mainly known from mass transport deposits (e.g. Consigliere et al. 2004; Vannucci et al. 2006; Aguirre et al. 2015).
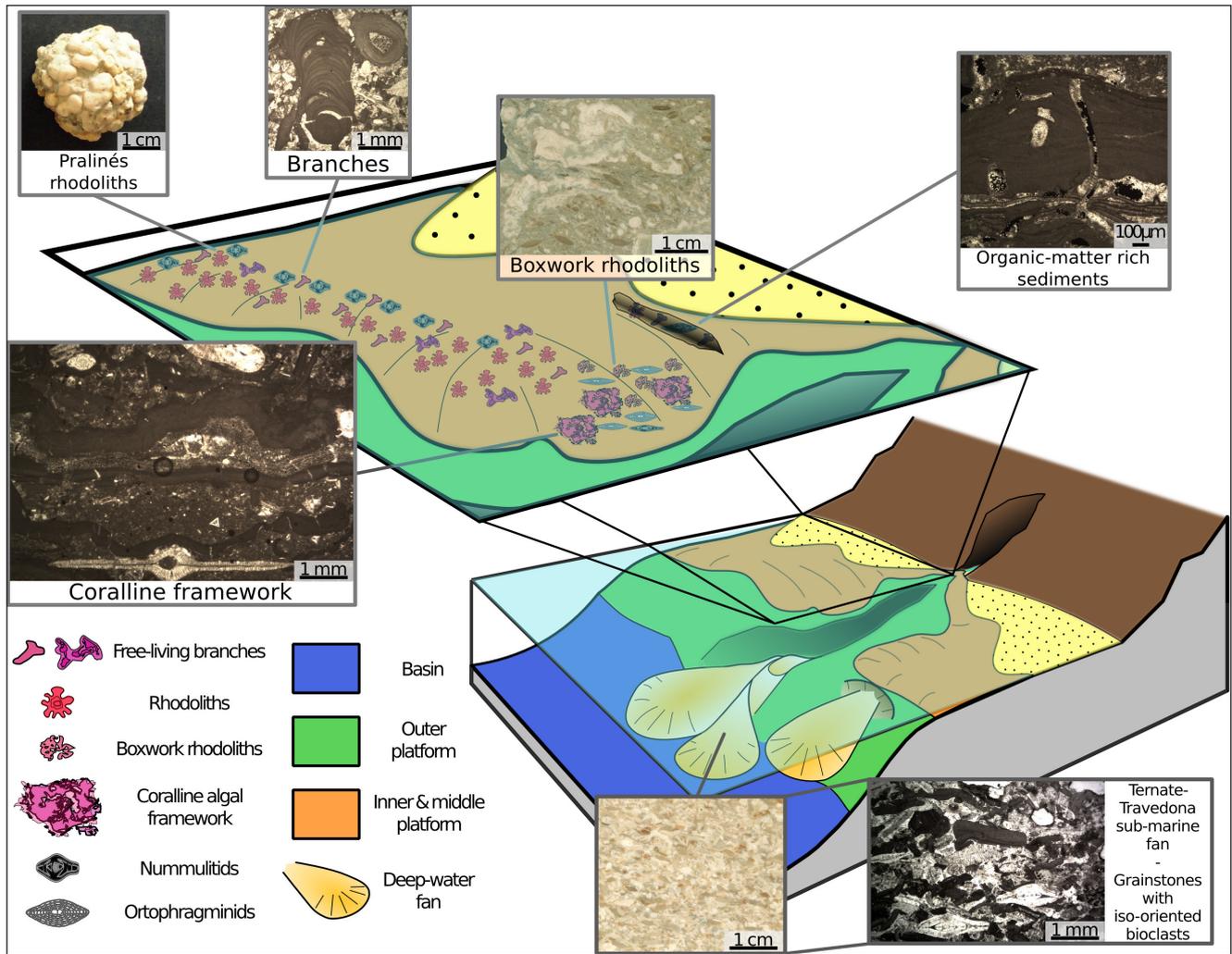
Fig. 12 - Paleoenvironmental reconstruction of the late Eocene carbonate factory and basin of the Ternate-Travedona Formation.

Large river-floods were also probably related to the formation of hydrocarbon-bearing elements. Within enclosed basins, even in shallow-water, anoxia may occur as long as oxygen demand, created by the decomposition of organic matter, exceeds the rate of oxygen supply (Tyson & Pearson 1991; Gardner et al. 2011). Small depressions present within the platform, created either by erosion or tectonic activity, might have acted as sedimentary traps for the large amounts of organic matter carried by river floods. The ensuing anoxic conditions within these depressions would have allowed organic matter preservation (Fig. 12). Subsequent river floods would have then eroded and transported into the basin also these organic-matter-rich deposits. This hypothesis is in accordance with the sedimentological evidence. Actually, since the hydrocarbon distribution is extremely patchy rather than being homogeneous, a later migration of fluids is unlikely (Suchý et al. 2012). Therefore, the organic matter was already within the sediment before it was carried basinward by gravity-flows. The sharp erosive borders that separate the hydrocarbon rich elements from the host lithology suggest that these elements were also partially-lithified before being transported.

Episodic pulses of river discharge would have also resulted in remarkable disturbances in the food web of the carbonate factory by favoring heterotrophs, due to the increase in nutrients and damage to light-dependent organisms, due to the decrease in water transparency (Hallock & Schlager 1986). The repeated mass transport events would have also resulted in unstable substrate, another condition detrimental to hermatypic corals (Lokier et al. 2009). Hermatypic corals were not observed in the studied skeletal assemblages. It is likely that substrate instability and high and irregular nutrient supply had a

combined stressful effect on the carbonate factory, hindering coral development. The distribution of this group in Northern Italy during the late Eocene (Fig. 1), suggests that these unstable conditions were prevalent, especially in the western part of the basin. The proximity to the active and growing Alpine orogenic prism (Stampfli 2005; Garzanti & Malusà 2008), was probably detrimental to the development of coral-dominated carbonate factories. This is remarkable because present-day corals thrive in well lit oligotrophic conditions, but Eocene corals were different. The occurrence of coral bioconstructions in delta settings and low-light conditions, suggests that Eocene corals were also adapted to environments unsuitable for their modern counterparts (e.g. Morsili et al. 2012). Environmental conditions in the studied area were therefore remarkably unfavorable to the setting of hermatypic corals, even by the standards of Eocene corals.

Facies distribution. Within the studied skeletal assemblages it is possible to recognize some of the major facies types which, according to Nebelsick et al. (2005), characterize Eocene Alpine carbonates.

Rhodolith facies is common in the studied carbonates and *L. melobesioides* and *S. aschersonii* are frequent and abundant rhodolith-forming species (Tab. 1). *L. melobesioides* is presently distributed from the intertidal to a depth of 85 m (Adey et al. 1982). Present-day *Sporolithon* prefers, in the tropics, low light conditions and consequently, but not always, deep-waters (Adey & Macintyre 1973; Adey 1979). However, *Sporolithon* species in very shallow-water are known both in the Recent (Basso et al. 2009) and in the fossil record (Fravega et al. 1989). The occurrence of numerous small miliolids, trapped between the thalli of *Sporolithon-Lithoporella* rhodoliths (Fig. 4E), indicates a shallow-water origin for these nodules. The presence of erosive truncations of the protuberances within rhodoliths indicates a moderate to high-energy environment of formation, further supporting a shallow-water origin for these nodules. Taking into account the existing models of Eocene Tethyan carbonate factories, an exposed middle-platform environment is conceivable as the area of formation of most of the rhodoliths (Rasser & Piller 2004; Bassi 2005; Nebelsick et al. 2005; Barattolo et al. 2007). The variable shapes and structures of

sampled rhodoliths suggest a range of different local conditions. According to existing models of rhodoliths distribution (e.g. Basso 1998), pralines rhodoliths must have formed under more active hydrodynamics, while boxwork rhodoliths with loosely packed thalli developed in more sheltered and probably deeper areas (Fig. 12).

Crustose coralline-algal framework facies is preserved, relatively unscathed, in the pebbles of the Villa Olmo Member. In this facies *Neogoniolithon* crusts are associated with abundant orthophragminids and nummulitids, both with a low T/D ratio (Fig. 3E), as well as boxwork rhodoliths and small benthic and planktonic foraminifera. Fragments of coralline-algal crusts are abundant in the Ternate-Travedona Formation, and although diagnostic characters are sometimes not sufficient for their identification, some of them could be attributed to the genus *Neogoniolithon* and they were therefore probably produced by the fragmentation of the framework. This genus is actually one of the most important framework-forming coralline algae in Eocene carbonate factories (Nebelsick et al. 2005), since it can develop directly over soft substrate (Fravega & Vannucci 1987; Rasser 2000; Rasser & Piller 2004; Nebelsick et al. 2005; Quaranta et al. 2007). Eocene coralline-algal bindstones, are thought to develop at depth comparable or slightly greater than the one of the rhodolith facies, although with lower energy and higher substrate stability (Rasser & Piller 2004; Bassi 2005; Nebelsick et al. 2005). This is also consistent with models of distribution of coralline-algal growth-form in modern oceans, which state that coralline-algal framework develops preferentially in environments with stable substrate, moderate to low hydrodynamic energy and low sedimentation rate (e.g. Basso 1998). Accordingly, a lower middle-platform depths, in a sheltered environment is conceivable for the studied coralline-algal bindstone (Fig. 12).

Maerl facies (unattached coralline-algal branches) and coralline-algal debris facies are very common in the studied samples. In the Ternate-Travedona Formation they are particularly common and are associated with fragments of articulated coralline algae and abundant thick-tested nummulitids, suggesting a shallow-water environment of formation for this facies (upper part of the middle-platform/lower part of the
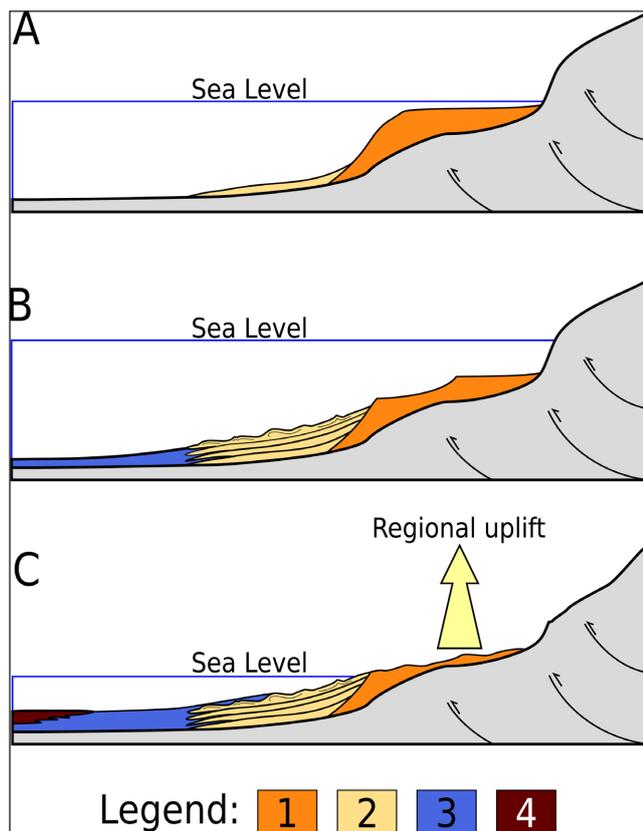
Fig. 13 - Paleoenvironmental reconstruction of the upper Eocene carbonate factory and basin of the Ternate-Travedona Fm.; 1=carbonate platform; 2=submarine delta (Ternate-Travedona Fm.); 3=hemipelagic marls (Chiasso Fm.); 4=deepwater turbite system (Gonfolite Lombarda Group). A) The thrust-top carbonate platform (sensu Bosence 2005) during the Upper Eocene. B) Approximately at Eocene-Oligocene boundary the rapid sea level rise induces the failure of part of the platform. This failure has been recorded on top of the Travedona-Ternate Fm. C) During the Oligocene, the platform is exposed and eroded as consequence of the regional uplift, and its detritus is discharged in the Como Conglomerate Fm.

inner-platform; Beavington-Penney & Racey 2004; Hallock 1979; Hallock & Glenn 1986; Nebelsick et al. 2005; Vannucci et al. 2006). On the other hand the dominance of Hapalidiales coralline algae suggests a deeper setting (Aguirre et al. 2000). However, it must be stressed that the formation of these facies is mostly related to hydrodynamic energy and sedimentation rate (Adey 1986; Basso 1998) and thus they may develop at various depth across the platform, wherever the suitable combination of environmental factors occur (Fig. 12). Furthermore, since the skeletal assemblages of Ternate-Travedona Formation were extensively transported, the mixing of skeletal grains from different parts of the platform cannot be ruled out (Coletti et al. 2015).

Taking in to account the distribution of the major facies, their characteristics and their fossil assemblages, the carbonate platform investigated in this study bears a striking resemblance to the other late Eocene carbonate systems of the Alpine area, and especially to those recorded in the Gàssino Formation (Fig. 1; Consigliere et al. 2004; Vannucci et al. 2006). On the other hand, it is clearly separated from those of Southern and Central Italy where coral facies are remarkably more common (Vecsei & Moussavian 1997; Parente 1994; Bosellini et al. 1999). The prevalence of high to moderate energy facies (rhodoliths, coralline-algal debris and maerl) and the associated paucity of lower energy facies (crustose coralline-algal framework), suggests a platform probably slightly more exposed to water energy when compared to the nearby western Lessini shelf (e.g. Bassi 1995b; Bassi 2005). Developing along an active compressive margin, the studied platform was probably narrow, with a steep topographic gradient and large areas directly exposed to waves.

The late Eocene to late Oligocene history of the carbonate platform

In the late Eocene, the platform was harboring rhodalgal carbonate factories (Carannante et al. 1988), dominated by coralline algae and larger benthic foraminifera. Small pralines rhodoliths, maerl and coralline-algal detritus, associated with thick-tested larger benthic foraminifera were common in the high-energy environments of the upper-middle platform (Fig. 12). Rhodoliths were especially common in the exposed sectors of the middle platform. In more sheltered environments, in the lower-middle platform, coralline-algal framework developed, associated with abundant thin-tested larger benthic foraminifera and box-work rhodoliths (Fig. 12). Further offshore the sedimentation was dominated by the deposition of planktonic foraminifera. During this period, the Ternate-Travedona Formation sub-marine fan was supplied by episodic gravity-flows triggered by river hyperpycnal flows (Fig. 12; 13A).

At the Eocene-Oligocene boundary (Mancin et al. 2001), the plurimetric slump deposit at the top of the sequence marks the end of the re-sedimentation of shallow-water carbonate skeletal grains. This slump deposit may be interpreted as a "highstand" failure deposit of the platform (sen-

su Grammer et al. 1993), following the rapid sea-level fluctuations recognized world-wide approximately around the Eocene-Oligocene boundary (Fig. 13B; Wade & Pälike 2004; Pälike et al. 2006; Sotak 2010). These fluctuations might also be responsible for the demise of the carbonate platform (Schlager 1981). Actually, the onset of the major phase of growth of the Alpine belt could not have been the primary cause of the demise of the carbonate factory, because at least 5 Ma separate the top of the Ternate-Travedona Formation from the tectonically-induced clastic sedimentation of the Gonfolite Lombarda Group.

In the late Oligocene, focused erosion of the Central Alps produced huge volumes of quartzo-feldspathic detritus, which was carried by the paleo-Ticino river to feed the foredeep formed on Adriatic crust (Garzanti & Malusà 2008). Approximately at that time the late Eocene platform had been uplifted and was being eroded, as testified by the pure-limestone pebbles and cobbles in the Como Conglomerate Formation (Fig. 13C). At the same time, deposits composed of reworked skeletal grains (originating in the late Eocene carbonate factory, like those of the Ternate-Travedona Formation) were also exposed to erosion, as testified by the impure-limestone pebbles. By the end of the deposition of the Gonfolite Lombarda Group, the carbonate platform was completely eroded.

Conclusions

Re-sedimented carbonate deposits and eroded fragments, dispersed in the Southalpine Foredeep Basin during the growth of the Alpine belt, disclosed sufficient information for the reconstruction of a late Eocene carbonate platform, now dismantled. Their common origin and provenance is supported by skeletal assemblages, benthic foraminiferal associations and particularly by coralline-algal flora. Whilst in the sub-marine fan of the Ternate-Travedona Formation only reworked skeletal assemblages are preserved, the pebbles of the Como Conglomerate Formation are pristine fragments of the original carbonate platform, preserving also the original fabric.

The late Eocene rhodalgal carbonate factory developed along a narrow platform bordering the Alpine belt. Rhodoliths, unattached coralline-branches and thick-tested larger benthic foraminifera dominated the high-energy environments of the middle platform while coralline framework, boxwork rhodoliths and thin-tested larger benthic foraminifera characterized more sheltered environments of the lower-middle platform. Further off-shore, outer platform sedimentation was dominated by planktonic foraminifers.

Episodic sediment-gravity flows, probably triggered by river floods, supplied the deep-water fan of the Ternate-Travedona Formation with bioclasts produced on the platform. Organic materials and nutrients discharged by rivers promoted localized oxygen-depletion and organic matter preservation in depressions of the platform with limited water circulation. The combined stressful effect of irregular nutrient supply and substrate instability were probably detrimental to hermatypic corals, whose presence is not recorded in the skeletal assemblages. Coral facies are generally uncommon in late Eocene carbonate platforms of Northern Italy, though are common in those of Southern and Central Italy, suggesting that the proximity to the growing Alpine orogenic prism was unfavourable for hermatypic corals.

At the beginning of the Oligocene, the frequent sea-level fluctuations and a general trend of global cooling caused the demise of the carbonate platform. Finally, during the Oligocene, the carbonate platform deposits were completely eroded and recycled, as pebbles, in the Southalpine Foredeep Basin.

In addition to improving the knowledge of the paleoecology of late Eocene Alpine carbonate factories, this study demonstrates how detailed analyses of carbonate detritus are a powerful tool for reconstructing dismantled paleonvironments and their evolutionary history.

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