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THE PLEISTOCENE MARINE TERRACES OF LE CASTELLA AND CAPO COLONNA (CALABRIA, SOUTHERN ITALY):

A PALEOECOLOGICAL STUDY OF THE CORALLIGENOUS BUILD-UPS AND ASSOCIATED BIOCLASTIC FACIES

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XXIV Ciclo

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AIM OF THE STUDY

Autochthonous coralline red algal structures are well known and occur in tropical regions, where they are the major contributor to reefs building (Minnery, 1990). Tropical coralline red algae build-ups are usually restricted to littoral or shallow environments, because they are able to withstand turbulent water motion and abrasion.

Red algal structures are also reported from beyond the tropics, at shallow water depth (wd) off northern Norway (Freiwald, 1998) and in the modern temperate-water Mediterranean Sea, at wd between 2and 120 m (Pruvot, 1894; Feldmann, 1937; Bacci, 1947; Tortonese, 1958; Rossi, 1958, 1961; Laborel, 1960, 1961; Molinier, 1960; Parenzan, 1960; Pérès & Picard, 1964; Gamulin Brida, 1965; Sarà, 1968, 1969; Hong 1980, 1982; Bosence, 1983a, 1983b, 1985; Gill & Rossi, 1984; Ballesteros, 2006; Casellato & Stefanon, 2008). Several types of red algal constructions are reported for the Mediterranean Sea, from the intertidal *trottoir* to the circalittoral *coralligène* (Pérès& Picard, 1964; Di Geronimo *et al.*, 2002; Ballesteros, 2006). In particular, the coralligenous facies is divided into the coralligenous on primary hard substrate (*coralligène de la roche littorale*) and coralligenous on detrital sediments (*coralligène de plateau*). Pérès & Picard (1964) defined furthermore a pre-coralligenous facies, representing a shallow-water precursor of the *coralligène* sensu strictu. Modern coralligenous communities build large autochthonous structures, up to 4 m high and 50 m across (Bosence, 1985).

Ballesteros (2006) suggests that the coralligenous facies develops where the surface irradiance level is reduced ranging between 0,05% and 3%, and depending on light penetration occurring between 20 and 160m wd, with an average optimal growth-interval between 40 and 60m wd (Pérès & Picard, 1964; Laubier, 1966; Di Geronimo *et al.*, 2002; Ballesteros, 2006; Nalin *et al.,* 2006). The coralligenous community is adapted to low nutrient levels, temperature from 10 to 23°C, and moderate to weak water agitation (Laubier, 1966; Bosence, 1985; Ballesteros, 2006). Environmental factors, like light penetration or water movements, are not dependent on water depth or topography, but can be strictly influenced by the complex cavernous structures of coralligenous build-ups. It must be highlighted that coralligenous build-ups provide ecological niches in which a very high diversity within the coralligenous community is attained (Pérès& Picard, 1964; Bosence, 1985; Balata *et al.*, 2005; Ballesteros, 2006).

Fossil counterparts of coralligenous build-ups are not so-well known, and rarely described. Ancient red-algal deposits (Eocene-Miocene) outcrop in different European regions, and have been compared with the coralligenous facies, but they formed under tropical paleo-conditions (Pedley, 1978; Bosence & Pedley, 1982; Bosence, 1983b; Bucur & Ianoliu, 1987; Bucur *et al.,* 1987; Carannante & Simone, 1996; Rasser, 2000; Rasser & Pillar, 2004). Younger comparable fossil counterparts of the coralligenous facies are reported from the mid to Upper Pleistocene of Sicily and Calabria, Italy (Gliozzi 1987; Nalin, 2003, 2006; Nalin *et al.,* 2006, 2007; Zecchin *et al.,* 2004b, 2009, 2010; Basso *et al*., 2007), and Rhodes Island, Greece (Titschack *et al*., 2008).

The present study aims at describing biogenic marine terrace deposits from uplifted coastal sections in the Crotone peninsula (Calabria, Italy), in which well-developed Pleistocene temperate red-algal reefs (*coralligène de plateau*) and their associated deposits are dominant. The paleoenvironmental and genetic-stratigraphic interpretation of the outcrops provides a specific and quantitative description of the fauna, and allow further insight regarding the temporal evolution and controls on development of this carbonate factory, and the Pleistocene geological evolution of the area.

1.CARBONATE SEDIMENTOLOGICAL STUDY: AN OVERVIEW

1.1 INTRODUCTION

The nature and distribution of continental shelf sediments cannot be encompassed by a single universal model.

The continental shelf is a complex area, where both physical processes and biological factors are at play, contributing to generate a wide range of sedimentary environments and facies.

Factors controlling the development of present-day shelves are: the amplitude and the inclination of the platform, tectonics and continental geology, climate and climate change, eustatic changes, the contribution of terrigenous sediment of continental origin, biogenic production, hydrodynamics, temperature, salinity, light, the interaction between biota and sediment.

From a sedimentological point of view, the continental shelf is considered a shallow-water environment.

Emery (1968) suggested that 70% of modern shelf sediments are continental or coastal Pleistocene deposits, which are not in equilibrium with the present environmental conditions. Currently the sediments accumulated on the shelf represent the result of integration between continental geology and eustatic oscillation during Pleistocene.

Shelves are located along continental margins. Therefore, fluvial input and continental erosion play the most important role in determining the nature, distribution and amount of sediment available for deposition.

Ricci Lucchi (1978) divided the carbonate-dominated and the siliciclastic-dominated shelves.

The production and deposition of carbonate are both biologically and chemically controlled.

Currently, the process of carbonate production is used to classify different types of carbonate factories, sensu Tucker & Wright (1990). Three types of factories are commonly recognized: tropical factories, cool-water controlled precipitates, and microbialite factories (Schlager 2000, 2003, 2005).

Carbonate shelves are generally considered as a low latitude phenomenon, between 30N and 30S (Rodgers, 1957), typically developed in tropical environments.

Siliciclastic dominated shelves are dominated by terrigenous sediments of continental erosion, and they are considered a medium and high latitude phenomenon.

The temperate latitude, which includes the Mediterranean area, is historically considered as a terrigenous domain, even if the presence of carbonate sediments is not excluded (Ricci Lucchi, 1978).

The objects of the present study are biogenic carbonate rocks forming marine terrace deposits characterizing the area of Crotone peninsula, along the Calabria coasts (Southern Italy).

In particular, the two most recent Pleistocene marine terraces, outcropping in Le Castella village and along the Capo Colonna peninsula, have been studied. These deposits are correlated to Marine Isotopic Stages 5.1 and 3 (Mauz & Hassler, 2000; Nalin *et al.*, 2006, 2007; Zecchin *et al.*, 2004b, 2006, 2009, 2010).

From a stratigraphic, sedimentological and chronological point of view several data exist in literature (Belluomini *et al.*, 1988; Palmentola *et al.*, 1990; Mauz & Hassler, 2000; Massari *et al.*, 2002; Nalin, 2003, 2006; Nalin *et al.*, 2006, 2007; Zecchin *et al.*, 2004a, 2004b, 2006, 2009, 2010). On the contrary very few notes are reported about the paleontological content (Gliozzi, 1987; Basso *et al.*, 2007; Bracchi *et al.*, 2011; Nalin *et al.*, *in press*).

The fact that the marine terrace deposits are dominated by biogenic carbonate rocks manifest that the paleontological scale is necessary to better interpret the nature of these deposits.

The aim of the project is to conduct a paleoecological study of the marine terrace deposits. This approach needs a very detailed study, both qualitatively and quantitatively, on the paleontological content forming these deposits. The work-scale is very low, because exactly in the specific description of the biogenic rocks lays the possibility to interpret and reconstruct the paleoenvironmental and temporal evolution of the marine terrace deposits.

Biogenic carbonates have always been an important argument of sedimentary geology. The core of carbonate sedimentology lies in warm tropical waters because these sediments and reefs are clear analogues of many ancient limestones, whereas cool-water carbonates were largely ignored until 1980s, as studies revealed what a powerful tool the modern tropical realm was for interpreting the rock record.

Chave (1967) first pointed out that carbonates could form at all latitudes, regardless of water temperature, as long as terrigenous clastic sediment input was low. Milliman (1974) illustrated numerous examples of cool water accumulations.

Temperate biogenic carbonates usually have been connected to cool water high latitudes carbonate, but they instead represent a transition between two end-members, the tropical carbonate and the cold-water carbonate factories. It is possible to recognize specific diagnostic features between carbonate systems and this represents a powerful tool for studying the geological records.

The temperate biogeographic province occupies two sections parallel to equator over 30N and 30S (Briggs, 1984). In these climatic bands biogenic carbonate sediments form and accumulate in shallow waters on the shelves.

The Mediterranean Sea is considered as a marginal sea in the temperate-water zone. Its only links with the ocean are the Gibraltar strait and the Suez channel. Water temperature in the Mediterranean undergoes seasonal fluctuations. Sea surface temperature ranges from 10C° to 32C° during the year (Acker & Leptoukh, 2007). The Mediterranean is considered an oligotrophic sea (Moutin & Raimbault, 2002), making it one of the largest nutrient-depleted areas in the world (Ignatiades, 2005). Nonetheless high biodiversity is registered, making the Mediterranean Sea a biodiversity hotspot (Coll *et al.*, 2010) and more than 28% of the total number of species are Mediterranean endemisms.

The carbonate factory in the Mediterranean Sea is characterized by the production and accumulation of skeletal grains, whereas inorganic grains are rare (Carannante *et al.*, 1988; Nelson, 1988).

The most important carbonate producers are considered CCA, mollusks, bryozoans, foraminifers, echinoids and crustacean (Carannante *et al.*, 1988; Bracchi & Basso, *in press*).

Various models exist in literature aiming at describing the distribution of biogenic carbonate facies along the shelf around the world.

These studies result in the recognition of a complex structure, and in the proposal of several carbonate lithofacies (Lees & Buller, 1972; Lees, 1975; Carannante *et al.*, 1988; Nelson, 1988; James, 1997).

The recognized facies are usually classified on the basis of the presence of different groups of organisms, or on the basis of the distribution of these groups of organisms respect to oceanic parameters like light conditions, nutrients availability, salinity or water-temperature.

Generally the over-simplification of models aimed at describing the world entire sedimentary shelf system is an important factor to consider respect to the scale at which the study is conducted. In fact the models are a very well define instrument for a wide scale, appropriate to describe the world nature system. On the other hand the classification and nomenclature proposed within tend to reduce the complexity of nature systems into wide classes, not allowing a very high detailed description of the facies.

As example, the occurrence of hermatypic corals is considered a key factor to distinguish at first the tropical biogenic carbonate (Photozoan or Chlorozoan facies) respect to the middle to high-latitude carbonates (Foramol facies) (Lees & Buller, 1972; Lees, 1975). Hermatypic corals characterize the shallow-water reefs in tropical and sub-tropical areas (Chlorozoan= Chlorophyta + Zoantharia, Lees & Buller, 1972). Recent studies on the occurrence of hermatypic corals, although without zooxanthellae (cold water coral), in deep waters of Mediterranean Sea (Taviani *et al*., 2005; Savini & Corselli, 2010; Vertino *et al*., 2010) or in NE Atlantic province (Freiwald & Roberts, 2005; Frank *et al*., 2009) weaken the meaning of the classification based on this occurrence for the fact that Chlorozoan facies is no more represented only by tropical coral reefs facies, but by similar organisms with a larger bathymetrical and geographical distribution, even if Chlorophyta algae are not present in cold-water coral provinces.

Moreover the Mediterranean Sea, being a marginal sea, is not well represented or framed in all the models proposed in literature The scheme proposed by Halfar *et al.* (2004) suggests slow possibility of carbonate production activity for the Mediterranean Sea, due to its oligotrophic conditions. Nevertheless lots of examples exist in literature reporting the dominance of biogenic carbonate sedimentation along Mediterranean shelves (as example: Brandano & Civitelli, 2007; Casellato & Stefanon, 2008; Bracchi & Basso, *in press*).

The solution of Carannante *et al.* (1988) is the most appropriated to define both the present-day shelf carbonate sediments in Mediterranean Sea and the geological record of Cenozoic carbonates from the Mediterranean region. The crustose coralline algae are one the most important carbonate producers in the Mediterranean Sea, but following this scheme all the red algae facies are comprised into *Rhodalgal* class. The definition is obviously correct and full of significant, but the loss of information about the distinct coralline algae facies, as example rhodoliths or coralligenous build-ups, is crucial following a paleoecological approach.

The marine benthic bionomic model of Pérès & Picard (1964) for the Mediterranean area lays on the definition of biocoenoses along the topographic profile of the sea-floor. The biocoenoses is defined by the specific identification of organisms, and on the rate of fidelity degree of species to defined oceanic factors. The key factor of this approach is a very low scale and the corresponding high details in the definition of the biogenic content of sediments and facies identification.

This model seems to be the most appropriated to describe the carbonate contribution by different biocoenosis on the shelf and to provide the most precise interpretation of fossil record in an actuo-paleontological way, considering it together with interaction of biology to abiotic and paleoabiotic factors. On the other hand the definition of biocoenosis is only qualitative and not quantitative in term of specific taxa contribution to carbonate production/accumulation. So the biocoenosis system is useful to interpret the depositional environments and should be accompanied by specific quantitative considerations.

This model has been developed for Mediterranean present-day temperate carbonate system and it is applicable also on recent fossil record of carbonate deposits accumulated under temperate conditions.

1.2 TOPOGRAPHIC SHELF PROFILE AND THE CORRESPONDING FOSSIL RECORD

The continental shelf is a shallow water environment, characterized largely by the presence of mobile sediments.

From a physiographic point of view, it represents the portion of the continental margin that extends as a gently sloping surface from the shoreline seaward to a marked change in slope at the top of the continental slope. Its width can vary from few meters to kilometers and seaward depth averages about 130 m. The lower limit is typically considered the isobath of 200 m while the upper limit is not clearly defined. According to some authors, it should be placed at the average level of low tide, while others also consider deltas, coastal, intertidal deposits as part of the shelf domain (Ricci Lucchi, 1978).

The shelf can be divided into internal and external portions. The internal shelf develops from the beach line until 50 m wd, whereas the external shelf typically extends beyond 50 m wd.

Schemes which subdivide the shelf areas usually follow as main criterion the water depth, which in turn determines the processes occurring on the sea floor (Reading & Collinson, 1996). It should be noted that only a range of wd can be given, because the depths to which tidal processes, waves and storms affect the shelf vary considerably.

The beach is a coastal environment where waves produce accumulation of loose sediment, usually a mixture of sand or gravel particles. Where the wave energy is strong, sand and gravel particles may be continuously reworked, abrading and effectively sorting. The wave energy is a function of hydrology and topography of the coast. In the case of carbonate platforms, the beach sediment derives from chemically precipitated carbonate sediments, by bioclasts or by reworked carbonate material, while the terrigenous component is directly derived by the contribution from rivers and transport along the coast by long shore currents of land-derived material. Generally the sediments accumulating on the beaches are a mixture of clastic and carbonate material.

Factors defining the separation of different areas of the beach are basically wetting, which is a function of tidal range, and hydrodynamics, which are a function of topography and climate.

The lateral limits of the beach are given by the transition to the intertidal flat. This zone is not always present because it is itself the result of the topography and tidal fluctuations.

The upper and lower limits of the beach are given by the degree of wave activity: the upper limit corresponds to the formation of the first eolic dunes, whereas the lower is the depth at which waves produce no more effect on the bottom. The limit of wave action is an energy barrier: it divides the sand deposits, typical of beach or other coastal prism, from muddy deposits which usually characterize more offshore areas of the continental shelf.

Following Prothero (1990), three sedimentological domains have been recognized along the beach profile (fig. 1.1):

- *backshore*, the back beach, which includes the washover fans and upper-tidal complexes formed as the result of winds, storms and tides and typically passes laterally to lagoonal or continental deposits. The limit seaward is a sandy ridge called berm. Only under storm conditions the seawater washes over the berm. The sediments are carried by the waves over the berm crest and formed layers gently deepened landward.

-*foreshore*, or swash zone, the intertidal littoral zone, which is edged by tidal levels. Depending on the tidal range, it may be a vertical distance of anything from a few tens of centimeters to many meters. The extension is governed also by the slope. Sediments forms laminated low-angle to planar cross *laminae*, broader lenticular, perpendicular to the shoreline.

-*shoreface*, the submerged beach, which ranges from the base of the average low tide and the area of long shore currents activity, where the wave base first begins to feel the bottom, around depths of 10 to 20 m. Here, the presence of sedimentary structures such as bars and ripples is common. Usually sandy sediments are deposited in *laminae* parallel to the slope of the shoreface, dipping few degrees offshore. This stratification is mostly composed by well rounded and well sorted sediments. In the deepest part the presence of mud and fine sand is reported. The depth to which the shoreface extends is very variable, from few meters to dozens of meters, and laterally passes to the offshore transition zone, typically lies between the level of good weather and the storm waves, and the offshore sensu strictu.

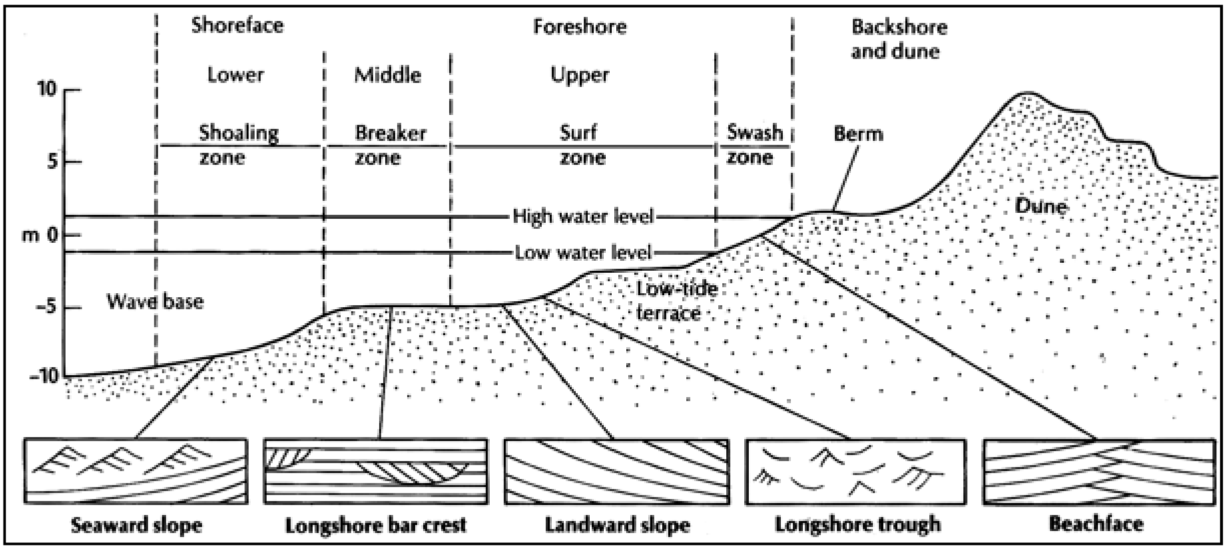


fig. 1.1: Schematic profile of the beach, from Prothero (1990)

Fossil beach deposits are well represented in the geologic record and thus, although these represent a boundary marine environment, they play a key role in paleoenvironmental analysis.

Beach sequences often record a progradational sequence of facies, with particle size increasing upward and superposition of facies from marine to frankly continental; even it is possible to find a fining-upward structure in transgressive sequences.

A progradational beach sequence is composed by:

- *foreshore* facies at the top, characterized by low angle or planar cross bedding which is perpendicular to the shore. It is formed by well sorted sediments. Typically the primary sedimentary structures are involved in intensive bioturbation, made by mollusks, echinoid and worms, that obliterate the original disposition of the sediments.
- *shoreface* facies, as the result of long shore current type sedimentation, and for that reason the shoreface layers dip generally perpendicular to the growth direction of the beach. In particular, we recognize:
    1. *upper shoreface* facies characterized by medium to coarse sand and wave rippled, trough, planar or swaley cross-laminated structures.
    2. *lower shoreface* facies, characterized by planar lamination in fine sand.

The lower shoreface passes to the offshore *transition zone* facies, characterized by hummocky cross stratified layers.

This terminology was first introduced to describe clastic shelves and sedimentary record and then applied to carbonate sedimentary environments. The environments of deposition on continental shelves vary according to wd, sediment supply, climate (tide, storm, wave energy processes) and biology. The products of these interacting processes are extremely variable in term of facies characters, sedimentary body geometry and obviously stratigraphic successions.

The peculiarity of biogenic carbonate sedimentary realm is the ability of organisms to interact with the sedimentary environment. In fact, different biotas play a crucial role in defining the texture of the sediment and properties of the substrate, defining particular geometry in the stratigraphic succession and partially upsetting the descriptive scheme reported above. On the other hand the occurrence of defined sedimentary structures or stratigraphic successions frames the interpretation of the deposits, and so the classical sedimentological descriptive scheme represents a primary useful approach.

In case of current biogenic-dominated sedimentation along the shelf or fossil biogenic shallow-water deposits, we need a more focused approach in the description of biogenic facies and paleontological content, due to the fact that the biogenic control of sedimentary processes results in different biotas, able to develop same sedimentary structures with similar textures but correlating to different environmental and paleoenvironmental conditions.

1.3 THE CARBONATE CLASSIFICATION

Two classes of carbonate sediments exist.

The first consists of sediments deposited mechanically and with particular textures. The second consists of sediment accreted *in situ*, both bioconstructed and through inorganic chemical precipitation.

First class is composed by granular carbonates, made of particles of various origins creating a clasts-supported and porous structure.

1) Carbonate particles that belong to this first class are:

1.A) <u>skeletal grains</u>, entire or fragmented skeletons of marine organisms. They show in a great variety, because they can derive from different organisms, plants or animals, which are quite different in size, shape, weight, internal microstructure, chemical and mineralogical composition.

1.B) <u>non skeletal grains</u>, not obviously derived from skeletal material of micro-organisms, invertebrates or thalli of plants. Following Folk (1959), four main types can be recognized:

  1.B.1) coated grains, polygenetic in origin, with different processes forming similar types like ooids, oncoids, and pisoids.

  1.B.2) peloids, carbonate granules, micro-sub-spherical or ellipsoidal, with no texture or internal structure. They can be of fecal origin or incorporated grains of matrix.

  1.B.3) aggregated grains, formed when several carbonate particles become bound and cemented together (grapestones, lumps, and botryoidal lumps).

  1.B.4) clasts, limestone reworked fragments.

2) The second class, *in situ* accreted carbonates, is characterized by the precipitation and growth of carbonate in a given place. They are able to create robust, 3-D and lithified structures. There are three basic types of *in situ* accreted carbonates:

  2.1) biolithes: organic sediment growing *in situ* through direct physiological activity of sedentary organisms, like corals.

  2.2) stromatolites: structures growing through the action of bacteria, able to trap particulate inorganic sediment.

  2.3) concretioned carbonates: carbonate formed by chemical inorganic precipitation.

The most common classifications of carbonate sediments are those of Folk (1959) and Dunham (1962).

Folk’s scheme was later modified by Embry & Klovan (1971), James (1984) and Kendall (2005).

to include coarse grained carbonates, highlighting the role each organism performed during deposition.

1.4 FACIES CLASSIFICATION

Gressly A. (1838) is credited with the first modern use and definition of "facies", he defined as the sedimentological and paleontological attributes of rocks reflecting the processes of deposition within specific geomorphic environments. He understood that facies occur independently of time, and he established that there are predictable patterns of facies relationships.

Several facies-classification schemes for carbonate sediments of shallow water exist in literature, considering the development of carbonate linked to benthic biological activity and its correlation with oceanic parameters. These models are very complex, because numerous inter-dependant parameters have to be considered, in a continuously changing environment where biogenic activity unfolds.

Different oceanographic parameters have been considered to describe and classify the present day distribution of biogenic carbonate along the shelf, such as climate, oceanic circulation, temperature, salinity (Lees & Buller, 1972; Milliman, 1974), nutrient availability (Hallock, 2001; Mutti & Hallock, 2003; Halfar *et al*., 2004; Halfar & Mutti, 2005), taxa present (Carannante *et al*., 1988) determining the distribution of different biotas responsible for the production and accumulation of carbonates. All these parameters are generally used to definition different carbonate facies, indicted by authors as communities or association.

Hydrodynamics is considered an important controlling factor, mostly if coupled with the morphology of the bottom. It could provide a steady influx of nutrients. For example, oceanic gyres transport warm waters towards poles on the western sides of oceans, and cool waters from the poles toward the equator on the eastern side. It turns out that carbonates are common on the eastern side of the oceans where the *upwelling* currents are also present (James, 1997).

Moreover precise knowledge on the effects of these parameters on carbonate sedimentation could represent an important instrument to define the paleooceanographic and paleoclimate conditions of the fossil counterpart.

In fossil carbonate systems, relative sea level and tectonic control are considered two of the most important factors to understand shelf geometry and the relative distribution of facies.

TEMPERATURE AND SALINITY:

Lees & Buller (1972) focused on shelf biogenic carbonate sand and gravel, between 60 N and 60 S, considering water temperature as discriminating factor.

They recognized 2 associations:

- "*cool water*" community, formed by mollusks, foraminifers, echinoids, bryozoans, crustaceans, ostracod, sponges, serpulids, ahermatypic corals and calcareous algae.

- "*warm water*" community, formed by cool-water organisms, except for rare bryozoans, plus hermatypic corals and calcareous green algae.

The authors called the first type *ForaMol* association, in which mollusks and foraminifers are dominant, and the second type *ChloroZoan* association in which hermatypic corals (Zoantharia) and calcareous green algae (Chlorophyta) are the dominant taxa (fig. 1.2).

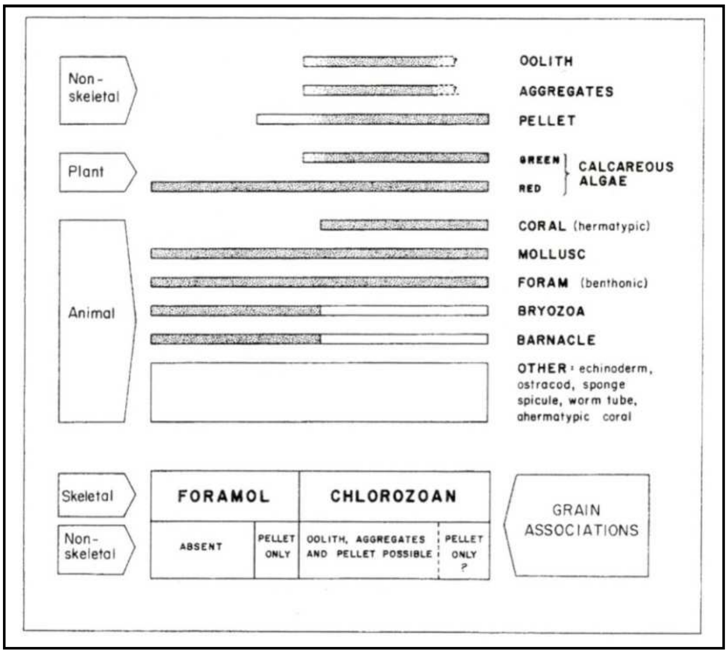


fig. 1.2: Distribution of skeletal and non skeletal grains plotted against the associations recognized on the shelf (Lees & Buller, 1972)

A thermal threshold has been identified for the *ChloroZoan* association: a minimum temperature of 14-15 °C and an annual medium temperature of 23 °C. The *ForaMol* association can be presents even if the water temperature is higher than 15 °C.

A complete summary on the relation between temperature and association distribution is proposed in Mutti & Hallock (2003) (fig. 1.3).

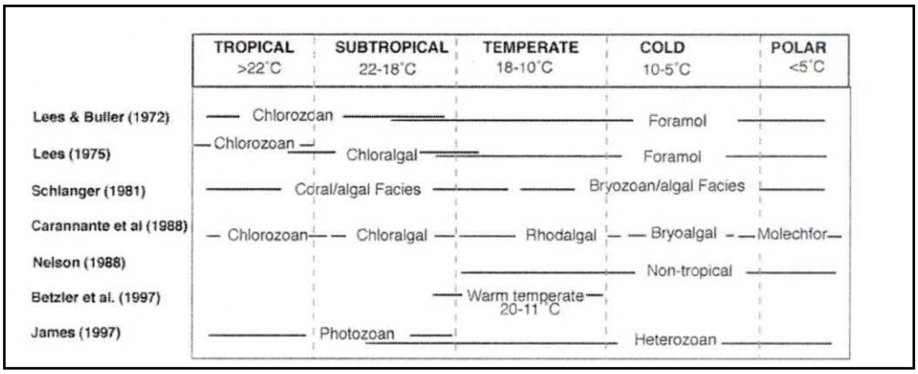


fig. 1.3: summary on the relation between temperature and association distribution in Mutti & Hallock (2003)

Lees (1975) considered the link between temperature and salinity, and found that the *ForaMol* association could be found in warm water where the salinity is lower than its typical oceanic value. He proposed a third association called *Chloralgal*, characterized by the presence of calcareous green algae and absence of hermatypic corals, with salinity values higher than 43-45‰ or lower than 33‰.

The limit between *Chloralgal* and *Chlorozoan* associations is not sharp and the first association could be considered as a particular facies of the second one.

Moreover, Lees (1975) proposed a scheme for the classification of non-skeletal carbonate grains: 1) only pellets; 2) ooliths and other aggregates; 3) absence of non-skeletal grains. The distribution of these grains is restricted to tropical areas, even if salinity was considered the most important factor defining which type of grains can be found.

TAXA OCCURRENCE

Carannante *et al*. (1988) studied both Miocene carbonate systems in the Mediterranean area and current example of carbonate sedimentation of Mediterranean Sea and along Brazilian coast.

They developed a descriptive nomenclature based on occurrence of certain groups of organisms as follows:

- *RhodAlgal Facies*, from rhodolith+algal, formed by encrusting calcareous red algae and bryozoans, with mollusks, echinoids, foraminifers, crustaceans, serpulids. This facies is reported from temperate to sub-tropical water.
- *MolEchFor Facies* formed by mollusks (Mol-), echinoids (-Ech-) and foraminifers (-For), whereas the calcareous algae are quite absent. This facies develops in temperate-cold water, and can be

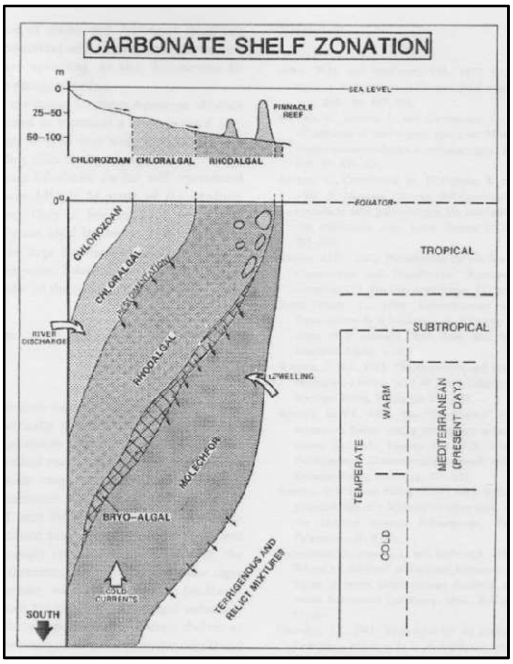


fig. 1.4: Facies distribution model on the basis of latitudes, water depth and environmental parameters in Carannante *et al*. (1988)

present also at tropical latitudes (fig. 1.4).

Nelson (1988) focused on the major features characterizing tropical and temperate-polar carbonate, offering a useful review of the available knowledge (tab. 1.1).

Furthermore, the author proposed a new association using the same structured name of Carannante *et al*. (1988): *BryoMol* association to indicate an association formed by bryozoans and mollusks.

tab. 1.1: Summary of the available information about major features of tropical and cool water carbonate in Nelson (1988)

ENVIRONMENTAL AND FACIES PARAMETERS	**TROPICAL-SUBTROPICAL CARBONATES**	**TEMPERATE-POLAR CARBONATE**
SETTING		
latitude	between 30N-30S	beyond 30N-30S
depositional	rimmed shelves or platform	open shelves or ramps
tectonic	stable	stable to unstable
terrigenous supply	low	low to high
WATER PROPERTIES		
min temperature	23C	20C
medium temperature	14C	12C
salinity	normal to hyper saline	normal
STRUCTURES		
reefs	abundant	rare or absent
algal mats	common	absent or not preserved
BULK SEDIMENT PROPERTIES		
carbonate content	>90%	moderate to high (50-100%)
texture	all	sands and gravels
sedimentation rate	high >10cm/1000y	relative low (<10cm/1000y)
NON SKELETAL COMPONENTS		
ooids	common	absent
aggregates	common	absent
peloids	common	rare to absent
MAJOR SKELETAL COMPONENTS		
flora	calcareous green algae, calcareous red algae	calcareous red algae, coccolithophorids
fauna	hermatypic corals, foraminifers, mollusks	bryozoans, foraminifers, mollusks, barnacles, echinoderms, serpulids, brachiopods
NON CARBONATE COMPONENTS		
terrigenous material	rare	rare to abundant
CARBONATE PETROGRAPHY		
	all	grainstone-packstone
SKELETAL GRAIN ASSOCIATION		
	chlorozoan-chloralgal	foramol-bryomol

TROPHIC CONDITION AND NUTRIENTS

James (1997) identified two associations highlighting the link with trophic conditions. He introduced the term *Photozoan* association, to indicate an association formed by corals, calcareous green algae, invertebrates and abiotically precipitated carbonate grains. With this term, he defined a benthic community characterizing warm shallow water, emphasizing the link between predominant organisms and light conditions.

He considered the term *ForaMol* of Carannante *et al.* (1988) over-specific to describe carbonate temperate-water associations, considering that there is no latitudinal well defined distribution and rejecting the presence of part of taxa names.

James (1997) proposed the *Heterozoan* association for all the non *Photozoan* cases*,* that is to say organogenous sediments formed by other calcareous algae and benthic invertebrates but no corals.

The *Heterozoan* association can accumulate in all types of environments, from pole to equator, down to the CCD level, and could be dominant where low siliciclastic input is registered or the *Photozoan* association can survive no more. James (1997) considered the term *Heterozoan* association as synonymous of “cool water carbonates”. This definition corresponds to “*temperate carbonates*” (Lees & Buller, 1972), “*non-tropical carbonates”* (Nelson, 1988) or “*extra tropical carbonates*” (McGowran, 1989).

Nutrient distribution is also considered a key factor (Mutti & Hallock, 2003; Halfar *et al*., 2004). Nutrients include inorganic phosphates and nitrates used by photosynthetic organisms during growth, develop and reproduction (Hallock, 2001). Nutrient rate becomes a really important aspect to consider. The source of nutrients could be continental input or the upwelling currents in shallow water.

High nutrients concentration or low temperature could produce the same association (Mutti & Hallock, 2003) (fig. 1.5). At the same temperature, the *Photozoan* association prefers oligotrophic conditions, whereas under mesotrophic condition the contribution of calcareous red algae prevails. On the other hand, heterotrophic organisms, like mollusks, bryozoans or crustaceans, increase under oligotrophic condition (Mutti & Hallock, 2003), and hardly survive into oligotrophic environments (Halfar *et al*., 2004). The *Photozoan* association can be found in mesotrophic environments if temperature is at least 18C, but is commonly poorly diversified forming the so called *Heterozoan-Photozoan transition* association (Halfar *et al*., 2004). The *Heterozoan* association should have less than 1% of photozoan organism, whereas the *transition* association ranges between 1% and 20 %.

This scheme derives from the observations of present-day carbonate sediments and can be directly applied to the fossil carbonate record, following a quantification of the contribution of organisms.

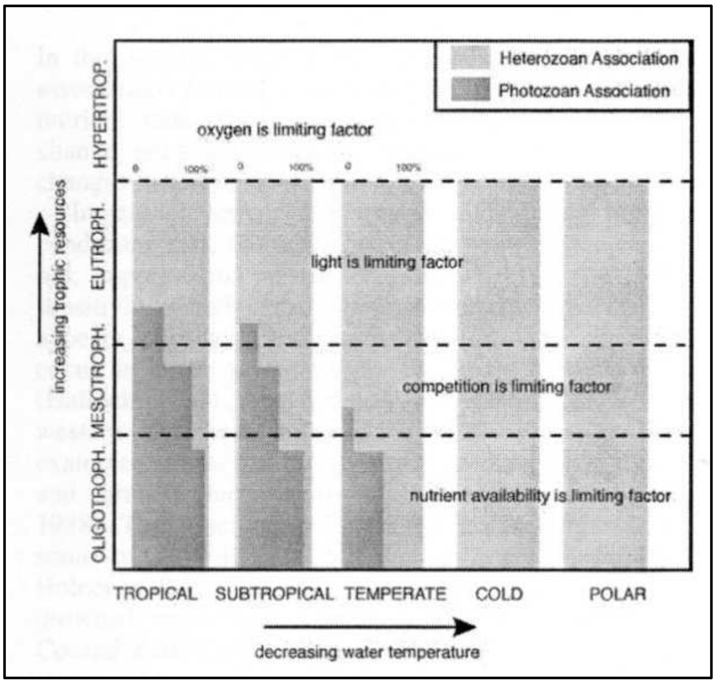


fig. 1.5: *Heterozoan* versus *Photozoan* association distribution considering temperature and trophic resources in Mutti & Hallock (2003)

The authors suggest finding the possible variation in term of nutrients flux to detect a fossil association, so considering as possible sources of nutrients continental input or hydrodynamics.

LIGHT

Pomar (2001), considering light conditions, proposed the distinction between *euphotic* association, needing high luminosity and characterizing shallow waters dominated by photosynthetic organisms, and a second association, typically oligophotic, placed in deep water and characterizing by a *heterozoan* association.

TERRIGENOUS INPUT

The terrigenous input represents the continental clastic input by fluvial or eolic transport reaching the shelf. As pointed out by Chave (1967) the key for the development of carbonate sediments along the shelf is the dilution rate of terrigenous input “thus rivers, not temperature, organisms or chemistry appear to control the distribution of carbonate sediments”. If the rate is low, carbonate sediments production could become volumetrically important also outside of tropical latitudes

Mount (1984) proposed a new classification scheme based on the type of mixing between siliciclastic and carbonate sediments (fig. 1.6).

A common theme in sedimentology is understanding and quantifying the inhibitory effect that siliciclastic input plays on the development of organisms producing carbonates, considering it as a factor that could determine no depositional mixing system.

However, the mixing pattern exists both in present-day environments and the geological record, and for some authors it represents a very common situation in geological history (McIlreath & Ginsbourg, 1982; Doyle & Roberts, 1983).

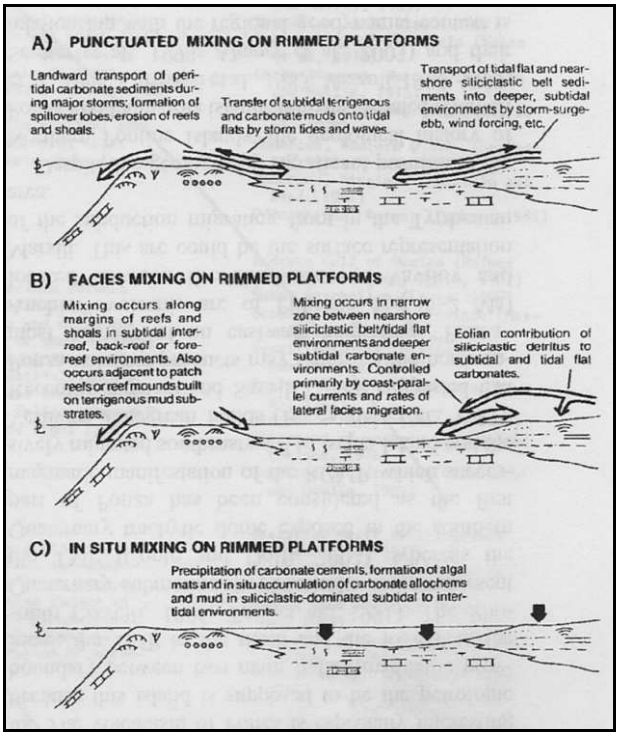


fig. 1.6: Classification scheme of Mount (1984)

Mount (1984) described 4 sedimentary processes forming mixed facies in shallow waters, as follows:

-*punctuated mixing*, consisting of sediments transported across different environments under rare extreme events.

- *facies mixing*, on the borders of the areal distribution of 2 different facies.
- *in situ mixing*, autochthonous carbonate sediments mixed with siliciclastic input.
- *source mixing*, carbonate sediments derived from erosion mixed with siliciclastic input.

Grain-size and textures of these mixed deposits are controlled by hydraulic conditions and continental input type, mediated by the effect of the organisms producing carbonate.

This is especially true in the case of *in situ mixing*, where the organisms create a coarse fraction together with very fine sediments as results of bio-destruction and bioerosion.

The *mixing* facies of Mount (1984) correspond mostly to the *Foramol* association, which is more tolerant to terrigenous input. On the contrary, the *Chlorozoan-Chloralgal* association seems to suffer turbidity more, as it can cause the formation of an instable substrate and the clogging of feeding systems of filtering organisms.

1.5 THE MARINE BENTHIC BIONOMY

A specific model of associations' distribution for Mediterranean Sea was given by Pérès & Picard (1964). The marine benthic bionomy of these authors splits the Mediterranean shelf into zones and studies the distribution of biogenic associations called biocoenosis within them (fig. 1.7).

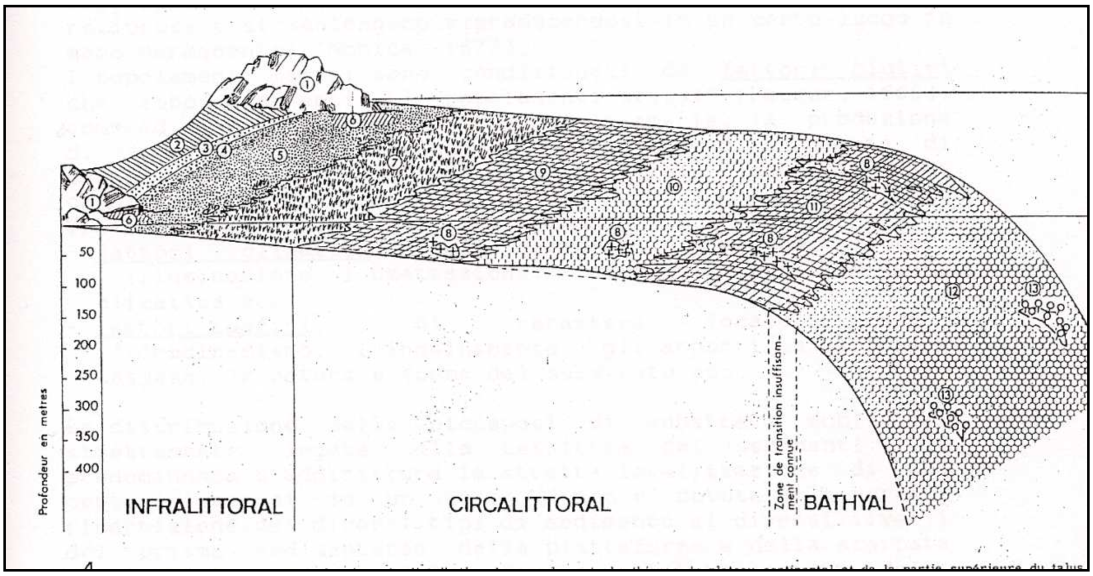


fig. 1.7: Biocoenosis distribution along the shelf profile. Numbers indicate the biocoenosis or the substrate types: 1) rock; 2) alluvional area; 3) upper- and infratidal beach; 4) SFHN biocoenosis; 5) SFBC biocoenosis; 6) AP biocoenosis; 7) HP biocoenosis; 8) C biocoenosis; 9) DC biocoenosis; 10) VTC biocoenosis; 11) DL biocoenosis; 12) VP biocoenosis; 13) deep coral biocoenosis. See text for the meaning of each biocoenoses. (Pérès, 1967)

The zone is defined by Peres & Picard (1964) as follows: "*l'espace vertical du domaine benthique marine où les conditions écologiques, fonction de la situation par rapport au niveau de la mer, sont sensiblement constants où variant régulièrement entre les deux niveaux critiques marquant les limites de l'Etage. Ces Etages ont chacun des peuplements caractéristiques et leurs limites sont relevées par un changement de ces peuplements au voisinage des niveaux critiques marquant les conditions limites des étages intéressées*".

The identified zones are 7, although those involving the beach and the continental shelf are only 4:

- Upperlittoral zone, defined as the continuously emerged zone. It is characterized by wetting, but only rarely by flooding.
- Mesolittoral zone, defined between the levels of high and low tide. The characteristic communities have the ability to withstand immersion alternating with emergence periods.
- Infralittoral zone, extending from the always submerged level, or very rarely emerged, to a depth compatible with survival of photosynthetic algae and seagrasses. Usually this limit does not go beyond 40 m wd in the Mediterranean Sea.
- Circalittoral zone, extending from the photosynthetic algae and seagrasses lower depth to the

sciaphilous algae, which tolerate low light, maximum depth.

One can easily notice that the limit among zones is not defined in terms of bathymetry but it is based on the presence of certain types of benthic populations. The presence of these populations throughout the world, even if represented by different genera and species, makes this model universally valid.

Biocoenosis means "the group of living organism corresponding for composition, number of species and specimens to certain medium environment conditions. These organism are linked by mutual dependence and keep reproducing in a certain place permanently" (Möbius, 1877).The definition of biocoenosis is strictly linked to the definition of biotope i.e. a geographical area, surface or variable volume, subjected to certain homogeneous conditions. The biotope is the natural space of a biocoenosis.

The distribution of marine biocoenoses is influenced both by biotic factors, related to the same populations and to intra-and inter-specific relations, and by abiotic factors. The latter include general climatic factors, such as light or pressure, and edaphic factors related to more specific environmental parameters.

Others important definition linked to biocoenosis are *enclave*, as the biocoenosis existing in the biotope of another one, due to local particular reasons, and *facies*, an emphasized aspect of a biocoenosis, represented by few species locally dominant because of the predominance of specific ecologic factors.

The concept of biocoenosis, meanwhile, expresses the interdependence between species and the intrinsic link to certain biotic and abiotic factors: the fidelity of a species to a particular biocoenosis is the key factor.

The fidelity degree of a species to a biocoenosis is expressed as follows:

- exclusive characteristic species: species that, whatever its abundance or dominance, is always in a given habitat. In other biotopes it is present only as an accidental species.
- preferential characteristic species: species that is found more abundantly in a given habitat than any other.
- accompanying species: species that can be found in different habitats. It is considered an indicator species, if it is related to any particular edaphic factor or ubiquitous if it has a large ecological breakdown.
- accidental species: exclusive species of another habitat, accidentally found in another biocoenosis, usually included with a few specimens and reduced vitality.

In case of unlithified substrate, the species can also be defined according to its favorite sediment texture as follows:

-mud-loving species = pelophilous.

-sand-loving species = psammophilous.

-gravel-loving species = psephofilous.

-mixed loving species = mistophilous, which prefers a sediment that contains, in variable percentages different grain-size fractions.

The list of the identified biocoenosis, both for rocky and mobile substrate, for the infralittoral and circalittoral zones (Fig. 1.7) is the following (Pérès, 1967):

<u>Infralittoral hard substrate:</u>

- biocoenosis of photophilous algae (AP)
- biocoenosis of invertebrates in very polluted waters (IETP)

<u>Infralittoral mobile substrate:</u>

- biocoenosis of infralittoral pebbles (GI)
- biocoenosis of coarse sands and gravels stirred up by waves (SGBV)
- biocoenosis of sand protected against breaking waves (SRPV)
- biocoenosis of the superficial muddy sands in sheltered areas (SVMC)
- euryhaline and eurithermal biocoenosis in brackish waters (LEE)
- biocoenosis of highly polluted sediments (STP)
- biocoenosis of fine well-sorted sand (SFBC)
- biocoenosis of the fine sands in very shallow waters (SFHN)
- biocoenosis of "*Posidonia"* meadow (HP)

<u>Circalittoral hard substrate:</u>

- biocoenosis of coralligenous (C)
- biocoenosis of semi-obscure caves (GSO)

<u>Circalittoral mobile substrate:</u>

- biocoenosis of the coastal detritic (DC)
- biocoenosis of muddy detritic bottoms (DE)
- biocoenosis of the shelf-edge detritic (DL)
- biocoenosis of the terrigenous mud (VTC)

Finally, there are biological communities defined as "independent non-climatic" which are represented by groups of species linked to a particular edaphic factor possibly found in both zones:

- biocoenosis of the coarse sands and fine gravels under bottom currents (SGCF).
- biocoenosis of heterogeneous populations (PE) (formerly biotic populations of unstable mobile substrates MI of Peres & Picard, 1964).

The distribution of the biocoenoses respect to the depth is controlled primarily by edaphic factors like light penetration, temperature and hydrodynamic conditions determining the changes in associations. The distribution of SGCF biocoenosis in particular is linked to the occurrence of moderate to high hydrodynamic conditions, which makes its distribution independent to the infralittoral zone limits (Fig. 1.8).

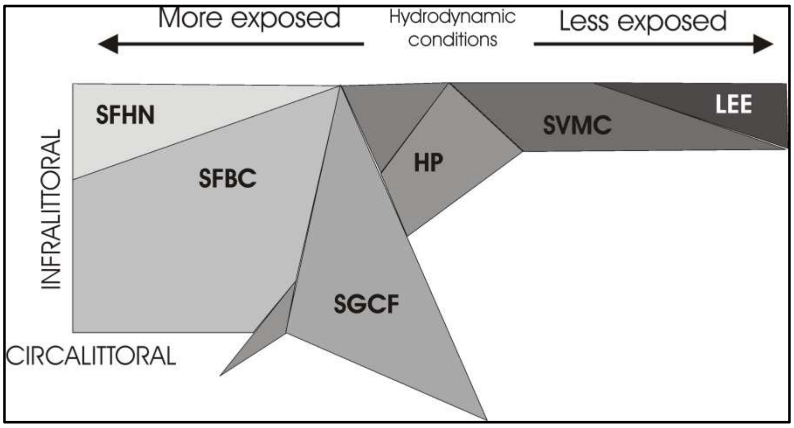


Fig. 1.8: distributional scheme of biocoenoses respect to infralittoral and circalittoral zones. Notes the distribution of SGCF biocoenosis. Modified from Picard (1983)

The benthic marine bionomy definitions were related to sedimentological data of the Mediterranean Sea, in order to create a model of carbonate sediments distribution on the shelf based on the concept of sedimentary area (Blanc, 1972).

The sedimentary area is the result of the combination of abiotic factors, such as bathymetry or hydrodynamics, and biological factors characterizing such area in a given time.

Blanc (1972) distinguished the production zone and the accumulation zone of Mediterranean biogenic sediments (fig. 1.9).

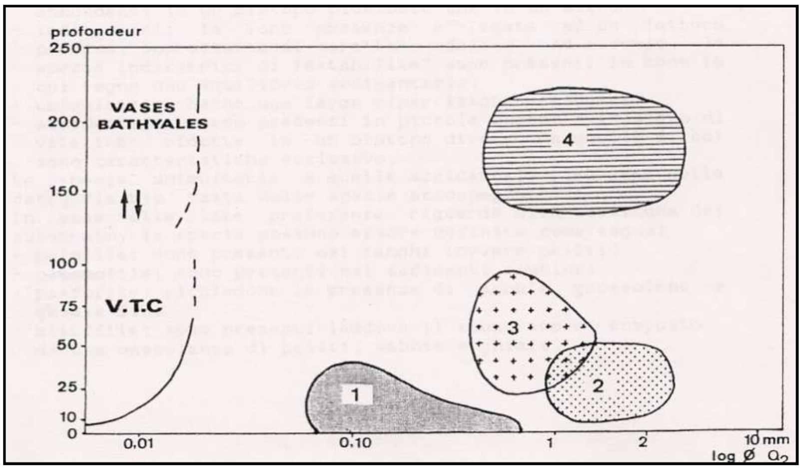


fig. 1.9 Sedimentary area versus grain-size and depth 1) fine beach and bay sand, 2) bio-detrital meadow sand, 3) biodetrital coralligenous sand, 4) coastal terrigenous mud (Blanc, 1972)

The author defined as production areas the zones characterized by the presence of two biological communities: the *Posidonia* meadows (HP) in the Infralittoral zone and the coralligenous build-ups (C) in the Circalittoral zone.

In the Mediterranean Sea, *Posidonia* meadows represent the infralittoral biotic climax.

Posidonia oceanica (L.) Delile, 1813 is the most widespread seagrass in the Mediterranean Sea. The peculiarity of this plant is to grow its rhizomes both laterally and upward. The leaves grow up and act as sediment trap at the base, creating the structure called *matte*. Upward growth proceeds until the leaves reach the surface, at which the plant stops growing and undergoes decay.

Within this biocoenosis it is possible to trace the presence of enclaves of other biotic communities: at the base of the meadow, for example, where light penetration is very low, sciaphilous populations may develop. Pérès & Picard (1964) pointed out that the HP biocoenosis does not represent a single biotic community, but at least two distinct populations: one photosynthetic on the surface of the *Posidonia* leaves, and a sciaphilous community at the base of the rhizome.

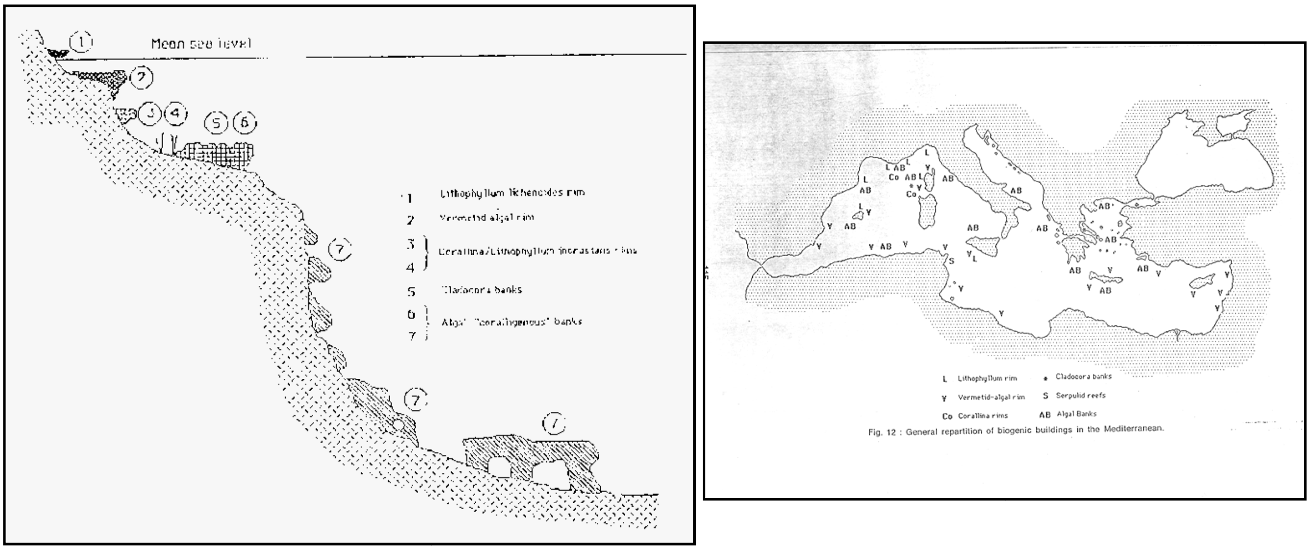
The coralligenous biocoenosis is the climax biotic communities of hard substrates in the circalittoral zone. It is formed primarily by sciaphilous algae and subordinately by other organisms. The coralligenous shows two types of structures: 1) a primary structure defined "coralligenous of the lower horizon of rocky coast" so directly on rock or cliff, developed on a primary hard substrate, or 2) a "coralligenous *de plateau*" in which the hard substrate is the algal concretion itself, originally growing on mobile sediments.

Muddy input along the circalittoral zone could define the development of others biocoenosis such as the VTC biocoenosis, which is usually found where continental terrigenous contributions prevail. If such contributions are rare, accumulation of both autochthonous or allochtonous organogenous sandy-gravelly fragments composed of shells of organisms can form the biocoenosis of coastal detritic bottom DC biocoenosis. The factor defining the sediment size is the type of organisms producing these sediments. This biotic community can itself evolve into DE biocoenosis if there is an input of mud or into a coralligenous bioconcretion C biocoenosis.

In the Mediterranean Sea there are other forms of biogenic constructions, less common and less important in terms of sediment production compared to the coralligenous, but which in fact have to be considered as production areas.

There are two fundamental aspects to be considered concerning such bio-constructions: the vertical and lateral development depth and the nature of the components.

fig. 1.10: Mediterranean bioconstruction zonation along the shelf profile (left) and geographic distribution of reported occurrences (right) in Laborel (1967)



Laborel (1987) recognized different types of biogenic construction (fig. 1.10):

a) surface and subsurface structures:

1. *Lithophyllum byssoides* (Lamark) Foslie1900 (as *Lithophyllum lichenoides* Philippi) rim, mesolittoral
2. Vermetids and algae rim, upper infralittoral
3. *Corallina* rim, upper infralittoral
4. *Lithophyllum incrustans* R. A. Philippi 1837 rim, upper infralittoral

b) submerged structures:

5. Serpulids rims, upper infralittoral
6. *Cladocora* banks, lower infralittoral
7. Coralligenous algal banks, from lower infralittoral as enclave, to upper circalittoral

The depth is not a significant factor, but it is more important to take care of the position that these bio-constructions occupied in marine benthic zoning as defined by Pérès and Picard (1964).

1.6 THE CALCAREOUS RED ALGAE

Red algae is the name for Rhodophyta Wettstein, 1922. They are one of the oldest groups of eukaryotic algae (Lee, 2008) and also one of the largest, with about 10,000 species (Woelkerling, 1988). They represented and still represent one of the most important components of benthic marine communities, throughout the world.

The phylum Rhodophyta is characterized by both soft and hard algae. The latter are characterized by the presence of calcareous thalli, both calcite and aragonite.

The largest group of present-day calcareous red algae are the corallines, belonging to the orders Corallinales and Sporolithales (taxonomic reference in Guiry & Guiry 2011)

The most ancient known algae species linked to red algae is a Proterozoic bangiophyta found in Canada. *Arenigiphyllum crustosum* Riding was the first identified species found in Wales and dated to the Ordovician. This species is considered as an ancestor of corallines, notwithstanding its morphologic differences.

Generally the Solenoporaceae Pia, 1927 family is considered the real ancestor of corallines.

The most ancient coralline species is *Sporolithon rude* Lemoine (1925), found in the Lower Cretaceous.

The peculiarity of corallines is that they often secrete high-Magnesium Calcium carbonate, in which $MgCO_3$ represents more than 4% of total calcite (Chave, 1954).

The mineralization phase develops for all the entire life of the alga, both during cellular division and biomass growing (Cabioch, 1969).

The cell walls of the calcareous red algae are completely calcified, with the exceptions of the reproductive cells and the superficial wall of the outermost epithallial cells.

Two layers of carbonate have been recognized: 1) *primary layer*, made of Mg-calcite elongated crystals with orientation parallel to the wall surface, within the cell wall polysaccharide matrix; 2) *secondary layer*, made of elongated crystals with orientation perpendicular to the cell surface (Borowitzka *et al.,* 1974; Flajs, 1977; Cabioch & Giraud, 1986).

Among Corallinales order two different anatomic groups can be distinguished on the basis of the occurrence of uncalcified flexible segments called *genicula* alternating with rigid calcareous segments called *intergenicula*: the geniculate, if *genicula* are present, and the non-geniculate algae, if *genicula* are absent (the latter also referred to as crustose coralline algae or CCA) (Cabioch, 1988). This division has no taxonomic value.

After death, geniculate algae undergo disarticulation into sand-sized particles, and can accumulate *in situ* or be easily transported away from the original habitat. On the contrary, non-geniculate algae inhabiting hard and soft substrates may enter the geologic record more or less in their original shape, or produce fragments of any size like rhodoliths, several centimeters large to millimeters detached protuberances or crusts, to heavily abraded fine-sand sized fragments (Agegian & Mackenzie, 1989; Tsuji, 1993; Fornos & Ahr, 1997; Harney *et al.,* 2000; Gherardi & Bosence, 2001; Toscano & Sorgente, 2002; Hetzinger *et al*., 2006; Brandano & Civitelli, 2007). Geniculate and non-geniculate coralline algae are one of the most active carbonate producers among seagrass epiphytes worldwide (Land, 1970; Nelsen & Ginsburg, 1986; Walker & Woelkerling, 1988; Perry & Beavington-Penney, 2005; Basso, *in press*).

The algal crust formed by CCA is called thallus, and it is calcified starting from a thin crust, composed of cell filaments that are connected together. The thallus grows by division of the filaments and by addition of one new cell at each filament tip (Cabioch, 1988; Woelkerling, 1988), forming a multi-axial structure.

Cabioch (1966) and Johansen (1981) proposed a specific terminology for the portions forming the CCA thallus:

- ipothallus, concerning one or more basal cell filaments, usually parallel to the substrate.
- perithallus, formed by filaments from the ipothallus and orientated vertically. It represents the thickening of the thallus.
- epithallus, the surface filaments, only partially cemented.

Wolkerling (1988) proposed a different description of thallus anatomical structure, based on the general orientation of algal filaments. The thallus could have:

- monomerous construction, with a single system of repeatedly branched filaments in which some derivatives of each filaments contribute to a core which runs more or less parallel to the thallus surface while others curve outwards forming a more peripheral region.
- dimerous construction, with two groups of filaments producing successively and usually oriented more or less at right angle to one another.

Other aspect of the thallus can be described, even in the fossil record, for example the thallus thickness or the presence of coaxial core development of the thallus.

The most important cytological characters are:

- the cytoplast connection, represented by cell lateral fusion or secondary pit connection; both allowing the inter-cellular exchanges. This represents a diagnostic feature, traceable also in the fossil record.

- trichocytes, specialized hair-producing cell, disposed singularly or in filaments, usually larger than other cells, with thicker walls. They represent a diagnostic feature, traceable also in the fossil record.
- conceptacles, formed by roof, wall and floor enclosing a chamber containing reproductive structures. Conceptacles bearing male, female and carpospores gametes are usually uniporate, whereas conceptacles bearing tetraspores may have a single pore or a number of pores. They represent a diagnostic feature, traceable also in the fossil record.

CCA may be semi-endophytic or epigenous, i.e. anchored to substrate, or growing unattached (Steneck, 1986).

Semi-endophytic species have a thallus buried within host tissues and consist mostly of unconsolidated filaments.

Epigenous species form unconsolidated, crustose, protuberant or taeniform thallus (Wolkerling, 1988).

Unconsolidated thallus is characterized by filaments creeping over the substrate.

Crustose thallus is pseudoparenchymatous, with ready recognizable dorsal and ventral surfaces, lack of taeniform habitats and without holdfasts. Crustose thallus is anchored only by local adhesion of cells or by a more or less tabular sleeve. It may be regular or amorphous and may have distinct lobes and planar lamellae. The dorsal surface may be smooth or have protuberances, possibly irregular in shape.

Protuberant thallus is mostly composed of branched, cylindrical to compressed, erect or ascending protuberances.

Taeniform thallus includes plants composed of flattened, ramified, ribbon-like branches.

Unattached forms are characterized by either crustose portions of unattached protuberances of other types of growth-form, or by plants that have completely enveloped small clasts, shell fragments or other material.

Other orders of red algae include calcified species, namely the aragonite precipitating Peyssonneliales and Nemaliales (Nelson, 2009; Guiry & Guiry, 2011; Basso, *in press*).

Peyssonneliales are a diverse group of platy, orbicular algae with a various but species-specific degree of calcification. *Peyssonnelia rosa-marina* Boudouresque & Denizot 1973 is an endemic species of the Mediterranean Sea and is fully calcified.

The CCA, due to the secretion of a carbonate skeletal structure, are considered as important biogenic sediment contributor on the shelf from the equator to the poles, and particularly in

Mediterranean Sea (fig. 1.11).

They are responsible for the accumulation of loose sediments, i.e. maërl facies, or are able to form hard substrate creating stable build-ups. Different species and assemblages of red algae can be found under different oceanic conditions, forming particular facies that represent a powerful tool for the study of the fossil record.

Moreover, CCA are considered an extraordinary fossil archive, useful to reconstruct geological, climate, and biological evolution in Mediterranean area since Oligocene.

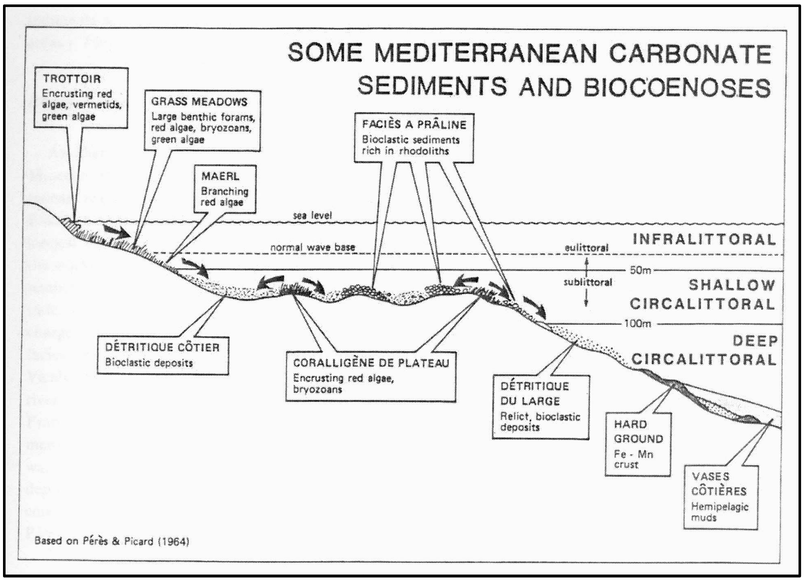


fig. 1.11: Distribution of the most important calcareous facies along the carbonate-shelf topographic profile (Carannante *et al*., 1988)

1.7 CCA BIOCONSTRUCTIONS

The bioconstruction is a biogenic rock forming by growth and overlap of organism (Bellan-Santini, *et al*., 1994; Laborel *et al*., 1994), both vegetables (coralligenous) and animals (coral reef, vermetids trottoirs) usually having a hard skeletal part.

A bioconstruction is a multi-specific formation, developing a 3-dimensional structure, forming a new morphologic, biologic and geologic environment.

It may occupy both shallow and deep environments, developing with different characteristics under various oceanographic conditions.

Different typologies of bioconstruction exist: they can differ because of the prevalence of animals or vegetable organism or for being in shallow or deep waters.

From a strictly morphological point of view, we can recognize:

- "*trottoir*", concretion developing as platform.
- "*bourrelet*", concretion with a truncate pyramid shape.
- "*encorbellement*", concretion projecting in counter slope on substrate.

In the Mediterranean Sea, CCA primarily participate to bioconstructions, developing different structures and facies.

Two CCA thalli may merge together or grow on one another. When one or more thalli join a substrate, the concretion starts growing as result of slow growth and overlap of thalli. The bioconstruction could then undergo a regressive phase, because of bio-destruction and mechanical abrasion

A classification of CCA bioconstruction is reported by Bressan & Babbini (2003), based on the landscape impact and geomorphologic importance. The authors distinguish:

1. Bio-construction more or less developed, even monumental
2. Minor buildings
3. Deep bio-constructions

A short description of each bioconstruction is reported.

<u>1. Bio-construction more or less developed, even monumental:</u>

1.1 *L. byssoides* encorbellement. It is a typical western Mediterranean bioconstruction. Usually it is found above sea level developing on a rocky substrate under the action of waves. It could be totally emerged and be only under the wetting activity. The coverage of thalli is dense, developing a 20-30 cm high and 1 m large structure. The surface portion is porous, red to violet, formed by living thalli without sedimentary deposits. The lower surface is the dead part of the encorbellement and it is characterized by sciaphilous organisms. The medium part is formed by detrital deposits produced by algae and other organisms and mud. The medium portion is lithified and a concentric structure could be preserved interiorly. Typically, in the interior part bio-eroders like the sponge *Cliona* or cavity-forming mollusks like *Lithophaga* can be recognized.

1.2 "*Trottoirs*" and "*bourrelets*" made by vermetids. The structure is formed by *Neogoniolithon brassica-florida* (= *Neogoniolithon notarisi* (Dufour)) Setchell & Mason 1943, an Atlantic species, and *Dendropoma petreum* (Monterosato, 1884), famous as *Vermetus cristatus* Biondi, 1857. It seems that *N. brassica-florida* concurs to the formation of vermetids trottoirs south of winter isotherm of 14°C (Chemello, 1989). Three morphological types exist involving vermetids: *i*) "*trottoirs*" or vermetids platform: horizontal surface that corresponds to the medium sea level forming from the littoral erosion of soft-bottoms (De Quatrefages, 1854); *ii*) "*corniche*" or "*encorbellement*": on rocky bottoms; *iii*) atoll: rounded structure with a depression in the centre.

1.3 "*bourrelet*" or "*corniche*" made by *Corallina elongata* Ellis & Solander, 1786. Highly common bioconstruction, on sub-vertical shady rocky bottoms, from the surface to some meters water depth. It is formed by *C. elongata* crusts, one on the other, entrapping also bryozoans and barnacles. *C. elongata* is a branching geniculate red algae species, typical in the Atlantic but also common in the Mediterranean Sea. It could be formed by one only corniche or parallel bourrelet. The shape could be elongated or spherical.

2. Minor bio-constructions:

2.1 *Titanoderma trochanter (*Boyr) Benhissoume, Peret-Boudouresque & Verlasque 2002 (non *Titanoderma byssoides* (Lamark) Chamberlain & Woelkerling in Woelkerling 1988). Infralittoral bioconstruction on rocky bottoms, exposed to moderate wave action and well lighting. It is characterized by truncated-pyramid structures, only partially anchored to the substrate. Thallus is calcified but it is formed by cylindrical hooks, branched, giving rise to a really fragile tangled structure.

2.2 *Lithophyllum tortuosum* (Esper) Foslie, 1900 (non *Tenarea tortuosa* (Esper) Lemoine 1910). *L. tortuosum* is a typical Mediterranean species of infralittoral photosynthetic assemblages, from the surface to 5 m wd, in conditions of good lighting and high wave activity. The bioconstruction is formed by fragile pillow-structures, partially anchored to the substrate. Each thallus is pink to ivory to white, forming crenulated or corrugated lamellae.

2.3 *Lithophyllum papillosum* Zanardini ex Hauck, 1885 (non *Goniolithon papillosum* (Zanardini) Foslie 1898). Mesolittoral bioconstruction, poorly developed, typically on rocky coasts, under wave action and good lighting. *L. papillosum* is a Mediterranean species.

3. Deep bioconstructions:

3.1 Coralligenous. Coralligenous is a hard bottom of biogenic origin mainly produced by the growth and accumulation of calcareous encrusting red algae, usually in dim light conditions. It represents the unique calcareous formation of biogenic origin in Mediterranean benthic environments (Ballesteros, 2006). The term "Coralligenous" was first proposed by Marion (1883) to identify hard bottoms that fishermen found offshore Marseille. They called it *broundo*, between 30 and 70 m wd, below *P. oceanica* meadows or on coastal detrital bottoms. Sartoretto (1994) suggests that it is possible to find coralligenous at very shallow waters, even at surface in caves and until 140 m wd in really clear waters. The term coralligenous is not linked with *Corallium rubrum* (Linnaeus, 1758), which belong to GO biocoenosis (Pérès & Picard, 1964) and develops in the cavities of the coralligenous.

Several authors documented coralligenous environment after Marion (1883), offering information on similar structures found along French and Italian coasts (Pruvot, 1894, 1895; Feldmann, 1937; Pérès & Picard, 1951, 1958; Bacci 1947; Tortonese, 1958; Rossi, 1958, 1961; Parenzan, 1960; Laborel 1960, 1961).

Pérès & Picard (1964) summarized the knowledge on the coralligenous, defining the notions of coralligenous on the lower horizon of rocky coasts, coralligenous *de plateau* and pre-coralligenous.

After the revision of Pérès & Picard (1964), other studies on the coralligenous have been conducted, focusing on biodiversity and geographical distribution, highlighting also the difficulty of finding a real definition of the term coralligenous (Gamulin-Brida, 1965; Laubier, 1966; Hong, 1980, 1982; Gill &Ros, 1984; Ballesteros *et al.*,1993; Bellan-Santini *et al.*, 1994; Sartoretto *et al.*, 1996; Ballesteros & Tomas, 1999; Ballesteros, 2006).

The coralligenous shows different morphologies and inner structure frameworks depending on depth, topography and the nature of prevailing algal builders (Laborel, 1961).

From a morphological point of view two main morphologies can be distinguished (Pérès & Picard, 1964; Laborel, 1987; Ballesteros, 2006): banks and rims.

Banks are flat frameworks with variable thickness from 0.5 to 4 m, mainly built over more or less horizontal substrate and have a cavernous structure (Laborel, 1987). Sometimes banks are surrounded by sedimentary substrates, derived from the coalescence of rhodoliths or maërl (Pérès & Picard, 1952).

Rims develop in outer part of marine caves and on vertical cliffs, usually in shallower waters than banks. Rims range from 20-25 cm to more than 2m (Laborel, 1987).

The presence of cavities and holes are extremely important because of the development of a complex community dominated by suspension feeders, showing a very rich vagile endofauna.

At least 315 species of macroalgae thrive in deep-water environment (Bouduresque, 1973) and most of them are found in coralligenous environments. The algal community of the Mediterranean coralligenous largely consists of Mediterranean endemic species, representing from 33% to 48% of the total flora (Bouduresque, 1985). The biodiversity should decrease with depth (Ballesteros, 1992).

CCA are the main coralligenous builders (Laborel, 1961; Laubier, 1966; Sartoretto *et al.,* 1996).

The most important CCA builders are: *Mesophyllum alternans* (Foslie) Cabioch& Mendoza 1998 (sub. nom. *Mesophyllum lichenoides* (Ellis) Lemoine), *Lithophyllum stictaeforme* (Areschoug) Hauck 1878 (sub. nom. *Pseudolithophyllum expansus* (Philippi)*, Neogoniolithon mamillosum* (Hauck) Setchell & Mason, Lemoine) 1943; among other coralline species: *Titanoderma pustulatum* (J. V. Lamouroux) Nägeli, 1858.

Peyssonneliaceae species are reported, among which *P. rosa-marina* should considered the most important.

According to Sartoretto *et al.* (1996) *M. alternans* may be considered the most important building species for both ancient and modern coralligenous in the NW Mediterranean Sea and it represents the currently dominant species in shallow waters, whereas *L. stictaeforme* is dominant in deep-water coralligenous environment.

The coralligenous is defined as a circalittoral bioconstruction, at times found in shallow water because of local particular conditions. It represents a delicate equilibrium between building and destruction processes controlled by different organisms. The regression of a bio-construction is linked primarily to natural phenomena, like bio-eroders (sponges, burrowing algae) or the effect of physical and mechanical environmental factors (Bressan *et* *al*., 2000). The bioconstruction and bioerosion activities are in contemporary and in opposition, so the we must consider that bioconstruction undergoes a permanent temporal evolution passing trough growing, erosion, fossilization and/or destruction (Bressan *et al*., 2000).

Knowledge about environmental factors favorable for the development of the coralligenous is rather poor because the coralligenous habitat is a highly heterogeneous system and environmental variables can differ greatly on both a geographical and micro scale. Irradiance seems to be the most critical factor for the development of coralligenous (Pérès & Picard, 1964; Laubier, 1966).

Moreover the growth-rate of coralligenous bioconstructions is slow. Sartoretto *et al.* (1996) suggests 1 mm/yr, which makes the growth process really sensible to high sedimentary rate. The input of sediment causing the burial of algal thalli, forming a screen against light and determining the possible depth of the structure (Laborel, 1961) but also preventing the recruitment of new plants (Sartoretto *et al.,* 1996). On the other hand the roughness of the structure promotes the deposition of particles, which partially contribute to the building up of the coralligenous structure through a complex process of lithification (Marshall, 1893). The sediment incorporated comes in part from the accumulation of calcareous components of organism living in the coralligenous environment (Laubier, 1966). The major contributors are coralline algae (57%), bryozoans (19%), mollusks (16%), corals and serpulids (3% each) (Laubier, 1966).

Laborel (1961), following Pérès & Picard (1964) described different facies of the coralligenous:

- *Halimeda tuna* (Ellis &Solander) Lamouroux1816 facies, where the red calcareous algae lose their importance replaced by *H. tuna*. This facies is linked with local high illumination conditions. *M. lichenoides* is considered the most important CCA species in this facies, and soft anti-sciaphilous algae increase. Molinier (1958) identified this facies as pre-coralligenous facies.
- *N. mamillosum* and *N. brassica- florida* facies develops between the upper and lower infralittoral.
- Coralligenous in caves, developed in shallow waters, in the shady portion of rocky coasts.
- Coralligenous of the lower horizon on littoral rocks, characterized by a vertical rocky portion colonized by gorgonians (*Paramuricea clavata* (Risso, 1826) and *Eunicella cavolini*

(Koch, 1887)).

- Coralligenous *de plateau* forming on secondary hard substrate originated on mobile substrate lithified by the action of calcareous red algae themselves. This facies develops from 15 to 12 m, typically is found at 40-80 m wd. The development of this facies starts from the colonization of thalli on little hard substrates, forming successively free plates on the bottom. Then, a leafy or concentric structure starts to develop, coupling with the bioerosion that could create new blocks.

2.2 Rhodoliths. A rhodolith is a free-living biogenic concretion in which the structure is formed by at least 50% of calcareous red algae (Adey & Macintyre, 1973; Bosence, 1983a, 1983b).The term is formed by *rhodo-* for rhodophyta and *–lithos* for rock (Bosellini & Ginsbourg, 1971; Ginsbourg & Bosellini, 1973).The thalli are living around all the surface of a nodule, which suggest that rhodoliths are frequently rolled by waves, currents or vagile fauna or completely formed by CCA thalli. Rhodoliths are free structures even if they may form more stable substrate merging with each other. Usually, rhodoliths colonize mobile substrate in the circalittoral zone, characterized by the SGCF or DC biocoenosis (Pérès & Picard, 1964), where currents and low light levels are predominant. High hydrodynamics, high sedimentation rate and high turbidity represent the most important limiting factors for coralligenous development (Basso*,* 1998).

Following Bosence (1983) diverse morphology of rhodoliths could be recognized, the boxwork-type, the prâlines and the free branches. The nature and density of free-living forms are considered a sensitive indicator of hydraulic conditions (Bosence, 1976).

The typical CCA species found in mobile circalittoral substrates are: *L. incrustans*, *L. stictaeforme*, *Lithophyllum racemus* Lamarck (Foslie, 1901), *N. brassica- florida, N. mamillosum, Spongites fruticulosa* Kützing 1841*, Lithothamnion corallioides* P. & H. Crouan 1867*, Lithothamnion minervae* Basso 1995*, Lithothamnion philippi* Foslie 1897*, Lithothamnion crispatum* Hauck 1878*, M. lichenoides*, *M. alternans*, *Phymatolithon calcareum* (Pallas) Adey & McKibbin 1970.

Rhodoliths may form particular facies in the DC biocoenosis (Pérès & Picard, 1964):

- maërl facies, forming by the accumulation of free-branching coralline like *P. calcareum*, *L. corallioides* or *L. minervae.* Cabioch (1970) suggests that the accumulation is not linked to transport but is the result of *in situ* production. Falconetti (1970) reported the presence of a bottom current is necessary to develop this facies.

- *Lithothamnion valens* Foslie 1909 facies, a free branching species often accompanied by the bivalve *Aequipecten commutatus* (Monterosato, 1875).
- prâlines facies, forming by the growth of calcareous algae thalli on terrigenous or biogenic nodules. Typical corallinales species are *S. fruticulosa, L. minervae* and *L. racemus*.
- boxwork rhodoliths facies, forming by crust overlapping of different species alternated to annelids or other organisms. The structure is irregularly ellipsoidal, and it is characterized by micro-cavities possibly filled by sediments (Basso, 1998).

Rhodoliths can change in volume and weight during their development, showing a change in species assemblages along the structure possibly linked to kinetic stability. Modern deep rhodoliths could preserve different portions representative of different developing stages, as a result of the Holocene transgression.

Basso (1998) suggests that boxwork rhodoliths are really similar to the coralligenous, for morphology, biotic assemblages and interior structure.

1.8 CONCLUSION

The temperate biogeographic province is characterized by shelves with biogenic carbonate formed by the accumulation of benthic carbonate sediments in shallow waters. Temperate carbonate usually have been connected to cool water high latitudes carbonate, but they instead represent a transition between 2 end-members: the tropical carbonates and the cool-water carbonates.

The decreasing in temperature seems to drive the change in associations producing carbonates.

The Mediterranean Sea is considered as a marginal sea in the temperate zone. Temperature and productivity undergo seasonal fluctuations. It is considered an oligotrophic sea, even if a high biodiversity is registered and more than 28% of the total species represent Mediterranean endemism.

The carbonate factory in Mediterranean Sea is characterized by the production and accumulation of benthic skeletal grains (Carannante *et al*., 1988; Nelson, 1988). The most important carbonate producers are considered calcareous red algae, molluscs, bryozoans, foraminifers and crustacean (Carannante *et al*., 1988; Brandano & Civitelli, 2009; Bracchi & Basso, *in press*).

This association is called *ForaMol* association (Lees & Buller, 1972) or *Molechfor Facies* and *Rhodalgal facies* (Carannante *et al*., 1988).

The solution of Carannante *et al.* (1988) seems to be the most appropriated to define both the present-day sediments in Mediterranean Sea and the geological record.

On the other hand this scheme as all the others proposed in literature for the carbonate distribution (Lees & Buller, 1972; Lees, 1975; Nelson, 1988; James, 1997; Mutti & Hallock, 2003) tends to be over-simplified, reducing the complexity of nature systems into classes applicable at a wordy scale.

The bionomy marine benthic system of Pérès & Picard (1964) for the Mediterranean area seems to be the most proper to describe the benthic carbonate contribution on the shelf at a very low scale. Moreover in an actuo-paleontological way it is useful to detect the most precise interpretation on the Pleistocene fossil record.

On the other hand the definition of biocoenosis of Pérès & Picard (1964) is only qualitative and not quantitative in term of contribution to carbonate production/accumulation. So the biocoenosis system is useful to interpret the environments and the temporal evolution of stratigraphic records and should be accompanied by specific quantitative considerations.

2. GEOLOGICAL SETTING

2.1 THE CALABRIAN ARC

The Calabrian Arc is located between the NW-trending southern Apennines and the E-trending Sicilian Maghrebides (Faccenna *et al.*, 2001) (fig.2.1). It is also called Calabria-Peloritani terrane by Bonardi *et al.* (2001). It is composed of pre-Mesozoic crystalline rocks. It is experiencing at the same time active NW oriented subduction on its south-eastern side and back-arc extension on the Tyrrhenian side (Faccenna *et al.*, 2001; Rosembaum & Lister, 2004).

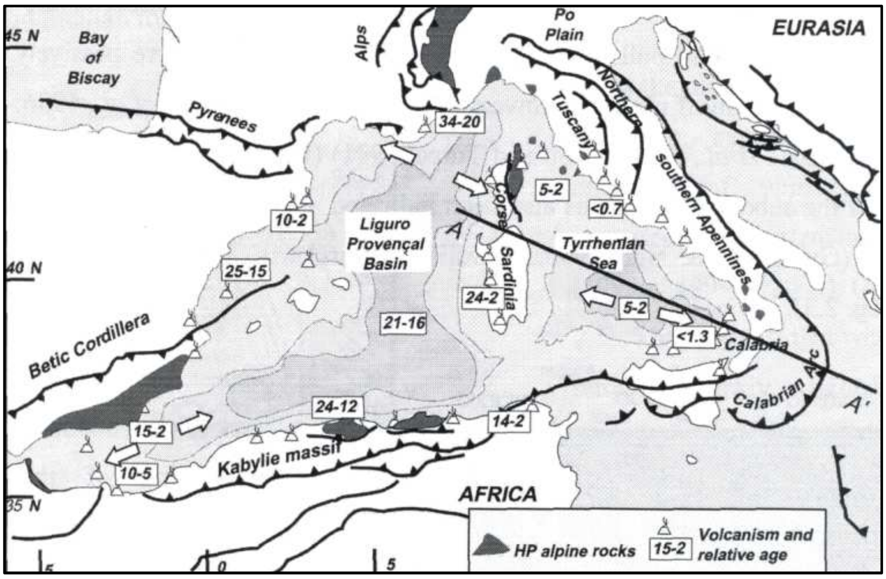


fig. 2.1: Simplified tectonic map of the Central Mediterranean Sea (Faccenna *et al.*, 2001)

Various aspects, like timing and evolution of the extension and subduction or nature of subducted crust, are still debated between scientists (Van Dijk & Scheepers, 1995; Faccenna *et al.*, 2001; Rosembaum & Lister, 2004).

The arc migrated south-eastward from mid-Miocene onwards as the consequence of slab rollback at the subduction zone, where Ionian crust dips along an inclined Benioff plane (Malinverno & Ryan, 1986; Moussat *et al.*, 1986; Rehault *et al.*, 1987; Patacca *et al.*, 1990; Knott & Turco, 1991), while the spreading of the back-arc Tyrrhenian basin and emplacement of oceanic crust initiated (Van Dijk & Scheepers, 1995; Bonardi *et al.*, 2001) (fig. 2.2). Several authors proposed that

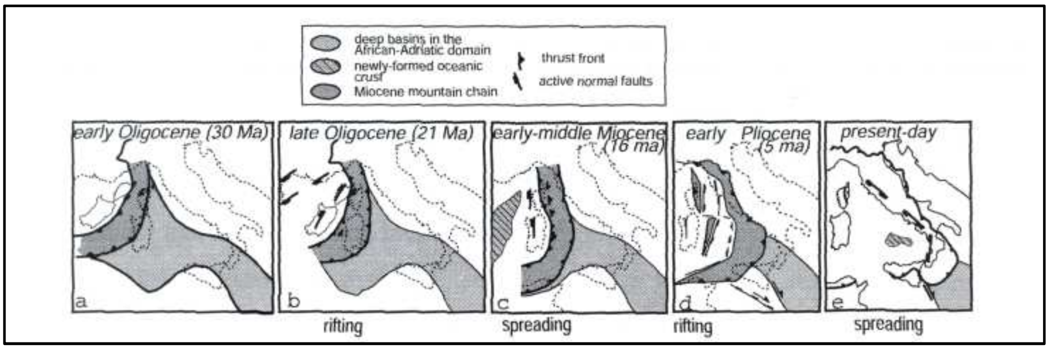


fig. 2.2: Paleo-geographic reconstruction of back-arc extension in the Central Mediterranean sea (Faccenna *et al.*, 2001)

subduction still continues today (Rehault *et al.*, 1987; Dewey *et al.*, 1989; Amato & Cimini, 2001).

The SE migration produced a dissection of the arc by NW trending strike slip faults characterized by left lateral movement in the central and northern part, and right-lateral movement in the south (Knott & Turco, 1991).

Strong uplift initiated from middle Pleistocene onwards (Westaway, 1993) and affected the whole Calabria-Peloritani terrane. The uplift led to the onshore exposure of some basins, formed during the evolution of the convergent margin.

The specific cause of the uplift is still debated. There are alternative hypotheses: a) the uplift could be the result of an isostatic rebound that followed the breaking of the Ionian lithosphere (Ritsema, 1972; Spakman, 1986; Westaway, 1993; Wortel & Spakman, 2000; Westaway & Bridgland, 2007); b) mantle flow into the wedge created at the top of Benioff plane during the retreat of the subduction hinge (Doglioni, 1991); c) distortion due to the resistance opposed to slab retreat by the Apulian and Sicilian forelands (Sartori, 2003); d) flow of astenospheric material into the plate contact during a quick slab retreat, leading to decoupling of the overriding plate from the sinking heavy slab (Gvirtzman & Nur, 1999a, 1999b, 2001) (fig.2.3).

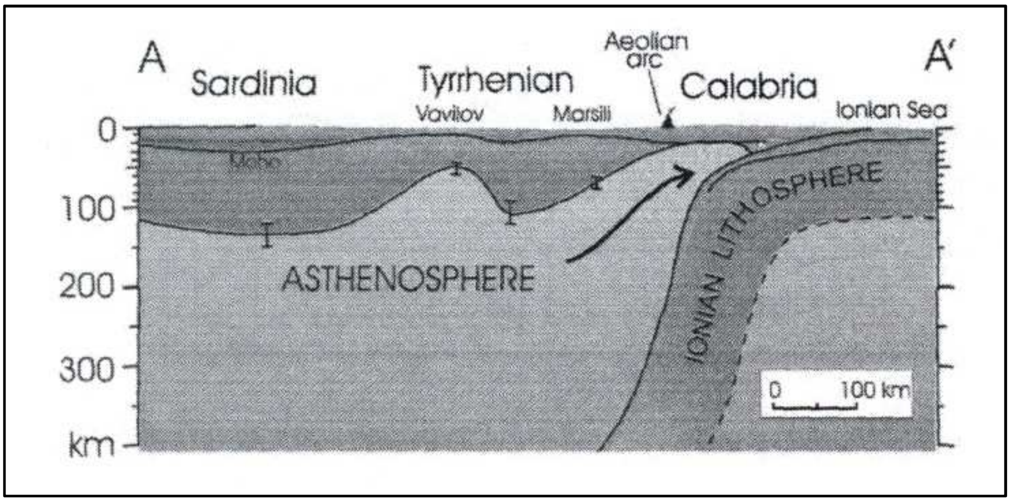


fig. 2.3: Lithospheric cross section (AA' in fig. 2.1) proposed by Gvirtzman & Nur (2001). Note the position of Calabria region

2.2 THE CROTONE BASIN

The Crotone basin is considered as a part of the Ionian fore-arc basin (Cavazza *et al.*, 1997) positioned on the internal part of the Calabrian accretionary wedge (Bonardi *et al.,* 2001; Zecchin *et al.*, 2004a). The development of the basin is linked to the south-eastward migration of the Calabrian arc and to the opening of the Tyrrhenian Sea during the Serravallian/Tortonian onwards (Mattei *et al.*, 2002).

The Crotone basin is bounded by two major NW trending left lateral zones: the Rossano-San Nicola shear zone to the north and Petilia-Sosti shear zone to the south (Meulenkamp *et al.*, 1986; Van Dijk, 1990, 1991a, 1991b; Van Dijk & Okkes, 1990, 1991; Massari *et al.*, 2002) (fig. 2.4).

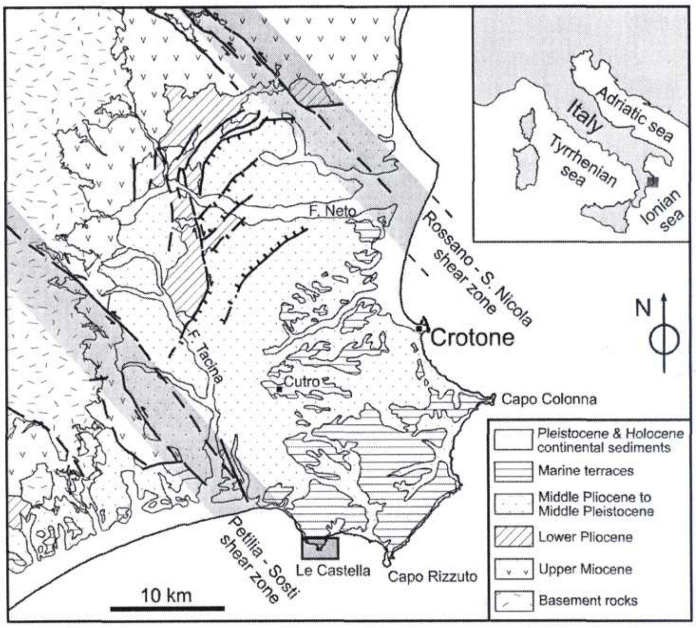


fig. 2.4: Location and geological sketch-up of the onshore portion of Crotone basin (Nalin, 2006 modified from Massari *et al.*, 2002)

The area registered an extensional tectonic regime, periodically interrupted by short compressional or transpressional phases in mid-Messinian, earliest mid-Pliocene and mid-Pleistocene time (Van Dijk, 1991a; Massari *et al.*, 2002; Zecchin *et al.*, 2004a).

The internal NW portion of the basin is exposed onshore as a result of the uplift, whereas the sedimentation is still active in the SE offshore portion (Barone *et al.*, 1982).

In particular, the uplift of the basin started in the mid-Pleistocene, as documented by flights of marine terraces developed along the Ionian coasts. The uplift rate calculated for the Crotone area varies from 1.8 mm y^{-1} (Cutro terrace) and 0.4-0.8 mm y^{-1} from 124 ky onwards (Carobene *et al.,* 1986; Cosentino *et al.*, 1989; Palmentola *et al.*, 1990; Zecchin *et al.*, 2004b; Nalin, 2006) (fig. 2.5).

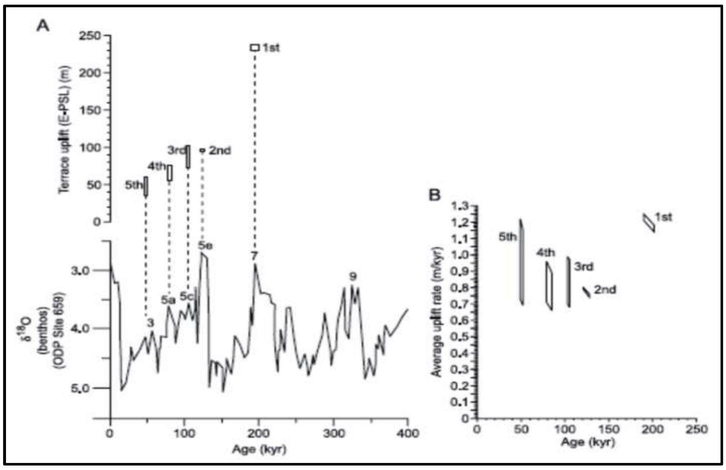


fig. 2.5: Rate of uplift relative to the five marine terraces of the Cutro area, showing also the relation with the inferred ages of deposition and $\delta^{18}O$ curve (Zecchin *et al.,* 2004b)

Roda (1964) first described the stratigraphy of the Crotone basin (fig.2.6). It consists of a Serravallian to mid Pleistocene marine to continental succession, whose thickness exceeds 3000 m (Van Dijk, 1991a, 1991b; Rio *et al.*, 1996; Massari *et al.*, 2002; Zecchin *et al.*, 2003, 2004a, 2004b, 2006; Mellere *et al.*, 2005). Three main tectono-stratigraphic units bounded by major unconformities have been recognized: a Serravallian to early Messinian unit, a middle Messinian to lower Pliocene unit, and a middle Pliocene to Pleistocene unit.

In the studied area only the third unit crops out, and is represented by a mudstone called Cutro Marly Clay formation (fig. 2.6).

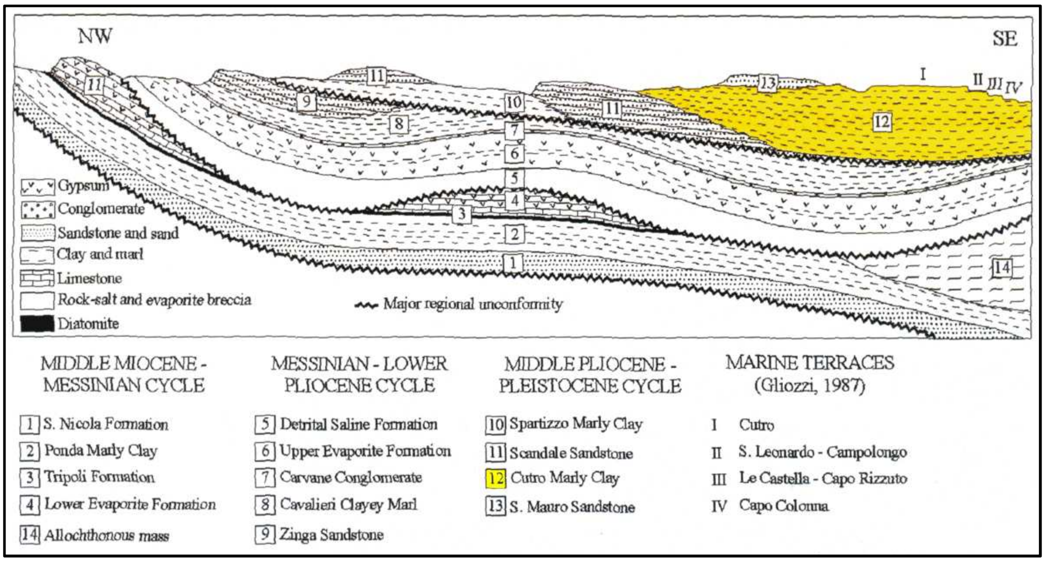


fig. 2.6: Stratigraphy of the Crotone basin as proposed by Roda (1964). In yellow the Cutro marly clay formation that represents the substrate of marine terraces. The author reports only four terraces

2.3 MARINE TERRACE

Marine terraces are a well known subject of geological interest. They are ephemeral planar landforms (Anderson *et al.*, 1999).

They are common features of emerging coasts (e.g. Barryman & Hull, 2003) and generally associated with sea-level transgressions, even if they may form also in subsiding areas at sea-level lowstands and/or stillstands during transgressions (Chiocci *et al.*, 2004). A marine terrace can be the result of marine abrasion and erosion of materials comprising the shoreline, accumulation of sediments in shallow-water to slightly emerged coastal environments or bioconstruction by coral reefs and accumulation of reef materials in tropical regions.

A satisfactory and correct definition of the term *marine terrace* is not easily achieved because of the different approaches that could be followed to define the nature of a terrace. Moreover there is no consensus on the specific terminology referring to marine terraces between different workers (Bradley, 1957; Bradley & Griggs, 1976; Kern, 1977). Local aspects interact in the formation of a marine terrace, such as nature of the substrate, sea-level trends, sea floor morphology, sediment supply, and tectonics.

Geomorphologists define a marine terrace as a flat, horizontal, or gently inclined geomorphic surface of marine origin delimitated partially or totally by scarps. A hypothetic transversal section of a terrace is presented in figure 2.7 and provides some definitions from a geometric point of view.

This definition is not satisfactory for scientists interested in the nature of marine terrace deposits. Recent studies apply the terminology of sequence stratigraphy to identify the different portions and surfaces in the deposits of marine terrace (Carobene, 2003; Nalin, 2006; Nalin *et al.*, 2006).

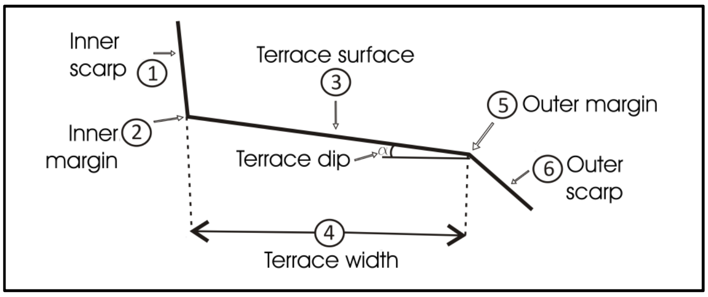
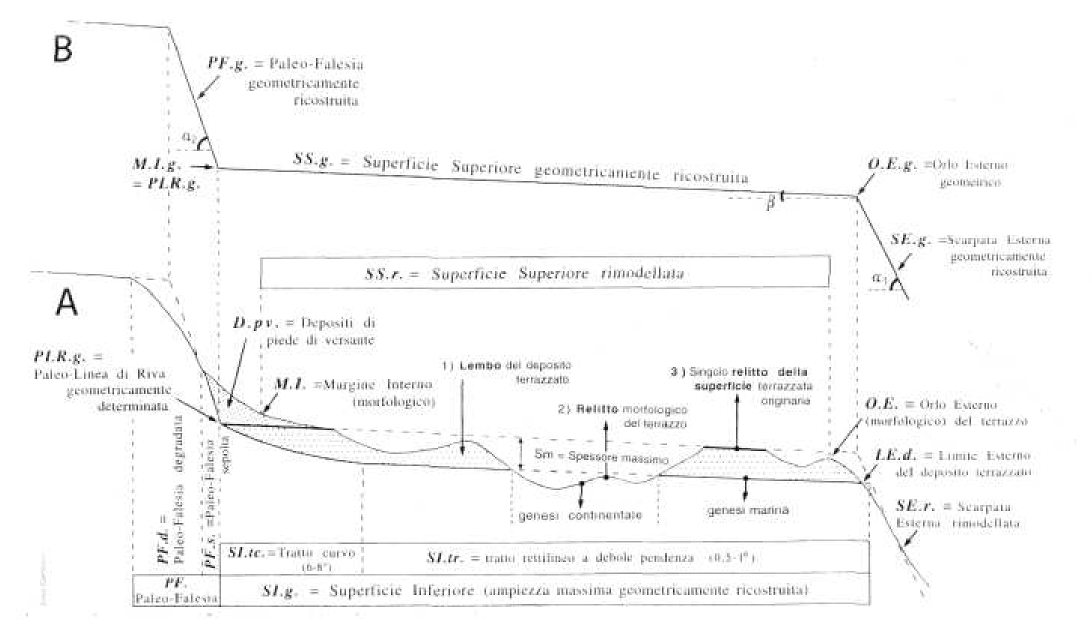


fig. 2.7: essential nomenclature of geometrical elements of a marine terrace (Carobene, 1980 readapted)

Carobene (2003) proposed a model of marine terrace as independent geological unit and defined the main portions and surfaces of a marine terrace (fig. 2.8).



Model of a marine terrace deduced from the study of the Crosia-Calopezzati area. The terrace should not be considered purely as a form, but also as a geological body (analogous to fan, moraine, etc.); however, the internal and external geometries have been accurately described and has enriched the relative nomenclature. The use of the model has made it possible to make quantitative descriptions (of distance, height, angles) indispensable for making reliable comparisons. A) Profile of a terrace showing the various features of the degraded upper surface (SS.r.), lower surface (SI.g.), landward paleoseacliff (PF.), external slope (SE.r.) and paleoshoreline (PLR.g). O.E. = outer morphological edge; M.I. = inner morphological margin; LE.d = external limit of the terraced deposit. The remodelling following the emersion and uplifting of the terrace (see Fig. 41) produced a series of relics (1, 2, 3) from which it is possible to geometrically reconstruct (profile B) the upper surface (SS.g.) and also the other characteristic elements, including the position of the inner geometric margin (M.I.g.) and the outer geometric edge (O.E.g.).

fig. 2.8: Model of marine terrace (Carobene, 2003)

Essentially, a marine terrace forms during a cycle of transgression-regression of sea-level (fig. 2.9) (Carobene, 1980; Anderson *et al.*, 1999), and the deposits should be delimited by two recognizable limits (inner and outer margin). It could be possible that no sedimentation is registered during a sea-level cycle.

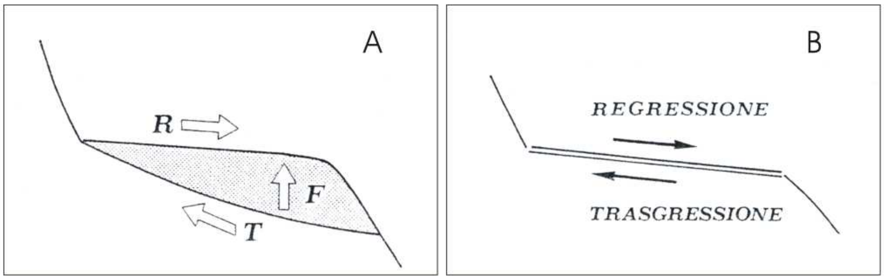


fig. 2.9: Relative events during the formation of a marine terrace. A) Section of a marine terrace with deposits: T=transgression; F=formation of the deposits; R=regression. B) Section of a marine terrace with no deposition during a sea-level change cycle (Carobene, 1980)

The importance of marine terraces in Quaternary stratigraphy and the identification of eustatic oscillations (Chappel *et al.*, 1996; Zazo, 1999; Dumas *et al.*, 2005) as well as for neotectonic and uplift studies (Cosentino & Gliozzi, 1988; Bordoni & Valensise, 1998; McNeill & Collier, 2004) is well known.

However a marine terrace represents a relevant archive from a geo-biological point of view, being a natural laboratory for stratigraphic and sedimentological analyses of shallow marine sequences under allocyclic controls.

The first stage in the generation of a marine terrace is the development of a wave-cut platform in a coastal area (fig. 2.10). During phases of sea-level rise the shoreline moves upwards or landwards forming an erosive diachronous surfaces named *ravinement* surface. This surface usually is overlain by a transgressive unit, represented by a typical basal conglomerate (Zecchin *et al.*, 2004b; Titschack *et al.*, 2008; Zecchin *et al.,* 2009) consisting of clasts eroded from the substrate or cliff or recycled from low stand deposits. This conglomerate rests on the lower surface of a marine terrace. The basal conglomerate could be covered by deposits of transgressive, high-stand and early falling stage system tracts. The upper surface could be sub-aerially exposed during the regressive phase, and be affected by erosion or pedogenesis. The upper surface could have lost its original continuity and planarity. The geometry and areal extension of the upper surface may be reconstructed by correlation of isolated relicts of the terraces. By definition, a marine terrace is bounded by a steeper ascending slope on its landward side, and a steeper descending slope on the seaward side, often exposed onshore because of uplift. The paleocliff could be very degraded and covered by colluvial deposits. If conserved, it is represented by a step marked by a slope. The point of slope changing is named *inner margin* of the terrace. The outer terrace portion could also be limited by a steep margin, named *outer margin*, because of the presence of the paleocliff of a younger terrace.

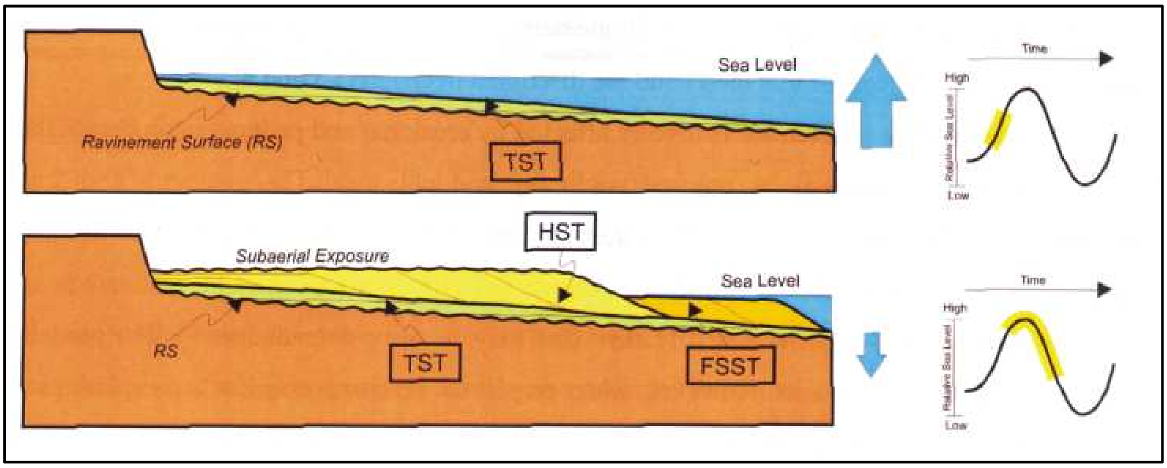


fig. 2.10: Evolutionary scheme of marine terrace, linked to sea-level oscillation. Transgressive system tract (TST), high stand system tract (HST) and fall stand system trace (FST) deposits could be preserved and forming the marine terrace. Upper scheme represents a situation of maximum flooding, while the lower a time of relative sea level fall (Nalin, 2006)

In uplifted areas, a new terrace will be progressively raised and the next transgressive event will cut an erosion platform at lower elevation (fig. 2.11). The deposits of the terrace could be exposed along a cliff and the product of erosion during cliff retreat becomes part of the basal conglomerate of the lower terrace. The interplay of continuous generation of terraces, uplift and sea level fluctuations could form a flight of terraces preserved in a step-like sequences as documented in the Crotone peninsula.

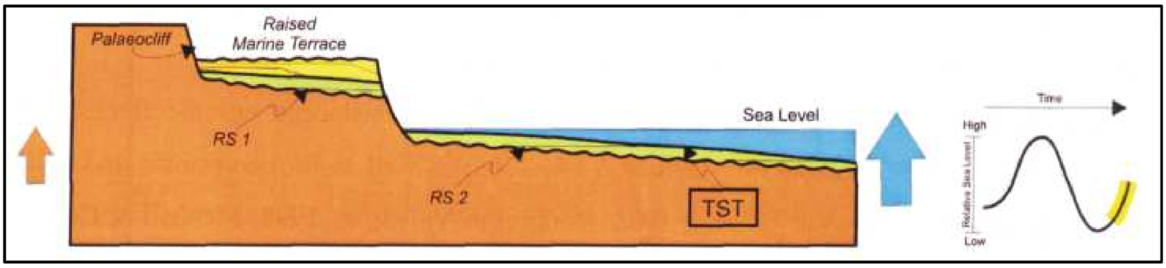


fig. 2.11: evolutionary scheme of an area with different generations of marine terrace deposits experiencing uplift (Nalin, 2006)

A marine terrace could be reworked by erosion, forming sub-horizontal or waved ridges, isolated reliefs or little patches (Carobene & Firpo, 2002). The final geomorphology of the terrace is the result of various processes, also during the uplift and emersion phases. Therefore, the identification of a terrace passes through correlation of different aspects, such as geometry, lithology, stratigraphy, paleontology, and tectonics.

The definition of the age of a marine terrace is also a challenging aspect.

Carobene (1980) distinguished between the age referred to the *formation* of marine terraced deposits and the age referred to the *development through time* of the terrace as an independent morphology. As previously proposed by Chappel *et al.* (1996) for coral terraces, Carobene (2003) suggested to attribute an age to the highest coast line recognized in the studied deposits, and then proceeded to correlate the obtained ages to the interglacial marine isotopic stages (odd MIS) of oxygen marine isotopic curve (fig. 2.12), on the basis also of data relative to uplift.

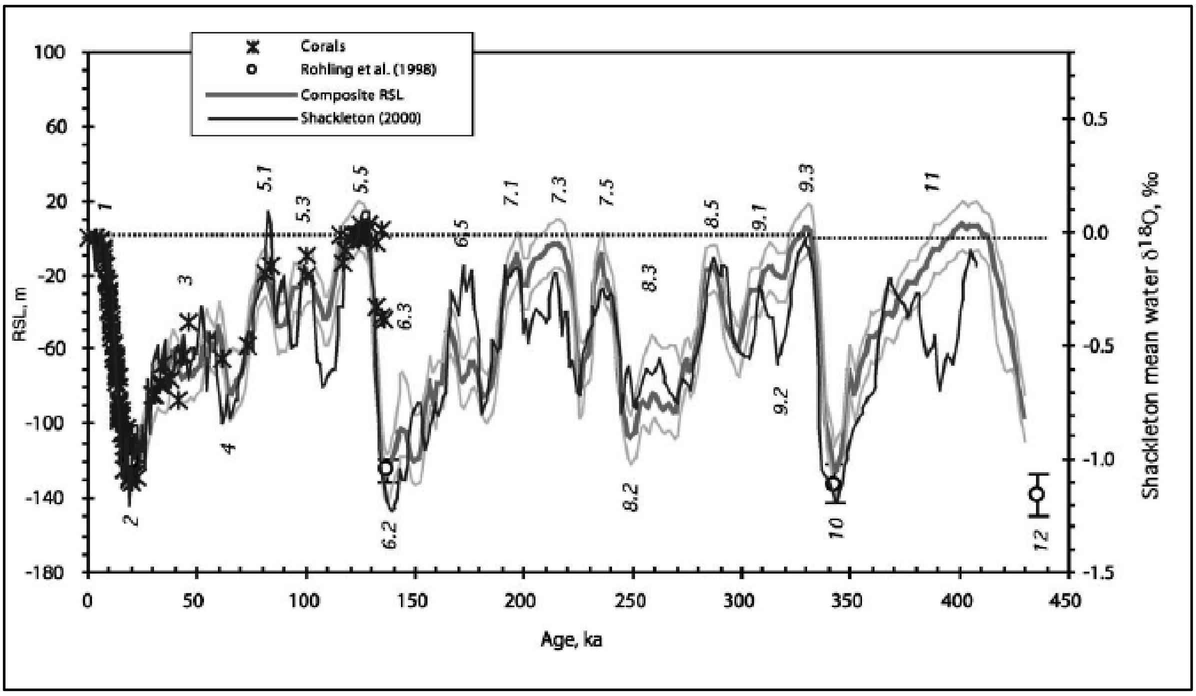


fig. 2.12: sea level curve of Waelbroeck *et al.* (2002)

2.4 MARINE TERRACES IN THE CROTONE PENINSULA

The marine terraces in the Crotone Peninsula are related to the interplay between Pleistocene sea level changes and the progressive uplift of the Calabrian arc (Ciaranfi *et al.*, 1982; Massari *et al.*, 2002).

They are dislocated by Quaternary faults recognized by Gueremy (1980), Gliozzi (1987), Cosentino *et al.* (1989) and Palmentola *et al.* (1990). The normal faults affected the marine terraces and generated some meter-high scarps (Zecchin *et al*., 2004a) in the context of an extensional regime. The intense neotectonic activity has disrupted the original surface of terraces leading to contrasts in interpretation (Cosentino *et al.*, 1989).

Terraces in this area usually consist of transgressive erosional surfaces overlain by shallow marine sediments covering unconformable a Plio-Pleistocene slope succession known as Cutro Marly Clay (Roda, 1964).

The morphological and geological study of the terraced Pleistocene deposits of Crotone peninsula was first conducted by Gignoux (1913), which recognized 3 orders of terraces, outcropping at different altitude above sea level (asl). The deposits were interpreted as littoral sandy sediments characterized by common fauna, and no *“Senegalese”* specimens. This aspect allowed the interpretation of these deposit as pre-Tyrrhenian.

Ruggieri (1948) confirmed the presence of 3 orders of marine terraces. Afterwards, the same author (1951) revised the cronostratigraphy of the terraces, in a broader context of correlation of Quaternary deposits along the Calabria Ionian coast. In particular he ascribed the outcrop of Le Castella to the Tyrrhenian stage, notwithstanding the lack of *Senegalese* specimens.

Selli (1962) recognized 7 orders of terraces, and correlated the 3 highest to the Milazzian eustatic oscillations, whereas the other four were linked to the Tyrrhenian stage because of the finding of *Persististrombus latus* (Gmelin, 1791)(= *Strombus bubonius*) specimens.

Other authors reported the same conclusions (Selli, 1962; Roda, 1964, 1967; Ogniben, 1973).

Between 1967 and 1971 geological maps of the area were produced with the funds of “Cassa del Mezzogiorno”. At least 4 orders of marine terraces were mapped in the area.

Ruggieri (1973) addressed another time the problem of the number and age of the terraces, and on the base of the finding of typically warm-specimen community he decided to attribute the highest terrace to the Tyrrhenian Stage.

Gueremy (1980) recognize 6 orders of terraces and he first reported the possibility of neo-tectonic activity causing dislocation of marine terrace surfaces.

Ciaranfi *et al.* (1982) identified 3 orders of terraces, furnishing more detailed information on the effect of the neotectonic activity in the dislocation of marine terrace deposits.

Gliozzi (1987) observed 6 orders of terraces, and she was the first to report a qualitative description of the fauna, furnishing detailed lists of recognized taxa for stratigraphic sections into different orders of terraces.

Belluomini *et al.* (1988) provided amino acid epimerization dates on fossil specimens of *Glycimeris sp*. and ^{230}Th/^{234}U ratio on corals, mollusks and travertine samples. The results suggest that terraces formed during high sea level episodes of marine isotopic stage (MIS) 7, 5.5, 5.3 and 5.1.

Palmentola *et al.* (1990) identified 4 orders of marine terraces on the basis of geomorphologic, sedimentological and paleontological analyses, considering the 1stofCrotonian age (MIS 9) and the other three related to 3 different sub-stages linked to MIS 5.

Recent works recognized up to 5 marine terraces in the Crotone peninsula, placed at progressively lower elevations (Mauz & Hassler, 2000; Zecchin *et al.,* 2004b, 2009; Nalin, 2006; Nalin *et al.,* 2006, 2007).

Mauz & Hassler (2000) and Nalin (2006) dated the deposits using luminescence techniques recognizing 5 orders of terraces representing MIS 7, 5.5, 5.3, 5.1 and 3 (fig. 2.13).

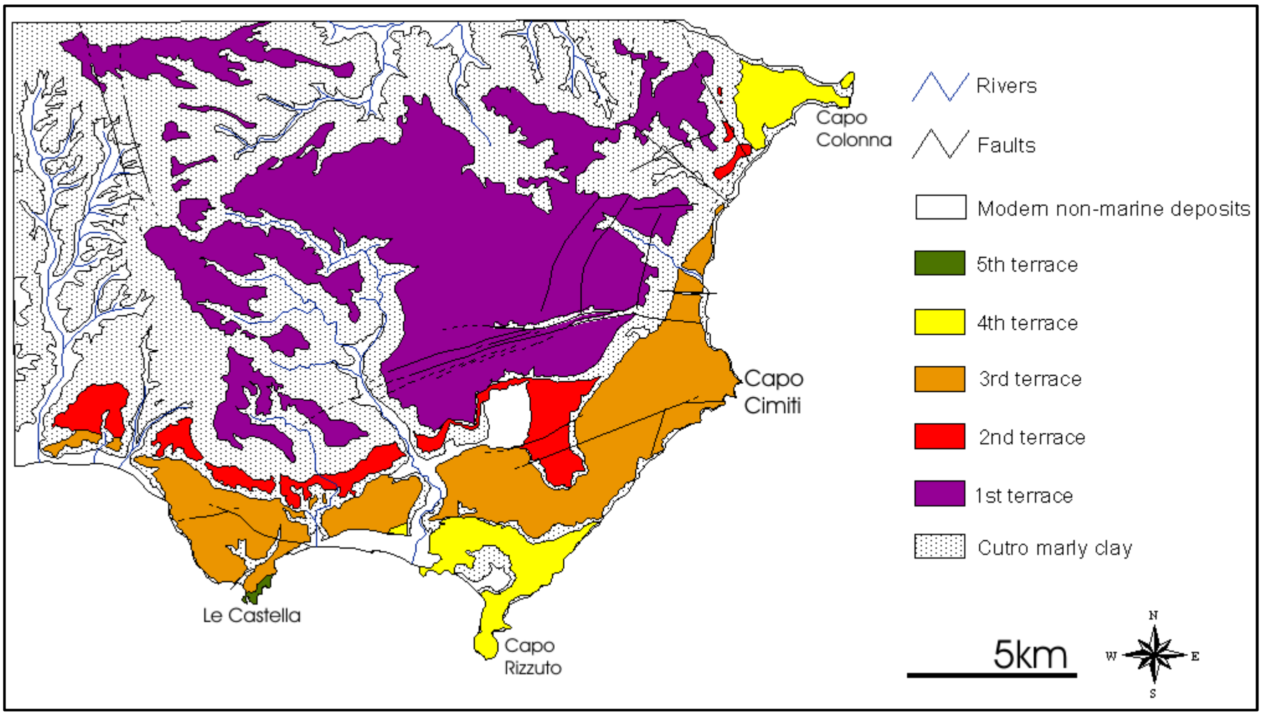


fig. 2.13: Ridigitalized geological map of the marine terraces in the studied area, major tectonin lineaments and geographic names, compiled from Palmentola *et al.*, 1990, and Zecchin *et al.,* 2004b (from Nalin, 2006)

The oldest terrace is named Cutro terrace and ascribed to marine isotopic stage (MIS) 7-200ky ca (Gliozzi, 1987; Zecchin *et al.*, 2004b) on the basis of U-series radiometric dating and aminostratigraphic techniques or MIS 9-300ky ca (Palmentola *et al.*, 1990) on the basis of backward extrapolation of the uplifting rates. It is placed between 90 and 200 m of elevation.

Some authors considered the Cutro terrace as a single depositional cycle (Gliozzi, 1987; Belluomini *et al.*, 1988; Palmentola *et al.*, 1990); Zecchin *et al.* (2004b) applied concepts of sequence stratigraphy to this terrace documenting the composite nature of this terrace.

The second, the third and the fourth terraces were ascribed by numerous authors to MIS 5 and represent the three warm peaks of this stage, respectively corresponding to sub-stages 5.5, 5.3 and 5.1.

The second terrace is placed at 45-80 m of elevation and it is dislocate by EW and NW-SE faults, and disjointed in patches (Palmentola *et al.*, 1990). The presence of *P. latus* is reported by Selli (1962), Gliozzi, (1987), Palmentola *et al.* (1990), Bracchi *et al.* (2011) and Nalin *et al.* (*in press*) and allows ascribing this terrace to MIS 5.5.

The third terrace (MIS 5.3) is preserved in a more or less continuous belt along the south to south-eastern margin of the peninsula.

The fourth terrace outcrops in the area of Capo Rizzuto and Capo Colonna and is ascribed to the last interstadial of MIS 5 (MIS 5.1) (Palmentola *et al.*, 1990; Nalin, 2006).

The portion of the marine terrace outcropping SE of Le Castella village has been dated using luminescence techniques by Mauz & Hassler (2000) and could be ascribed to the last interglacial phase (MIS3), confirmed by data obtained by Nalin (2006). Zecchin *et al.* (2004b) supported the interpretation of these authors. It could be considered as the fifth terrace.

A synthesis of the correlation between deposits and isotope stages proposed by different authors is reported in fig. 2.14.

The marine terrace deposits of Capo Colonna (4th) and Le Castella (5th) are correlated with the two last MIS (5.1 and 3). The reconstructed paleo sea-levels derived from the sea-level curves of Waelbroeck *et al.* (2002) are -48±13 m. for MIS 3 (peak around 60 ky BP) and -20±13 m for MIS 5.1 (peak around 70 ky BP).

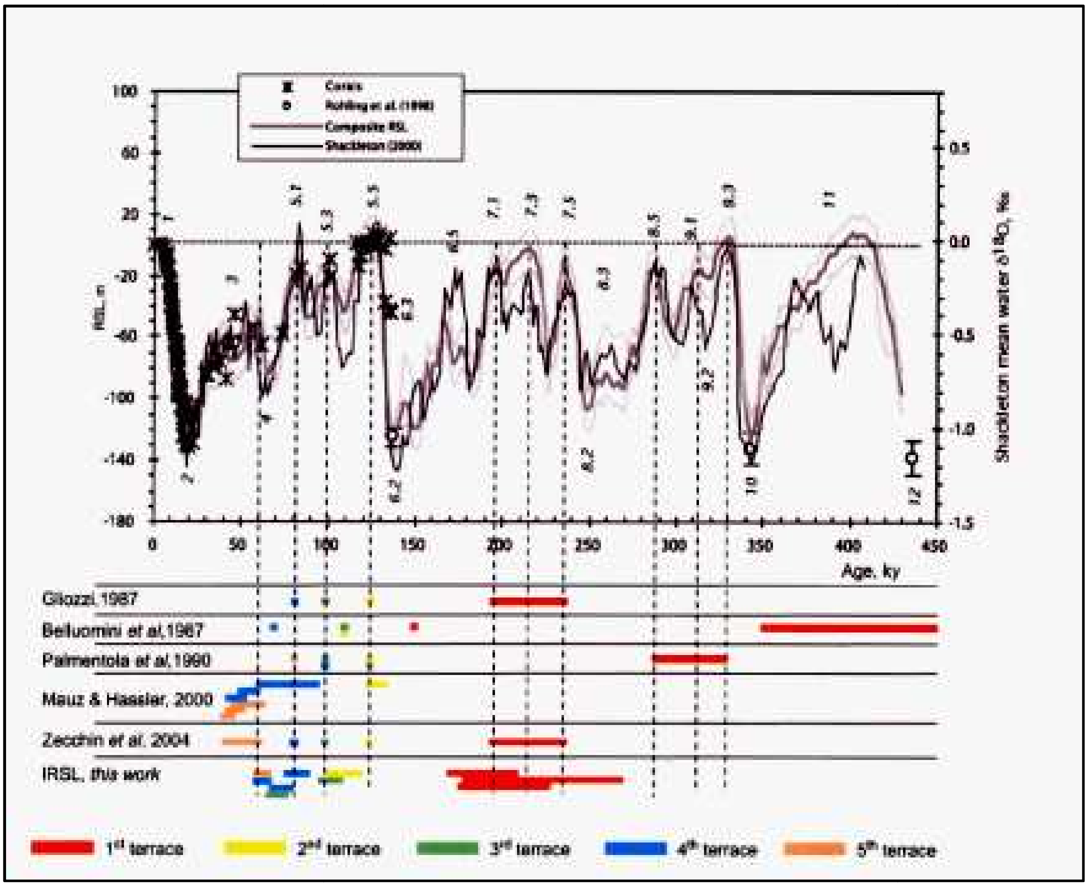


fig. 2.14: Synthesis of the stratigraphic interpretation and correlation with eustatic peaks on sea-level curve of Waelbroeck *et al.* (2002) of the marine terraces of Cutro area (from Nalin, 2006)

2.4.1 CAPO COLONNA TERRACE (4TH ORDER)

Capo Colonna is a W-E oriented peninsula, located a few kilometers south of the Crotone city.

It occupies the easternmost tip of the Crotone peninsula into Ionian Sea and it is 3 km long, showing a triangular shape.

The name derives from the presence of a Doric temple, of which only a column remains, dedicated to Hera Lacinia and built in the 5th century b.C. (Lena, 2001).

Today, the peninsula represents the relict of a formerly wider marine terrace, destroyed by strong cliff retreat erosion, due to the intense activity of marine erosion combined with the high erodibility of the cliff.

The Capo Colonna peninsula is gently inclined toward the E; the internal part is up to 50 m above sea level (asl) whereas the external part is only 10 m asl.

In the internal part, two orders of terrace deposits could be recognized, interpreted as part of the Cutro terrace (1st) and relicts of the Campolongo terrace (2nd) (Nalin, 2006).

The paleocliff of the inner margin of the Capo Colonna terrace is orientated N-S roughly. Along the northern coast of the peninsula a quite continuous, W-E orientated exposure of the deposits is preserved, approximately perpendicular to the paleo-shoreline.

Capo Colonna has been correlated to MIS 5.1 on the basis of aminoacid racemization data by Gliozzi (1987) or MIS 5.3 on the basis of geomorphic field evidences by Palmentola *et al.* (1990).

Nalin (2006) dated 3 samples using optically stimulated luminescence technique and confirmed the MIS 5.1 age.

Reports on finding of specimens of *P. latus* (Gmelin, 1791), considered as classical biomarker of MIS 5.5 (Gignoux, 1913), in the deposits of Capo Colonna, have been published (Palmentola *et al.*, 1990; Nalin *et al.*, *in press*). These authors, however, rejected the MIS 5.5 age for the terrace.

Nalin (2006) first described the deposits of this terrace, recognizing 3 different units: the Cutro marly clay substrate, the deposits of the terraces, varying in thickness from 1 to 10 m and a capping cover of colluvium.

The facies and cycle architecture of Capo Colonna terrace have been described in details by Nalin & Massari (2002) and Zecchin *et al.* (2009).

The Capo Colonna terrace deposits overlay unconformable the Cutro marly clay and consist of well developed algal build-ups and biogenic packstone. The proximal portion is characterized by a basal conglomerate, overlain by a progradational sequence of shoreface facies, whereas the distal one is dominated by algal build-ups growing on the basal conglomerate and in lateral contact with bioclastic packstone.

The sequence is bounded by an erosional surface at its base, forming during the transgressive phase, and by a surface of subaerial exposure at its top (Nalin, 2006; Zecchin *et al.*, 2009). The regressive surface of marine erosion has been identified, partially cutting the algal build-ups in the central portion of the deposits and conserved above a well-defined packstone body, which implies an accretionary forced regression phase (Nalin, 2006; Zecchin *et al.*, 2009).

Capo Colonna terrace is considered an example of composite terrace, because of the changes in stratigraphy observable in the easternmost portion of the peninsula, where the base of the deposits drops from several meters asl to approximately sea-level and two transgressive-regressive sequences are observable (Nalin, 2006; Zecchin *et al.,* 2009). The presence of two sub-orbital sea level fluctuations during MIS 5.1, which is considered the age of Capo Colonna terrace, peaked at 84 and 77 ky BP is reported in Potter & Lambeck (2003); Potter *et al.* (2004); Schellmann *et al.* (2004), estimating the second fluctuation 2 m higher than the peak of the first.

2.4.2 LE CASTELLA TERRACE (5TH ORDER)

Le Castella terrace is a very small terrace (fig. 15), on which the Le Castella village rests. It is the youngest terrace in the Crotone area. It forms a nearly horizontal table, with a preserved extension of ~ 1 km^2, and gently seaward inclined to the SE from 15 m asl in the proximal area to below sea level (bsl) in the distal part (Zecchin *et al.*, 2009).

The deposits of the terrace are exposed all along the Le Castella coastline and unconformable overlie the Cutro marly clay unit, varying from 3 m thick in the proximal part to over 10 m seaward.

Gliozzi (1987) and Cosentino *et al.* (1989) documented the intensive extensional tectonic activity that displaced the deposits of the Crotone marine terrace (fig. 15). In the Le Castella area different authors recognize two major faults: one ENE striking and one WNW striking. These faults displace the deposits of the 3rd terrace and mark the inner boundary of the Le Castella promontory (fig.2.15) (Zecchin *et al.*, 2010).

The paleocliff of the inner margin of Le Castella terrace is NE-SW oriented (Palmentola *et al.*, 1990).

Gliozzi (1987) considered this terrace as a part of the Le Castella-Capo Rizzuto terrace (MIS 5.3, about 100 ky), downthrown by a normal fault, but the author found no evidence of tectonic activity. Palmentola *et al.* (1990) ascribed this terrace to MIS 5.1 (about 80 ky B.P., Toscano & Lumberg, 1999). Mauz& Hassler (2000) dated these terraces using luminescence techniques, obtaining an age of about 50ky B.P., ascribing these terraces to MIS 3. This age attribution was confirmed by data from Nalin (2006). Zecchin (2004b) interpreted the Le Castella terrace as a younger independent terrace related to a more recent eustatic cycle, possibly one of the highstand of MIS 3.

Gliozzi (1987) described 3 stratigraphic sections in the area of Le Castella, and even if she attributed these deposits to MIS 5.1, she reported relevant data on the paleontological content of the deposits suggesting an infralittoral paleo-environment.

Zecchin *et al.* (2009) divided the deposits inferred to Le Castella terrace into two associations: normal shoreface and shelf facies (A) and Clinoform facies (B). The facies A consists of basal lag, coral and algal reef, and biogenic packstone subdivided in different sub-facies. The facies B consists of a sigmoid to oblique clinoforms characterized by cross-stratified biogenic packstone and interpreted as fossil example of a prograding spit system.

3. MATERIALS AND METHODS

3.1 FIELDWORK

Fieldwork in the Crotone area was conducted in September 2009 to sample the red algal bioconstructions and the associated biogenic sediments in order to define the main features of the youngest Pleistocene carbonate factories in the Crotone area and to improve the knowledge on development of marine terraces from a geobiological point of view.

In particular, 11stratigraphic sections were measured and 78 samples collected at Capo Colonna, whereas 11 stratigraphic sections and 56 samples at Le Castella village.

3.2 LABORATORY ANALYSES

All the samples have been analyzed and stored in the geo-biological laboratories of the Geology Department of the University of Milano-Bicocca.

Each sample has been described, catalogued and pictured (see Appendixes II and III, chapter 4.1).

3.2.1 SAMPLES COLLECTED IN RED ALGAE FACIES

Samples collected in the coralligenous build-ups and other crustose coralline algae facies have been treated in order to make thin sections and detect the algae genera and species.

The size of each samples allow preparing more than 1 thin section per sample. The first cut of sample has been brought perpendicular to the recognized direction of development, so perpendicular to the algae crusts. Than the choice of how many and where to prepare the thin section is conducted on the base of the interior development of algae crusts. The cutting operation is a very crucial operation. The best direction to cut algae crusts is longitudinal to the thallus development, in order to visualize the diagnostic features across the thallus in order to identify the species or genus. Two types of problem have to be considered. On one hand the nature of samples, often characterized by a compacted overlapping of algae crusts with a multi-directional development. On the other hand the low precision and the destructive power of the cutter, that often does not allow a precise control on the direction of the cutting operation.

Each sample was than poured into small cylinders filled with epoxy resin. The hardened sample-resin block was removed, UV-glued to glass plates 4.5 cm x 2.7 cm and thinned to 80-110 µm. The thin sections were examined under optical microscope at 40x or 100x magnification.

A total of 74 thin sections have been prepared for Capo Colonna marine terrace and 76 for Le Castella marine terrace.

A quantitative assessment of the coralline algae distribution on thin section has been made. Genera and species circumpscription follows Woelkerling (1988), Bressan & Babbini (2003), Cabioch & Mendoza (2003) and Athanasiadis & Neto (2010). Coralline algae growth-forms terminology follows Woelkerling *et al*., 1993. Taxonomic list of recognized species follows Guiry & Guiry (2009). Geographic distribution follows Bressan & Babbini (2003). Stratigraphic distribution has been reconstructed on the base of literature published data. Taxonomic uncertainties concerning fossil coralline taxonomy are discussed by Braga & Aguirre (1995) and Bassi & Nebelsick (2000).

3.2.2 SAMPLES COLLECTED IN BIOGENIC GRAINSTONE, PACKSTONE AND WACKESTONE UNITS

These samples present different lithification degree. A tentative dissolution of samples has been tried, looking after the preservation of all the fractions, in order to "recreate" the sediments as it was during deposition and reconstruct the original sedimentary setting as far as possible. This procedure also allows the manual picking of biogenic shells and fragments to produce a quantitative list of mollusk and bryozoan fossil assemblages.

Various thermal techniques are reported in literature for dissolution of consolidated samples, to exploit the disaggregation of particles through frost/defrost cycles. Following Green (2001), we could select one of the following techniques: a) tap-water (Hanna and Church, 1928); b) water and sodium acetate 3-hydrate (Sohn, 1961; Sohn *et al.,* 1965); c) water and sodium sulphate 10-hydrate, named Glauber salt (Surlyk, 1972).

In order to save time the first technique was rejected because it needed more than 25 frost/defrost cycles to disaggregate the packstone. In order to be conservative the second technique was rejected because we lost too much material during processing. The third technique is conservative and time-saving. Each sample undergoes frost/defrost cycles into holder with water and sodium sulphate 10-hydrate. It needed from 8 to 15 cycles to completely disaggregate a sample. The obtained sediments seem to be really similar to the original sample.

FOSSIL ASSEMBLAGES

On 300 grams of disaggregated sediments the manual picking of macro-benthic components is carried out, focusing on the mollusk and bryozoan fauna, using only the >1mm fractions (Basso & Corselli, 2007).

The manual picking operation consists on manual selection of shell or shell fragments considered useful for genera and species identification. For mollusk fossil assemblages, bivalves are considered identifiable if the shell preserves the entire hinge, whereas gastropods must preserve the apex or at least the 2/3 of sub-apical shell (Di Geronimo & Robba, 1976; Basso & Corselli, 2007). For bryozoan fossil assemblages each fragment has been considered.

The biogenic content has been analyzed using a binocular microscope (at 40X) in order to produce a list of identified genera/species (see Appendix V and VI, chapter 4.3).

For mollusk fossil assemblage, a table reporting the list of identified species has been prepared for each sample, reporting the abundance (A), the dominance (Dm), the status (S), the conservation degree (C), the ecology and the preferential substrate.

The abundance represents the number of specimens for each species. The counting of mollusk follows Di Geronimo & Robba (1976).

The dominance represents the number of specimens for a *i*th species, respect to the total number of specimens for sample, expressed in percentage.

The status and the conservation degree are two qualitative indexes expressed following Basso & Corselli (2007).

The status is a qualitative index expressing which generation prevails in the specimens for each species. It is indicated as: J for only juvenile specimens; A for only adult specimens; P for population, where juvenile and adult specimens are present.

The conservation degree is a qualitative index expressing how the specimens are conserved. It is indicated with a number from 1 to 5: 1) quite unrecognizable; 2) broken fragments, large part of shell missing, or largely eroded, abraded, encrusted, perforated; 3) entire shell or broken, but conserving the 75% of the shell, opaque, partially perforated, abraded or encrusted; 4) entire shell, well-conserved, fresh, bright, conserving the shell ornamentation; 5) specimen collected alive.

The ecology and the preferential substrate indicate the ecological meaning of each species, like habitus, trophism, and link to biocoenosis, following Parenzan (1960), Pérès & Picard (1964), Tebble (1976), Fretter & Graham (1976, 1978, 1982) and Riedl (1991).

For bryozoan fossil assemblage, a table reporting the list of identified species has been prepared for each sample, reporting the ecology and the preferential substrate, following Gautier (1962) and Pérès & Picard (1964).

Taxonomic list of identified mollusk and bryozoan species/genera follows WoRMS (World Register of Marine Species) (Appeltans *et al.*, 2011). Geographic and stratigraphic distributions follow the PaleoBiology Database (http://paleodb.org/).

The fossil assemblage data have been statistically analyzed using PRIMER (version 6.1.12; Clarke & Gorley, 2006). Univariate diversity measures of samples have been conducted: the species richness, given a total number of species (S) and total number of individuals (N); the Shannon diversity Index (H'), as the proportion of the total count arising from the *i*th species; the Simpson Index (λ'), as the probability that any two specimens from the sample, chosen at random, are from the same species (always ≤1).

Hierarchical cluster analysis and non-metric Multidimensional Scaling (MDS) ordination based on the Bray-Curtis similarity of mollusk and bryozoan fossil assemblage components. Results of the statistical analysis have been used to identify to group samples in order to better reconstruct the paleoenvironmental conditions.

On 200 grams of disaggregated sediments wet grain-size analyses have been carried out using a 6 sieves vibrating column with decreasing mesh (2 mm, 1 mm, 0,5 mm, 250 µm, 125 µm and 63 µm). On 100 grams of disaggregated sediments the dissolution of carbonate portion has been conducted using HCl (37%), in order to measure the carbonate in term of weight, and to conduct dry grain-size analyses on the siliciclastic residual. On the siliciclastic residual wet or dry analyses have been conducted using a 7 sieves vibrating column with decreasing mesh (2 mm, 1 mm, 0,5 mm, 250 µm, 125 µm, 63 µm and < 63 µm). Grain-size curves have been prepared.

The results of grain size analyses on original disaggregated sediments (named Total sediment) and siliciclastic residual (named Residual sediment) have been compared to highlight the composition for each grain-size class, and to understand the contribution of the benthic fauna in the definition of the sediment grain-size.

Thin sections have been made, on the original sample, in order to analyze the inner structure of packstone and grainstone units under microscope and to estimate the contribute of corallines and other major benthic components. Seven categories of sedimentary components were identified at 40X magnification (coralline algae, bryozoans, mollusks, foraminifers, echinoids, annelids and corals). They were recognized by diagnostic features observable in thin section (Sholle 1978; Sholle & Ulmer-Sholle 2003). The distribution of the seven groups was digitally mapped on the thin sections (AutoCAD 2008; ArcView GIS version 3.1).

Quantitative estimates on the contribution of each recognized biogenic components are based on the counting of the recognized component on thin section. A sub-areas of 2x1,3 cm has been considered on each thin section, and all the fragments recognizable using a binocular microscope at 40X magnification have been counted.

4. RESULTS

4.1 STRATIGRAPHIC SECTIONS

4.1.1 CAPO COLONNA MARINE TERRACE

Eleven stratigraphic sections were measured and sampled along the northern coast of the Capo Colonna peninsula (Fig. 4.1). The cliff exposure represents a quite continuous outcrop, W-E oriented, roughly perpendicular to the paleo-shoreline. The Cutro Marly Clay constitutes the substrate of all the terrace deposits. A well recognizable ravinement surface unconformable cuts the clay substrate, and is overlain by a basal conglomerate. The deposits have been subdivided into four portions with different facies architecture by Nalin (2006), Nalin & Massari (2009); Zecchin *et al*. (2009).

GPS position list of the studied sections is reported in Appendix I.

A short description and a picture of each collected sample are given in Appendix II.

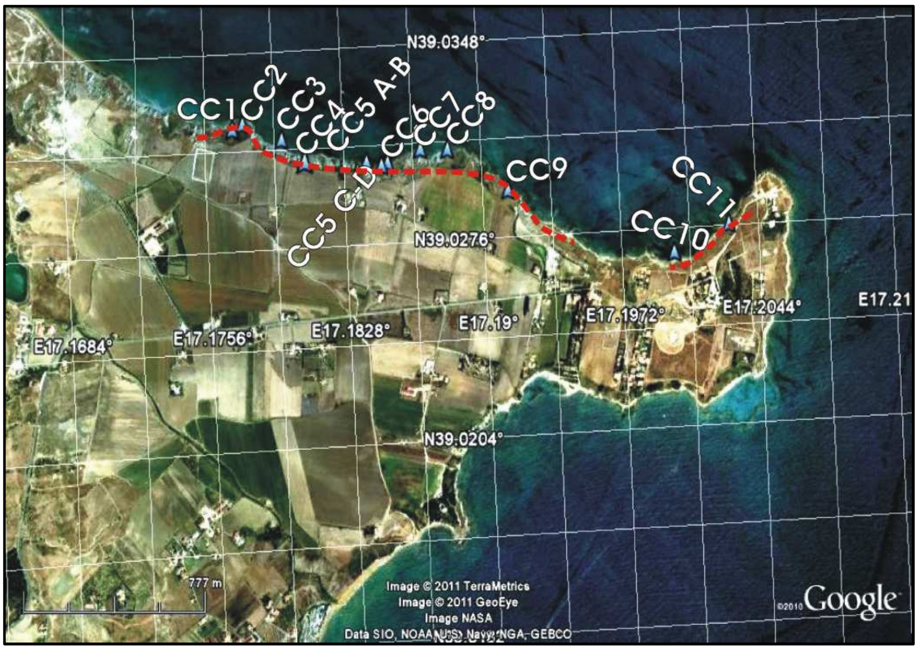


Fig. 4.1: map of the Capo Colonna peninsula, showing the location of the studied sections

SECTION CC1

The innermost section is characterized by well sorted, unconsolidated fine sand, alternated to coarser and more biogenic deposits showing planar horizontal cross lamination, overlying a basal conglomerate or directly above the Cutro marly clay (Fig. 4.2). The unlithified sand erodes more recessively than the coarse unit.

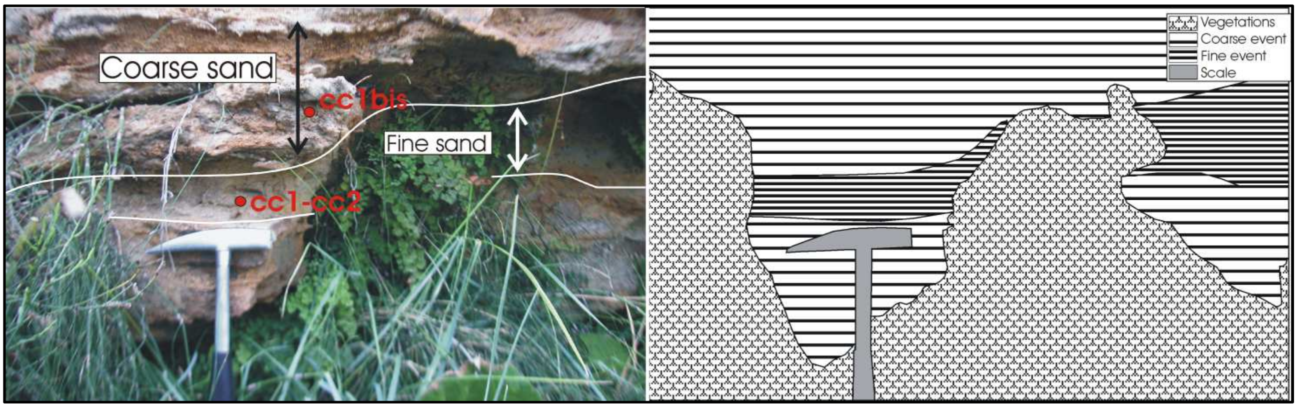


Fig. 4.2: section CC1. Left: picture of the section, with indication of samples.; right: interpretative sketch of the section. Hammer as scale, 33 cm long.

SECTION CC2

The innermost algal build-up observed in the Capo Colonna terrace deposits is exposed in section CC2, in an outcrop 6 m thick and more than 10 m long.

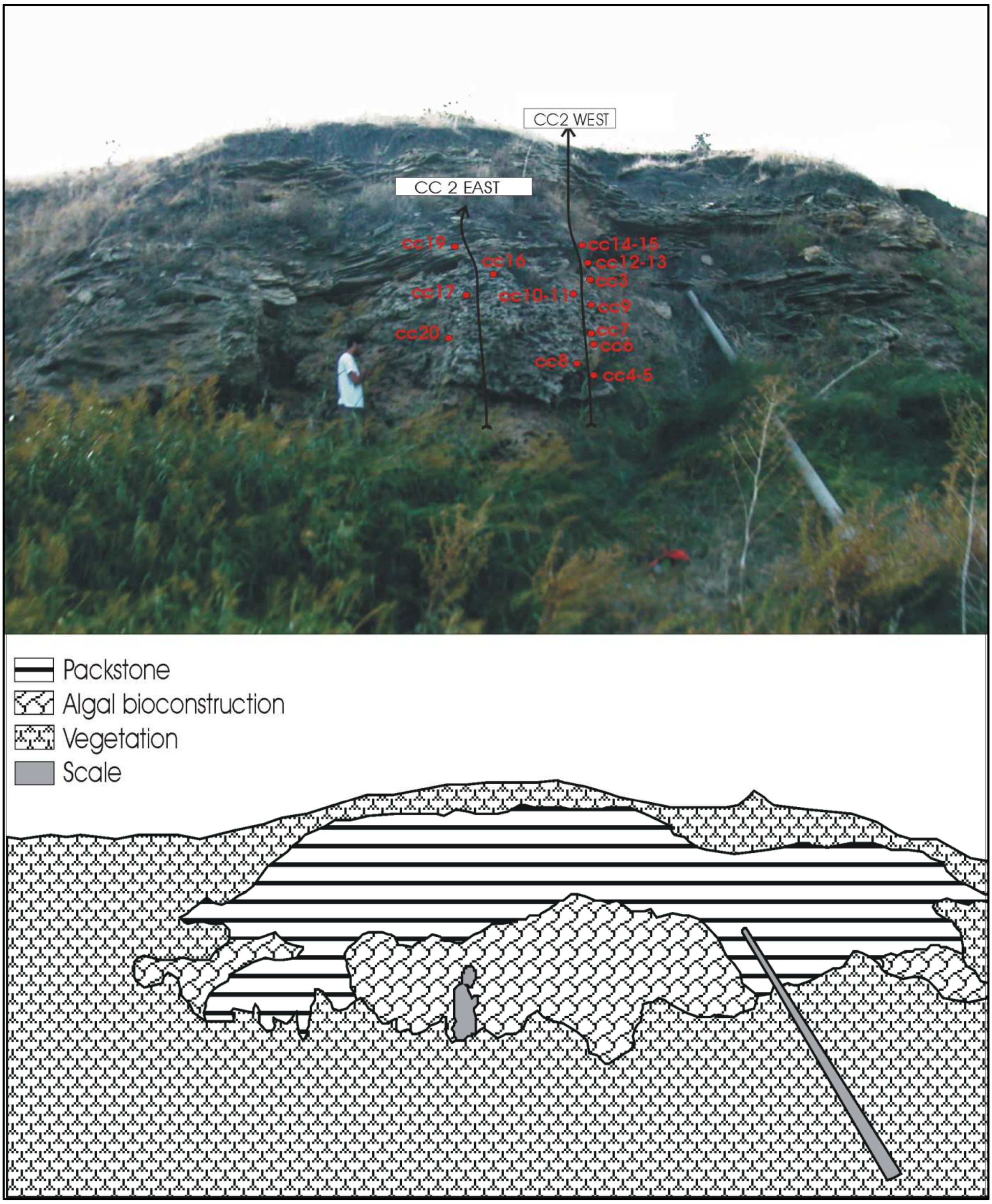


Fig. 4.3: section CC2. Top: picture of the section, with indication of the measured sections and samples; bottom: interpretative sketch of the section. Person as scale, 1.70 m tall

The algal build-up is formed by structures, at least 3 m thick and 3 m long. The build-up is surrounded and overlain by packstone, with hummocky-cross stratification at the base turning to planar cross lamination at the top. On the side of the build-up facing the paleocliff, levels of local accumulation of coarse biogenic fragments are observed, in which gastropod shells are the dominant component.

Two sections have been measured.

The West section is characterized by a direct contact between the Cutro Marly Clay and the overlying algal build-up.

The basal portion of the bioconstruction is dominated by erected bryozoans in a muddy matrix, overlain by a local accumulation of coarse sand and gravel (Fig. 4.4)

Fig. 4.4: examples of bryozoan wackestone at the base of the algal build-up

The algal build-up developed partially on the Cutro Marly Clay, and it was partially affected by bioturbation (Fig. 4.5 right). In particular the build-up shows intensive burrowing, probably made by decapods. The bioturbated portion develops almost to the top, but it does not affect all the build-up. The build-up is 3 m thick. Pocket in the build-ups are filled by coarse packstone (Fig. 4.5 left).

Fig. 4.5: the coarse packstone filling the pockets of the bioconstruction, on the left, and the typical vacuolar aspect of the build-up, due to bioturbation

The algal build-up is characterized by high compacted leafy crusts, rarely branched. The main framework builders are red algae.

Cladocora caespitosa Linneo, 1758 and accumulations of terrigenous cobbles are observed in the build-up below and laterally to the bryozoans-rich facies (Fig. 4.6).

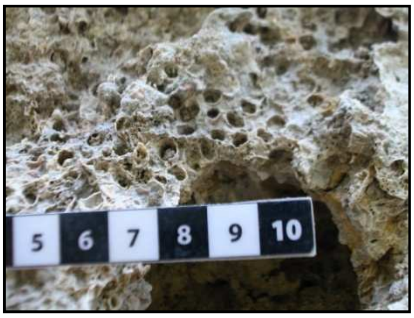


fig. 4.6: *C. caespitosa* in the build-up in section CC2 west

The top of the succession is capped by a 2 m thick packstone/grainstone unit, showing planar lamination.

The eastern section is characterized by a basal conglomerate at the base, 1 m thick, directly in contact with the bioconstructed body. The pockets in the build-up are filled by the same coarse packstone, locally enriched in *Spondylus sp.* shell fragments, and show a particular crust, made by serpulids, at the contact with the build-up. At the top of the build-up, a 1.5 m thick unit of fine packstone is reported.

SECTION CC3

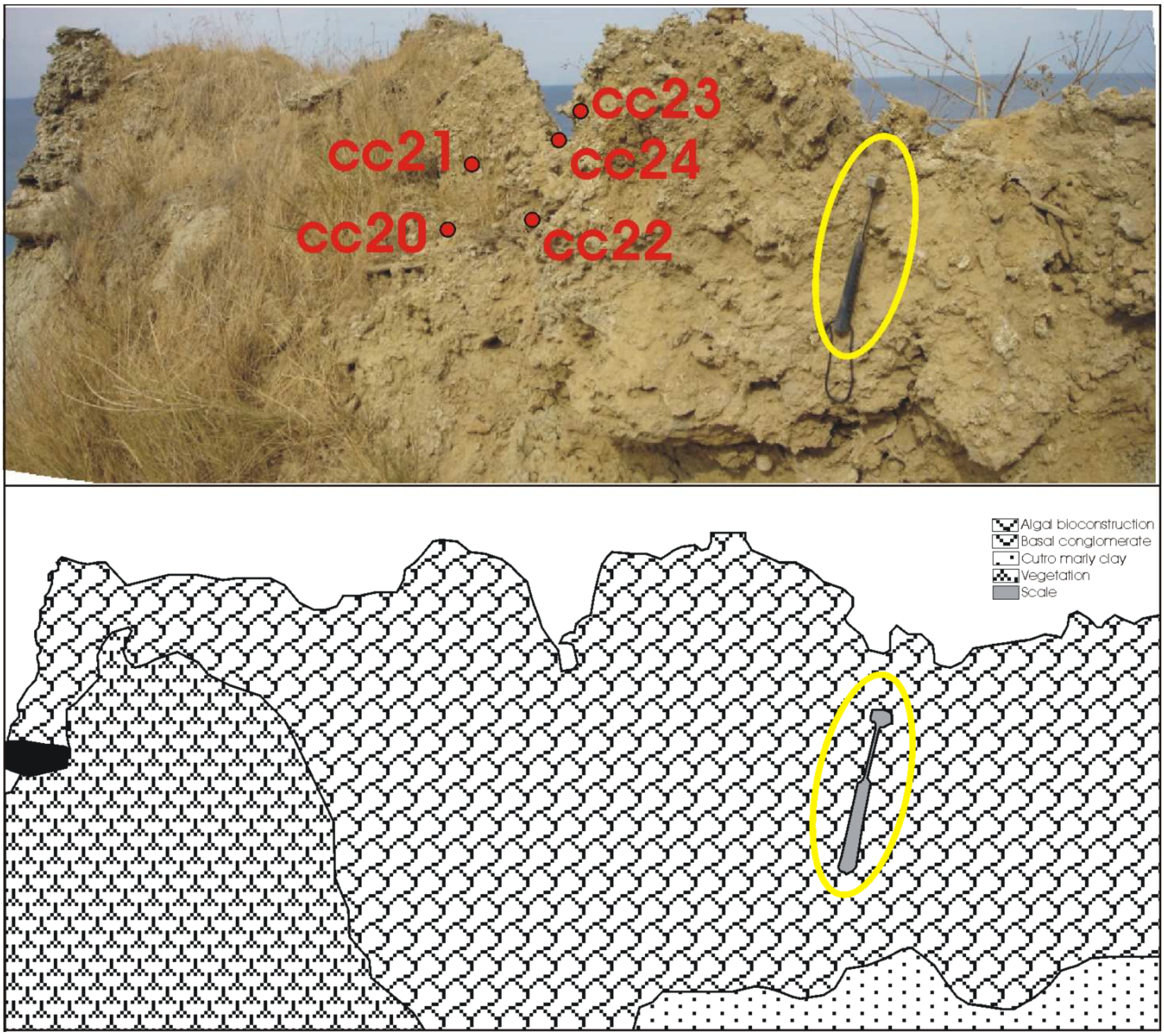


Fig 4.7: section CC3. Top: picture of the section, with indication of samples; bottom: interpretative sketch of the section. Yellow circles indicate hammer as scale, 33 cm long.

A 1 m thick algal build-up directly overlays the basal conglomerate or the Cutro Marly Clay. Cavities of the build-ups are partially filled by coarse bioclastic packstone. The same packstone caps the build-up structures, with a thickness of 50 cm.

SECTIONS CC4- CC5 (A-D)-CC6- CC7 (A-B)

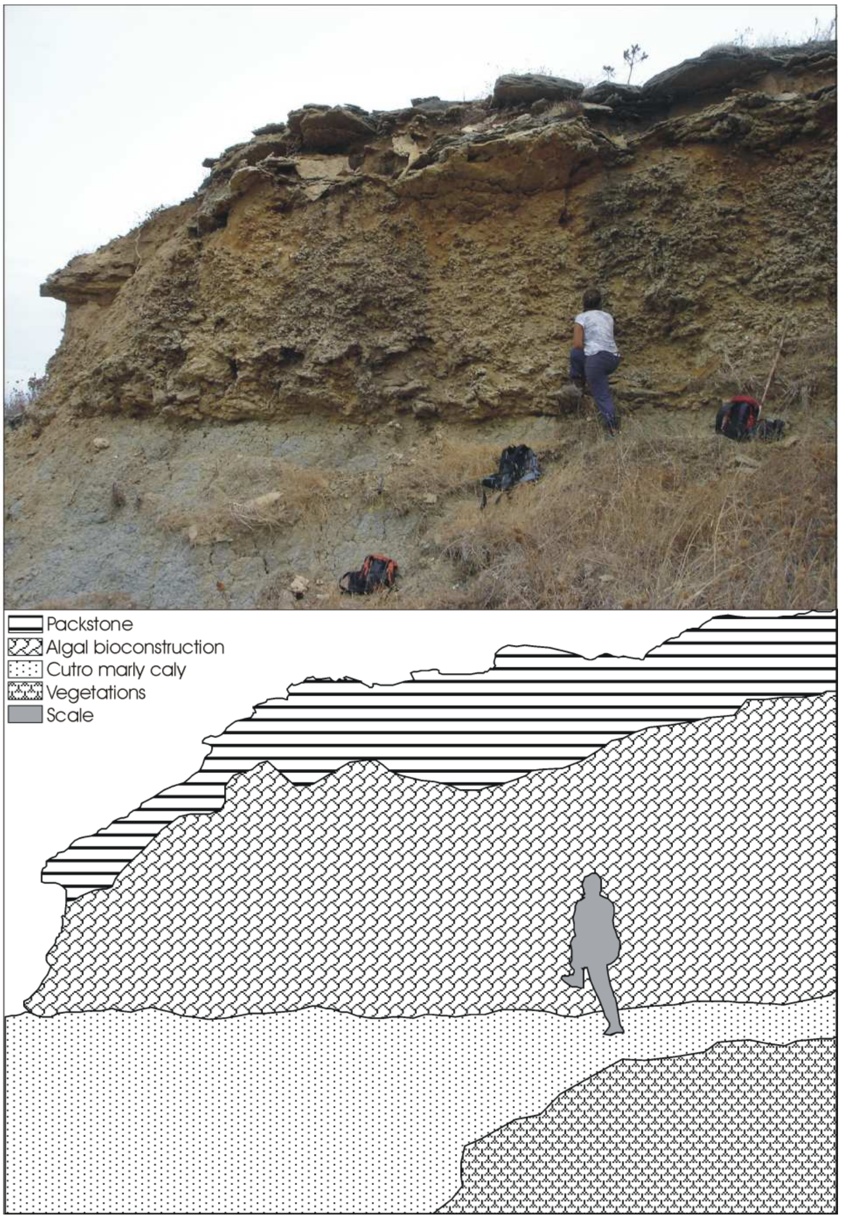


Fig. 4.8: quite continuous outcrop, including sections CC4, CC5, CC6 and CC7. Left: picture of the sections, right: interpretative sketch of the sections. Person as scale, 1.60 m tall

Sections CC4, CC5, CC6 and CC7 cover a quite continuous outcrop more than 100 m long.

The Cutro Marly Clay is continuously exposed at the base of the deposits.

Section CC4 presents a basal conglomerate, overlying the clay substrate, with clasts bored by lithodomes. Above the conglomerate, a 2 m-thick algal build-up with rhodoliths at its base is present. The build-up is overlain by coarse biogenic packstone with planar cross-bedding and planar horizontal-bedding at the top.

Section CC5a presents a basal conglomerate, overlying the clay, with clasts bored by lithodomes.

Over the conglomerate, a coarse biogenic packstone, 50 cm thick, apparently reworked and well cemented is present. Bryozoans and rhodoliths are dominant components of the packstone.

The top of the packstone is characterized by a hardground, preserving *Gaestrochaenolites lapidicus* Kelly & Bromley, 1984 bioturbation traces (Fig. 4.9).

Fig. 4.9: *G. lapidicus* developed below the hardground (left); borings of lithodomes in clasts of the basal conglomerate (right)

Over the hardground a well developed algal bank is present, with a thickness of 2 to 3 m.

Moving to the E the basal unit passes from coarse biogenic packstone (sections CC4 and CC5a) to a bryozoans-dominated wackestone (sections CC5 b), 50 cm thick, overlain by the same coarse biogenic packstone (40 cm thick).

The hardground is covered by a well developed algal bank, 4 m thick and 40 m long. The framework of the build-up is very compact, with few pockets filled by packstone.

At the top of the build-up, a fine packstone, 1m thick, with planar horizontal bedding structures is observed.

Section CC5c shows the same sequence, but the coarse biogenic packstone presents a particular gastropod-rich facies (Fig. 4.10).

Fig 4.10: view of the gastropod-rich facies in coarse packstone outcropping in section CC5c

Sections CC5d and CC6 are characterized by a basal bryozoans wackestone (40-60 cm thick), directly overlying the Cutro Marly Clay, capped by a well developed packstone (1 m thick) in which prâline rhodoliths are present in the lower part (Fig. 4.11 below). At the top of the packstone unit, a local accumulation of bivalve shells of *Glycimeris* and *Venus* is observed (Fig. 4.11 above).

Fig 4.11: top: details of the bivalve-rich packstone level in sections CC5d and CC6. Pen is 13 cm long. Bottom: view of the prâline rhodoliths sparsely distributed in the packstone unit in sections CC5d and CC6

The shells are 3-6 cm in size, rarely still articulated, in a packstone matrix. The distribution of the shells forms traces of horizontal lamination.

Section CC7a presents the same sequence of section 6, but a level of siliciclastic pebbles is present at the passage from the bryozoans' wackestone to the packstone. This layer occupies the same level of the branching rhodoliths. Moreover, the top of the packstone is characterized by the bioturbated hardground, which in this section is directly covered by smaller algal build-ups (70 cm-thick) alternated to channels filled by packstone. Section CC7b differs because of the presence of a basal conglomerate below the bryozoans' wackestone. In the packstone, just 5 cm below the hardground, an individual specimen of *Persististrombus latus* (Gmelin, 1791) has been founded (Nalin *et al*., *in press*) (Fig. 4.12).

Fig 4.12: view of the *P. latus* specimen found in the packstone unit (Nalin *et al., in press*), in section CC7b

SECTION CC8

The basal unit is formed by bryozoans wackestone (20 cm) and coarse bioclastic packstone 70 cm-thick, with the hardground on top, on which a well develop algal build-up is preserved (Fig. 4.13).

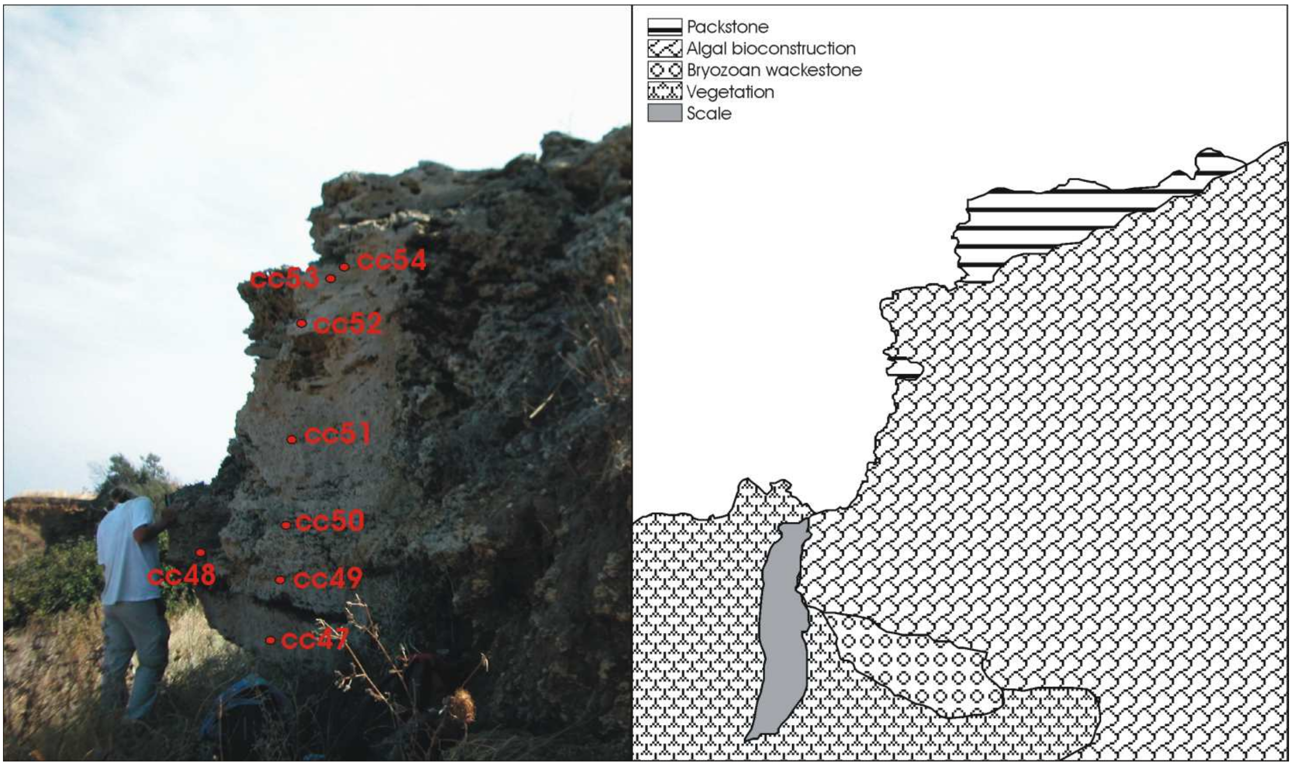


Fig. 4.13: section CC8. Left: picture of the section, with indication of samples; right: interpretative sketch of the section. Person as scale, 1.7 m tall

The build-up is characterized by an open framework, with a vacuolar and highly bioturbated structure (Fig. 4.14). Numerous *Spondylus sp.* specimens are observed in the bioconstruction. At the top of the build-up, a 40 cm layer of finely laminated packstone is present.

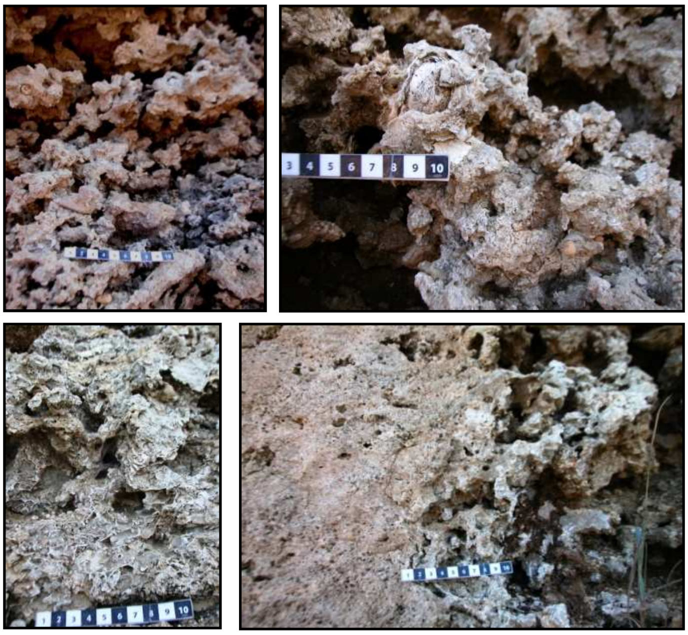


Fig. 4.14: Typical aspect of the build-up at section CC8, showing vacuolar framework due to bioturbation. The algal crusts are very dense. Bottom: contact between algal build-up and packstone filling a cavity

SECTIONS CC9

Section CC9 shows a well develop algal bank.

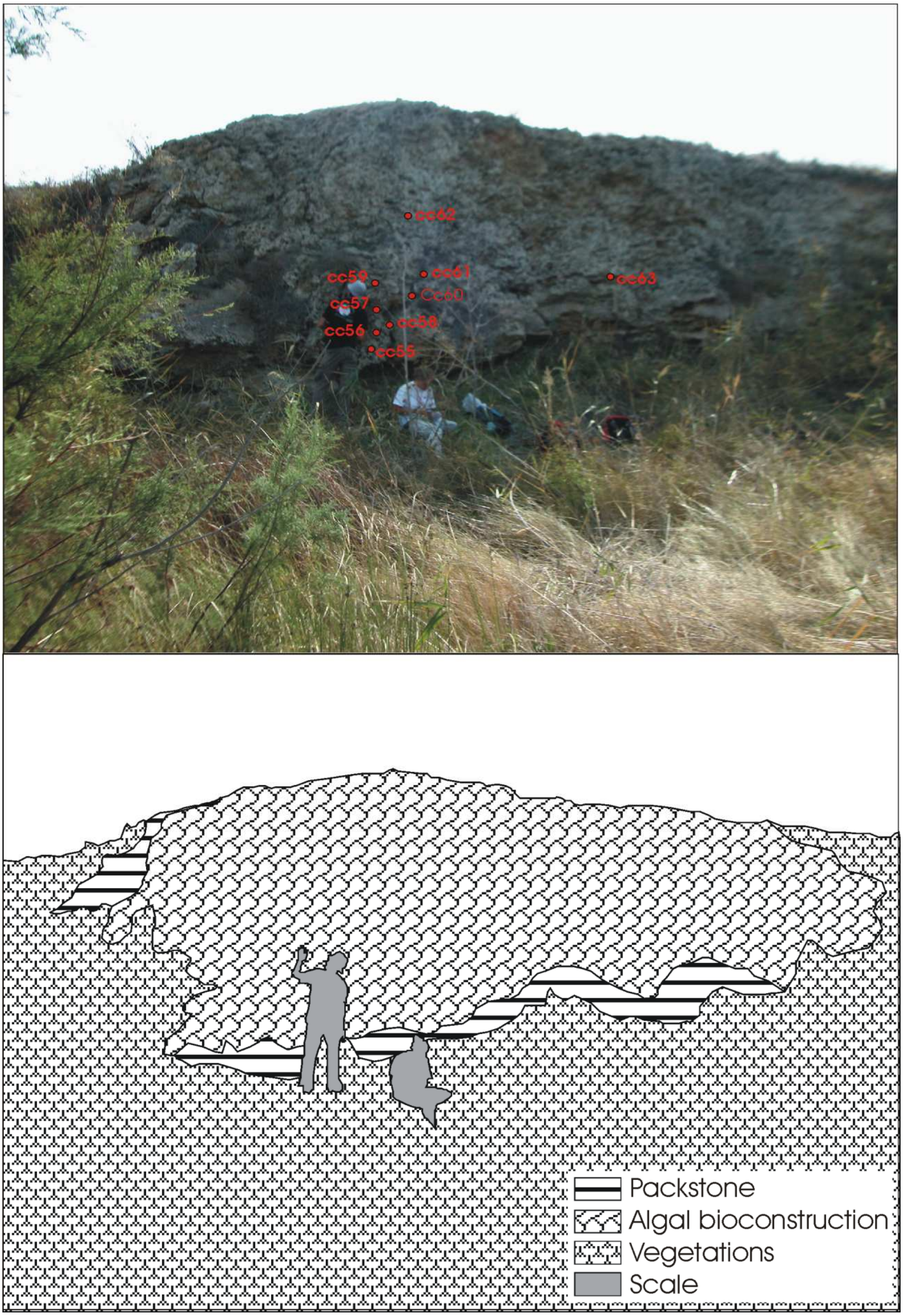


Fig. 4.15: section CC9. Left: picture of the section, with indication of samples ; right: interpretative sketch of the section. Person as scale, 1.7 m tall

The build-up has a leafy growth form. Borings made by lithodomes and their internal moulds are present at the base of the build-up and along the edges of vacuolar cavities. Pockets in the bioconstruction are filled by coarse packstone. On the western side of the section, at the base of the bioconstruction, a level rich in siliciclastic cobbles is present. This level could represent a facies of the basal conglomerate or an equivalent facies of the packstone of the previous sections, filling some original pockets into the build-up.

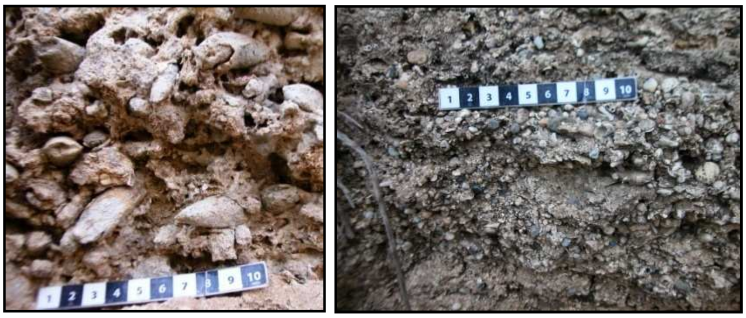


Fig. 4.16: Left: lithodomes found in the build-up; right: local accumulation of coarse siliciclastic pebbles, forming a basal micro-conglomerate. Both in section CC9

SECTION CC10

Section CC10 presents at the base a bioclastic packstone-rudstone (1.5 m thick), directly overlying the basal conglomerate, 30 cm thick (Fig. 4.17).

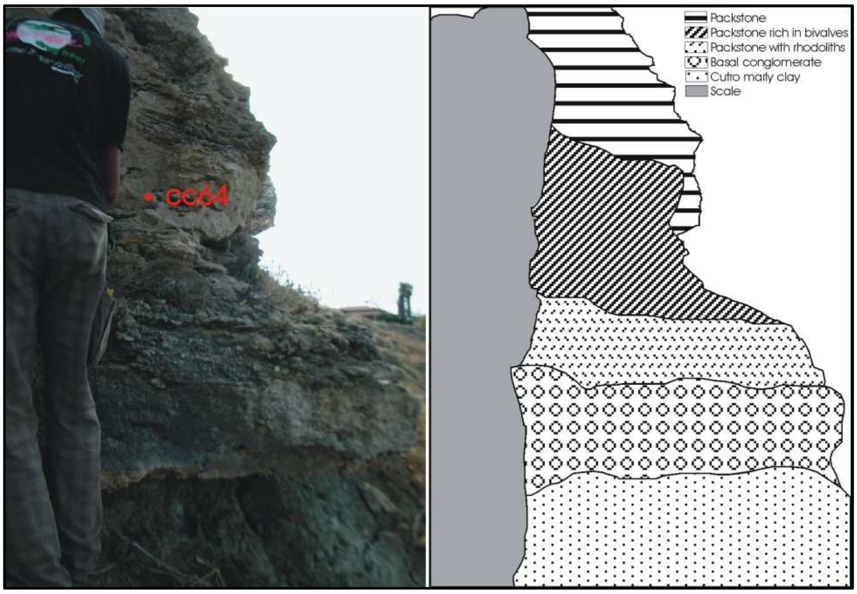


Fig. 4.17: Section CC10. Left: picture of the section, with indication of sample; right: interpretative sketch of the section. Person as scale, 1.7 m tall

Three levels can be distinguished in the packstone-rudstone: the lower is a laminated coarse bioclastic packstone with a significant siliciclastic fraction; the middle is a finer-grained packstone, rich in branched rhodoliths; the top is a coarse packstone rich in bivalves shell.

Fig. 4.18: prâline rhodoliths in the packstone-rudstone unit outcropping in section CC10

Section CC11

The base of section CC11 is characterized by the presence of an old calcarenite unit, rich in both bioclastic and siliciclastic fraction. This layer has been interpreted as the deposits related to a previous positive eustatic oscillation during the same MIS (Nalin, 2006). This calcarenite is superiorly truncated by an unconformity surface.

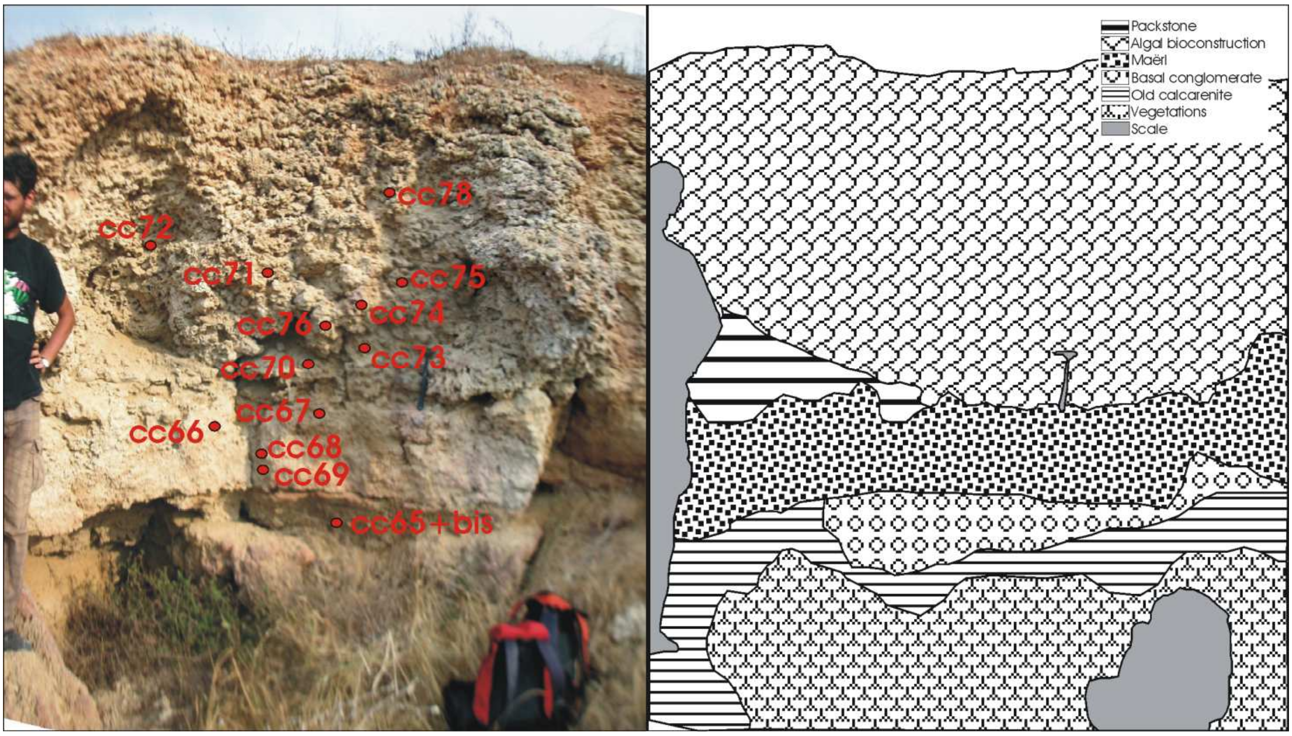


Fig. 4.19: section CC11. Left: picture of the section, with indication of samples; right: interpretative sketch of the section. Person as scale, 1.7 m tall

Above the unconformity, a basal micro-conglomerate rich in siliciclastic pebbles and biogenic fragments in a muddy matrix is present (Fig. 4.20 up-left).

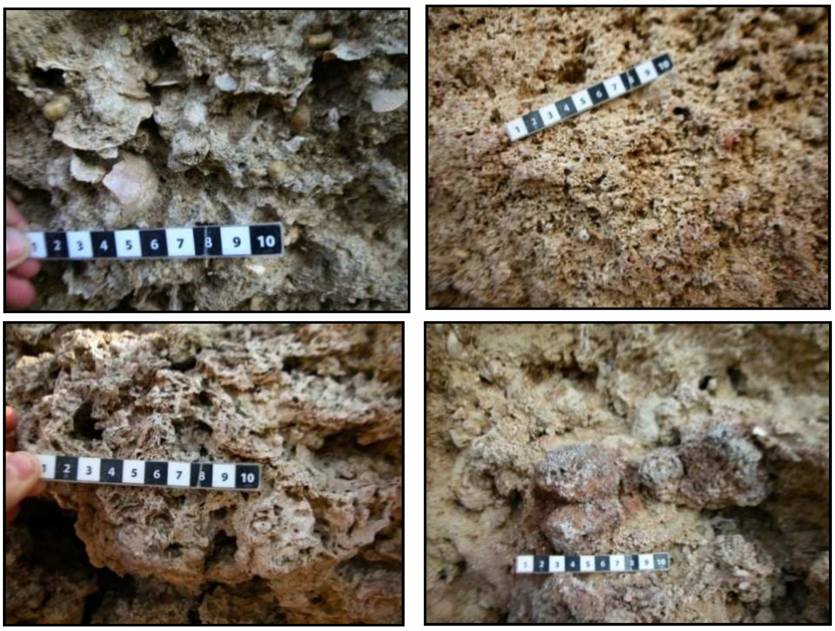


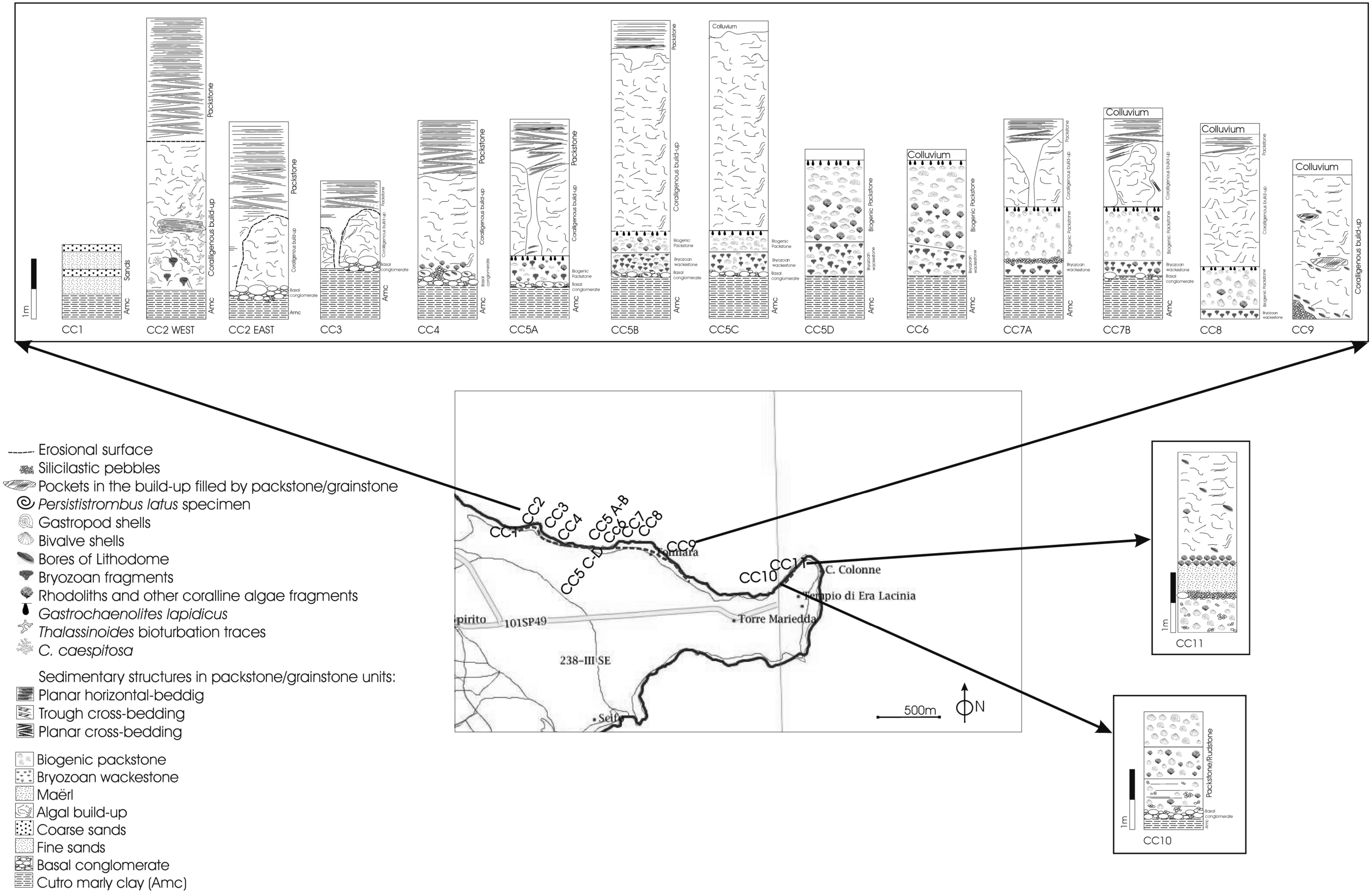
Fig. 4.20: up-left: detail of the basal micro-conglomerate facies; up-right: details on maërl bed; down-left: rhodoliths at the top of the maërl level; down-right: detail of algal build-up, rich in bryozoans alternated to algal crusts; all outcropping in section CC11

The micro-conglomerate is overlain by a well developed layer of maërl, 40-50 cm thick (Fig. 4.20 up-right).

At the top of maërl bed, abraded rhodoliths, originally branched, are observed (Fig. 4.20 down-left).

Above the rhodolith layer, a well developed algal build-up, up to 2 m-thick, is present. The framework of the bioconstruction is very dense (Fig. 4.20 down-right), rich in *Spondylus sp.* valves and laterally in contact with packstone. *Lithophaga* borings have been observed on the surface of the build-up.

Fig. 4.21: Interpretative sketch and correlation of stratigraphic sections of Capo Colonna.



4.1.2 LE CASTELLA MARINE TERRACE

Eleven stratigraphic sections (Fig. 4.22) were measured and sampled along the coast of the Le Castella headland.

Fig. 4.22: maps showing the location of the studied sections

The sections are placed at a comparable distance from the paleocliff, as it was recognized during the field work and reported in the structural and stratigraphic interpreted map (Fig. 4.23).

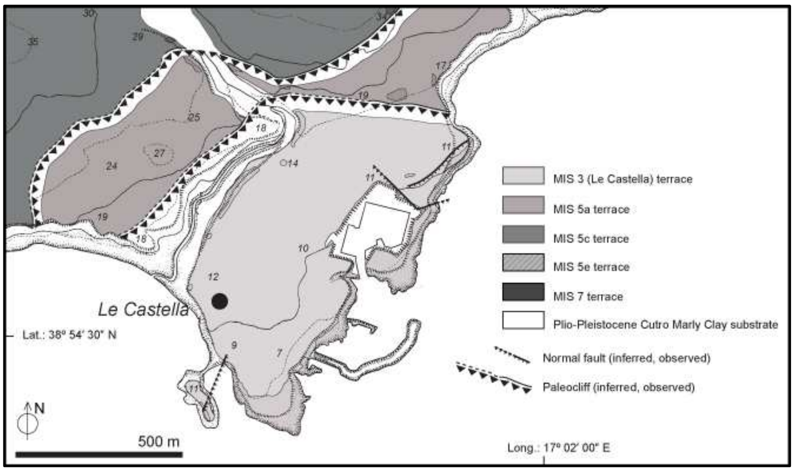


Fig. 4.23: stratigraphic and sedimentological interpretation sketch map of Le Castella

At all locations, the Cutro Marly Clay represents the substrate of the terrace deposits.

The sections are characterized by 1) a basal conglomerate resting directly on the *ravinement* surface, and formed by the erosion of older terrace deposits under the action of the sea on the paleocliff during the transgressive phase; 2) algal build-ups; 3) calcarenite units, whit different grain-size and presenting different sedimentary structures. Not all units are present at every section. GPS position list of the studied sections is reported in Appendix I. A short description and a picture of each sample are given in Appendix III.

SECTION LC1

This section is located along the cliff NE of Le Castella village. The section is characterized by the presence of an individual algal build-up, 2.5 m thick and 3 m large, cavernous and rich in sandy-muddy matrix, intersected by pockets filled by coarse biogenic packstone (Fig. 4.24). The base of the build-up is not exposed.

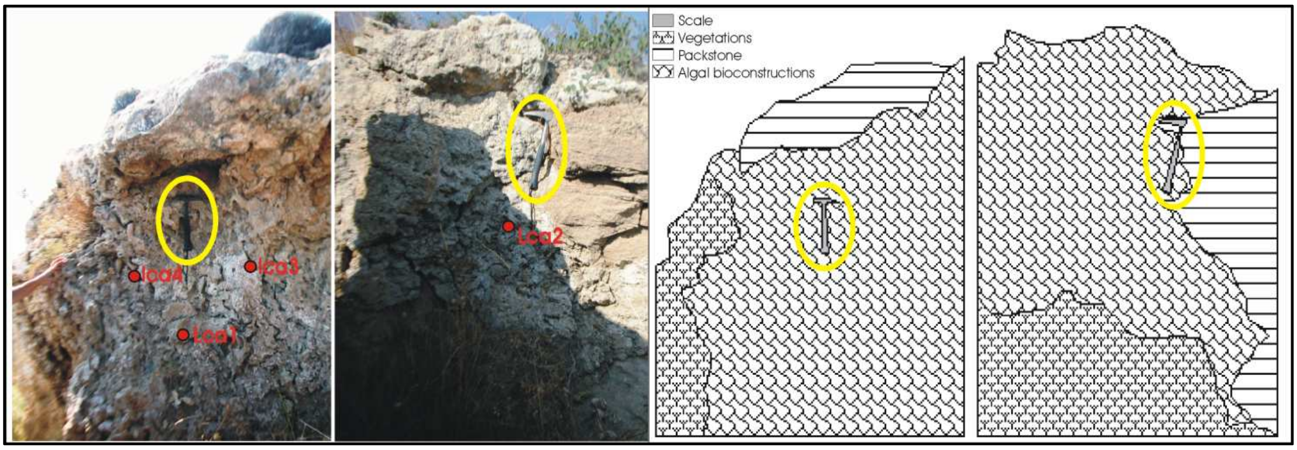


Fig. 4.24: section LC1. Left: pictures of the sections, with the indication of the sample; right: interpretative sketches of the sections. Yellow circles indicate hammer as scale, 33 cm long.

The algal build-up is characterized by a massive structure, formed by compacted leafy crusts (Fig. 4.25).

Fig. 4.25: Example of compacted algal crusts.

SECTION LC2

This section is located along the cliff NE of Le Castella village. The outcrop is 10m wide and 4m thick (Fig. 4.26). It is characterized by two algal bioconstruction bodies, compact and moderately bioturbated, in lateral contact with a channel filled by packstone. Directly over the bioconstruction there is a 1.5-2m thick unit of similar packstone This unit also fills the pockets in the bioconstructed structure and preserves traces of planar lamination, highlighted by accumulation levels internal moulds of bivalve shells.

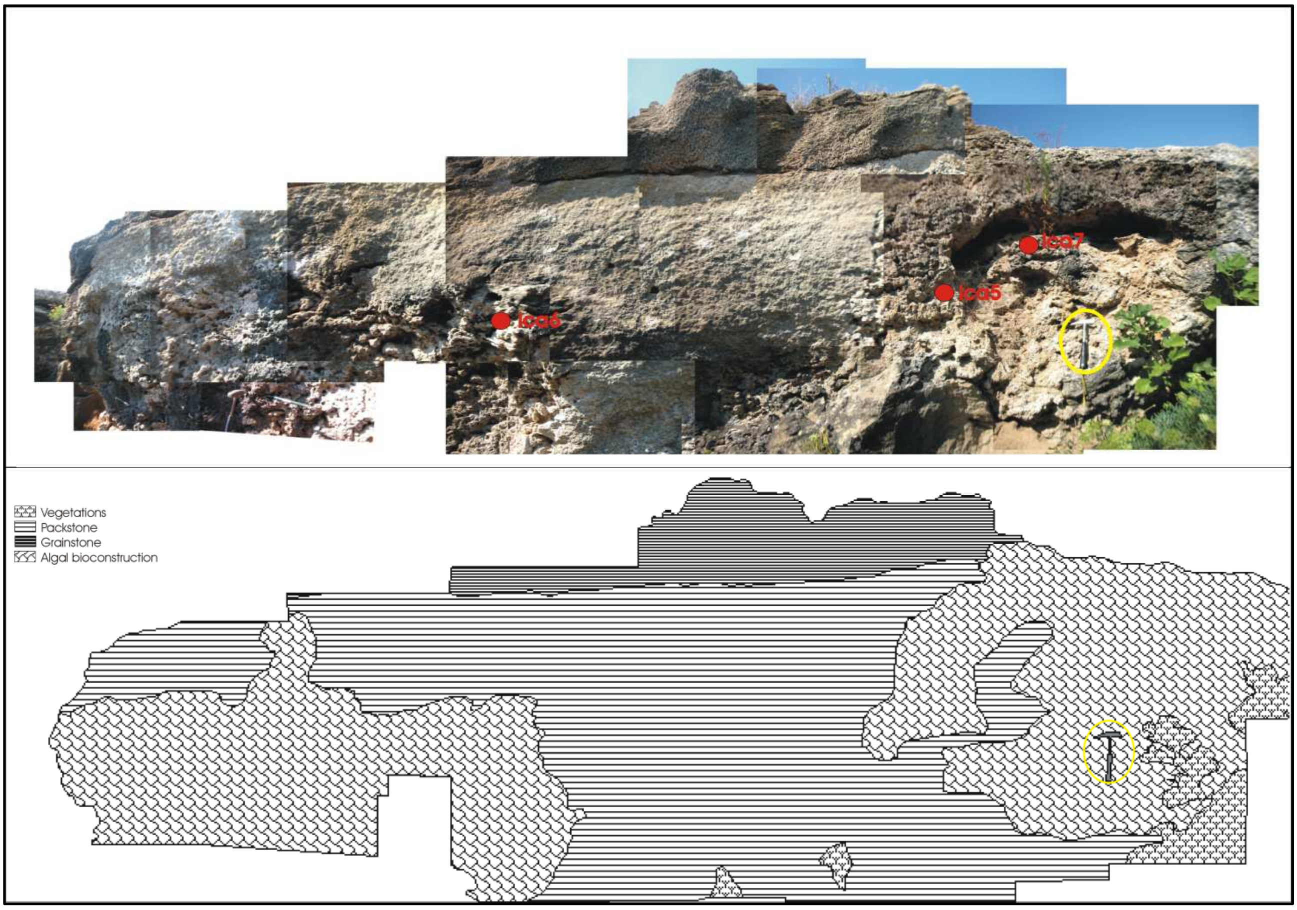


Fig. 4.26: section LC2.Top: picture of the section, with indication of the samples; bottom: interpretative sketch of the section. Yellow circles indicate hammer as scale, 33 cm long

The top of the outcrop is characterized by a coarse grainstone unit, coarser and more biogenic than the packstone, 0.5m thick. The contact between the two units is sharp. The limit between packstone and grainstone units is sharp, characterized by an unconformity which can represent the regressive surface of marine erosion. The unit presents sedimentary structures varying from trough-cross bedding at the base to planar lamination to the top.

The algal build-up is characterized by massive structure, formed by high compacted leafy crusts.

SECTIONS LC3 AND LC4

Sections LC3 and LC4 are in close proximity, located along the cliff NE of Le Castella village, and present the same features.

The basal conglomerate unit is present in these sections. It is characterized by decimetric to metric blocks, originally forming older terrace deposits and then eroded by the action of the sea on the paleocliff during the transgressive phase. In some cases, the basal conglomerate is characterized by accumulation of shells of the bivalve *Spondylus gaederopus* (Linneo, 1758).

The bioconstructed body lies directly over the basal conglomerate (Fig. 4.27). It is 2.5m thick, is characterized by a vacuolar structure. The algal build-up is characterized by a massive structure, formed by compacted leafy crusts.

A grainstone unit, locally rich in bioclasts, fills the pockets of the algal bioconstructed structure.

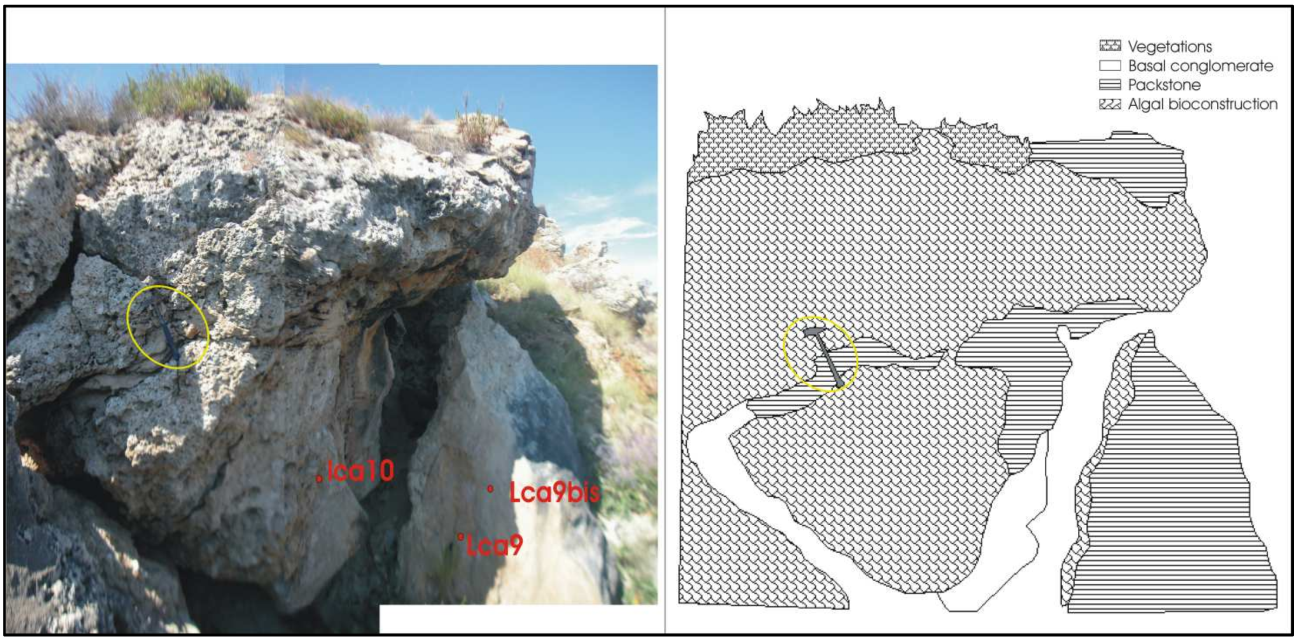


Fig. 4.27: section LC4. Left: picture of the section, with indication of samples; right: interpretative sketch of the section. Yellow circles indicate hammer as scale, 33 cm long

SECTIONS LC5 AND LC6

These two sections are in close proximity and characterized by a main algal bioconstructed body, 2 m thick and 7 m long, overlain by a grainstone unit at the top (Figs. 4.28 and 4.29).

The algal build up is well developed, forming a bank-like structure, and characterized by a vacuolar framework not filled by sediment.

The grainstone unit is rich in bioclasts at the contact with the algal build-up and presents planar horizontal lamination at the top.

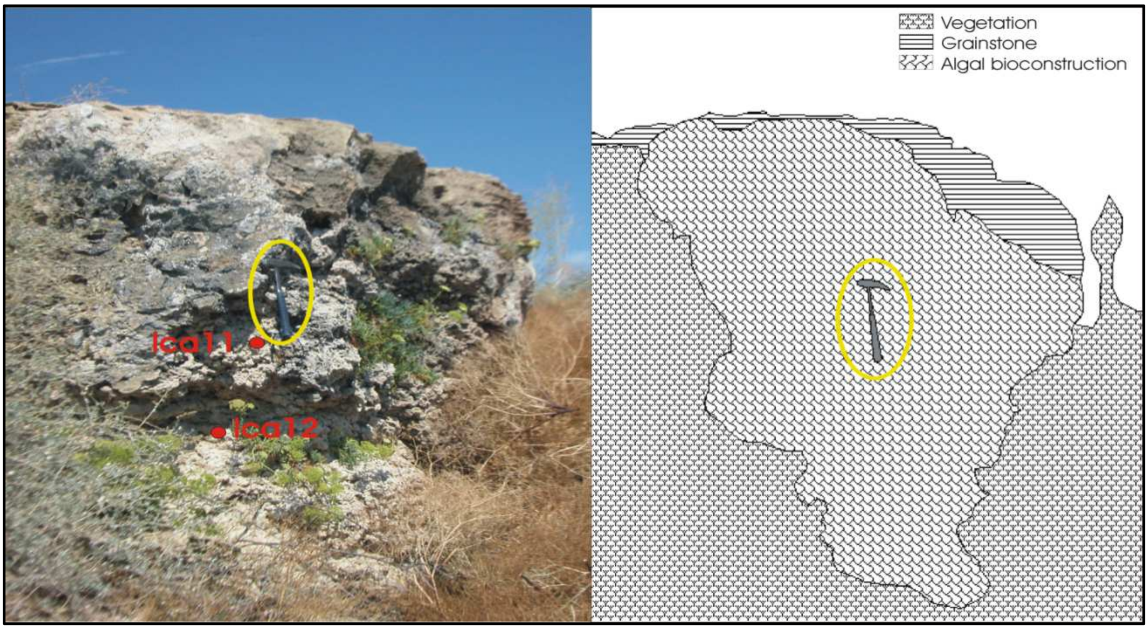


Fig. 4.28: section LC5. Left: picture of the section, with indication of samples; right: interpretative sketch of the section. Yellow circles indicate hammer as scale, 33 cm long.

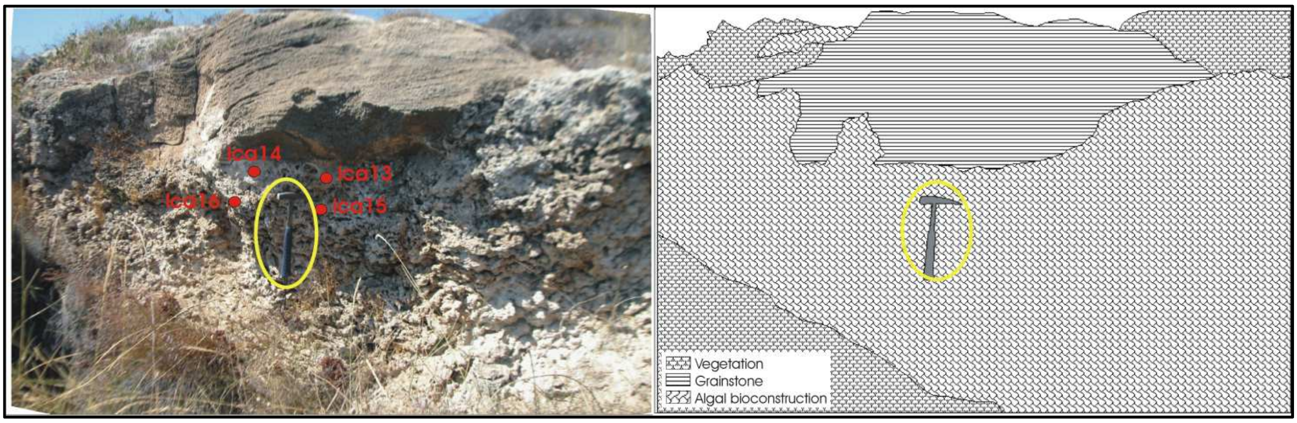


Fig. 4.29: section LC6. Left: picture of the section, with indication of samples; right: interpretative sketch of the section. Yellow circles indicate hammer as scale, 33 cm long

The algal build-ups are characterized by massive structure, formed by compacted leafy crusts, partially filled by fine matrix.

Fig. 4.30: algal crusts, with inter-laminar spaces filled by a fine matrix

These two sections crop out along a morphological step towards the coast. The top of these steps is a planar surface characterized by the outcropping of “heads” of the bioconstructed body (fig. 4.31). This aspect testifies to the presence of algal bioconstructions in inner portions than the cliff exposures of the marine terrace.

Fig. 4.31: example of the algal “heads” of bioconstructed bodies on the planar surface

SECTION LC7

Section LC7 is a 3 m thick section characterized by packstone/grainstone units, in which a succession of sedimentary structures is found.

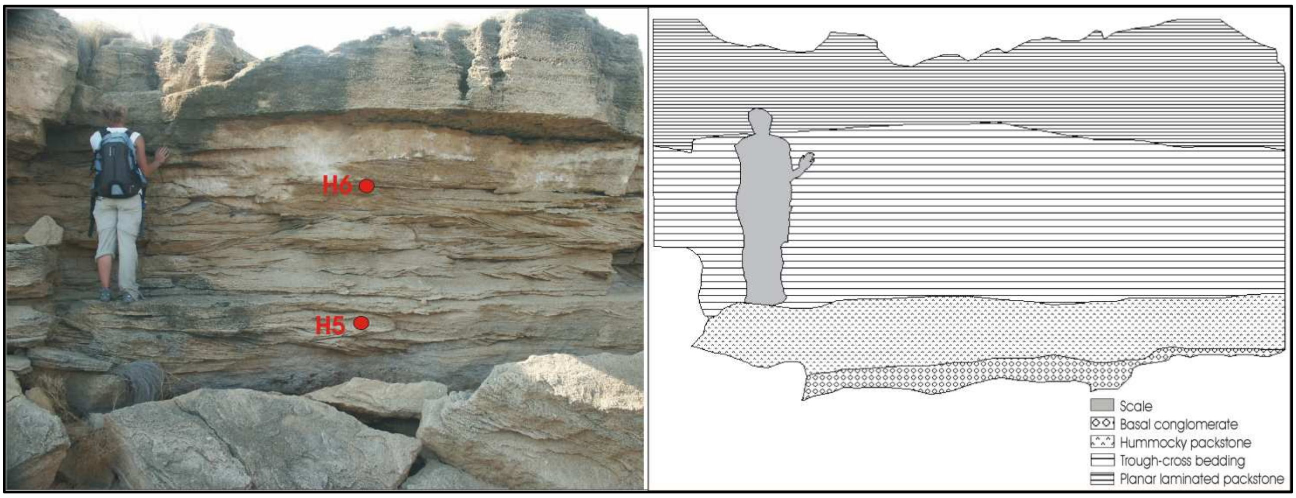


Fig. 4.32: section LC7. Left: photograph of the section, with indication of samples; right: interpretative sketch of the section. Person as scale, 170 cm tall

The base of the deposits consists of a micro-conglomerate, characterized by the accumulation of rounded pebbles and cobbles.

Above the micro-conglomerate, a 40cm layer of fine packstone is present, showing typical hummocky cross-stratification. The main portion of the deposits is characterized by a 1.5m packstone/grainstone unit displaying pervasive trough cross-bedding (Fig. 4.33 left). The troughs are well defined, and are characterized by a coarser packstone. The uppermost unit is a 70cm-thick layer of coarse and planar horizontal laminated grainstone (Fig. 4.33 right). The contact between the trough cross-bedded and planar laminated unit is sharp, similarly to section 2.

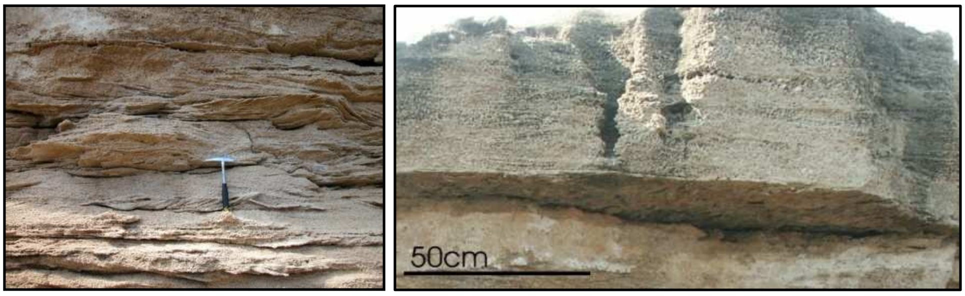


Fig. 4.33: details of sedimentary structures: a) trough-cross bedding, hammer as scale 33 cm long; b) planar lamination at the top. Both in section LC7

Section LC8

Section LC8 is located north of the dock of the Le Castella village.

The basal unit is a conglomerate, not always exposed. Red algal build-ups, directly overlying the basal conglomerate, are characterized by a “mushroom” shape. The framework is vacuolar and shows signs of intensive bioturbation activity (*Thalassinoides*).The build-ups are not well developed, reaching 1 m thickness at most.

Directly on the algal bioconstruction, a packstone is present. In this unit, 0.8 to 1.8 m thick, trough cross-bedding structures are common. Biogenic fragments are abundant and equally distributed, even if layers with preferential accumulation of biogenic fragments are detectable.

At the top of the section another packstone/grainstone unit, 1.5m thick, is present.

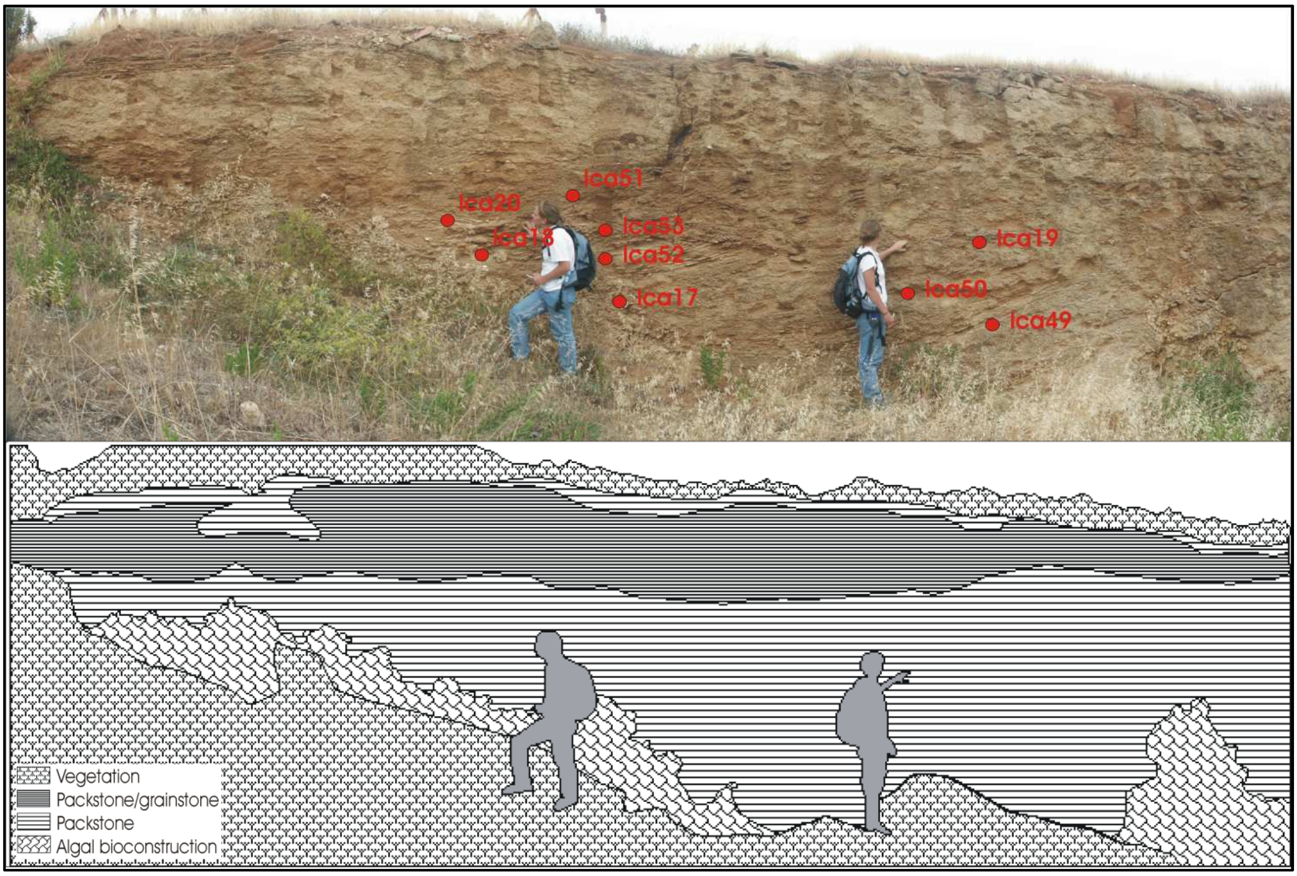


Fig. 4.34: section LC8. Top: picture of the section, with indication of the samples; bottom: interpretative sketch of the section. Person for scale, 1.7 m tall

The algal build-up is characterized by a massive structure, formed by high compacted leafy crusts, partially filled by fine matrix. The build-ups are bored by lithodomes.

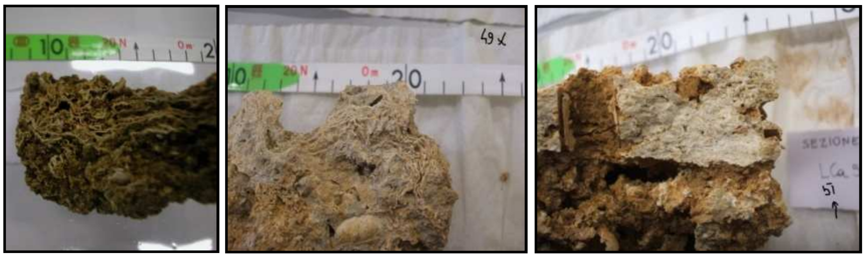


Fig. 4.35: examples of massive structure of the algal build-up, partially filled by fine matrix in section LC8

SECTION LC9

Section LC9 is the corresponding portion of section 8 outcropping towards the coast.

This section is characterized by a basal conglomerate unit, and the bulk of the deposits is a spectacular red algal build-up, well preserved, and vacuolar. A cross-laminated coarse packstone fills the pockets of the bioconstruction. The packstone unit observed in section 7 are not present.

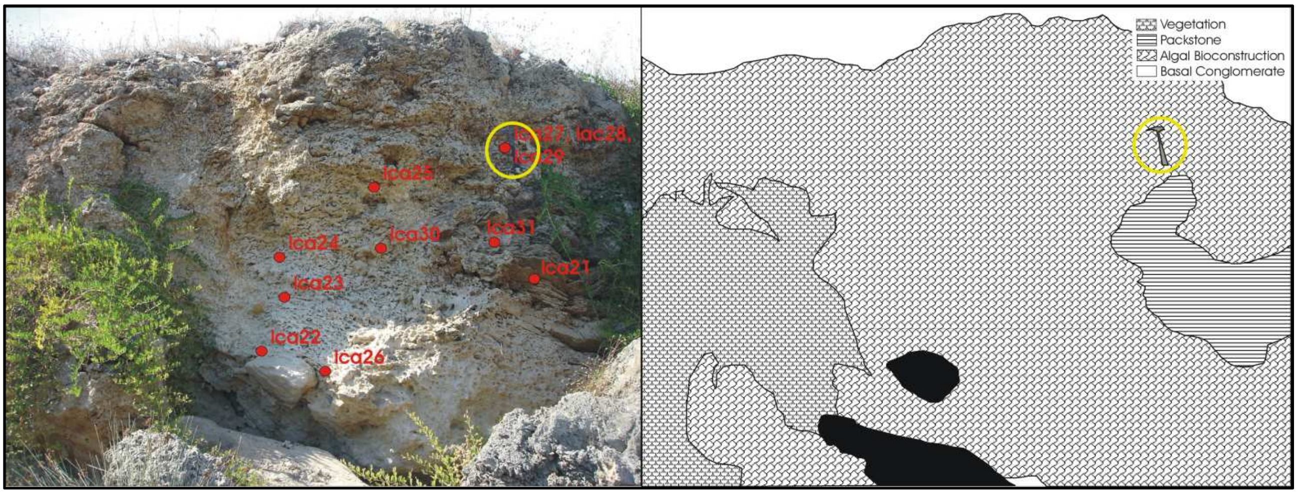


Fig. 4.36: section LC9. Left: photograph of the section, with indication of samples. Right: interpretative sketch of the section. Yellow circle indicates hammer 32 cm long used as scale

The algal build-up is characterized by a massive structure, formed by high compacted leafy crusts (Fig. 4.37).

Fig. 4.37: examples of the massive structure of the LC9 section build-up, formed by high compacted leafy crusts

A bioclastic packstone/grainstone fills the pockets of the bioconstruction (Fig. 4.38), and shows traces of planar lamination. It is coarse-grained, rich in well preserved shells.

Fig. 4.38: coarse bioclastic packstone/grainstone filling the pockets of the bioconstruction

SECTION LC10

Section LC10 is located south of Le Castella village, along the coastline toward the W, starting from the road to the medieval castle. It is a continuous section, longer than 100m and approximately NW-SE orientated.

Bioconstructed bodies outcrop on the western part of the section. They are less than 1 m thick, rich in muddy matrix and characterized by the occurrence of hermatypic coral *C. caespitosa*, *in situ*.

Moving to the SE the bioconstructed bodies disappear, or probably does not outcrop because the ravinement surface at the base is inclined and covered by well developed sedimentary clinoformal bodies.

The unit overlying the bioconstruction is a10m-thick accumulation of packstone and grainstone characterized by large scale oblique to sigmoidal clino-stratification, with trough-cross bedded grainstone at the top (Fig. 4.39).

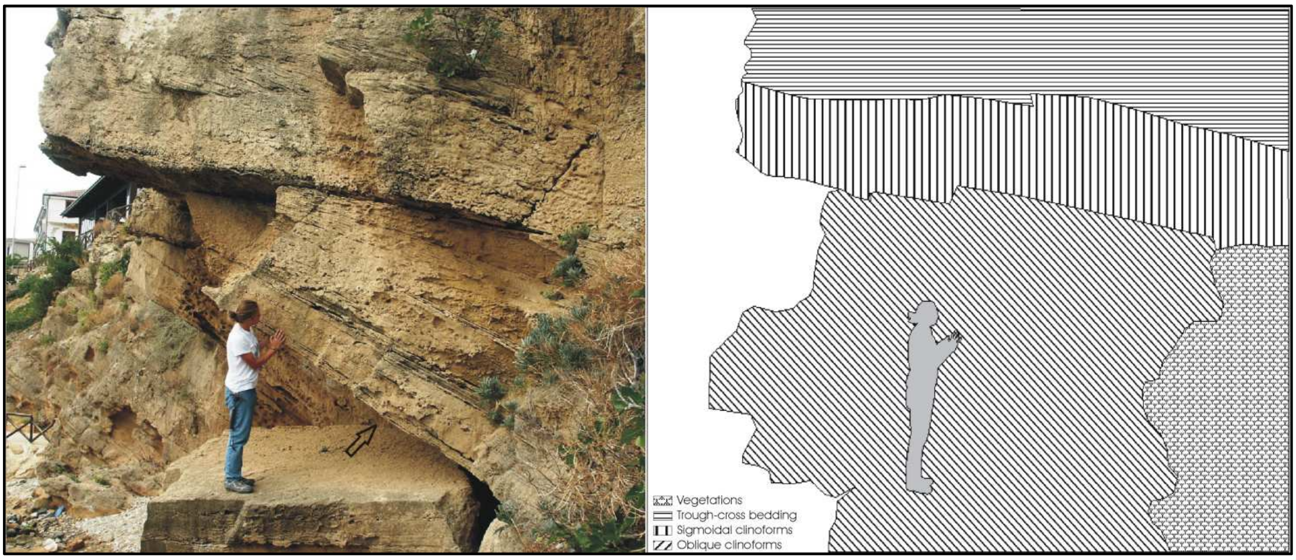


Fig. 4.39: section LC10. Left: picture of the section; right: interpretative sketch of the section. Black arrow indicates the bioturbated surface shown in Figure 4.41 middle. Person as scale, 1.7 m tall

The clinoforms show an alternation of laminated and bioturbated layers (Fig. 4.40).

Fig. 4.40: alternation of laminated and bioturbated layers in section LC10

The laminated layers show coarsening upward (Fig. 4.41 left). Occasional coarse biogenic gravel levels are present. Furthermore, structures of water escape are present, deforming and obliterating the lamination (Fig.4.41 middle). All these aspects suggest the presence of a high energy environment.

Bioturbated layers are characterized by the preservation of *Echinocardium cordatum* (Pennant, 1977) traces (Fig. 4.41 right).

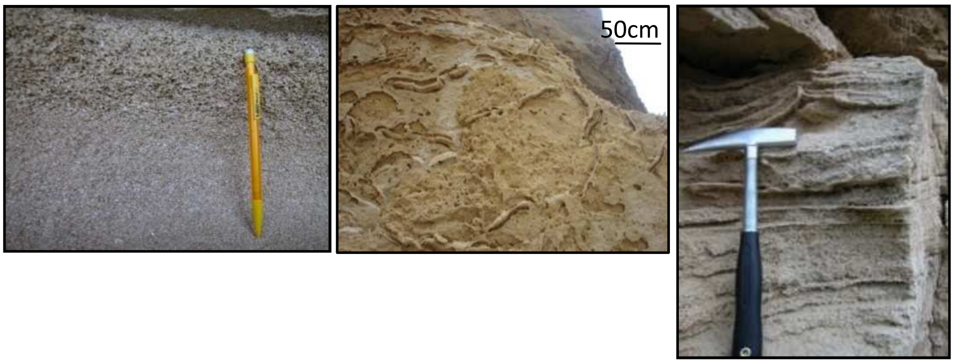


Fig. 4.41: left) example of coarsening upward of a planar laminated bed in the clinoformal unit; middle) the bioturbated surface, indicated by a black arrow in Fig. 39, with traces of *Echinocardium cordatum*; right) example of water-escape structure (above hammer head)

The top of the section is characterized by a fine packstone in which trough-cross bedding is the predominant structure.

Toward the W, the clinoforms become intensively bioturbated, and the laminated layers are no longer detectable.

At the eastern limit of the section, the clinoforms are characterized by high inclination, and levels of coarse biogenic rudstone appear, alternated to laminated grainstone (Fig. 4.42).

A normal fault, buried in the northern part of the terrace, crops out in the western part of the section, generating the topographic step which influenced the formation of the clinoforms bodies, as discussed in Zecchin *et al*. (2010).

Fig. 4.42: Clinoforms at the SE limit of the section LC10

SECTION LC11

Along the promontory of the castle of Le Castella a continuous NW-SE orientated, more than 70m long outcrop is present. Two sections, LC11 a and b have been measured. Samples have been collected along the entire outcrop.

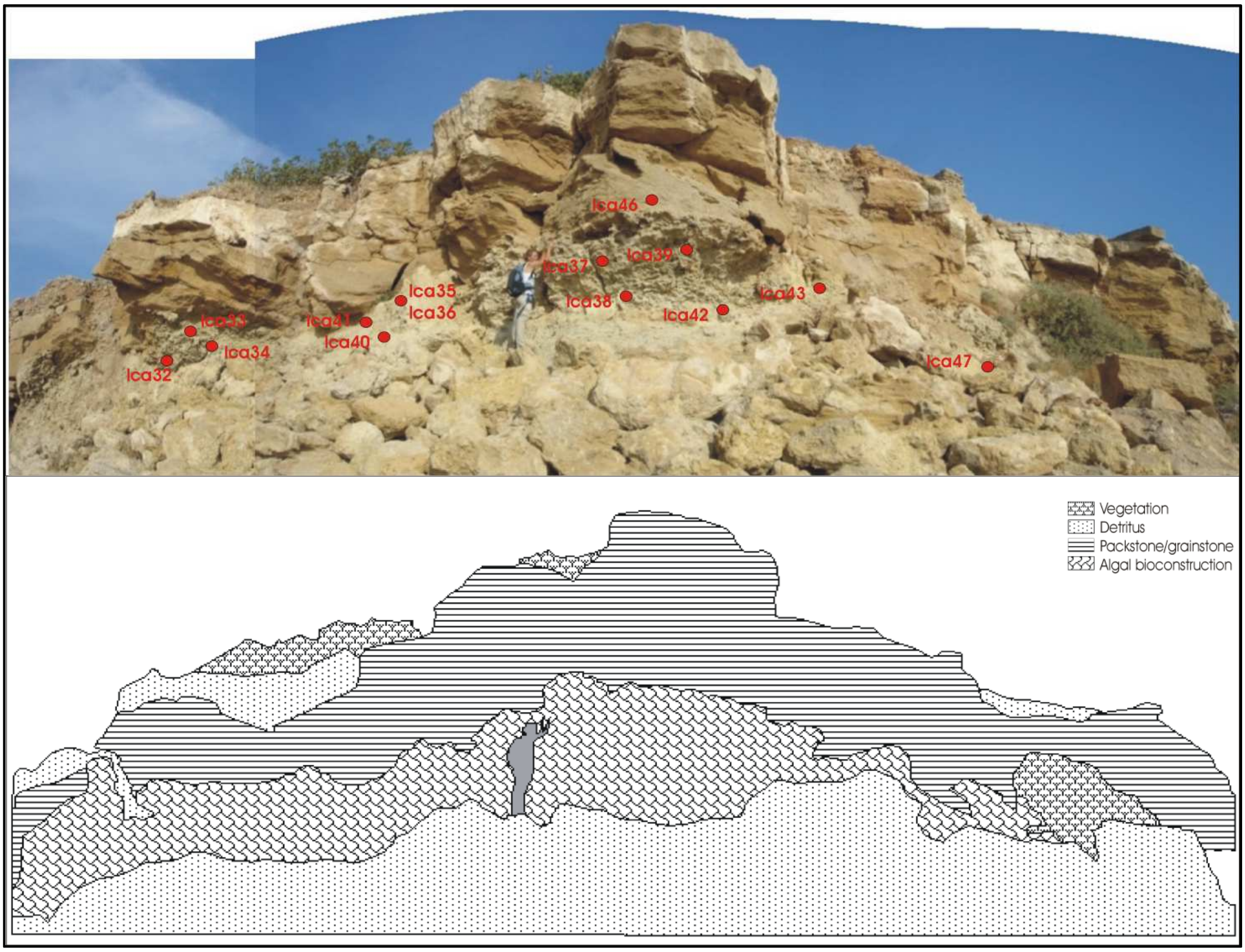


Fig.4.43: NW part of section LC11. Top: picture of the section, with indication of the samples; bottom: interpretative sketch of the section. Person for scale, 1.7 m tall

Section LC11a is characterized by the Cutro Marly Clay exposed at the base of the section. Above it, red algal bioconstructions formed a continuous bank, more than 25 m long and 0.7-1.5 m thick. The bioconstructions are vacuolar, showing typical leafy growth form, and their upper part shows intensive bioturbation. Presence of bryozoans, bivalve fragments and echinoids is reported (Fig. 4.44).

Fig. 4.44: details of echinoids or bivalve shells into the algal build-up in section LC11

C. caespitosa is present alternatively to the algal build-ups and partially integrated and each coral structure reaches more than 30cm (Fig. 4.45 left). The build-up is characterized by muddy matrix (Fig. 4.45 right).

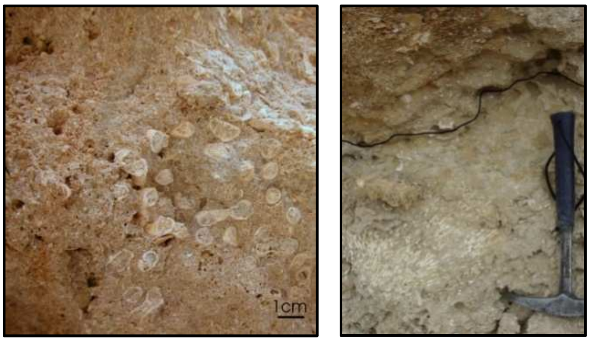


Fig. 4.45: left) example of echinoids and *Cladocora caespitosa;* right) the sharp contact (black line) between algal/coral bioconstruction and the packstone. Both in section LC11

Over the algal bioconstruction there is a grainstone unit and the contact between these two units is an unconformity (Fig. 4.45 right). The unconformity surface could be interpreted as a regressive surface of marine erosion. This packstone is coarse, less consolidated, and rich in biogenic fragments and includes a 1.5 m thick set with planar cross-stratification overlain by 1 m of trough-cross bedded deposits.

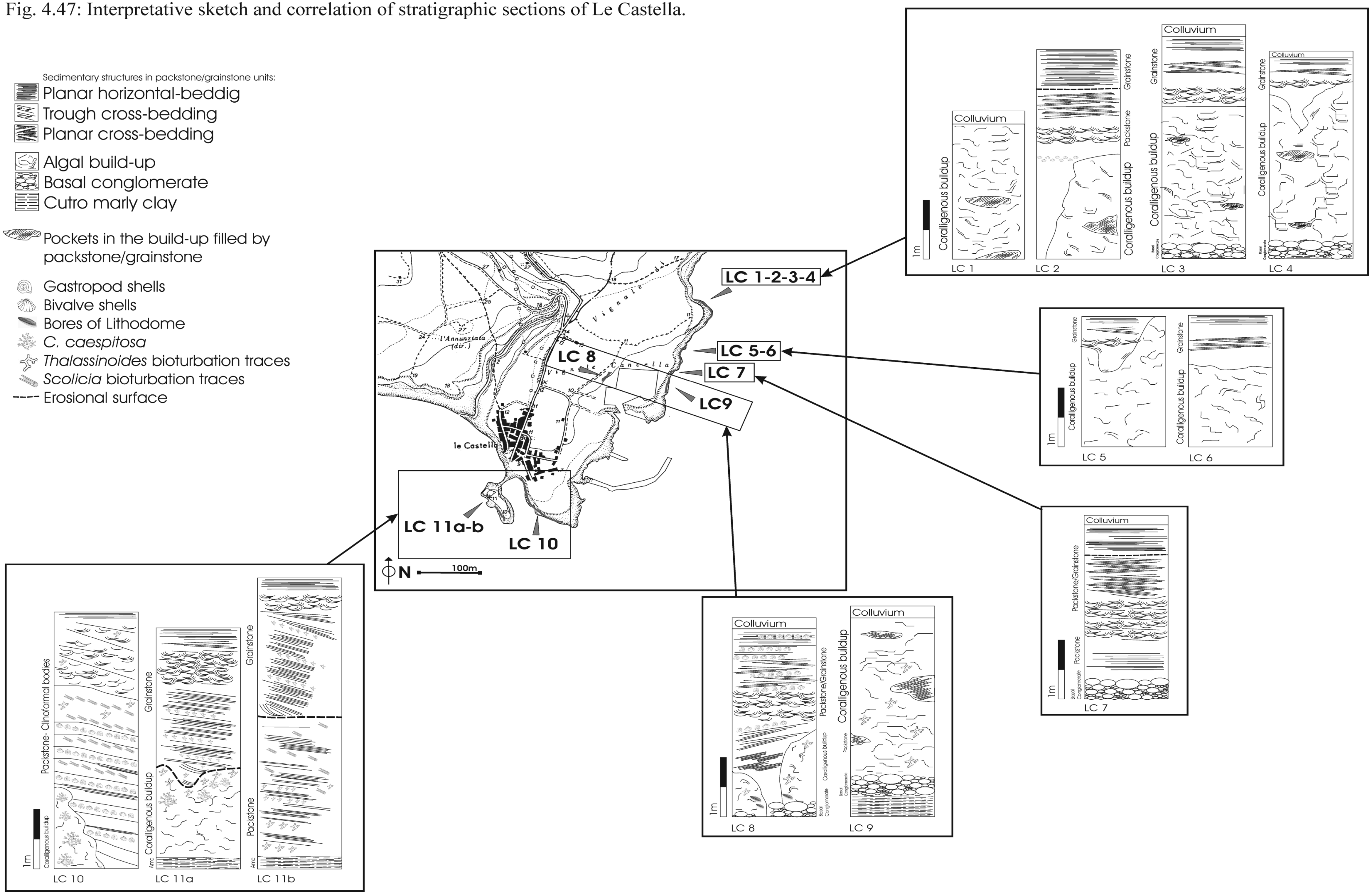
Moving to the SE (section LC11b) algal bioconstructions are absent and a coarse packstone directly overlies the Cutro Marly Clay (Fig.4.46). It shows traces of planar lamination.

Fig. 4.46: Coarse packstone sampled from the SW part of the section, showing traces of planar lamination, in SE portion of section LC11

This packstone is coarse (in the basal part) and well cemented, and shows intensive bioturbation dominated by *Thalassinoides* traces in the lower part and *Scolicia* traces in the upper part. Above this unit, the same grainstone outcropping at the top of the build-ups unit is still present. The contact between these two units is still represented by the unconformity surface. A planar horizontal to slightly inclined stratification is observed in the grainstone.

The same normal fault affecting section 10, oriented NE-SW, cuts the deposits of this section, down throwing the SE portion of the deposits. An apparent step of 4 m has been reconstructed on the base of the decreasing altitude of the outcropping Cutro marly clay, moving from NW (7 m asl) to SE (3 m asl) along the same section.

Fig. 4.47: Interpretative sketch and correlation of stratigraphic sections of Le Castella.



4.1.3 APPENDIX I

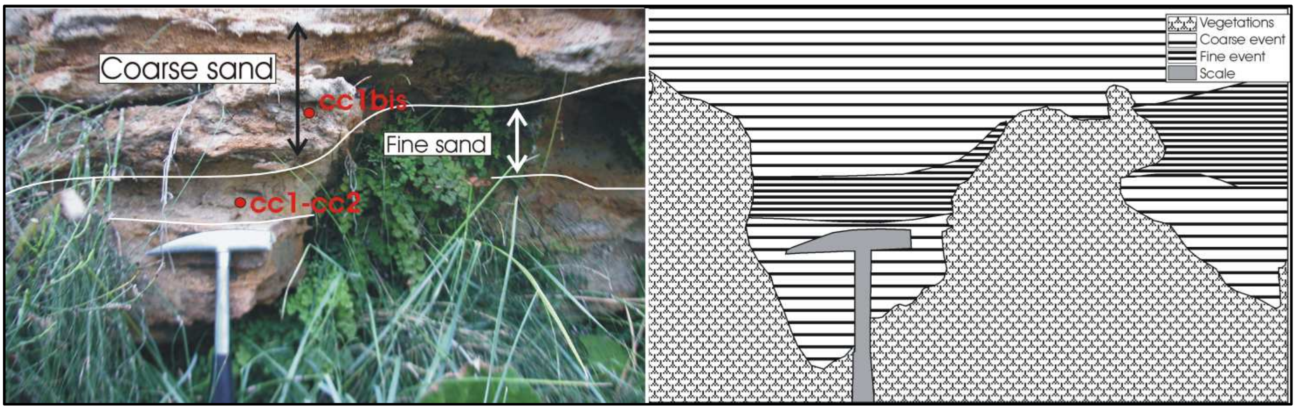
List of GPS position and altitude of studied Sections: Capo Colonna (CC); Le Castella village (LC).

Section	Altitude (m asl)	GPS position	
		Latitude	Longitude
CC1	34	N39°01.889	E17°10.621
CC2	36	N39°01.900	E17°10.652
CC3	36	N39°01.841	E17°10.845
CC4	32	N39°01.804	E17°11.037
CC5	26	N39°01.795	E17°11.084
CC6	39	N39°01.801	E17°11.103
CC7	22	N39°01.826	E17°11.208
CC8	22	N39°01.822	E17°11.293
CC9	28	N39°01.727	E17°11.479
CC10	12	N39°01.573	E17°11.995
CC11	11	N39°01.628	E17°12.170
LC1	4	N38°54.820	E17°01.852
LC2	5	N38°54.803	E17°01.853
LC3	12	N38°54.888	E17°01.785
LC4	12	N38°54.888	E17°01.785
LC5	5	N38°54.779	E17°01.819
LC6	5	N38°54.779	E17°01.819
LC7	5	N38°54.753	E17°01.795
LC8	5	N38°54.726	E17°01.705
LC9	3	N38°54.723	E17°01.770
LC10	7	N38°54.433	E17°01.366
LC11	7	N38°54.397	E17°01.285

4.1.4 APPENDIX II

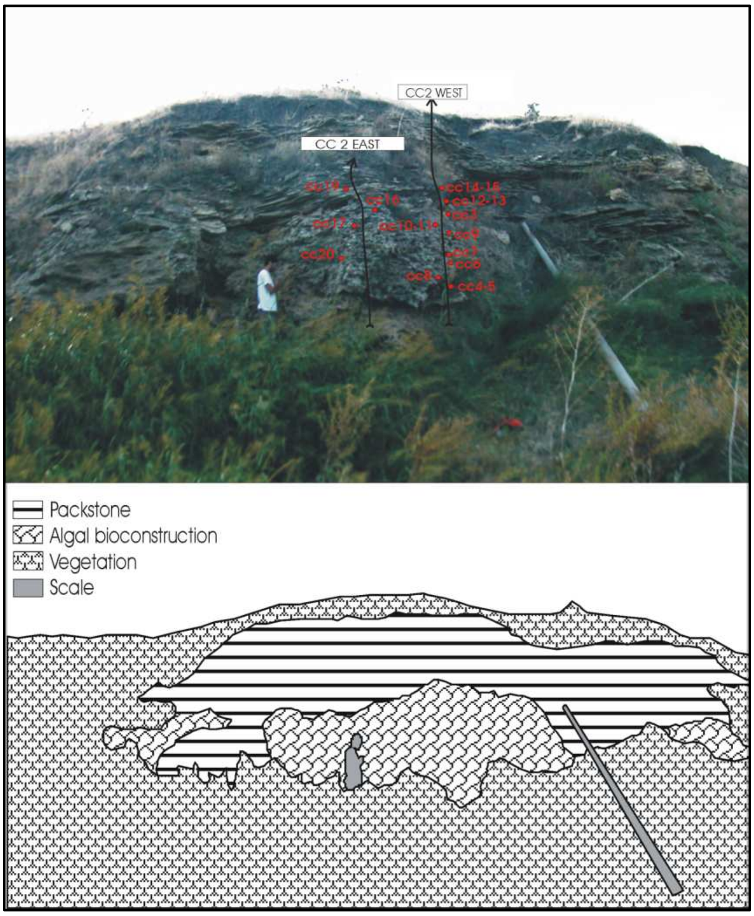
List, short description and picture of Capo Colonna samples per each section.

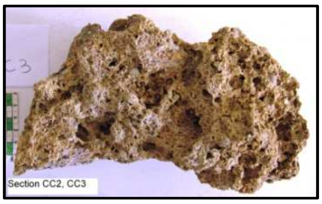
Section CC1

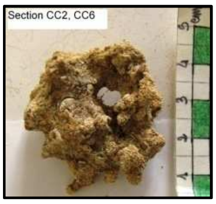


Sample	Short Description	Picture
cc1	Very fine unlithified sand	
cc1bis	Coarse bioclastic lithified sandy gravel	
cc2	Very fine unlithified sand	

Section CC2

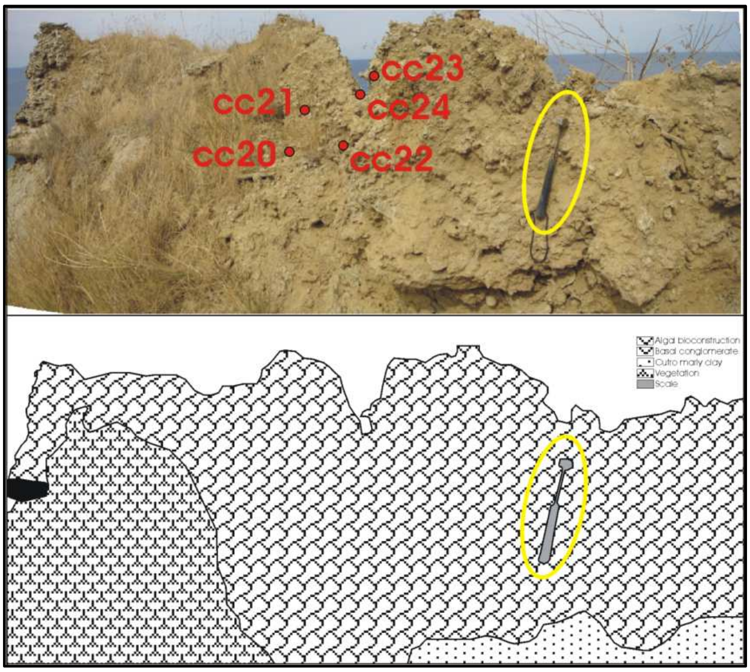


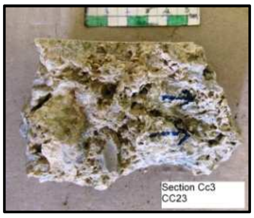
Sample	Short Description	Picture
cc3	Bioclastic sandstone directly in contact with the build-up	
cc4	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc5	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

cc6	Bryozoan wackestone	
cc7	Bryozoan and serpulids wackestone	
cc8	Grainstone	
cc9	Algal build-up partially bio-eroded Leafy bioconstruction, showing layered to foliose crusts	
cc10	Algal build-up partially bio-eroded Leafy bioconstruction, showing layered to foliose crusts	
cc11	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc12	Algal build-up partially bio-eroded Leafy bioconstruction, showing layered to foliose crusts	

cc13	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc14	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc15	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc16	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc17	Algal build-up Leafy bioconstruction, showing layered to foliose crusts	
cc18	Serpulids crust formed between the build-up and a pocket filled by coarse packstone	
cc19	Bioclastic packstone directly in contact with the build-up	

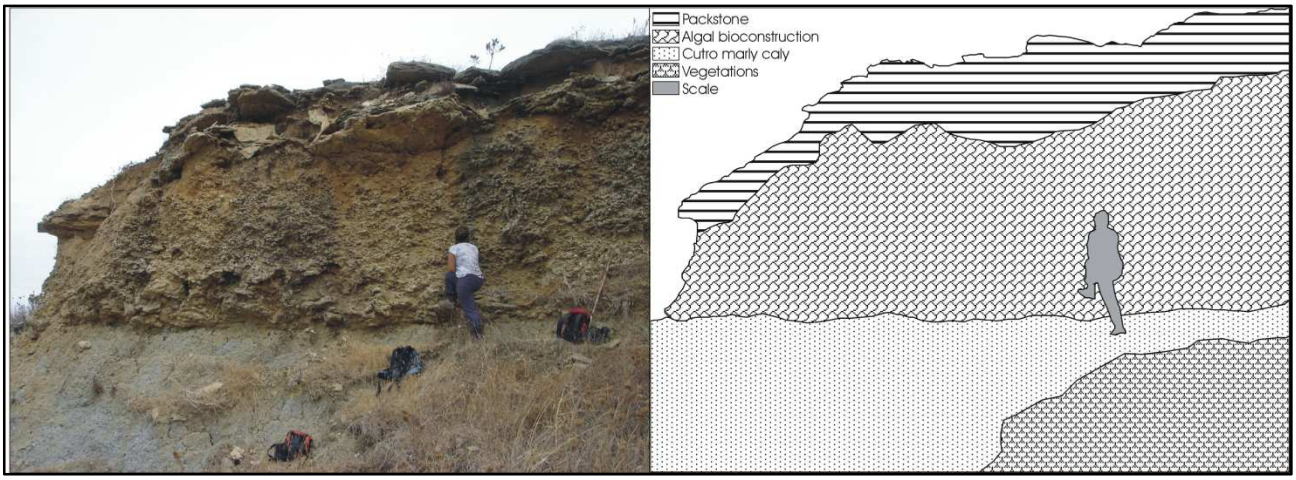
Section CC3

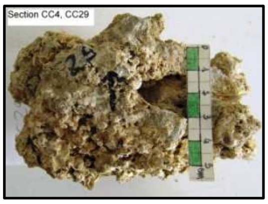


Sample	Short Description	Picture
cc20	Bioclastic packstone directly in contact with the Cutro marly clay, filling channels into the build-up	
cc21	Bioclastic packstone directly in contact with the Cutro marly clay, filling channels into the build-up	
cc22	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc23	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

cc24	Algal build-up Massive bioconstruction, showing layered to foliose crusts, partially filled by gray micrite	
cc25	Algal build-up Massive bioconstruction, showing layered to foliose crusts, partially filled by gray micrite	

Section CC4



Sample	Short Description	Picture
cc26	Algal build-up Massive bioconstruction, showing layered to foliose crusts, partially filled by gray micrite	
cc27	Algal build-up Massive bioconstruction, showing layered to foliose crusts, partially filled by gray micrite	
cc28	Algal build-up Massive bioconstruction, showing layered to foliose crusts, partially filled by gray micrite	
cc29	Algal build-up, forming by both planar crusts and branching-type form Massive bioconstruction, showing layered to foliose crusts	
cc30	Algal build-up, forming by both planar crusts and branching-type form Massive bioconstruction, showing layered to foliose crusts	

Section CC5

Sample	Short Description	Picture
cc31	Hardground at the top of the packstone	
cc32	Algal build-up, forming by planar crusts directly on the hardground , partially filled by gray micrite	
cc33	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc34	Coarse bioclastic packstone and hardground sampled along the outcrop	
cc35 a+b	Bryozoan wackestone	
cc36	Gastropod packstone	
cc37	Bryozoan wackestone	

cc38	Prâline rhodoliths sampled from the packstone	
cc39	Very coarse biogenic packstone, poorly lithified	

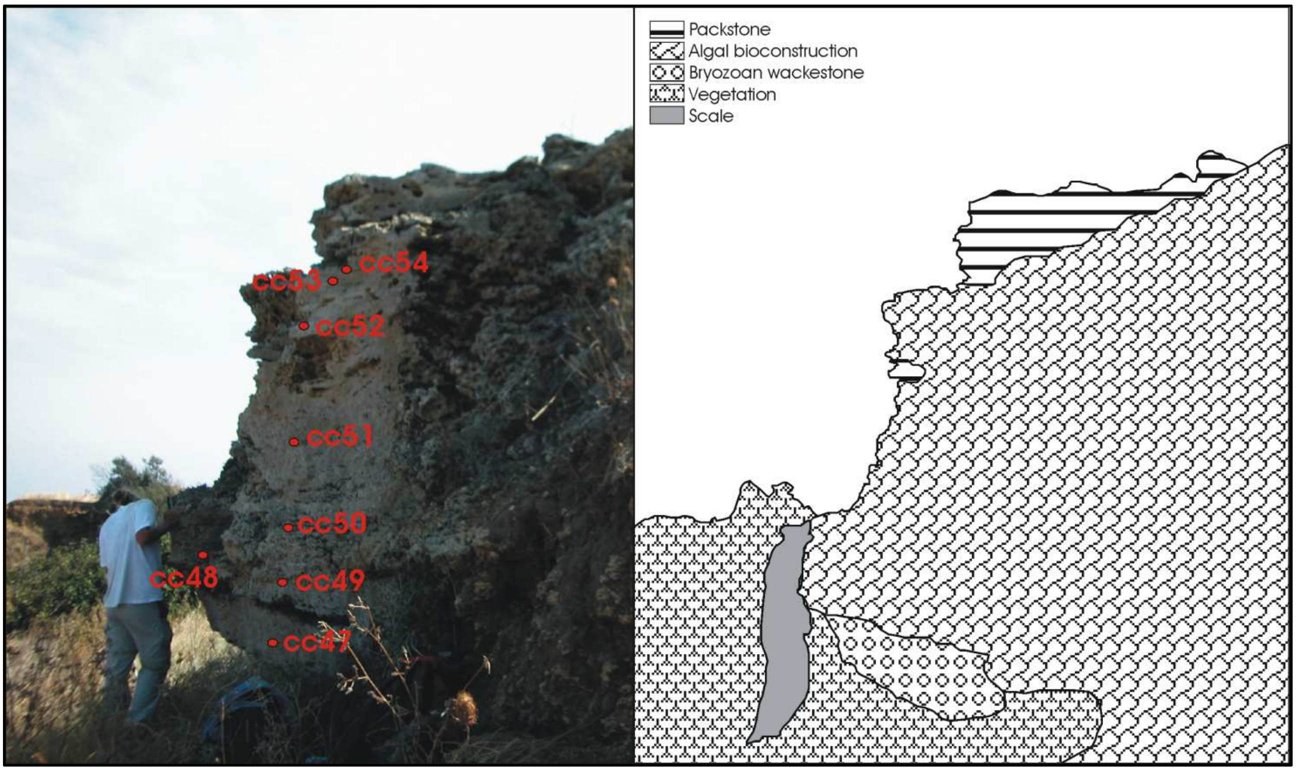
Section CC6

Sample	Short Description	Picture
cc40	Prâline rhodoliths sampled from the bioclastic packstone	
cc41	Bioclastic coarse packstone	
cc42=cc44	Very large bivalve shells at the top of the bioclastic packstone	
cc43	Bioclastic coarse packstone	
cc44=cc42	Very large bivalve shells at the top of the bioclastic packstone	

Section CC7

Sample	Short Description	Picture
cc45	Basal level of cobbles/pebbles (micro-conglomerate facies)	
cc46	Bryozoan wackestone	

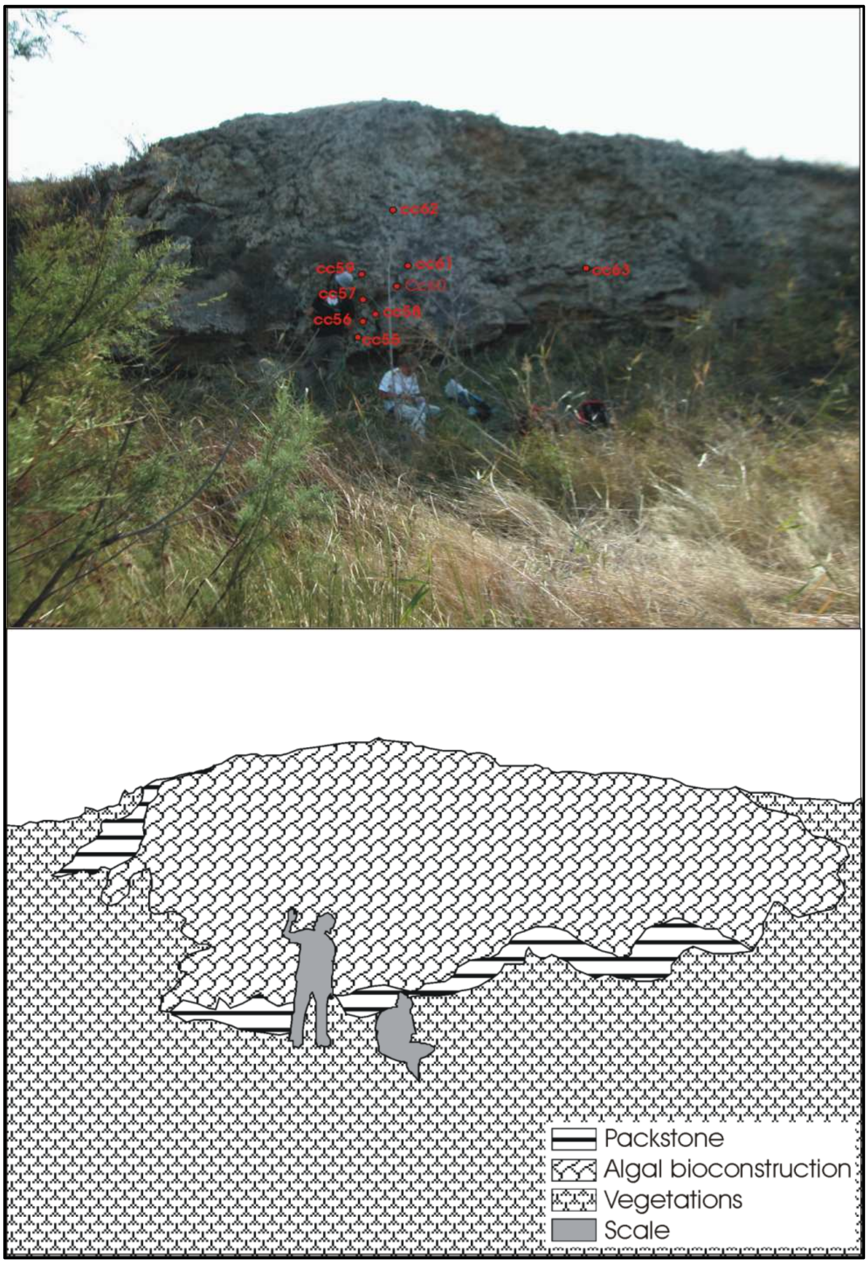
Section CC8



Sample	Short Description	Picture
cc47	Basal bioconstruction, directly on the hardground	
cc48	Algal build-up, directly in contact with lateral packstone	
cc49	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	

cc50	Internal fine packstone, rich in siliciclastic fraction	
cc51	Internal fine packstone, rich in siliciclastic fraction, with bores made by lithodomes	
cc52	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	
cc53	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	
cc54	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	

Section CC9

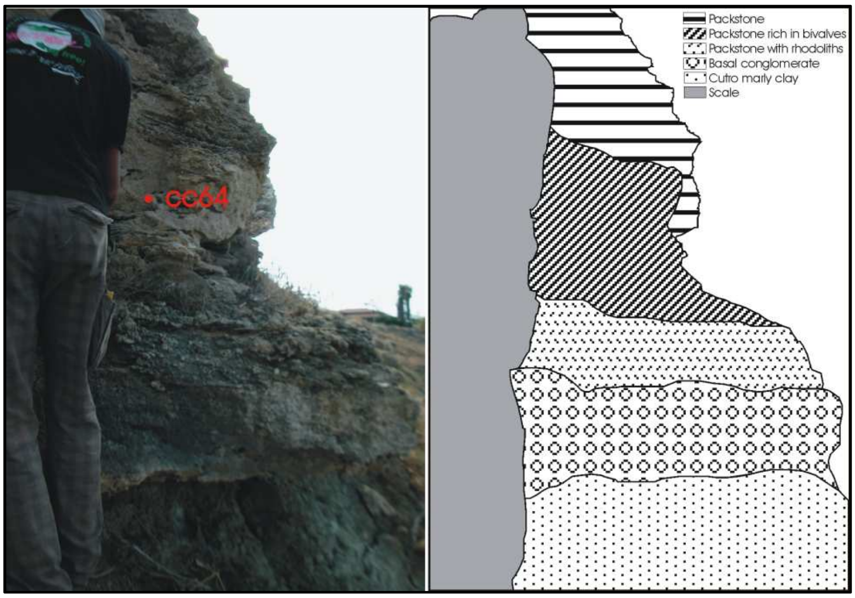


Sample	Short Description	Picture
cc55	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	

cc56	Algal build-up Massive bioconstruction, showing layered to foliose crusts partially covered by serpulids	
cc57	Algal build-up partially bio-eroded Massive bioconstruction, showing layered to foliose crusts	
cc58	Algal build-up Massive bioconstruction, showing layered to foliose crusts and locally dissolved at the top	
cc59	Algal build-up Massive bioconstruction, showing low frequency of leafy crusts and directly in contact with internal packstone	
cc60	Algal build-up Massive bioconstruction, showing low frequency of leafy crusts, partially filled by gray micrite	
cc61	Algal build-up Massive bioconstruction, showing low frequency of leafy crusts, partially filled by gray micrite	
cc62	Algal build-up Massive bioconstruction, showing low frequency of leafy crusts, partially filled by gray micrite	

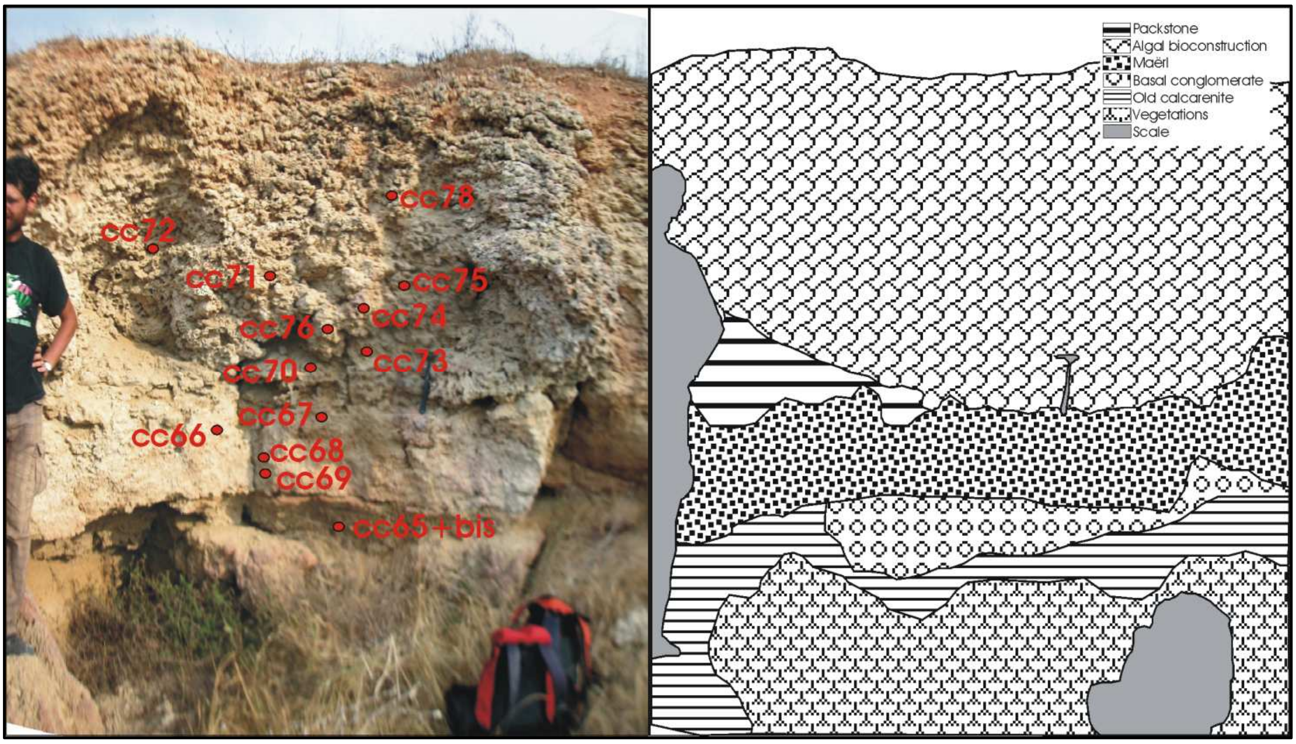
cc63	Algal build-up Massive bioconstruction, showing low frequency of leafy crusts, partially filled by gray micrite	

Section CC10

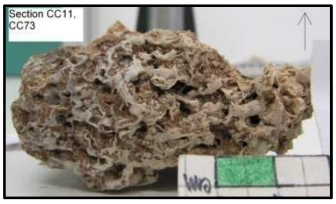


Sample	Short Description	Picture
cc64	Branching rhodoliths (Prâline?) showing a lumpy growth form	

Section CC11



Sample	Short Description	Picture
cc65+bis	Basal conglomerate	
cc66	Maërl	
cc67	Maërl	
cc68	Maërl	

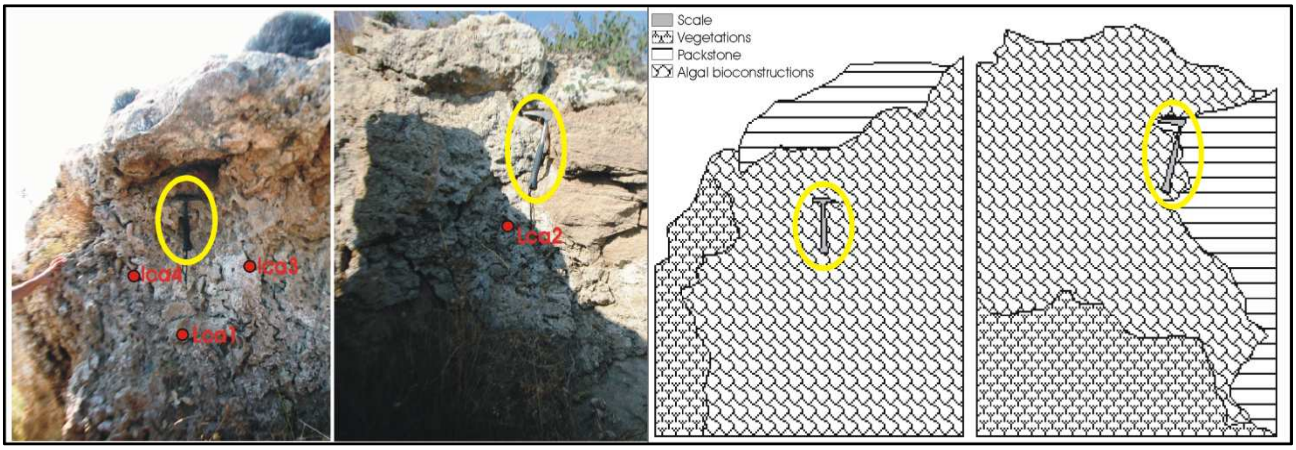
cc69	Maërl	
cc70	Basal algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc71	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc72	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc73	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc74	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
cc75	Algal and bryozoan build-up Massive bioconstruction, showing layered to foliose crusts alternated to bryozoan	

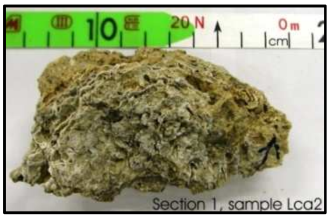
cc76	Algal and Bryozoan build-up Massive bioconstruction, showing layered to foliose crusts alternated to Bryozoan	
cc77	Rhodoliths bed formed by abraded praline-form	
cc78	Algal and Bryozoan build-up Massive bioconstruction, showing layered to foliose crusts alternated to Bryozoan	

4.1.5 APPENDIX III

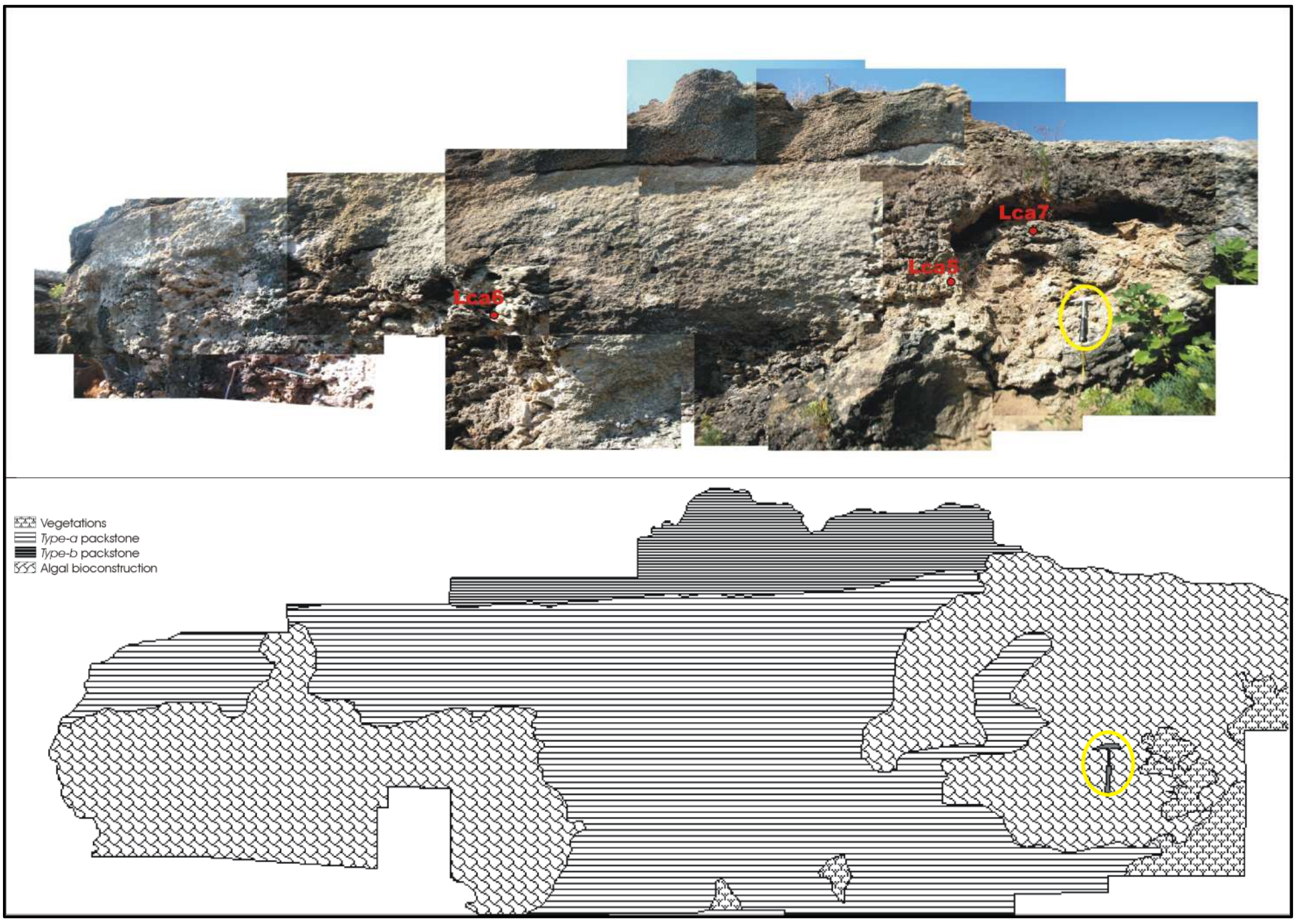
List, short description and picture of Le Castella samples per each section.

Section LC1



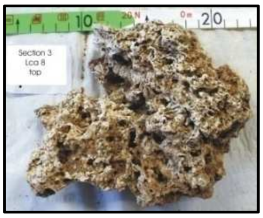
Sample	Short Description	Picture
lca1	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca2	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca3	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca4	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

Section LC2

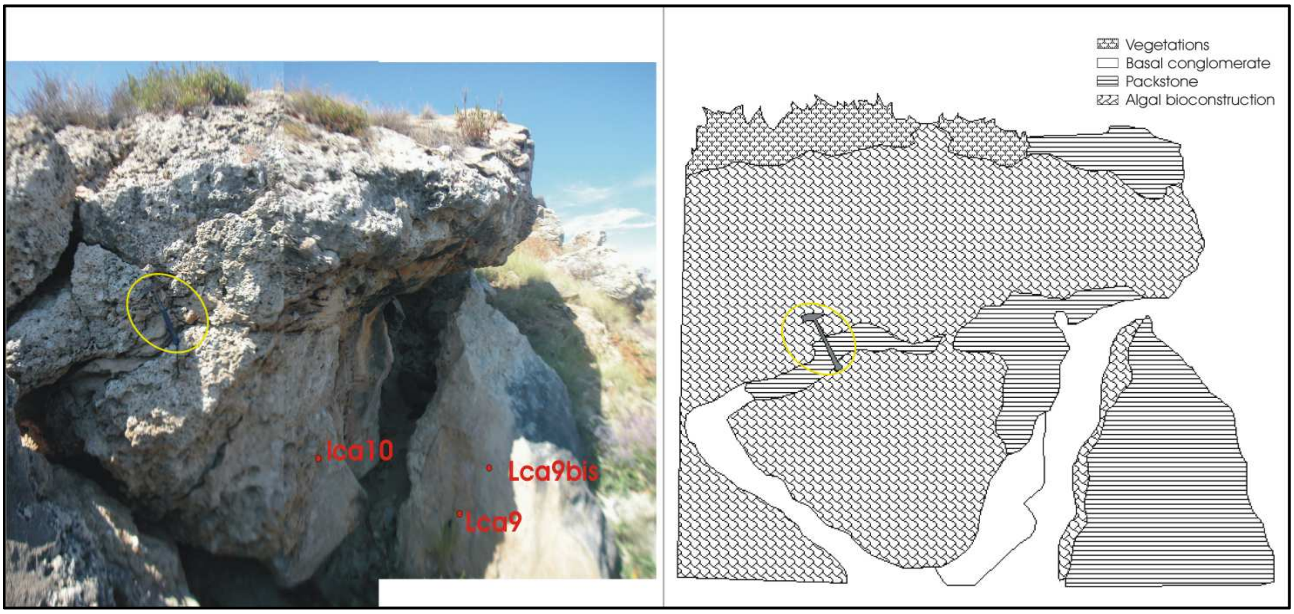


Sample	Short Description	Picture
lca5	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca6	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca7	Algal build-up Massive bioconstruction, showing layered crusts, partially filled by fine micrite	

Section LC3

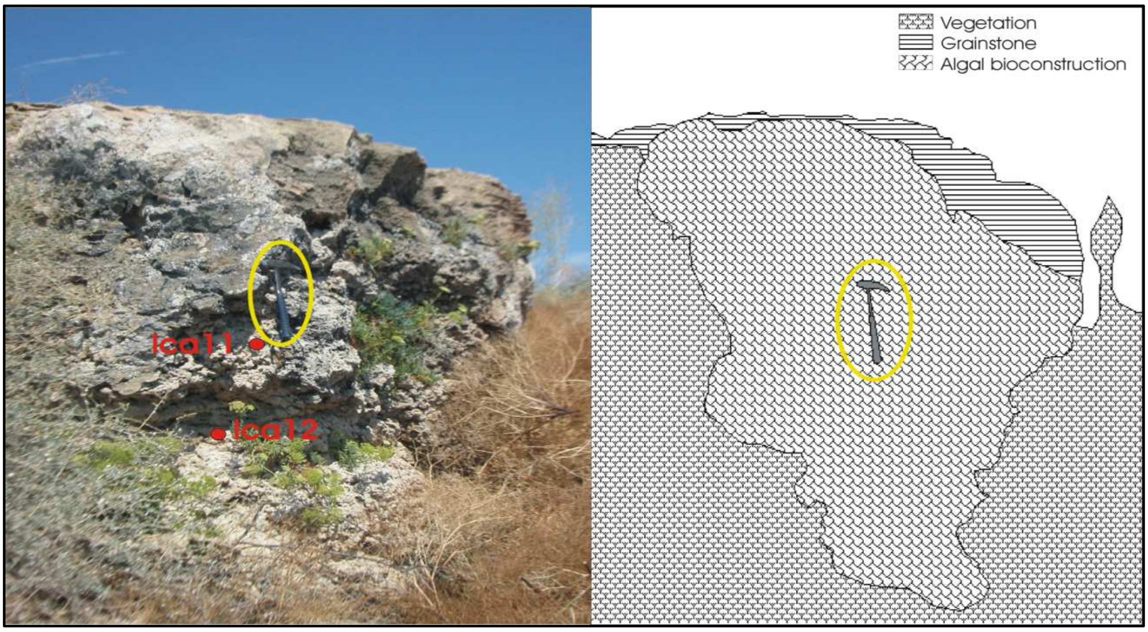
Sample	Short Description	Picture
lca8	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

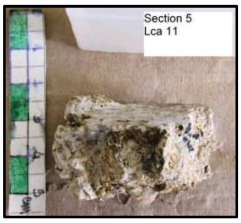
Section LC4



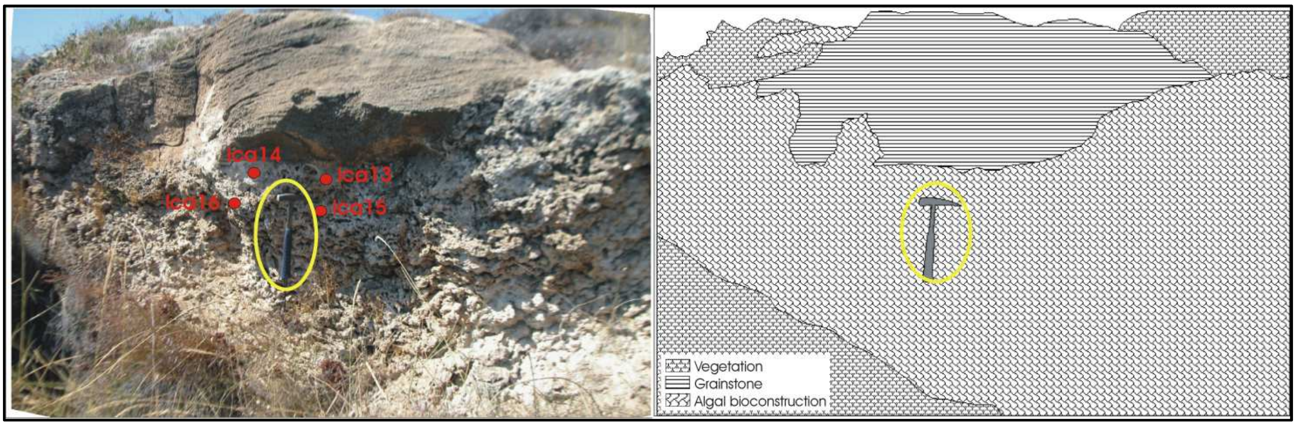
Sample	Short Description	Picture
lca9	Bioclastic grainstone, well lithified	
lca9bis	Coarse bioclastic packstone next to the build-up	
lca10	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

Section LC5



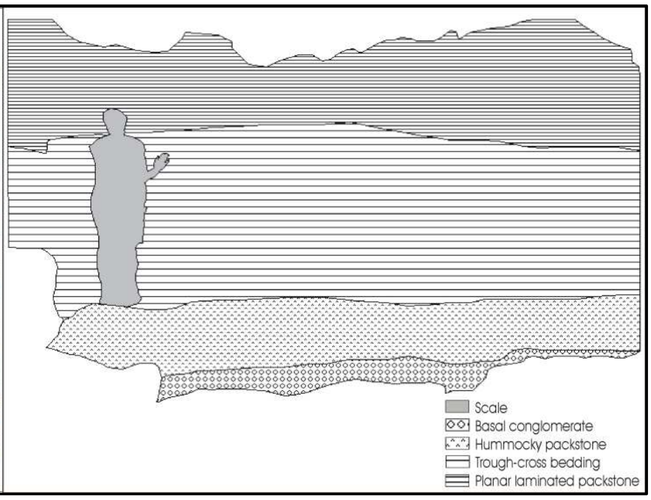
Sample	Short Description	Picture
lca11	Algal build-up Massive bioconstruction, showing layered crusts, partially filled by fine micrite	
lca12	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

Section LC6



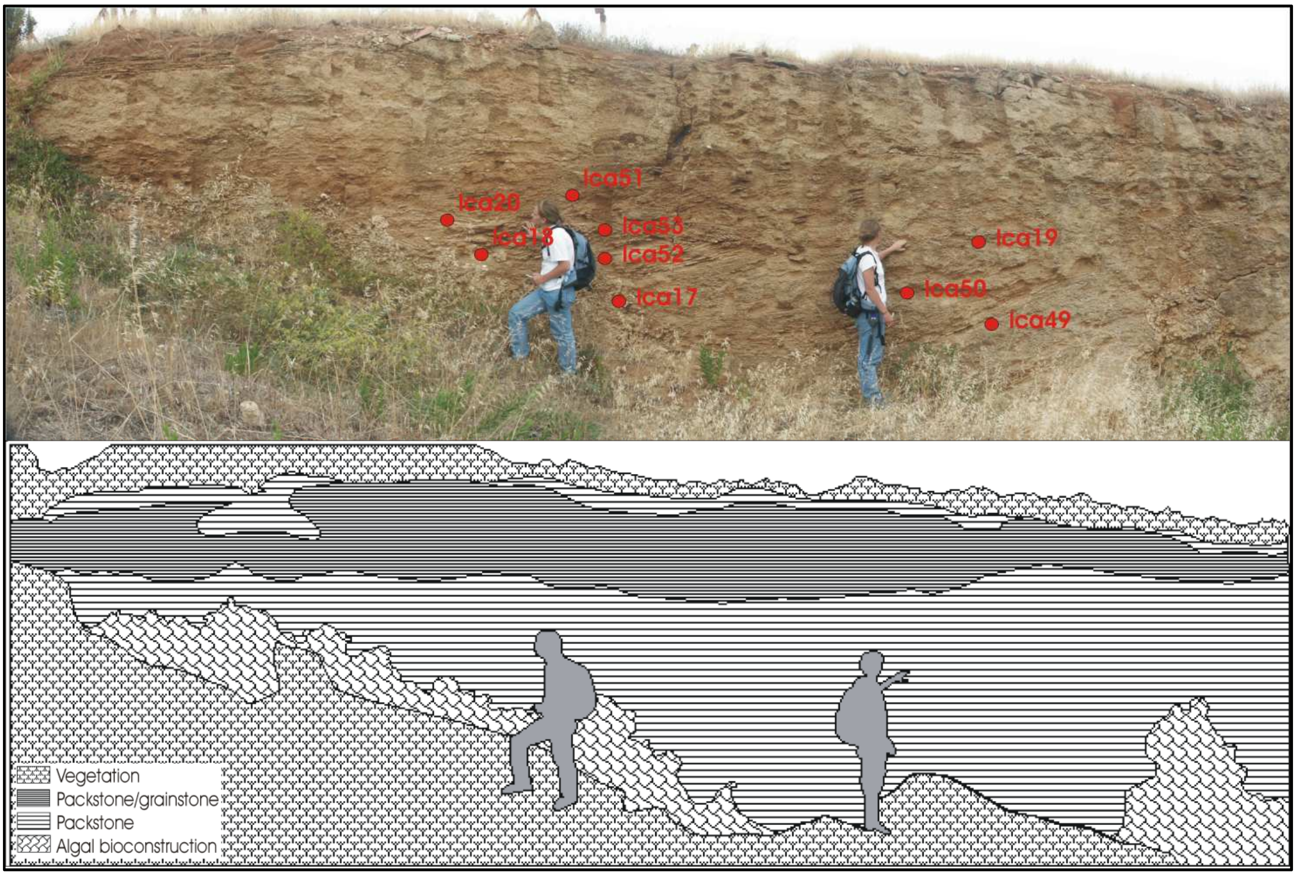
Sample	Short Description	Picture
lca13	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca14	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca15	Bioclastic grainstone with dispersed red algae crusts	
lca16	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

Section LC7



Sample	Short Description	Picture
h5	Coarse bioclastic packstone Lots of shells are dissolved or not well preserved	
h6	Packstone/grainstone	

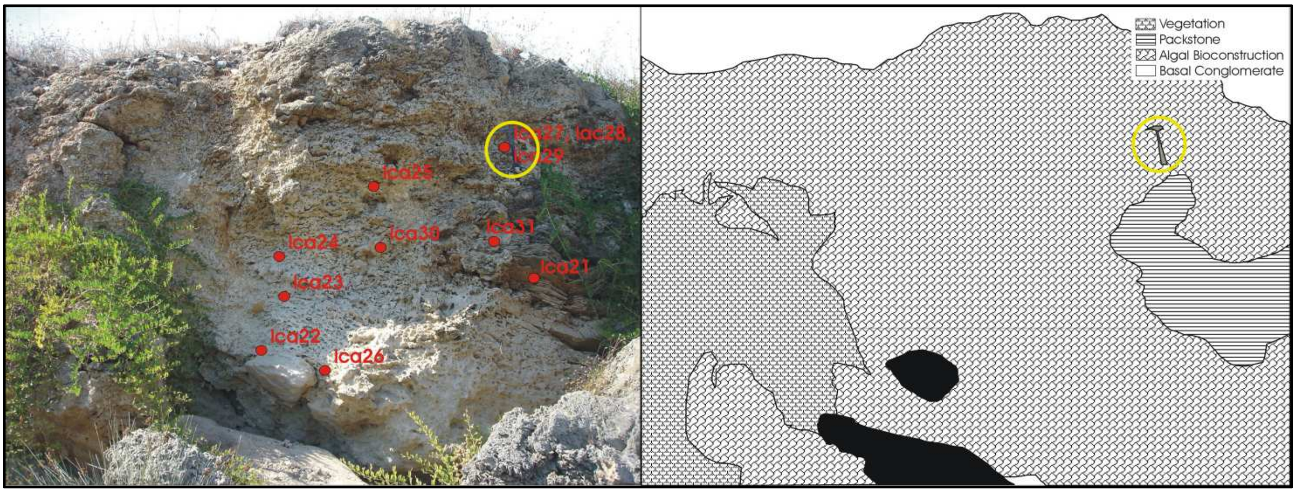
Section LC8

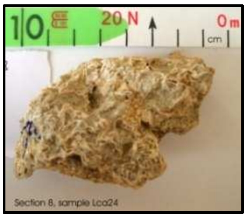


Sample	Short Description	Picture
lca17	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca18	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca19	Packstone	

lca20	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca 49	Algal build-up Massive bioconstruction, layered crusts, filled by fine matrix, and laterally in contact with coarse bioclastic packstone Presence of lithodomes bores	
lca 50	Fine bioclastic packstone, intensively bioturbated	
lca 51	Algal build-up Massive bioconstruction, showing layered crusts and bores made by lithodomes	
lca 52	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca 53	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

Section LC9



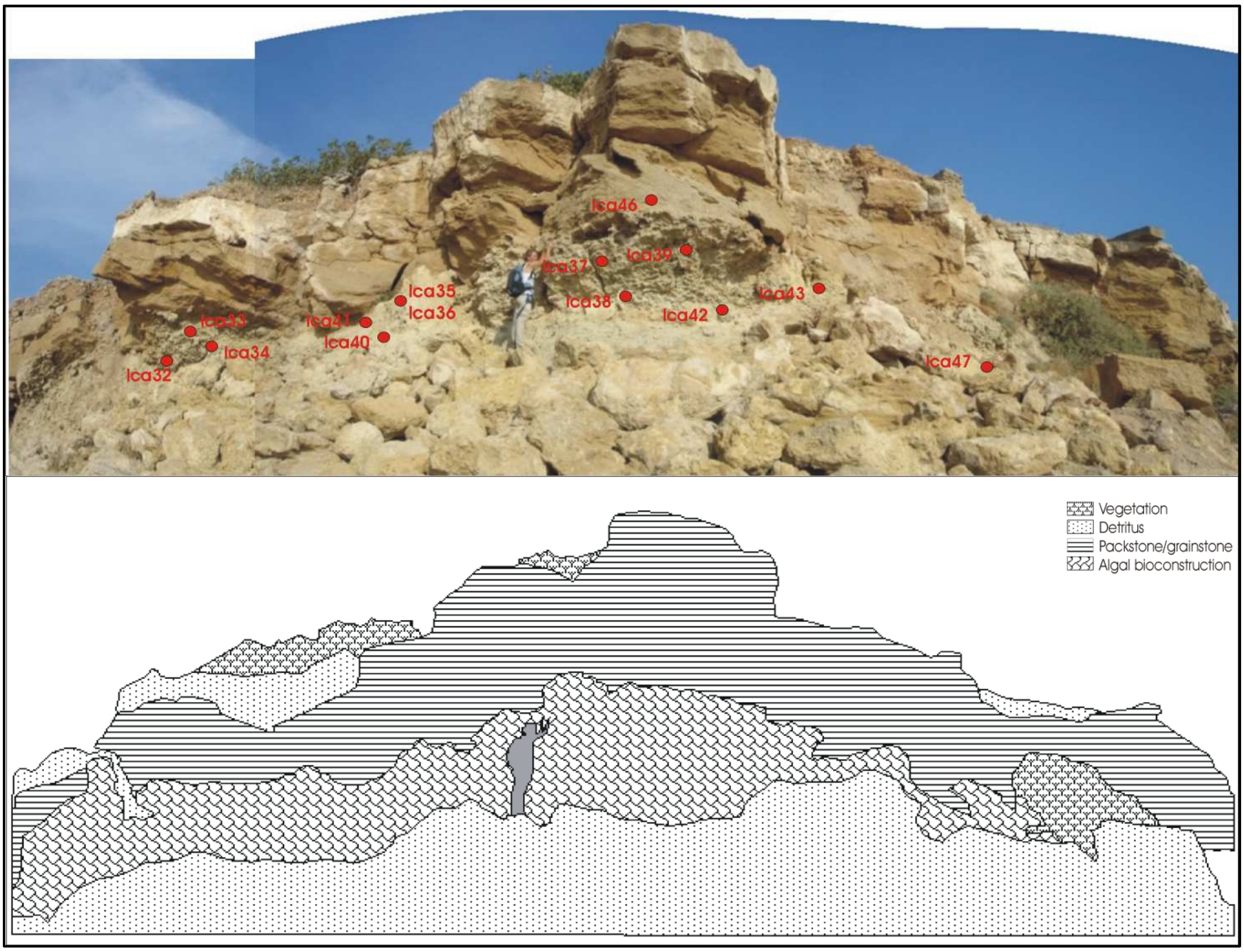
Sample	Short Description	Picture
lca21	Very fine siliciclastic-bioclastic packstone	
lca22	Basal massive bioconstruction, sampled directly in contact with basal conglomerate	
lca23	Algal build-up Massive bioconstruction, showing layered crusts, partially filled by fine micrite	
lca24	Algal build-up Massive bioconstruction, showing layered crusts, partially filled by fine micrite	
lca25	Algal build-up Massive bioconstruction, showing layered to foliose crusts	

lca26	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca27	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca28	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca29	Algal build-up, formed by both layered and lumpy crusts	
lca30	Algal build-up Massive bioconstruction, showing layered crusts, directly in contact with bioclastic packstone A *Spondylussp.* specimens is present into the build-up	
lca31	Coarse packstone, sampled into the cross-set bedding and low lithified	

Section LC10

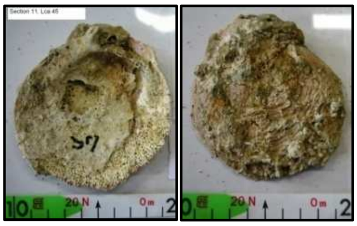
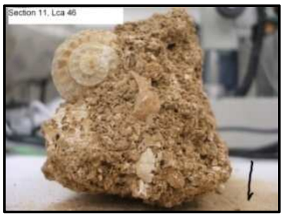
Sample	Short Description	Picture
lca48	Very coarse bioclastic packstone, sampled into the clinoforms bodies and low lithified	
lca48bis	Very coarse bioclastic packstone, sampled into the clinoforms bodies and low lithified	

Section LC11



Sample	Short Description	Picture
lca32	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca33	*C. caespitosa* at the base of the build-up	
lca34	*C. caespitosa* at the base of the build-up	

lca35	Algal build-up Massive bioconstruction, showing layered crusts, directly in contact with bioclastic packstone	
lca36	Algal build-up Massive bioconstruction, showing layered crusts, directly in contact with bioclastic packstone Spaces among crusts filled by fine micrite	
lca37	Algal build-up Massive bioconstruction, showing layered dispersed crusts, directly in contact with bioclastic packstone Spaces among crusts filled by fine micrite	
lca38	Algal build-up Massive bioconstruction, showing layered crusts, directly in contact with bioclastic packstone	
lca39	Algal build-up Massive bioconstruction, showing layered crusts, directly in contact with bioclastic packstone Presence of rhodoliths	
lca40	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca41	Algal build-up Massive bioconstruction, showing layered crusts Little rhodoliths are reported	

lca42	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca43	Algal build-up Massive bioconstruction, showing layered to foliose crusts	
lca44	Fine packstone with coarse fraction made by valves, and rest of echinoids shells	
lca45	Valves	
lca46	Coarse and fine alternated biogenic grainstone directly over the algal build-ups	
lca47	Coarse biogenic grainstone directly on the Cutro marly clay	

4.2 CORALLINE ALGAL BUILD-UPS AND OTHER CORALLINE FACIES

4.2.1 CAPO COLONNA MARINE TERRACE

CORALLIGENOUS BUILD-UPS

The peculiarity of Capo Colonna marine terrace is that a quite continuous outcrop is observable along the northern coast of the peninsula, showing a well preserved transect across the paleo-shelf. The outcrop is more or less perpendicular to the reconstructed inner margin of the terrace deposits.

The deposits of Capo Colonna marine terrace are characterized by red algae build-ups overlying different substrates (Fig. 4.48).

Fig. 4.48: different facies of the coralligenous substrates

Section CC1 is not characterized by the presence of algal build-up.

In the proximal sections (CC2-CC3) the build-ups overlay directly the basal conglomerate, which is formed by decimetric to metric fragments of older terrace deposits, derived by the erosion of the paleocliff during the transgressive phase and mostly composed by clasts of older bioconstructed bodies or lithified packstone. In some cases the build-ups overlay directly the Cutro marly clay unit (see chapter 4.2).

In the central sections (CC4-CC8) the build-ups overlay the hardground at the top of the packstone unit (see chapter 4.2), whereas section 9 is characterized by a micro-conglomerate at the base of the build-up.

Section CC10 does not show the presence of algal bioconstruction.

Section CC11 is the most distal section and it is characterized by algal build-up overlying rhodoliths beds.

The basal units (conglomerate, packstone or rhodoliths beds) directly overlay a transgressive ravinement surface, cutting the clayey substrate with an abrupt contact.

Sections CC2 and CC3 are characterized by independent algal build-ups, ranging between 1 and 3 m thick, with lateral continuity of 4 m. The channels between different build-ups are filled by bioclastic packstone. The bioconstructions have a “mushroom” shape, enhancing the presence of channels filled by packstone. These build-ups are dominated by *M. alternans, P. calcareum,* locally *T. pustulatum* sparsely occurs whereas *L. stictaeforme,*. At the base of section CC2east the presence of a rich encrusting bryozoans' facies and *C. caespitosa*, showing loosely ramification, is reported (Fig. 4.49).

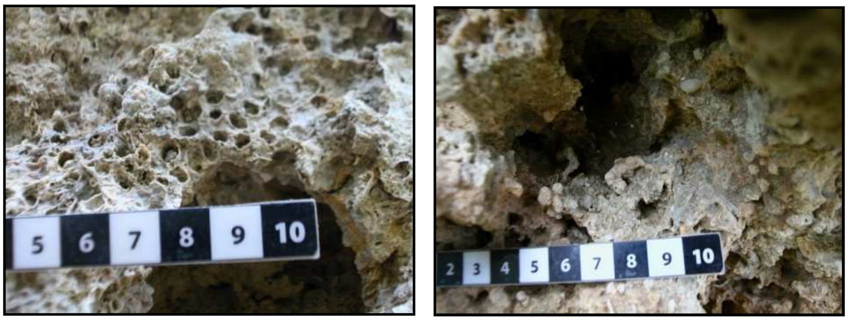


Fig. 4.49: *C. caespitosa*, left, and bryozoans, right, at the base of section CC3

Sections CC4 and CC5a-b-c are characterized by an individual algal bank, 2-4 m thick and more than 40 m long. The build-up shows a massive, dense structure. The thickness reaches at least 4 m and keeps regular for several meters. The build-ups are bioconstructed by *M. exspansum* and *P. calcareum*.

Sections CC7, CC8 and CC9 are characterized by algal build-up ranging between 1.5 and 2.5 m thick, with lateral continuity of several meters, partially alternated to pockets filled by organogenous packstone. The build-ups are bioconstructed by *Mesophyllum sp.* and *Lithophyllum sp., Titanoderma sp.* sparsely occurs. At the base of section CC8, a bryozoan-rich facies is reported. The base of CC9 sections is dominated by *M. alternans* and *P. calcareum.*

Section CC11 is the most distal section and it is characterized by the presence of layers of abraded prâline rhodoliths forming the base of the coralligenous build-up. The build-up is 1-2 m thick and 5 m long and it is characterized by a dense, compact framework. The build-up is dominated by *M. alternans* and *Mesophyllum sp.*

RHODOLITH FACIES

The deposits of Capo Colonna marine terrace contain other red algae facies.

In particular, prâline rhodoliths are sparsely present into the biogenic packstone in sections CC5d, CC6, CC7 and CC10 (Fig 4.50).

Fig. 4.50: prâline rhodoliths sampled into the packstone outcropping at sections CC5d, CC6, CC7 and CC10

Section CC5d presents an accumulation of rhodoliths at the base of the packstone, and some other sparse rhodoliths in the unit, whereas section CC6, CC7 and CC10 present prâline rhodoliths randomly distributed.

Rhodoliths at sections CC5d, CC6, CC7 and CC10 are well preserved, with unbroken branches. They have been measured and the dimensions are reported in Tab. 4.1.

height (cm)	**width (cm)**	**thickness (cm)**
3,5	4	1,4
0,9	1,4	1
2,1	1,8	1,5
1,5	1,2	1,1
1,8	3,1	2,3
2,8	2,1	1
1	1,3	1,8
2,8	2,1	1,8
2	1,5	0,8
2,1	1,5	1

Tab. 4.1: measured dimension of branching rhodoliths sampled in sections CC5D, CC6, CC7 and CC10

These rhodoliths are formed primarily by *M. alternans* and rarely *T. pustulatum.* The nuclei of the rhodoliths consist of skeletal fragments, clasts of older bioconstructed bodies, and siliciclastic pebbles similar to the lithic micro-conglomerate facies reported in section CC7 (Fig. 4.51).

Fig. 4.51: example of the nuclei of rhodoliths: left, a fragment of coralligenous origin; right, a pebble partially encrusted by the algae

Abraded branching rhodoliths (Fig. 4.52) are present also in section CC11, at the base of the algal build-up. These rhodoliths show a quite flattened surface and a rounded shape, where the branching structure is not always recognizable. They are completely integrated in the overlying build-ups. These rhodoliths are formed mostly by *Lithothamnion sp.*

Fig. 4.52: abraded prâline rhodoliths sampled at the base of the build-up exposed at section CC11

MAËRL FACIES

The basal portion of sectionsCC10 and CC11 is characterized by a maërl layer. This unit is 40-50 cm thick. The coralline branches are at maximum 2 cm long, and 0.5 cm in thickness (Fig. 4.53).

Fig. 4.53: samples of maërl facies collected in section CC11

The maërl facies is formed by *L. corallioides, Lithothamnion sp., Lithophyllum sp*. and *Phymatolithon sp.*

IDENTIFIED SPECIES IN CAPO COLONNA RED-ALGAE FACIES

M. alternans

This species presents different shapes, from dense layered to foliose crusts to lumpy crust forming prâline rhodoliths. Cell fusion is detected. Trichocytes are not present. Hypothallus is often coaxial and measures 210-250 µm, whereas perithallus measures 450-470 µm.

The male gametangial conceptacles are buried into the perithallus, the external diameter of conceptacles ranges between 150 and 200µm, their height between 25 and 35 µm.

Epithallial cells have a polygonal shape in surface view.

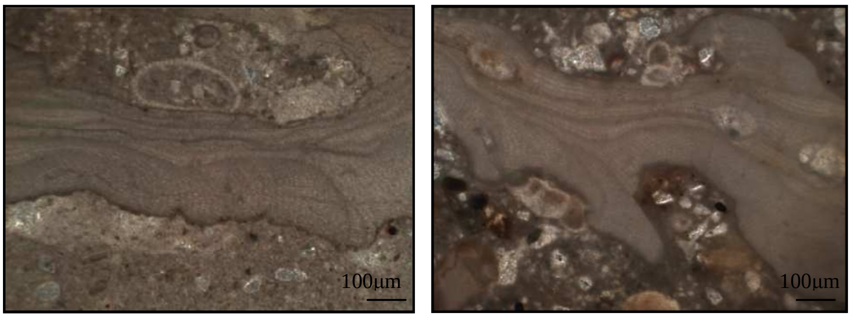


Fig. 4.54: details on *M. alternans* crusts

M. exspansum

This species presents foliose crusts, with well developed coaxial hypothallus. Cell fusion is detected. Trichocytes are not present.

Hypothallus measures 200-280 µm, whereas perithallus measures at least 100 µm. Epithallial cells have a rounded shape in surface view.

T. pustulatum

This species presents laminar crusts, adhering to other algal crusts or fragments. It presents typical palisade cells, with height ranging between 10 and 50 µm and diameter of at least 10 µm.

Conceptacles are ovoidal and prolonged in longitudinal view, and measure 280-410 µm in diameter, and 70-120 in height.

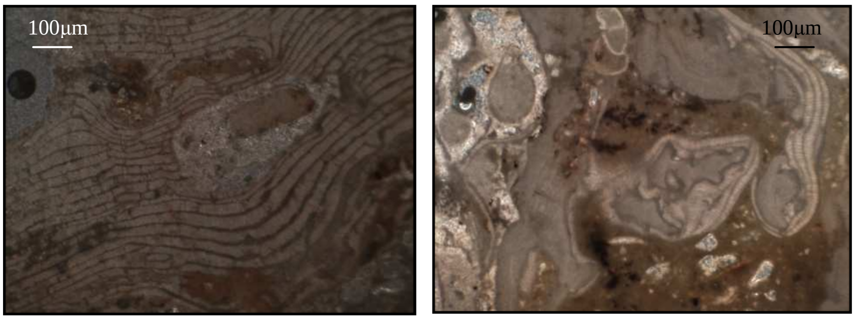


Fig. 4.55: details on *T. pustulatum* crusts

L. stictaeforme

This species presents thin laminar crusts. Cell fusion and trichocytes are not present.

Thallus is formed by well-ordered cell lines, similar to bricks in longitudinal view.

Asexual conceptacles range 330-440 µm in diameter and 80-100 µm in height.

Gametangial conceptacles (Fig. 3.55) measure 120-170 µm in diameter and 20-30 µm in height.

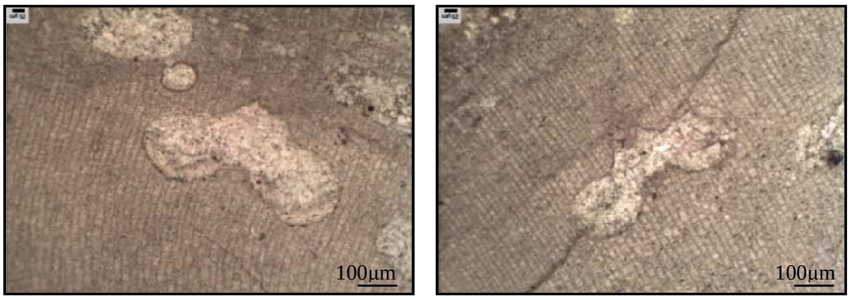


Fig. 4.56: gametangial conceptacles within *L. stictaeforme* thallus

P. calcareum

Branching crusts, with very small cells.

Presence of flattened ovoidal conceptacles, smaller than tetrasporangial conceptacles, probably female gametangial apparently concentrated in the fruticose protuberances.

Lithothamnion corallioides

Free branching crusts, 1-2 cm in diameter and 0.5 mm in thickness. The hypothallus is non coaxial. The perithallus is multilayered and formed by rectangular cells in longitudinal view. Presence of cell fusions.

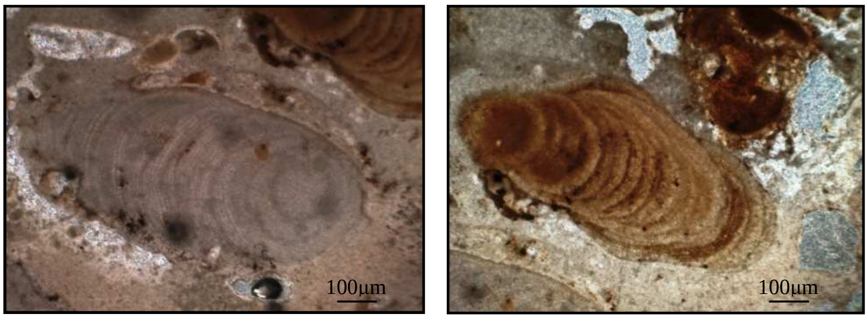


Fig. 4.57: *L. corallioides* free branches

Identified red algae list with short description of morphology, ecology, geographic and stratigraphic distribution is reported in Appendix IV.

A quantitative assessment of the coralline algae distribution in thin section is reported in Tab. 4.2, whit a short description of algal framework.

		Sample	Algae species	Algal framework
CC1		cc1	x	x
		cc1bis	x	x
		cc2	x	x
CC2	**CC2 WEST**	cc3	*L. stictaeforme, Mesophyllum sp.*	Layered crusts
		cc4base	*M. alternans, L. stictaeforme, Amphiroa sp., Titanoderma sp.*	Layered crusts
		cc4centre	*M. alternans, Titanoderma sp.*	
		cc4top	*T. pustulatum*	
		cc5	*Mesophyllum sp., T. pustulatum*	Layered crusts
		cc6	x	x
		cc7	x	x
		cc8	x	x
		cc9	*M. alternans, Mesophyllum sp.*	Layered crusts
		cc10a	*M. alternans, P. calcareum*	Layered and lumpy crusts
		cc10b	*M. alternans, P. calcareum*	
		cc10c	*P. calcareum, L. stictaeforme, Sporolithon sp.*	
		cc11	*M. exspansum*	Layered crusts
		cc12	*M. exspansum*	Layered crusts
		cc13	*Mesophyllum sp.*	Layered crusts
		cc14	*Mesophyllum sp.*	Layered crusts
		cc15	*Mesophyllum sp.*	Layered crusts
	CC2 EAST	cc16a	*P. calcareum*	Layered and lumpy crusts
		cc16b	*Lithophyllum sp.*	
		cc16c	*Mesophyllum sp., Sporolithon sp.*	
		cc17a	x	Layered crusts
		cc17b	*Mesophyllum sp., Amphiroa sp.*	
		cc18	*M. alternans, Lithophyllum sp., Titanoderma sp.*	Layered crusts
		cc19	x	x
CC3		cc20	x	x
		cc21	x	x
		cc22	*P. calcareum*	Lumpy crusts
		cc23	*P. calcareum*	Lumpy crusts
		cc24	*Mesophyllum sp.*	Layered crusts
		cc25	x	x
CC4		cc26	*P. calcareum*	Lumpy crusts
		cc27	*Mesophyllum sp.*	Layered crusts

		cc28	*M. alternans, Mesophyllum sp., Amphiroa sp.*	Layered crusts
		cc29	*P. calcareum*	Lumpy crusts
		cc30	*Mesophyllum sp.*	Layered and lumpy crusts
CC5	**a**	cc31	*Lithothamnion sp.*	Fruticose crusts
	a	cc32	*Mesophyllum sp.*	Layered leafy crusts
	a	cc33	*M. alternans*	Layered leafy crusts
	a	cc34	x	x
	b	cc35 a+b	x	x
	c	cc36	x	x
	d	cc37	x	x
	d	cc38	x	x
	d	cc39	x	x
CC6		cc40	*M. alternans, Titanoderma sp.*	Fruticose crusts
		cc41	x	x
		cc42	x	x
		cc43	x	x
		cc44	x	x
CC7		cc45	x	x
		cc46	x	x
CC8		cc47	x	x
		cc48	x	x
		cc49	*Mesophyllum sp., Titanoderma sp.*	Layered crusts
		cc50	x	x
		cc51	x	x
		cc52	*Mesophyllum sp.*	Layered crusts
		cc53	x	x
		cc54	*Mesophyllum sp.*	Layered crusts
CC9		cc55a	*M. alternans, Titanoderma sp., P. calcareum*	Layered and lumpy crusts
		cc55b	*Lithophyllum sp., Neogoniolithon sp.*	Layered crusts
		cc56a	x	x
		cc56b	*Titanoderma sp.*	Layered crusts
		cc57	*Titanoderma sp.*	Layered crusts
		cc58	x	x
		cc59	*Lithophyllum sp.*	Layered crusts
		cc60	*Lithophyllum sp.*	Layered crusts
		cc61	*Lithophyllum sp.*	Layered crusts
		cc62	*Lithophyllum sp.*	Layered crusts
		cc63	*Lithophyllum sp.*	Layered crusts
CC10		cc64	x	x
CC 11		cc65+bis	x	x

	cc66	x	x
	cc67	x	x
	cc68	*Lithothamnion sp., Lithophyllum sp.*	Fruticose crusts
	cc69	*L. corallioides, Phymatolithon sp.*	Fruticose crusts
	cc70	*M. alternans*	Layered crusts
	cc71	*Mesophyllum sp., Titanoderma sp.*	Layered crusts
	cc72	*Mesophyllum sp.*	Layered crusts
	cc73	x	x
	cc74	*M. alternans, Lithothamnion sp., Titanoderma sp.*	Layered and lumpy crusts
	cc75	x	x
	cc76	x	x
	cc77	*Lithothamnion sp, P. calcareum*	Lumpy crusts
	cc78	x	x

Tab. 4.2: Quantitative assessment of coralline algae in Capo Colonna samples.

4.2.2 LE CASTELLA MARINE TERRACE

The deposits of Le Castella marine terrace are characterized by algal build-ups usually directly overlying the basal conglomerate, which is formed by decimetric to metric fragments of older terrace deposits, derived by the erosion of the paleocliff during the transgressive phase. The basal conglomerate overlies a transgressive ravinement surface, cutting the Cutro Marly Clay substrate. The contact is abrupt. The conglomerate is mostly composed by clasts of older bioconstructed bodies or lithified packstone/grainstone units. In some cases, it is characterized by the accumulation of shells of the bivalve *S. gaederopus.* In rare cases, the build-ups apparently grew directly on the clayey substrate.

Algal reefs characterize the lower interval of all measured stratigraphic sections, except for sections LC7 and LC11b where no algal build-up is present.

In particular, 5 main algal banks have been recognized on the basis of the studied sections. They are quite equidistant from the inner margin. The first body crops out in sections LC1, LC2, LC3 and LC4; the second in sections LC5 and LC6; the third in sections LC8 and LC9; the fourth and the fifth in sectionsLC10 and LC11 (Fig. 4.58).

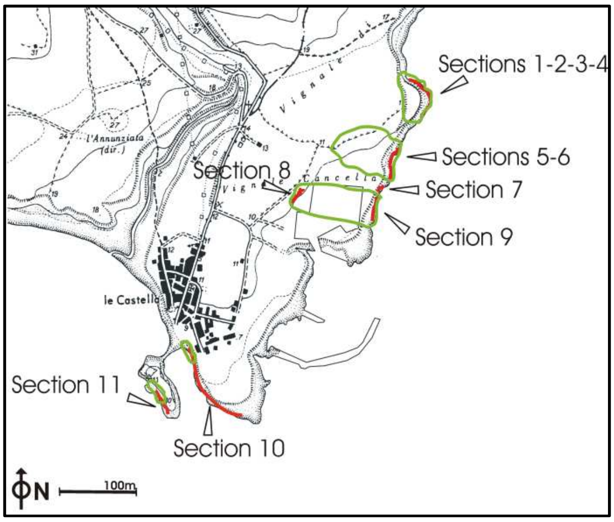


Fig. 4.58: map with the reconstruction of the 5 main algal banks recognized. Red lines indicates the stratigraphic sections studied; green lines indicate the algal banks

The 3 northern build-ups are 1-3 m thick and 5-10 m long, forming little banks quite perpendicular to the inner margin, alternated to channels filled by thick coarse organogenous packstone/grainstone deposits. These build-ups show a crustose red algae-dominated structure. The framework is dense, crustose (*sensu* Bosence, 1983), with a layered fabric, in which a patchwork of corallines occurs, with plants overgrowing or being overgrown by neighboring plants. A intensive bioturbation activity produces a vacuolar aspect.

The southernmost build-ups characterize sections LC10 and LC11. They are smaller than the others, 1-2 m thick and 3-8 m long, and characterized by the presence of the coral *C. caespitosa* and a more open framework, with algal crusts sparsely distributed in a grey fine matrix. *C. caespitosa* is an endemic Mediterranean species, typically developed on rocky or stable bottom, with cobbles and pebbles, between 3 and 40 m wd and low-energy environment (Kružić & Benković, 2008).

The coral *C. caespitosa* occurs where the algal crust framework is more open (Fig. 4.59), with layered leafy overgrowing crusts trapping fine sediments between crusts showing a more open framework.

Fig. 4.59: samples collected in section LC11 testifying the more open algal framework

C. caespitosa in Le Castella terrace shows thick dendroid corallites up to 20 cm high or loosely ramified and erect colonies (Fig. 4.60).

Fig. 4.60: *C. caespitosa* dendroid corallites outcropping in section LC11

These build-ups are placed at the base and laterally in contact with a metric, coarse-grained bioclastic clinoformal body interpreted as an example of prograding spit system, developed on a topographic step on the basement due to the previous tectonic activity combined to the presence of a long shore current (Zecchin *et al.*, 2010).

The coralligenous little banks are exposed only at the base of the succession on the up thrown block of the topographic step, and usually overlay the basal conglomerate unit. In the northern part of Le Castella marine terrace, where no topographic step is present, the build-ups have larger dimension.

The bioconstructions have generally an irregular form, enhancing the presence of channels filled by packstone/grainstone units and rich in internal cavities and pockets, usually filled by coarse bioclastic packstone.

The contact between the algal build-ups and the internal pockets filled by packstone is sharp and sometimes characterized by a local accumulation of serpulids, forming a thin crust (Fig. 4.61).

Fig. 4.61: serpulids crust formed at the contact between coralligenous build-up and pocket filled by packstone/grainstone units

The direction of the algal crusts is not univocal, and often a preferential growth-direction is not detectable. At the contact with lateral channels filled by packstone, the algal crusts show usually a sub-vertical orientation (Fig. 4.62).

Fig. 4.62: examples of the sub-vertical growth direction of algal crusts at the contact with lateral packstone units

Other encrusting organisms competed for space and were incorporated into the framework of the build-ups: bryozoans and serpulids primarily, but often the bivalve *S. gaederopus* and more rarely *Echinocardium sp*. (Fig. 4.63).

Fig. 4.63: examples of the bryozoans, left, *S. gaederopus* valve, middle, and echinoids, right, in the coralligenous build-ups

Throughout the algal reef facies, the red algal assemblage is dominated by *Mesophyllum alternans* (Foslie) Cabioch & Mendoza 1998, *Mesophyllum exspansum* (Philippi) Cabioch & Mendoza 2003, *T. pustulatum*, and subordinately by *P. calcareum*, *Mesophyllum sp.1*, *Mesophyllum sp., Phymatolithon sp., L. stictaeforme, Neogoniolithon sp., Lithophyllum sp., Titanoderma sp., Amphiroa sp.* .

IDENTIFIED RED-ALGAE SPECIES IN LE CASTELLA RED-ALGAE FACIES:

M. alternans

This species presents layered crusts, sometimes lumpy. Cell fusion is detected. Trichocytes are not present.

The hypothallus is often coaxial and measures 230-250 µm, whereas the perithallus measures 450-470µm. The asexual conceptacles are buried into the perithallus (Fig. 4.64). The external diameter of conceptacles ranges between 520 and 880 µm, whereas their height varies between 200 and 300 µm. Epithallial cells have a polygonal shape in surface view.

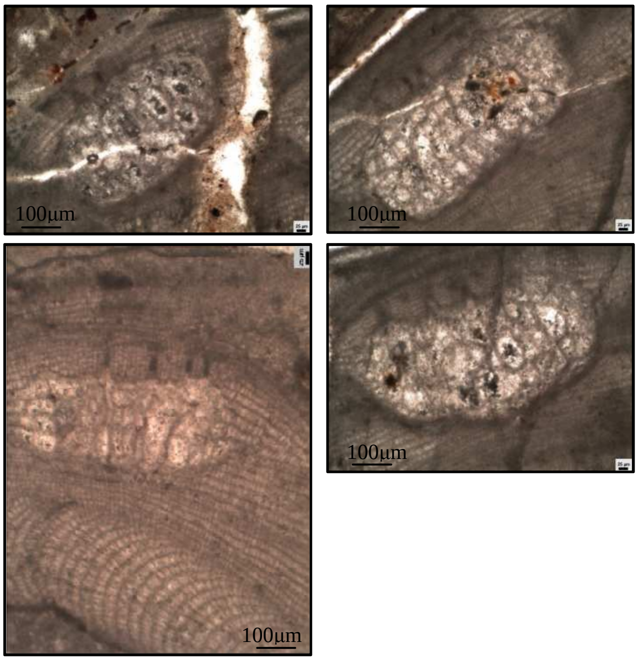


Fig. 4.64: details on the tetrasporangial conceptacles in thallus of *M. alternans*

M. exspansum

This species presents thin layered crusts, with well developed coaxial hypothallus. Cell fusion is detected. Trichocytes are not present.

The hypothallus measures 200-300 µm, whereas the perithallus measures at least 100 µm. Epithallial cells have a rounded shape in surface view.

Mesophyllum sp.1

This species presents very thin layered crusts, with well developed coaxial hypothallus (Fig. 4.65). Cell fusion is detected. Trichocytes are not present.

The hypothallus measures 80-120 µm, whereas the perithallus measures 20-40 µm. No asexual conceptacles have been founded. Epithallial cells are polygonal in surface view.

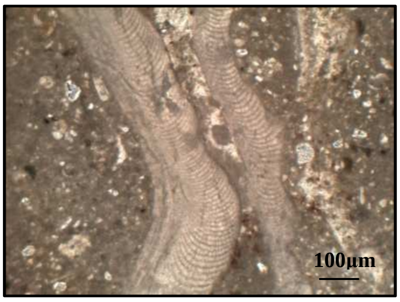


Fig. 4.65: detail of thallus of *Mesophyllum sp.1*

T. pustulatum

This species presents very thin layered crusts, adhering other algal crusts or fragments. It presents typical palisade cells in longitudinal view (Fig. 4.66 left), with height ranging between 20 and 60 µm and diameter of at least 10 µm.

Conceptacles are ovoidal and prolonged in longitudinal view (Fig. 4.66 right), and measure 330-570 µm in diameter, and 100-150 in height.

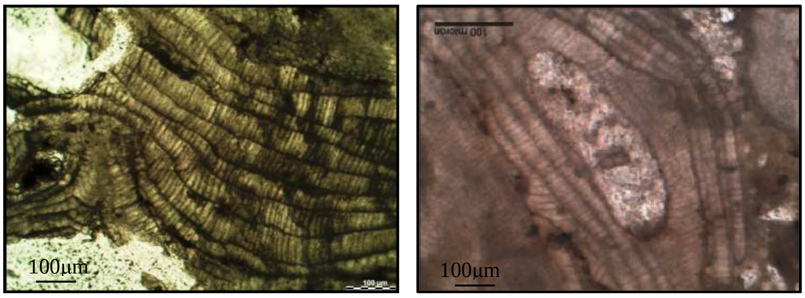


Fig. 4.66: details of *T. pustulatum.* Left: *palisada* cells; right: a tetrasporangial conceptacle

L. stictaeforme

This species presents thin layered crusts. Cell fusion and trichocytes are not present. Thallus is formed by well-ordered cell lines, similar to bricks in longitudinal view.

Asexual conceptacles range 330-410 µm in diameter and 80-110 µm in height (Fig. 4.67)

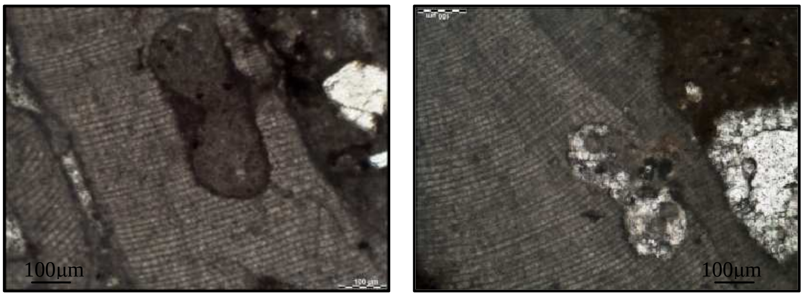


Fig. 4.67: details on *L. stictaeforme* tetrasporangial conceptacles

P. calcareum

Crusts are characterized by lumpy to fruticose shape. Cells are very small. Asexual conceptacles are multiporate, and measure 220-330 µm in diameter and 90-120 µm in height.

Flattened ovoidal conceptacles (Fig. 4.68), smaller than tetrasporangial conceptacles, are present and probably represent female gametangial conceptacles.

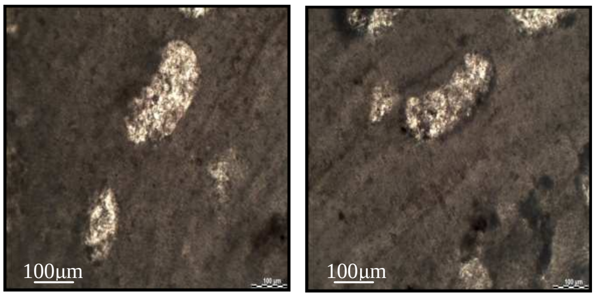


Fig. 4.68: details of *P. calcareum.* flattened and ovoidal conceptacles

Neogoniolithon sp.

Cell fusion is detected. Trichocytes (Fig. 4.69) are sparsely present into the perithallus. No conceptacles have been found.

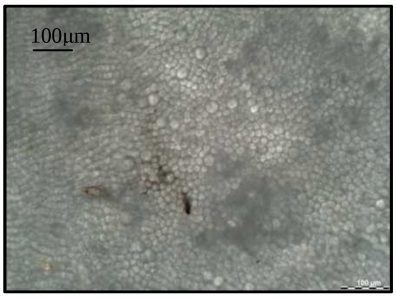


Fig. 4.69: details of trichocytes of *Neogoniolithon sp.*

Identified red algae list with short description of morphology, ecology, geographic and stratigraphic distribution is reported in Appendix IV.

A quantitative assessment of the coralline algae distribution in thin section is reported in Tab. 4.3, whit a short description of algal framework.

	Sample	**Algae species**	**Algal Framework**
LC1	lca1a	*Phymatolithon sp.,* rare *T. pustulatum*	Layered and lumpy crusts
	lca1b	*Phymatolithon sp.*	
	lca2	*L. stictaeforme, Titanoderma sp.*	Layered crusts
	lca3	x	x
	lca4a	*Neogoniolithon sp., Amphiroa sp.*	Layered crusts, not continuous
LC2	lca5top	*T. pustulatum*	Layered crusts, partially recrystallized
	lca5base	*P. calcareum, Titanoderma sp.*	
	lca6a	*M. alternans, Mesophyllum sp.1*	Layered crusts partially recrystallized
	lca6b	*M. Alternans, Mesophyllum sp.*	
	lca6c	*M. expansum*	
	lca7	*M. Alternans, T. pustulatum* rare	Layered to foliose crusts
LC3	lca8 top	*Mesophyllum sp.*	Layered to foliose crusts

	lca8 base	*Mesophyllum sp.*, rare fragmented *Lithophyllum sp.*	
	lca8b	*Mesophyllum sp.1* , *Titanoderma sp.*, rare fragmented *Lithophyllum sp.*	
LC4	lca9	Fragmented *Lithophyllum sp.* and *Titanoderma sp.*	Layered crusts
	lca9bis	Fragmented *Lithophyllum sp.* and *Titanoderma sp.*	Layered crusts
	lca10a	*Mesophyllum sp.* and *Titanoderma sp.*	Layered crusts
	lca10b	*M. Alternans*	
LC5	lca11	*M. Alternans, M. expansum, T. pustulatum*	Layered crusts
	lca12a	*M. Alternans* and rare *Lithophyllum sp., Titanoderma sp.*	Layered to foliose crusts
	lca12b	Rare *Mesophyllum sp., T. pustulatum*	
	lca12c top	*M. expansum, T .pustulatum, Neogoniolithon sp.*	
	lca12c base	x	
LC6	lca13	*M. alternans, Mesophyllum sp.*, rare *titano derma sp.*	Layered crusts
	lca14	*Mesophyllum sp., Neogoniolithon sp., Titanoderma sp.*	Layered crusts
	lca15a	x	x
	lca15b	x	
	lca16a	*T. pustulatum, L. stictaeforme*	Layered crusts
	lca16b	*Mesophyllum sp.1, Lithophyllum sp.*	
	lca16c	x	
LC7	H5	x	x
	H6	x	x
LC8	lca17	*M. alternans, T. pustulatum, Amphiroa sp.*	Layered to foliose crusts
	lca18 a	*Mesophyllum sp.*	Layered to foliose crusts
	lca18b	*Mesophyllum sp., Mesophyllum sp.1*	
	lca19	x	x
	lca20	*M. alternans*	Layered to foliose crusts
	lca49a	Rare *Lithophyllum sp.*	Layered to foliose crusts
	lca49b	*Titanoderma sp.*	
	lca49c	*Titanoderma sp.*	
	lca50	x	x
	lca51	*T. pustulatum*	Layered crusts
	lca52	*Titanoderma sp.*	Layered crusts
	lca53	*M. alternans, Titanoderma sp.*	Layered crusts
LC 9	lca21c	x	x
	lca22	*Mesophyllum sp.*	Layered crusts
	lca23	x	x
	lca24	*M. alternans, Mesophyllum sp.*	Layered to foliose crusts
	lca25	*Mesophyllum sp.1*	Layered to foliose crusts
	lca26	*Titanoderma sp.*	Layered to foliose crusts
	lca27a	*M. alternans, Mesophyllum sp., Titanoderma sp.*	Layered to foliose crusts
	lca27b	*M. alternans, M. expansum*	

	lca28a	*Mesophyllum sp.*	Layered to lumpy crusts
	lca28b	*Titanoderma sp.*	
	lca29	*Phymatolithon sp., Mesophyllum sp.*	Layered to lumpy crusts
LC10	lca30	x	x
	lca31	x	x
	lca48	x	x
	lca48 bis	x	x
LC11	lca32a	*M. alternans, T. pustulatum*	Layered crusts
	lca32b	*M. alternans, M. expansum, T. pustulatum*	
	lca33	x	x
	lca34a	*Titanoderma sp.*	Layered crusts
	lca34b	x	
	lca35	x	Layered crusts
	lca36	*Mesophyllum sp.*	Layered and lumpy crusts
	lca37	*Mesophyllum sp., Titanoderma sp.*	Layered crusts
	lca38top	x	x
	lca38 base	x	
	lca39	x	x
	lca40	*Mesophyllum sp.*	Layered and lumpy crusts
	lca41	x	x
	lca42	*M. alternans*	Layered and lumpy crusts
	lca43base	*M. alternans*	Layered and lumpy crusts
	lca43top	*M. alternans*	
	lca44	x	x
	lca45	x	x
	lca46	x	x
	lca47	x	x

Tab. 4.3: quantitative assessment of coralline algae in Le Castella samples

4.2.3 APPENDIX IV

Identified red algae list with short description of morphology, ecology, geographic and stratigraphic distribution.

Phylum RHODOPHYTA Wettstein 1922

Class FLORIDEOPHYCEAE Cronquist, 1960

Order CORALLINALES P.C. Silva & H.W. Johansen, 1986

Subfamily LITHOPHYLLOIDEA Setchell, 1943

Titanoderma pustulatum (J.V.Lamouroux) Nägeli in Nägeli & Cramer 1858

Titanoderma litorale (P.L.Crouan & H.M.Crouan) Boudouresque & Perret

Melobesia pustulata var. *canellata* Kützing 1849

Melobesia macrocarpa Rosanoff 1866

Melobesia simulans P.L.Crouan & H.M.Crouan 1867

Dermatolithon pustulatum var. *macrocarpum* (Rosanoff) Foslie 1893

Dermatolithon macrocarpum (Rosanoff) Foslie 1899

Dermatolithon adplicitum (Foslie) Foslie 1900

Dermatolithon pustulatum f. *faroense* Foslie 1900

Dermatolithon macrocarpum f. faeroensis Foslie 1900

Lithophyllum macrocarpum (Rosanoff) Foslie 1904

Lithophyllum pustulatum f. *intermedium* Foslie 1905

Lithophyllum macrocarpum f. *intermedium* (Foslie) Foslie 1905

Lithophyllum pustulatum f. *macrocarpum* (Rosanoff) Foslie 1905

Lithophyllum macrocarpum f. *faroense* (Foslie) Foslie 1905

Lithophyllum macrocarpum f. *faeroensis* (Foslie) Foslie 1905

Lithophyllum pustulatum var. *australe* Foslie 1905

Lithophyllum pustulatum f. *ascripticium* Foslie 1907

Lithophyllum pustulatum f. *similis* Foslie 1909

Lithophyllum pustulatum var. *macrocarpum* (Rosanoff) Marie Lemoine 1913

Dermatolithon pustulatum f. *ascripticium* (Foslie) Foslie ex De Toni 1924

Dermatolithon macrocarpum f. *intermedium* (Foslie) Foslie ex De Toni 1924

Fosliella ascripticia (Foslie) G.M.Smith 1944

Fosliella intermedia (Foslie) G.M.Smith 1944

Dermatolithon pustulatum f. *similis* (Foslie) Hamel & Lemoine 1953

Tenarea ascripticia (Foslie) Adey 1970

Titanoderma ascripticium (Foslie) Woelkerling, Y.M.Chamberlain & P.C.Silva 1985

Titanoderma verrucatum (J.V.Lamouroux) Y.M.Chamberlain 1986

Titanoderma macrocarpum (Rosanoff) Y.M.Chamberlain 1986

Titanoderma pustulatum var. *macrocarpum* (Rosanoff) Y.M.Chamberlain 1991

Titanoderma pustulatum var. *canellatum* (Kützing) Y.M.Chamberlain 1991

Morphology: thin crusts, smooth or warty. It presents thalli attached to substrate or covering other mobile fragments. Thallus is dorsiventral and dimerous. Cells have a palisade form, more or less oblique and sinuous. Primigenous cell height is 16-39 µm, whereas diameter is 16-23 µm; postigenous cell are not often present. Secondary pit-connections are present.

Asexual conceptacles are uniporate, sparse and with convex roof.

Ecology: epiphyte, in mesolittoral and infralittoral environments.

Geographic Distribution: very common, across the whole Mediterranean Sea.

Stratigraphic distribution: since Miocene. Lower Pleistocene of Sicilia region (Di Geronimo, 1995); mid-Pleistocene deposits of Calabria region (Basso *et al.*, 2007). Upper-Pleistocene deposits of Calabria region (this thesis).

As *Lithophyllum gr. pustulatum* in Messinian deposits of Spain and Southern Italy (Braga *et al.*, 2009).

Lithophyllum stictaeforme **(Areschoug) Hauck 1878**

Pseudolithophyllum expansum f. *decumbens* Foslie

Pseudolithophyllum expansum f. *strictaeforme* Philippi

Titanoderma bemudense (Foslie & M.A.Howe) Woelkerling *et al.*

Melobesia frondosa Dufour 1861

Lithophyllum expansum f. *agariciforme* Hauck 1885

Lithophyllum bermudense Foslie & M.A.Howe 1906

Dermatolithon bermudense (Foslie & M.A.Howe) Foslie & M.A.Howe 1909

Tenarea bermudensis (Foslie & M.A.Howe) Adey 1970

Pseudolithophyllum cabiochiae Boudouresque & Verlaque 1978

Titanoderma bermudense (Foslie & M.A.Howe) Woelkerling, Y.M.Chamberlain & P.C.Silva 1985

Lithophyllum grandiusculum (Montagne) Woelkerling, Penrose & Y.M.Chamberlain 1993

Lithophyllum frondosum (Dufour) G.Furnari, Cormaci & Alongi 1996

Morphology: encrusting thallus, with smooth or lumpy surface. Thallus not always anchored to the substrate. Secondary pit-connections are present. Asexual conceptacles are uniporate, sparse, planar or slightly prominent and presenting central columella, with diameter 320-410 µm per height 90-125 µm.

Ecology:

on the rhizomes of *Posidonia* or typically in coralligenous environment.

Geographic distribution: common across the whole Mediterranean Sea.

Stratigraphic distribution: Messinian deposits of Spain (Braga *et al.*, 2009); mid-Pleistocene deposit of Calabria region (Basso *et al.*, 1997). Upper-Pleistocene deposits of Calabria region (this thesis).

Family HAPALIDIACEAE J.E.Gray, 1864

Subfamily MELOBESIOIDEAE Bizzozero, 1885

Lithothamnion corallioides **(P.L.Crouan & H.M.Crouan) P.L.Crouan & H.M.Crouan 1867**

Lithothamnion corallioides f. *saxatile* Foslie 1895
Lithothamnion corallioides f. *minuta* Foslie 1899
Lithothamnion fruticulosum f. *soluta* Foslie 1905
Lithothamnion solutum f. *effusa* Foslie 1906
Lithothamnion solutum Foslie 1908
Lithophyllum solutum (Foslie) Lemoine 1915

Morphology: thallus is crustose to ramified. The typical morphology is free branches, or incorporating substrate forming pralines. Thallus is dorsiventral and monomerous. The hypothallus is multilayered, thin and not coaxial. The perithallus is multilayered, formed by rectangular cells. Ramifications present radial organization of cells. Asexual conceptacles are multiporate, convex-shape and with external diameter of 300-440 µm.

Ecology: circalittoral. It is a typical facies in SGCF and DC biocoenoses (Pérès & Picard, 1964).

Geographic distribution: common, across the whole Mediterranean Sea.

Stratigraphic distribution: Since Messinian deposits of Spain and Southern Italy (Braga *et al.*, 2009).

As *Lithophyllum solutum* in the Tyrrhenian deposit of Taranto (Lemoine, 1919); in the Lower Pleistocene of Sicilia region (Di Geronimo, 1995); Holocene marine sediments of Pontian islands (Corselli *et al.*, 1994). Upper-Pleistocene deposits of Calabria region (this thesis).

Mesophyllum alternans **(Foslie) Cabioch & Mendoza, 1998**

Lithothamnion philippi f. *alternans* Foslie 1907

Morphology: monomerous thallus, with dorsiventral organization in the crust and radial in the protuberances.

The hypothallus is coaxial or non coaxial, with a thickness ranging from 60 to 250 µm. The perithallus is layered, with a thickness of 100-1000 µm. The epithallus presents flattened polygonal cells.

Asexual conceptacles are multiporate, elliptic, prominent, flattened, and very large, with external diameter between 500 and 1550 µm. They are placed into the perithallus.

Ecology: usually in coralligenous environment, between 20 and 40 m wd. Typically it forms twisted crusts adhering the roughness of the substrate.

Geographic distribution: across the whole Mediterranean Sea.

Stratigraphic distribution: Lower Pleistocene of Sicilia region (Di Geronimo, 1995).

Mid-Pleistocene of Calabria region (Basso *et al.*, 2007); Upper-Pleistocene deposits of Calabria region (this thesis).

Mesophyllum expansum **(Philippi) Cabioch & Mendoza, 2003**

Lithothamnion expansum (Philippi) Foslie 1895

Lithophyllum expansum f. *genuinum* Foslie 1897

Tenarea expansa (Philippi) Kuntze 1898

Hyperantherella expansa (Philippi) Heydrich 1901

Crodelia incrustans var. *expansa* (Philippi) Heydrich 1911

Morphology: thallus is thick (350-550 µm), typically adhering lightly to shells and pebbles, forming large complex substrate. Thallus surface is flattened or ondulate. The hypothallus is coaxial, with a thickness of 150-400 µm. The perithallus is stratified and thin (50-150 µm). Epithallus presents flattened rounded cells. Trichocytes are absent. Cells fusion is present. Asexual conceptacles are multiporate, with convex to flattened roof. They are placed in contact with hypothallus. External diameter is 850-1330 µm, and 250-400 µm high.

Ecology: infralittoral.

Geographic distribution: common, across the whole Mediterranean Sea.

Stratigraphic distribution: as *M. lichenoides* in Lower-Pleistocene deposits of Sicily (Di Geronimo, 1995); in the mid-Pleistocene of Calabria region (Basso *et al.*, 2007); in Holocene marine sediments of Pontian islands (Corselli *et al.*, 1994). Upper-Pleistocene deposits of Calabria region (this thesis).

Mesophyllum sp.1 **as** ***Mesophyllum lichenoides*** **(J.Ellis) Marie Lemoine, 1928**

Corallium lichenoides J.Ellis 1768

Millepora lichenoides (J.Ellis) J.Ellis & Solander 1786

Nullipora lichenoides (J.Ellis) Templeton 1836

Melobesia lichenoides (J.Ellis) Harvey 1849

Mastophora lichenoides (Ellis) Kützing 1849

Lithophyllum lichenoides (Ellis) Rosanoff ex Hauck 1883

Lithothamnion lichenoides (J.Ellis) Foslie 1895

Tenarea lichenoides (Ellis) Küntze 1898

Sphaeranthera lichenoides (Ellis) Heydrich 1907

Millepora byssoides var. *fasciculus* Lamarck

Mesophyllum lichenoides f. *heterophylla* Foslie

Millepora agariciformis Pallas 1766

Millepora alga Gmelin 1791

Nullipora agariciformis (Pallas) Lamarck 1801

Pocillopora agariciformis (Pallas) Ehrenberg 1834

Spongites agariciformis (Pallas) Kützing 1849

Lithophyllum agariciformis (Pallas) Falkenberg 1879

Lithothamnion agariciforme Foslie 1898

Lithothamnion lichenoides var. *agariciformis* (Pallas) Foslie 1900

Lithophyllum lichenoides f. *agariciformis* (Pallas) Lemoine 1911

Lithophyllum lichenoides var. *agariciformis* (Pallas) Cotton 1912

Lithothamnion lichenoides var. *agariciformis* (Pallas) Newton 1931

Mesophyllum lichenoides f. *agariciformis* (Pallas) Hamel & Lemoine 1953

Morphology: monomerous thallus, with multilayered coaxial core. Core cells are rectangular (23-31 µm diameter per 7-12 µm height) and decrease in dimension in the peripheral thallus. This species presents cellular fusions. Hypothallus is coaxial, rarely non coaxial with a thickness of 120 µm. Perithallus is 50 µm thick and does not show stratification. Epithallial cells are rounded. Asexual conceptacles are multiporate, prominent and hemispherical, with an external diameter at least 1250 µm and height of 159-230 µm. They are placed in contact with hypothallus.

Ecology: both on hard and mobile substrates, presenting different morphologies, usually in high hydrodynamic conditions. It is considered as epiphyte by Basso (1995). It is often found in coralligenous environment. On mobile substrate it characterizes DC and SGCF biocoenoses, forming also boxwork rhodoliths.

Geographic distribution: the occurrence of this species currently in Mediterranean Sea is still debated.

Stratigraphic distribution: Upper-Pleistocene deposits of Calabria region (this thesis).

Phymatolithon calcareum **(Pallas) W.H. Adey & D.L. McKibbin 1970**

Millepora calcarea Pallas 1766

Melobesia calcarea (Pallas) Harvey 1849

Spongites calcarea (Pallas) Kützing 1849

Lithothamnion calcareum (Pallas) Areschoug 1852

Lithophyllum calcareum (Pallas) Foslie 1898

Paraspora calcarea (Pallas) Heydrich 1908

Millepora polymorpha Linnaeus 1767

Apora polymorpha Gunnerus 1768

Melobesia compressa M'Calla 1849

Lithothamnion polymorphum (Linnaeus) Areschoug 1852

Eleutherospora polymorpha (Linnaeus) Heydrich 1900

Morphology: fragile crustose plants, living attached to the substrate or unattached plants, varying from single branches to sub-globular or flattened branching systems, sparsely to densely branches, forming both maërl and prâline rhodoliths. Usually it is associated to *L. pustulatum*, forming multi-specific rhodoliths. Unattached plants may reach about 7 cm in diameter with branches up to 6 mm in diameter. The surface can be smooth or flaky.

Hypothallus presents rectangular cells. Perithallus is multilayered presenting ovoid cells. Asexual conceptacles are multiporate and submerged into the thallus.

Ecology: both infralittoral and circalittoral. Exclusive species of DC biocoenosis, usually associated to *Lithothamnion corallioides*, forming maërl beds (Pérès & Picard, 1964). Typically found in less than 20 m depth on sand, mud or gravel substrata in areas that are protected from strong wave action but have moderate to high water flow.

Geographic distribution: common in all the Mediterranean Sea.

Stratigraphic distribution: since Oligocene. It has been reported for: Tortonian deposits near Alessandria (Italy) (Vannucci *et al.*, 1997); Burdigalian deposits in Piemonte region (Conti, 1943; Vannucci *et al.*, 1993) and Crosica region (Bellini & Mastrorilli, 1975; Basso *et al.*, 1997); Messinian deposits (Spain and Southern Italy) (Braga *et al.*, 2009); Piacenzian deposits near Alessandria (Italy) (Vannucci *et al.*, 1994) and Cadiz (Spain) (Aguirre *et al.*, 1993); Pleistocene deposit of Sicilia region (Di Geronimo, 1995); Upper-Pleistocene deposits of Calabria region (this thesis; Holocene marine sediments of Pontian islands (Corselli *et al.*, 1994).

As *Lithothamnion calcareum* in Tyrrhenian deposits near Alicante (Spain) (Segonzac, 1990).

4.3 BIOGENIC GRAINSTONE, PACKSTONE AND WACKESTONE UNITS

4.3.1 MOLLUSK AND BRYOZOAN FOSSIL ASSEMBLAGES

4.3.1.1 CAPO COLONNA MARINE TERRACE

Bioclastic packstone units characterized the deposits of Capo Colonna marine terrace.

First stratigraphic sections CC5 (a-d), CC6, CC7 (a-b), CC8 are characterized at the base by thick layers dominated by bryozoans wackestone and a well-developed biogenic packstones showing different facies dominated by mollusks or rhodoliths. These sections present at the top of bioclastic packstone a well-defined hardground, marked by the presences of *G. lapidicus*.

Moreover the cavities of algal build-ups and the spaces among different bioconstructed algal build-ups are characterized by packstone/grainstone units, as the top of several stratigraphic sections, with deposits more than 1 m thick presenting different sedimentary structures.

The packstone units are diversely lithified, and show different grain-size.

Identified mollusk and bryozoan list with short description of shell morphology, ecology, geographic and stratigraphic distribution is reported in Appendix V and VI.

cc35

Bryozoan wackestone sampled at the base of section CC5b.

3 bivalve species have been identified.

Species	A	Dm (%)	S	C	Ecology	Substrate
Chlamys sp.	2	33,33	A	3	epifaunal	
Anomia sp.	1	16,67	J	2	epifaunal	
Spondylus sp.	3	50,00	J	2	epifaunal	

This unit is characterized by the accumulation of bryozoan’s fragments. 6 species of bryozoans have been identified. These species are strictly linked to coralligenous environment (C), among which *Pentapora fascialis* (Pallas, 1776) is an exclusive species of C biocoenosis (Pérès 6 Picard, 1964).

Species	Ecology	Substrate
Reteporella beaniana	C	rocky
Pentapora fascialis	exl. C	
Membranipora membranacea		hard substrate
Celleporaria sp.		
Miriapora truncata	C	
Frondipora verrucosa	C	

cc36

Gastropods-facies packstone, sampled into section CC5c.

28 gastropods species have been identified.

Species	A	Dm (%)	S	C	Ecology	Substrate
Bolma rugosa	4	0,95	A	3	epifaunal	hard substrate
Homalopoma sanguineum	6	1,43	P	4	HP-C	hard substrate
Clanculus corallinus	8	1,90	P	4	epifaunal	hard substrate
Jujubinus exasperatus	49	11,64	P	4	C	
Jujubinus striatus	23	5,46	P	4	infralittoral	
Gibbula ardens	8	1,90	A	4	infralittoral	
Gibbula adriatica	3	0,71	A	3	infralittoral	
Rissoina bruguieri	46	10,93	A	4	infralittoral	
Mangelia barashi	3	0,71	A	2		
Raphitoma horrida	1	0,24	A	4	infralittoral	
Bela nebula	1	0,24	J	3	epifaunal	muddy sandy gravel
Tricolia pullus	68	16,15	P	4	epifaunal, infralittoral	sandy bottom
Alvania cancellata	39	9,26	A	4	epifaunal, infralittoral	hard substrate
Conus mediterraneus	3	0,71	A	3	infralittoral	
Gibberula philippii	7	1,66	A	2	epifaunal	muddy sand
Trivia multilirata	5	1,19	A	4	epifaunal	hard substrate
Cerithium sp.		0,00				
Notocochlis gualteriana	2	0,48	A	4	infaunal	
Nassarius incrassatus	16	3,80	A	4	epifaunal	hard substrate
Nassarius sp.	1	0,24	A	2		
Rissoa variabilis	24	5,70	P	4	epifaunal, infralittoral	
Columbella rustica	10	2,38	A	2	exl AP	
Vexillum ebenus	4	0,95	A	3		
Cyclope neritea	3	0,71	A	2	epifaunal	
Nassarius lima	11	2,61	P	3	infralittoral	muddy sand
Ocinebrina aciculata	7	1,66	P	3		
Bittium reticulatum	58	13,78	P	3	AP/HP	hard substrate
Monophorus perversus	3	0,71	A	2	C	hard substrate
Bittium latreilli	8	1,90	P	3	infralittoral	hard substrate

The mollusk fossil assemblage shows infralittoral affinity (81%= infra+AP+HP species), with exclusive or preferential species of AP (6%) and HP (6%) biocoenosis, mixed to species representative of coralligenous biocoenosis. Generally species prefer hard substrate (69%) (Fig. 4.70).

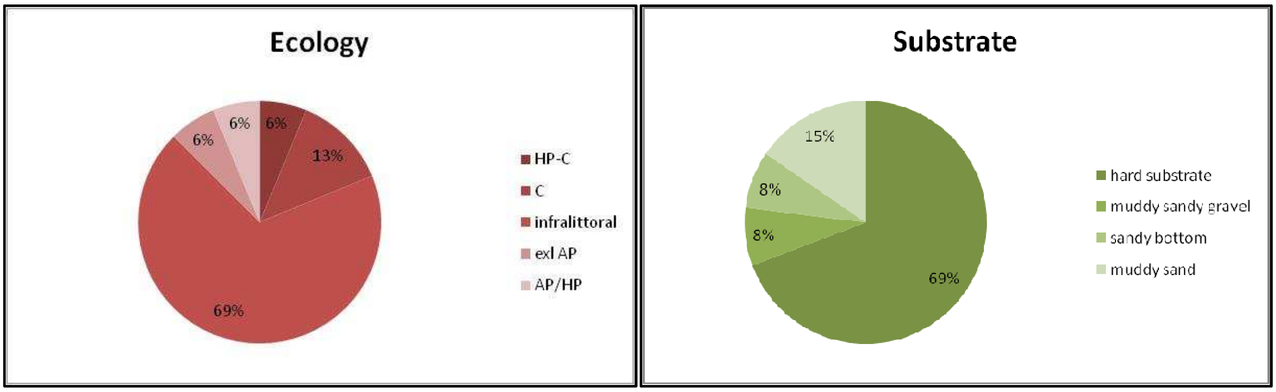


Fig. 4.70: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

cc37

Bryozoans wackestone, sampled at the base of section CC5d.

5 mollusk species have been identified, 4 bivalves and 1 gastropod.

Species	A	Dm (%)	S	C	Ecology	Substrate
Aequipecten commutatus	1	12,50	A	4	epifaunal	
Aequipecten opercularis	2	25,00	A	3	epifaunal	gravelly sand
Pseudamussium sulcatum	1	12,50	A	2	epifaunal	all type of bottoms
Heteranomia squamula	3	37,50	A	3	epifaunal	hard substrate
Alvania cancellata	1	12,50	A	4	epifaunal, infralittoral	hard substrate

The mollusk species are typically linked to hard substrate.

This unit is characterized by the accumulation of bryozoan' fragments. 7 species of bryozoans have been identified. These species are strictly linked to coralligenous environment (C), among which *P. fascialis* is an exclusive species of C biocoenosis (Pérès 6 Picard, 1964).

Species	Ecology	Substrate
Reteporella beaniana	C	rocky
Pentapora fascialis	exl C	
Membranipora membranacea		hard substrate
Disporella sp.		
Celleporaria sp.		
Lichenopora sp.		
Myriapora truncata	C	

cc39

Gastropods packstone, sampled into section CC5d.

38 mollusk species have been identified, 19 bivalves, 20 gastropod and 1 scaphopod.

Species	A	Dm (%)	S	C	Ecology	Substrate
Corbula gibba	5	1,74	P	3	pref PE	
Arca tetragona	2	0,69	J	2	pref DC	little hard substrate
Barbatia clathrata	9	3,13	P	3	epifaunal	
Arca noae	1	0,35	J	3	epifaunal	hard substrate
Limatula subauriculata	1	0,35	A	4		
Bathyarca philippiana	1	0,35	J	3	infra-circalittoral	hard substrate
Nuculana minuta	1	0,35	J	3	infaunal	muddy sand
Clausinella fasciata	2	0,69	J	3	infaunal	coarse bottom
Clausinella brognartii	2	0,69	J	4	infaunal	coarse bottom
Glycymeris glycymeris	4	1,39	J	3	exl SGCF	each type of bottom
Plagiocardium papillosum	3	1,04	J	3	pref DC, also in SFBC	
Parvicardium exiguum	5	1,74	P	3	infaunal	
Ctena decussata	3	1,04	A	2	epifaunal	muddy bottoms
Dosinia lupinus	3	1,04	P	4	exl PE	
Nucula sulcata	1	0,35	A	2	exl VTC	muddy-sandy
Mimachlamys varia	1	0,35	J	3	C	
Pododesmus aculeatus	2	0,69	A	2		
Tricolia pullus	4	1,39	P	3	epifaunal, infralittoral	sandy bottoms
Bittium reticulatum	120	41,67	P	3	AP/HP	hard substrate
Rissoa variabilis	21	7,29	P	3	epifaunal, infralittoral	
Alvania cancellata	46	15,97	A	4	epifaunal, infralittoral	hard substrate
Alvania hirta	4	1,39	A	3	epifaunal, infralittoral	
Rissoina bruguieri	3	1,04	A	3	epifaunal, infralittoral	
Vexillum ebenus	3	1,04	P	3		
Conus mediterraneus	1	0,35	A	2	infralittoral	hard substrate
Trivia sp.	1	0,35	A	1		
Jujubinus striatus	15	5,21	P	2	infralittoral	
Jujubinus exasperatus	2	0,69	A	2	C	
Clanculus corallinus	1	0,35	J	4	epifaunal	hard substrate
Bolma rugosa	4	1,39	J	2	epifaunal	hard substrate
Gibbula ardens	4	1,39	J	2	infralittoral	
Gibbula magus	4	1,39	J	2	infralittoral	muddy sand
Raphitoma echinata	3	1,04	J	4	infralittoral	muddy sand
Raphitoma sp.	1	0,35	J	2		
Cocculina mamilla	2	0,69	J	2		
Diodora graeca	1	0,35	A	4	epifaunal	
Raphitoma linearis	1	0,35	J	4	shallow infralittoral	gravel
Dentalium sp.	1	0,35	A	2		

The mollusk fossil assemblage is strictly infralittoral (46%), with species typically linked to coarse and hard substrate (55%) (Fig. 4.71).

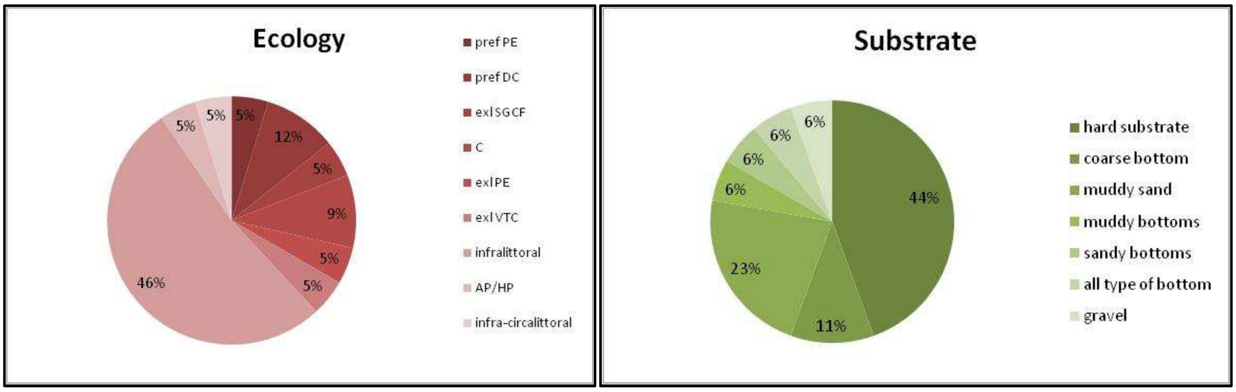


Fig. 4.71: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

cc41

Coarse bioclastic packstone, sampled into the section Cc6.

23 mollusk species have been identified, 11 bivalves and 12 gastropods.

Species	A	Dm (%)	S	C	Ecology	Substrate
Barbatia clathrata	3	2,42	J	3		
Bathyarca philippiana	3	2,42	J	3	infra-circalittoral	hard substrate
Nucula nucleus	3	2,42	J	2	infaunal	coarse bottom
Clausinella brognartii	2	1,61	A	2	infaunal	coarse bottom
Glycymeris glycymeris	1	0,81	J	3	exl SGCF	each type of bottom
Corbula gibba	1	0,81	J	2	pref PE	
Dosinia lupinus	5	4,03	J	3	exc PE	
Parvicardium exiguum	2	1,61	J	3	infaunal	
Spondylus gaederopus	1	0,81	J	2	epifaunal	hard substrate
Acanthocardia sp.	1	0,81	J	2		
Mimachlamys varia	3	2,42	J	4	C	
Bittium reticulatum	64	51,61	P	3	AP/HP	hard substrate
Bolma rugosa	1	0,81	J	3	epifaunal	hard substrate
Gibbula magus	1	0,81	J	2	infralittoral	muddy-sandy
Homalopoma sanguineum	1	0,81	J	2	HP-C	hard substrate
Clanculus corallinus	1	0,81	J	4	epifaunal	hard substrate
Natica sp.	2	1,61	J	1		
Alvania cancellata	21	16,94	A	3	epifaunal, infralittoral	hard substrate
Alvania hirta	1	0,81	A	4	epifaunal, infralittoral	
Jujubinus exasperatus	3	2,42	A	2	C	
Columbella rustica	1	0,81	A	1	exl AP	
Diodora gibberula	2	1,61	A	1	epifaunal	coarse, hard substrate
Bela sp.	1	0,81	A	2		

The mollusk fossil assemblage is infralittoral (53%), even if species linked to coralligenous biocoenosis are present (18,5%). The species are typically of hard substrate (Fig. 4.72).

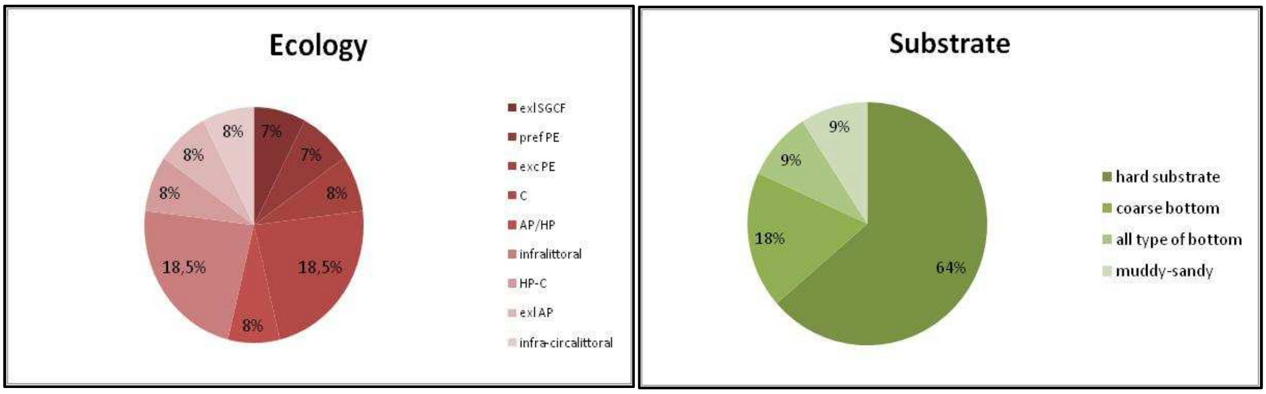


Fig. 4.72: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

A unique species of bryozoans has been identified.

Species	Ecology	Substrate
Celleporaria sp.		

cc43

Coarse bioclastic packstone, sampled at the top of section CC6.

36 mollusk species have been identified, 14 bivalves and 22 gastropods.

Species	A	Dm (%)	S	C	Ecology	Substrate
Arca tetragona	1	0,40	J	2	pref DC	
Heteranomia squamula	1	0,40	J	2	epifaunal	hard substrate
Glycymeris glycymeris	5	1,98	J	3	exl SGCF	
Nucula nucleus	4	1,58	J	2	infaunal	coarse substrate
Corbula gibba	1	0,40	J	3	pref PE	
Dosinia lupinus	3	1,19	J	3	exl PE	
Clausinella fasciata	2	0,79	J	3	infaunal	coarse substrate
Clausinella brognartii	1	0,40	J	2	infaunal	coarse substrate
Plagiocardium papillosum	1	0,40	J	3	pref DC, also in SFBC	
Parvicardium pinnulatum	1	0,40	A	3	infralittoral	
Parvicardium exiguum	5	1,98	P	3	infaunal	all type of bottom
Cardita senegalensis	3	1,19	J	2	infralittoral	
Bathyarca philippiana	8	3,16	P	3	infra-circalittoral	hard substrate
Barbatia clathrata	12	4,74	P	3		
Jujubinus exasperatus	3	1,19	J	2	C	
Alvania cancellata	28	11,07	A	3		hard substrate
Alvania hirta	2	0,79	A	3	infralittoral	
Alvania testae	8	3,16	A	3	deep	
Tricolia pullus	2	0,79	J	4	epifaunal, infralittoral	sandy bottoms
Emarginula adriatica	1	0,40	A	4	epifaunal, infralittoral	
Diodora gibberula	1	0,40	J	3	epifaunal	coarse, hard substrate
Clanculus corallinus	1	0,40	J	3	epifaunal	hard substrate
Notocochlis gualteriana	1	0,40	J	4	infaunal	
Homalopoma sanguineum	5	1,98	J	3	HP-C	hard substrate
Conus sp.	1	0,40	A	2		
Gibbula magus	1	0,40	A	2	infralittoral	muddy-sandy
Gibbula ardens	3	1,19	A	2	infralittoral	
Gibbula sp.	1	0,40	A	1		
Rissoina bruguieri	8	3,16	A	2	infralittoral	
Rissoa variabilis	7	2,77	A	3	epifaunal, infralittoral	
Bolma rugosa	1	0,40	J	1	epifaunal	hard substrate
Epitonium sp.	2	0,79	A	2		
Vexillum ebenus	1	0,40	J	2		
Columbella rustica	2	0,79	J	3	exl AP	
Bittium reticulatum	125	49,41	P	4	AP/HP	hard substrate
Ocinebrina aciculata	1	0,40	J	4		

The mollusk assemblage is characterized by species linked to biocoenoses AP, SGCF, DC and PE, so it has an infralittoral affinity and characterized usually coarse or hard substrate (69%) (Fig. 4.73).

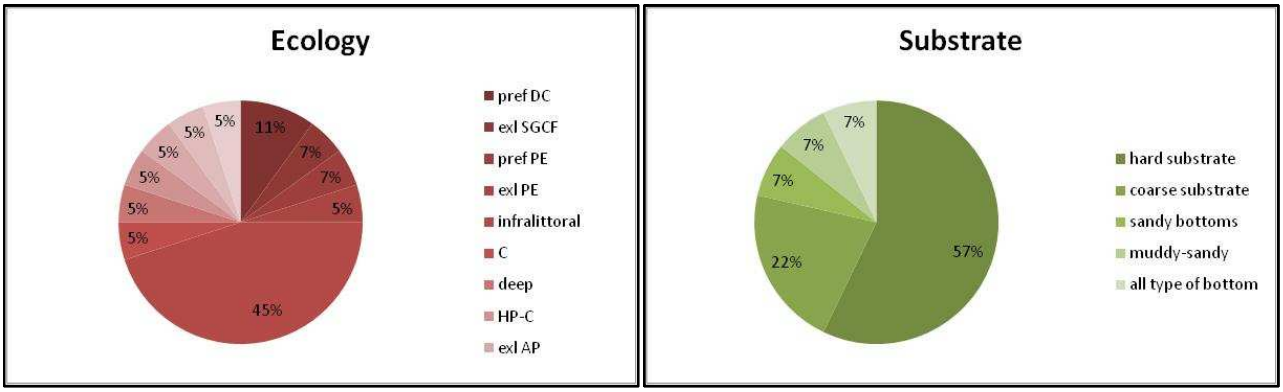


Fig. 4.73: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

Two species of bryozoans have been identified. *Myriapora truncata* (Pallas, 1766) is linked to coralligenous environment (C).

Species	Ecology	Substrate
Celleporaria sp.		
Myriapora truncata	C	

cc44

Large bivalves sampled randomly at the top of section CC6.

3 species have been identified, among which *Glycymeris glycymeris* (Linneo, 1758) is an exclusive species of SGCF biocoenosis (Pérès & Picard, 1964).

Species	A	Dm (%)	S	C	Ecology	Substrate
Glycymeris glycymeris	3	42,86	a	4	exl SGCF	all type of bottom
Chlamys sp.	1	14,29	a	4	epifaunal	
Venus nux	3	42,86	a	3		

cc45

Basal wackestone characterized by the presence of biogenic cobbles, sampled into the section CC7.

4 mollusk species have been identified, 2 bivalves and 2 gastropods.

Species	A	Dm (%)	S	C	Ecology	Substrate
Acanthocardia echinata	1	25,00	A	1	infaunal	gravelly sand
Parvicardium exiguum	1	25,00	J	1	infaunal	all type of bottom
Rissoina bruguieri	1	25,00	A	2	infralittoral	
Alvania cancellata	1	25,00	A	3	epifaunal, infralittoral	

6 species of bryozoans have been identified. They are linked to coralligenous environment (C). *M. truncata* e *Frondipora verrucosa* (Lamouroux, 1821) are linked to C biocoenosis (Pérès & Picard, 1964).

Species	Ecology	Substrate
Celleporaria sp.		
Membranipora membranacea		hard substrate
Reteporella sp.		
Lichenopora sp.		
Myriapora truncata	C	
Frondipora verrucosa	C	

cc46

Bryozoans wackestone, sampled at the top of section CC7.

4 bivalve’s species have been identified.

Species	A	Dm (%)	S	C	Ecology	Substrate
Spondylus sp.	1	8,33	J	4	epifaunal	
Anomia sp.	5	41,67	J	3		
Mimachlamys varia	5	41,67	P	3	C	
Talochlamys multistriata	1	8,33	A	4	epifaunal	coarse bottom

This unit is formed by the accumulation of bryozoan’ fragments. 9 species of bryozoans have been identified, showing a link to coralligenous environment.

Species	Ecology	Substrate
Rethoporella sp.		
Frondipora verrucosa	C	
Membranipora sp.		
Lichenopora sp.		
Hippodisia sp.		
Membranipora membranacea		hard substrate
Myriapora truncata	C	
Celleporaria sp.		
Onychocella sp.		

cc65

Maërl, sampled at the base of section CC11.

1 bivalve species has been identified.

Species	A	Dm (%)	S	C	Ecology	Substrate
Talochlamys multistriata	4	100	A	3	epifaunal	coarse bottom

3 species of bryozoans have been identified.

Species	Ecology	Substrate
Retheporella sp.		
Onychocella sp.		
Celleporaria sp.		

4.3.1.2 LE CASTELLA MARINE TERRACE

Bioclastic packstone and grainstone characterize the deposits of Le Castella marine terrace.

These units fill the cavities of cavernous algal build-ups and the channels formed among different bioconstructed banks.

Moreover packstone/grainstone units characterize the top of several stratigraphic sections, with deposits more than 1 m thick.

The biogenic components mostly contribute to this packstone. The packstone are diversely lithified, and shows different grain-size. Furthermore samples have been collected in packstones characterized by different sedimentary structures, connected to different shelf paleoenvironment.

Identified mollusk and bryozoan list with short description of shell morphology, ecology, geographic and stratigraphic distribution is reported in Appendix V and VI.

lca 31

Coarse bioclastic packstone sampled into the cross-bedding structures at the top of section Lca9.

12 mollusks species have been identified, 5 bivalves and 7 gastropods. The residual is rich in annelids, corals, bryozoans and siliciclastic grains.

Species	A	Dm (%)	S	C	Ecology	Substrate
Pteromeris minuta	2	6,90	J	4		
Venus sp.	1	3,45	A	2	epifaunal	
Plagiocardium papillosum	2	6,90	A	2	pref DC, also in SFBC	
Glycymeris glycymeris	2	6,90	A	2	exl SGCF	each type of bottom
Corbula gibba	7	24,14	A	2	pref PE	
Conus mediterraneus	1	3,45	J	3	infralittoral	hard substrate
Homalopoma sanguineum	1	3,45	A	4	HP-C	hard substrate
Bittium reticulatum	8	27,59	A	3	AP/HP	hard substrate
Nassarius corniculum	1	3,45	A	3		
Jujubinus striatus	2	6,90	A	2	epifaunal	
Alvania cancellata	1	3,45	J	3	epifaunal, infralittoral	hard substrate
Rissoina bruguieri	1	3,45	A	2	infralittoral	

The mollusk fossil assemblage is strictly infralittoral (30%), with species typically linked to hard substrate (67%) (Fig. 4.74).

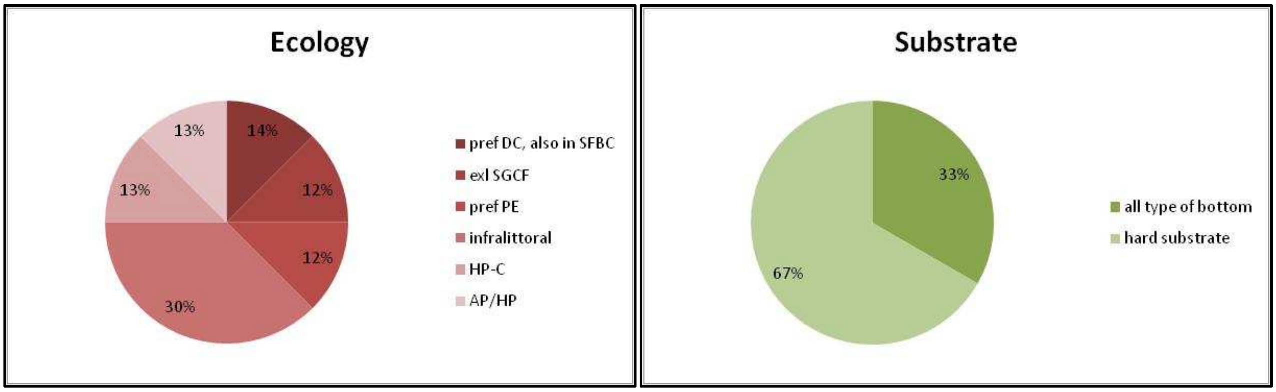


Fig. 4.74: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

lca 46

Coarse bioclastic packstone directly over the algal build-ups sampled into section Lca11.

42 mollusk species have been identified, 16 bivalves, 24 gastropods and 2 scaphopods. The residual is rich in annelids, corals, bryozoans and serpulids. *Rissoa violacea* Desmarest, 1814 and *Gibbula magus* (Linneo, 1758) still present their original colors.

Species	A	Dm (%)	S	C	Ecology	Substrate
Mimachlamys varia	2	1,05	A	1	C	
Chlamys sp.	1	0,52	A	1	epifaunal	
Plagiocardium sp.	1	0,52	A	2		
Corbula gibba	12	6,28	A	1	pref PE	
Asperarca nodulosa	8	4,19	P	4	coralligenous	hard bottom
Arca tetragona	2	1,05	J	2	pref DC	little hard substrate
Nucula sulcata	1	0,52	A	4	exl VTC	muddy-sandy
Nucula sp.	1	0,52	J	2		
Bathyarca philippiana	1	0,52	J	4	infra-circalittoral	hard substrate
Anomia sp.	1	0,52	J	3		
Glycymeris glycymeris	2	1,05	P	3	exl SGCF	each type of bottom
Pteromeris minuta	2	1,05	J	3		
Dosinia lupinus	2	1,05	J	3	exc PE	
Acanthocardia echinata	1	0,52	A	3	infaunal	
Cardita calyculata	3	1,57	J	2	infralittoral	hard substrate
Nuculana pella	4	2,09	J	3	infra-circalittoral	muddy-sandy
Cocculina sp.	1	0,52	A	3-4		
Homalopoma sanguineum	19	9,95	A	4	HP-C	hard substrate
Rissoina bruguieri	13	6,81	A	3	infralittoral	
Diodora sp.	1	0,52	A	3		
Epitonium candidissimum	1	0,52	J	3		
Alvania cancellata	19	9,95	A	3	epifaunal, infralittoral	hard substrate
Clanculus corallinus	1	0,52	A	1	epifaunal	hard substrate
Jujubinus exasperatus	14	7,33	A	3	C	
Bolma rugosa	2	1,05	P	3	epifaunal	hard substrate
Alvania punctura	6	3,14	A	4	epifaunal, DC	
Pusillina radiata	6	3,14	A	4	infralittoral	
Rissoa violacea	1	0,52	A	3	AP	sandy gravelly
Rissoa variabilis	4	2,09	A	4	epifaunal	
Nassarius lima	2	1,05	J	3	semi-infaunal	muddy sandy
Chauvetia sp.	1	0,52	A	2		
Gibbula magus	4	2,09	P	4	infralittoral	muddy-sandy
Monophorus perversus	3	1,57	J	3	C	hard substrate
Bittium reticulatum	30	15,71	P	4	AP/HP	hard substrate
Turritella communis	1	0,52	J	3	pref VTC, accomp DL	muddy
Diodora gibberula	3	1,57	A	3	epifaunal	coarse, hard substrate
Tricolia pullus	3	1,57	A	3	epifaunal, infralittoral	sandy bottoms
Nassarius corniculum	1	0,52	A	4		
Columbella rustica	1	0,52	A	3	exl AP	hard substrate
Notocochlis gualteriana	3	1,57	J	3	infaunal	
Antalis inaequicostata	4	2,09	A	2		hard substrate
Dentalium sp.	3	1,57	A	2		

The mollusk fossil assemblage is linked to infralittoral paleoenvironment (25%), AP (18%) and HP-C biocoenoses (10%), influenced by species of coralligenous (C=8%), of DC biocoenosis (16%) and mostly linked to hard substrate (62%) (Fig. 4.75)

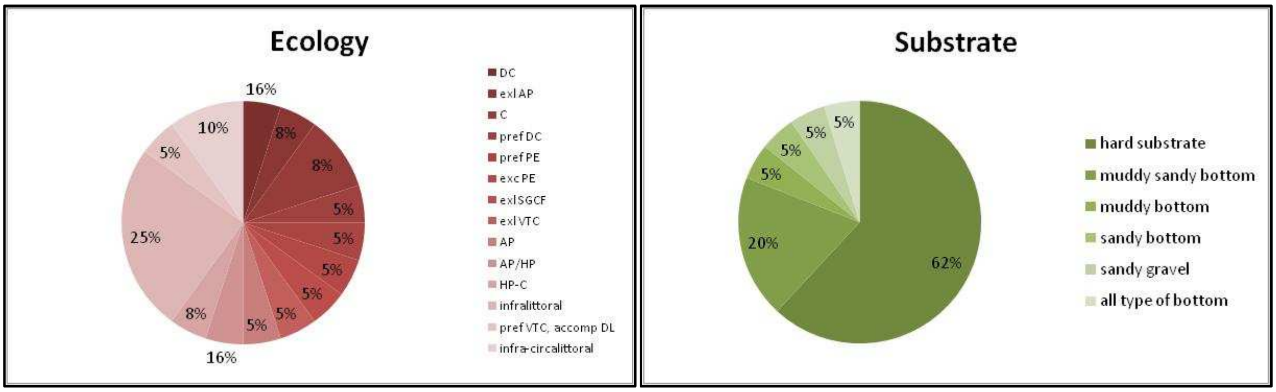


Fig. 4.75: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

lca 47

Coarse bioclastic packstone directly over the Cutro marly clay sampled into section Lca11. From a stratigraphic point of view it corresponds to algal build-up, placed below the packstone of sample lca46.

5 mollusk species have been identified, 1 bivalve and 4 gastropods. The biogenic fragments are not preserved, often abraded, broken or presenting decalcification and not useful to identification.

Species	**A**	**Dm (%)**	**S**	**C**	**Ecology**	**Substrate**
Nucula sp.	2	22,22	A	1		
Turritella sp.	1	11,11	A	1		
Conus sp.	4	44,44	P	1		
Rissoina bruguieri	1	11,11	J	2	infra	
Homalopoma sanguineum	1	11,11	J	2	HP-C	hard substrate

lca 48

Coarse bioclastic packstone sampled into section Lca10, at the top into the clinoformal bodies.

57 mollusk species have been identified, 24 bivalve, 31 gastropods and 2 scaphopods. The residual is rich in annelids, corals, bryozoans, serpulids and coralline crusts.

Species	A	Dm (%)	S	C	Ecology	Substrate
Glycymeris glycymeris	3	0,77	J	3	exl SGCF	all type of bottom
Nuculana pella	11	2,82	J	4	infra-circalittoral	muddy-sandy
Nucula nucleus	7	1,79	J	4	epifaunal	coarse bottom
Nucula sulcata	6	1,54	J	4	exl VTC	muddy-sandy
Arca tetragona	8	2,05	J	4	pref DC	little hard substrate
Asperarca nodulosa	25	6,41	J	4	coralligenous	hard bottom
Barbatia clathrata	15	3,85	J	3		
Mimachlamys varia	6	1,54	J	4	C	
Chlamys sp.	2	0,51			epifaunal	
Pseudamussium peslutrae	1	0,26	A	4	pref DE	
Lutraria angustior	17	4,36	P	3	infralittoral	soft bottom
Plagiocardium papillosum	15	3,85	P	4	pref DC, also in SFBC	
Parvicardium exiguum	2	0,51	J	3	infralittoral	all type of bottom
Lucinella divaricata	2	0,51	J	4		sandy bottoms
Ctena decussata	6	1,54	J	3	infralittoral	muddy bottoms
Venus casina	2	0,51	J	4	exl SGCF	
Chama gryphoides	4	1,03	J	2		hard substrate
Acanthocardia echinata	5	1,28	J	2	infaunal	
Anomia sp.		0,00				
Loripes lacteus	24	6,15	J	4	pref SVMC	sand
Corbula gibba	63	16,15	J	3	pref PE	
Astarte sulcata	4	1,03	J	3	exl DL	all type of bottom
Mactra stultorum	5	1,28	J	4	infaunal	sandy bottoms
Pteromeris minuta	1	0,26	J	4	infaunal	
Emarginula rosae	4	1,03	J	3	epifaunal, circalittoral	
Emarginula papillosa	8	2,05	J	4	infra-circalittoral	
Puncturella noachina	5	1,28	J	4	infralittoral	hard substrate
Diodora gibberula	7	1,79	P	4	epifaunal	coarse, hard substrate
Diodora sp.	1	0,26	A	2		
Alvania cimex	5	1,28	A	4	epifaunal, infralittoral	hard substrate
Alvania mamillata	1	0,26	A	4	epifaunal, infralittoral	
Turritella turbona	1	0,26	A	2	exl DC	sandy bottoms
Bolma rugosa	1	0,26	A	1	epifaunal	hard substrate
Haliotis tuberculata f. lamellosa	4	1,03	P	4	epifaunal, infralittoral	hard substrate
Emarginula sp.	1	0,26	A	1		
Clanculus corallinus	12	3,08	P	4	epifaunal	hard substrate
Homalopoma sanguineum	8	2,05	P	4	HP-C	hard substrate
Gibbula richardi	1	0,26	A	4	acc GI	
Gibbula racketti	1	0,26	J	4	infralittoral	
Gibbula guttadauri	3	0,77	J	3	infralittoral	
Gibbula magus	3	0,77	J	3	infralittoral	muddy-sandy
Gibbula sp.	1	0,26	J	2		
Epitonium candidissimum	1	0,26	J	2		
Tricolia tenuis	12	3,08	P	4	epifaunal, infralittoral	sandy bottoms
Tricolia pullus	3	0,77	J	4	epifaunal, infralittoral	sandy bottoms
Rissoina bruguieri	4	1,03	J	3	infralittoral	
Cerithium sp.	2	0,51	A	2		

Rissoa ventricosa	1	0,26	J	4	infralittoral	
Rissoa sp.	4	1,03	J	2		
Trophonopsis muricata	1	0,26	J	3	epifaunal	hard substrate
Bittium reticulatum	32	8,21	P	4	AP/HP	hard substrate
Cerithium vulgatum	2	0,51	J	3		hard substrate
Monophorus perversus	2	0,51	J	3	C	hard substrate
Jujubinus exasperatus	19	4,87	P	4	C	
Natica hebraea	1	0,26	A	3	epifaunal	
Antalis vulgaris	2	0,51	J	4	exl DC	
Antalis agilis	3	0,77	J	3		muddy-sandy

The mollusk fossil assemblages is infralittoral (40%), even if species typical of circalittoral biocoenoses (DC=9%, VTC=3%) are present. Coralligenous species represent the 33%. Usually the mollusk species are linked to coarse and hard bottoms (fig. 4.76).

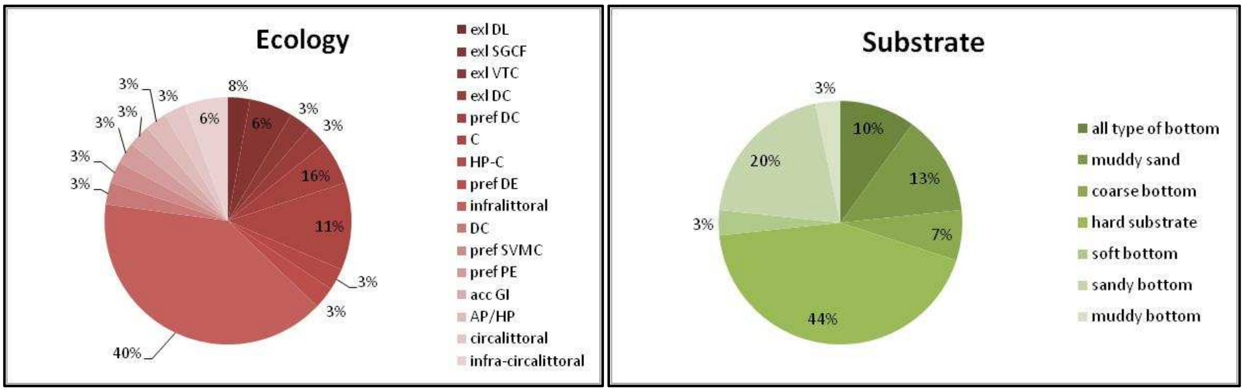


Fig. 4.76: pie charts showing the percentage of species linked to ecological meaning (left) or substrate (right)

4.3.2 UNIVARIATE AND MULTIVARIATE STATISTICAL ANALYSES ON FOSSIL ASSEMBLAGES

4.3.2.1 CAPO COLONNA MARINE TERRACE

Univariate statistical analyses have been conducted on mollusk fossil assemblages.

Species richness varies from 1 to 38 for the total number of species and from 4 to 421 for the total number of individuals. The Shannon diversity Index ranges from 0 (c65) to 2,35 (cc39). The Simpson Index ranges from 0 (cc65) to 0,91 (cc36). Results are reported in Tab. 4.4.

Sample	S	N	Shannon Index H' (log e)	Simpson Index 1-λ'
cc35	3	6	1,01	0,73
cc36	28	421	2,72	0,91
cc37	5	8	1,50	0,86
cc39	38	287	2,35	0,79
cc41	23	124	1,92	0,70
cc43	36	248	2,16	0,73
cc44	3	7	1,00	0,71
cc45	4	4	1,39	1
cc46	4	8	1,07	0,64
cc65	1	4	0	0

Tab. 4.4: results of univariate statistical analyses for Capo Colonna samples

The Shannon diversity Index and 95% confidence intervals are reported in Fig. 4.77 for Capo Colonna samples. Samples cc65 is composed by only one species and it is not reported in the graph.

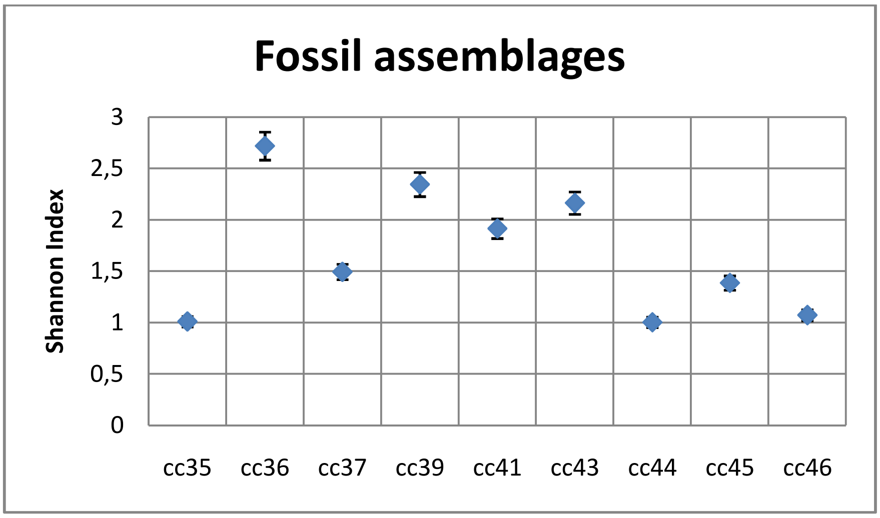


Fig. 4.77: Shannon diversity Index and 95% confidence intervals for Capo Colonna mollusk death assemblages

Samples cc36, cc39 and cc43 have a Shannon Index higher than 2 and present the highest biodiversity, whereas cc35, cc44 and cc46 present the lowest biodiversity with index of 1.

K-dominance curves, representing cumulative rank abundance plotted against species rank, are reported in Fig. 4.78. The most elevated curves, except for cc65 represented by a only 1 species, are those of cc35 and cc44 and represent the lowest variable samples with low numbers of species and specimens for each species, whereas the highest are cc39 and cc43, with the highest diversity in term of number of species.

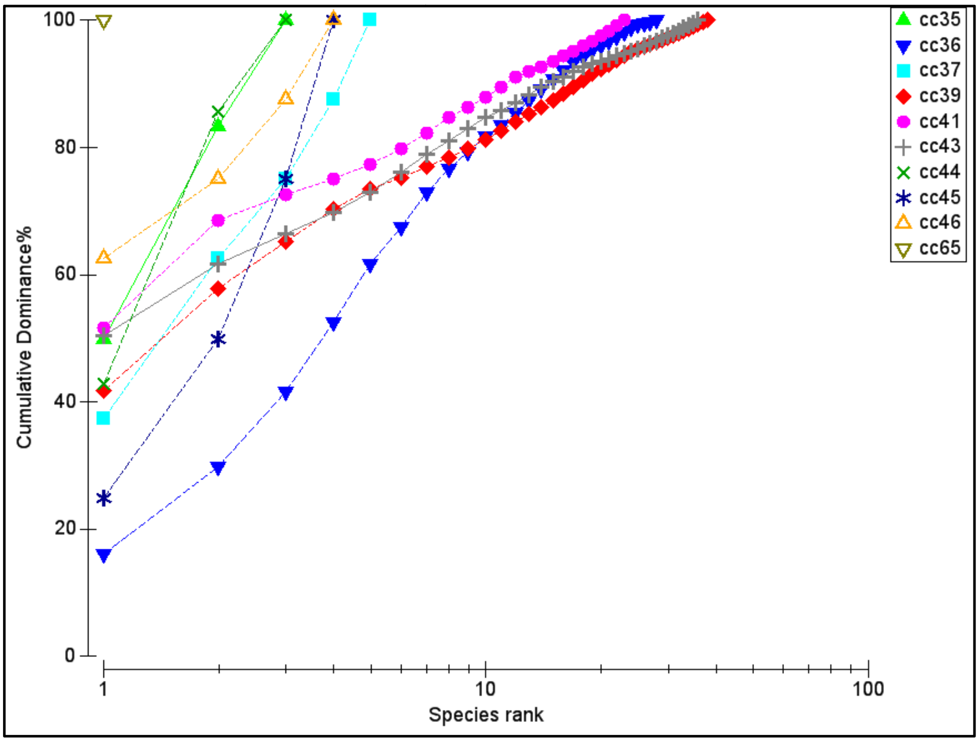


Fig. 4.78: K-dominance curves for Capo Colonna mollusk fossil assemblages

Graphs of hierarchical cluster and MDS ordination analyses, conducted both on the base of the biocenosis meaning of species identified into samples, and on the base of the substrate as edaphic factor linked to the identified species, are reported in Figs. 4.79 and 4.80. A similarity rank of 60% is reported.

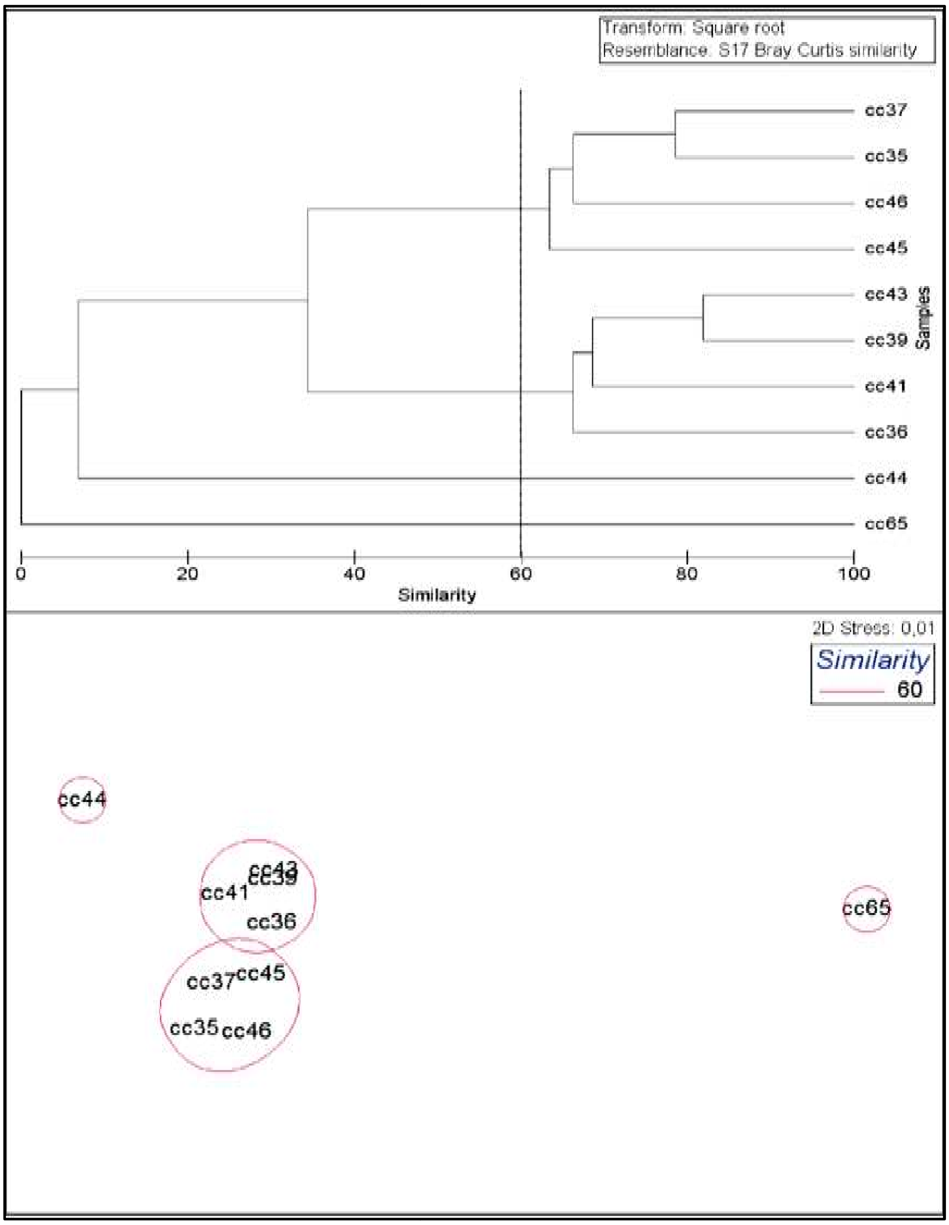


Fig. 4.79: hierarchical cluster and MDS ordination graphs respect to biocoenoses for Capo Colonna fossil assemblages

Hierarchical cluster and MDS ordination on the biocoenoses meaning with a similarity of 60% divided the samples into 4 groups. The first group is characterized by samples cc35, cc37, cc45 and cc46 collected in the bryozoans wackestone showing a high coralligenous affinity. Samples cc36, cc39, cc41 and cc43 form the second group and have been collected in the biogenic packstone above the wackestone. The samples have strong infralittoral affinity. Sample cc44 and sample cc65 represent the third and fourth groups. Samples cc44 is formed by valves randomly sampled at the top of the biogenic packstone, whereas sample cc65 has been collected into the maërl unit.

Similar results are visible into the MDS ordination graph (Fig. 4.80).

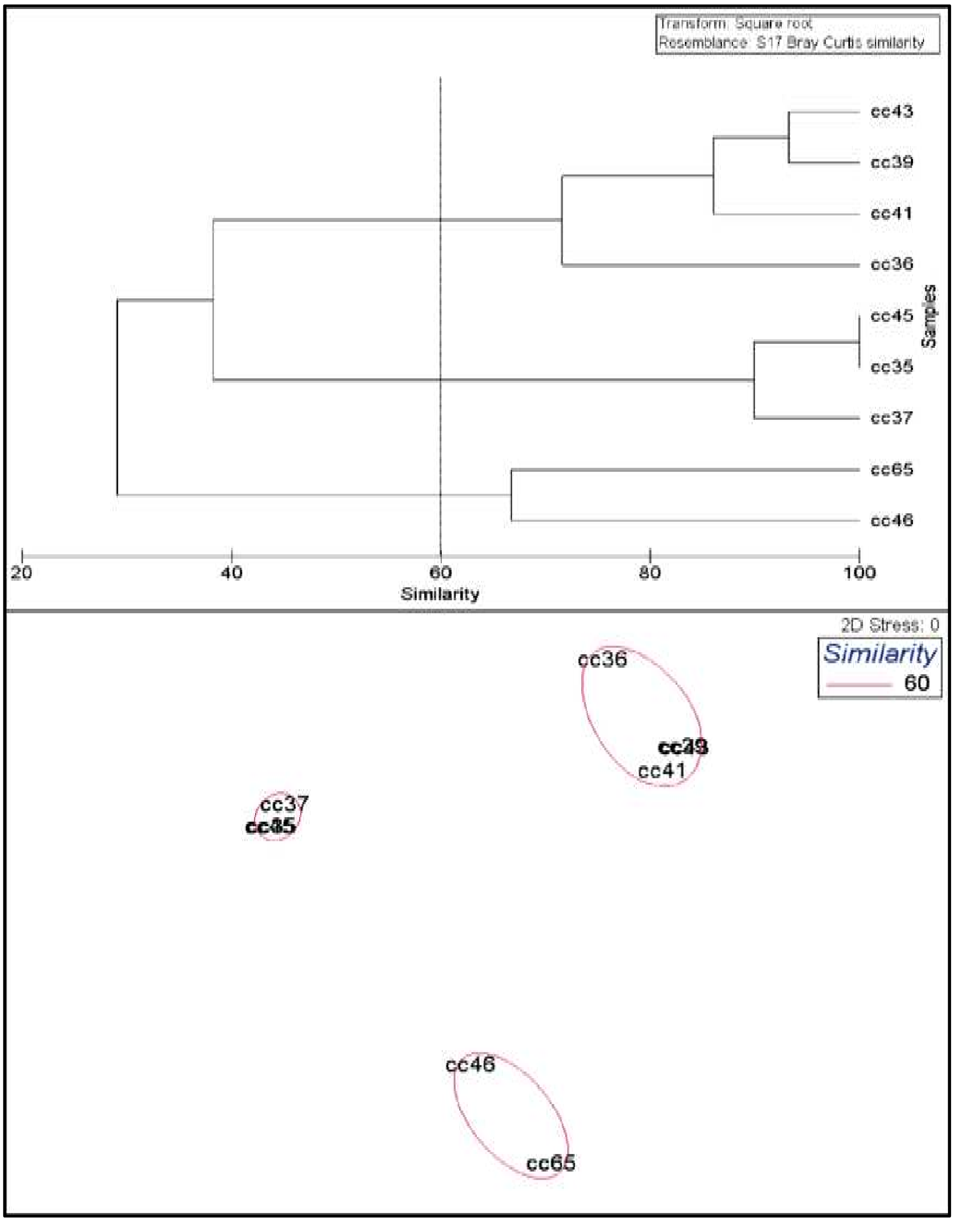


Fig. 4.80: hierarchical cluster and MDS ordination graphs respect to substrate for Capo Colonna fossil assemblages

Samples cc43, cc36, cc39 and cc41 form the bioclastic packstone group samples, and they need coarse or hard substrates. The second group is formed by samples collected in the bryozoan' wackestone (cc35, cc37 and cc45) except for cc46, and they needed hard substrate.

The third group is formed by samples cc46 and cc65, presenting species that need coarse substrate.

4.3.2.2 LE CASTELLA MARINE TERRACE

Species richness varies from 5 to 56 for the total number of species and from 9 to 390 for the total number of individuals. The Shannon diversity Index ranges from 1,43 (lca47) to 3,40 (lca48). The Simpson Index ranges from 0,81 (lca47) to 0,95 (lca48). Results are reported in Tab. 4.5.

Sample	S	N	Shannon Index H' (log e)	Simpson Index 1-λ'
lca31	12	29	2,13	0,87
lca46	42	191	3,14	0,94
lca47	5	9	1,43	0,81
lca48	56	390	3,40	0,95

Tab. 4.5: results of univariate statistical analyses for Le Castella samples

The Shannon diversity Index and 95% confidence intervals are reported in Fig. 4.81 , for mollusk fossil assemblages of Le Castella samples. Samples lca46 and lca48 show high biodiversity, with index higher than 3, whereas samples lca31 and lca47 show the lowest values.

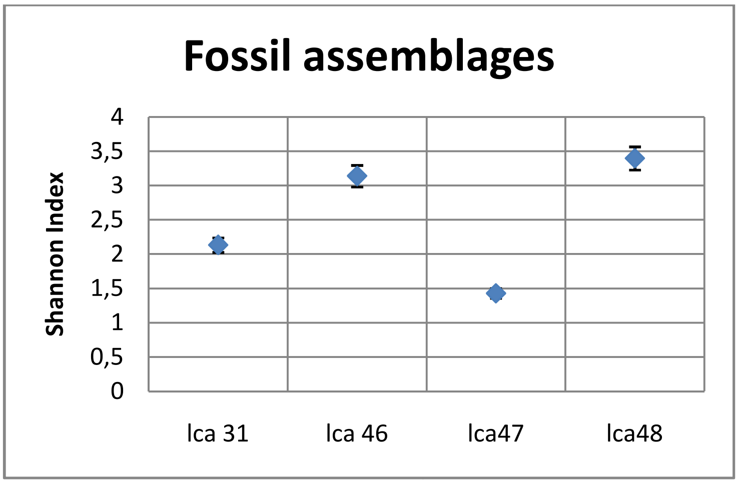


Fig. 4.81: Shannon diversity Index and 95% confidence intervals for Le Castella mollusk fossil assemblages

K-dominance curves, representing cumulative rank abundance plotted against species rank, are reported in Fig. 4.82. The most elevated curve is the lca47 curve, showing the lowest variability, whereas the highest variability, and the corresponding lowest curve, is that of sample lca48.

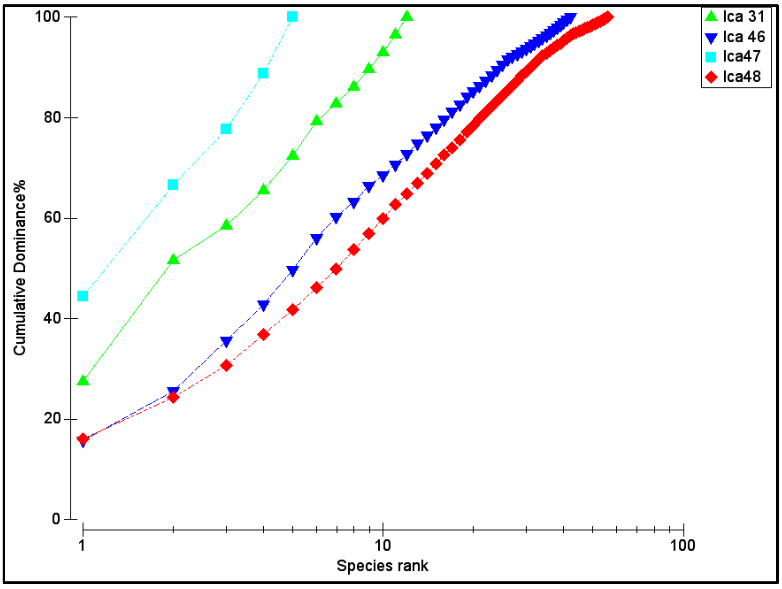


Fig. 4.82: K-dominance curves for Le Castella molluskan fossil assemblages

Graphs of hierarchical cluster and MDS ordination analysis, conducted both on the base of the biocenosis meaning of species identified into samples, and on the base of the substrate as edaphic factor linked to the identified species, are reported in Figs. 4.83 and 4.84. A similarity rank of 60% is reported.

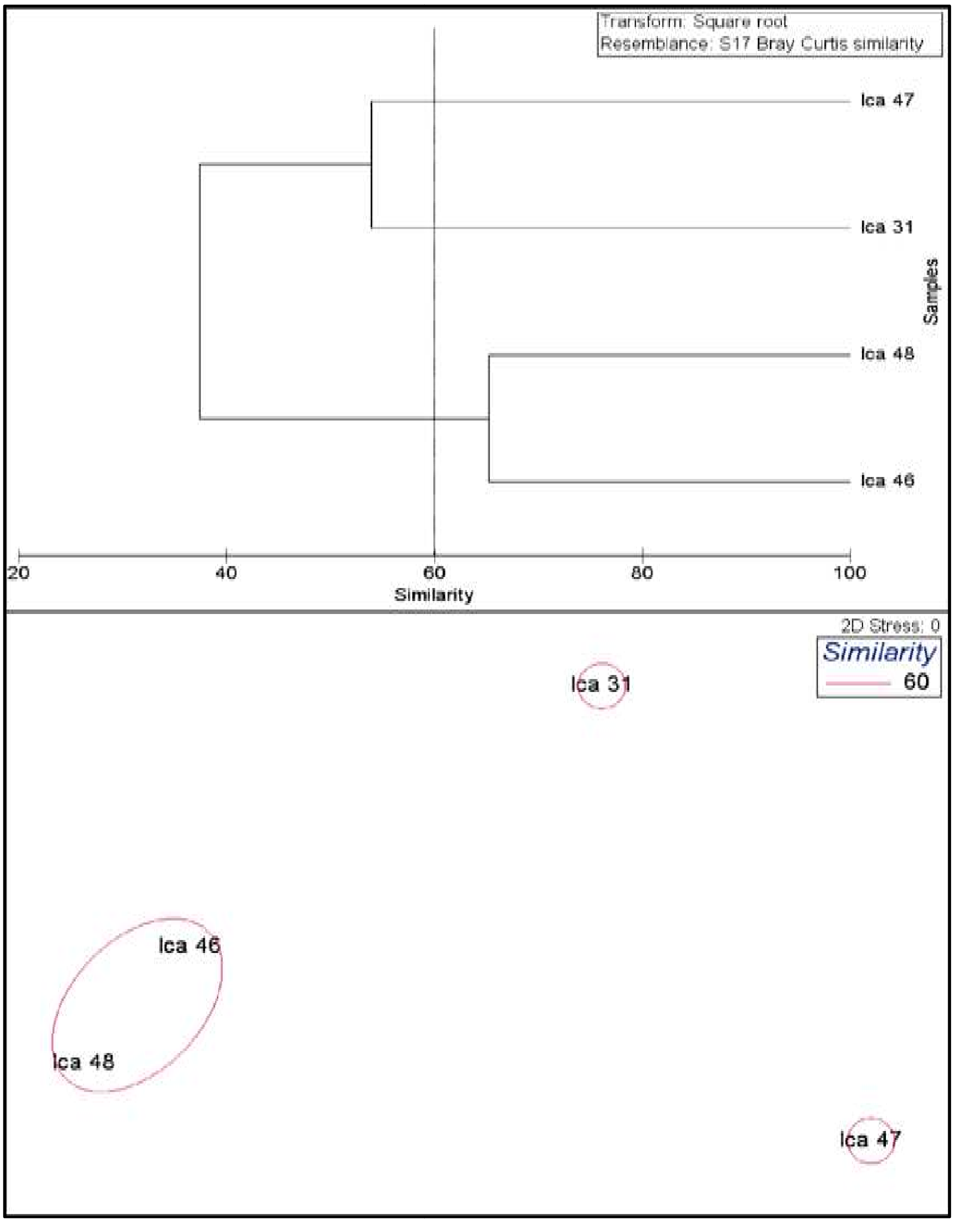


Fig. 4.83: hierarchical cluster and MDS ordination graphs for Le Castella mollusk death assemblages

Samples are divided into two groups with a similarity of 60 % on the base of both the biocoenosis meaning. In particular, the first group is composed by samples lca46 and lca48, collected both on the packstone7grainstone unit characterizing the top of section Lca10 and Lca11. These samples are characterized by strictly infralittoral associations, with species of AP, AP/HP, exl SGCF, but also pref DC, exl and pref VTC species. Species linked to coralligenous environment are reported.

Samples lca31 and lca47 are characterized by infralittoral or HP/C species and hard substrate. These samples are characterized by lower diversity in term of number of species, and also lower values of conservation.

Results are similar considering the substrate (Fig. 4.84). Samples lca46 and lca48 are grouped because they are characterized by species needing hard, coarse and soft bottoms, whereas samples lca31 and 46 form in this case another group, characterized by species linked only to hard substrate.

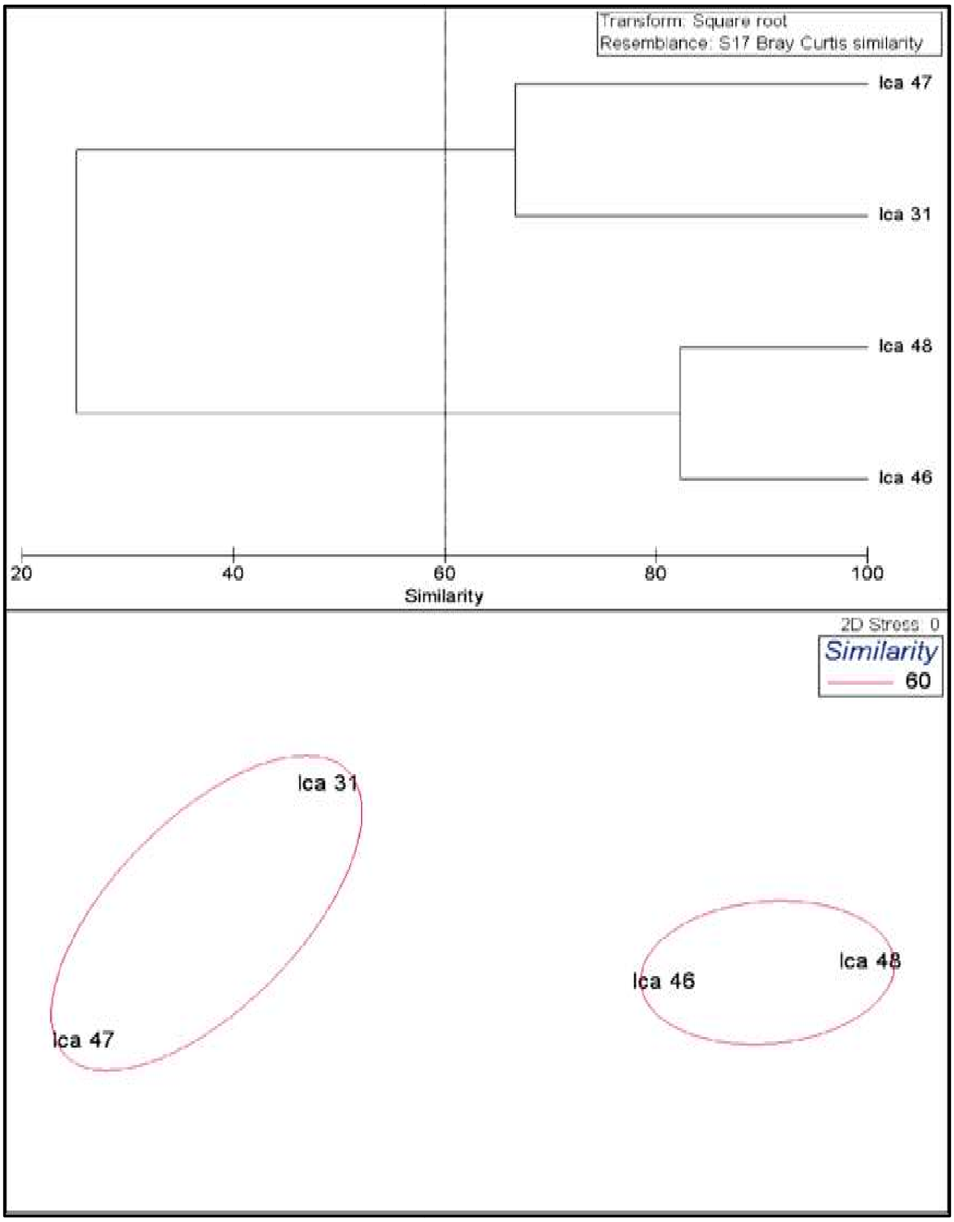


Fig. 4.84: hierarchical cluster and MDS ordination graphs for Le Castella mollusk death assemblages

4.3.3 GRAIN SIZE ANALYSES AND CARBONATE PERCENTAGE

4.3.3.1 CAPO COLONNA MARINE TERRACE

The packstone in Capo Colonna are generally characterized by high percentage of carbonate, ranging from 53,78 % to 90,63 % except for samples cc1 and cc2. These samples have been collected in the most proximal outcrop of Capo colonna marine terrace, and they are characterized by high siliciclastic fraction, respectively 85% and 83,33%. Results are reported in Tab. 4.6.

Sample	Initial weight (g)	Final weight (g)	Loss weight	% $CaCO_3$ fraction	% residual fraction
cc1	20	19	1	5,00	95,00
cc2	30	25	5	16,67	83,33
cc1bis	119	55	64	53,78	46,22
cc19	110	27	83	75,45	24,55
cc20	50	7,5	42,5	85,00	15,00
cc21	93	20	73	78,49	21,51
cc25	39	5	34	87,18	12,82
cc36	30	7	23	76,67	23,33
cc37	30	7	23	76,67	23,33
cc39	25	5	20	80,00	20,00
cc41	30	3,5	26,5	88,33	11,67
cc43	20	3,5	16,5	82,50	17,50
cc46	30	3	27	90,00	10,00
cc50	21	4	17	80,95	19,05
cc64	16	1,5	14,5	90,63	9,38

Tab. 4.6: results of grain-size analyses for total sediment of Capo Colonna samples. Data are expressed in grams

The results of grain-size analyses on total sediment sample are reported in Tab. 4.7.

µm	Φ	cc1	cc35	cc36	cc37	cc39	cc41	cc43	cc45	cc46
2000	-1	94	177	133	185	109	75	169	38	183
1000-2000	0	39	5	10	8	26	19	17	8	5
500-1000	1	37	5	9	3	9	7	5	47	4
250-500	2	4	4	14	2	10	3	4	11	2
125-250	3	4	5	19	1	14	5	5	28	1
63-125	4	10	3	16	3	15	5	2	22	6
< 63	> 4	4	2	16	1	20	3	3	25	4

Tab. 4.7: results of grain-size analyses for total sediment of Capo Colonna samples. Data are expressed in grams

Cumulative grain-size curves on total sediment are reported in Fig. 4.85. Samples cc1, cc35, cc37, cc41, cc43 and cc46 are dominated by the coarsest fraction (very coarse sand and gravel). Samples cc36, cc39 and cc45 show a more variable distribution.

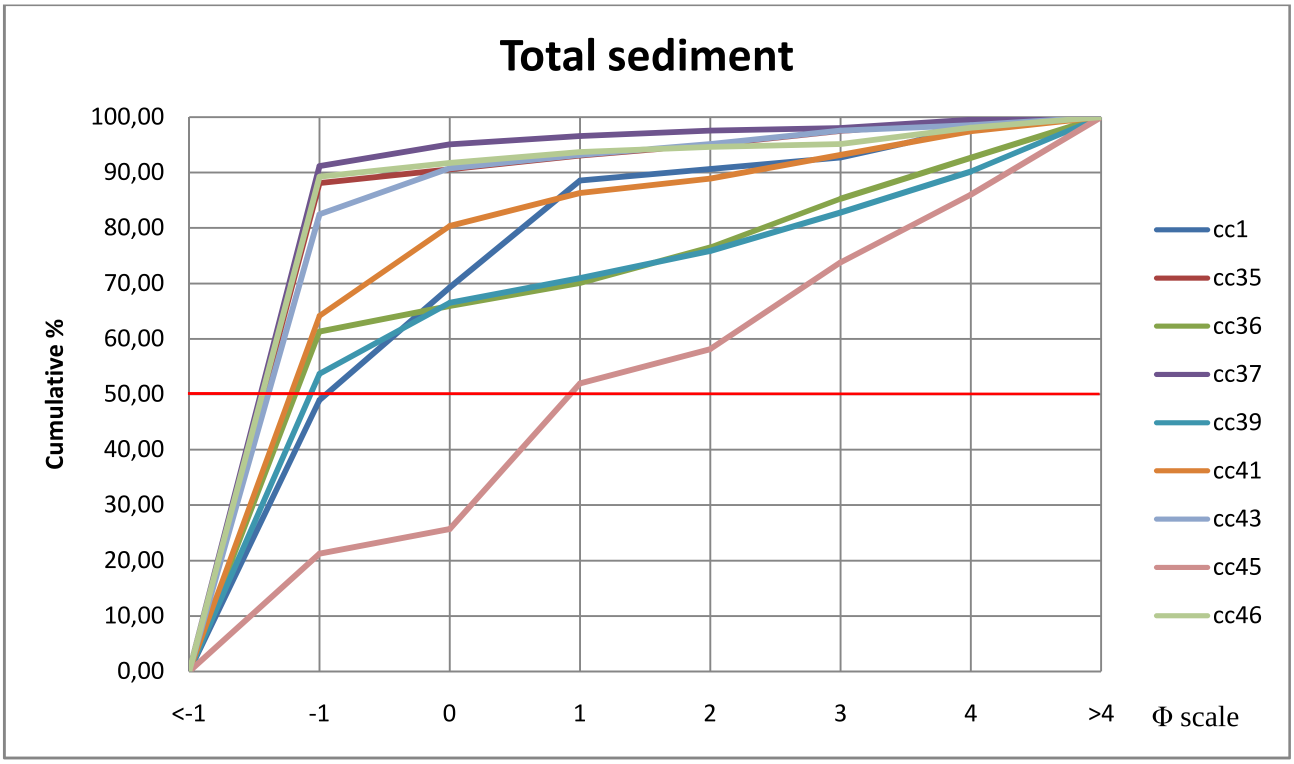


Fig. 4.85: cumulative grain-size curves on total sediment for Capo Colonna samples

The results of grain-size analyses on residual sediment sample are reported in Tab. 4.8.

µm	Φ	cc1	cc1bis	cc2	cc19	cc20	cc21	cc25	cc34	cc36	cc37	cc39	cc41	cc43	cc46	cc50	cc65
2000	-1	0,00	0,53	0,00	0,17	0,33	0,12	0,00	0,34	0,00	0,15	0,00	0,00	0,00	0,03	0,00	1,72
1000-2000	0	0,00	5,15	0,02	2,37	0,21	1,34	0,19	0,71	0,04	1,00	0,02	0,00	0,00	0,02	0,02	0,48
500-1000	1	0,00	7,71	0,47	3,36	0,54	3,22	1,48	0,65	0,19	2,03	0,02	0,04	0,05	0,33	0,27	2,39
250-500	2	0,01	0,41	0,09	0,50	0,69	0,88	0,15	0,89	0,77	1,78	0,06	0,33	0,15	0,47	0,27	6,77
125-250	3	2,91	1,92	4,19	1,33	0,61	1,99	0,25	0,33	0,81	0,95	0,59	0,72	0,52	0,14	0,22	1,17
63-250	4	16,11	10,56	19,63	9,12	3,57	14,56	3,29	0,66	2,82	1,09	1,77	1,09	1,05	0,34	1,04	0,37
< 63	> 4	0,19	5,15	0,38	1,89	1,74	4,97	1,05	0,11	2,75	0,24	2,41	1,35	1,79	1,05	2,04	3,86

Tab. 4.8: results of grain-size analyses for total sediment of Capo Colonna samples. Data are expressed in grams

Cumulative grain size curves on residual sediment are reported in Fig. 4.86. All the samples show that the siliciclastic residual is dominated by the finest grain-size classes, fine sand and silt, except of samples cc1bis, cc19 and cc65 showing a more variable distribution, with a considerable percentage of medium sand.

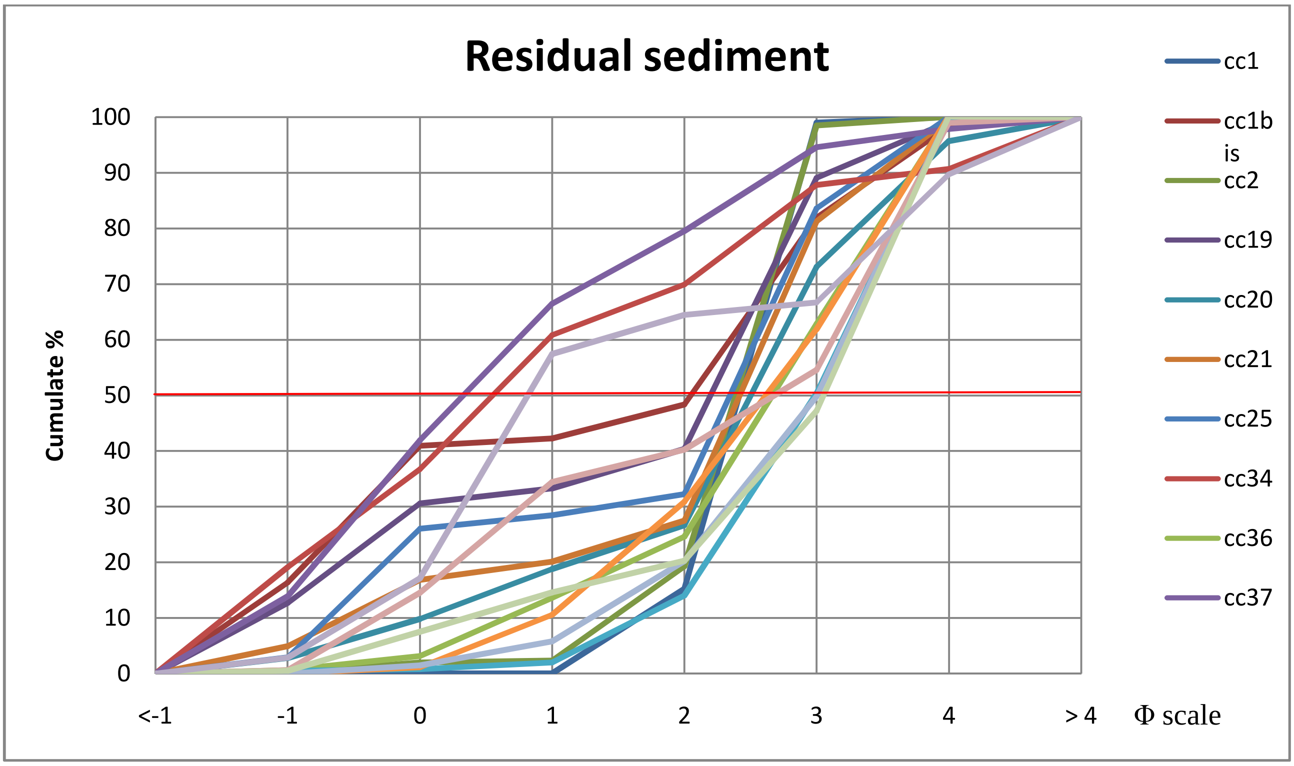


Fig. 4.86: cumulative grain-size curves on residual sediment for Capo Colonna samples

Results on grain size analyses on total and residual sediments of samples cc1bis, cc36, cc37, cc39, cc41, cc43 and cc46 have been compared in order to define the main contributor for each grain-size class, as reported in Tab. 4.9.

		cc1bis		cc36		cc37		cc39		cc41		cc43		cc46	
µm	**Φ**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**
2000	-1	0,57	99,43	0,00	100,00	0,08	99,92	0,00	100,00	0,00	100,00	0,00	100,00	0,02	99,98
1000-2000	0	13,20	86,80	0,44	99,56	12,55	87,45	0,09	99,91	0,00	100,00	0,00	100,00	0,30	99,70
500-1000	1	20,84	79,16	2,07	97,93	67,63	32,37	0,17	99,83	0,57	99,43	1,04	98,96	8,23	91,78
250-500	2	10,30	89,70	5,52	94,48	88,90	11,10	0,58	99,42	11,07	88,93	3,83	96,18	23,60	76,40
125-250	3	48,03	51,98	4,27	95,73	94,50	5,50	4,19	95,81	14,30	85,70	10,30	89,70	13,80	86,20
63-250	4	100,00	0,00	17,61	82,39	36,37	63,63	11,79	88,21	21,82	78,18	52,60	47,40	5,65	94,35
< 63	>4	100,00	0,00	17,19	82,81	23,90	76,10	12,07	87,93	44,87	55,13	59,73	40,27	26,30	73,70

Tab. 4.9: results of mineralogical analysis for Capo Colonna samples. Data are expressed in percentage. %R indicates the percentage of residual sediment; %C indicates the percentage of carbonate sediments

Histograms comparing the carbonate and siliciclastic percentages for each grain-size classes per samples are reported in Fig. 4.87.

Fig. 4.87: histograms reporting the carbonate *versus* siliciclastic percentages for each grain-size classes (Φ scale) for Capo Colonna samples

The carbonates characterizes the coarsest fraction of the sediments, form medium sand to gravel, whereas the siliciclastic fraction characterized the medium-fine sand and silt/mud grain size classes for samples cc1bis, cc36, cc39, cc41 and cc43.

Samples cc37 and cc46 are characterized by a major variability. Sample cc37 is characterized by carbonate fraction for the coarsest and the finest grain size classes, whereas siliciclastic fraction is more important from fine to coarse sands, whereas cc46 is dominated by carbonate fraction in all the grain size classes, although the siliciclastic fraction in important in medium to fine sand, and silt fraction.

4.3.3.2 LE CASTELLA MARINE TERRACE

The packstone and grainstone units of Le Castella are generally characterized by high percentage of carbonate, ranging from 67 % to 96 %. Results are reported in Table 4.10.

Sample	Initial weight (g)	Final weight (g)	Loss weight	% CaCO3 fraction	% residual fraction
Lca9bis	90	18	72	80,00	20,00
H5	63	9	54	85,71	14,29
H6	70	23	47	67,14	32,86
Lca19	100	26	74	74,00	26,00
Lca31	100	24	76	76,00	24,00
Lca48	100	4	96	96,00	4,00
Lca48bis	100	30	70	70,00	30,00
Lca46	100	11	89	89,00	11,00
Lca47	100	7	93	93,00	7,00

Tab. 4.10: Results of grain-size analyses for total sediment of Le Castella samples. Data are expressed in grams

The results of grain-size analyses on total sediment sample are reported in Tab. 4.11.

µm	Φ	lca31	lca46	lca47	lca48	lca48bis
2000	-1	133	134	175	66	99
1000-2000	0	38	38	38	56	50
500-1000	1	15	14	2	34	26
250-500	2	6	4	1	20	8
125-250	3	3	0	1	7	4
63-125	4	6	2	3	7	5
< 63	>4	6	6	2	10	8

Tab. 4.11: results of grain-size analyses for total sediment of Le Castella samples. Data are expressed in grams

Cumulative grain-size curves on total sediments are reported in Fig. 4.88. Samples are dominated by coarsest grain-size classes, except for sample lca48 showing a considerable percentage

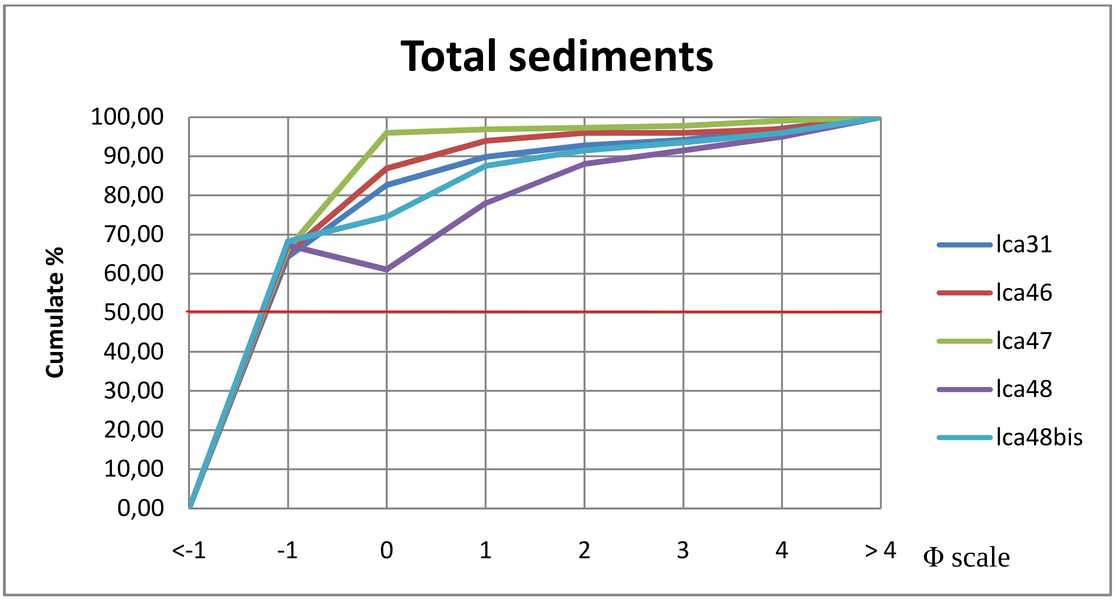


Fig. 4.88: cumulative grain-size curves on total sediment for Le Castella samples

The results of grain-size analyses on residual sediment sample are reported in Tab. 4.12.

µm	Φ	h5	h6	lca9bis	lca19	lca31	lca46	lca47	lca48bis	lca48
2000	-1	0,87	1,01	0,34	0,06	1,36	0,00	0,00	0,00	0,00
1000-2000	0	3,47	1,79	2,18	0,33	3,82	0,00	0,07	1,54	0,00
500-1000	1	1,10	9,27	1,12	6,59	6,56	0,00	0,61	11,33	0,01
250-500	2	0,64	1,69	0,37	9,00	2,62	0,01	0,72	8,37	0,05
125-250	3	1,39	1,52	4,60	5,80	0,81	2,91	1,12	2,64	0,04
63-250	4	1,28	0,85	4,90	1,96	2,38	16,11	3,13	2,87	0,21
< 63	> 4	0,92	2,53	2,23	2,15	6,17	0,19	1,32	7,13	3,81

Tab. 4.12: results of grain-size analyses for residual sediment of Le Castella samples. Data are expressed in grams

Cumulative grain-size curves on total residual sediments are reported in Fig. 4.89. Samples are dominated by the finest grain-size classes. In particular, samples h5, h6, lca19, lca31 and lca48bis show a more variable distribution, with considerable percentages of medium sand, whereas the other samples are dominated by very fine sand and silt.

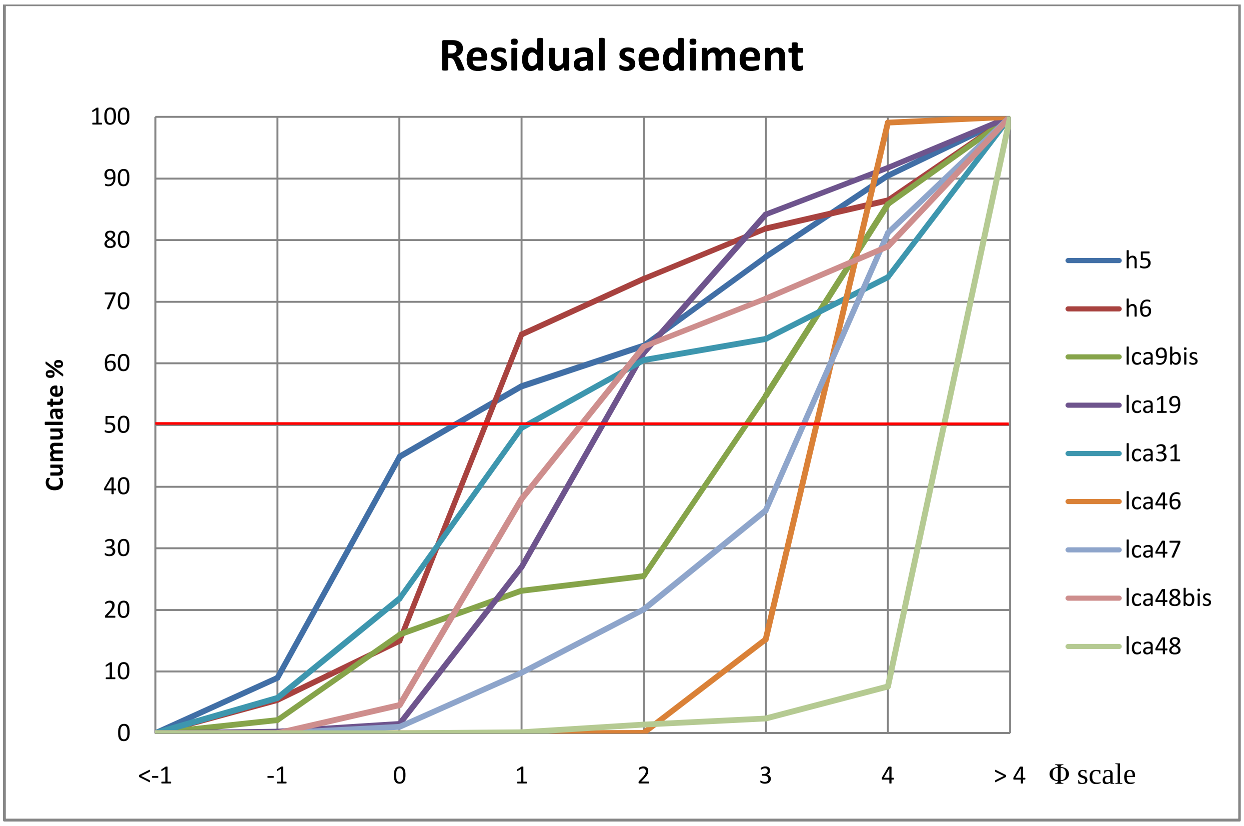


Fig. 4.89: cumulative grain-size curves on total sediment for Le Castella samples

Grain size analyses on total and residual sediments of samples lca31, lca46, lca47, lca48 and lca48bis have been compared in order to define the main contributor for each grain-size class (Tab. 4.13).

		lca31		**lca46**		**lca47**		**lca48**		**lca48bis**	
µm	**Φ**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**	**% R**	**% C**
2000	-1	1,02	98,98	0,02	99,98	0,00	100,00	0,00	100,00	100,00	0,00
1000-2000	0	10,06	89,94	1,80	98,20	0,19	14,41	0,00	100,00	96,92	3,08
500-1000	1	43,73	56,27	38,95	61,05	30,45	0,03	0,02	99,98	56,43	43,57
250-500	2	43,58	56,42	13,24	86,76	71,70	28,30	0,26	99,74	0,00	100,00
125-250	3	27,10	72,90	17,30	82,70	100,00	0,00	0,57	99,43	34,05	65,95
63-250	4	39,62	60,38	50,80	49,20	100,00	0,00	3,06	96,94	42,66	57,34
< 63	>4	100,00	0,00	74,90	25,10	65,85	68,30	38,10	61,90	10,83	89,18

Tab. 4.13: results of mineralogical analysis for Capo Colonna samples. Data are expressed in percentage. %R indicates the percentage of residual sediment; %C indicates the percentage of carbonate sediments

Histograms comparing the carbonate and siliciclastic percentages for each grain-size classes per samples are reported in Fig. 4.90.

The carbonates characterizes the coarsest fraction of the sediments, form medium sand to gravel, whereas the siliciclastic fraction characterized the medium-fine sand and silt/mud grain size classes.

Sample lca48bis is completely dominated by the carbonate fraction, except for the finest fraction where the siliciclastic portion is reported.

Fig. 4.90: histograms reporting the carbonate *versus* siliciclastic percentages for each grain-size classes (Φ scale) for Le Castella samples

4.3.4 THIN SECTION MAPPING

4.3.4.1 CAPO COLONNA MARINE TERRACE

Thin sections mapping result are reported in Fig. 4.91 for Capo Colonna samples. The red-fragments are the most abundant, and they correspond to calcareous red algae fragments, that seem to be dominant.

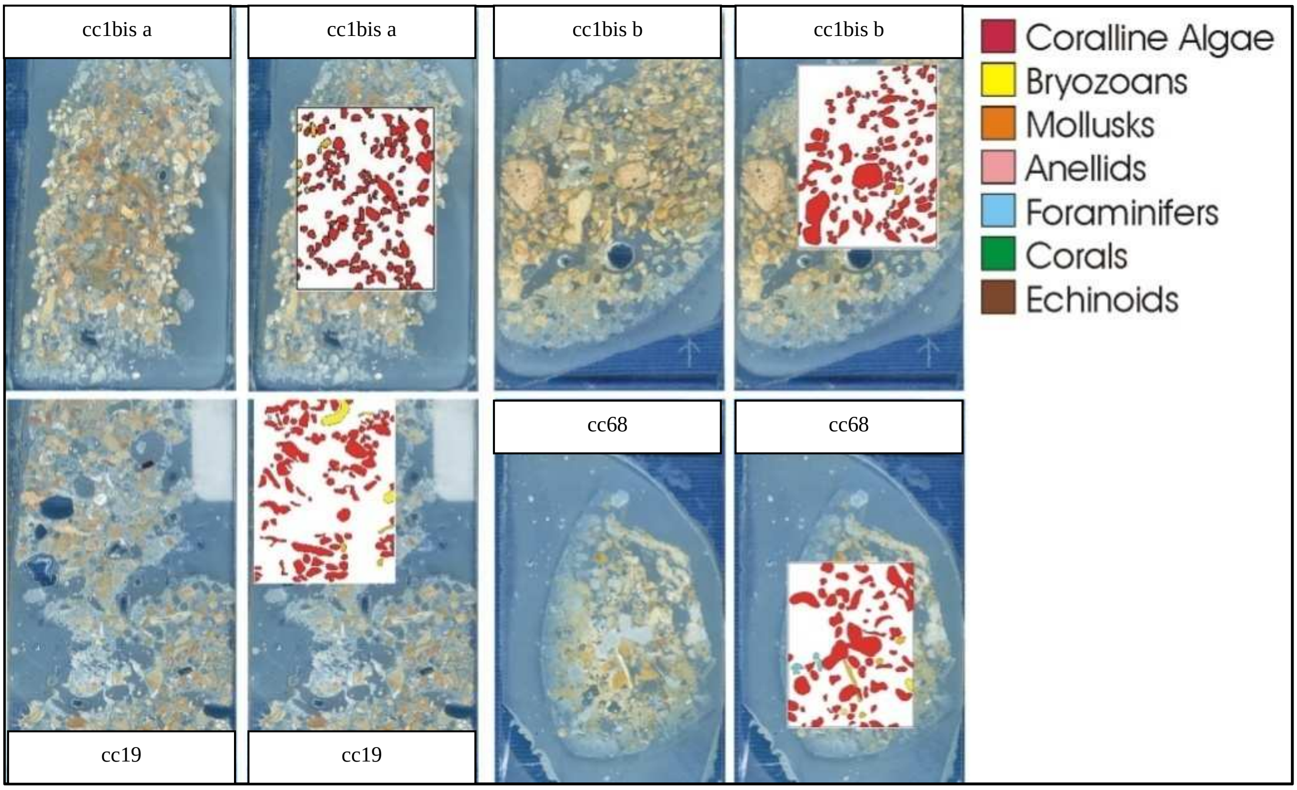


Fig. 4.91: thin sections mapping results for Capo Colonna samples

Counting of sediments components recognizable at 40X magnification, using a binocular microscope are reported in Tab. 4.14 and Fig. 4.92.

Samples	Coralline Algae	Coral	Mollusk	Bryozoan	Annelid	Foraminifer	Echinoid
cc1bis-a	118	0	1	0	0	0	0
cc1bis-b	108	0	1	0	0	0	0
cc19	83	0	4	2	2	0	0
cc68	67	0	4	2	0	4	0

Tab. 4.14: Results of thin sections counting for Capo Colonna samples

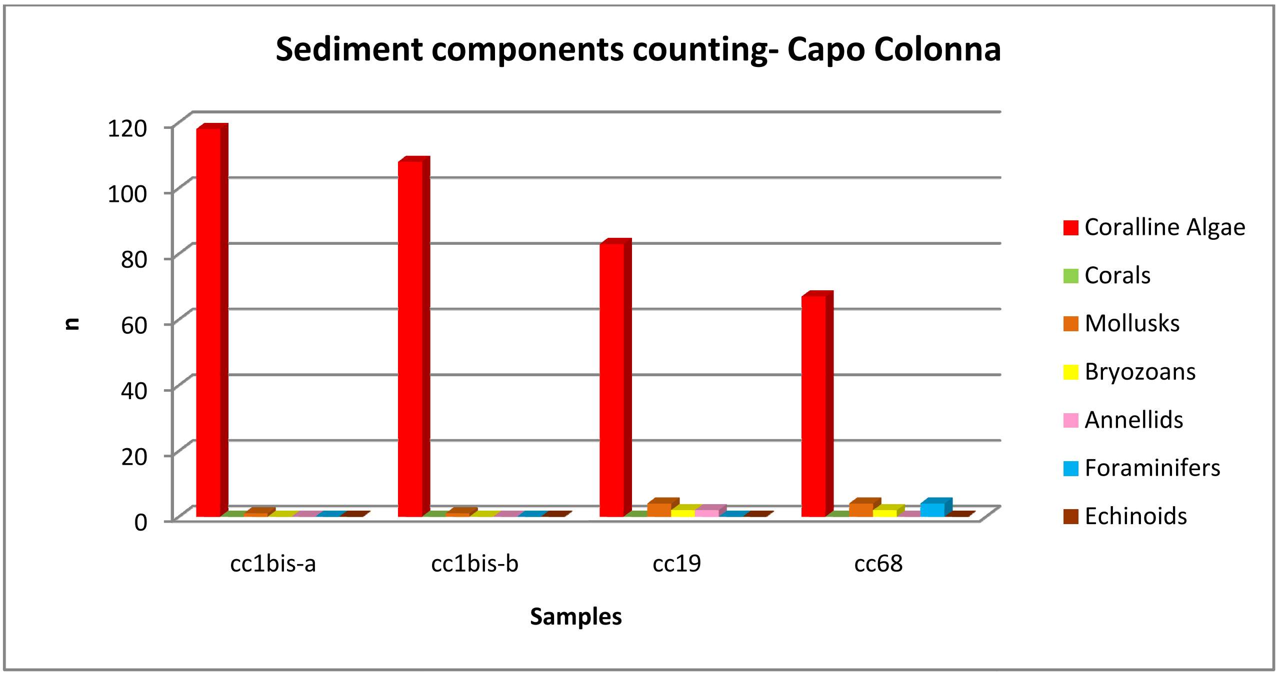


Fig. 4.92: histogram of thin section counting results for Capo Colonna samples. n indicates the number of counted fragments per each component class

Coralline red algae fragments play the major role in term of sediment contribution, followed by mollusks, bryozoans and foraminifers.

4.3.4.2 LE CASTELLA MARINE TERRACE

Thin sections mapping result are reported in Fig. 4.93 for Le Castella samples. The red-fragments are the most abundant, and they correspond to calcareous red algae fragments, that seem to be dominant.

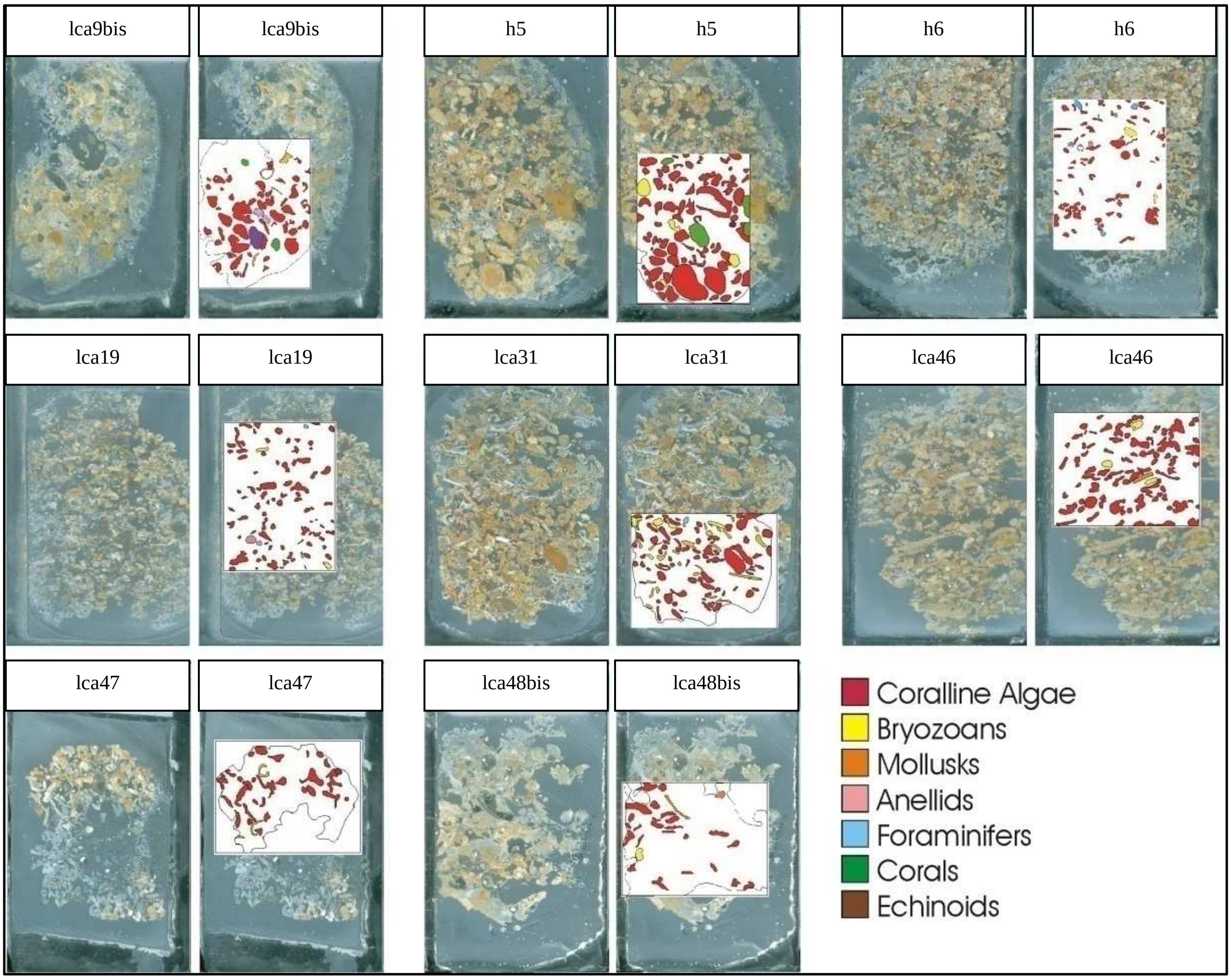


Fig. 4.93: thin sections mapping results for Le Castella samples

Counting of sediments components recognizable at 40X magnification, using a binocular microscope are reported in Tab. 4.15 and Fig. 4.94.

Samples	Coralline Algae	Coral	Mollusk	Bryozoan	Annelid	Foraminifer	Echinoid
lca9bis	53	2	4	2	4	0	0
h5	77	4	0	4	0	0	1
h6	72	0	0	2	2	6	0
lca19	80	0	1	2	1	4	0
lca31	66	0	28	6	2	2	1
lca46	33	0	3	0	0	0	2
lca47	24	0	2	1	0	0	0
lca48bis	85	0	1	3	0	0	1

Tab. 4.15: results of thin sections counting for Le Castella samples

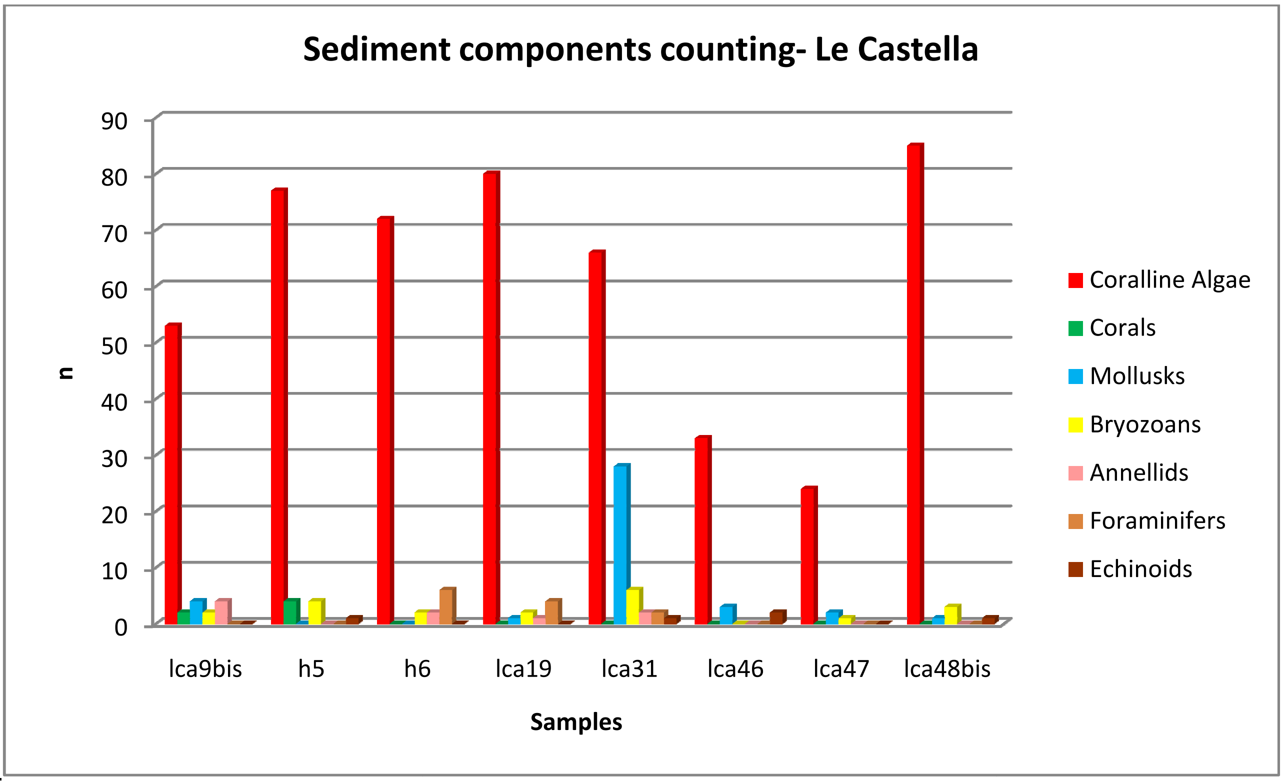


Fig. 4.94: histogram of thin section counting results for Le Castella samples. n indicates the number of counted fragments per each component class

Coralline red algae fragments play the major role in term of sediment contribution, followed by mollusks, bryozoans and foraminifers.

4.3.5 APPENDIX V

Systematic list of identified mollusk species with short description of shell-morphology, ecology, size, geographic and stratigraphic distribution.

Phylum MOLLUSCA

Classis BIVALVIA Linneo, 1758
Subclassis PROTOBRANCHIA Pelseneer, 1889

Order NUCULOIDA Dall, 1889

Superfamily NUCULOIDEA Gray J.E., 1824
Family NUCULIDAE Gray J.E., 1824

***Nucula nucleus* (Linneo, 1758)**

Shell: shell solid, equivalve, inequilateral, triangular in outline. Fine radiating striations visible with hand lens, with coarse concentric lines. Lightly decussate posterior. 16-25 hinge teeth anterior, 10-14 posterior. Margin of shell crenulated.

Ecology: on coarse bottom, from gravel to sand (Tebble, 1976). Mistophilous. Infaunal, deposit or suspension feeder.

Size: 4-13 mm.

Geographic distribution: common.

Stratigraphic distribution: from the base of the Middle Bathonian (France) to Holocene. Reported for Lower Pleistocene of Calabria region from Bernasconi *et al.* (1997). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Nucula sulcata* (Bronn, 1831)**

Shell: solid, equivalve, inequilateral, triangular in outline. Fine radiating striations and coarser concentric lines. 20-30 hinge teeth anterior, 10-14 posterior. Margin of shell crenulated.

Ecology: exclusive species in VTC biocoenosis (Pérès & Picard, 1964). Infaunal, strictly in muddy or muddy-sand bottoms, detritivor.

Size: 0-20mm.

Geographic distribution: until 2000m wd in Mediterranean Sea (Parenzan, 1974). Common.

Stratigraphic distribution: Pleistocene-Holocene of Mediterranean Sea. In the Pleistocene of Greece (Nielsen *et al*., 2006) and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Nucula sp.

Superfamily NUCULANOIDEA Adams H. & A., 1858

Family NUCULANIDAEAdams H. & A., 1858

Nuculana pella **(Linneo, 1767)**

Shell: elongated with a long tail bent, surface thickly lined with concentric lines, sometimes with dark speckles. Hinge line with 14-22 teeth.

Ecology: infra-circalittoral. Suspension feeder.

Size: 0-15mm.

Geographic distribution: common, muddy to sandy bottoms.

Stratigraphic distribution: Holocene. In the Pleistocene of Greece (Nielsen *et al*., 2006).

Nuculana minuta **(Müller, 1776)**

Shell: brittle, equivalve and inequilateral, beaks are in front of the midline. Outline is rounded anterior but drawn out posterior into a blunt bicarinate rostrum. Sculpture of 30 or bolder concentric ridges. Hinge line with 15-18 teeth in the anterior group and 18-20 in the posterior.

Ecology: muddy sand and gravel from 9-183 m. Infaunal, suspension feeder.

Size: up to 19 mm.

Geographic distribution: across the whole northern hemisphere.

Stratigraphic distribution: base of the Middle Pleistocene (Iceland) to the top of Holocene.

Subclassis PTEROMORPHIA Beurlen, 1944

Order ARCOIDA Stoliczka, 1871

Superfamily ARCOIDEA Lamarck, 1818

Family ARCIDAE Lamarck, 1818

Arca noae **Linnaeus, 1758**

Shell: solid, equivalve, elongated, slightly trapezoidal. Surface with dense radial ribs. Hinge line is straight and flat.

Ecology: on rocky or detrital substrate.

Size: 50-90 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Since Lower Pliocene to Holocene (Raffi *et al*., 1985). In the Pleistocene of Greece (Nielsen *et al*., 2006), and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Arca tetragona* Poli, 1795**

Shell: elongate, very irregular, anterior and deeper than posterior, prominent umbo and widely spaced, with a sharp, raised ridge running from the beak to posterior margin. Cardinal area broadly triangular. Sculpture of fine radiating ridges. Ventral margin is irregular and variable, usually convex, occasionally concave, finely crenulated.

Ecology: infaunal, suspension feeder, preferential species of DC; on little hard substrates (Falconetti, 1980), in crevices among rocks and shell debris, often encrusted with other organisms, or abraded by the substratum. Sessile, attached by a thick, green byssus.

Size: up to 50 mm long.

Geographic distribution: from the lower shore to about 100 m depth, both Atlantic and Mediterranean.

Stratigraphic distribution: Since Lower Pliocene to Holocene (Raffi *et al*., 1985). Reported for Pleistocene of Greece (Nielsen *et al*., 2006).

***Barbatia clathrata* (Defrance, 1816)**

Shell: compressed, triangular with well-developed ribs.

Ecology: hard substrate.

Size: 5 mm.

Geographic distribution: not common.

Stratigraphic distribution: middle Miocene (Poland, Spain), Pliocene (Spain) (Lozano Francisco *et al*., 1993). As *Barbatia barbata* in the Pleistocene of Greece (Nielsen *et al*., 2006).

***Asperarca nodulosa* (Müller, 1776)**

Shell: elongate, relatively compressed, strongly inequilateral and narrowing anterior. Exterior with radial ribs and with dense commarginal cords, sometimes confluent with each other, the ribs forming elongated tubercles where they overrun the commarginal cords.

Ecology: infra-circalittoral. Known from seamounts and knolls.

Size: up to 15 mm.

Geographic distribution: common on hard bottoms, usually coralligenous environments. Mediterranean at least in the Western Basin.

Stratigraphic distribution: Since Lower Pliocene to Holocene (Raffi et al., 1985). Pleistocene of Tuscan Archipelago (Italy) (Remia & Taviani, 2005).

Bathyarca philippiana **(Nyst, 1848)**

Shell: oval in contour, inequilateral with hardly prominent umbo situated towards the anterior one-third and maximum shell height situated on the posterior one-fourth. Cardinal line with 4-5 teeth anterior to the umbo and about ten posterior to it, increasing in size and becoming more oblique as they are situated further away from the umbo.

Ecology: infra-circalittoral. Known from seamounts and knolls.

Size: 3-7 mm.

Geographic distribution: widely distributed, very common.

Stratigraphic distribution: base of the Serravallian to Holocene.

Family GLYCIMERIDAE Newton, 1922

Glycymeris glycymeris **(Linneo, 1758)**

Shell: large, solid, equivalve, circular in shape and inflated, equilateral. Umbo situated on the vertical midline, very slightly prosogyrous, separated from the hinge line by a narrow triangular area covered by the ligament, which is dark brown. Sculpture of very fine commarginal cords and radial striae, giving a reticulated appearance under high magnification. Hinge wide and arched, taxodont, with no teeth under the umbo and between 6 and 12 teeth on each side.

Ecology: epifaunal, on any type of bottoms. Typical in low water-depth, even if recorded also in high depth, maybe accidental (Parenzan, 1974). Exclusive species of SGCF biocoenosis (Pérès & Picard, 1964).

Size: 0-90 mm.

Geographic distribution: common.

Stratigraphic distribution: since Lower Pliocene to Holocene (Raffi *et al*., 1985). Reported for the Upper Pleistocene of Italy (Gliozzi, 1987).

Order PTERIOIDA Newell, 1965

Superfamily PECTINOIDEA Rafinesque, 1815

Family PECTINIDAE Rafinesque, 1815

Pseudamussium peslutrae **(Linneo, 1771)**

Shell: thin and fairly brittle, almost circular. Equilateral. Almost equivalve. Sculpture of fine radiating striations and coarser concentric lines (occasionally spinous); each valve with three to ten, most frequently five to seven, evenly spaced, broad rounded ribs, increasing rapidly in width from umbo to margin. Ears with about six ribs each, and concentric corrugations.

Ecology: infralittoral. Preferential species of DE biocoenosis (Pérès & Picard, 1964). Suspension feeder

Size: up to 50 mm long.

Geographic distribution: occurs offshore to about 200 m. Common.

Stratigraphic distribution: since Lower Pliocene to Holocene (Raffi *et al.*, 1985). Piacenzian of Greece (Dermitzakis & Georgiades-Dikeoulia, 1987). As *Pseudamussium septemradiatum* is indicated as boreal guest of Lower Pleistocene of Sicilia region (Italy) (Di Geronimo *et al.*, 2000)

Pseudamussium sulcatum **(Müller O.F., 1776)**

Shell: brittle, inequilateral, inequivalve; anterior ears about three times as long as the posterior. Almost circular in outline except for the protruding ears. Sculpture of up to 40 radiating ribs interspersed with as many narrower riblets. Numerous small broad spiny tubercles occur in single rows on the riblets but often in double rows on the ribs; these tubercles are so abundant that they almost cover the ribs completely. Fine concentric lines also ornament the shell. Growth stages are not clear. Ears with strong concentric folds and radial ribs without spiny tubercles.

Ecology: all type of bottoms.

Size: up to 25 mm.

Geographic distribution: very common, overall distributed.

Stratigraphic distribution: since Burdigalian to Holocene.

Mimachlamys varia **(Linneo, 1758)**

Shell: thin, more or less oval, inequivalve. Right valve with a distinct, rounded byssal notch in anterior ear, with fine teeth on lower border. Inequilateral: both valves with anterior ear more pronounced, twice as long as posterior. Sculpture of 25-35 bold ribs, and a few corrugated concentric lines, raised into prominent spines along ribs, most pronounced close to margin. Ears similarly ribbed. Sculpture visible on inner surface, margin crenulated.

Ecology: epifaunal, both free and attached to the substrate (Tebble, 1976), infralittoral. Link to biocoenosis C.

Size: up to 60 mm long

Geographic distribution: very common.

Stratigraphic distribution: middle Miocene (Madagascar) to Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and Bernasconi *et al.* (1997). As *Chlamys varia* in the Pleistocene of Greece Nielsen *et al*., 2006) and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Talochlamys multistriata **(Poli, 1795)**

Shell: thin, fragile, inequilateral, the anterior ears three or four times as long as the posterior. Inequivalve, a large byssal notch in the right anterior ear. Circular in outline, except for the projecting ears. Sculpture of valves is different: right valve with fine radiating and concentric lines, its surface smooth except for small spines which sometimes occur near the margins; left valve rough, with numerous, very fine, radiating ribs carrying small spines. Growth stages are clear. Margin is smooth.

Ecology: generally on coarse bottoms of muddy sand, gravel or shell.

Size: up to 19 mm.

Geographic distribution: overall distributed.

Stratigraphic distribution: base of the Oligocene (Bulgaria) to Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and for Upper Pleistocene of Greece (Nielsen *et al*., 2006; Titschack *et al*., 2008). As *Chlamys multistriata* the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Chlamys sp.

***Aequipecten commutatus* (Monterosato, 1875)**

Shell: thin, fragile, circular in outline. Sculpture of valves presents radial thin ribs.

Ecology: suspension feeder.

Size: 25-30 mm.

Geographic distribution: uncommon, western Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Aequipecten opercularis* (Linneo, 1758)**

Shell: thin and brittle. Inequivalve: left valve more convex than right one. Ears are more or less equal. Ventral margin constituting more than a semicircle. Sculpture of about 20 bold, radiating ribs, finer ridges and concentric corrugated grooves, ears similarly sculptured; growth stages unclear; margin very crenulated.

Ecology: on sand and fine gravel. Suspension feeder.

Size: up to 90 mm.

Geographic distribution: widespread and common.

Stratigraphic distribution: base of the Burdigalian (Austria) to Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and for Upper Pleistocene of Spain (Vera-Pelaez *et al*., 2004). As *Chlamys opercularis* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Spondylus gaederopus* Linneo, 1758**

Shell: robust, with very large valves. Attached to the substrate with one shell. The shells are roundish with numerous spines in rows. The spines can be up to 4 cm. long.

Ecology: epifaunal, on hard substrate, often found on reef. Suspension feeder.

Size: up to 10 cm.

Geographic distribution: common.

Stratigraphic distribution: since Lower Miocene (Madagascar) to Holocene. Upper Pleistocene of Greece (Titschack *et al.*, 2008), Italy (Gliozzi, 1987) and France (Zibrowius, 2005).

Spondylus sp.

Superfamily ANOMIOIDEA Rafinesque, 1815

Family ANOMIIDAE Rafinesque, 1815

***Heteranomia squamula* (Linneo, 1758)**

Shell: very thin and delicate, circular in outline and almost flat. Left valve only slightly convex, umbo distinct, forming a short cone; right valve very thin, translucent sculpture with concentric and radial lines forming a rippled and wrinkled surface.

Ecology: on hard substrate and algae.

Size: 10-14 mm.

Geographic distribution: uncommon, in all the Mediterranean Sea.

Stratigraphic distribution: since Chattian (Denmark) as *Pododesmus squamula.* Lower Pleistocene of Italy (Bellomo, 1993) and Upper Pleistocene of Netherlands (Meijer, 1983). As *Pododesmus squama* in the Pleistocene of Greece (Nielsen *et al*., 2006).

***Pododesmus aculeatus* (O.F. Müller, 1776)**

Shell: thin and delicate, circular in outline and almost flat. Both valve and right valve present a structure formed by radial spiny ribs, mostly on the outer margin.

Ecology:

Size: 10-15 mm.

Geographic distribution: uncommon, western Mediterranean Sea.

Stratigraphic distribution: Holocene.

Anomia sp.

Order LIMOIDA Moore, 1952

Superfamily LIMOIDEA Rafinesque, 1815

Family LIMIDAE Rafinesque, 1815

***Limatula subauriculata* (Montagu, 1808)**

Shell: thin, equivalve and equilateral. Ears are small and equal. Regularly oval in outline, except for the slightly protruding ears. Sculpture of 24 radiating ribs, of which the central one is slightly wider and concentric line; ribs are not present on the ears or nearby lateral areas of the valves. Growth stages are clear. Margin is crenulated where the ribs cut it.

Ecology: preferring bottoms of mud, sandy mud, gravel and sandy gravel.

Size: 6 mm.

Geographic distribution: wide distributed.

Stratigraphic distribution: since Burdigalian (Austria) to Holocene. Reported for the Plio-Pleistocene of Calabria region (Barrier *et al*., 1986).

Order VENEROIDA Adams H. & A., 1857

Superfamily LUCINOIDEA Fleming, 1828

Family LUCINIDAEFleming, 1828

***Ctena decussata* (Costa O.G., 1829)**

Shell: round shape, surface marked by strong concentric growth lines, sometimes with slight radial striae forming a sort of reticulate. Hinge is formed by 2 teeth for valve, on right valve anterior teeth is more robust than on left valve.

Ecology: usually on muddy bottoms, shallow waters.

Size: 10-20 mm.

Geographic distribution: common.

Stratigraphic distribution: since middle Miocene (Poland) to Holocene (Raffi *et al*., 1985). Reported for the Lower Pleistocene of Italy (Bellomo, 1993) and Upper Pleistocene of Spain (Vera-Pelaez *et al.*, 2004) and Italy (Gliozzi, 1987).

***Loripes lacteus* (Linneo, 1758)**

Shell: approximately circular, almost equivalve. Umbo is distinct, medially situated but curving anterior beyond midline. Left valve with a bifid anterior and a single posterior cardinal tooth, right valve with a single anterior and bifid posterior. Each valve with single anterior and posterior lateral teeth, often indistinct. Sculptures of numerous fine, concentric lines, growth stages are clear.

Ecology: in sand and fine gravel, burrower, infralittoral. Exclusive species of SVMC biocoenosis (Pérès & Picard, 1964).

Size: up to 20 mm long.

Geographic distribution: from the lower shore to at least 150 m.

Stratigraphic distribution: since Messinian (Algeria) to Holocene (France). Upper Pleistocene marine terrace of Turkey (Schneider *et al.,* 2005). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Lucinella divaricata* (Linneo, 1758)**

Shell: solid, equivalve and almost equilateral; beaks are about the midline and directed inwards and slightly forwards. Outline is approximately circular in outline but tending to be a little deeper than long. Sculpture of lines diverging from the centre of the shell to the margins; concentric lines also present. Growth lines are clear. Right valve with one conspicuous cardinal tooth and two small laterals; left valve with two cardinals and two anterior and two posterior laterals. The shell margin is crenulated.

Ecology: Muddy or gravelly sand.

Size: up to 13 mm in length.

Geographic distribution: common in all Mediterranean Sea.

Stratigraphic distribution: since Chattian (Austria) to Holocene (Raffi *et al*., 1985). Reported for the Upper Pleistocene of Netherlands (Meijer, 1983) and Turkey (Schneider *et al*., 2005), and for the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Superfamily CHAMOIDEA Blainville, 1825

Family CHAMIDAE Blainville, 1825

***Chama gryphoides* Linneo, 1758**

Shell: round, concentric ribs, gills, sometimes thorny, with valve performance always right-handed.

Ecology: epifaunal, on hard substrates in shallow waters. Known from rocky shores. Suspension feeder.

Size: 20-28 mm.

Geographic distribution: common in all Mediterranean Sea.

Stratigraphic distribution: since Burdigalian (France) to Holocene (Raffi *et al*., 1985). Reported for Lower Pleistocene from Bernasconi *et al.* (1997) and the Upper Pleistocene (Gliozzi, 1987) of Calabria region, Italy.

Superfamily CARDITOIDEA Fleming, 1828

Family ASTARTIDAE D'Orbigny, 1844

***Astarte sulcata* (Da Costa, 1778)**

Shell: thick and robust, broadly oval, prominent umbo imparting sub triangular outline. Sculpture of bold concentric ridges, growth stages indiscernible. Left valve with two prominent cardinal teeth below umbo and a third, slender, indistinct and often abraded, extending below ligament. Right valve with very thick anterior cardinal tooth and slender one posterior. Inner shell margin distinctly crenulated, rarely smooth.

Ecology: infaunal in mud or fine gravels with sand, shells, or mud, offshore. Suspension feeder. Exclusive species of DL biocoenosis (Pérès & Picard, 1964).

Size: up to 30 mm long.

Geographic distribution: distributed from southern Arctic waters to the Mediterranean and NW Africa.

Stratigraphic distribution: since Lower Pleistocene of Calabria region from Bellomo (1993) to Holocene (Raffi *et al*., 1985).

Family CARDITIDAE Fleming, 1828

***Pteromeris minuta* (Scacchi, 1836)**

Shell: rounded shape with apex curved. surface with faint radial ribs and concentric lines marked.

Ecology: unknown.

Size: 4-5 mm.

Geographic distribution: across the whole Mediterranean Sea. Rare.

Stratigraphic distribution: Holocene.

***Cardita calyculata* (Linneo, 1758)**

Shell: trapezoidal shape, surface decorated with large and thorny radial ribs, usually 17-20. Equivalve, inequlateral, Ventral margin is usually sinuous. Right valve presents two cardinal teeth, posterior prolonged and a little anterior tooth. Left valve presents with a short anterior tooth and a posterior lateral prolonged tooth.

Ecology: known for rocky shore. Infralittoral.

Size: 15-25 mm.

Geographic distribution: common in all Mediterranean Sea.

Stratigraphic distribution: since Middle Miocene (Bulgaria) to Holocene (Raffi *et al*., 1985). Reported for Lower Pleistocene of Italy from Bellomo (1993) and for Upper Pleistocene f Spain (Vera-Pelaez *et al*., 2004).

***Cardita senegalensis* Reeve, 1843**

Shell: trapezoidal shape, but the outer margin presents a typical undulation. The surface is decorated with large and thorny radial ribs, forming crests in the outer margin.

Ecology: known for rocky shore. This species is considered as part of the *Senegalese* fauna.

Size: 15-25 mm.

Geographic distribution: Senegal – Cape Verde coasts.

Stratigraphic distribution: Pleistocene, considered as *Senegalese-warm* species of MIS 5.5. Reported for Tyrrhenian deposits of Taranto, Italy (Caldara, 1986). Reported as extinct species for present-day Mediterranean Sea by Raffi *et al*. (1985)

Superfamily CARDIOIDEA Lamarck, 1809

Family CARDIIDAE Lamarck, 1809

***Acanthocardia echinata* (Linneo, 1758)**

Shell: brittle, obliquely oval, anterior hinge line sloping gently to convex anterior margin; posterior hinge line more steeply inclined, posterior margin only slightly convex. Spines most prominent on anterior ribs. Concentric sculptures of numerous wavy ridges, pronounced between ribs. Two cardinal teeth in each valve; right valve with two anterior and one posterior lateral teeth, left valve with single anterior and posterior laterals, the anterior being longer, thicker, and more prominent.

Ecology: suspension feeder. In fine sand and gravel, usually with mud.

Size: up to 75 mm long.

Geographic distribution: common.

Stratigraphic distribution: from Serravallian (Greece) to Holocene (Raffi *et al*., 1985). Reported for Calabrian of Italy (Ragaini *et al*., 2007) and for Upper Pleistocene of Poland (Makowska, 1986).

Acanthocardia sp.

***Parvicardium exiguum* (Gmelin, 1791)**

Shell: thick, obliquely oval, umbo well in front of midline. Up to 22 broad ribs, with well-marked concentric ridges between; small tubercle-like spines present on all ribs in young specimens, later persisting only at anterior and posterior margins, and sparingly ventrally. Growth stages distinct. Each valve with two small cardinal teeth. Distributed from Norway to the Mediterranean and Black Sea (distr. *P. exiguum*). Suspension feeder

Ecology: infaunal, in sand, gravel, or mud; from lower shore into the shallow sub littoral, often extending into estuaries, stand variability in salinity, found also in deltas (Tebble, 1976).

Size: 5- 14 mm.

Geographic distribution: 0-60m of water depth (Tebble, 1976).

Stratigraphic distribution: since Zanclean (Belgium) to Holocene (Raffi *et al.*, 1985). Reported for Upper Pleistocene marine terrace of Turkey (Schneider *et al.*, 2005). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Parvicardium pinnulatum **(Conrad, 1831)**

Shell: ovoidal, equivalve, inequilateral. Sculpture formed by 20-22 radial ribs, among which the anterior present tubercles. Spaces between ribs are characterized by concentric deep striae. Right valve hinge presents 2 small cardinal teeth, and 2 anterior and 1 posterior lateral tooth. Left valve hinge presents 2 small cardinal teeth, one anterior lateral very robust tooth, and one small posterior lateral tooth.

Ecology: infralittoral, between algae.

Size: 9-13 mm.

Geographic distribution: uncommon, western Mediterranean Sea.

Stratigraphic distribution: as *Parvicardium ovale* in the Miocene of Germany and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987). As *Cardium ovale* since Pliocene.

Plagiocardium papillosum **(Poli, 1795)**

Shell: Vaguely round shape, covered with radiating rounded ribs, and few concentric lines.

Ecology: infaunal, infra-circalittoral, mistophilous (Tebble, 1976). Preferential species DC, found also in SFBC. Picard (1965) reported also as a species of high ecological distribution.

Size: 12-16 mm.

Geographic distribution: both in Atlantic Ocean and Mediterranean Sea.

Stratigraphic distribution: since Badenian of Slovakia to Holocene (Raffi *et al.*, 1985). Reported in Lower Pleistocene of Italy from Bellomo (1993). In the In the Pleistocene of Greece (Nielsen *et al.*, 2006) and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Plagiocardium sp.

Superfamily MACTROIDEA Lamarck, 1809

Family MACTRIDAE Lamarck, 1809

Mactra stultorum **(Linneo, 1758)**

Shell: thin and brittle, oval, umbo just anterior to midline. Sculpture of very fine concentric lines, growth stages clear. Shell margin prominent. Right valve with two cardinal teeth. Left valve with three cardinal teeth.

Ecology: infaunal in sandy bottoms. Burrowing in clean sand, from the lower shore into the shallow sub-littoral.

Size: up to 50 mm long.

Geographic distribution: widespread, from Norway to the Mediterranean and West Africa, and often abundant.

Stratigraphic distribution: since Upper Pliocene to Holocene.

***Lutraria angustior* Philippi, 1844**

Shell: elongate, somewhat quadrate, anterior hinge line sloping more steeply than posterior; gaping at both ends. Umbo anterior to mid-line. Sculpture of numerous fine grooves, developing as fine ridges close to the margin; growth stages clear. Right valve with two cardinal teeth and a single, poorly developed, posterior lateral. Left valve with anterior two cardinal teeth and single, thin anterior and posterior laterals.

Ecology: in mixed soft substrata, offshore to about 50 m.

Size: up to 100 mm.

Geographic distribution: uncommon.

Stratigraphic distribution: since Messinian to Holocene (Raffi *et al.*, 1985).

Superfamily VENEROIDEA Rafinesque, 1815

Family VENERIDAE Rafinesque, 1815

***Venus casina* Linneo, 1758**

Shell: solid, equivalve and inequilateral, beaks are in front of the midline. Approximately circular in outline, with a slight truncation on the posterior margin.Shell sculpture of prominent concentric ridges interspersed with small ridges; between the ridges and troughs there are fine concentric striae. Growth stages are not clear. There are three cardinal teeth in each valve Inner margins of the valves are crenulated.

Ecology: shallow burrower into sand, muddy sand, gravel. Infralittoral. Marker of the presence of a current (Pérès & Picard, 1964). Exclusive species of SGCF biocoenosis (Picard, 1965).

Size: up to 51 mm in diameter.

Geographic distribution: common. It has a wide distribution from the south of Norway to the Iberian Peninsula, the Mediterranean Sea, the Atlantic coast of Morocco, the Canary Isles, and Senegal.

Stratigraphic distribution: Since Zanclean (Belgium) to Holocene (Raffi *et al.*, 1985). Reported for Lower Pleistocene of Calabria region from Bernasconi *et al.* (1997).

***Venus nux* Gmelin, 1791**

Shell: globular. Sculpture with very fine concentric ribs, sometimes forming lamellae.

Ecology: unknown.

Size: 30-45 mm.

Geographic distribution: uncommon, eastern Mediterranean Sea.

Stratigraphic distribution: since Miocene to Holocene.

Venus sp.

Dosinia lupinus **(Linneo, 1758)**

Shell: approximately circular, inequilateral, umbo just anterior to midline, small but prominent. Sculpture of numerous fine concentric ridges, shell surface smooth to touch. Growth stages clear. Each valve with three cardinal teeth.

Ecology: deep burrower into fine or coarse sand, sandy mud, silty-sand or shell-gravel. Infralittoral. Common. Exclusive species of MI biocoenosis (Pérès & Picard, 1964).

Size: up to 40 mm long.

Geographic distribution: distributed from Iceland to the Mediterranean and West Africa.

Stratigraphic distribution: since Serravallian of Italy (Bernasconi & Robba, 1993) to Holocene (Raffi *et al.*, 1985). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Clausinella brogniarti **(Payraudeau, 1826)**

Shell: sub triangular, rather flat, umbo prominent. Sculpture of up to 15 broad, bold, concentric ribs, round in section with fine concentric striations between. The ribs are more evident than *Clausinella fasciata* (da Costa, 1778), forming lamellae. Each growth stage indicated by two closely conjoined ribs. Three cardinal teeth in each valve. Margin very finely crenulated.

Ecology: in coarse gravel, usually with sand or shell.

Size: 15-20 mm.

Geographic distribution: uncommon, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Clausinella fasciata **(da Costa, 1778)**

Shell: sub triangular, rather flat, umbo prominent. Sculpture of up to 15 broad, bold, concentric ribs, round in section with fine concentric striations between. Each growth stage indicated by two closely joined ribs. Three cardinal teeth in each valve. Margin very finely crenulated.

Ecology: in coarse gravels, usually with sand or shell.

Size: up to 25 mm long.

Geographic distribution: wide geographic distribution.

Stratigraphic distribution: Lower Pleistocene of Italy (Bellomo, 1993) to Holocene (Raffi *et al*., 1985). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Order MYOIDA Stoliczka, 1870

Superfamily MYOIDEA Lamarck, 1809

Family CORBULIDAE Lamarck, 1818

Corbula gibba **(Olivi, 1792)**

Shell: thick, broadly oval to sub triangular, umbo close to midline; right valve convex, enclosing and overlapping left, its ventral margin covered only by a fringe of periostracum from the left valve. Sculpture of coarse concentric grooves and ridges, and a few radiating striae on left valve. Right valve with a single, massive tooth, and single elongate anterior and posterior lateral teeth. Left valve with no lateral teeth.

Ecology: epifaunal, on hard substrates, meso-infralittoral. Common. High ecological distribution. Preferential species in MI biocoenosis (Pérès & Picard, 1964).

Size: up to 15 mm long

Geographic distribution: distributed from Norway south to the Mediterranean Sea.

Stratigraphic distribution: since Bartonian (France) to Holocene (Raffi *et al*., 1985). Reported for Calabrian of Italy (Ragaini *et al.*, 2007), and Pleistocene of Greece (Nielsen *et al*., 2006), Upper Pleistocene marine terrace of Turkey (Schneider *et al*., 2005) and Italy (Gliozzi, 1987).

Classis GASTROPODA Cuvier, 1797

Subclassis PROSOBRANCHIA Milne Edwards, 1848

SuperOrder ARCHEOGASTROPODA Thiele, 1925

Order COCCULINIFORMIA Haszprunar, 1987

Superfamily COCCULINOIDEA Dall, 1882

Family COCCULINIDAE Dall, 1882

Cocculina mamilla **Di Geronimo, 1974**

Shell: solid, oval, with the apex cuts off and closed to anterior margin. The profile is lumpy.

Ecology: unknown.

Size: 2-5 mm.

Geographic distribution: rare, found only offshore Crotone peninsula.

Stratigraphic distribution: Holocene.

Cocculina sp.

Order VETIGASTROPODA Salvini-Plawen & Haszprunar, 1987

Superfamily FISSURELLOIDEA Fleming, 1822

Family FISSURELLIDAE Fleming, 1822

Diodora gibberula **(Lamarck, 1822)**

Shell: solid, oval, with the apex cutting off and closed to anterior margin. The profile is lumpy. Radial ribs, rather thick and striae concentric form the sculpture.

Ecology: on coarse or hard substrates. Known from rocky shores.

Size: 8-16 mm.

Geographic distribution: common, from 10m wd (Riedl, 1991).

Stratigraphic distribution: since Zanclean (Spain) to Holocene. Reported for Lower Pleistocene (Bellomo, 1993) and Upper Pleistocene(Gliozzi, 1987) of Italy.

Diodora graeca **(Linneo, 1758)**

Shell: solid, oval, with the apex cutting off and closed to anterior margin. Radial ribs, rather thick and concentric striae, form the sculpture. The outer margin is finely barbed.

Ecology: epifaunal, grazer, carnivore

Size: 20-25 mm.

Geographic distribution: uncommon, in all the Mediterranean Sea.

Stratigraphic distribution: since Miocene (Poland) to Holocene. Reported for the Lower Pleistocene of Italy (Bellomo, 1993). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987). Reported for Pleistocene of Greece (Nielsen *et al.*, 2006).

Diodora sp.1

Emarginula adriatica Costa O.G., 1829

Shell: with oval-elongate contour and moderately elevated profile, apex very close to posterior margin, definitely coiled. Sculpture of numerous radial ribs, high and rugged.

Ecology: epifaunal, detritivor-suspension feeder. Meso-infralittoral. Wide distribution.

Size: 12-15 mm.

Geographic distribution: eastern Atlantic, from Bay of Biscay to Morocco; rare in the Western Mediterranean and the Adriatic Sea, generally on rather deep rocky bottoms.

Stratigraphic distribution: reported for Lower Pleistocene of Calabria region from Bellomo (1993).

Emarginula rosea Bell T., 1824

Shell: small, thin and with prominently curved beak, with oval contour and elevated profile, strongly curled backwards with the apex overhanging posterior margin. There are 35-40 radiating ridges and about 20 parallel to the aperture edge. Sculpture of thick radial ribs, narrower than the interspaces, forming a coarse lattice with strong commarginal cords.

Ecology: circalittoral. Epifaunal, grazer, carnivore. Sponges feeder (Fretter & Graham, 1976). Rare. Species linked to biocoenosis DC and C.

Size: 6 mm.

Geographic distribution: widely distributed.

Stratigraphic distribution: reported for Lower Pleistocene of Calabria region from Bellomo (1993).

Emarginula papillosa Risso, 1826

Shell: very similar to *E. granulosa*, it has the same size, shape and habitat. The difference is in the sculpture's surface that is formed by lines of ordinate radial papillae.

Ecology: infra-circalittoral, on rocks and boulders.

Size: 2-4 mm.

Geographic distribution: western Mediterranean Sea. Rare.

Stratigraphic distribution: Holocene.

Emarginula sp.

Puncturella noachina (Linneo, 1771)

Shell: cap-shaped with recurved beak terminating in a small spire of one or one and a half whorls; slit-like hole opens on anterior slope just below beak, in dead shells an internal hemi-conical septum is seen below this opening.

Ecology: epifaunal, on rocky and stony substrates between 20 and 165 m. Intertidal in high latitudes. Grazer.

Size: 7 mm.

Geographic distribution: a circumpolar species, which extends south to Portugal and the Mediterranean Sea.

Stratigraphic distribution: since Middle Pleistocene to Holocene.

Superfamily HALIOTOIDEA Rafinesque, 1815

Family HALIOTIDEE Rafinesque, 1815

***Haliotis tuberculata f. lamellosa* Lamarck, 1822**

Shell: flattened, ear-shaped spiral with a series of funnel-shaped holes, only the most recently formed, usually five to seven, perforate, surmounting a flattened peripheral band. Shell sculpture is enhanced by narrow spiral ridges, traversed by growth lines accentuated at intervals to form ridges. Operculum absent.

Ecology: on hard substrates in shallow waters.

Size: up to 90 mm.

Geographic distribution: all Mediterranean Sea.

Stratigraphic distribution: since Laghian (Romania) to Holocene. Reported for Upper Pleistocene of Greece (Nielsen *et al*., 2006; Titschack *et al*., 2008).In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Superfamily TROCHOIDEA Rafinesque, 1815

Family TROCHIDAE Rafinesque, 1815

***Clanculus corallinus* (Linneo, 1758)**

Shell: solid, globular, typically red. It consists of five or six whorls separated by convex deep suture. The protoconch is one and a half smooth. On the first whorl of the teleoconch two spirals gritty cords are present, dividing it into three sections. On the following whorls spiral cords, all of equal size are separated by intervals and take a closer look consumptive. The basis of the last round, broad and rounded, is flattened, with six or seven concentric cords more or less grainy. The whole surface is covered with streaks of robust growth evident. The opening is sub-quadrate; the lip is robust and internally denticulate. One bifid tooth.

Ecology: on hard-rocky substrates, usually under 10 m wd.

Size: 9-11 mm.

Geographic distribution: common in all the Mediterranean Sea.

Stratigraphic distribution: since Zanclean (Spain) to Holocene. Reported for Lower Pleistocene of Italy (Bellomo, 1993). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Gibbula adriatica* (Philippi, 1844)**

Shell: conical, moderately scalariforme. Open rounded umbilicus. The base of the shell is convex and separated from the side by a rounded corner. The sculpture consists of fine spiral grooves, just visible along the sides, just more visible on the base.

Ecology: infralittoral (Riedl, 1991).

Size: 10 mm.

Geographic distribution: uncommon, in central and eastern Mediterranean Sea. Very common in Adriatic Sea.

Stratigraphic distribution: Holocene.

***Gibbula ardens* (Von Salis, 1793)**

Shell: solid, conical made up of five or six whorls slightly convex and slightly nodulose on the edge, separated by deep suture entrapment, with stepped profile and with pointed pink apex. Sculpture of spiral ribs thin, irregular costae. Large deep umbilicus present.

Ecology: infralittoral (Riedl, 1991).

Size: 5 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Gibbula magus* (Linneo, 1758)**

Shell: solid, conical, with stepped profile and marked peripheral keel on last whorl; on upper whorls keel lies immediately above deep suture line. Up to eight whorls. Sculpture of short, nodular costae on apical part of each whorl, below which are a variable number of spiral ridges and grooves.

Ecology: infralittoral, on both muddy and sandy bottoms. Diatoms and detritus feeder. On weed, under stones.

Size: more than 30mm.

Geographic distribution: distributed from Mediterranean and Azores to western basin of English Channel, west coast of Britain, and north to Shetland.

Stratigraphic distribution: since Lowe Pliocene of Sardegna region (Italy) (Dieni & Omenetto, 1960) to Holocene. Reported for lower Pleistocene of Calabria, Italy, from Bellomo (1993) and Bernasconi *et al.* (1997). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Gibbula racketti* (Payraudeau, 1826)**

Shell: globular shape, with very fine spirally strings.

Ecology: infralittoral (Riedl, 1991).

Size: 3-6 mm.

Geographic distribution: uncommon, western Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Gibbula guttadauri* (Philippi, 1836)**

Shell: typical sculpture with 3 large ribs on the whorls, obliquely striated and separated by two

Deep grooves in which numerous axial lamellae are present, ranging from a cord to another.

The whorls are convex, angular, and slightly grainy in top. The suture is canalicular, and travelled from the usual axial lamellae. The umbilicus is very large and deep and the columella forms a straight tooth quite pronounced.

Ecology: infralittoral (Riedl, 1991).

Size: 6-12 mm.

Geographic distribution: uncommon, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for the Pleistocene of Greece (Nielsen *et al.*, 2006).In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Gibbula richardi* (Payreaudeau, 1826)**

Shell: typical smooth surface of the shell, neritiform with large ombilicus.

Ecology: Infralittoral, shallow waters. Accidental species in GI biocoenosis (Pérès & Picard, 1964).

Size: 11-23 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993).

***Gibbula sp*.**

***Jujubinus exasperatus* (Pennant, 1777)**

Shell: pyramidal, flat-sided, apex pointed; taller than broad. It may be distinguished from *Jujubinus striatus* by more nodular ornamentation to the spiral ridges, which are fewer in numbers (4-5 compared with 8-9) on the upper part of the body whorl.

Ecology: epifaunal, vagile, detritivor, on algae like *Zosteria,* 0-200m wd. Preferential species of C biocoenosis- Found in the *Posidonia* meadows.

Size: up to 8 mm.

Geographic distribution: common.

Stratigraphic distribution: since Piacenzian (Spain) to Holocene. In Pleistocene of Greece (Nielsen *et al*., 2006); in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Jujubinus striatus* (Linneo, 1758)**

Shell: solid, conical with six or eight flat-sided whorls. Sculpture of spiral ridges; growth lines fine, may give nodular appearance to spiral ridges, especially in apical and basal areas of shell.

Ecology: on weeds, especially on *Zostera* down to 200 m.

Size: 6-13 mm.

Geographic distribution: common.

Stratigraphic distribution: since Zanclean (Spain) to Holocene. Reported for Lower Pleistocene of Calabria region (Italy) from Bellomo (1993) and Bernasconi *et al*. (1997). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Jujubinus sp.

Family COLLONIIDAE Cossmann, 1916

***Homalopoma sanguineum* (Linneo, 1758)**

Shell: typically bright red, small, fairly solid, depressed-loop formed by two or three laps the last of which is very large and convex, suture evident. The surface is covered by four or five spiral cords smooth but not flat, separated by very large intervals which are also smooth, axial sculpture absent. Umbilicus absent. The spiral cords can also be found based on more widely spaced. The operculum is calcareous.

Ecology: epifaunal, infralittoral, on hard substrates. Linked to HP and C biocoenoses.

Size: 7-8 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene of Calabria region (Italy) from Bellomo (1993) and Upper Pleistocene of Greece (Nielsen *et al*., 2006; Titschack *et al*., 2008) and Italy (Gliozzi, 1987).

Family TRICOLIIDAE Robertson, 1985

***Tricolia tenuis* (Michaud, 1829)**

Shell: it consists of 4 whorls that create a convex suture, light and smooth; there is no presence of any type of sculpture. Open oval operculum.

Ecology: epifaunal, on sandy bottoms or typically attached to *Posidonia* leaves. Grazer.

Size: 8-11 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: since Piacenzian (Spain) to Holocene.

***Tricolia pullus* (Linneo, 1758)**

Shell: conical or turban-shaped, with deep sutures; solid, smooth, and glossy. Last whorl approximately two-thirds of shell length. There is no presence of any type of sculpture

Ecology: epifaunal, on green-algae community or sandy bottoms. Grazer.

Size: up to 9 mm.

Geographic distribution: a southern species extending from the Mediterranean to the North Sea.

Stratigraphic distribution: since Piacenzian (Spain) to Holocene. Reported for Lower Pleistocene of Calabria region (Italy) from Bellomo (1993) and Spain from Vera-Pelaez *et al*. (2004). As *Tricolia pulla* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Bolma rugosa* (Linneo, 1767)**

Shell: typically sculpture from smooth to very spiny.

Ecology: epifaunal, on rocky substrates, usually circalittoral. Grazer. Species linked with sciaphilous conditions.

Size: 40-55mm.

Geographic distribution: common in all the Mediterranean Sea.

Stratigraphic distribution: as *Astrea rugosa* since Serravallian (Greece), to Holocene. Reported for Upper Pleistocene of Greece (Nielsen *et al.*2006; Titschack *et al.*, 2008) and France (Zibrowius, 2005). Reported as *Astrea rugosa* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

SuperOrder CAENOGASTROPODA Cox, 1959

Order LITTORINIMORPHA Golikov & Starobogatov, 1975

Superfamily VELUTINOIDEA GRAY, 1840
Family TRIVIIDAE Troschel, 1863

***Trivia multilirata* (G.B. Sowerby II, 1870)**

Shell: egg-shape, light and delicate, presenting numerous thick and clear spiral cords, which wrap the entire shell. The outer lip shows regular small teeth.

Ecology: hard substrate.

Size: 14-16 mm.

Geographic distribution: rare, Adriatic Sea.

Stratigraphic distribution: Holocene.

Trivia sp.

Order NEOTAENIOGLOSSA Haller, 1882

Superfamily CERITHIOIDEA Férussac, 1819
Family CERITHIIDAE Férussac, 1819

***Cerithium vulgatum* Bruguière, 1792**

Shell: elongated conic shell, with spiral ribs sometimes very tricky, sometimes almost smooth.

Ecology: epifaunal, on hard substrates, lower than 10m wd. Known from rocky shores. Herbivore.

Size: 50-70 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: since Lower Miocene (Austria) to Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and Bernasconi *et al.* (1997), and Upper Pleistocene of Spain (Vera-Pelaez *et al.*, 2004).

Cerithium sp.

***Bittium reticulatum* (Da Costa, 1778)**

Shell: elongate, conical, up to 16 (usually 10-12) whorls; apex pointed. Sculpture of strong costae and spiral striae, interacting to give oval tubercles: four rows on lower whorls, three on upper whorls. Varix of last whorl close to aperture. Aperture oval, drawn out to a short sinus at the base, outer lip crenulated.

Ecology: epifaunal, herbivore or detritus feeder. Grazer. Infra-circalittoral. It is linked with AP and HP biocoenosis. On soft substrata, associated with *Zostera* and other weeds.

Size: up to 15 mm.

Geographic distribution: widely distributed, locally abundant.

Stratigraphic distribution: since Lower Miocene (Austria) to Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and Bernasconi *et al*. (1997). Reported for Upper Pleistocene of Netherland (Meijer, 1983), Greece (Nielsen *et al*.2006) and Spain (Vera-Pelaez *et al.*, 2004). In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Bittium latreilli* (Payraudeau, 1826)**

Shell: more slim than *B. reticulatum*, very variable. Sculpture formed by spiral and axial beads, sometimes varixes.

Ecology: infralittoral rocky bottoms and reefs.

Size: 8-13 mm.

Geographic distribution: eastern Mediterranean Sea.

Stratigraphic distribution: Holocene.

Family TURRITELLIDAE Lovén, 1847

***Turritella communis* Risso, 1826**

Shell: tall, sharply pointed, conical, with 16-20 tumid whorls. Sculpture of numerous spiral striae of varying proportions: three (or up to six) usually more prominent than others; sinuous growth lines may interact with spiral striae to give them a beaded appearance. Aperture small, angulated; outer lip crenulated. No umbilicus.

Ecology: infaunal, suspension feeder, mud-loving species. Infra-circalittoral. Preferential species of VTC biocoenosis, accompanying species in DL biocoenosis (Pérès & Picard, 1964). Locally abundant sub littoral, down to 220 m, on soft bottoms.

Size: up to 55 mm, commonly 30 mm.

Geographic distribution: common.

Stratigraphic distribution: since Pliocene of Cyprus (Dornbos & Wilson, 1999) to Holocene.

***Turritella turbona* Monterosato, 1877**

Shell: each whorl presents two spirally strings.

Ecology: infaunal, suspension feeder, sand-lover. Infra-circalittoral. Exclusive species of DC biocoenosis (Pérès & Picard, 1964).

Size: 25-50 mm.

Geographic distribution: widely distributed.

Stratigraphic distribution: Reported for Lower Pleistocene of Calabria region from Bellomo (1993) to Holocene.

Turritella sp.1

Superfamily RISSOOIDEA Gray J.E., 1847

Family RISSOIDAE Gray J.E., 1847

***Rissoa variabilis* (Von Muehlfeldt, 1824)**

Shell: elongated, conical with nipple-shaped apex. Whorls are convex-shaped with a distinct suture. The aperture is ovate.

Ecology: common on meadows of *Cystoseira, Laurencia* e *Cladophora*, shallow waters (Riedl, 1991).

Size: 5-9 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: since Lower Pleistocene of Calabria region from Bellomo (1993) to Holocene. In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Rissoa ventricosa* Desmarest, 1814**

Shell: elongated, conical with nipple-shaped apex. Whorls are convex-shaped with a distinct suture. The aperture is ovate, bigger than other *Rissoa spp.* and has a large mouth and a thick lip.

Ecology: shallow waters (Riedl, 1991), between green-algae community and detrital bottoms. Grazer. Rare. Known from the near shore.

Size: 5 mm.

Geographic distribution: uncommon, on each type of bottoms. Infralittoral.

Stratigraphic distribution: since Upper Pleistocene of Italy (Gliozzi, 1987) to Holocene.

***Rissoa violacea* Desmarest, 1814**

Shell: elongated, conical with nipple-shaped apex. Whorls are convex-shaped with a distinct suture. The aperture is ovate. This species present a typical bounded violet decoration.

Ecology: common between the upper infralittoral algae.

Size: 5 mm.

Geographic distribution: common on each type of bottoms, typically between the infralittoral algae. Linked to the AP biocoenosis (Pérès & Picard, 1964).

Stratigraphic distribution: Holocene.

Rissoa sp.

***Alvania cancellata* (Da Costa, 1788)**

Shell: quite solid. Sculpture of protoconch with 3 convex whorls showing spiral rows of fine granules, indistinct in optical microscopy. Sculpture of teleoconch with a coarse lattice of high spiral cords narrower than the interspaces (4 whorls). Aperture with outer lip thickened, finely denticulate inside.

Ecology: known from seamounts and knolls.

Size: 4-5 mm.

Geographic distribution: across the whole Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Alvania cimex* (Linneo, 1758)**

Shell: small, little convex, globular consisting of 7 whorls separated by deep sutures. Protoconch is formed by 2-3 whorls decorated with thin papillosa stripes separated by wide intervals. Whorls of the teleoconch are decorated with 15-16 axial ribs, sub-continuous and separated by longer intervals. The outer lip is varicose. The edge is smooth columellar callus with little extended. This species is similar to *A. mamillata* but apex is smaller.

Ecology: known from rocky shores, between algae.

Size: 3-6 mm.

Geographic distribution: very common in Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Alvania hirta* (Monterosato, 1884)**

Shell: small, little convex, globular consisting of 7 whorls separated by deep sutures. Axial and spiral ribs, forming a sort of reticulate and spines when the ribs cross.

Ecology: Infralittoral.

Size: 3-6 mm.

Geographic distribution: common.

Stratigraphic distribution: Holocene.

***Alvania mamillata* Risso, 1826**

Shell: very similar to *A. cimex*, with a smaller apex and wider intervals are present among spiral stripes.

Ecology: infralittoral.

Size: 4-5 mm.

Geographic distribution: not common, in the whole Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Alvania punctura* (Montagu, 1803)**

Shell: moderately solid, with a large protoconch of 2.5 whorls and teleoconch of 2.5 whorls. Sculpture of protoconch of minute granules in spiral rows hardly visible through the optical microscope. Teleoconch sculpture of fine spiral cords, narrower than interspaces and delicate, somewhat flexuous axial ribs forming a fine lattice with the cords.

Ecology: epifaunal, detritus feeder. Species linked to bottoms with a grain-size ranging between 50 and 250 microns, with organic content (Fretter &Graham, 1978). Accompanying species of DC biocoenosis (Pérès & Picard, 1964).

Size: 2 mm.

Geographic distribution: rare, intertidal to ca. 100 m WD reaching 200 m locally in the Western Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Alvania testae* (Aradas & Maggiore, 1844)**

Shell: pyramidal, with low-convex whorls, and a fine axial ornamentation. The lip is very thick. The apex is obtuse.

Ecology: deep species.

Size: 2mm.

Geographic distribution: uncommon, distributed in all the Mediterranean Sea.

Stratigraphic distribution: since Zanclean (Italy) to Holocene.

Pusillina radiata* (Philippi, 1836*)

Shell: pyramidal, with low-convex whorls, and a fine axial ornamentation not visible in the last whorl.

Ecology: infralittoral.

Size: 2-4 mm.

Geographic distribution: uncommon, distributed in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Rissoina bruguieri **(Payraudeau, 1826)**

Shell: slim shape, massive mouth, strong axial and thick spiral ribs.

Ecology: infralittoral (Riedl, 1991).

Geographic distribution: very common, all the Mediterranean Sea.

Size: 6-8 mm.

Stratigraphic distribution: since Messinian (Morocco) to Holocene. Reported for Lower Pleistocene of Calabria region from Bernasconi *et al.* (1997).

Superfamily NATICOIDEA Forbes, 1838

Family NATICIDAE Forbes, 1838

Natica hebraea **(Martyn, 1784)**

Shell: globular, with a large last whorls and a quite circular aperture.

Ecology: carnivorous, on sandy bottoms.

Size: 50-60 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Natica sp.

Notocochlis gualteriana **(Récluz, 1844)**

Shell: globular, smashed, with a very large umbilicus and a well-developed callus.

Ecology: infaunal, carnivore.

Size: 18-21 mm.

Geographic distribution: uncommon, western-southern Mediterranean Sea.

Stratigraphic distribution: since Middle Miocene (Indonesia) to Holocene. Reported for Upper Pleistocene of Australia region.

Superfamily TRIPHOROIDEA Gray J.E., 1847

Family TRIPHORIIDAE Gray J.E., 1847

Monophorus perversus **(Linneo, 1758)**

Shell: sinistral, tower-shaped, with 15 flat-sides whorls; sutures are shallow. Sculpture of spiral striae and transverse costae producing spiral rows of tubercles. Last whorl with three rows of tubercles above two or three nodular spiral ridges. Penultimate and two or three whorls above with three rows of tubercles, the central row being smaller; upper whorls with two rows. Aperture is angular, with small, narrow, almost tubular siphonal canal.

Ecology: epifaunal, carnivorous, sponges feeder, widely distributed. Usually on hard substrates, linked with C biocoenosis.

Size: up to 7 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Upper Pleistocene of Spain (Vera-Pelaez *et al.,* 2004) to Holocene. As *Triphora perversa* in the Pleistocene of Greece (Nielsen *et al*., 2006) and Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Superfamily JANTHINOIDEA Lamarck, 1810

Family JANTHINIDAE Leach, 1823

Epitonium candidissimum **(Monterosato, 1877)**

Shell: convex whorls, continuative axial ribs.

Ecology: unknown.

Size: 13-15 mm.

Geographic distribution: rare, eastern Mediterranean Sea.

Stratigraphic distribution: Holocene.

Epitonium sp.

Order NEOGASTROPODA Thiele, 1929

Superfamily BUCCINOIDEA Rafinesque, 1815

Family COLUMBELLIDAE Swainson, 1840

Columbella rustica **(Linneo, 1758)**

Shell: the shell profile varies widely, from slender to stout, it presents a mouth tightly notched, and an acute apex.

Ecology: known from rocky shores. Exclusive species of AP biocoenosis (Pérès & Picard, 1964).

Size: 15-20 mm.

Geographic distribution: very common in all the Mediterranean Sea.

Stratigraphic distribution: since Upper Pleistocene of Greece (Titschack *et al.,* 2008) and Italy (Gliozzi, 1987) to Holocene.

Family NASSARIDAE Iredale, 1916

Nassarius incrassatus **(Strøm, 1768)**

Shell: solid, tall, conical, with up to eight whorls; periostracum confined to grooves between striae. Sculpture of strong, slightly flexuous costae, strap-like spiral striae, and fine growth lines. Costae more prominent than spiral striae on all whorls, 12-15 on whorls of spire; last whorl with strong labial varix. Aperture oval, markedly oblique siphonal canal. Outer thickened internally in mature shells, with seven teeth below labial varix.

Ecology: epifaunal, on rocky shores, below stones and in crevices, more abundant in shallow sub littoral. Carnivore.

Geographic distribution: common, in all the Mediterranean Sea.

Size: 12 mm.

Stratigraphic distribution: since Serravallian (Greece) to Holocene. Reported for Lower Pleistocene of Calabria region from Bernasconi *et al.* (1997). As *Hinia incrassata* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Nassarius lima **(Dillwin, 1817)**

Shell: convex whorls with very deep suture, sinuous axial ribs, thick and thin spiral ribs.

Ecology: semi- infaunal, shallow waters, in muddy-sandy bottoms.

Size: 20-40 mm.

Geographic distribution: rare, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. As *Nassa limata* in Pliocene of Italy (Bondi & Sandrucci, 1949). As *Hinia limata* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Nassarius corniculum **(Olivi, 1792)**

Shell: rounded pyramid shape, slightly convex whorls, massive and jagged mouth.

Ecology: unknown.

Size: 12- 18 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Nassarius* sp.**

***Cyclope neritea* (Linneo, 1758)**

Shell: pyramid pressed profile with rounded base, slightly convex whorls.

Ecology: epifaunal, carnivore.

Size: 8-15 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Superfamily MURICOIDEA Rafinesque, 1815

Family MURICIDAE Rafinesque, 1815

***Trophonopsis muricata* (Montagu, 1803)**

Shell: a tall, narrow cone of seven or eight whorls presenting deep sutures. Sculpture of numerous costae, spiral striae and fine growth lines. Protoconch rather inflated, set obliquely on teleoconch. Aperture elongate-oval, with straight siphonal canal.

Ecology: epifaunal, carnivore, probably worm's feeder (Fretter & Graham, 1982). Widely distributed, circalittoral. On little hard substrates.

Size: 19 mm.

Geographic distribution: common, distributed from Mediterranean to south and west coasts of British Isles.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993).

***Ocinebrina aciculata* (Lamarck, 1822)**

Shell: very convex whorls with deep marked suture. Thin axial costae crossed by thin spiral spiny costae. Open siphonal channel.

Ecology: unknown.

Size: 10-20 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene of Calabria region from Bellomo (1993) and in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

***Chauvetia* sp.**

Family COSTELLARIDAE MacDonald, 1860

***Vexillum (Pusia) ebenus* (Lamarck, 1811)**

Shell: convex whorls, possibly presence of costae.

Ecology: unknown.

Size: 15-30 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Vexillum sp.

Family CYSTISCIDAE Stimpson, 1865

***Gibberula philippii* (Monterosato, 1878)**

Shell: slightly triangular shape, very delicate, presenting rounded apex.

Ecology: muddy sand.

Size: 2-3 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Lower Pleistocene from Bellomo (1993) and for Upper Pleistocene from Gliozzi (1987) of Calabria region, Italy.

Superfamily CONOIDEA Rafinesque, 1815

Family CONIDAE Rafinesque, 1815

***Conus mediterraneus* Hwass in Bruguière 1792**

Shell: very variable. It has a very strong shell, roughly biconical. The operculum is long and narrow.

Ecology: strictly infralittoral. Known from rocky shores. Epifaunal. It is a carnivorous predator and like all *Conidae* has a poisonous sting with which immobilizes the prey.

Size: 40-65 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: since Upper Pleistocene of Spain (Vera-Pelaez *et al.*, 2004) to Holocene. In the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Conus sp.

Family RAPHITOMIDAE Bellardi, 1875

***Raphitoma echinata* (Brocchi, 1814)**

Shell: elongate, turreted, with seven to nine whorls; sutures deep, sinuous. Sculpture presents a reticulate, due to the presence of both axial and spiral costae, sometimes spiny.

Ecology: Infralittoral muddy-sand.

Size: 10-20 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

***Raphitoma linearis* (Montagu, 1803)**

Shell: elongate, turreted, with seven to nine whorls; sutures deep, sinuous, with narrow, minutely granular sub-sutural band. Sculpture of strong costae, spiral striae, and fine growth lines. Costae rather narrow, about 11-12 on last whorl. Spiral striae narrow, slightly nodular where they cross costae, much reduced on sub-sutural band, 16-20 on last whorl. Protoconch of three or four whorls, finely reticulated, with distinctive diamond pattern. Aperture elongate-oval, with short siphonal canal. Outer lip thin, crenulated, without a varix.

Ecology: more commonly sub littoral on sand, shell, and gravel bottoms at 10- 200 m.

Size: 12 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Upper Pleistocene of Netherlands (Meijer, 1983).

***Raphitoma horrida* (Monterosato, 1884)**

Shell: elongate, turreted, with seven to nine whorls; sutures deep, sinuous. Sculpture present a well defined reticulate, due to the presence of both axial and spiral costae, usually very spiny.

Ecology: unknown.

Size: 15-18 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Raphitoma sp.

Family MANGELIIDAE P. Fischer, 1883

***Mangelia barashi* (Van Aartsen & Fehr-de Wal, 1978)**

Shell: robust, with angled whorls presenting rare thick axial costae. The mouth is close and shows a thick tip.

Ecology: unknown.

Size: 5 mm.

Geographic distribution: uncommon, central Mediterranean Sea.

Stratigraphic distribution: Holocene.

Bela nebula **(Montagu, 1803)**

Shell: elongate cone of eight or nine whorls, with deep sutures accentuated by a slightly swollen, often beaded sub-sutural band. Sculpture of strong, flexuous transverse costae, spiral striae and growth lines. Interaction with growth lines gives them a finely beaded appearance and fine reticulate pattern to shell. Protoconch of three or four whorls, initially smooth, becoming tuberculate before merging with teleoconch. Aperture elongate-oval, with a wide siphonal canal.

Ecology: on sand and muddy gravel bottoms.

Size: 14 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. Reported for Upper Pleistocene of Spain (Vera-Pelaez *et al*., 2004).

Bela sp.

Classis SCAPHOPODA Bronn, 1862

Order DENTALIIDAE Starobogatov, 1974

Family DENTALIIDAE Children, 1834

Antalis agilis **(M. Sars in G.O. Sars, 1872)**

Shell: long, thin, gently curved. The surface is smooth and shiny.

Ecology: muddy-sandy bottoms, below 50m wd.

Size: 30-60 mm.

Geographic distribution: uncommon, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene.

Antalis inaequicostata **(Dautzenberg, 1891)**

Shell: slim, gently curved with pointed apex. The surface presents slight longitudinal ribs.

Ecology: unconsolidated bottoms, on little hard substrates, below 5 m wd. Mistophilous.

Size: 30-40 mm.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: Holocene. As *Dentalium inaequicostatum* in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Antalis vulgaris **(Da Costa, 1778)**

Shell: thick, with a few marked, oblique, concentric growth lines or ridges. Less curved than *Antalis dentalis* (Linneo, 1758). Posterior portion of shell with fine, closely spaced, longitudinal striations.

Ecology: infralittoral, on all type of substrates, preferably sand. Exclusive species of DC biocoenosis (Pérès & Picard, 1964).

Size: up to 60 mm.

Geographic distribution: not common.

Stratigraphic distribution: Holocene. As *Dentalium vulgare* Da Costa, 1778 in the Upper Pleistocene of Calabria region, Italy (Gliozzi, 1987).

Antalis sp.

4.3.6 APPENDIX VI

Systematic list of identified bryozoan species with short description of shell-morphology, ecology, geographic and stratigraphic distribution.

Phylum BRYOZOA
Class GYMNOLAEMATA Allman, 1856
Order CHEILOSTOMATIDA Busk, 1852

Superfamily CELLEPOROIDEA Johnston, 1838
Family PHIDOLOPORIDAE Gabb & Horn, 1862

Reteporella beaniana **(King, 1846)**

Sertella beaniana King

Shell: colonies are similar to fragile rolled nets, reaching 10 cm in diameter. Zoecium is cylindrical, with an interior aperture presenting 4-6 spines. Oecium is dome-shape, with a longiutudinal crevice.

Ecology: on dark rocky bottoms, or caves from 5 to 50 m wd usually on gorgonian *Paramuricea clavata* and on coralligenous bottom.

Geographic distribution: common, in all the Mediterranean Sea.

Stratigraphic distribution: since Middle Pliocene of Italy (Poluzzi *et al*., 1988) to Holocene.

Reteporella sp.

Superfamily MEMBRANIPOROIDEA Busk, 1854
Family MEMBRANIPORIDAE Busk, 1852

Membranipora membranacea **(Linneo, 1767)**

Flustra membranacea Linneo, 1767

Flustra teleacea [sic]

Shell: encrusting lazy mat-like colonies, formed by delicate small white grid. Zoecium is oblong, rectangular, with a small plug at each corner. Zooids are rectangular with tubercles or short spines in the corners. Tower zooids may also be present. Colonies may vary in size.

Ecology: infralittoral. On hard substrate, also on algae in shallow environment. *M. membranacea* most commonly grows on kelp from the lower shore down to the lower limit of the kelp forests. It may also colonize *Fucus* species in rock pools. Common on sheltered rocky shores, colonies will grow best in areas of fast flowing water or high tidal influx. Suspension feeder.

Geographic distribution: common across the whole Mediterranean Sea. Reported from the boreal to temperate water (Gautier, 1962).

Geographic distribution: since Pliocene of United Kingdom to Holocene (Gautier, 1962).

Membranipora sp.

Superfamily LEPRALIELLOIDEA Vigneaux, 1949

Family LEPRALIELLIDAE Vigneaux, 1949

Celleporaria sp.

Superfamily SCHIZOPORELLOIDEA Jullien, 1883

Family MYRIAPORIDAE Gray, 1841

***Myriapora truncata* (Pallas, 1766)**

Millepora truncata Pallas, 1766

Shell: vinculariform, ramified and usually broken. It is famous as false coral. Zoarium is erected and rigid. Zoecium is disposed regularly, on 14-18 longitudinal lines. Usually it develops starting from a small encrusting base (Gautier, 1962).

Ecology: infralittoral. Typically abundant in coralligenous, between 30 and 60 m wd (Gautier, 1962). Generally unattached and fragmented (Gautier, 1962).

Geographic distribution: common, across the whole Mediterranean Sea.

Geographic distribution: since Miocene in the Mediterranean area (Gautier, 1962) to Holocene.

Superfamily MICROPOROIDEA Gray, 1848

Family ONYCHOCELLIDAE Jullien, 1882

Onychocella sp.

Superfamily SMITTINOIDEA Levinsen, 1909

Family BITECTIPORIDAE MacGillivray, 1895

***Pentapora fascialis* (Pallas, 1766)**

Hippodiplosia fascialis Pallas, 1766

Eschara fascialis Pallas, 1766

Lepralia foliacea (Ellis & Solander, 1786)

Millepora foliacea Ellis & Solander, 1786

Pentapora foliacea (Ellis & Solander, 1786)

Shell: zoarium adeoniform, erected, fragile, reaching 15-20 cm. Zoecium is convex, perforated by polygonal pores. Usually it develops on a small encrusted base.

Ecology: infralittoral, on hard substrate or detritic bottoms. Typically in pre-coralligenous or coralligenous environments. Exclusive species of C biocoenosis (Pérès & Picard, 1964). Between 30 and 60 m wd (Gautier, 1962).

Geographic distribution: common across the whole Mediterranean Sea (Gautier, 1962).

Geographic distribution: since Pliocene of Italy to Holocene (Gautier, 1962).

Class STENOLAEMATA Borg, 1926

Order CYCLOSTOMATIDA Busk, 1852

Family FRONDIPORIDAE Busk, 1875

***Frondipora verrucosa* (Lamouroux, 1821)**

Shell: ramified, presenting dichotomous ramification. Porous aspect.

Ecology: typically in coralligenous environment, or on shell fragments.

Geographic distribution: uncommon.

Geographic distribution: since Messinian of Morocco to Holocene.

Family LICHENOPORIDAE Smitt, 1867

Disporella sp.

Lichenopora sp.

5. DISCUSSION

5.1 CORALLIGENOUS BUILD-UPS AND OTHER RED ALGAE FACIES

5.1.1 CAPO COLONNA MARINE TERRACE

Two types of coralligenous structures have been recognized in the literature from a morphological point of view (Pérès & Picard, 1964; Laborel, 1987; Ballesteros, 2006): a) banks, in the case of flat frameworks with variable thickness, usually built over more or less horizontal substrate and showing a cavernous structure; b) rims, typically shallower and less thick than banks. The framework of rims is dense and leafy, and the structure is vacuolar, partially filled by fine sediments. The coralligenous build-ups of Capo Colonna form banks. Nevertheless, they show some important differences in term of morphology and size.

The coralligenous build-ups are distributed along the outcrop and can be grouped into three portions: the inner, the central and the distal coralligenous build-ups.

The substrate is characterized by an originally coarse mobile substrate in the inner and distal build-ups, and by a hardground developed at the top of biogenic packstone in the central part of the peninsula.

The coralligenous on coarse mobile substrate is coralligenous *de plateau*. The portions of coralligenous *de plateau* are characterized by "mushroom" morphology, with a variable thickness ranging between 1 and 4 m and a lateral continuity of 5-10 m. The structure is cavernous, irregular, and rich in internal cavities and pockets, usually filled by coarse bioclastic packstone. The alternation of coralligenous build-ups and channels filled by organogenous packstones is related to the patchy distribution of the coralligenous itself on the mobile substrate.

The central portion of the build-ups represents a coralligenous on primary hard substrate, named originally "of the lower horizon of littoral rocks" from Pérès & Picard (1964).

These coralligenous build-ups are characterized by banks, 3-4 m thick and several tens of meters long. The thickness is quite regular along the outcrops. The macro-structure is vacuolar but apparently more compact than the coralligenous *de plateau*.

The availability and the heterogeneity of the substrate is the most important control in the development of the two different types of coralligenous build-ups.

The coralligenous on primary hard substrate is apparently characterized by larger and more continuous structures than the coralligenous *de plateau,* meaning that the hard substrate could be considered a control on the maximum size of the bioconstruction.

The dominant species in the coralligenous *de plateau* are *M. alternans, P. calcareum* and *L. stictaeforme,* whereas the other coralligenous type is dominated by *M. alternans, M. expansum, Mesophyllum sp.*, *L. stictaeforme, Lithophyllum sp.* and *P. calcareum*, showing a higher algal biodiversity.

The encrusting bryozoans are important components of the build-ups, alternating with the red algae crusts, usually at the base, directly on the basal conglomerate or on the hardground, or alternatively at the top of the build-ups, like in section CC11.

Coralligenous in the modern Mediterranean Sea is reported from 20 to 120 m wd (Ballesteros, 2006), but has been observed at shallower depth (Marti, 2002; Ballesteros, 2006; Casellato & Stefanon, 2009). *M. alternans* is considered the main algal builder in shallow water, ranging from 10 to 20 m wd, whereas *L. stictaeforme* is predominant in deep water, below 20 m wd (Pérès& Picard, 1964; Sartoretto *et al.*, 1996; Ballesteros, 2006). The occurrence of one of these species should not be used as the sole indicator of paleo-bathymetry. Relative dominance is also important, because the two species could share the same substrate, with one species dominant over the other, or they could occupy different portions in the cavernous structure. A zoning of these two species may sometimes be present in a build-up, recording a sequential development in term of bathymetry of the bioconstruction.

In particular, the build-ups of the inner sections are characterized by *L. stictaeforme* and encrusting bryozoans at the base, passing to *M. alternans* and *Mesophyllum sp*. at the top. The direction of growth of the bioconstruction is not univocal, but we can consider the vertical direction as indicative. The change in qualitative dominance in red-algae species along the vertical direction suggests in this case a shallowing-upward trend.

The central sections are characterized by build-ups dominated by *Lithophyllum sp., Mesophyllum sp*. *M. expansum* and *P. calcareum*, changing to *M. alternans* and *Mesophyllum sp.* moving eastward and upward. Therefore it is possible to detect a significant trend of shallowing upward and eastward. The coralligenous build-ups represent, in this case, an infra-circalittoral bioconstruction. The availability of large portion of hard substrate and probably a long time for development, since highstand and during the regressive phase, represent the optimal conditions to generate thick banks of coralligenous, apparently with a metrical lateral continuity, in a perpendicular view of the deposits respect to the inner margin.

The outer coralligenous build-up, exposed in section CC11, is a coralligenous *de plateau* developing on a rhodoliths bed. The dominance of *M. alternans* and *Mesophyllum sp*. suggests that the build-up developed in shallow water. At the top, the dominance of red-algae is counteracted by crustose bryozoans that actively participate to the bioconstruction, probably indicating a switch to high terrigenous influx, during the regressive phase.

The rhodolith bed, characterizing in this case the substrate of the coralligenous, is formed by maërl facies, presenting abraded prâline rhodoliths at the top. The maërl facies is characterized by small unattached branches, mostly composed by *L. corallioides* and *Phymatolithon sp.,* but also *Lithophyllum sp.* and *Lithothamnion sp.* These features could be comparable with the present-day Mediterranean maërl (Bourcier, 1982; Babbini *et al*., 2006; Sciberras *et al*., 2009; Savini *et al*., in press), which forms sandy-gravelly sediments, showing a higher red-algae biodiversity than the Atlantic maërl facies (Peña & Bárbara, 2009; Riosmena-Rodríguez *et al*., 1999; Birkett *et al.*, 1998; Bressan *et al.*, 2001; Babbini *et al*., 2006; Giaccone *et al.*, 2009). It develops under moderate to high hydrodynamic conditions which prevent rhodolith burial (Steller & Foster, 1995; Foster *et al,.* 1997; Basso 1998; Birkett *et al.,* 1998; Marrack, 1999; Barbera *et al.,* 2003; Wilson *et al.,* 2004). Light and salinity are considered two other environmental factors influencing its distribution (Littler *et al*., 1991; Wilson *et al*., 2004; Steller *et al*., 2007) with a depth range between 30 and 100 m wd (Bourcier, 1982; Babbini *et al*., 2006; Sciberras *et al*., 2009;) and an *optimum* around 40-60 m wd (Babbini *et al*., 2006; Savini *et al*., in press).

The occurrence of the maërl bed, overgrown by *M. alternans*-dominated coralligenous build-ups represents a shallowing upward sequence, in terms of red-algae facies.

At the top of maërl the presence of rounded abraded fruticose rhodoliths is reported. The origin of the abraded rhodoliths is not clear, and they could be possibly transported or be even more ancient than the other deposits. They are linked to high hydrodynamic energy condition and could testify a phase of non-deposition.

The coralligenous build-ups are placed between 36-39 m asl in the inner section (CC2) and 12-14 m asl in the outer section (CC11). The inner margin of Capo Colonna is placed around 60 m asl (Nalin & Massari, 2009), and the inferred paleo-depth for coralline facies at the highstand ranges at least between 24 and 49 m, that is consistent with the present-day depth range for the coralline facies development.

Maërl develops only in the outer section that represents the deepest observable facies in the studied area. The deposits do not show any evidence of neotectonic activity.

On the basis of all these considerations, the development of the coralligenous for the inner sector seems to start during the high-stand phase of the eustatic cycle, whereas in the distal sector local conditions allow the development of the maërl at a reconstructed paleodepth of 50 m wd, consistent with the optimum bathymetric interval for maërl development (Babbini *et al.*, 2006). The coralligenous on hard substrate characterizing the central sector and the coralligenous *de plateau* of the outer section developed and grew instead during the regressive phase of the eustatic cycle. This is also consistent with the smaller size of the coralligenous occurring in the distal portion of the marine terrace deposits.

The well preserved prâline rhodoliths in sections CC5d, CC6, CC7 and CC10 were collected from the coarse biogenic packstone unit, characterized by several meters of lateral continuity (see paragraph 5.2 and details within), a thickness ranging between 40 cm and 1 m, and a sharp upper surface at the top for the presence of a hardground, the interpretation of which is still debated (Nalin & Massari, 2009). The molluskan assemblage, identified within this packstone, is related to a strictly infralittoral environment, (AP-HP) (see paragraph 5.2 and details within), and moderate to high hydrodynamic condition for the presence of exclusive species of SGCF biocoenosis. Basso (1998) suggests that in the framework of the Mediterranean benthos zonation, the development of prâlines is favored by high hydrodynamic conditions, medium sedimentation rate and low bottom stability (fig. 5.1), linking prâlines to the DC and SGCF biocoenoses (Pérès & Picard, 1964).

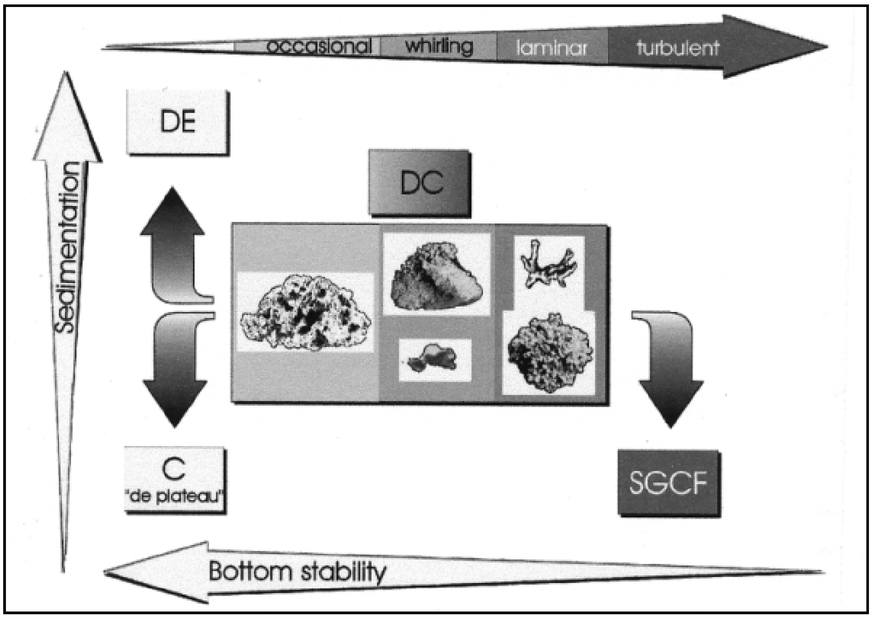


fig. 5.1: Distribution of rhodolith types in the framework of Mediterranean benthos zonation, with respect to hydrodynamic condition, sedimentation rate, bottom stability (Basso, 1998)

The prâline rhodoliths facies is considered a particular facies of the DC biocoenosis (Pérès& Picard, 1964), mainly characterized by *Lithothamnion minervae* (Basso, 1995) or *Lithophyllum racemus* (Lamarck) Foslie (1901).

At Capo Colonna, rhodoliths in this coarse biogenic packstone unit are sparsely distributed, not forming a well developed facies. They often present a nucleus and the recognized dominant species is *M. alternans*. The availability of coarse fragments (biogenic or lithic) for colonization, together with the shallow water conditions and the inferred moderate-to-high hydrodynamics that prevented burial from fine sediment (see grain-size analyses, next chapter 4.3), allowed the development of fruticose rhodoliths.

Due to the dominance of coralline algae as producer, followed by other taxa, the coralligenous facies and the rhodoliths are named *RhodAlgal* facies *sensu* Carannante *et al*. (1988).

5.1.2 LE CASTELLA MARINE TERRACE

Five main algal build-ups have been recognized on the basis of the studied sections.

The build-ups always grew on a basal conglomerate unit, formed by blocks from ancient terrace deposits eroded during the transgressive phase, or local shell accumulations. The build-ups generally developed on the basal conglomerate unit, and the distribution of these blocks could represent the first important controlling-factor on the coralligenous distribution.

The build-ups are defined as coralligenous *de plateau* sensu Pérès & Picard (1964).

The dominant coralline algae species are *M. alternans* and *T. pustulatum.*

M. alternans is considered the main algal builder in shallow water, from 10 to 20 m wd (Pérès & Picard, 1964; Sartoretto *et al.*, 1996; Ballesteros, 2006), building flat or slightly rounded banks or rims with a typical foliaceous structure (Ballesteros, 2006). It is reported as epiphyte at the base of *Posidonia* meadows, or as really abundant associated to *L. stictaeforme* in coralligenous environments (Cabioch & Mendoza, 2003). *T. pustulatum* appears sparsely and often encrusts other biogenic or lithic fragments incorporated into the build-ups.

Other coralline species (*L. stictaeforme, P. calcareum, M. expansum, Mesophyllum sp.1*) occur sparsely, and are never dominant.

Algal builds-ups composed by *M. alternans, T. pustulatum* and *M. expansum* grow usually between fair-weather base and storm wave base (Carannante & Simone, 1996; Sartoretto *et al*., 1996). Similar development has been reconstructed by Nalin *et al*. (2006) and Basso *et al.* (2007) for the Cutro terrace (MIS 7).

The build-ups in the northern sections differ from those in the southern outcrops in term of build-up size, algal framework, and for the occurrence of *C. caespitosa* in the southern outcrops.

In particular, the northern sector is characterized by well developed coralligenous banks, forming elongated structures regularly distributed and quite perpendicular to the inner margin with very dense closely superposed algal crusts, whereas the southern sector is characterized by a more open leafy algal framework and by the presence of *C. caespitosa* as reef builder, suggesting a lower water-energy environment than in the north-eastern part, coupling with the sedimentary input by long-shore current as suggested by Zecchin *et al*. (2010). The occurrence of *C. caespitosa* confirms the sub-littoral paleoenvironmental conditions (Fornos *et al*., 1996).

From a morphological point of view, following the current nomenclature, all of Le Castella build-ups are defined as banks (Ballesteros, 2006).

Bosence (1983a) proposed to distinguish the crustose algal framework morphologies on the base of the hydrodynamic conditions, from low to very high, into algal biostrome, algal reefs and algal ridges.

In particular algal reefs are linked to moderate hydrodynamic condition and form metrical 3-D structures, characterized by both open and very close algal framework. Ridges are instead defined mostly windward features settled in inter-tidal environment, 15 m abroad and up to 60 cm high.

The coralligenous build-ups of Le Castella, following Bosence (1983a), form algal reefs.

Comparing to the specific nomenclature developed for the coral-reef morphologies, the macro-structure of algal build-ups in Le Castella, for the northern outcrop, appears to be comparable to the *spur and groove* or *buttress and canyons* morphologies, due to the alternation of bioconstructed morphology and channel filled by sediments.

Roberts *et al.* (1992) reported that *spur and groove* morphology is controlled by the physical energy of waves and current and represents an erosional morphology. The high hydrodynamic conditions shape the sea floor morphologies.

Goreau (1959) reported that *buttress-and-canyons* represent morphology in which huge spurs or buttresses of living coral project outward the reef crest, separated by a series of very narrow canyons. The development of these morphologies lay in the ability of the biogenic builders to give positive relief on a generally flat bottom, making this morphology a constructive form.

The three northern coralligenous build-ups at Le Castella could be compared to *buttress and canyons* structure typical of coral reef environment, in term of morphologic description and genetic development.

The evidence of tectonic activity is reported by Zecchin *et al.* (2010) in the southern sector and recognized during the fieldwork for this project in 2009.

The normal fault, interpreted as predating the deposits by Zecchin *et al*. (2010), is responsible for the formation of a topographic step, estimated in 4 m that contributed to lower the south-eastern portion of the terrace deposits and form a decametric clinoformal body, as reported in section LC10.

The small coralligenous build-ups outcrop along the profile marked by the topographic step (section LC10a and LC11-NW) but they are no more recognizable moving to sections LC10b, where, however, the basal contact with the substrate does not outcrop, and LC11SE.

The differentiation among coralligenous structures in term of size and algal framework from N and S Le Castella sectors can be interpreted as primarily linked to local differences in hydrodynamics and sedimentary input. Moreover, in the southern part it is coupled with a sin-sedimentary tectonic activity with important reject that partially inhibited the development of large coralligenous banks as in the northern area.

Due to the dominance of coralline algae as producer, followed by other taxa, the coralligenous facies is named *RhodAlgal* facies *sensu* Carannante *et al*. (1988).

The presence of normal faults is reported also in the northern sector (Fig. 4.23) where probably the tectonic activity and the sedimentary input were less intense, and do not dislocate the deposits or affect the development of the coralligenous banks.

Literature data are not concordant on the number of positive peaks recorded during the MIS 3 positive sea level oscillation, and on the maximum height reached by the sea during this interglacial phase.

Mauz & Hassler (2000) dated the deposit of Le Castella using luminescence techniques. They obtained ages correlated with MIS 3 (56±10 ky using the TL method and 43±4, 47±6 and 48±4 ky using the OSL method).

Nalin (2006) dated the deposits of Le Castella terrace and obtained an age of 63.3±6.2 ky using the OSL method.

Estimates of sea level position during MIS 3 are around -45/-60 m (Chappel *et al.*, 1996; Yokoyama *et al.*, 2001; Lea *et al.*, 2001; Waelbroeck *et al.*, 2002; Siddal *et al.*, 2003).

Waelbroeck *et al.* (2002) report a MIS 3 sea-level value at -48±13 m with respect to present-day situation, with a peak for MIS 3 dated at 60 ky BP.

The inner margin of Le Castella terrace is placed at 18 m asl (Fig. 4.23). The maximum height of the innermost coralligenous build-ups is 10 m asl, whereas the minimum, in the most distal section, is 3 m asl. The paleo-depth inferred for the coralligenous development ranges between 8 and 15 m wd, which is concordant with the development of shallow coralligenous build-ups dominated by *M. alternans.*

5.1.3 OPEN PROBLEMS ON CORALLIGENOUS RED-ALGAE SPECIES

Mesophyllum sp.1

Among the identified coralline algae, the genus *Mesophyllum* plays the major role as builder of the coralligenous banks, where it occurs as *M. alternans, M. expansum* and *Mesophyllum sp.*

As reported by Guiry & Guiry (2011) only few species of the genus *Mesophyllum* are currently present into the Mediterranean Sea: *M. alternans*, *M. expansum*, *Mesophyllum macroblastum* (Foslie) Adey 1970, and *Mesophyllum macedonis* (Athanasiadis, 1999). The species of Mesophyllum reported so far in many localities of the Mediterranean Sea by several authors, is probably *M. expansum* and not *M. lichenoides* (Athanasiadis & Neto, 2010). The occurrence of the Atlantic species *M. lichenoides* in the present-day Mediterranean Sea is still to be verified.

Cabioch & Mendoza (2003) reported a synthesis of the diagnostic anatomical characters to separate the species of *Mesophyllum*. The scarce possibility to observe and use many of them, due to the low preservation potential, abrasion and erosion during geological time added to sample preparation techniques (see Chapter 3) is a major obstacle in studying the fossil red-algae.

Following the scheme of Cabioch & Mendoza (2003), the species *M. alternans* and *M. expansum* were distinguished in the studied samples on the basis of the size of the tetrasporangial conceptacle and its position in the thallus, total thickness of the thallus, and the main vegetative anatomy of hypothallus and perithallus.

Among the unidentified *Mesophyllum* crusts, *Mesophyllum sp. 1*, an unidentified species characterized by a very thin thallus, maximum 150 µm thick, has been frequently observed. The hypothallus occupies most of the thallus (up to 100 µm) and can be often coaxial, whereas the perithallus measures at least 40 µm, in longitudinal radial sections. Epithallial cells are squared in surface view. These characters resemble those of *M. lichenoides*, but the lack of fertilities prevents a complete identification.

Although *M. lichenoides* is considered as not present in the present-day Mediterranean Sea, the possibility to identify it in Pleistocene deposits should not be ruled out, since different environmental conditions could have allowed its presence.

T. pustulatum and *Titanoderma sp.*

The genus *Titanoderma* Nägeli in Nägeli & Cramer, 1858 is characterized by crusts irregularly shaped or crowded with protuberances; dorsi-ventral and/or radial in organization. Filaments are monomerous or dimerous, with the primigenous filaments growing along substrate or into protuberances often containing stratified elongated cells, the so called *palisade* cells. Cells in contiguous filaments frequently join by secondary pit-connections, whereas cell fusions are absent.

The genus *Titanoderma* is close to the genus *Lithophyllum*. The practice of citing stratified elongate cells in *Titanoderma* to separate it from *Lithophyllum* has been questioned by Woelkerling *et al.* (1985). For that reason, Campbell & Woelkerling (1990) and Womersley (1996) consider *Titanoderma* Nägeli 1858 to be a heterotypic synonym of *Lithophyllum* Philippi 1837. However, Irvine and Chamberlain (1994) consider *Titanoderma* to be a distinct genus.

Schneider & Wynne (2007) note that the results of Bailey's (1999) study using a molecular comparison demonstrated that *Titanoderma* is distinct from *Lithophyllum*.

The recorded species in the studied samples is characterized by thin thallus, dominated by large *palisade* cells. The thallus is always a thin crust, characterized by few cell filaments, completely adhering to other substrate, algal crust or shell fragments.

In the examined material, the *Titanoderma* species present evident *palisade* cells throughout the thallus and reproductive anatomy that differs from the recognized *Lithophyllum* species. On the basis of the anatomical observations and following Bailey (1999), these two genera are here considered as distinct taxa.

Following Basso (1998), *Titanoderma* occurs as a pioneer colonizer of new substrates, whereas it is indicated as major builder for the build-ups of Cutro terrace (Basso *et al.,* 2007), suggesting circalittoral paleodepth and presence of turbidity, inhibiting the development of other red-algae species typical of the coralligenous.

In the coralligenous frameworks of Le Castella and Capo Colonna, the identified *Titanoderma* species (*T. pustulatum* and *Titanoderma* sp.) are ubiquitously but randomly distributed, confirming that they may play an important role as a framework builder (Sartoretto *et al*., 1996), but never dominant. They often alternate with *M. alternans* or *Mesophyllum sp.*, occupying the lower surface of the *Mesophyllum* crusts, or the internal sciaphilous portion of the cavernous structure.

5.2 BIOGENIC GRAINSTONE, PACKSTONE AND WACKESTONE UNITS

5.2.1 CAPO COLONNA MARINE TERRACE

The paleoecological analyses on fossil assemblages of calcarenite units in Capo Colonna outcrops provide several details for paleo-environmental reconstruction and interpretation.

The base of the central portion of Capo colonna outcrops are characterized by a well developed bryozoan wackestone below a biogenic packstone.

The wackestone is dominated by bryozoan fragments with an exclusive species of C biocoenosis (*P. fascialis*) and a stock of species with C affinity (*M. truncata, R. beaniana, F. verrucosa*). The associated mollusk assemblage is related to hard substrates, which is concordant with the substrate need of the bryozoan assemblage.

Moreover the identified bryozoans are typical of littoral environment (Bianchi *et al.,* 1990).

The conservation of bryozoan fragments, broken but generally well conserved and scarcely abraded as already reported by Nalin & Braga (2008) and Nalin & Massari (2009), suggests the accumulation *in situ* of local, well developed bryozoan-dominated unit, forming a wide lens at the base of the biogenic packstone.

This facies is named *Bryomol* facies following Nelson (1988).

The biogenic packstone is dominated by fossil assemblages strictly linked to littoral environment. The fossil assemblages show high biodiversity, represented by a conspicuous number of species and specimens for each species. The assemblages are characterized by a mixing of species linked both to biocoenoses like AP and HP (*C. rustica, B. reticulatum, J. striatus, G. ardens, G. adriatica, R. bruguieri, C. mediterraneus, R. echinata, A. hirta, P. pinnulatum*), representing the photophilous counterpart, and C/DC biocoenoses, representing the sciaphilous counterpart (Pérès & Picard, 1964). This assemblage is interpretable as *Posidonia* meadow paleo-environment. A stock of coralligenous species completes the assemblage (*P. papillosum, A. tetragona*). Moderate to high hydrodynamic conditions could be inferred for the presence of exclusive species of SGCF biocoenosis (*G. glycymeris*). The reconstructed assemblage of this unit suggests warm-water condition, as already suggested by Gliozzi (1987) which attributes the Capo Colonna marine terrace to MIS 5.1.

This facies is named *MolEchFor* facies following Carannante *et al.* (1988).

A particular aspect to be considered is the occurrence of *Persististrombus latus* Gmelin 1791 (= *Strombus bubonius* Lamarck 1822) in this unit (section CC7b). This species is a shallow warm-water marine gastropod, presently living along the tropical coasts of Africa. It entered the Mediterranean in the late Pleistocene as part of the so called *Senegalese* fauna. *P. latus* found as fossil in the Mediterranean is commonly considered a marker of MIS 5.5.

The deposits of Capo Colonna have been correlated with MIS 5.1 by Palmentola *et al.* (1990) and Zecchin *et al.* (2004b). Gliozzi (1987), Belluomini *et al.* (1988) and Nalin (2006) dated the deposits using different techniques (eperimerization of isoleucine in *Glycimeris* shells, OSL) and confirmed the correlation, obtaining an age of MIS 5.1 (Gliozzi, 1987), 70 ky (Belluomini *et al.*, 1988), and 74.1±6.5 (LU10) and 63.0±6.0 (LU6) (Nalin, 2006).

Age data from Nalin (2006) for the outer portion of the terrace deposits (LU10) are obtained from a littoral facies association sampled from a former sedimentary cycle interpreted by the author as the result of a previous sea level fluctuation within MIS 5.1.

Possible interpretation of the anomalous occurrence of specimen of *P. latus* in deposits dated to more recent stages (MIS 5.1) are reported in Nalin *et al.* (in press).

Generally the calcarenite units (packstone, grainstone or wackestone) are dominated by carbonate fractions, as the result of benthos activity producing carbonate skeletons. The grain-size is defined by the carbonate biogenic production, ranging generally from coarse sand to gravel. The siliciclastic input, connected to eolian or fluvial transport from continent, is represented only by the finest fraction of the sediment, with a very low weight percentage.

The deposition is produced and controlled by the benthos.

The quantitative counting of the components was conducted for samples collected in very inner sector (cc1bis) or in the coralligenous build-ups (cc19) or in the maërl bed (cc68). The sediment composition is dominated by coralline algae fragments. This aspect is really important because it shows that coralline algae contribute not only to build-ups but they are also primary sediment producers. The coralline algae contribute to the bioconstruction of the build-ups, which at the same time undergo abrasion and erosion, bringing coralline fragments into the sediments. Coralline fragments are mostly derived from the coeval build-ups (cc1bis or cc19) or forming by unattached branches themselves (cc68). The predominance of coralline algae fragments suggests naming this facies as *RhodAlgal* facies *sensu* Carannante *et al.* (1988), even the evident different features characterizing the coralligenous itself from maërl facies or these calcarenite facies.

5.2.2 LE CASTELLA MARINE TERRACE

The calcarenite units of Le Castella are packstone coeval with the coralligenous build-ups and grainstone generally at the top of the bioconstruction, thus interpreted as coeval as younger than the coralligenous. These units characterize a wide portion of Le Castella deposits.

Two different mollusk fossil assemblages have been reconstructed.

Lca46 and lca48, both sampled in the grainstone at the top, show an infralittoral affinity, with stock of species linked to AP/HP biocoenoses (*P. exiguum, C. decussata, R. violacea, H. sanguineum, B. reticulatum*) and some species linked to coralligenous environments (*M. varia, A. nodulosa, M. perversus, J. exasperatus*) and DC biocoenosis (*A. tetragona, T. turbona, A. vulgaris*). These samples show the highest biodiversity. The occurrence of species of SGCF biocoenosis (*G. glycymeris, V. casina*) suggests moderate to high hydrodynamic conditions. These assemblages are interpretable as *Posidonia* meadow paleo-environment.

A typical coralligenous assemblage is recognizable for samples coeval with the coralligenous build-up (lca47 and lca31), with the predominance of species linked to DC and C biocoenoses (*A. tetragona, J. exasperatus, M. perversus, M. varia, P. papillosum*) and other species linked to infralittoral biocoenoses (*H. sanguineum, B. reticulatum*).

These facies are named *MolEchFor* facies following Carannante *et al.* (1988).

Generally these units are dominated by carbonate fractions, as the result of benthos activity producing carbonate skeletons. The grain-size is defined by the carbonate biogenic production, ranging generally from coarse sand to gravel. The siliciclastic input, connected to eolian or fluvial transport from continent, is represented only by the finest part of sediment, characterizing a very low weight percentage.

The quantitative counting of the components is conducted for a wide range of samples. The fragments composing the sediments are quantitatively dominated by coralline algae fragments, both for samples collected in the cavities of the build-ups, and for samples collected in stratigraphic sections dominated by only calcarenite units (LCA7) or again in the grainstone at the top of the build-up.

This aspect supports the infralittoral paleo-environment interpretation, with the presence of coeval coralligenous build-up and *Posidonia* meadow. The occurrence of coralligenous build-ups, acting also as source of sediments that are dominated by eroded crust fragments, testified the high production rate of coralline algae carbonate, probably encrusting also the base of *Posidonia* rhizomes.

On this basis the predominance of coralline algae fragments suggests to re-name this facies as *RhodAlgal* facies *sensu* Carannante *et al.* (1988), even the evident different features characterizing the coralligenous itself from these facies.

5.3 PALEOENVIRONMENT INTERPRETATION AND TEMPORAL EVOLUTION

5.3.1 CAPO COLONNA MARINE TERRACE

The general architecture of Capo Colonna marine terrace deposits, consisting on a basal erosional surface overlain by a basal conglomerate unit and a succession of shallow water facies corresponds to that of a transgressive-regressive cycle (Nalin & Massari, 2009; Zecchin *et al.*, 2009).

This terrace has been already studied by Nalin (2006) and Nalin & Massari (2009) from a stratigraphic and sedimentological point of view in order to reconstruct the geological evolution of these deposits in this framework (fig. 5.2).

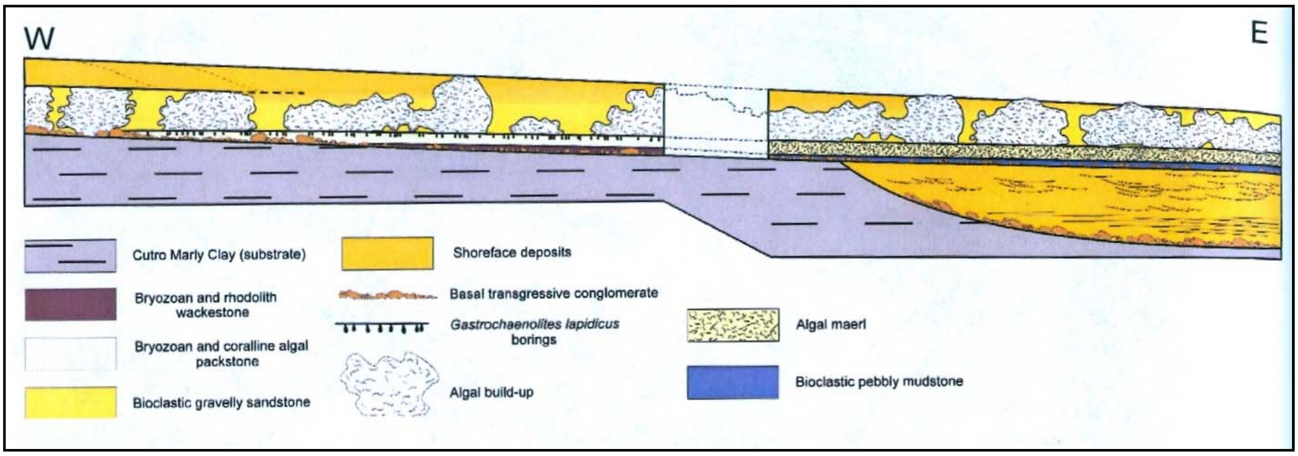


fig. 5.2: Correlation diagram of the deposits of Capo Colonna marine terrace (Nalin, 2006)

Further paleontological insight into the biogenic-dominated units allow to detail even better this interpretation, attributing whit high precision the units to different phases of the eustatic cycles.

During the transgressive phase the basal conglomerate unit forms, as result of the erosion and reworking of oldest deposits at the paleo-cliff (Fig. 5.3-1) (Tamura *et al*., 2003).

Along the continental shelf profile different facies start to develop.

In particular, in the central portion, the base of the outcrop is characterized by the bryozoan-wackestone. Two possible solutions can be proposed to explain the origin of the bryozoan-dominated facies.

The wackestone could be interpreted as the result of transport and accumulation of bryozoans placed more superficially, or as the result of *in situ* growing and accumulation of bryozoan during the sea-level rise. The bryozoan fragments are broken, but apparently well preserved. Due to the brittle structure of the identified species (*P. fascialis*, *M. truncata, R. beaniana, F. verrucosa*) the broken fragments are not *per se* an evidence of transport. The absence of traces of abrasion and erosion suggests the second solution as possible.

During the final transgressive and highstand phases (Fig. 5.3-2) the coralligenous build-ups start to develop, in the inner part, due to the availability of basal conglomerate blocks for coralline settlement. The inner build-ups are characterized at the base by *L. stictaeforme* and encrusting bryozoans, primarily settled on the basal conglomerate. The presence of this assemblage is concordant with the maximum wd reached at the highstand phase. Along the continental shelf profile others facies develop. A *Posidonia* meadow develops in the central portion of the outcrop, whereas maërl facies settles in the outer portion.

The origin of the hardground at the top of the biogenic packstone (Fig. 5.3-3) lays probably in a non-depositional phase due to low sedimentation coupled with increasing water agitation (James & Bone, 1994; Nelson & James, 2000) at the beginning of the regressive phase (Nalin & Massari, 2009). The occurrence of hardground is documented both for tropical (Tucker & Wright, 1990) and non-tropical real (Mutti & Bernoulli, 2003).

In the distal part of the Capo Colonna outcrop the accumulation of abraded fruticose rhodoliths, probably transported, at the top of maërl facies (Fig. 5.3-3) could be considered coeval.

After the non-deposition phase, the various types of coralligenous (Fig. 5.3-4) colonize the entire continental shelf-profile, actively growing during the regressive phase.

The forced sea-level fall at the beginning of the regressive phase is testified by the Regressive Surface of Marine Erosion (RSME) recognizable at the top of the build-ups in the inner portion, sharply cutting the algal bioconstructions at the top. The algal assemblages record the shallowing of the wd, turning to *M. alternans*-dominated facies.

During the regressive phase the coralligenous build-ups continue developing until the burial by sediment (Fig. 5.3-5).

The subsequent uplift set out the deposits as they outcrop now (Fig. 5.3-6).

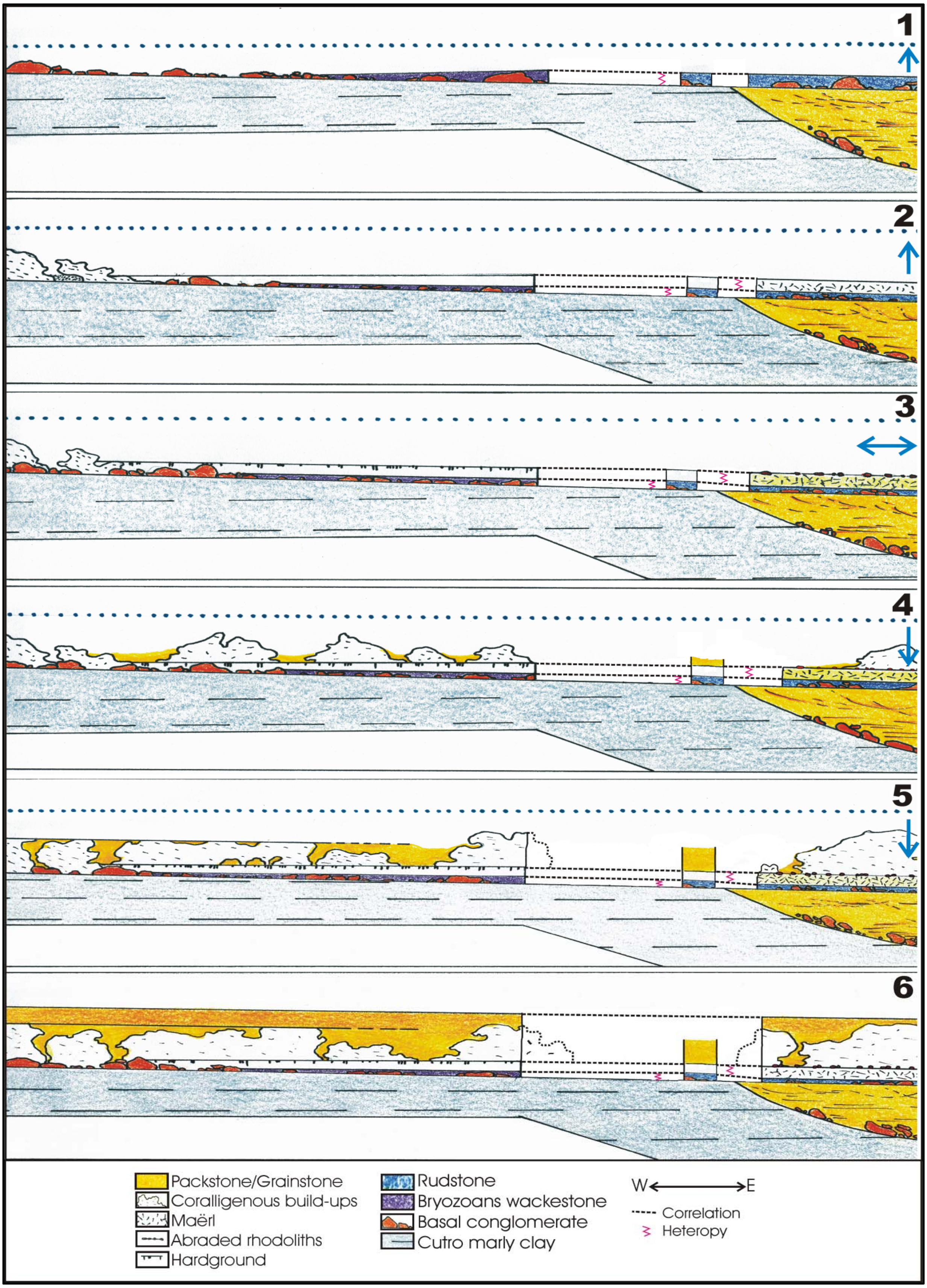


Fig. 5.3, 1-6: reconstructive diagrams of the temporal evolution of Capo Colonna during the eustatic cycle. Blue arrows indicate the sea-level variation during the eustatic cycle

The inferred correlation from central to outer portions proposed by Nalin (2006) is correct (fig. 5.2), because the development of inner and outer facies is coeval. Considering the facies with a paleoecological approach, these are in heteropy, corresponding to two different paleo-environments along the continental shelf (Fig. 5.4). In particular, above the ravinement surface the bryozoan wackestone is considered coeval with the bioclastic mudstone, the *Posidonia* meadow with the maërl, the hardground with the abraded rhodoliths accumulation, and the coralligenous at the top should be the most recent coralline facies.

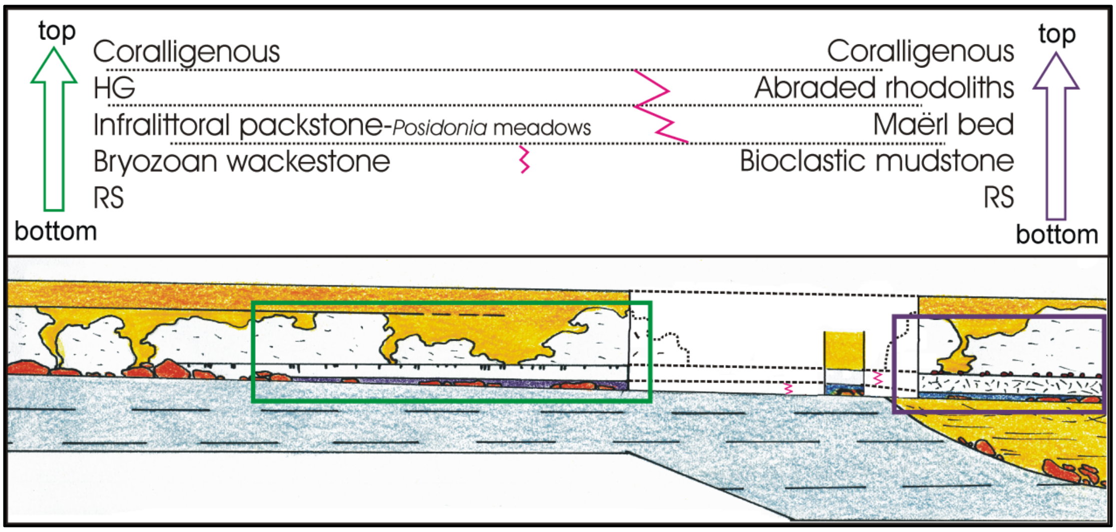


Fig. 5.4: correlation diagram of the deposits of Capo Colonna marine terrace

The change of algal assemblages, in the inner build-ups upward, and in the central build-ups eastward, testifies a shallowing upward, recorded during the regressive phase.

At the top of the distal build-ups the local dominance of encrusting bryozoans forebodes the final burial of coralligenous by sediment.

Section CC10 is placed next to section CC11, but it shows intermediate passages in term of facies detected from central to the outer sectors of the entire outcrop. Moreover it allows distinguishing different positions of heteropy among the facies along the stratigraphic succession.

The deposits of Capo colonna marine terrace testify the existence of a shallow-water temperate carbonate factory, active during the MIS 5.1. The role of the most important biogenic producer is played by crustose red algae. Corallines are able not only to produce carbonate sediments, but also to modify the environment, stabilize the substrate and create 3-D structures, the coralligenous build-ups, with large lateral development and thickness of several meters, piloting the morphological development of the continental shelf. The low terrigenous input and an absent tectonic activity favored the development of algal banks along the continental shelf.

The coralligenous environments represent the most developed coralline algae facies.

Other coralline facies occurs, placed to observable deepest paleo-environment, as maërl facies.

The observable maximum reconstructed paleo-depth for coralline facies is around 45-50 m wd, a valid bathymetric interval both for coralligenous build-ups and maërl development. The occurrence of maërl instead of coralligenous build-ups, could be linked first to the heterogeneity of the substrate, but testify also to the ability of coralline algae to develop different facies under different oceanographic condition.

5.3.2 LE CASTELLA MARINE TERRACE

The general architecture of Le Castella marine terrace deposits, consisting on a basal erosional surface overlain by a basal conglomerate unit and a succession of shallow water facies corresponds to that of a transgressive-regressive cycle (Zecchin *et al.*, 2009, 2010).

Le Castella marine terrace deposits testify the presence of a shallow-water temperate carbonate factory, active during the MIS 3.

Even in the Le Castella deposits, crustose red algae play the role of most important biogenic producers. The dominant facies is represented by coralligenous build-ups.

The availability of basal conglomerate as substrate, the moderate to high hydrodynamic conditions, he low terrigenous input and generally a low tectonic activity favored the development of algal banks.

The maximum wd reconstructed for Le Castella deposits during the highstand ranged between -8 and -20 m below sea-level. The paleo-environment is strictly infralittoral. This result is concordant with the development of a shallow type of coralligenous *de plateau*, dominated by *M. alternans* forming little banks as islands in the *Posidonia* meadow.

During the sea level rise the erosion of blocks along the paleo-cliff forming the basal conglomerate unit (Tamura *et al.*, 2003) is recorded. The blocks are sparsely distributed along the continental shelf profile (Fig. 5.5).

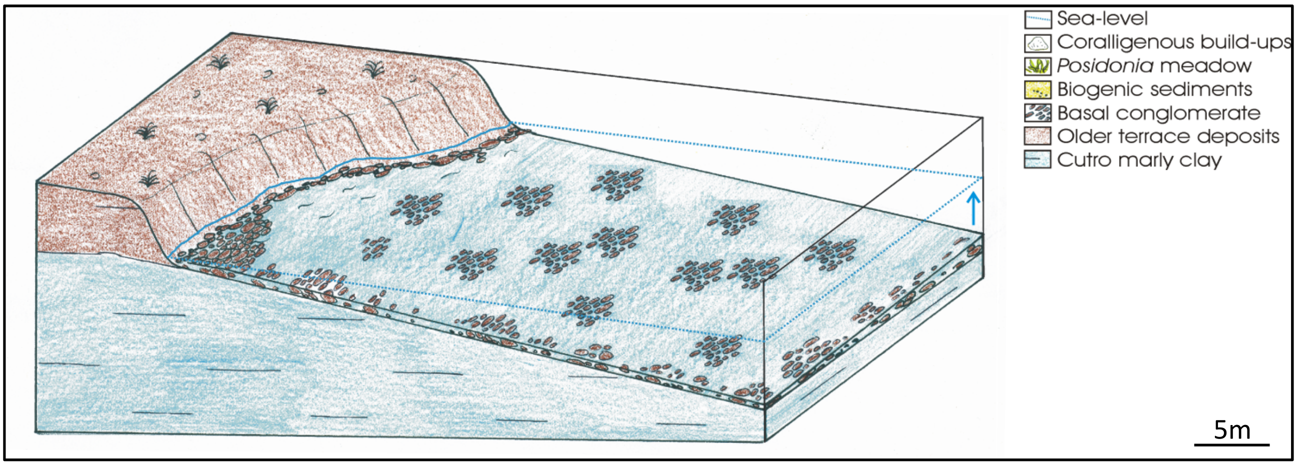


Fig. 5.5: model of development of Le Castella marine deposits. The blocks of basal conglomerate randomly distributed along the continental shelf profile. Blue arrow indicate the sea-level variation during the eustatic cycle

Since the end of transgressive phase the coralligenous starts growing. The build-ups are distributed as “coralligenous islands” in an infralittoral environment interpretable as the *Posidonia* meadows (Fig. 5.6).

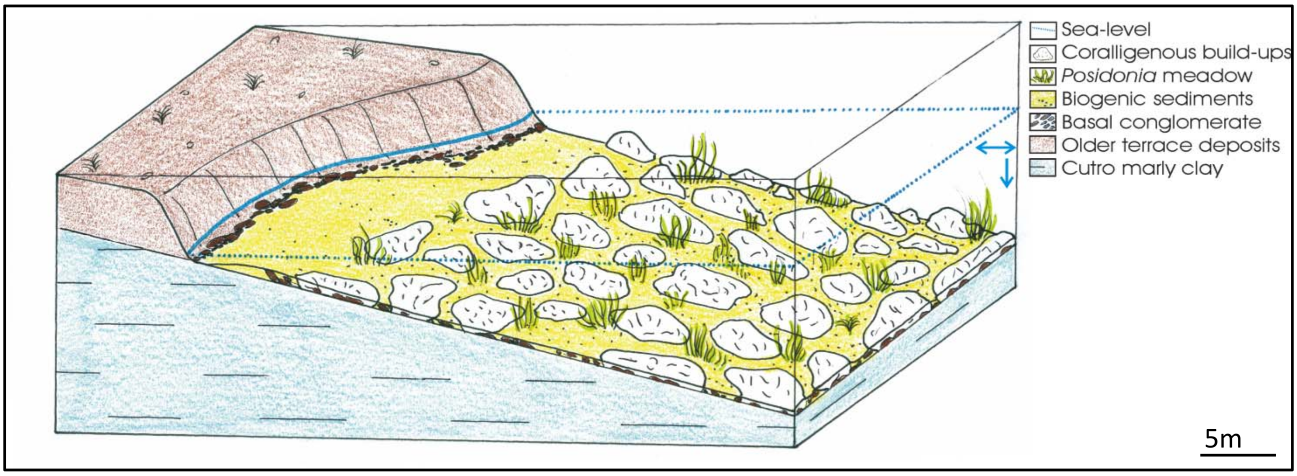


Fig. 5.6: model of development of Le Castella marine deposits. The coralligenous build-ups are settled as islands in the *Posidonia* meadow. Blue arrows indicate the sea-level variation during the eustatic cycle

The associated deposits coarse sediments, linked to high hydrodynamic energy. The non-stop growing-up of the structure probably coupled with high hydrodynamic condition, fostering the algal development, produces structures similar to algal reefs (Bosence, 1983a) or *buttresses and canyons* (Goreau, 1959) in the northern part of the outcrops. Similar reconstruction is proposed by Nalin *et al.* (2006) for Cutro marine terrace (MIS 7).

The occurrence of coralligenous *de plateau*, which requires low to moderate energy for its growth (Basso, 1998; Rasser & Pillar, 2004), alternated to channels filled by coarse sediments, needing high hydrodynamic regime to settle, could represent a paradox. On the contrary, these two aspects could cohabit: the relief provided by the build-ups structure, actively growing in low to moderate hydrodynamic regime, could enhance the occasionally high hydrodynamic regime linked to storm-driven currents impacting the environment and accumulating coarse sediments amid the coralligenous build-ups.

The coralligenous build-ups in the southern sector are similarly infralittoral structures, but the occurrence of non-favorable conditions, as higher flux of terrigenous sediment as reconstructed by Zecchin *et al*. (2010), affects the minor development of coralligenous build-ups in terms of size, a more open algal framework and the occurrence of *C. caespitosa* as builder. In the southern outcrops the sin-sedimentary normal fault contributes to drive the disposition of the facies along the continental-shelf profile, and partially inhibits the development of coralligenous respect to the build-ups of the northern sector (Fig. 5.7).

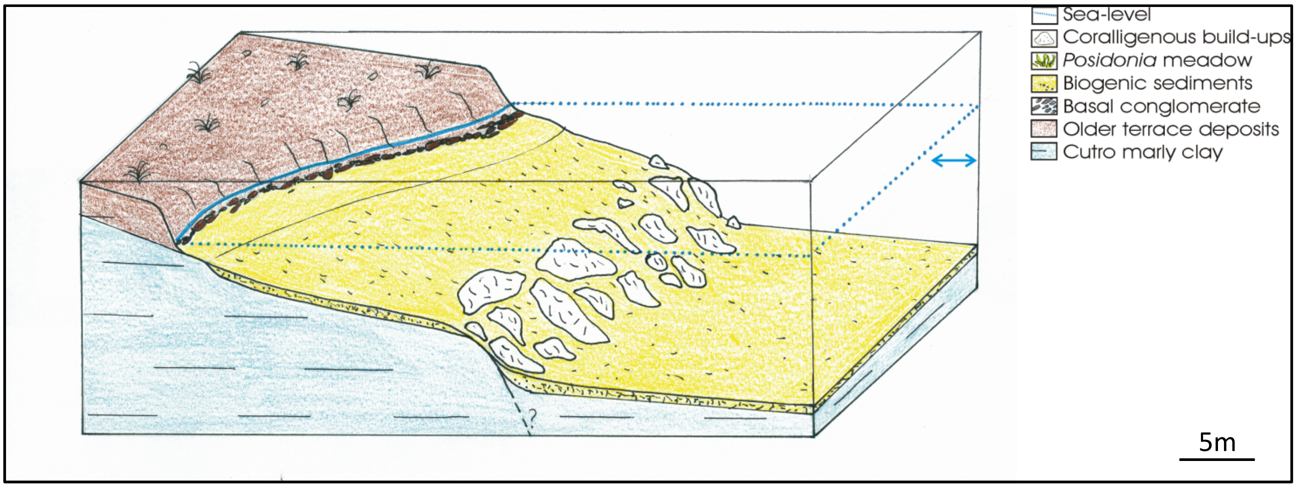


Fig. 5.7: model of development of Le Castella marine deposits in the southern sector. The coralligenous build-ups are distributed along the shelf profile, but partially inhibited by the occurrence of high sediments flux and the topographic step formed by a normal fault. Blue arrow indicate the sea-level variation during the eustatic cycle

The presence of a well recognizable RSME, cutting the deposits in the northern outcrops, could be linked to the forced sea-level fall at the beginning of the regressive phase.

During the regressive phase the coralligenous build-ups continue developing until the burial by sediments (Fig. 5.8).

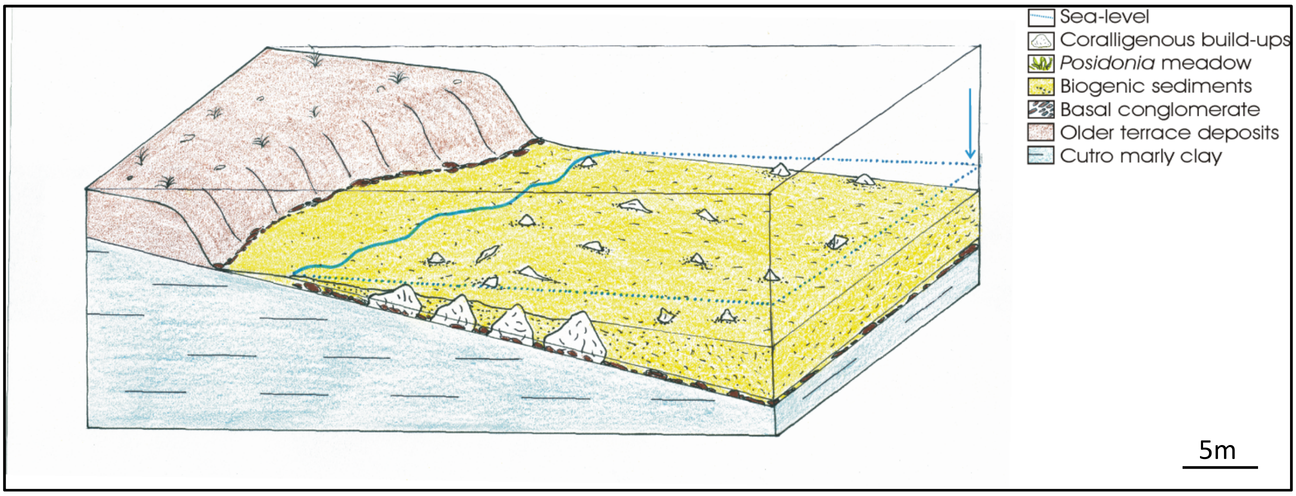


Fig. 5.8: model of development of Le Castella marine deposits during the regressive phase, with the burial by sediments. Blue arrow indicate the sea-level variation during the eustatic cycle

5.4 A COMPARISON BETWEEN THE TWO STUDIED MARINE TERRACES

The outcrops of Capo Colonna and Le Castella represent the deposits of the two last interglacial stages, both examples of shallow-water temperate carbonate factories, active during the Upper Pleistocene in the area of Crotone peninsula. The general architecture of both marine terrace deposits, consisting on a basal erosional surface overlain by a basal conglomerate unit and a succession of shallow water facies, corresponds to that of a transgressive-regressive cycle (Massari & Nalin, 2002; Nalin *et al*., 2006; Nalin & Massari, 2009; Zecchin *et al.*, 2009, 2010).

Some common features can be identified between the two marine terraces.

The most important carbonate producer is represented by crustose coralline algae, and the most common facies is the coralligenous.

The coralligenous build-up is infralittoral coralligenous type, bioconstructed mostly by *M. alternans*. The infralittoral affinity is confirmed by the study of associated fossil assemblages, representing the *Posidonia* meadow environment and the paleo wd inferred.

The occurrence of mobile and hard substrate to settle and the coexistence of moderately to high hydrodynamic condition coupled with low terrigenous input favor the growth of coralligenous facies. These paleo-environmental conditions lasted enough to obtain the development of metrical build-ups.

The identified facies, following the nomenclature of Carannante *et al.* (1998), form *RhodAlgal* facies.

The deposits of Le Castella, due to their position along the coasts, show both perpendicular and parallel disposition towards the inner margin. This aspect allows a complete view on the arrangement of the build-ups and their lateral development, finding out that they form isolated structures, extended irregularly or in some cases quite perpendicular towards the inner margin, and alternated to channels filled by packstone and grainstone. This disposition is comparable to *buttresses and canyons* structures of coral reefs (Goreau, 1959).

Moreover the vertical development of Le Castella build-ups is irregular, showing typical “mushroom” form.

In the Capo Colonna outcrops, the profile of the paleo continental shelf can be followed moving from the W to the E. This peculiarity makes possible the overview of deeper paleoenvironment than Le Castella outcrops.

The coralligenous build-ups in Capo Colonna inner and outer sections are similar to Le Castella outcrops. The central portion of Capo Colonna is instead characterized by well-developed banks of coralligenous, with several tens of meters of lateral continuity and regular thickness. The occurrence of continuous lateral hard substrate probably favors the development of this type of macro-structures. On the other hand the coralligenous on basal conglomerate develops more irregularly due to the heterogeneous distribution of basal conglomerate blocks.

The different disposition of the outcrops in the two studied marine terraces allow to point out aspects like the morphology of coralligenous structures or the variability of crustose coralline facies along the continental shelf profile.

The paleontological study and the paleoecological approach makes possible to reconstruct in both cases the paleoenvironment and the hydrodynamic condition of these facies, and to correlate them to different stages of deposit development in the framework of a transgressive-regressive cycle.

6. CONCLUSION

This Ph.D. project was aimed to conduct a paleoecological study improving the knowledge about the biogenic deposit of marine terraces outcropping in the Crotone peninsula.

Pleistocene marine terraces are the results of the interplay between regional uplift and high-amplitude glacio-eustatic changes (Carobene, 1980; Trenhaile, 2002).

The deposits have been already studied in term of morphology (Palmentola *et al*., 1990), stratigraphy (Nalin, 2006; Nalin & Massari, 2002; Nalin *et al.* 2007, 2009; Zecchin *et al.,* 2004b, 2009, 2010) and paleontological content (Gliozzi, 1987; Basso *et al*., 2007). They have been dated using different techniques (Gliozzi, 1987; Belluomini *et al*., 1988; Mauz & Hassler, 2000; Nalin, 2006) and correlated to the last five interglacial phases: MIS 7, named Cutro terrace, MIS 5.5, named Campolongo-La Mazzotta terrace, MIS 5.3, named Le Castella-Capo Cimiti terrace, MIS 5.1, named Capo Rizzuto-Capo Colonna terrace and MIS 3, named Le Castella terrace.

The object of this study is the two youngest marine terrace deposits.

The deposit of Le Castella and Capo Colonna record the evolution of non-tropical carbonate sedimentation during high-frequency sea-level fluctuations during the Upper Pleistocene.

A new investigation of the facies of Le Castella marine terrace is proposed, whereas further insights into the Capo Colonna facies model are reported.

The paleoenvironment interpretation and the temporal evolution, modeling the development for both marine terraces, are reconstructed on the base of high-resolution study of fossil assemblages in an actuo-paleontological way and in the framework of a transgressive-regressive cycle.

A fieldwork in the area was conducted aimed to measure the outcrops and collect samples in the recognized facies.

The samples have been treated in order to conduct different type of analyses. The production of thin sections has been done to identify the red algae species or at least genera, and to conduct a quantitative analyses on arenite units.

The disaggregation of the coarse calcarenite in conservative way units was useful to conduct quantitative paleontological and grain-size analyses, aimed to reconstruct the paleoenvironment and to define quantitatively the contribution of different benthonic taxa to the sedimentation.

The deposits present generally a basal conglomerate unit, overlapped by coralligenous build-ups, buried by coarse calcarenite. The associated calcarenite units are dominated by biogenic carbonate sediments, in which the calcareous red algae represent the most conspicuous counterparts.

The stratigraphic succession has been interpreted in the framework of sequence stratigraphy model (Catuneanu, 2006).

The transgressive phase is represented by the formation of an erosional surface at the base of the deposits cutting the clayey substrate and the accumulation of a basal conglomerate unit as the result of the erosion and reworking of oldest deposits at the paleo-cliff (Tamura *et al.*, 2003).

In Capo Colonna deposits the transgressive phase is probably represented by also the development of a bryozoan-dominated facies in the central sector and a mudstone rich in coarse bioclasts in the outer sector.

The highstand phases are connected to the development of different facies in the two marine terraces.

Le Castella deposits are characterized by the development of infralittoral coralligenous build-up, settled as islands in a *Posidonia* meadow.

The Capo Colonna deposits show higher complexity. During the highstand phase the coralligenous start developing in the inner sector, whereas a *Posidonia* meadow occupies the central sector and the maërl facies developed in the outer portion.

The end of highstand and the passage to regressive phase is in both deposits characterized by the development of a well recognizable erosional surface, interpretable as the RSME, cutting abruptly the build-ups or the arenite unit at the top of the coralligenous build-ups and formed as result of a forced sea-level fall.

In Capo Colonna outcrops this phase is marked by the development of a hardground in the central sector and the accumulation of abraded fruticose rhodoliths at the top of maërl facies in the outer sector.

During the regressive phase the coralligenous build-ups continue developing until the burial of sediments.

The biogenic carbonates dominate the deposits and they are represented by both 3-Dstructures, piloting the development of the continental-shelf profile, forming reliefs and new environments to settle, and by coarse sediments, generating thick deposits both coeval to the build-ups development and posterior.

The coralligenous build-ups is the most developed facies formed by corallines. The build-ups are metrical in size, and colonize both mobile, as coralligenous *de plateau*, and hard substrate, as coralligenous on rocky bottom, in an infralittoral paleo-environment.

The deposits of Capo colonna are interested by other coralline facies, like maërl or pralines rhodoliths. The occurrence of these facies on one hand demonstrate the ability of coralline algae to form different types of sediments, and on the other hand let a high-resolution understanding and knowledge of marine terrace deposits.

An interesting aspect highlighted during the study is the lack of morphological nomenclature strictly developed for the coralligenous build-ups.

The morphology differs primarily due to the occurrence of different substrate to colonize by red crustose algae. The coralligenous de plateau develops on coarse basal conglomerate, and form isolated structures 1-3 m thick and 10 m long, whereas the coralligenous on hard substrate forms structures 4 m thing and tens of m long.

Comparing all the studied coralline build-ups with the present-day nomenclature, they are identifiable as algal reef (Bosence, 1983a) or banks (Ballesteros, 2006).

A better interpretation for a paleoenvironmental reconstruction could be obtained comparing the algal build-ups to the terminology developed for coral reef, in term of morphology and genetic development. The build-ups in the northern sector of Le Castella are comparable to the *buttresses-and-canyons* of Goreau (1959). They form irregular structures, developed along the continental shelf on the basis of the availability of coarse or hard substrate to colonize, and they are alternated to canyons, filled by coarse sediments partially coeval to the build-ups and generally dominated by sediments formed by the erosion of build-ups themselves. The development of these morphologies laid in the ability of the biogenic builders, in this case the coralline algae, to give positive relief on a generally flat bottom, making this morphology a constructive form. The relief is developed and controlled by the growth of coralline, settled on a coarse/hard substrate, under low to moderate hydrodynamic conditions testified by coarse sediment accumulation.

The coralligenous is considered a circalittoral biocoenosis (Pérès & Picard, 1964), even if it is reported for a wide bathymetric interval, from 10 to 120 m wd (Sartoretto *et al*., 1996; Ballesteros, 2006) due primarily to light conditions and substrate availability. On the base of the dominance of several species in algal assemblages, like *M. alternans* or *L. stictaeforme*, it is possible to define infralittoral or circalittoral coralligenous type (Sartoretto *et al*., 1996; Ballesteros, 2006). The distinction is based on the occurrence and quantitative dominance of one of these species, even they could coexist.

In the coralligenous build-ups of Le Castella the occurrence of metrical coralligenous structures, with a closely dense and layered framework dominated by *M. alternans,* lead to shallow infralittoral environment interpretation, 10-30 m (Sartoretto *et al.*, 1996; Ballesteros, 2006). The build-ups are disposed randomly, on the base of basal conglomerate blocks disposition, in a shallow water environment, in a flat and quite tectonically undisturbed continental shelf. The framework is usually.

At Capo Colonna, in the inner and outer sectors, the build-ups are similar to Le Castella, whereas the central sector is characterized by bigger banks, showing a high biodiversity in terms of algal assemblages. The framework is usually dense and layered. The algal assemblages is mostly dominated by *M. alternans*, that suggests a generally shallow wd environment, 10-30 m (Sartoretto *et al.*, 1996; Ballesteros, 2006), even if a shallowing-upward trend has been reconstructed on the basis of the change in algal assemblages for the inner sector of the outcrops. The shallowing-upward red-algae assemblage testifies that the inner sector has been characterized by the development of coralligenous build-ups since the highstand phase and during the regressive phase, until the burial by sediments.

The outer section is characterized by the presence of maërl bed, making as substrate for the coralligenous facies. The stratigraphic position of maërl laid to interpret these facies as related to highstand facies, with a reconstructed paleodepth around 50 m wd. This depth is consistent for the development of both maërl facies (Bourcier, 1982; Babbini *et al*., 2006; Sciberras *et al*., 2009; Savini *et al*., in press) and coralligenous build-ups (Sartoretto *et al.*, 1996; Ballesteros, 2006). The occurrence of maërl, and not coralligenous, laid probably in the favourable oceanographic conditions, moderate hydrodynamics and sedimentation rate (Steller & Foster, 1995; Foster *et al,.* 1997; Basso 1998; Birkett *et al.,* 1998; Marrack, 1999; Barbera *et al.,* 2003; Wilson *et al.,* 2004; Riul *et al*., 2008). Moreover, the unavailability of coarse or hard substrate to colonize inhibits the development of the coralligenous facies.

The occurrence of the maërl bed, overgrown by *M. alternans*-dominated coralligenous build-ups represents a shallowing upward sequence, in terms of red-algae facies.

The occurrence of prâline rhodoliths, sparsely distributed in the central sector of the Capo colonna outcrops, testifies the variability of coralline algae facies, their ability to adapt and developed structures and produces sediments under different oceanographic condition and in different environments along the continental shelf profile, and allows a better interpretation of the unit in which they have been collected.

Both the terraces are characterized by the presence of calcarenite units.

The paleontological study of molluskan and bryozoans fossil assemblages of these units furnish, first, high detailed description of the benthic fauna driving the sedimentation process along the continental shelf.

The base of the central portion of Capo colonna outcrops are characterized by a bryozoan wackestone, dominated by bryozoan fragments with species linked to C biocoenosis (*P. fascialis, M. truncata, R. beaniana, F. verrucosa),* typical of littoral environment (Bianchi *et al.,* 1990). The associated mollusk assemblage is related to hard substrates, which is concordant with the substrate need of the bryozoan assemblage.

The conservation of bryozoan fragments, broken but generally well conserved and scarcely abraded as already reported by Nalin & Braga (2008) and Nalin & Massari (2009), suggests the accumulation *in situ* of local bryozoan-dominated unit, forming a wide lens at the base of the biogenic packstone, called *Bryomol* facies following Nelson (1988).

The biogenic packstone overlies the wackestone and occupies all the central sector of Capo Colonna outcrops. It is dominated by fossil assemblages strictly linked to littoral environment. The fossil assemblages show high biodiversity, and are characterized by a mixing of species linked both to biocoenoses AP and HP (*C. rustica, B. reticulatum, J. striatus, G. ardens, G. adriatica, R. bruguieri, C. mediterraneus, R. echinata, A. hirta, P. pinnulatum*), representing the photophilous counterpart, and C/DC biocoenoses, representing the sciaphilous counterpart (Pérès & Picard, 1964). This assemblage is interpretable as infralittoral *Posidonia* meadow paleo-environment, named *MolEchFor* facies following Carannante *et al.* (1988). Moderate to high hydrodynamic conditions could be inferred for the presence of exclusive species of SGCF biocoenosis (*G. glycymeris*). The reconstructed assemblage of this unit suggests warm-water condition, as already suggested by Gliozzi (1987).

Similar aspects have been reconstructed for the calcarenite units of Le Castella outcrops.

These units characterize a wide portion of Le Castella deposits, being both coeval with the coralligenous build-ups, filling the canyons among the coralligenous build-ups, and at the top of the bioconstruction, thus interpreted as coeval as younger than the coralligenous structures

Two different mollusk fossil assemblages have been reconstructed.

The grainstone at the top as the samples collected in calcarenite units filling canyons among coralligenous build-ups show infralittoral affinity and highest biodiversity, with stock of species linked to AP/HP biocoenoses (*P. exiguum, C. decussata, R. violacea, H. sanguineum, B. reticulatum*) and some species linked to coralligenous environments (*M. varia, A. nodulosa, M. perversus, J. exasperatus*) and DC biocoenosis (*A. tetragona, T. turbona, A. vulgaris*). The occurrence of species of SGCF biocoenosis (*G. glycymeris, V. casina*) suggests moderate to high hydrodynamic conditions. These assemblages are interpretable as *Posidonia* meadow paleo-environment.

A typical coralligenous assemblage is recognizable for samples coeval with the coralligenous build-up with the predominance of species linked to DC and C biocoenoses (*A. tetragona, J. exasperatus, M. perversus, M. varia, P. papillosum*) and other species linked to infralittoral biocoenoses (*H. sanguineum, B. reticulatum*).

Both these facies are named *MolEchFor* facies following Carannante *et al.* (1988).

In Le Castella outcrops, the occurrence of coralligenous *de plateau*, which requires low to moderate energy for its growth (Basso, 1998; Rasser & Pillar, 2004), alternated to channels filled by coarse sediments, needing high hydrodynamic regime to settle could represent a paradox. On the contrary, these two aspects cohabit. The relief provided by the build-ups structure, actively growing in low to moderate hydrodynamic regime, could enhance the occasionally high hydrodynamic regime linked to storm-driven currents impacting the environment and accumulating coarse sediments amid the coralligenous build-ups.

The calcarenite units, both in Capo Colonna and Le Castella, are dominated by carbonate fractions, as the result of benthos activity producing carbonate skeletons. The grain-size is defined by the carbonate biogenic production, ranging generally from coarse sand to gravel.

The quantitative counting of the components in all samples shows that the sediments are quantitatively dominated by coralline algae fragments, as result of abrasion and erosion of red-algae crusts from the build-ups and at the base of *Posidonia* rhizomes.

On this basis the predominance of coralline algae fragments suggests to re-name these facies as *RhodAlgal* facies *sensu* Carannante *et al.* (1988), even the evident different features characterizing the coralligenous itself from these facies.

The paleoecological approach in the framework of the marine benthic ecology of Pérès & Picard (1964) enables the most correct interpretation of paleoenvironment and the prompt temporal correlation of the facies during the eustatic cycles.

The paleontological scale results to be the most appropriate instrument to investigate these deposits, because it allows a highly detailed description of deposits and a better collocation of the facies during different phases of eustatic cycle.

The quantitative approach in studying the components of the sediment and the biogenic carbonate contribution provides the confirmation of the temperate carbonate-domain developed in the Upper Pleistocene in the area, and details the quantitative contribution of each taxon to the carbonate sediment production in temperate shallow water conditions.

The present case studies contribute to improve the knowledge on the development of carbonate temperate-water deposits, to define the main important biogenic carbonate producers in temperate areas, and to develop a model for distribution of red algae facies along the continental shelf profile. Moreover this study also highlights the role of crustose algae facies to control the development and the architecture of continental shelf margin physiography.

7. REFERENCES

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ACKNOWLEDGEMENTS

Many people contributed in different ways to the realization of this thesis.

My first tribute goes to my tutor, Professor Daniela Basso.
My sincere gratitude to the woman
who introduced me to the geo-biology,
who believed with me in this project,
who made me grow up from a scientific perspective,
who shared with me joys and pains of these three long years.

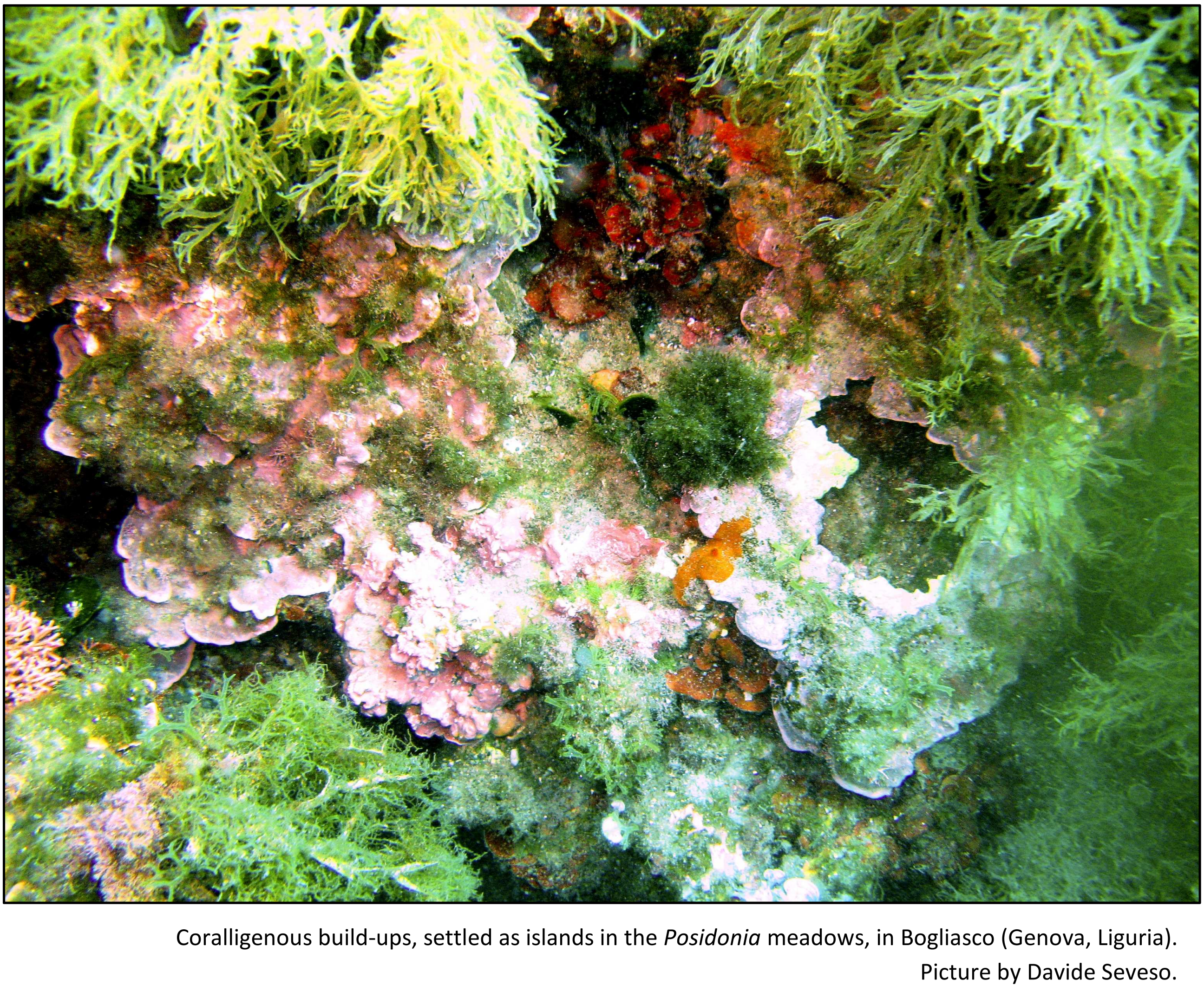
In the course of the research I had the pleasure to open a collaboration with Dr. R. Nalin who is the co-tutor of this thesis.
This is now a true friendship and I hope it may last for a long time.
You have not only taught me to marine terraces of Crotone peninsula
but you have contributed significantly to the good output of this thesis.
Thank you very much for always have been there, even if in the other side of the world.

I am very grateful to Prof. F. Massari and K. Gariboldi,
helping me during the fieldwork.

Prof. C. Corselli provided me fruitful suggestions for the final version of this thesis.

The three years of Ph.D. were amongst the most difficult of my life.
I therefore feel obliged to acknowledge all the people
who helped and supported me to reach this result
by giving not only scientific but above all moral and emotional support:
my “husband” Adriano,
my beloved sisters Monnalisa and Maddalena,
my wonderful family,
my best friend ever Emma,
my dear friends (Marta, Silvia, Paolo, Daniel, Diego),
my university friends (Karen, Lela, Claudio, Francesca, Ale S., Paolo, Fabio),
my Ph.D. colleagues (Annalisa, Marta, Stefano),
my university colleagues (Francesca, Alessandra, Paola, Agostina).

This research was carried with the authorization of the Area Marina Protetta Capo Rizzuto (prot. 42737).
The financial support was provided by Italian MIUR as a PhD fellowship.



Coralligenous build-ups, settled as islands in the *Posidonia* meadows, in Bogliasco (Genova, Liguria).
Picture by Davide Seveso.