Pleistocene coralline algal build-ups (*coralligène de plateau*) and associated bioclastic deposits in the sedimentary cover of Cutro marine terrace (Calabria, southern Italy)

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Abstract: Carbonate build-ups mainly constructed by encrusting coralline red algae are currently developing on Mediterranean soft bottoms, at depths ranging from 20 m to 160 m. They are usually referred to as '*coralligène de plateau*'. Few fossil examples of these bioconstructions have been described in the literature and their evolution in the context of a stratigraphic cycle has never been modelled in detail. Cutro marine terrace (Calabria, southern Italy) preserves mid-Pleistocene deposits assigned to Marine Isotope Stage (MIS) 7 or MIS 9. Extensive algal build-ups representing the deepest unit of the succession occur in the outer and central portion of the terrace, interpreted as the most distal setting from the palaeo-shoreline. Two studied sections, Vrica and Telegrafo, showed that the solid biogenic framework grew over a basal rhodolith layer, which was stabilized by the binding activity and overgrowth of non-geniculate Corallinales (calcareous red algae). Therefore, these bioconstructions represent a rare fossil example of *coralligène de plateau*. At the Telegrafo section, *Titanoderma pustulatum* has been identified as the major rhodolith component. The build-ups are dominated by *T. pustulatum*, associated mainly with *Mesophyllum* spp. and locally with *Lithophyllum stictaeforme*. Rhodalgic bioclastic deposits are found in lateral contact with the build-ups. The two facies developed together under a hydrodynamic regime where phases of sedimentation from storm-driven currents alternated with phases of calm conditions. They were deposited during a single stratigraphic cycle beginning with the generation of a ravinement surface during the transgressive systems tract (TST) and ending with the burial of the *coralligène* by well-sorted shoreface bioclastic sands. Optimal and extensive growth of the *coralligène* took place during the highstand systems tract (HST).

The Mediterranean Sea represents an excellent example of a temperate domain where carbonate sediments of the Heterozoan Association are produced and deposited widely (James 1997). Pérès & Picard (1964) offered a synopsis of recent Mediterranean biocoenoses, aiming at the definition of characteristic subenvironments and related sedimentary products. With the term '*coralligène de plateau*', also translated as 'coralligenous bank' (Pérès 1967, 1982), they referred to a rigid framework built mainly by encrusting coralline red algae, developing on Mediterranean soft bottoms at depths ranging from 20 m to 160 m. This variable distribution is a function of light penetration, with deeper settlements occurring in the highly transparent waters of the Eastern Mediterranean Sea but average optimal growth-depth between 40 m and 60 m. Secondary framework builders, such as bryozoans, encrusting foraminifers and serpulids, may contribute to the growth of the build-up.

Apart from its palaeoecological significance, the study of the *coralligène de plateau* is very attractive for several reasons. First, the ability to colonize mobile substrates is a key element which distinguishes the *coralligène de plateau* from other types of coralline algal frameworks growing in shallower settings, such as algal ridges, algal cup reefs and *trottoirs*, or the *coralligène* installed on rocky substrate (Laborel 1961). Secondly, the *coralligène de plateau* is characterized usually by an open algal framework infilled with fine interstitial sediment, suggesting growth in quiet environmental conditions; nevertheless, it is often found in lateral contact with coarse mainly bioclastic deposits, with bedforms and sedimentary structures indicative of current activity. This paradox raises the question as to what type of hydrodynamic regime may account for the coexistence of such apparently contrasting features. Finally, very few fossil examples have been interpreted as

coralligène de plateau (Bosence & Pedley 1982; Carannante & Simone 1996; Rasser 2000; Nelson *et al.* 2001; Rasser & Piller 2004) and most are Tertiary analogues that formed under very different climatic and palaeo-biological conditions than those of the modern Mediterranean. Moreover, despite its relatively well-documented modern occurrence in the Mediterranean Sea, knowledge of the genesis and structure of this temperate-water bioconstruction is rather poor.

The study of mid-Pleistocene algal build-ups of the Crotona Peninsula (southern Italy), which appear to be a manifest example of *coralligène de plateau* and associated bioclastic deposits, offered the possibility to gain further insights into the above-mentioned topics. The observations were framed in a simple sequence-stratigraphic scheme, with the aim of modelling the response of these peculiar sedimentary products to a single transgressive–regressive cycle.

Study area

The Crotona peninsula (Calabria, southern Italy) is characterized by the presence of a flight of well-developed marine terraces (Zecchin *et al.* 2004), originating from the interplay of glacio-eustatic sea-level fluctuations and continuous uplift of the area. The highest and oldest terrace, named Cutro terrace, preserves a thin (max. 15 m thick) sedimentary cover lying unconformably on a Plio-Pleistocene substrate of outer shelf to slope marly clays (Massari *et al.* 2002), named Cutro Marly Clay by Roda (1964). The deposits of Cutro terrace are mid-Pleistocene in age and have been assigned to MIS 7 (Gliozzi 1987) or to MIS 9 (Palmentola *et al.* 1990). Detailed observation of the facies distribution of the deposits (Gliozzi 1987; Zecchin *et al.* 2004) revealed the presence of extensive algal build-ups, which represent the deepest-water unit of the succession. The build-ups are found prevalently in the outer and central portions of the terrace, therefore indicating growth in the most distal settings with respect to the palaeo-shoreline.

In order to investigate the coralline algal bioconstructions and associated deposits, two sections were selected in the outer portion of the terrace (Fig. 1), one on the external margin (Vrica) and the other on an abandoned quarry (Telegrafo).

Methods

At the Telegrafo section (UTM coordinates: 685 050, 4316 134) the walls of the quarry are orientated in several directions, allowing a three-dimensional view of the build-up architecture. For taxonomic and palaeoecological characterization

of coralline algae, two bioconstructions (4.5 m and 1.3 m high) were selected and sampled every 30 cm along a vertical transect, collecting 15 and 5 samples, respectively. Thin sections were obtained from these samples. The basal contact with the Cutro Marly Clay substrate corresponds with the floor of the quarry; therefore, even if the contact could not actually be seen, the first sample of the transects (taken at the base of the section) is inferred to be only a few centimetres above the contact. Four additional samples were taken at the contact between algal build-ups and laterally occurring bioclastic deposits and 14 samples were taken within the bioclastic deposits, to be analysed in thin section.

At the Vrica section (UTM coordinates: 684 654, 4324 388) the contact with the substrate is well exposed. Three samples were collected from a basal rhodolitic unit and thin sections of rhodoliths were obtained from these samples. Five samples of *c.* 10 cm in size were also collected every 30 cm from the bottom to top of an algal build-up *c.* 1.5 m high.

Corallinales taxonomy follows the biological nomenclature, when applicable (see Woelkerling (1988) for criteria to be used in the definition of genera). Non-geniculate corallines growth forms are defined following Woelkerling *et al.* (1993). Form and internal structure of rhodoliths are described following Bosence (1983c) and Basso (1998). A short description of the Mediterranean benthic biocoenoses cited in the text may be found in Basso (1998).

Description of basal rhodolitic unit

The build-ups grew directly on a transgressive ravinement surface, cutting the clayey substrate. Although the contact is abrupt in most cases, both sections preserve a thin basal rhodolitic unit locally, which acted as a pavement for the settlement of the early bioconstruction. Locally, V-shaped gutters up to 15 cm deep infilled with rhodoliths have been found below the build-ups at the contact with the substrate (Fig. 2).

At Telegrafo section, sub-centimetric, sparse rhodoliths of *Titanoderma pustulatum* (Lamouroux) Nägeli were observed at the base of the *coralligène* framework, associated with mostly unidentified fragments of corallines, among which are *Mesophyllum* sp. and *Amphiroa* sp., abundant planktonic foraminifera, sub-millimetric fragments of bryozoans, annelids and rare molluscs in a fine matrix. The rhodoliths have a laminar, very loose internal structure, with a clayey nucleus.

At Vrica section, corallines comprise *c.* 90% of the biogenic sediment at the base of the *coralligène* framework. Some pluricentimetric mud clasts

Fig. 1. Geographical location and geological sketch map of the Crotona Peninsula (after Palmentola *et al.* 1990 and Zecchin *et al.* 2004). Note wide areal extension of Cutro terrace. Inner margin of this terrace is to the NW, therefore, studied sections are located on most distal settings with respect to the palaeo-shoreline.

Fig. 2. Vrica section: detail of contact between clayey substrate and algal build-up. Dashed line marks gutter scoured in the substrate, infilled with rhodoliths. Head of hammer 18 cm long.

also occur, together with a minor contribution of coarse and unworn shell fragments, rare serpulids and bryozoans. Most rhodoliths are spheroidal, with a long axis (maximum diameter) of 10–40 mm. Well-preserved to heavily abraded rhodoliths are mixed together. The largest rhodoliths show fruticose growth form, with a cauliflower-like internal structure composed of numerous columnar protuberances, becoming confluent and platy toward the rhodolith surface (Fig. 3). A macroscopic nucleus is absent but fragments of geniculate corallines (*Amphiroa* sp.) and benthic foraminifers are included commonly in the algal nodules. The Vrica rhodoliths are mostly monospecific, generated by a still unidentified mastophoroid coralline and rarely by *Titanoderma pustulatum*. Local accumulations of broken coralline branches also occur.

Fig. 3. External view and longitudinal section of a rhodolith taken from basal unit at Vrica section. Note abrasion of external surface and fruticose growth form of coralline algae.

Description of algal build-ups

The build-ups vary from isolated masses up to 1.5 m high and 3 m wide, to remarkably developed banks of heights up to 4.5 m and widths that can be tens of metres square. The first type is found prevalently in the inner and central portions of the terrace. These isolated build-ups generally present an overall ellipsoidal shape (Fig. 4) and their internal cavities have diameters of several centimetres. On the contrary, the banks, which are present only in the external area of the terrace, show a very irregular morphology, with many cavernous cavities and depressions up to 3.5 m deep and 6 m wide between prominent bioconstructed bodies, infilled with sediment (Fig. 5). Protruding ledges departing from the main mass (Fig. 5c, d) and vertically orientated algal laminae on the external surfaces of the build-ups were observed at times. This suggests that the build-ups accreted both in a lateral and vertical direction.

At Telegrafo, the most common species in the *coralligène* solid framework is *T. pustulatum*, which proves to be a major framework builder, accompanied by *Mesophyllum lichenoides* (Ellis)

Fig. 4. View of isolated algal build-up, with overall ellipsoidal shape, lying on lower Pleistocene Cutro Marly Clay. Hammer 34 cm long.

Lemoine and *Mesophyllum alternans* (Foslie) Cabioch & Mendoza. *Lithophyllum stictaeforme* (J. E. Areschoug) Hauck is never dominant, but apparently more abundant at the base of the build-ups. Mastophoroids (*Spongites fruticulosus* Kützinger and ?*Neogoniolithon* sp.) were also recognized. The molluscan association identified in the Telegrafo section includes the molluscs *Lima lima* (Linné), *Haliotis tuberculata lamellosa* Lamarck, *Bolma rugosa* (Linné), *Striarca lactea* (Linné), *Myoforceps aristata* (Dillwyn), *Chlamys glabra* (Linné), *Chlamys multistriata* (Poli), *Glycymeris* sp. and the brachiopod *Argyrotheca* sp. It is comparable with the fauna of the modern *coralligène* and associated biotretic sediments. In the upper part of the section, some large specimens of the bivalve *Spondylus gaederopus* Linné also occur.

At Vrica, the *coralligène* build-up, about 1.5 m high, shows a dominance of *T. pustulatum*, with abundant serpulids and bryozoans. *Lithophyllum stictaeforme* also occurs, overgrown by *T. pustulatum*.

As observed at the Telegrafo section, other framework builders were *Mesophyllum lichenoides*, *M. alternans*, *Lithophyllum stictaeforme* and mastophoroids, in variable abundance. Fragments of the geniculate coralline *Amphiroa cryptarthrodia* Zanardini are present throughout.

Description of bioclastic deposits

Coarse- to medium-grained bioclastic deposits are found in lateral contact with the build-ups and infill their cavities (Fig. 5). Towards the top of the cavity infills, which may reach 4.5 m, they gradually change into well-sorted medium-grained calcarenite recurrently covering the bioconstructions (Figs 5a, b). Bioclastic components are mainly

Fig. 5. Telegrafo section: views and schematic drawings of outcrops, illustrating the geometrical relationships of algal build-ups and associated bioclastic deposits. (a, b) Wide cavity between two prominent bioconstructed bodies infilled with bioclastic sediment showing traces of stratification. Overall morphology of build-up on the left is the result of equally important lateral and vertical growth; note also how the bioclastic deposits cover the build-ups. (c, d) Large cavity within algal build-up infilled with bioclastic trough cross-bedded deposits. Abraded rhodoliths are abundant in the basal portion of the infilling sediment and are shown in detail in Figure 6. Hammer for scale.

bryozoans and corallines (c. 40% each), with c. 15% of molluscan fragments. Remains of serpulids, brachiopods and echinoids also occur. Whenever identification was possible, corallines and bryozoans correspond to those occurring in the solid framework. The basal 1 m of the deposits is characterized by the dominance of well-rounded rhodoliths, on average 2–3 cm in size (Fig. 6). Several rhodolitic layers are found higher in the unit, but they differ in the limited thickness (up to 4 cm) and smaller size of the rhodoliths. The

association of bioclasts of very different size results in poor to moderate sorting of these skeletal gravels and sands. Thin section analysis reveals also the presence of a fine micritic matrix, containing dispersed angular silt-sized quartz grains, fragments of bryozoans and corallines, molluscan larval shells, benthic and subordinate planktonic foraminifers. Another common feature is the co-existence of highly abraded allochems, such as the rhodoliths of the basal layer, and unworn delicate algal crust fragments (Fig. 7).

Fig. 6. Telegrafo section: detail of rhodolitic unit found within the bioclastic deposits at base of a cavity infill (see Figures 5c,d for precise location). Note roundness due to intense abrasion and ellipsoidal shape, as well as poor sorting resulting from mixing with various skeletal elements (mainly corallines and bryozoans debris).

Fig. 7. Telegrafo section: well-rounded abraded rhodoliths associated with thin fragmented algal crusts within the bioclastic deposits. Pencil cap is 3 cm long.

The same contrasting taphonomic signal is also reflected by the common association of well-rounded siliciclastic granules with poorly elaborated bioclasts. However, a general trend of in-

creasing sorting and rounding has been recognized moving towards the top of the unit, as well as a gradual increment in the siliciclastic fraction forming up to 40% of the granules. Indication of moderate activity of infaunal organisms is recorded by sparse *Scolicia* traces, and encrustation of mollusc shells by corallines is locally observed.

Special attention has been paid to the contact between algal build-ups and associated bioclastic deposits. Millimetric columnar algal growths and intact branched algal crusts are often found along this contact (Fig. 8), suggesting absence of significant erosion. Nevertheless, a certain degree of erosion is implied by the abundance of coralline algal fragments and by very rare cobbles of algal bioconstruction found within the associated bioclastic sediment.

Although the bioclastic deposits locally show a massive appearance, they are generally well stratified in centimetre-thick layers. In some places, individual beds are normally graded (Fig. 9). Layers preserving concentrations of isodiametric *Bolma rugosa* shells are also observed locally. Two main sedimentary structures can be recognized within the detrital facies. The first is a spectacular festoon-like stratification draping the inter-build-up cavities, predominantly developed in the lower to middle portion of the deposits (Fig. 10). It consists of festoon-shaped centimetre-thick laminae up to 3 m wide, with the concavity maximum 30 cm deep, in lateral contact with prominent build-ups. The second sedimentary structure, which can be found throughout the deposits, is a well-defined trough cross-stratification, with troughs up to 50 cm wide (Fig. 11).

Fig. 8. Telegrafo section: detail of contact between algal build-up and associated bioclastic deposits. Arrows point to columnar algal growths preserved along this contact. Diameter of coin is 2 cm.

Fig. 9. Telegrafo section: normally graded layers and concentrations of hydraulically sorted *Bolma rugosa* shells within festoon-stratified bioclastic deposits of Figure 10.

Ecological characterization of algal associations

Soft bottom: the rhodoliths

In the modern Mediterranean, the coralline species with the widest bathymetric distribution, reaching the maximum water depth of about

Fig. 11. Telegrafo section: trough cross-bedding within the bioclastic deposits. Hammer for scale.

90 m in the western Mediterranean, is *Titanoderma* spp. In contrast, a diversified coralline association normally occurs in rhodoliths at 40–60 m of water depth. The internal structure, growth form and species comprising deep rhodoliths have been schematized by Basso (1998) into three major groups: (1) **free-living branches**, monospecific; (2) **prâlines**, compact, mono- or oligospecific rhodoliths; and (3) **boxwork rhodoliths** (*sensu* Bosence 1983c), normally multispecific, loose internal structure with cavities infilled by sediment. They characterize the circalittoral (corresponding to the lower sublittoral of Hedg-

Fig. 10. Telegrafo section: large festooned stratification within bioclastic deposits infilling a wide cavity between algal build-ups. Close up of this structure is shown in Figure 9. Hammer for scale.

peth 1957) benthic environments with soft substrates that can be described on the basis of different combinations of water energy (bottom currents and/or storm waves) and sedimentation rate (Basso 1998). Following the Mediterranean benthic bionomy (Pérès & Picard 1964; Pérès 1982) these environments span from the biocoenosis of Sands and Gravels under bottom currents (SGCF) to the *coralligène de plateau* (C) through the several facies of the Coastal Detritic biocoenosis (DC). Fruticose rhodoliths growing under the strongest water energy (SGCF) show a distinct morphology, with protuberances enlarging toward the tips, where they coalesce to create an apparently flat external surface. The constant abrasion of the thallus surface at the tip of protuberances due to frequent rolling on the coarse sediment is responsible for this cauliflower-like internal structure, which is interpreted as an adaptive strategy to mechanical disturbance, leading different coralline species to a morphological convergence (Steneck 1986; Basso 1996).

Rhodoliths at the base of Telegrafo section are small, with a loose internal structure and composed of *Titanoderma* sp. In contrast, rhodoliths at the base of Vrica section are cauliflower-like, compact and monospecific. Therefore, on the basis of shape, internal structure, species composition and accompanying microfacies, a comparatively deeper and quieter palaeoenvironment is suggested for the Telegrafo rhodoliths (lower circalittoral zone) than for the Vrica rhodoliths (upper circalittoral).

Hard bottom: the coralligène

Crustose, relatively fast-expanding algal thalli are the best adapted to compete for space on a hard bottom. Actually, the crustose *Mesophyllum lichenoides*, *Titanoderma pustulatum* and *Lithophyllum stictaeforme* (= *L. grandiusculum*, = *L. cabiochae*) are major framework builders, since they are able to form crustose, more or less laminar protuberances creating bridges between the plant and neighbouring substrate to be occupied. This peculiarity also allows the early stabilization of the rhodoliths and the creation of the first hard substrate on which the framework can develop. The constant competition for space with other hard bottom dwellers such as bryozoans, annelids, and sessile molluscs, and the frequent superposition of different organisms lead to the formation of the characteristically porous structure of the *coralligène*. The algal association of the solid framework, though rather monotonous in species composition, shows the best development of algal thalli toward the top of the build-ups.

According to Sartoretto *et al.* (1996) the accretion rate in present-day Mediterranean *coralligène* is very low or non-existent below 50 m; conversely, the maximum growth rate is recorded between 10 m and 35 m depth (Sartoretto *et al.* 1996). The coralline species responsible for most of the biogenic solid structure of the Crotona Pleistocene *coralligène* are consistent with those identified in the modern Mediterranean rocky shore *coralligène*, including the ubiquitous occurrence of *Amphiroa cryptarthrodia* fragments (Sartoretto *et al.* 1996). Among the major framework builders, it appears that, at present, *Mesophyllum* is dominant in the shallowest *coralligène* (about 10–20 m), while *Lithophyllum* dominates below 20 m (Sartoretto *et al.* 1996).

Discussion

Both studied sections illustrate how the first growth stage of *coralligène de plateau* is the stabilization of a very coarse biogenic detritus of the rhodalgal type (Carannante *et al.* 1988), due to the binding action of non-geniculate corallines overgrowing each other.

The bioclastic deposits accumulated synchronously with the growth of the adjacent algal banks, with the exception of the upper portion covering the build-ups. This is substantiated by the high percentage of algal detritus within the deposits, which is compositionally equivalent to the flora and fauna of the build-ups and is preserved in fresh taphonomical conditions. The build-ups were therefore a major source of carbonate particles, under the combined action of physical and biological erosion. However, in spite of the coeval development of build-ups and bioclastic sediments, these two facies rarely present erosional contacts. Instead, it is more common to find algal crusts encroaching over the bioclastic deposits. This progressive growth resulted in prominent bioconstructed bodies displaying laterally overhanging ledges in places, but original average elevation above the surrounding sea bottom is difficult to estimate. Data on modern *coralligène* show variations in relief from 10–30 cm (Bosence 1983a, b) to 1–4 m (Laborel 1961; Sarà 1967; Bosence 1985; Toscano & Sorgente 2002), which suggests that an irregular seafloor morphology existed also during the formation of the Cutro terrace algal banks.

Intermittent sedimentation from storm-driven currents alternating with phases of low hydrodynamic regime seems to explain the observed sedimentological features of the studied units better. Low sedimentation rates, low hydrodynamic energy and weak luminosity are known to be important abiotic factors for the development of

coralligène de plateau (Laborel 1961, 1987; Pérès 1982; Carannante *et al.* 1988). Therefore, Cutro terrace build-ups extensively grew below fair-weather wave base, where the background sedimentation was given by deposition from suspension. Fine-grained sediment is, in fact, found within the bioclastic deposits and is trapped in the interstitial spaces of the crustose algal framework. Calm water conditions favoured encrustation of skeletal elements, bioturbation of detrital gravels and sands by echinoids and predominance of open leafy frameworks within the build-ups. On the other hand, recurrence of moderate to high-energy events is recorded by the sedimentary structures of the bioclastic deposits. Storm-induced currents may have had enough competence to generate trough cross-bedding and normally graded layers, especially if the flows were channelled by lateral confinement due to the relief of the build-ups. The observed festoon-like stratification is considered as a secondary structure instead, originating from differential compaction of the porous unconsolidated bioclastic sands and gravels with respect to the adjacent bioconstructions. Material transported from shallower higher-energy settings during storm events, mixed with the autochthonous carbonate production, generated a distinctive rounding bimodality, with co-existence of well-rounded and abraded particles and poorly reworked allochems.

A clear shallowing-upward trend is indicated both by the build-ups and the bioclastic deposits. Changes in framework morphology and ecological association of the crustose coralline algae within the bioconstructions are echoed by changes within the bioclastic deposits towards better sorted and rounded high-energy facies (Fig. 12), containing a significant fraction of siliciclastic grains. This gradual transition culminates with the burial of the build-ups by well-sorted bioclastic sands, interpreted as shoreface deposits.

Sequence-stratigraphic model

A simple sequence-stratigraphic model enables framing of the temporal evolution of the *coralligène de plateau* and associated deposits of Cutro marine terrace in the context of a single transgressive–regressive cycle. Three distinct phases have been identified (Fig. 13).

1. TST: a ravinement surface is created by shoreface retreat during transgression. A thin basal transgressive lag, consisting of siliciclastic pebbles, reworked mud-clasts, bioclasts and abundant rhodoliths, acts as substrate colonized by crustose coralline algae, which give rise to a solid framework. Spaces between these incipient build-ups

Fig. 12. Telegrafo section: thin section of sample taken from uppermost interval of bioclastic unit. Note good sorting and rounding of granules. Abraded particles of coralline algal debris (labelled 'c') may preserve an elongated shape and have larger size. Siliciclastic grains ('s') are well represented. Viewed in cross-polarized light.

- with moderate relief are infilled partly with abraded rhodoliths transported from shallower settings during storm events.
2. HST: maximum development of algal build-ups. Areas between individual bioconstructions are affected by intermittent sedimentation from storm-driven currents, as shown by traces of cross-stratification. Sparse *Scolicia* burrows, locally truncated by storm-related erosional surfaces, document the intermittence of high-energy events. Storm-driven flows commonly lead to mixing of locally produced coralline algal detritus with granules transported from inner shallower settings.
3. Falling-stage systems tract (FSST): changes in framework fabric and ecological association within the build-ups, as well as better sorting and an increase in siliciclastic component within the bioclastic deposits, are consistent with a shallowing trend. The bioconstructions are eventually buried by calcarenite shoreface deposits of the regressive phase, which gradationally overlie the bioclastic sands and gravels infilling the spaces between the build-ups. No evidence of a regressive surface of marine erosion was found in the studied sections. However, other localities in the more internal portion of the terrace show abrupt erosive contacts between the build-ups and upper shoreface deposits, providing evidence of forced regression.

Conclusions

Valuable insights into the genesis and development of *coralligène de plateau* and associated

Fig. 13. Stages of development of *coralligène de plateau* and associated bioclastic deposits. See text for discussion.

bioclastic deposits have been gained from the study of Pleistocene outcrops in the sedimentary cover of Cutro marine terrace.

1. Algal build-ups, composed primarily of *Titanoderma pustulatum*, *Mesophyllum alternans* and *M. lichenoides*, grew between fair-weather wave base and storm wave base at depths between 30 m and 60 m (Henrich *et al.* 1995; Carannante & Simone 1996; Sartoretto *et al.* 1996). They occur as isolated masses of limited extent but also as remarkably developed banks, covering tens of square metres of sea bottom. Their preserved maximum thickness does not exceed 4.5 m and their morphology is very cavernous, with many large

cavities and areas several metres wide between prominent bodies infilled with sediments. A thin unit up to 10 cm thick, consisting predominantly of rhodoliths, is commonly found at the base of the algal bioconstructions. This indicates that the first stage of *coralligène* settlement is the stabilization of a loose rhodolithic pavement through the binding action of coralline algal crusts. On the basis of thalli development and species associations and dominance, the early formation of *coralligène* on the rhodoliths is interpreted to be triggered by conditions of sediment starvation, slackening of water energy and weak luminosity induced by deepening of the palaeobiotope. During their growth, the build-ups maintained a discrete relief above the surrounding seafloor and represented a local source of carbonate detritus under the action of physical and biological erosion. The intervening phase of regression allowed the algal association to flourish towards the top of the build-ups, as observed particularly at Telegrafo section. Thus, the highest growth rate and probably the maximum relief of the build-ups occurred during the early stage of regression, before their final burial.

2. Bioclastic deposits, varying from rudstones to grainstones and packstones, are found in lateral contact with the build-ups. They may be considered rhodalgal-type carbonates (Carannante *et al.* 1988), consisting of rhodoliths, coralline algal crusts and debris, bryozoans and echinoids fragments, molluscs shells and fragments. Their composition and taphonomic signature indicate an autochthonous and parautochthonous provenance, with part of the sediment transported from shallower settings during high-energy events. Observed sedimentary structures indicate phases of sedimentation from storm-driven currents alternating with phases of calm-water conditions. This scenario seems to solve the apparent paradox of the co-existence of *coralligène de plateau* – which requires low to moderate energy for its growth (Basso 1998; Rasser & Piller 2004) – with deposits indicating an active hydrodynamic regime. Although these two facies developed at the same time, the overall sedimentation rate of the bioclastic limestone should have been low; otherwise, the build-ups would have been covered and their growth prevented. The studied units were deposited during a single stratigraphic cycle. This cycle began with generation of a ravinement surface during transgression and ended with burial of the

coralligène by shoreface calcarenites. Sedimentological features of the bioclastic deposits, gradually passing into the uppermost calcarenite, clearly document a shallowing-upward trend. Such a trend is also mirrored by variations in framework morphology and ecological association of the crustose coralline algae within the build-ups.

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