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Coral bioconstruction in a Burdigalian mixed siliciclastic-carbonate coastal system (Cala Paraguano, Corsica)

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ABSTRACT - This study presents facies analysis and a depositional model of a middle-lower Burdigalian mixed siliciclastic-carbonate system, characterized by coral bioconstructions, cropping out at Cala Paraguano (southern Corsica). Sedimentary facies, tracing stratigraphic surfaces, stratal and bioconstruction geometries were identified along a sea-cliff exposure. The sedimentary facies described and interpreted are coral rudstone to floatstone, coral domestone and maerl. The coral rudstone to floatstone indicates a highly energetic environment and possibly associated with vegetated areas, whereas the coral domestone was originated by small size patch reefs. These facies grade basinward into the maerl facies, which represents a deeper zone colonized by red algae and subordinate large benthic foraminifers.

The Cala Paraguano deposits document a case were terrigenous input in a mixed siliciclastic-carbonate coastal setting does not prevent the development of coral patch reefs.

Key words: Burdigalian, corals, siliciclastic-carbonate, Corsica, coastal system, maerl, facies

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INTRODUCTION

It is commonly assumed that corals flourish in oligotrophic and well-lit environments characterized by low siliciclastic input (James and Macintyre 1985; Hallock and Schlager, 1986). Siliclastic sediments have several negative effects on coral communities and carbonate producers (Rogers, 1990; Wilson and Lokier, 2002; Sanders and Baron-Szabo, 2005; Lokier et al., 2009): i) damage of coral tissue by abrasion and impact of sandy particles; ii) physical covering, causing expenditure of metabolic energy in activating rejection mechanisms, potentially leading to burial and demise of coral communities in case of exceptionally high sediment input; iii) increased turbidity due to high levels of suspended matter in the water column, resulting in a reduction of light penetration and consequently affecting the distribution of the light-dependent biota; iiii) changes in water chemistry, which involve reduced salinity, pH variations and an increase in nutrient levels.

Nevertheless, many studies have reported the occurence of coral reef growth associated with terrigenous input and high turbidity levels, both in present-day settings and fossil examples (Santisteban and Taberner, 1988; Woolfe and Larcombe, 1998; Wilson and Lokier, 2002; Perry, 2003; Sanders and Baron-Szabo 2005; Perry and Smithers, 2006; Lokier et al., 2009). These works show coral communities in delta and fan delta environments, on the contray development of coral bioconstructions in mixed carbonate-siliciclastic in coastal settings are poorly documented.

This paper presents the result of a stratigraphic-sedimentological analysis of coral-rich mixed carbonate-siliciclastic deposits exposed at Cala Paraguano (South Corsica) in the central Mediterranean Sea.

The deposits of Cala Paraguano and their reconstructed depositional setting document an example of coral patch reef development in costal settings dominated by a mixed siliciclastic-carbonate sedimentation.

GEOLOGICAL SETTING

The island of Corsica (France) is divided in two different domains (Fig. 1): Hercynian Corsica and Alpine Corsica (Durand-Delga, 1978, 1984). The former is represented by Carboniferous-Permian granitoid and acid volcanic rocks, related to calc-alkaline to high K – calc-alkaline granitic magmatism (Ferré and Leake, 2001), Precambrian-middle Paleozoic metamorphic host rocks and scattered outcrops of Paleozoic sedimentary rocks. The latter consist of a complex tectonic stack of thrust sheets, constituted by methamorphosed oceanic- and continental-derived crust nappes, non-metamorphic or low grade and ophiolitic units (Durand-Delga, 1984; Garfagnoli et al., 2009 and references therein).

In the Late Oligocene an important extensional phase affected the Sardinia-Corsica micro-plate with the development of a NE-SW oriented rifting system. This system evolved into a continental drifting related to the opening of the Ligurian-Provençal Basin (Jolivet and Faccenna, 2000), which was located in the back-arc region of the Apennines-Maghrebides Subduction Zone (Gueguen, 1998; Carminati and Doglioni, 2005). Therefore, in the time span between 22 and 15 Ma, Sardinia-Corsica Block rotated counter-clockwise away from southern Europe paleo-margin with an angle of 45° or 60° (Gattacceca et al., 2007; Lustrino et al., 2009; Carminati et al., 2010 and references therein).

During the Burdigalian, southern Corsica was affected by acid volcanism and the deposition of rhyolitic and dacitic tuff (Ottaviani-Spella et al., 2001). The deposition of marine sediments sarted also in the Early Miocene (Ferrandini et al., 2003). In Corsica, these sediments crop out in the southern part (Bonifacio), in the northern (Saint Florent and

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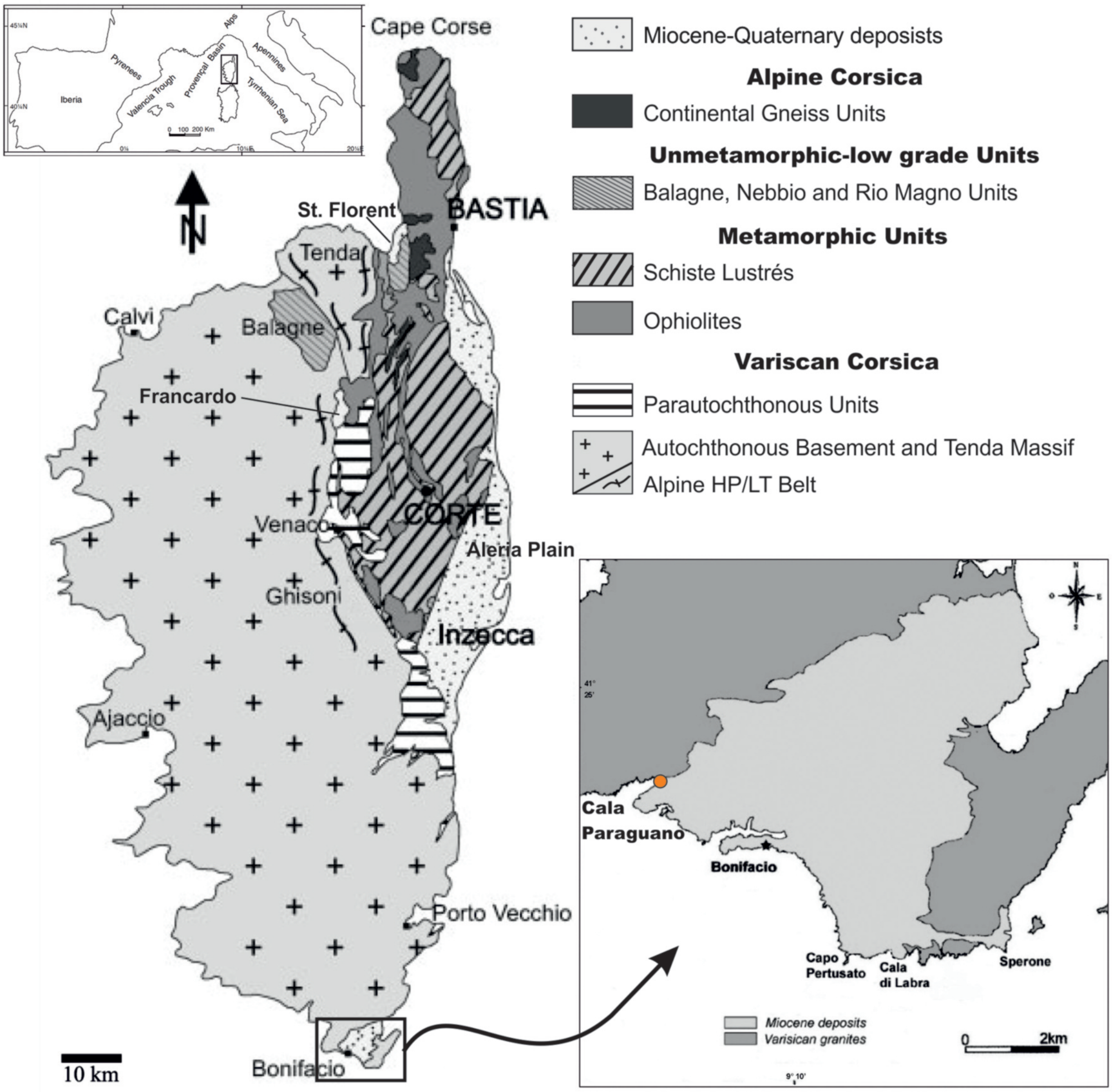

Fig. 1 - Geological sketch map of Corsica with close up of the investigated area (modified from Brandano et al., 2009; Garfagnoli et al., 2009).

Francardo) and in the eastern region (Aleria plain). Two formations are distinguished in the Early Miocene sedimentary succession of the Bonifacio Basin by Ferrandini et al. (2002, 2003): the Cala di Labra Fm. and the overlying Bonifacio Formation.

The Cala di Labra Formation (middle to late Burdigalian) is related to the trangression, that took place in the Bonifacio Basin in the middle to late Burdigalian. The base of this formation is characterized by coral-rich horizons. The corals are scatterd in a terrigenous matrix (fine conglomerates to hybrid sandstones with heterozoan biotic constituents). Galloni et al. (2001) interpreted these coral-rich deposits as two types of fringing reefs, one with low biotic diversity and another with high biotic diversity. This depositional unit is overlain by hybrid quartz-feldspathic sandstones with large pectinids, echinoids and encrusting red algae and marly sandstones to siltstones with planktonic foraminifera. The top of Cala di Labra Fm. is represented by bioclastic calcarenites and fine calcirudites dominated by red algae, bryozoans, echinoids and pectinid fragments (Brandano et al., 2009). The overlying Bonifacio Formation (late Burdigalian-lower Langhian) is made up of hybrid sandstones, fine conglomerates, bioturbated siltstones and cross-bedded calcarenites with heterozoan bioclastic components (Brandano et al., 2008; 2009). The Bonifacio Fm. is divided into two members (André et al., 2011), the Pertusato Member at the base and the Bonifacio Member at the top. André et al. (2011) interpreted the Pertusato Member as deposited in a wave-dominated nearshore to shoreface setting and the Bonifacio Member as an offshore tidal system.

MATERIALS AND METHODS

Description of coral bioconstructions at Cala Paraguano follows the terminology proposed by Insalaco (1998).

Microfacies analysis base on seventy thin sections of 4.5 x 3.5 cm. The $CaCO_3$ contents were determined through gasometric analysis using a Dietrich-Fruhling calcimeter. This analysis had required 0.5 g of sample powder, which was kept in oven for 24 h at 40 °C.

RESULTS

The sea cliffs of Cala Paraguano are situated 2 km north-west of Bonifacio (Fig. 1) It exposes the granitic Hercynian basement and the marine sediments of the Cala di Labra and Bonifacio Formations.

However, the contact between the marine deposits and crystalline basement is not exposed, while the contact of the Cala di Labra Fm. and the Bonifacio Fm. is an angular unconformity.

At Cala Paraguano, the presence of *Miogypsina globulina* in sediments of the Cala di Labra Fm. indicates that this unit was deposited in the lower-middle Burdigalian (Cahuzac and Poignant, 1997).

Sedimentary facies

The deposits of the Cala di Labra Fm. at Cala Paraguano were assigned to three distinct sedimentary facies based on physical sedimentary structures, biotic constituents, coral growth fabric (sensu Insalaco, 1998) and carbonate content ($CaCO_3$%).

Coral rudstone to floatstone facies

This facies consists of a well bedded coral rudstone to floatstone. The beds are from 0.3 to 1.2 m thick (Fig. 2) and gently dipping (up to 10°) to SW. Coral colonies are abundant in this facies, although they are mostly not in life position. Corals belong mostly to the *Porites* genus; the Favidae family is represented only by a few colonies. Coral colonies are predominantly small in size, with massive-globular morphology, although subordinate plate and rare branching forms are also present (Fig. 3A, B). The bigger colonies are 30 cm in diameter and 10-15 cm in height. Moreover, coral colonies are commonly affected by bioerosion, due to bivalves (*Gastrochaenolites*), clionid sponges (*Entobia*) and serpulids (*Caulostrepsis*). The siliciclastic content is rather high (up to 40%). The inter-coral sediment is a hybrid sandstone (Fig. 3C; 4A, B) with bivalves, echinoids, gastropods, small benthic foraminifera (*Lobatula lobatula* and rare miliolids). Less common geniculate and non-geniculate coralline red algae debris, larger benthic foraminifera (LBF), such as *Miogypsina* and *Amphistegina*, and barnacles also occur. Cortoids and peloids are also present.

Coral domestone facies

The coral rudstone to floatstone facies is overlain by the coral domestone facies. This facies is characterized by a domestone growth fabric (sensu Insalaco, 1998). The coral colonies are mostly in living position and show a main massive-globular morphology and only few platy-encrusting forms. Corals range in size from 5 to 60 cm in diameter and from 2 to 20 cm in height. The colonies form a dense and rather laterally continuous bioconstruction. Therefore, this facies shows a massive to crude stratification and build-up

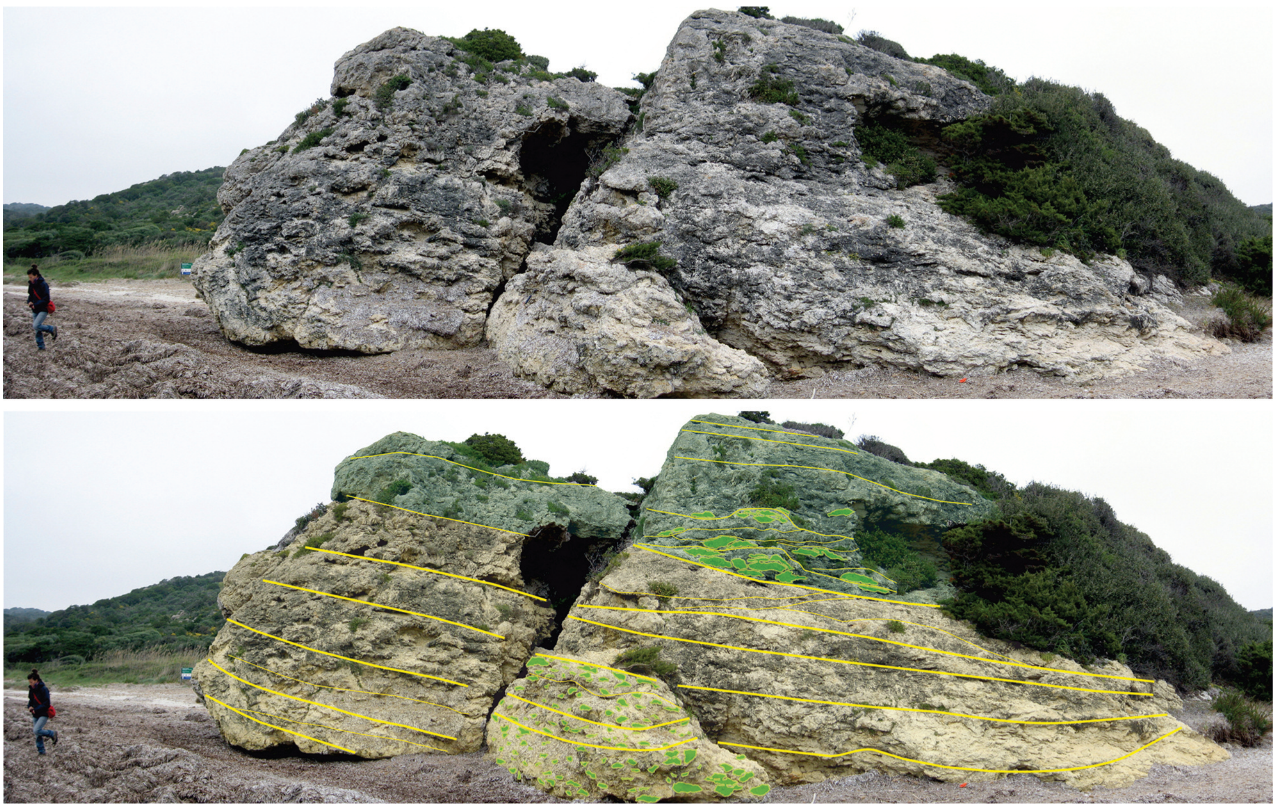

Fig. 2 - Photomosaic and line-drawing showing the organization of the coral rudstone to floatstone (yellow) and the coral domestone (green). This strike section shows the fairly continuous crude horizontal stratification of the coral rudstone to floatstone facies, compared to the massive to poorly stratified aspect, with internal mound geometries, of the coral domestone facies.

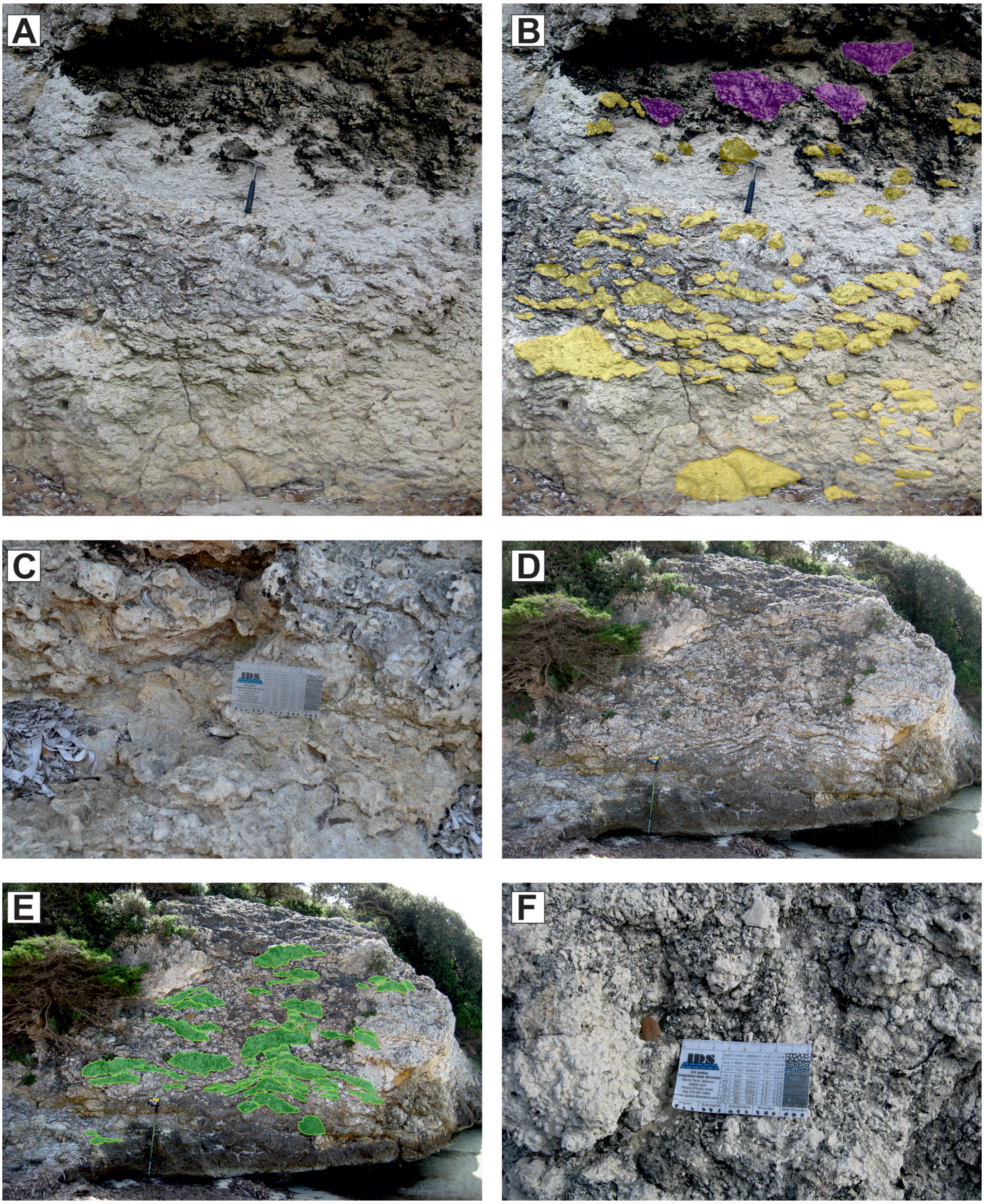

Fig. 3 - Sedimentary facies. A, B, C) The coral rudstone to floatstone is characterized by many reworked coral colonies (hammer for scale is 32 cm long in A, B) and a hybrid sandstone matrix (the ruler for scale is 8 cm long). D, E) The coral domestone consists of mostly massive colonies (highlighted in green in E) in living position. These show a dense and laterally continuous structure, usually resulting in mound geometries (the stick for scale is 1m long). F) The red algae floatstone to packstone is a bioclastic-rich facies dominated by red algae (the ruler for scale is 8 cm long).

geometries, which are not bigger than 5 m in height. Small-size mound geometries (up to 50 cm) commonly characterize the internal structure of the coral build-ups (Fig. 3D, E). These geometries are related to coral vertical piling, with dome and globose to platy corals growing one over another and creating a positive topographic relief. The massive colonies characterize the mound core. Indeed, they form the basic structure that permits the subsequent growth of platy and encrusting corals, which form the top and the flanks of the mound. The coral assemblage is dominated by *Porites* (Fig. 4C, D), *Tarbellastrea* and faviids are less common. Bioerosion traces have been observed within several coral colonies. The macro-boring traces belong to three ichnogenera: *Gastrochaenolites*, *Entobia* and *Caulostrepsis* (sensu Bromley and D'Alessandro, 1983; Kelly and Bromley, 1984; Gibert et al., 1998). Coral rubble is insignificant. The interstitial sediment consists of a moderately/poorly sorted, bioclastic floatstone to packstone (Fig. 4E, F). The main components are nodules, crusts and debris of red algae, bivalves, echinoids and small benthic foraminifers (rotaliids and textularids). Less common occur balanids, bryozoans, serpulids, LBF (*Miogypsina*, *Amphistegina* and rare *Heterostegina* fragments) and planktonic foraminifers. The terrigenous content is highly variable, but does not exceed 16%.

Maerl facies

The maerl facies interfingers with the coral domestone one. This facies consists of poorly sorted floatstone to rudstone, in a packstone matrix, composite parallel beds, ranging in thickness from 10 to 30 cm, with low angle dip (10-15°). These are characterized by planar to slightly ondulate internal stratification. The major constituents are red algae (Fig. 3F), which occur commonly as free living branches and small size rhodoliths. Red algae are represented by *Spongites*, *Sporolithon* and melobesoids. The red algae thalli are intensively bored by clionid sponges.

Besides the dominant red algae, other allochems include bryozoans, pectinids, serpulids, LBF (*Miogypsina globulina*, small, thick and fragmented tests of *Amphistegina* and rare *Heterostegina* tests), echinoids (Fig. 4G, H), subordinate balanids and small benthic foraminifers (textularids and rotaliids). Rare coral fragments occur at the base of this facies. The maerl facies is marked by the absence of corals in living position. The siliciclastic content is low and does not exceed the 8%.

DISCUSSION

Facies interpretation

The coral rudstone to floatstone facies is charaterized by inter-coral sediment with high terrigenous content (up to 40%) and several coral colonies with dome to branching morphology. Massive-globular corals and branching growth forms are able to tolerate moderate terrigeous input, up to 40% of medium sand (Wilson and Lokier, 2002; Lokier et al., 2009). The abundance of reworked coral colonies suggests highly energetic conditions. The coral colonies which grew on the soft sediment substrate would be easily reworked due to the normal and storm waves action. Riegl (2001) investigated the inhibition of reef framework by frequent disturbance in present-day settings. In the South Africa case of study, the high coral cover was suppressed by regular high wave-stress events, consequently forming a coral rudstone or floatstone. Moreover, is widely reported in literature that the storms lead to coral breakage and rubble generation (Perry, 2005; Montaggioni, 2005 and references therein).

The lack of rubble encrustation may be related to disturbance and abundance of siliciclastic sediment (Perry, 2005 and references therein).

The presence of articulated coralline algae, epiphytic small benthic foraminifers (*Lobatula lobatula*), echinoids and gastropods with micrite envelopes may suggest the presence of an environment vegetated by seagrass meadows (Beavington-Penney et al., 2004 and references therein). The seagrasses contribute to trap the sediment, inhibiting the generation of sedimentary structures (Brasier, 1975; Pomar, 2001). Nevertheless, the absence of sedimentary structures may be related to the bioturbation activity.

Concerning the coral domestone facies, its specific coral assemblage, colonies growth form, inter-coral sediment texture and the low siliciclastic content suggest a well-lit and moderately energetic environment. The abundant bioerosion indicates slow sedimentation rates allowing macro-borers to thrive and affect the coral colonies (Scoffin and Bradshaw, 2000; Reuter and Brachert, 2007). In the works of Bromley and D'Alessandro (1990) and Bromley and Asgaard (1993) on the Pliocene to Recent marine sediments from the Mediterranean area, the association of *Gastrochaenolites*, abundant *Entobia*, *Trypanites*, *Meandropolydora* and/or *Caulostrepsis* is regarded as indicative of a very shallow, clear marine environment. The inter-coral sediment biota, which consists of abundant red algae and subordinate LBF, is typical of mainly mesophotic condition and oligo- to slightly mesotrophic environments, as denoted by detritus- and filter-feeding organisms (echinoids, bivalves, bryozoans and serpulids) and by intense bioerosion (Hallock, 1988; Brasier, 1995). For the coral domestone facies a depth up to 20 m or even little more is estimated by the dominance of large massive coral colonies (c.f. Perrin et al., 1995; Esteban, 1996; Brandano et al., 2010).

The Cala Paraguano bioconstruction could be compared with two Early Miocene mixed carbonate-siliciclastic coral-rich deposits of Sardinia Island (Cherchi et al., 2000; Brandano et al., 2010). Comparing the Cala Paraguano coral build-ups with the Aquitanian coral patch reefs of the Dolianova area (Southern Sardinia) studied by Cherchi et al. (2000) reveals some differences and only few similarities. At Dolianova coral-rich communities characterize laterally discontinuous lens-shaped calcareous bodies intercalated within breccias and conglomerates. The *Porites*-dominated coral assemblage of Dolianova consists of branching and globular morphologies, while massive growth and subordinate platy forms dominate the coral domestone facies at Cala Paraguano. Cherchi et al. (2000) interpreted the coral-rich communities as patch reefs which developed on fan deltas, consisting of thick wedges of terrigenous material, during major quiescence periods of sedimentary input. Cala Paraguano coral build-ups show internal mound geometries and developed in a totally different setting, probably more similar to the Burdigalian Capo Testa mixed carbonate-siliciclastic system described by Brandano et al. (2010). Consistent analogies with the Capo Testa site are much detectable. At Capo Testa, scleractinian coral patch reefs are characterized by a *Porites*-dominated assemblage and mostly massive-globular coral colonies associated with a poorly sorted bioclastic packstone rich in red algae, LBF, echinoids and bivalves. Brandano et al. (2010) set this facies in the middle to lower part of the photic zone at a depth range of 35-45 m. Probably the Cala Paraguano massive *Porites*-dominated bioconstruction, characterized by a poorly/moderately sorted interstitial sediment rich in red algae, bivalves, larger benthic foraminifers and bryozoans, developed in the middle part of the photic zone in a moderately energetic zone.

The Maerl facies, widely reported in the literature both from fossil and present-day examples, can occur in different

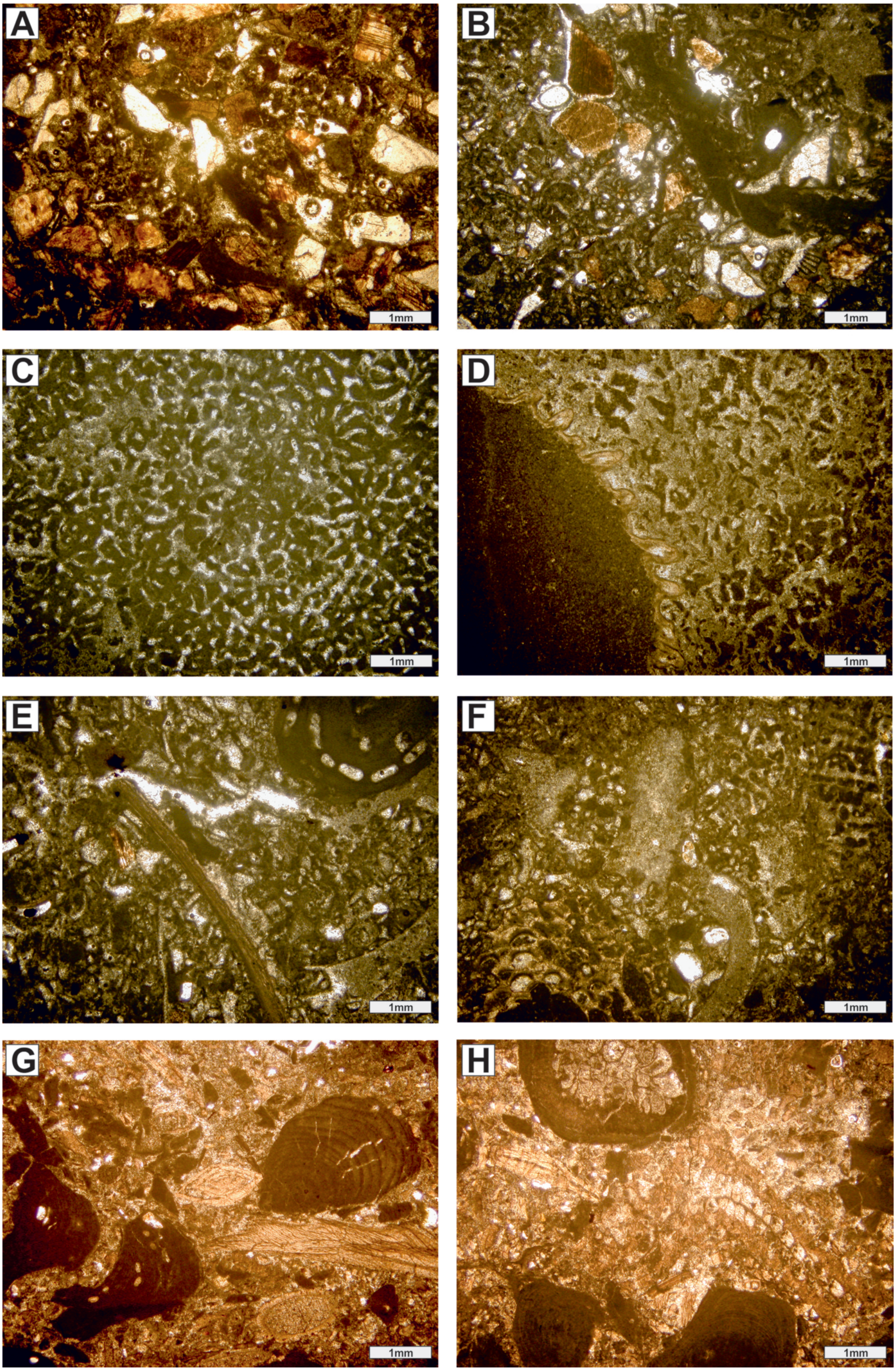

Fig. 4 - Thin sections (plan polarized light): A, B) Coral rudstone to floatstone facies, the main components are terrigenous grains (quartz and feldspars) and corals; gastropods are characterized by micrite envelopes. C, D, E, F) The coral domestone facies is dominated by Porites colonies, which are often bioeroded by bivalves (D), showing a moderately/poorly sorted texture characterized by common red algae and bivalves and subordinate other constituents, such as bryozoans and gastropods. G, H) Maerl facies; red algae dominate the biotic assemblage, consisting of larger benthic foraminifers (*Amphistegina*), bivalves, echinoids and bryozoans.

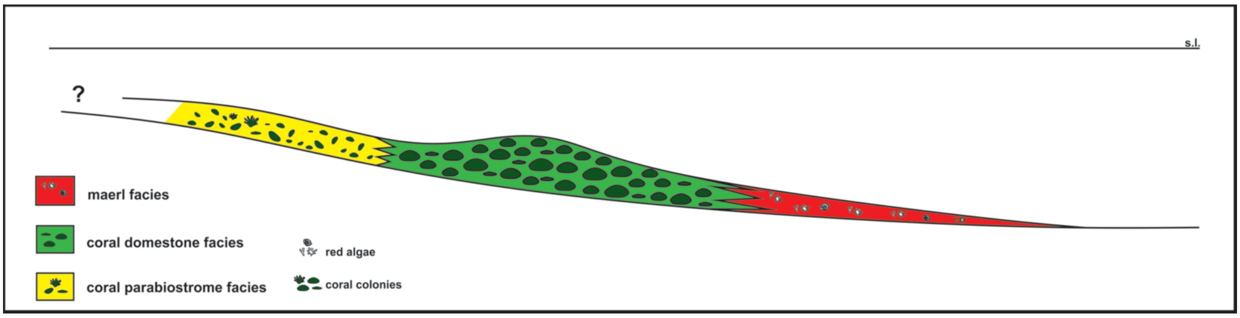

Fig. 5 - Sketch of the depositional model proposed for the Cala Paraguano succession (not in scale).

settings at variable depth. In the present-day Mediterrannean Sea, maerl deposits are restricted to shallow and moderately deep zones, below the deepest occurrence of *Posidonia* meadows (Canals and Ballesteros, 1997), whereas in tropical present-day environments maerl occurs in a very shallow zone commonly associated with seagrass meadows (Bosence, 1985; Steneck, 1986). Nevertheless, the biotic composition of the Cala Paraguano maerl facies, red algae-dominated with abundant LBF (*Miogypsina* and *Amphistegina*) and subordinate aphotic components, indicates mostly oligophotic condition (sensu Pomar, 2001). The moderate to poorly sorted texture, frequent bioclasts abrasion and bioclastic constituents (fragmented LBF tests and red algae debris) suggest that sediment accumulation resulted from both in situ production and transported material.

Facies association and depositional model

The coral rudstone to floatstone facies occurred in an energetic environment as indicated by the many reworked coral colonies. The biotic constituents (articulated coralline red algae, epiphytic foraminifers, such as *Lobatula lobatula*, echinoids and gastropods) and the sand-size terrigenous component are indicative of the possibly presence of a poorly developed associated vegetated areas. Frezza et al. (in press) investigated the mixed carbonate-siliciclastic sediments from *Posidonia oceanica* meadows of the present-day central Tyrrhenian shelf. These authors have reported that seagrass sediments are sand-dominated and characterized by highly terrigeous material (up to 86%) and a bioclastic component manly consisting of foraminifera (e.g. *Lobatula lobatula*, *Peneroplis pertusus*, *Miliolinella subrotunda*), mollusc fragments, non-geniculate and geniculate red algae. The coral rudstone to floatstone probably grades basinward to the coral domestone (Fig. 5), that was less directly influenced by the terrigenous input and characterized by mostly massive coral colonies. These formed small size patch reefs: limited build-up (up to 5 m in height) and mound geometries are commonly observed. Considering the domestone growth fabric of the colonies, the lower siliciclastic content (up to 16%) and the more abundant and diversified biotic assemblage these patch reefs occupied an interval of the photic zone deeper than the coral rudstone to floatstone. The patch reefs pass basinward to the mearl facies. This facies occupies the deepest part of the depositional system, as suggested by the red algae and LBF dominated biota, in oligophotic and moderate to low energetic conditions.

CONCLUSION

Based on facies analysis, three sedimentary facies have been delineated from the deposits exposed at Cala Paraguano: coral rudstone to floatstone, coral domestone and maerl.

The coral rudstone to floatstone facies is characterized by many reworked coral colonies and high siliciclastic content. Its inter-coral sediment is represented mostly by soft-sediment dwellers (bivalves, echinoids and gastropods), subordinate articulated coralline red algae and few epiphytic foraminifers. This facies indicates a highly energetic environment possibly associated with vegetated environments. The coral domestone facies consists of mainly massive-globular coral colonies in living position. The colonies have produced dense bioconstructions, marked by internal mound geometries, which resulted into small size build-up (up to 5 m in height) in a well-lit and moderately energetic environment. The maerl facies, dominated by red algae and with abundant large benthic foraminifers, consists of a poorly sorted floatstone to rudstone containing many different bioclastic components. These last denote both in situ production and sediment transfer, occurring in an oligophotic and moderate- to low-energy environment.

In the proposed depositional model, the coral rudstone to floatstone occupies a more proximal part along a coastal transect. This high energetic environment with high terrigenous input grades into a well-lit and less energetic one, characterized by the small-size coral patch reefs of the coral domestone facies. These coral bioconstructions pass basinward to the maerl facies. This last occurs in a deeper and more distal environment in oligophotic conditions.

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