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Coral-algal Reef Complex of Vigoleno, Piacenza, Northern Italy

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Abstract. During the late Miocene, reef complexes characterised by poorly diversified coral associations (mainly *Porites*, occasionally associated with *Tarbellastraea* and/or *Siderastraea*), became widespread in the Mediterranean area. One of these complexes crops out at Vigoleno (Castell’Arquato, Piacenza, Northern Italy). According to the regional palaeogeographic and palinspastic reconstructions, it can be considered up to now the northernmost late Miocene (Tortonian-Messinian) reef of the Mediterranean area. Despite the limited outcropping and the faulting, the multidisciplinary investigations reveal the anatomy of this reef complex along two reference sections. In addition, a marked cyclicity characterises both carbonate and siliciclastic deposits of the Vigoleno wedge-top basin. At present, the lack of reliable geochronological markers and unsuitability of the material for stable isotope analyses are not sufficient to constrain the time-span and the main controlling environmental factors of these depositional cycles.

1. Introduction

One of the outstanding peculiarities of the upper Miocene shallow-water carbonate platforms of the Mediterranean is the occurrence of coral reefs, characterised by low-diversity scleractinian coral assemblages, dominated by *Porites* with less frequent *Tarbellastraea* and *Siderastraea* [1].

During the late Miocene, the formation of the above-mentioned low-diversity zooxanthellate reef complexes is related to a general deterioration of suitable environmental conditions with a global lowering of temperature and/or an increase in seasonality that led to a reduction of favourable habitat for the z-corals communities [2]. The Occurrence and growth of coral reefs suggested in any case, that in the Mediterranean, the winter sea mean surface temperature was not lower than 16-18°C, which is a widely accepted threshold for coral construction [3]. One of these low-diversity reef complexes crops out at Vigoleno (Northern Italy; Figure 1A).

The Vigoleno coral-algal reef complex, developed in a mixed carbonate-siliciclastic depositional system and, despite its complex geological setting (see below), has points of great interest. First, as hinted in [4], it could be northernmost reported zooxanthellate coral reef in the Mediterranean during



the late Miocene. Second, a persistent meter scale facies alternation is observable both in its biogenic and siliciclastic deposits. Our aim is to investigate these main points by integrating sedimentologic and palaeoecological evidence, especially to interpret the main environmental dynamics recorded in the Vigoleno coral-algal reef.

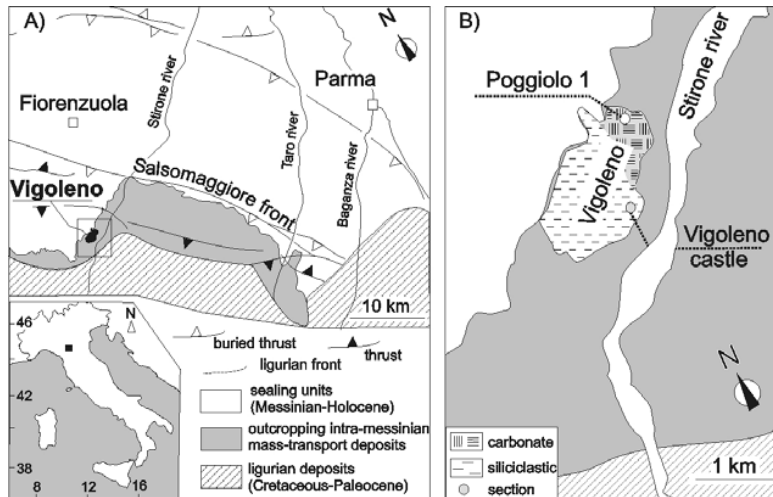


Figure 1 A) Structural and geological sketch map of Salsomaggiore area (Italy), and B) the Vigoleno “olistolite” with location of the carbonate (Poggiolo 1) and siliciclastic (Vigoleno castle) studied sections

2. Methods

Exploration efforts to characterise facies associations was undertaken along the entire Vigoleno basin. We reported results only from the two most expanded sections: Poggiolo 1 and Vigoleno castle (Figure 1B), retained representatively for biogenic and siliciclastic deposits.

Following the procedures illustrated in [5], facies analyses were carried out through the identification of lithology, grain size variations, boundary types, sedimentary structures and, in particular, the fossiliferous content. In order to better characterise these persistent meter scale alternations, palaeoecological macrobenthic-derived inferences were aimed at reconstructing past water depth, energy conditions on the sea floor and, ultimately, paleoenvironmental dynamics through investigated outcrops. As for macrobenthic fauna, sampling effort consisted of quick counts, performed by delimiting rectangles on vertical outcrop exposures and recording all macrofossils exposed following the procedure described in [6].

3. The Vigoleno wedge-top basin

The remnants of the epi-Ligurian Vigoleno basin outcrops in the north-western foothill area of the Apennines, near Parma and south of the Salsomaggiore front (Northern Italy).

The Vigoleno succession, as seen today, is an outlier surrounded by Ligurian deposits and a kilometric-scale, faulted “olistolite” belonging to the intra-Messinian mass-transport deposits (Figure 1A-B). Indeed, the mass transport processes related to the Messinian tectonic pulse, faulted and dismembered the Vigoleno wedge-top basin, while causing a northward translation of about 6 km [7].

3.1. Biostratigraphic and palinspastic inferences

Biostratigraphic analyses conducted on the Vigoleno castle section suggest a late Tortonian-early Messinian age [4]. However, the presence of the foraminifera *Bulimina echinata* and *Borelis melo melo* supports a possible attribution of the lower part of Vigoleno biogenic deposits to the early Messinian [8]. Even if the position of the coastline and the extension of the adjacent emerged land remains unknown because not preserved [9], the remnants of the Vigoleno marginal marine succession, approximate (given the short translation), the late Tortonian-early Messinian palaeocoastal area. Thus, located to a palaeolatitude of 44°N (Figure 1A; ~12° north of modern Bermuda Islands’

coral reefs), the Vigoleno coral-algal complex is the northernmost late Tortonian-early Messinian reef of the Northern Hemisphere.

4. The Vigoleno coral-algal reef complex

These faulted reef deposits show variable thickness (metres to decametres), and crop out in the eastern margin of the Vigoleno basin, whereas the remaining portion is represented by a thick siliciclastic succession (Figure 1B).

Vigoleno biogenic deposits are characterised by the different morphologies of *Porites* colonies, which, together with the associated taxa, are retained to reflect environmental parameters. The integrated facies analysis allowed recognition of a distinctive cyclic alternation (~30 cycles detected) of non-reefal and reefal units (biofacies *a* and *b* respectively in figure 2).

Biofacies *a* is principally made of oligophotic-dominated carbonate producers such as larger benthic foraminifera, coralline red algae, echinoderms, bryozoans and molluscs (Figure 2A). In contrast, biofacies *b* is characterised by mesophotic and euphotic carbonate producers, such as z-corals, coralline red algae, and porcellaneous smaller benthic foraminifera (Figure 2B).

4.1. Carbonate: Poggiolo 1 section

The Poggiolo 1, is the most expanded section (about 30m thick) of the Vigoleno biogenic succession (Figure 1B), and shows a distinctive cyclical facies pattern (~21 cycles inferred).

Biofacies *a* (non-reefal unit) is made of bioclastic wackestone-packstone rich in benthic foraminifera (such as *Elphidium* and *Nonion*) along with unidentifiable macrobenthic fragments and coralline red algae (mainly *Lithophyllum* and *Hydrolithon*) that increase in an abundance going up-section.

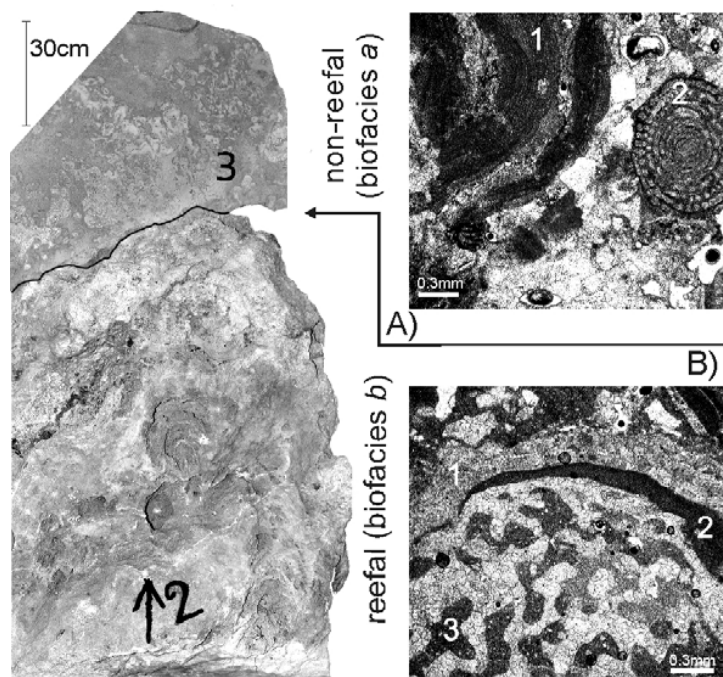


Figure 2 Biofacies alternation in Vigoleno carbonates: A) non-reefal unit, coralline red algae and bioclastic debris, in thin section (right upper panel), the coralline algae *Melobesia* (1) and the benthic foraminifer *Borelis melo melo* (2); B) reefal unit with *Porites* bushes, in thin section (right lower panel), the benthic foraminifer *Acervulina* (1), encrusting coralline algae (2), and the z-coral *Porites* (3). The black line highlight the boundary between reefal and non-reefal units.

In the lower part of Poggiolo 1, biofacies *b* (reefal) shows carpets of slender and branching bushes of *Porites* (20-25cm high), encrusted by coralline algae (*Spongites* and rarely *Lithophyllum*), scanty *Siderastrea crenulata* and benthic foraminifera (mainly *Acervulina*). Whereas, in the middle-upper part of Poggiolo 1, the reefal unit shows pillar-like (40-50cm high) and massive (30-40cm large) *Porites* colonies. Biofacies *b* is also characterised by a small branching coralline algae (e.g.,

Neogoniolithon), abundant fragments of bryozoans and molluscs, echinoid spines and plates, benthic foraminifera and rare *Porites* fragments.

Interpretation. The presence, in the lower part of the section, of slender and branching *Porites* associated with the sporadic occurrence of *S. crenulata* (an indicator of back reef environments), point towards a slightly protected depositional environment, passing up-section to high-energy settings. Indeed, in middle-upper Poggiolo 1, the concomitant presence of large hemispherical and pillar-shaped *Porites*, associated with a strong increase in coralline algae and lack of *S. crenulata* suggest a reef crest zone, similar to that described by [10] from Mallorca Island (Spain).

4.2. Siliciclastic: Vigoleno castle section

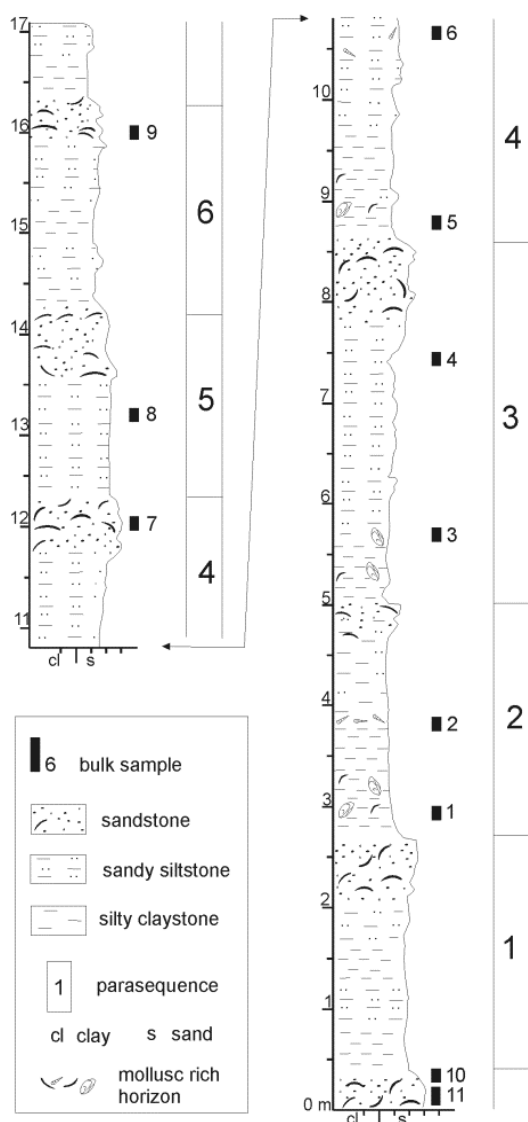


Figure 3 Vigoleno Castel section: columnar log and meter-scale sedimentary packages recovered.

The Vigoleno siliciclastic deposits show a distinctive cyclical facies pattern and reach maximum thickness (i.e., ~120m) near the castle of Vigoleno. In order to characterise the environmental dynamics within the persistent meter-scale alternations, integrated facies analyses were conducted only in the middle portion (~17 m thick; figure 3) of the Vigoleno castle section.

The lower part of each cycle is represented by sandy siltstone and sand-silt alternations with dispersed and relatively diverse molluscs assemblages (Bks 1, 3, 5 in figure 3), dominated by *Venus multilamella*, *Turritella tricarinata*, and *Nassarius dertonensis* along with subordinate *Anadara fichteli*, *Corbula gibba* and nuculids. The presence of sparse *Neverita olla* is also recorded. The middle part of each cycle is made up of homogeneous sandy siltstone or siltstone-sandstone alternations with scarce fossil content (Bk 8) or low diversity assemblages dominated by *Turritella tricarinata* or *Corbula gibba* with subordinate *Tectonatica astensis* and *Ditrupa* sp. (Bks 2, 4, 6 in figure 3). The uppermost part of these cyclic deposits is the most easily recognizable, being represented by the decimetre scale sandstone beds often including fossil rich horizons dominated by convex-up valves of *Glycymeris cor*, *Acanthocardia paucicostata*, *Paphia vetula*, and *Chamelea gallina* var. (Bks 7, 9, 10-11 in figure 3).

Interpretation. Along the investigated segment of the Vigoleno castle, 6 high-order facies association successions were recovered (Figure 3). The meter-scale sedimentary packages, from the base to the top, appear to be characterised by an increasing sedimentation rates (and possibly shallowing upward trends), as documented by repetitive alternations of mollusc biofacies. In the lower part of each unit (siltstone-sandstone alternations), a shallow marine setting (palaeodepth <30m), with a moderate sedimentation rate, is suggested by the occurrence of *V. multilamella*-*N. dertonensis* or -*T. tricarinata* biofacies (Bks 1, 3, 5). Indeed, all of these taxa are widespread in Mio-Pleistocene sublittoral settings, usually characterised by

moderate to relatively high sedimentation rates [11,12]. The presence of molluscs related to nearshore environments, such as *N. olla*, reinforce this interpretation. In the middle part (homogeneous sandy siltstone), oligotypic macrobenthic assemblages dominated by *C. gibba* or *T. tricarinata* (Bks 2, 6) point toward shallow marine settings under high sedimentary inputs (e.g., prodelta to distal delta front deposits; [13,14,15]). Within this unit, the transition to sandy bodies, usually devoid of fossils (Bk 8), is consistent with increasing sedimentation rates. Whereas, in the upper part of these units (Bks 7, 9, 10-11), hydraulic concentrations of shells (*C. gallina* var., *A. paucicostata* and *P. vetula*) testify lower shoreface-offshore transition environments [16].

4.3. Vigoleno cyclicity

Miocene biogenic shallow-water deposits of the Vigoleno basin reveal ~30 high-frequency cyclic alternations of reefal and non-reefal carbonates. At present biostratigraphic and bio-sedimentary inferences are not sufficient to constrain the time-span of these depositional cycles. The literature-based data on corals and coralline algae growth rates [3,17] hint that the duration of cycles may fall within a sub-Milankovitch-scale periodicity.

The siliciclastic Vigoleno castle section is 120m thick if the high-frequency pattern revealed in the central segment of Vigoleno castle holds for the entire section, the distinctive cyclic arrangement documented (i.e., ~50 cycles inferred), reflects the repeated alternation of phases of low to high fluvial discharge. The high-frequency cyclicity detected in both siliciclastic and biogenic deposits suggest a common origin, here attributed to the same causal mechanism determined for the siliciclastic succession. The higher number of cycles recovered from the siliciclastic succession with respect to those detected in the biogenic succession (i.e., ~50 vs. ~30 cycles), may be due to the mass-transport processes that affected the Vigoleno basin during the Messinian, which dismembered and/or buried some of the reef deposits. Alternatively, the discrepancy may point towards a more complex picture, in which the formation of high-frequency depositional cycles in the Vigoleno siliclastic succession is also controlled by autogenic factors not strictly (or only partially) linked to the ones controlling the cyclicity in reef environments.

5. Conclusions

Since the late Miocene, the Vigoleno basin has been located beyond the northern margin of the early Messinian reef belt of [18], at an estimated palaeolatitude of ~44° N. Hence, the Vigoleno reef can be considered the northernmost reef complex known in the Mediterranean area since the late Tortonian-early Messinian. Despite the poor outcrop conditions and diffuse faulting, the integrated sedimentological and palaeontological analyses conducted on the Vigoleno wedge-top basin remnants, refined palaeoenvironment dynamics of the studied sections allowed the recognition of a high-frequency cyclicity in both the biogenic and siliciclastic deposits.

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