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CORAL FACIES AND CYCLICITY IN THE CASTELGOMBERTO LIMESTONE (Early Oligocene, Eastern Lessini Mountains, Northern Italy)

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Key-words: Stratigraphy, Cycles, Facies, Corals, Early Oligocene, Lessini Mountains (Northern Italy).

Riassunto. Il Calcare di Castelgomberto è una formazione dell'Oligocene inferiore (Rupeliano), spessa circa 200 metri, che affiora nei Lessini orientali (provincia di Vicenza). Quest'unità presenta una peculiare organizzazione interna che viene documentata da quattro sezioni misurate e studiate in dettaglio; si tratta di circa tredici cicli in cui unità biocalcarenitiche, depositate in condizioni idrodinamiche di energia relativamente elevata, si alternano a livelli calcareo-marnosi e marnosi ricchi di coralli, con predominanza della specie *Actinacis rollei* Reuss. Questa peculiare ciclicità viene imputata alle variabili condizioni idrodinamiche della piattaforma dei Lessini, causate da ripetute fluttuazioni eustatiche. In altri termini si propone che durante i periodi di stazionamento alto del livello marino (*highstand*) la piattaforma (*shelf-lagoon complex*) fosse aperta e relativamente profonda (20-50 m), sicché correnti tidali e periodiche tempeste erano in grado di produrre, mantenere e distribuire sabbie bioclastiche sotto forma di barre e dune subacquee. Durante i periodi di stazionamento basso del livello marino (*lowstand*), invece, la piattaforma, che era orlata dalle scogliere marginali dei Berici, risultava più protetta ed era estesamente colonizzata da coralli poritidi di forma prevalentemente ramificata. A questo si aggiungeva la contemporanea esposizione subaerea, e conseguente degradazione chimica, di vaste aree settentrionali che apportava fine detrito ai bassi fondali della piattaforma.

Abstract. The Castelgomberto Limestone is a 200 m thick unit of Early Oligocene age (Rupelian) outcropping in the Eastern Lessini Mountains (Southern Alps of Northern Italy). The internal cyclic organization of this Oligocene unit is described and analyzed on the basis of four selected sections; about thirteen well-bedded grainstone units alternate with marly horizons rich in corals. This peculiar cyclicity is here interpreted as a response to variations in platform hydrodynamics, i. e. to smaller eustatic fluctuations affecting the Lessini Shelf reef-lagoonal complex. During highstand periods, the shelf was open and relatively deep (20-50 m), and tidal currents and periodic storms were able to distribute bioclastic sands (bars, sand waves and spillovers). During lowstands the shelf was more protected by the occurrence of marginal reefs and was colonized by patches of poritid corals, mainly branching. Moreover, the largely exposed northern areas supplied fine detritus to the shelf itself.

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Introduction.

The extensive outcrops of Oligocene terrains in the Vicentin Southern Alps (Eastern Lessini and Colli Berici; Fig. 1) have attracted the interest of many authors since the last century, especially as regards to their famous and rich coral fauna. These corals are part of a 200 m thick reefal complex of Early Oligocene age (Rupelian) known to pioneering workers as the "strati di Castelgomberto" (Maraschini, 1824) and to modern authors as the "Calcareniti di Castelgomberto" (Bosellini A. et al., 1967) or "Calcare di Castelgomberto" (Coletti et al., 1973).

During Rupelian time, the Castelgomberto Limestone was represented by a barrier reef-lagoonal complex. A barrier reef developed in the southeastern part of the Colli Berici (Rossi & Semenza, 1958; Geister & Ungaro, 1977; Frost, 1981) while a shelf-lagoon extended northwestward behind the barrier for about 30 km. This shelf was scattered with more protected "patch reefs" characterized in the lower part of the succession by a quasi-mono or paucispecific coral community dominated by the poritid coral species *Actinacis rollei* Reuss (Bosellini F.R. & Russo, 1988).

During recent studies on the stratigraphy, paleoecology and taxonomy of the Lessini coral communities (Bosellini F. R., 1988a; Bosellini F. R., 1988b; Bosellini F.

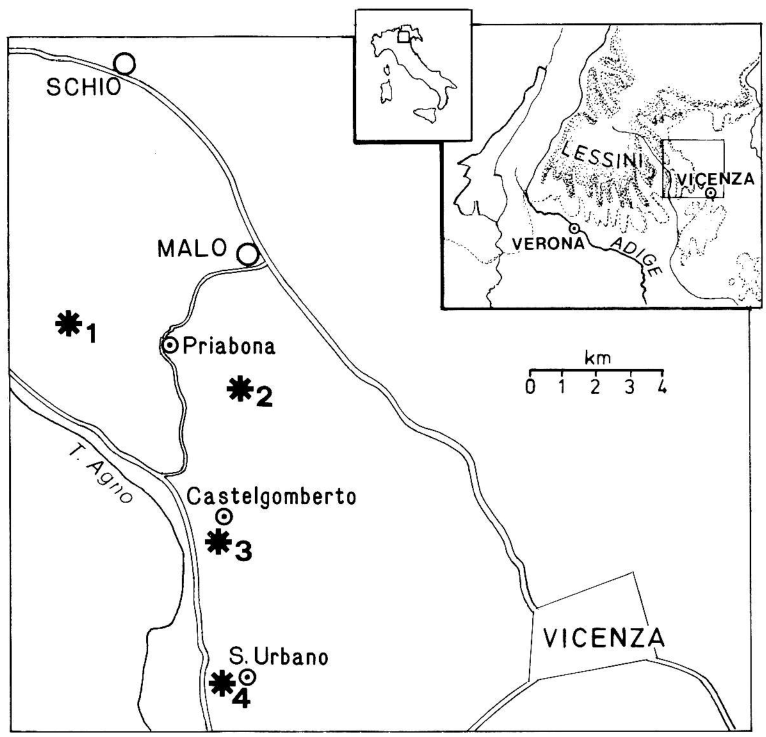


Fig. 1 - Location map of the study area and ubication of the measured sections. 1) Faedo; 2) M. Pulgo; 3) Castelgomberto; 4) S. Urbano.

R. & Russo, 1988), a cyclic organization of the coral bearing Castelgomberto Limestone was recognized in the shelf-lagoon facies: coral-rich marly horizons alternate with rhodolite-nummulitid grainstones.

The purpose of our contribution is the analysis and interpretation of this peculiar stratigraphic organization, on the basis of four selected sections which have been sampled and described in detail. Quite good exposures, due to several fresh road cuts, allowed a detailed observation of the rock structure and texture, as well as of the coral growth distribution in the carbonate sequence.

Geological and stratigraphic setting.

The study area belongs to the eastern part of the Lessini Shelf, a sort of "resurrected" Trento Platform (Bosellini A., 1989) which, during Eocene-Oligocene time, represented a relatively undeformed structural plateau that was scattered with reefs, lagoons, islands and volcanoes.

The sedimentary succession of the Eastern Lessini Mountains was deposited entirely in a shallow-water environment and can be subdivided into three well developed depositional sequences (Fig. 2).

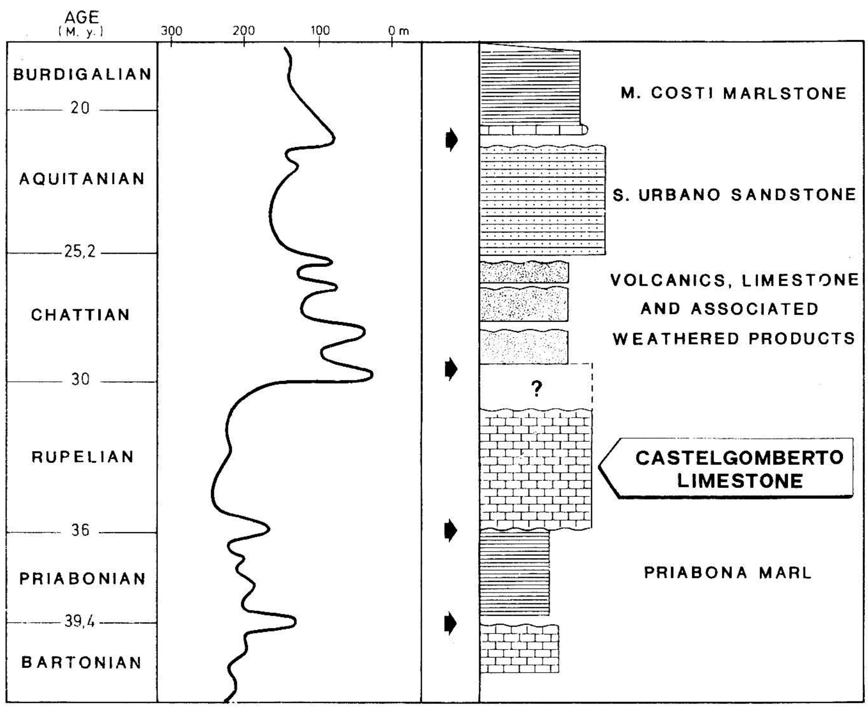


Fig. 2 - The stratigraphic succession of the Eastern Lessini Mountains, compared with the global sea-level curve by Haq et. al. (1988). Arrows indicate probable sequence boundaries associated with major lowstands (modified from Bosellini F. R. & Russo, 1988).

The Priabona Marl (Late Eocene) constitutes the first depositional sequence and is represented by a burrowed, soft, gray marlstone and shale with macroforaminifera, ostracods, coralline algae, bryozoans and some corals. Though seven units have been recognized in this sequence (Sirotti, 1978), only the upper one, the so called "Bryozoa beds", outcrops in the study area. The second depositional sequence is represented by the Castelgomberto Limestone. This unit is certainly of Early Oligocene (Rupelian) age. Its base has been sampled in detail in the S. Urbano section (Fig. 3), where it is represented by grey marls and discontinuous marly limestones. Micropaleontological analysis of these basal marls has revealed the occurrence of several stratigraphically significant benthic foraminifera, including *Asterigerina rotula haeringensis* Lühr (8.76 %), *Rotalia lithotamnica* (Uhlig) (2.27 %), *Schlosserina asterites* (Gümbel) (0.64 %), *Stomatorbina torrei* Cushman & Bermudez (0.97 %), *Queraltina epistominoides* Marie (6.16 %). The presence of *Asterigerina rotula haeringensis*, commonly associated with *Rotalia lithotamnica*, places the studied samples in the Early Oligocene. Moreover, the presence and relative frequency of *Queraltina epistominoides*, which is a common species of Priabonian age but also known from the basal Lower Oligocene, and its association with the very rare *Shlosserina asterites* and *Stomatorbina torrei*, indicates a very Early Oligocene age.

Finally, the occurrence in all studied sections of a nummulitic association typical of Rupelian age (*Nummulites intermedius* d'Archiac, *N. vascus* Joly & Leymerie, *N. bouillei* de la Harpe) and the total absence of *Lepidocyclinae*, which constitute a most important faunal element of Chattian reef communities in Italy (Bosellini F. R. & Russo, 1992), confirms a Rupelian age for the Castelgomberto Limestone.

The Castelgomberto Limestone abruptly overlies the Priabona Marl, displaying clear evidence of the pronounced lowering of sea level which, at 36 M.A. (Haq et. al., 1988), exposed the shelf and led to the establishment of frame-builder coral communities.

The uppermost part of the Castelgomberto Limestone is preserved in the summits of the higher hills where it appears disconformably overlain by a Late Oligocene assemblage of red clays, volcanics and scattered carbonates. These products represent the lowstand deposits of the third depositional sequence, most probably the result of the dramatic eustatic drop which occurred 30 M.A. ago at the end of Rupelian time (Haq et. al., 1988).

Facies and cycles in the Castelgomberto Limestone.

As mentioned in the introduction, identification and analysis of the Castelgomberto Limestone cyclicity is basically provided by comparison of four measured sections (Fig. 3). These sections have been selected for their almost complete and excellent outcrop conditions and are grossly aligned along a north-south tract which can be considered an ideal cross-section of the shelf-lagoon. In particular, their location is the

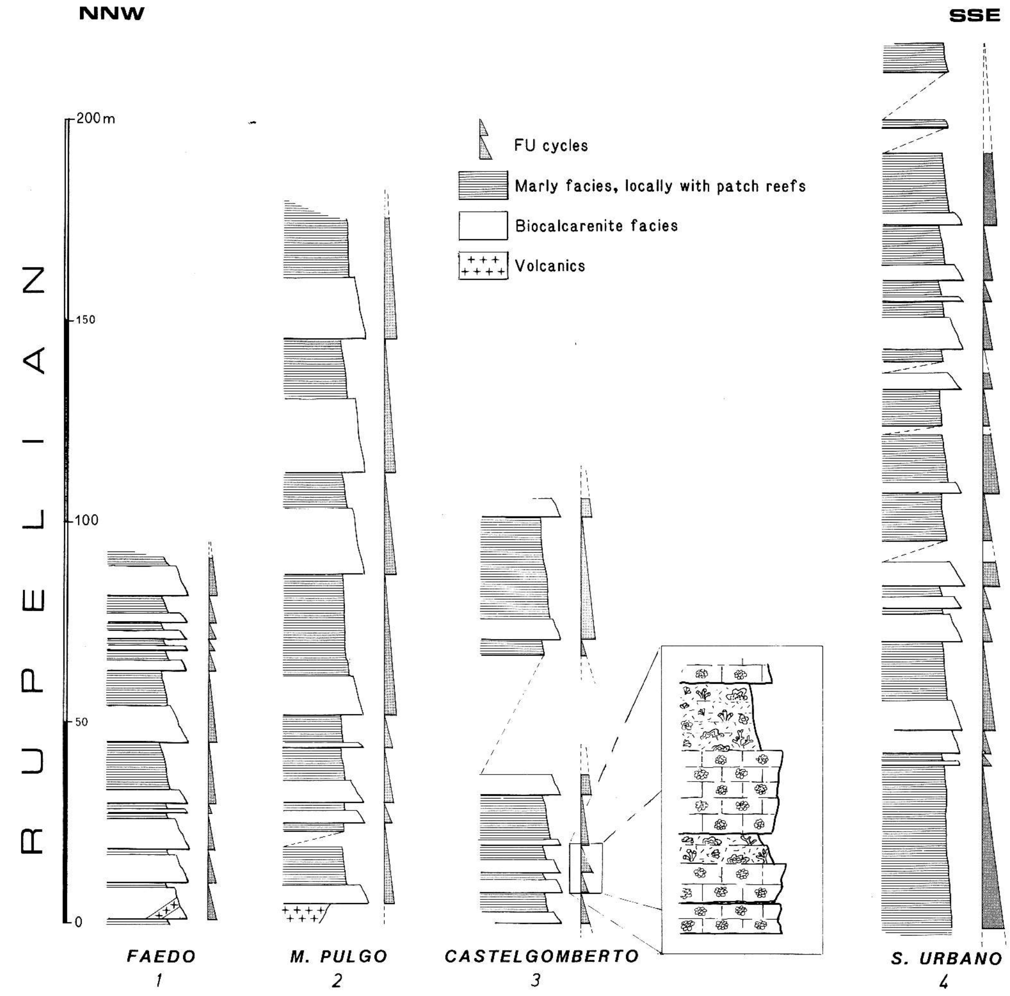


Fig. 3 - Stratigraphic sections of the Castelgomberto Limestone, schematically represented to show the cyclic organization of the succession.

following: 1) Faedo section: it is located between Faedo and M. Stommita, along the road connecting the settlements of Crestani and Milani; 2) M. Pulgo section: it has been measured along the road connecting Priabona to the small village of Montepulgo, along the eastern flank of M. Pulgo; 3) Castelgomberto section: it has been measured along the narrow road which connects the south entrance of Castelgomberto to Capitello Cocca, along the western slope of M. Grumi; 4) S. Urbano section: it has been measured along the winding road, starting from the bottom valley of Ghisa, up to Rio Secco near S. Urbano.

As shown in Fig. 4, the Castelgomberto Limestone appears clearly constituted of several asymmetric fining upward cycles (FU) of variable thickness (from 2-3 m to

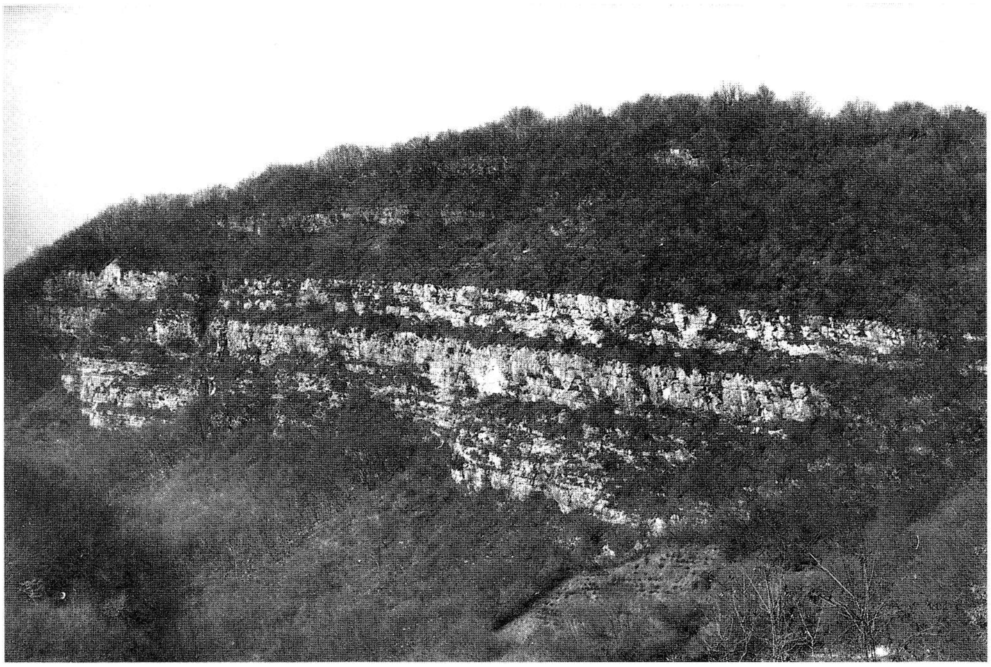


Fig. 4 - Field evidence of the cyclic organization of the Castelgomberto Limestone (M. Stommita).

30-35 m). Each cycle consists of a lower well sorted biocalcarenite, with an abrupt basal boundary (Fig. 5), which grades upward into marly biomicrites and marls rich in corals. In places, however, "truncated" cycles, represented by erosionally superimposed graded biocalcarenite units, have been observed. Unfortunately, the measured sections lack a common reference *datum*; physical correlation is impossible and biostratigraphic resolution is of no use at the parasequence level.

Therefore, we are unable to correlate our four sections and cycles: they are "floating" within the Rupelian stage.

Biocalcarenite facies.

This facies consists of pale and white biocalcarenite beds, variable in thickness from 0.5 to 3 m (more commonly 0.5-1 m) and separated by even parallel surfaces which become wavy when marl interbeds are present. Tractive current structures are generally lacking as the sediment appears thoroughly bioturbated. Coarse and graded biorudites (rhodolites, fragments of corals, bivalves, echinoderms and gastropods), 40-60 cm thick, with a basal erosional contact are quite common; they are interpreted as basal lags of storm layers. Locally, large scale cross-bedding has been observed (Fig. 6), documenting the lateral migration of large sand bodies. The contact with the underlying marls is quite clear-cut, in places distinctly erosional (Fig. 5).

Fig. 5 - Basal boundary of a cycle, showing the abrupt, in place erosional, contact between massive biocalcarenite and underlying coral bearing marlstone (M. Pulgo section).

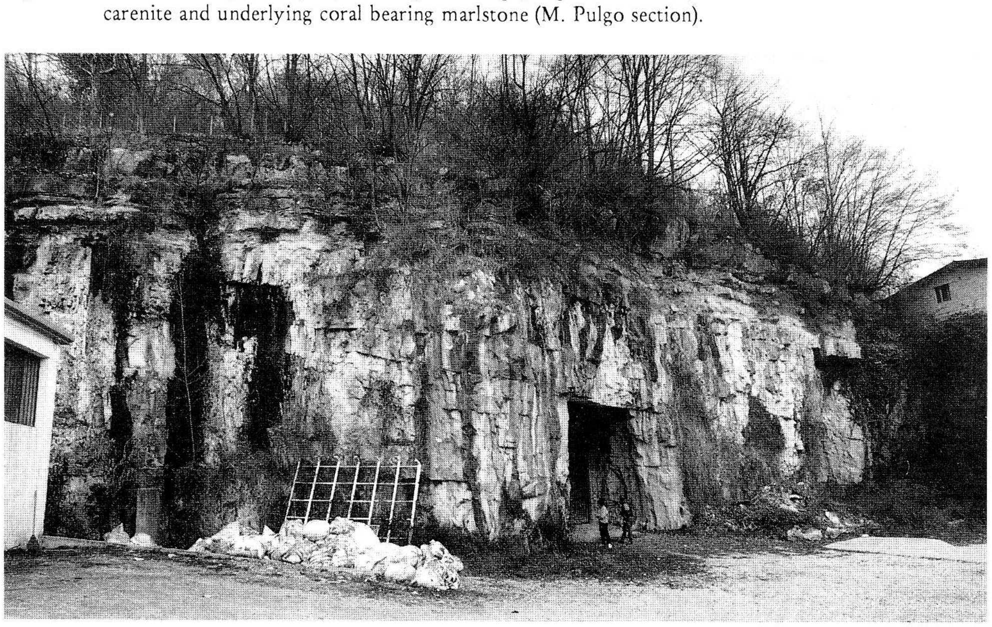


Fig. 6 - Low-angle foresets in a thick biocalcarenite unit, documenting the lateral migration of the sand mass (Tezzati, near Castelgomberto). Note the transition to the overlying marly unit.

From the textural point of view, the biocalcarenites consist of grainstone and packstone, variously rich in miliolids, rhodolites, nummulitids, peloids, intraclasts and bioclasts (coralline algae, corals, echinoderms, molluscs, bryozoans, brachiopods). In places, however (M. Pulgo section), some massive-globose and laminar coral colonies (mainly *Actinacis rollei*) occur associated with the biocalcarenite facies.

A remarkable terrigenous component characterizes the upper 20-25 m of the Faedo section. It consists of calcareous sandstone beds, 40-80 cm thick, with parallel and low-angle cross laminations, ripples and hummocky structures; subvertical burrow traces are also common. Texturally, these sandstones are fine, well sorted and angular to subangular, while compositionally they are quartz-feldspathic with rare mica crystals and an abundant calcareous component represented by micrite clasts and nummulites.

Marly facies.

This facies is represented by grossly stratified marly limestone followed upward by gray-blueish marls and calcareous claystones. The transition to the underlying biocalcarenites is usually gradual.

The marly limestones are massive, burrowed and occur in 0.5-1 m thick beds. They consist of wackestone/packstone rich in foraminifera (mainly miliolids), coralline algae (*Lithophyllum, Lithothamnium, Archaeolithothamnium*) and subordinate echinoderms, ostracods, bivalves, peloids and micrite intraclasts. The washed residues of some marl samples revealed the presence of benthic foraminifera (*Anomalina, Discorbis, Bolivina, Halkyardia, Cribrononion, Cribroelphidium*), bryozoans, echinoderm fragments, ostracods and rare planktic foraminifera.

The marls are associated with a very abundant coral fauna. In fact, the most relevant feature of this facies is represented by wavy, irregular and "bumpy" intervals extremely rich in the poritid species *Actinacis rollei*. Usually, *Actinacis* colonies occur with a branching growth form, characterized both by thin and stocky sticks (Fig. 7). In places, where the original growth position is still preserved (S. Urbano and M. Pulgo sections), coral thickets and knolls are recognizable; these coral masses, which can be up to 10-12 m thick, are laterally interfingered with muddy sediments.

Well sorted calcarenite layers, here interpreted as intrareef channels, occur both laterally and inside these bioconstructed masses. Quite commonly, however, *Actinacis* sticks lay down to form rudstone accumulations, where individual components appear encrusted by algae, serpulids and small ostreids.

Less commonly, *Actinacis rollei* occurs with massive-globose and laminar growth forms which, associated with encrusting algae, drape the top of the underlying calcarenite units and, in places, even the coarse grained storm layers. A peculiar association of big rhodolites (5 cm in diameter) and *Actinacis* sticks has been observed in characteristic "globular" or "lumpy" layers in the Castelgomberto section.

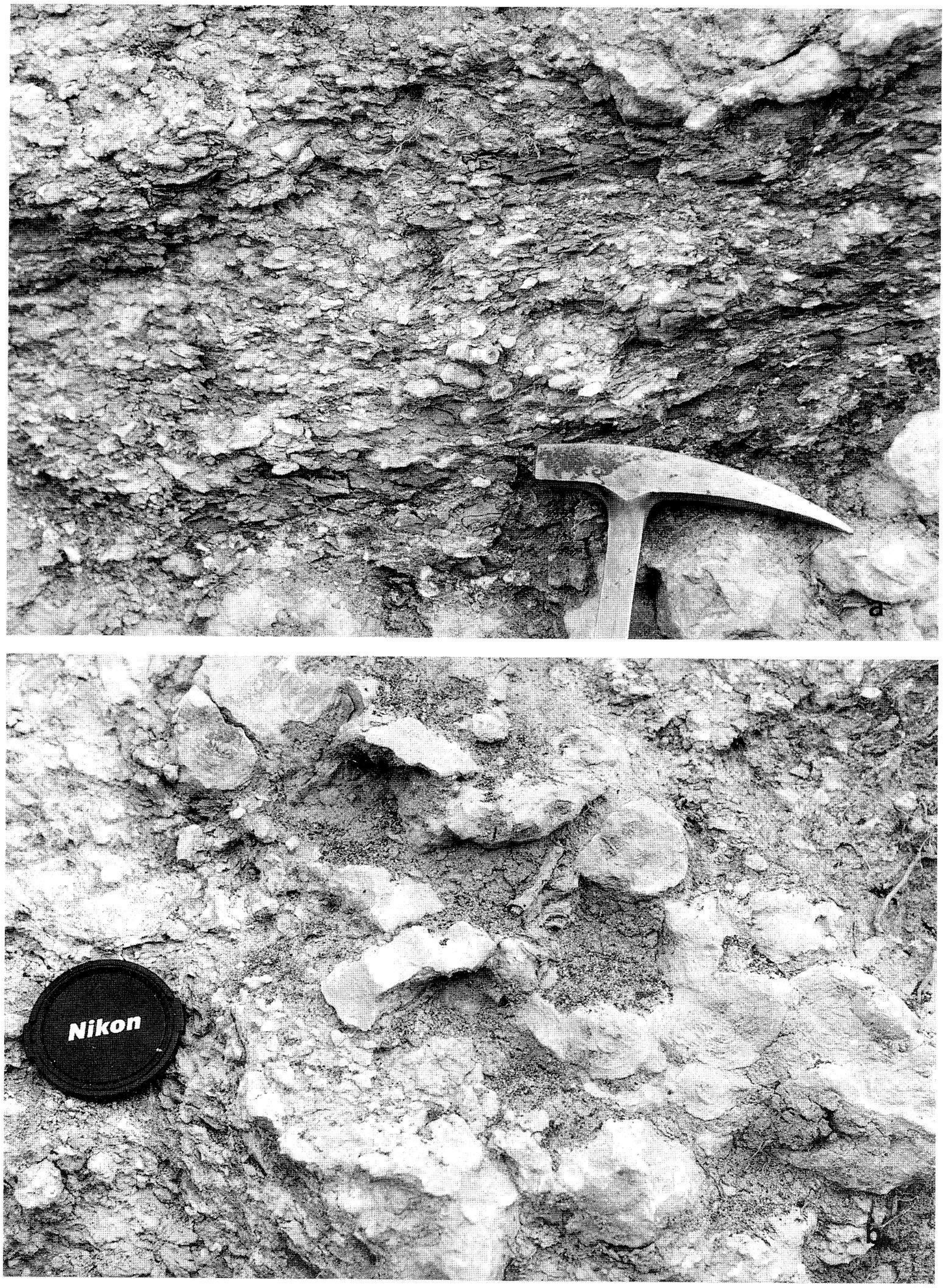


Fig. 7 - Sticks of the branching coral *Actinacis rollei*, enbedded in a marly matrix. A) Thin sticks; B) stocky sticks.

The coral community of the Castelgomberto Limestone and its paleoecology.

The coral community of the Castelgomberto Limestone is characterized by a preferential growth and development on marly-unstable bottoms, in contrast with the many examples of reef tract biota and communities growing under conditions of relatively pure carbonate sedimentation. However, the apparently strange association of muddy sediment and corals should not be surprising. It is well known, in fact, that the presence of very turbid water and muddy bottom does not mean that coral growth is prohibited. In the lagoon of Fanning Island (Central Pacific), coral knolls in the turbid water are ecologically different from the ones in clear water (Roy & Smith, 1971). The major difference in the coral fauna of the two environments lies in the relative abundance of individuals of a species and in growth forms present: in the turbid water of the lagoon of Fanning Island, ramose growth forms make up 50% of the individuals while in the clear water they make up only 10%.

Because of the difference in faunal composition, the reefs in the turbid water tend to be structurally different from those in the clear water. Clear-water reefs are made up primarily of encrusting and massive corals and tend to be massive with vertical walls and overhangs. The turbid water reefs, because of the abundance of ramose growth forms, are more open and are infilled by fine sediment as a result of the baffling effect of the corals on the knolls.

Also the patch reefs of the back-reef lagoon at Discovery Bay, Jamaica (Bonem & Stanley, 1977), occur on a muddy substrate, covered with rubble and debris of the finger coral *Porites*, at shallow depth ranging from 4.5 to 9 m.

Analogously, the coral community of the Castelgomberto Limestone is characterized by the luxuriant growth of the poritid coral *Actinacis rollei* on muddy substrates. As previously described, *Actinacis* exhibits mostly a branching form, even though massive-globose and laminar-encrusting colonies are present. This variable growth form of *Actinacis* is mostly related to the genetic plasticity (a common character of poritid corals) of this species which allows adaptation to different kinds of substrate (Bosellini F. R. & Russo, 1988).

Together with the cyclicity, an ecologic succession is present throughout the Rupelian sequence: the coral species diversity increases gradually upward until it reaches a maximun at the top of the Rupelian succession (Bosellini F. R. & Russo, 1988).

This trend can be generally observed in all studied sections, but it is particularly clear in the S. Urbano section. Here, the base is well characterized by the occurrence of a quasi-monospecific community dominated by laminar sheets of *Actinacis rollei* and encrusting red algae, locally associated to few other species (*Astreopora, Goniopora*). Increasing species diversity occurs gradually upward: about 15 fast-growing species, mostly faviids [*Favia subdenticulata* (Catullo), *Antiguastrea lucasiana* (Defrance), *Montastrea inaequalis* (Gümbel), *M. irradians* (Milne-Edwards & Haime), *Agathiphyllia gregaria* (Catullo), *Caulastrea pseudoflabellum* (Catullo), *C. fusinieri* (Catullo), *Colpophyllia* *stellata* (Catullo), *Tarbellastrea ovalis* (Gümbel), *Cereiphyllia tenuis* (Reuss)], have been recognized in the middle-upper part of the successions. The top-most Rupelian community, which inhabited muddy and mobile substrates, is constituted of about 59 species.

Structure and evolution of the Rupelian coral community seem to have been controlled by two main ecological factors:

1) the remarkable decrease in sea-water temperature documented at the Eocene/Oligocene boundary (Shackleton & Kennett, 1975) which favoured the most tolerant species, like the poritids. Subsequently, the ameliorating sea-water temperature conditions led to a gradual increase in coral species diversity;

2) the occurrence of muddy substrates which preferentially influenced the coral growth form.

The above mentioned ecological factors acted together in determining the peculiar coral community association of the Castelgomberto Limestone.

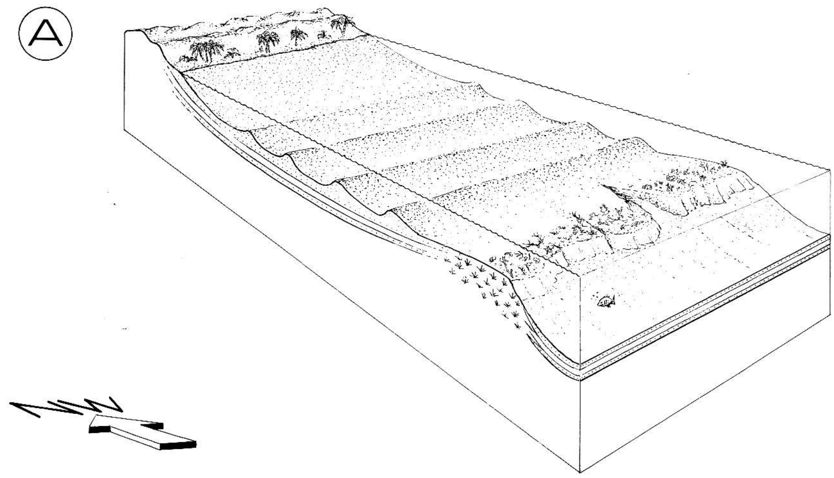
Depositional model and cyclicity interpretation.

To explain the cyclicity of the Castelgomberto Limestone, alternating conditions of high and low hydrodynamic energy appear essential. During "high-energy" times the Lessini Shelf was floored with vast sand bodies, probably migrating laterally under control of strong tidal currents, storm surges and swells. No coral communities were present on the shelf, but benthic foraminifera and coralline algae were very abundant and constituted a relevant part of the sandy deposits. During "low-energy" times, the shelf-lagoon was undoubtedly more protected, quiet and polluted by terrigenous sediments. These conditions allowed the establishment of a peculiar coral fauna, mainly constituted of branching poritids.

It seems to us that these alternating environmental conditions could be best explained if we take into consideration the possibility of minor, short-term sea-level oscillations during the Rupelian highstand (Fig. 8).

As a matter of fact, the alternating sandy and marly deposits could be interpreted in terms of water depth, the calcarenites being shallow and nearshore and the marlstones deeper and offshore. However, several difficulties arise from this model, including the almost exclusive occurrence of corals in the marly facies, the occurrence of terrigenous deposits in more distal position with respect to the clean carbonate sands and the presence of a reef tract along the Berici margin of the shelf. We prefer to consider the calcarenites as high-energy, open shelf deposits and the marlstones as low-energy, protected and quiet-water sediments. Accordingly, during relative highstands, the Lessini Shelf had no shallow rim, was relatively deep (20-50 m) and connected with the open sea (Fig. 8A); rough sea, swells and periodic storms, entering directly into the shelf, were able to sweep the bioclastic sand masses into sand waves and subaqueous dunes. During relative lowstands, the marginal reefs of the Berici Hills (Geister & Ungaro, 1977; Frost, 1981) acted as a true barrier, protecting the shallower shelf interior from waves (Fig. 8B). Meanwhile vast sectors of the Lessini Shelf were exposed to chemical weathering: Oligocene climate was tropical in this area, as documented by the fauna and flora of famous localities such as Lonedo, Monteviale etc. (Fabiani, 1915). The fine products of this weathering were then washed into the muddy shelf-lagoon.

RELATIVE HIGHSTAND



RELATIVE LOWSTAND

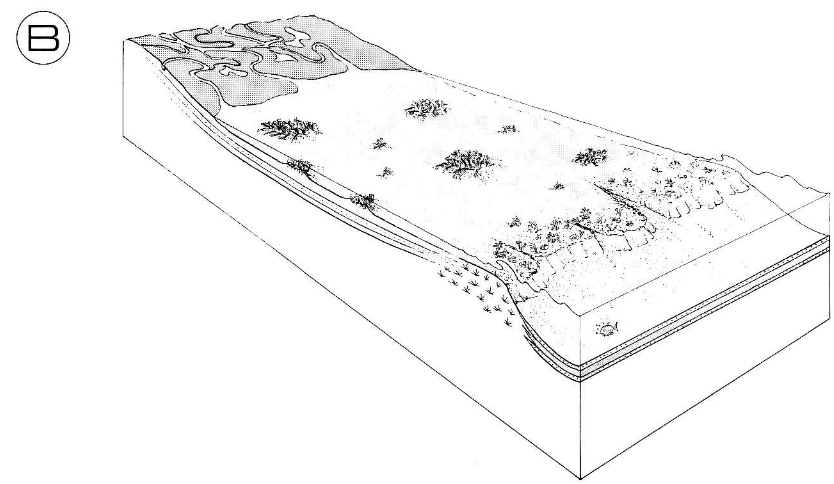


Fig. 8 - Depositional model of the Castelgomberto Limestone: alternating high-energy and low-energy conditions as a result of short term sea-level fluctuations.

Our open shelf reconstruction is analogous to recently described Oligo-Miocene limestone and Recent deep shelf sediments of the southern continental margin of Australia, where bioclastic calcarenites have been interpreted as a cool-water, deep-shelf deposit which accumulated in water depths generally greater than 50 m (James & Bone, 1991; James & von der Borch, 1991). In fact, according to James and von der Borch (1991), the shelf bordering the present southern continental margin of Australia is deep (40 to 100 m) and swept by high-energy waves and swells throughout the year. All areas of the shelf are characterized by bioclastic sediments, composed primarly of bryozoa, benthic foraminifera and mollusc fragments.

Conclusions.

Early Oligocene time (c. 36-30 M.A.) is inferred by Haq et. al. (1988; version 3.1 B) to have been a period of relative sea-level highstand. We correlate this time period with the Castelgomberto Limestone deposition and present evidence that this rock unit consists of a number of cycles with alternating high-energy and low-energy hydrodynamic conditions. A coral fauna with mainly branching growth forms (*Actinacis rollei*), proliferated in the lagoonal muddy bottoms during "low-energy" intervals, while bioclastic sands were swept across the shelf during "high-energy" times.

The peculiar structure and evolution of the Rupelian coral community appears primarly controlled by the strong decrease in sea-water temperature at the Eocene/Oligocene boundary, followed by gradual ameliorating conditions during Rupelian time, and by the occurrence of muddy substrates.

Our interpretation is that the Rupelian relative highstand (about 6 M.A.) was most probably punctuated by numerous short-term (400-500 K.A.) sea-level oscillations producing a number of parasequences. The possible eustatic nature of these cycles should be investigated, however, by other studies.

At the end of Rupelian time (c. 30 M.A.), a dramatic drop (100-150 m) of sea-level (Haq et. al., 1988) exposed the entire Lessini Shelf. The Rupelian carbonates underwent karstification, the volcanic edifices were dismantled while coastal lakes and ponds were the sites of a prolific growth of tropical fauna and flora. The eustatic event is documented by the pronounced discontinuity surface occuring at the top of the Castelgomberto Limestone, locally infilled with bentonite clay, probably related to subaerial weathering of the Middle Oligocene volcanics.

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