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Paleocene Reefs on the Maiella Platform Margin, Italy: An Example of the Effects of the Cretaceous/Tertiary Boundary Events on Reefs and Carbonate Platforms

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KEYWORDS: PLATFORM-MARGIN REEFS - CORAL FAUNA - MAIELLLA PLATFORM (ITALY) - CRETACEOUS/ TERTIARY BOUNDARY

SUMMARY

Reef facies, reef types and their biotic associations in the Maiella platform margin (central Italy) provide qualitative evidence for a significant reef decline across the Cretaceous/Tertiary (K/T) boundary, and indicate two phases of reef recovery during the Paleocene. Rudists dominated the reef community until the latest Cretaceous. A significant sea-level fall around the time of the K/T boundary is documented by a truncation surface associated with emersion.

During sea-level highstands in the Danian to Early Thanetian and, more extensively, during the Late Thanetian, coral-algal patch-reefs grew along the platform margin and top. Already in the Danian to Early Thanetian, the reef communities were more diverse and the constructional types more evolved than previously known from this time. Differences between the Danian to Early Thanetian coral association, the Late Thanetian association, and Late Cretaceous coral faunas may have ecological or evolutionary causes.

Repeated emergence produced a complex diagenetic history in the Danian to Lower Thanetian limestones. All Paleocene reefs were displaced by gravitative redeposition. Coral-algal reefs are less important in the Early to mid Eocene, when alveolinid foraminifera dominated on the Maiella shelf. Reefs on the Maiella platform diversified and attained large sizes in the Late Eocene to Early Oligocene, as known from other Mediterranean platforms.

The external controls on the Late Cretaceous to Oligocene evolution and demise of reef communities that are most easily demonstrated with our data are sea-level fluctuations and climate change. We propose that the change in reef biota and reef types across the K/T boundary and during the Early Tertiary were important causes of the parallel changes in platform growth style.

1 INTRODUCTION

Several Phanerozoic mass extinctions (i.e. intervals with extinction at rates significantly higher than the "background" rate) punctuated the history of ecological continuity and general radiation in the reef community (e.g., Newell, 1967; Boucot, 1983; Stanley, 1984; Sheehan, 1985; Fagerstrom 1987; Talent, 1988; Hallam, 1989). Undisputedly one of these mass extinctions occurred around the K/T boundary. However, except for the rudist, which were prolific reef builders in the Cretaceous (Kauffman, 1984; Johnson & Kauffman, 1990), relatively little is known about the evolution of reefs and reef organisms around the time of the K/T boundary and during the Paleocene (cf. Flügel & Flügel-Kahler, 1992; see also Moussavian, 1992).

The Paleocene is commonly thought to have been a time of reorganization in reef and level-bottom communities, following the mass extinction (Boucot, 1983; Sheehan, 1985). This reorganization was the cause of the absence or minor significance of reef growth until the Late Thanetian (cf. Newell, 1971; Stanley, 1984; Talent, 1988; Copper, 1989). One reason for this conclusion is that shallow-marine carbonate sediments of this age are not widespread, due to relative sea-level lowstands that prevented deposition and caused widespread erosion.

Recent studies have revealed increasing evidence for reef growth during the Early Paleocene (Danian) and the Early Thanetian, suggesting that reef growth may have been more important than commonly thought (cf. Moussavian, 1992; James & Bourque, 1992). Fagerstrom (1987) has stressed that there was virtually no reef-free time in the Early Paleocene, i.e., reef recovery was almost instantaneous when viewed in the Phanerozoic perspective. Bryan (1991) has provided an excellent review, documenting the general smallness of Paleocene reefs: they can be classified as patch reefs, build-ups, or poorly defined "bioconstructions". These reefs are dominated by corals and red algae, although little

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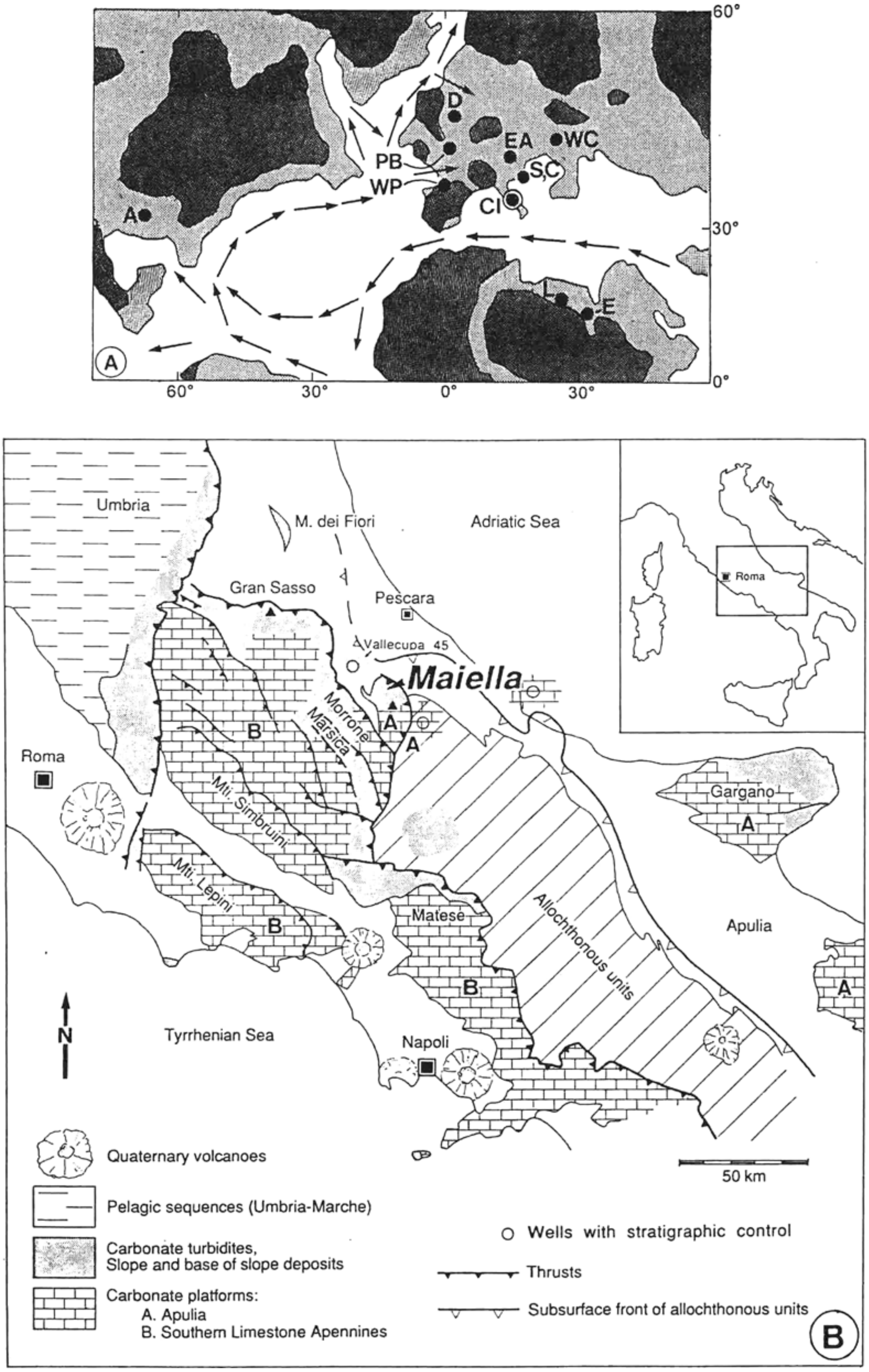


Fig. 1. A. Mentioned Paleocene coral reefs in the Mediterranean-Atlantic realm. CI = central Italy, S,C = Slovenia and Croatia, EA = eastern Alps, WC = Western Carpathians, WP = western Pyrenees, PB = Paris Basin, D = Denmark, L = Lybia, E = Egypt, A = Alabama. Simplified paleo-geography after MacLeod & Keller (1991, originally from various sources). White = ocean basins, light grey = continental platforms, dark grey = land. Arrows indicate surface currents inferred for a similar reconstruction by Berggren & Hollister (1974).

B. Location of the Maiella carbonate platform margin in the external Apennines and tectonic position of Mesozoic to Paleogene platforms and basins in Central Italy. The Maiella platform margin is probably a fragment of the Apulian platform. After Eberli et al. (1993, reprinted by permission).

is known about the associations of reef biota. Most of these reefs grew in the tropical and subtropical climate zones on the margins of Tethys and the opening Atlantic (Fig. 1A).

An extensive Paleocene reef system has been reported from the shallow cratonic Sirte Basin (located on the southern Tethyan margin in Libya) where coral-algal reefs and associated facies reach a few hundred meters of total thickness and four to five kilometers in lateral extent (Terry & Williams, 1969; Gumanti, 1992). The age of these reefs, which have several growth phases, is probably Late Thanetian to Early Ypresian (Ilerdian; E. Moussavian, unpublished); their constructional types, biotic associations and thickness are poorly known. Small coral reefs of Late Paleocene age occur on the same continental margin in southern Egypt (Schröder, 1986; Schuster, 1995). In the western Pyrenees, where an inner platform-basin transect

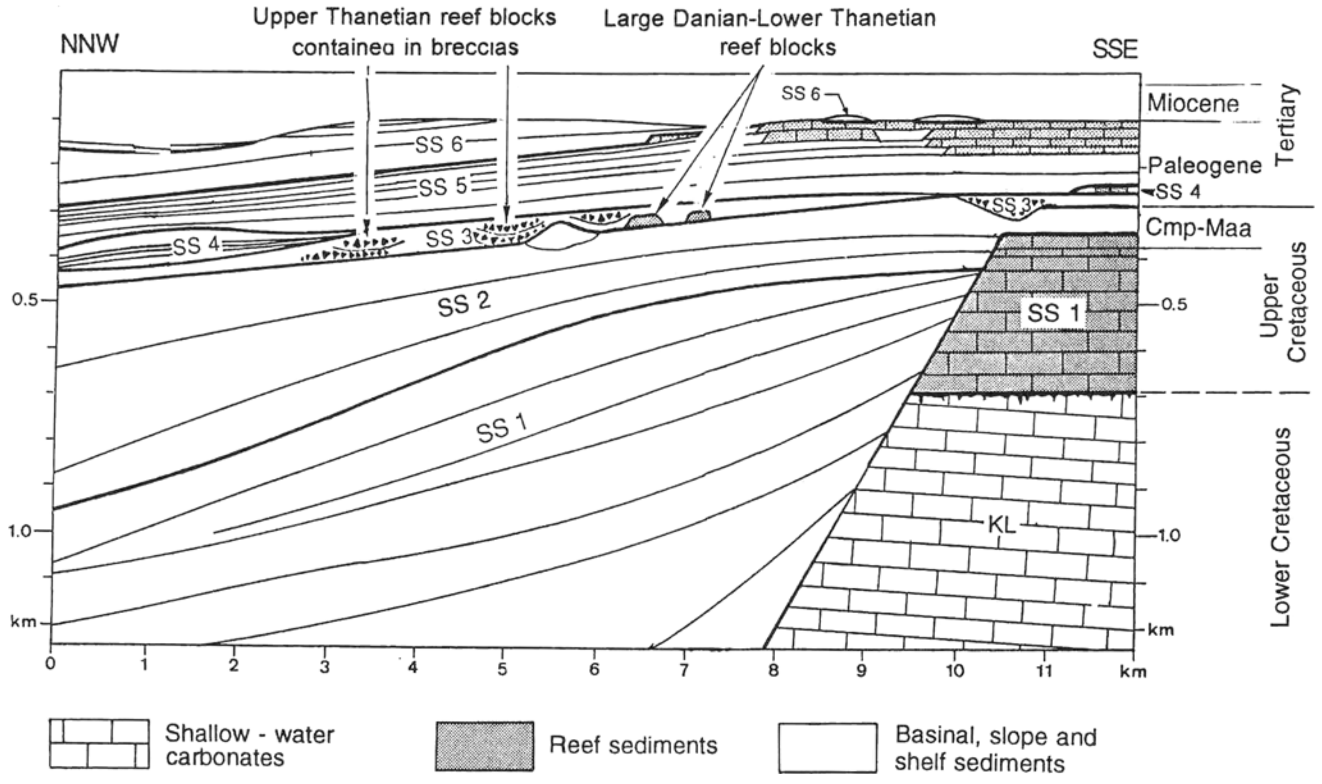


Fig. 2. Schematic platform to basin cross-section perpendicular to the Maiella platform margin. Shallow-water carbonates are shown with brick signature; Sequences which include important occurrences of reef sediments are shaded. Lower Cretaceous platform carbonates (KL) are bounded to the north by a steep escarpment. Cenomanian to Late Campanian platform carbonates (Supersequence = SS 1) were deposited on their top, and contemporaneous basinal strata onlap the escarpment. Platform morphology changed to a physically continuous shelf and slope in the Late Campanian to mid-Oligocene (SS 2 to SS 5). Paleocene coral-algal reefs were eroded and redeposited onto the slope in SS 3. Lower to Middle Eocene (SS 4), Upper Eocene to Lower Oligocene (SS 5), and mid-Oligocene (also SS 5) reefs are largely preserved in situ. A carbonate ramp developed in the Miocene (SS 6). Thick lines indicate supersequence boundaries. Modified from Vecsei (1991) and Eberli et al. (1993).

is preserved, the reefs were built by corals, algae, and bryozoans (Pujalte et al., 1993). In a reef in Alabama, part of a large reef trend in the southeastern USA, sponges are a dominant constructional element in addition to corals and algae (Bryan, 1991).

Many small Paleocene reefs occur along the northern margins of the Tertiary Mediterranean Sea (Fig. 1A). This "Alpine-Carpathian reef belt" includes: the Maiella carbonate platform margin (Moussavian & Vecsei, 1995; this paper); orogenic foreland settings of Slovenia (Drobne et al., 1988); and isolated occurrences in syn-orogenic settings, e.g., in Croatia (Babic & Zupanic, 1981; Polsak, 1985), the Eastern Alps (Moussavian, 1984), and the western Carpathians (Scheibner, 1968). These reefs were dominated by red algae and corals; they did not form barriers (Moussavian, 1993). Danian coral-algal reefs are also found farther north in the central Paris Basin (Guillevin, 1977; Cros & Lucas, 1982). Azooxanthellate corals and bryozoans built deep-water patch reefs in cooler water at margins of the Chalk Basin in Denmark; these represent a different reef type (Bernecker & Weidlich, 1990). Paleocene shallow-water reefs of the cooler-water bryozoan-algal lithofacies, poor in corals, occur on northwest Pacific guyots (Hagn et al., 1980).

Knowledge of most Paleocene reefs is still lacking important details, but it has become clear that innovation in reef communities already resulted in the growth of small reefs by the Danian (cf. Moussavian, 1992). In this paper, we provide data on the coral faunas, describe the diagenesis, and reconstruct the growth environments of the Paleocene reef sediments along the Maiella platform margin. Comparison with Upper Cretaceous and Eocene to Oligocene reefal environments from the same platform (which we briefly desribe) allows insights into how the reef community was affected by environmental stresses during a global biogenic crisis, and how it reorganized. We propose links between changes in reef types and platform development. Correlations of benthic and planktonic foraminferal zones and ages are based on the scheme of Haq et al. (1988) as modified by Vecsei et al. (1996a).

2 GEOLOGIC SETTING

The Maiella platform margin is considered a fragment of the areally extensive isolated Liassic to Miocene Apulian carbonate platform (Eberli et al., 1993; Fig. 1B). Its setting was characterized by decreasing thermal subsidence, a changing platform morphology, a generally cool-

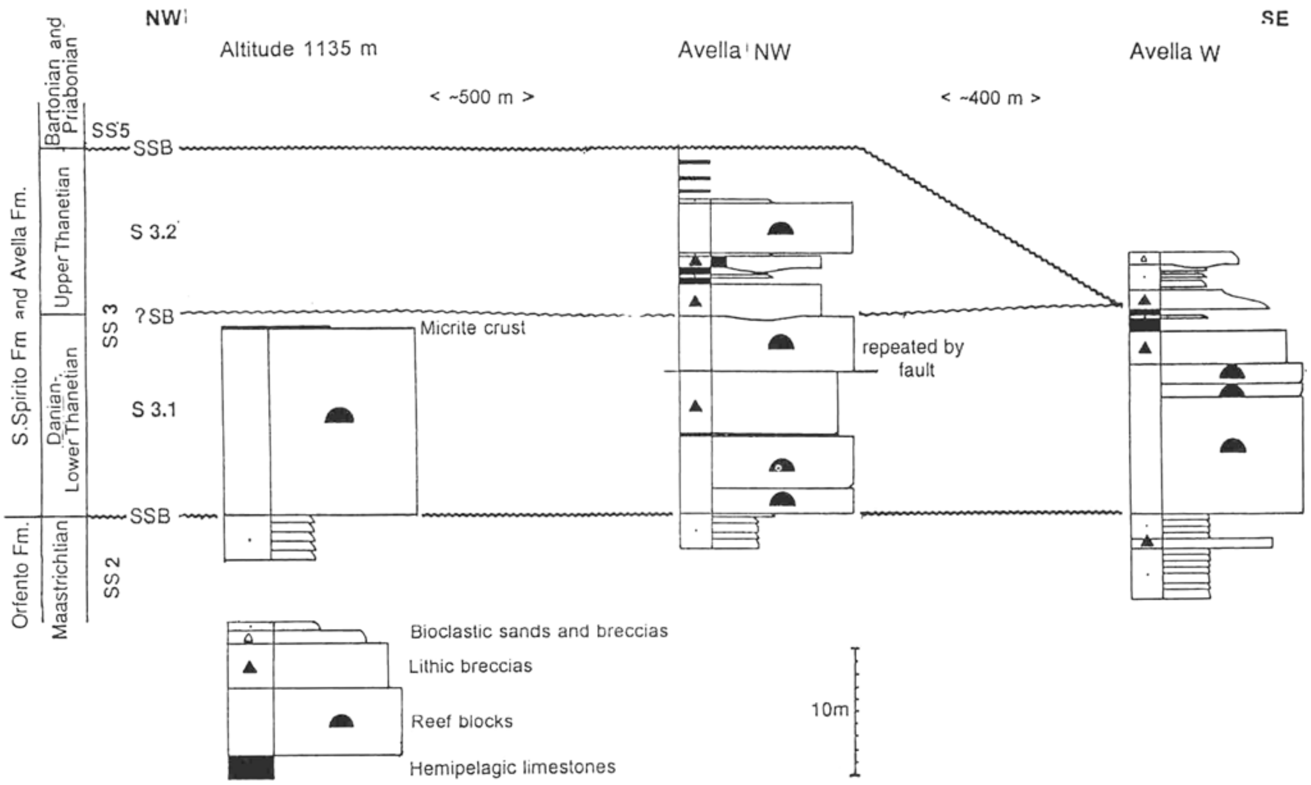
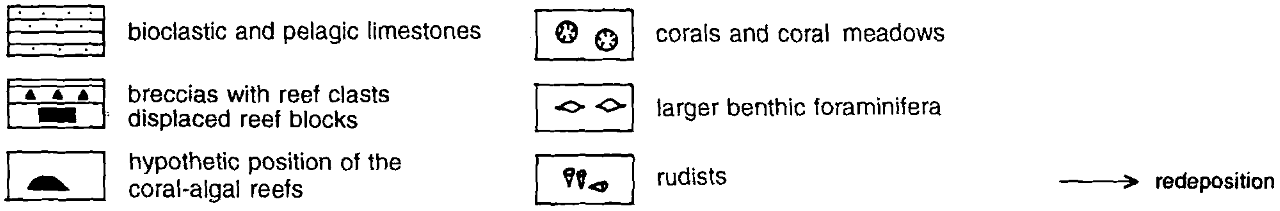


Fig. 3. Stratigraphy of slope sections containing large Danian-Lower Thanetian reef blocks and a single Upper Thanetian reef block. Sections Avella NW and Avella W cross the same laterally extensive Danian-Lower Thanetian reef block. North side of Tre Grotte Valley, see Moussavian & Vecsei (1995) for exact location.

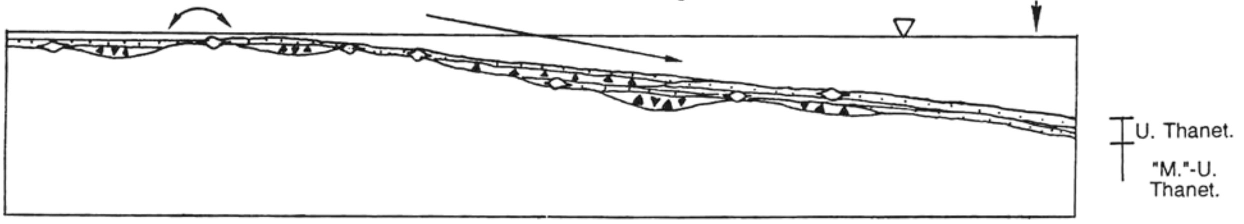
ing climate, and 2nd-4th order relative sea-level fluctuations, which exerted major controls on the Late Cretaceous to Miocene evolution of the Maiella platform (Vecsei et al., 1996a). The 2nd-order fluctuations caused the development of supersequences along the platform margin (Fig. 2). Long-term aggradation rates generally decreased as a function of subsidence, probably since the Liassic. Tectonic movements in the Tethyan realm were superimposed on this general trend. Possibly already during the Early Tertiary but certainly during the Miocene the platform was influenced by tectonic movements in the foreland of the Apenninic orogen.

During the Late Cretaceous, the Maiella platform aggraded substantially by deposition of peritidal limestones and rudist biostromes, while it was at the same time bordered by a steep erosional escarpment (Eberli et al., 1993; Fig. 2). The escarpment was buried after the adjacent basin was filled by the Maastrichtian. The resulting physically continuous shelf and slope morphology prevailed until the Oligocene. The Paleocene reefs grew on the upper slope during two intervals of time (Danian to Early Thanetian and Late Thanetian; Moussavian & Vecsei, 1995). Shortly after their formation and still during the Paleocene, they were gravitatively transported downslope within a thick wedge of pelagic and bioclastic limestones and within shallow channels cut into the former platform top (Fig. 2). In the Late Eocene to Early Oligocene, a shallow-water platform with marginal reefs established above and prograded over slope sediments (Vecsei et al., 1996a). The youngest reefs of the Maiella platform margin are small mid-Oligocene coral-algal buildups, which grew during a brief sea-level rise that interrupted the long-lasting Oligocene sea-level lowstand. A Miocene carbonate ramp represents the last episode of platform growth. Its biotic associations suggest deposition under a temperate climate regime.

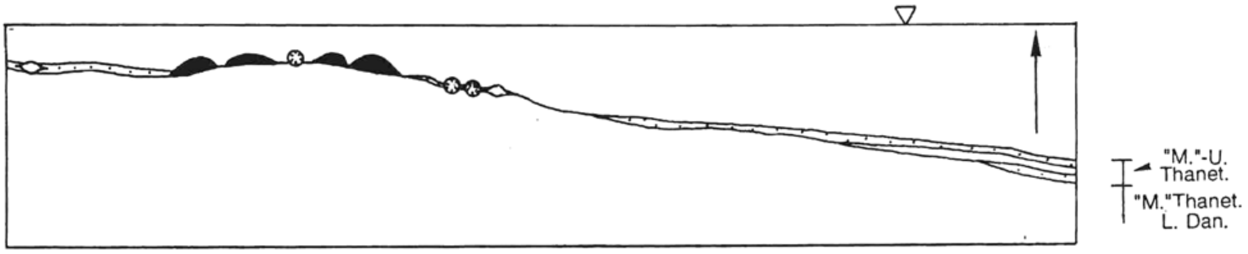
Fig. 4. Reconstructed Late Maastrichtian to Late Thanetian platform morphology, phases of reef growth and sea-level fluctuations recorded on the Maiella carbonate platform margin. Note complete erosion and gravitational redeposition of the Danian to Lower Thanetian and also the areally more extensive Upper Thanetian reef sediments.



f. Late Thanetian: sea-level fall ––> reef erosion and redeposition

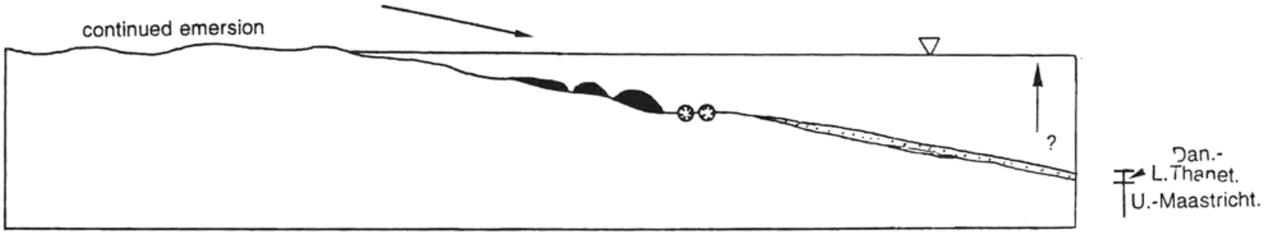


e. "Middle" - Late Thanetian: transgression ––> 2nd reef-growth phase

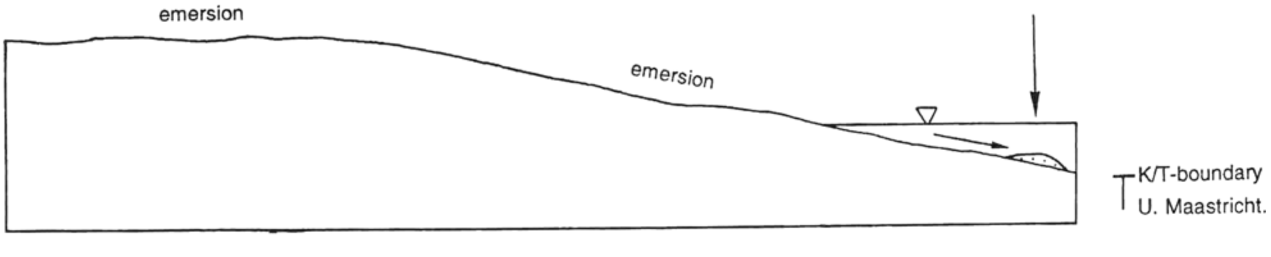


d. "Middle" Thanetian: sea-level fall ––> emersion and redeposition

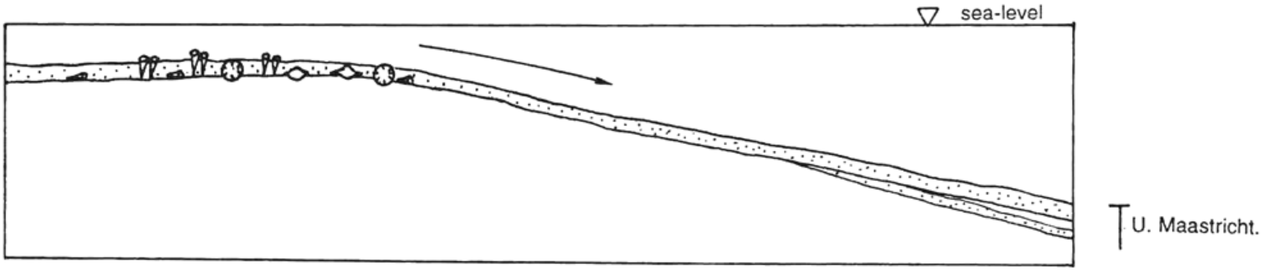
c. Danian - Early Thanetian: moderate transgression ––> 1st reef-growth phase



b. Cretaceous/Tertiary - boundary interval: strong sea-level fall ––> slope bypass and local redeposition



a. Late Maastrichtian: repeated transgressions ––> platform and slope sedimentation



3 LATE CRETACEOUS TO OLIGOCENE REEFS AND PLATFORM DEVELOPMENT

3.1 Cenomanian to Maastrichtian

In the mid-Cenomanian to Late Campanian, rudist-dominated biostromes and tidal sandwaves built an about 700 m thick belt of peritidal carbonates along the escarpment-type platform margin (Bally, 1954; Accarie et al., 1986; Vecsei, 1991; Eberli et al., 1993; Sanders, 1994; Supersequence 1, Fig. 2). This belt intermittently functioned as an effective barrier to the inner platform. About 20 % of the entire section is made up of rudists in life position (I. Stössel, pers. comm.). Behind the shoals, mudstones to grainstones accumulated in a lagoon that over long periods was hydrodynamically protected and restricted.

Despite the continuing high sediment-production rate by rudists during the Maastrichtian (Supersequence 2, Fig. 2), biostromes preserved *in situ* are here restricted to the inner shelf, indicating that strong currents prevented rudists from building a persistent barrier (Mutti et al., 1996).

3.2 The K/T boundary

An angular unconformity, eroding locally up to 100 m deep into the Cretaceous deposits, formed around the time of the K/T boundary (between Supersequences 2/3, Fig. 2). Extensive diffuse karstification of the underlying Upper Cretaceous bioclastic limestones and local silicification (arising from the percolation of meteoric waters) document one or more long-lasting periods of emersion and sea-level lowstand during the time around the K/T boundary (Mutti, 1995). *Microcodium* veins testify to the existence of paleosols in the Maiella. Similar occurrences of *Microcodium* in the southeastward continuation of the Apulian platform margin, on Monte Gargano (where the Paleocene is represented by thin pelagic limestones), suggest widespread and deep erosion along this margin around the time of the K/T boundary (Matteucci & Pignatti, 1991). In the same way, pure pelagic limestone sedimentation on the lower slope in front of the neighbouring Abruzzi carbonate platform (cf. Fig. 1B) in the lowermost Danian suggests a prolonged interruption of platform activity and thus an emersion phase (van Konijnenburg et al., 1996). Macroscopic karst features are absent in sediments from this time in the Maiella, in contrast to other contemporaneous Mediterranean carbonate platforms (cf. Esteban, 1991).

The unconformity in the Maiella may have started to form during the latest Maastrichtian (1-2 m.y. before the K/T boundary, cf. Haq et al., 1988), because this is the age of the youngest sediments preserved below the boundary (dated by the planktonic foraminifera *Gansserina gansseri*, *Rosita contusa*, and *Abatomphalus* cf. *mayaroensis* that indicate the G. gansseri or A. mayaroensis zones; Vecsei, 1991). On the slope, the oldest sediments above the boundary are slide blocks of reef sediments, which have been dated as Danian to Early Thanetian (probably Late Danian; Moussavian & Vecsei, 1995, see below). These are overlain by pelagic limestones with planktonic foraminifera that indicate a Late Danian to Early Thanetian age, and by lithoclastic breccias of imprecisely known age. Emersion continued on the former shelf, where *Microcodium* in lowermost Thanetian sediments documents paleosols (Matteucci & Pignatti, 1991)

3.3 Danian to Early Thanetian

Danian to Early Thanetian reef sediments occur as gravitatively displaced blocks up to 400 m long and 15 m high on the upper slope, about four km north of the reconstructed contemporaneous shelf edge (Figs. 3, 4). They directly overlie the K/T boundary unconformity. The oldest sediments above the reef blocks, a few beds of

Plate 35 Danian to Early Thanetian corals of the Maiella Platform, central Italy (negative prints of thin sections, x 6; det. D. Turnsek).

Fig. 1. *Agathiphyllia* cf. *blaviensis* Chevalier, 1954. Transverse section of plocoid colony showing distinct corallites and costate peritheca. Reef block at altitude 1135 m (Fig. 3).

Fig. 2. *Rhabdophylliopsis alloiteaui* (Alloiteau & Tissier, 1958). Transverse section of phaceloid colony, corallites often overgrown by algae. Reef block at altitude 1135 m (Fig. 3).

Fig. 3. *Dendrophyllia candelabrum* Hennig, 1902. Transverse to oblique section of dendroid corallites. Reef block between sections Avella NW and Avella W (Fig. 3).

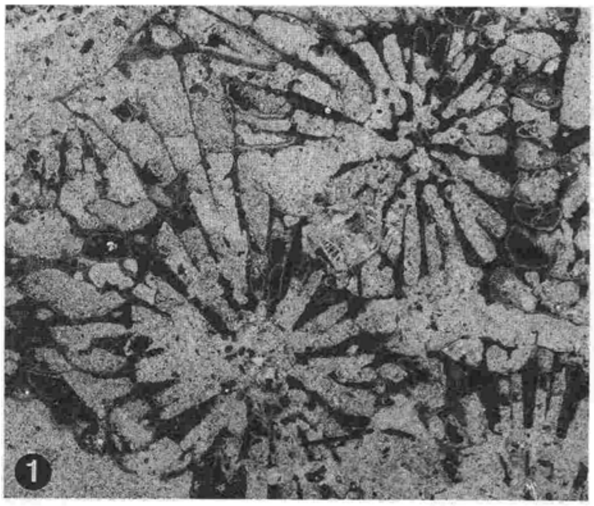
Fig. 4. *Rhizangia sp.* Transverse section of reptoid colony, corallites connected with stolonal offsets, overgrown by algae. Reef block at altitude 1135 m (Fig. 3).

Fig. 5. *Stylocoenia montium* (Oppenheim, 1912). Transverse section of massive plocoid colony showing small corallites with large dissepimental peritheca. Reef block at altitude 1135 m (Fig. 3).

Fig. 6. *Goniopora elegans* (Leymerie, 1846). Transverse section of plocoid colony with branching or cylindrical form. Corallites connected with spongy peritheca. Reef block between sections Avella NW and Avella W (Fig. 3).

Fig. 7. *Actinacis cognata* (Oppenheim, 1912). Longitudinal section of massive colony with encrusting or lamellar growth. Note fine regular perpendicular porous skeleton. Reef block at altitude 1135 m (Fig. 3).

Fig. 8. ?*Porites sp.* Transverse section of small cylindrical colony with spongy skeleton and poorly recognizable corallites. Reef block at altitude 1135 m (Fig. 3).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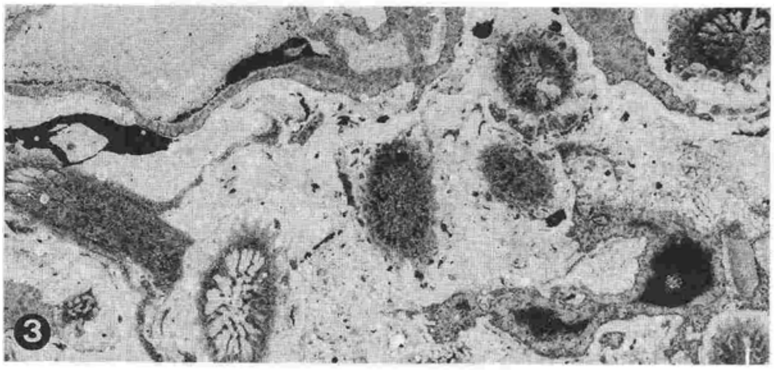
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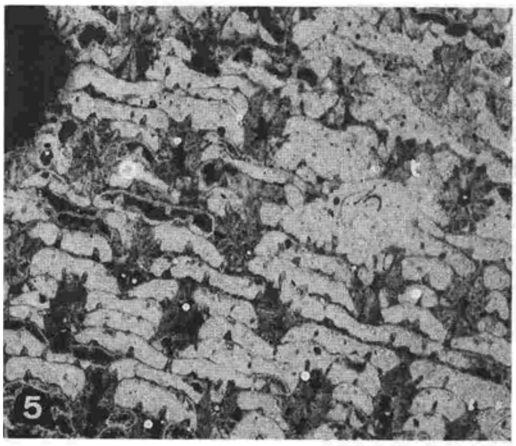
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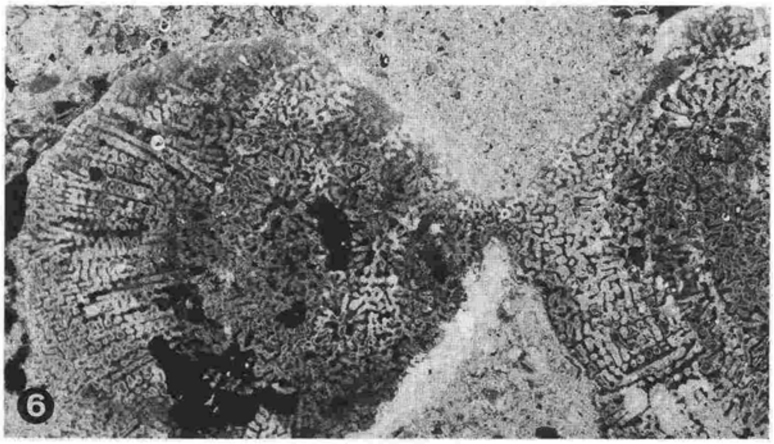
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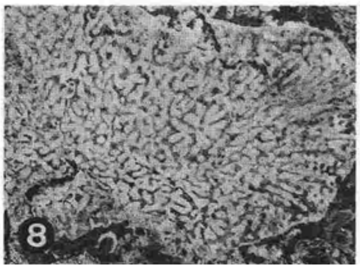
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Paleocene pelagic limestones and bioclastic turbidites, have been preserved above a large reef block (between sections Avella NW and Avella W, Fig. 3). The complex history and the diagenetic overprint (neomorphism and silicification) hamper the reconstruction of the original reef structures, facies relations, and depositional setting of these reefs.

The Danian to Early Thanetian (probably Late Danian) age of the reef block between sections Avella NW and Avella W is based on the foraminiferal and algal associations within the reef sediments and the ages of the limestones overlying the reefs (see MOUSSAVIAN & VECSEI, 1995, for details). The sediments overlying another large reef block (at altitude 1135 m, Fig. 3) are eroded. The Danian to Early Thanetian age of this block is based on the biostratigraphy of the reef sediments. This age is supported by the known age distribution of the coral species in the block (see below), by the foraminiferal and algal associations, and by occurrence of the same facies types and diagenesis as in the reef block between sections Avella NW and Avella W.

The reef blocks are relics of formerly larger structures, probably patch-reefs, which developed during a period of high sea-level interrupted by at least one short phase of emersion. The reefs stopped growing during a subsequent phase of emersion that was more pronounced (see below). Finally, the reefs were displaced by sliding onto the slope, where Danian to mid/Late Ypresian bioclastic turbidites and pelagic limestones overlie them (Supersequence 3, Fig. 3; VECSEI, 1991). Thus, resedimentation of the reef blocks must have occurred within a few million years after their formation. Where the older Paleocene sediments are missing laterally due to non-deposition and/or erosion along the unconformity, the hiatus around the K/T boundary increases to include the mid-Thanetian (cf. Fig. 2).

MOUSSAVIAN & VECSEI (1995) have described four facies types in the Danian to Lower Thanetian reef sediments.

(1) Massive framestones with dendroid or with massive, encrusting, and bulbous corals.

(2) Massive to thick-bedded bindstones dominated by successions of encrusting to massive corals and red algae. In the framestone and bindstone facies, actinacidids, goniopors, and dendrophylliids are the most frequent corals (see below). Nine coral species were determined in one reef block (at altitude 1135 m) and four species in another (between sections Avella NW and Avella W, Fig. 3; Plates 35/1-8 and 36/1). The known world distribution of these corals corroborates the Danian to Early Thanetian age assignment in both blocks (Table 1; determination improved with respect to the preliminary data in VECSEI et al., 1996b).

(3) Packstones and bindstones, in which fragments of the reef organisms are partly encrusted and bound together by coral-algal associations.

(4) Bafflestones with dendroid corals.

The Danian to Lower Thanetian reef limestones in both occurrences show evidence of marine and early meteoric diagenesis and karstification. Thin isopachous fibrous calcite is almost ubiquitous and it eliminated permeability between the smaller pores (Plate 37/1). It is either overgrown by thicker isopachous bladed calcite or is followed by peloidal and massive crystal silt or hanging cements (indicating that these reef limestones were in the vadose zone; Plate 37/2). The remaining large pores and a few syndepositional fractures are lined by a thick isopachous rim of fascicular-optic fibrous calcite (Plate 37/2). The inner parts of large pores partly contain geopetal micrite. Late blocky calcite fills the remaining pores.

Plate 36 Danian to Early Thanetian (Fig. 1) and Late Thanetian (Figs. 2-7) corals of the Maiella Platform, central Italy (negative prints of thin sections, x 6 except where stated; det. D. Turnsek).

Fig. 1. *Placocoeniopsis katzi* KUZMICHEVA 1975. Transverse section of plocoid colony with round corralites in costate and pitted peritheca. Reef block in breccia bed in Scrima Cavallo section (Fig. 5).

Fig. 2. *Stylocenia neutra* BARTA-CALMUS, 1973. Transverse section of plocoid colony with densely spaced corallites. Reef block in the upper part of section Avella NW (Fig. 3).

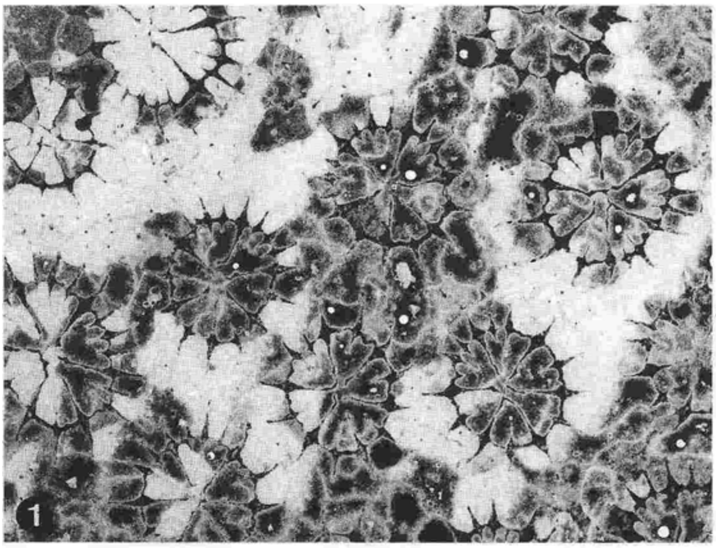
Fig. 3. *Actinacis barretti* WELLS, 1934. Transverse section of large plocoid colony with encrusting or lamellar growth. Small corallites in wide spongy peritheca. Reef block in breccia bed in Scrima Cavallo section (Fig. 5).

Fig. 4. *Polytremacis bellardi* (HAIME, 1848). Transverse section of plocoid colony showing round corallites with very short septa, peritheca narrow and porous. Reef block in the upper part of section Avella NW (Fig. 3).

Fig. 5. *Cladocora sp.* Transverse section of two corallites from phaceloid colony. x 4. Reef block in breccia bed in Scrima Cavallo section (Fig. 5).

Fig. 6. *"Acropora" esperanza* FROST & LANGENHEIM, 1974. Transverse section of irregular reptoid to massive colony with spongy structure of corallites and peritheca. Reef block in breccia bed in Scrima Cavallo section (Fig. 5).

Fig. 7. *Alveopora sp.* Transverse and radial (laterally longitudinal) section of colony with cyclindrical shape. Reef block in the upper part of section Avella NW (Fig. 3).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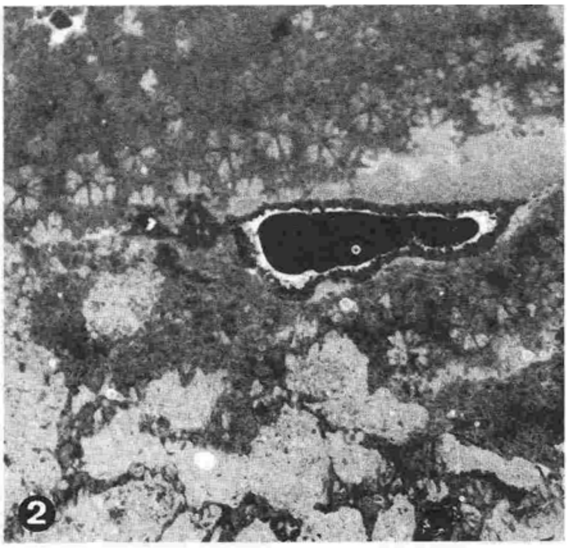
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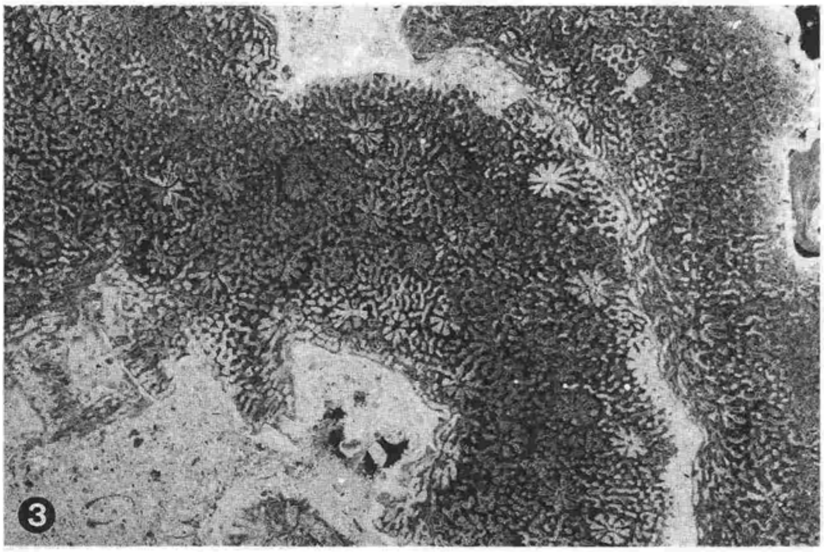
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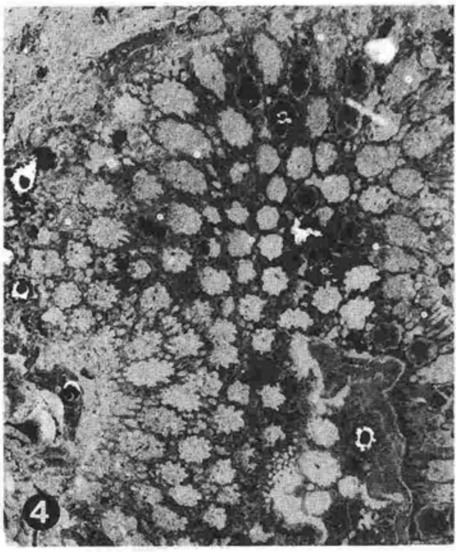
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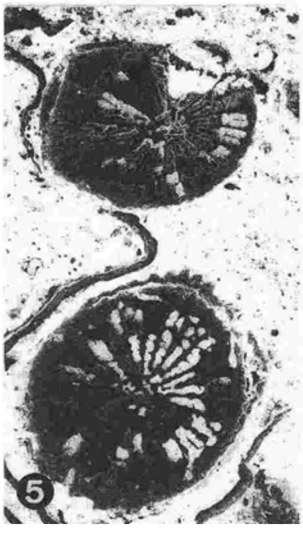
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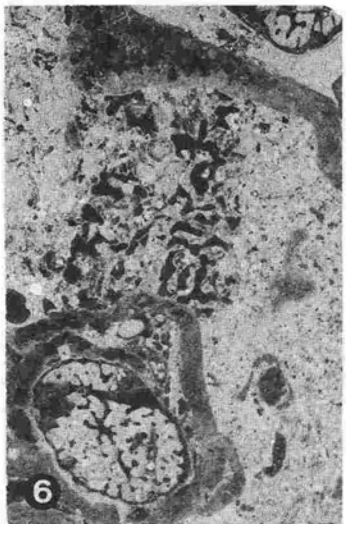
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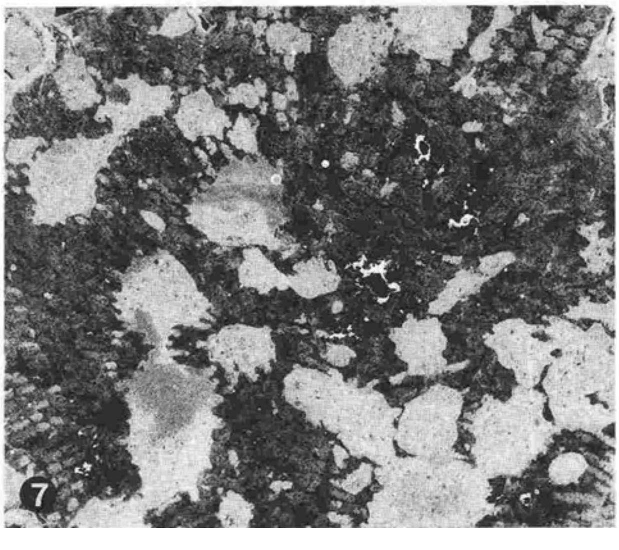
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The reef block at altitude 1135 m (Fig. 3) is covered by a laminated and clotted micrite crust (Plate 37/3). The same block is perforated by several meters deep karst cavities (Plate 37/4). The cavities are filled with geopetal silt, sand and breccias embedded in a terra rossa-like matrix. Many of the angular breccia components are overgrown by thin hanging cements. Karstification of the Danian to Lower Thanetian reef sediments indicates emersion and a sea-level lowstand during the Late Danian/Early Thanetian and (at latest) the early Late Thanetian. Silicification and pervasive neomorphism probably also occurred during this emersion. The exact chronology of the karstification, formation of the micrite crust, and the hanging cements in the reef pores is as yet unresolved. Rudstone blocks on the platform top were similarly cemented by thick isopachous fibrous calcite (Sanders, 1994). These blocks are dated as ?Danian to Early Thanetian with the foraminifera *"Cyclorbiculina" sphaeroidea*, *Anatoliella* cf. *ozalpiensis*, and cf. *Schlosserina*.

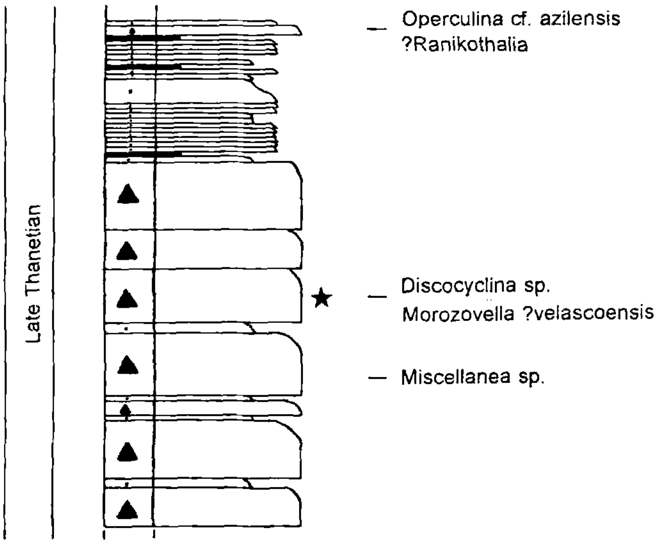


Fig. 5. Section sampled for Upper Thanetian reef blocks. Black triangles denote lithic breccias, asterisk marks sampled bed. Scrima Cavallo, central Montagna della Maiella.

A complex diagenetic history, caused by reef emersion after initial cementation and before burial, was also described from a small coral reef in Egypt (Schröder, 1986). Such complex diagenesis with particularly strong evidence of emersion appears to be characteristic for reefs formed under the influence of strongly fluctuating sea-level in the Early Paleocene.

3.4 Late Thanetian to Early/mid-Ypresian

The Late Thanetian to Early/mid-Ypresian interval (Supersequence 3, Fig. 2) contains only Upper Thanetian reef sediments, besides bioclastic and pelagic limestones. The reefs are preserved as clasts and as blocks up to several meters across, which were eroded from the platform top and redeposited as breccias in channels eroded into the former platform top and slope sediments, probably during a mid-Paleocene sea-level lowstand (Matteucci & Pignatti, 1991; Vecsei, 1991; Sanders, 1994). The sampled reef boulders are embedded in breccias in the Scrima Cavallo section (Fig. 5; these contain most of the determined coral taxa) and are intercalated in the Thanetian deposits in section Avella NW (Fig. 3). All these occurrences document resedimentation. The large total volume and wide areal distribution of Upper Thanetian reef clasts indicate that the reefs were volumetrically important and areally extensive. The breccias are interbedded with Upper Thanetian bioclastic turbidites and pelagic limestones (e.g. along the Avella NW section, dated with spinose acarinids in the *P. pseudomenardii*/*M. velascoensis* zones).

Two main facies have been distinguished (Moussavian & Vecsei, 1995):

(1) Framestones and bindstones built by encrusting, massive, and bulbous corals or by encrusting coral-algal and red algal-dominated associations. The seven determined coral taxa (including poritids, helioporids, and stylocoeniids) are different from those in the Danian to Lower Thanetian reefs (Plate 36/2-7; Table 1).

(2) Well-cemented grainstones dominated by rotaliids, miliolids, textulariids, ataxophragmids, and other small

Plate 37 Diagenesis of Danian to Lower Thanetian (Figs. 1 to 4) and Upper Thanetian (Figs. 5 and 6) reef sediments of the Maiella Platform, central Italy.

Fig. 1. Thin isopachous fibrous calcite (inner rim) followed by thicker isopachous bladed calcite (outer rim). Dark space (OP) is open pore. Section Avella W. x 100 crossed nicols.

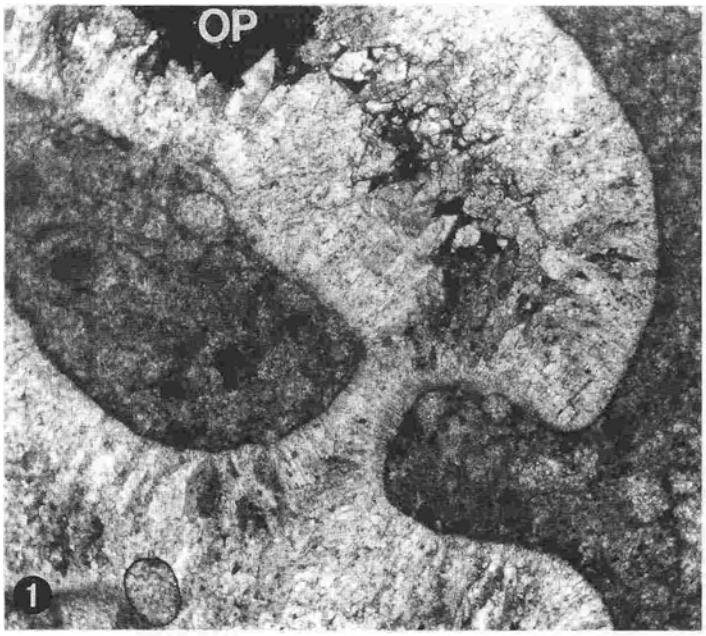
Fig. 2. Pending cement (P) on biogenic crust. Fascicular-optic calcite (F) fills most remaining porosity. Reef block at altitude 1135 m (Fig. 3). x 15.

Fig. 3. Crust of laminated micrite (lower part) and clotted micrite (upper part) that covers reef block at altitude 1135 m (Fig. 3). x 6.

Fig. 4. Karst cavity in reef block filled by breccia (with angular clasts, e.g. marked C) and laminated, color-banded, geopetal sand/silt (G). Reef block at altitude 1135 m (Fig. 3). Hammer for scale.

Fig. 5. Isopachous fibrous calcite (F) followed by blocky calcite (Bl). Section Avella NW (Fig. 3). x 60.

Fig. 6. Thin isopachous fibrous calcite (FC) partly followed by a thin micrite rim (M) and then by bladed calcite (BC). Geopetal peloidal micrite (P) occurs in interparticle pore. Blocky calcite (BL) fills remaining pore. Reef block in breccia bed in Scrima Cavallo section (Fig. 5). x 40.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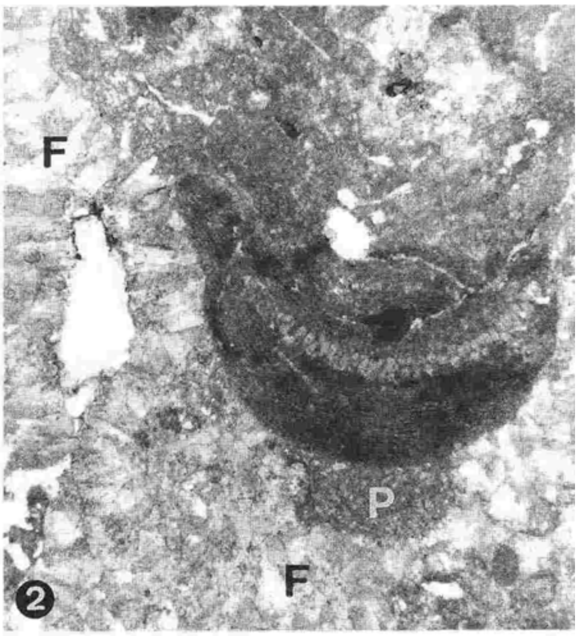
F
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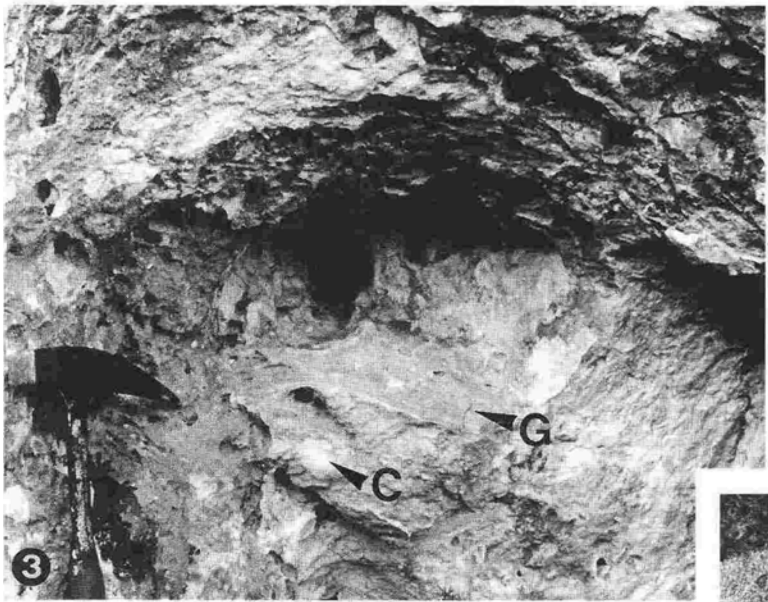
F
2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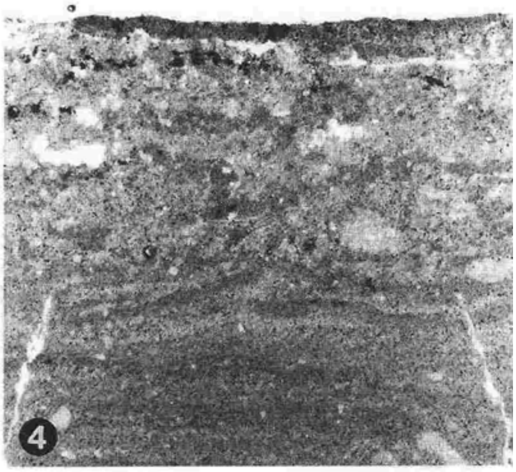
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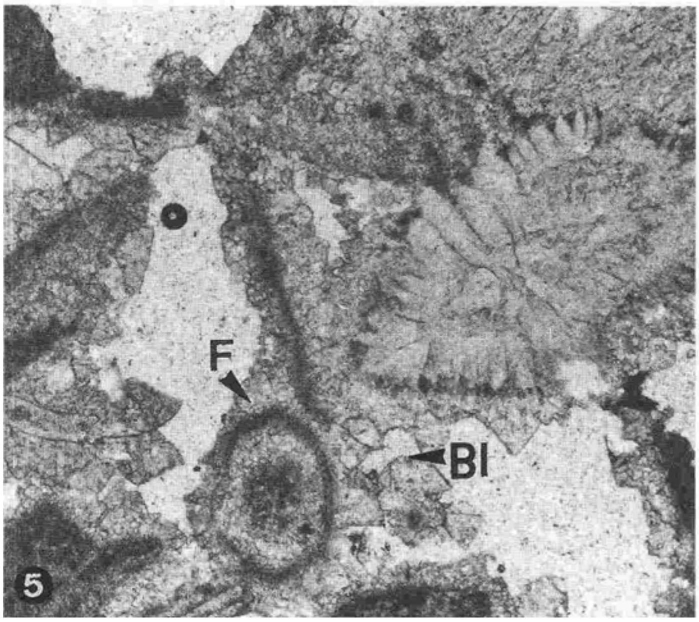
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Bl
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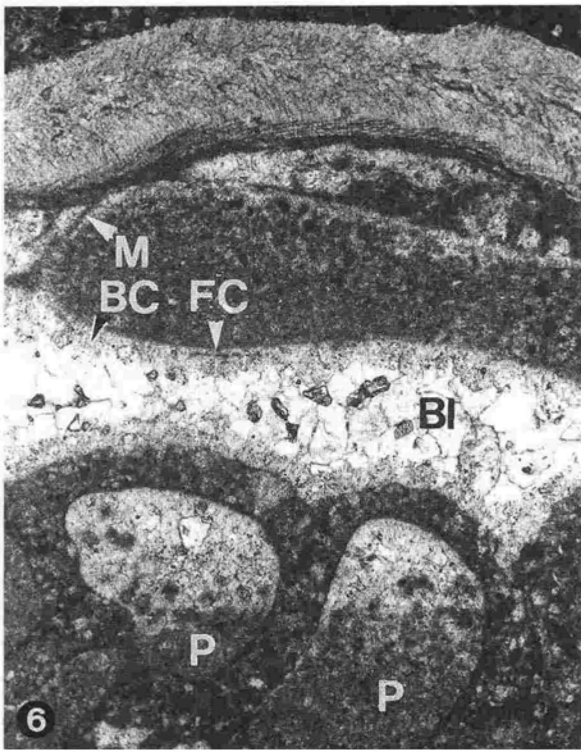
M
BC
FC
Bl
P
P
6

benthic foraminifera. In these sediments larger benthic foraminifera (e.g., discocyclinids and *Ranikothalia sp.*) appear.

As in the Danian to Lower Thanetian reefs, isopachous short fibrous calcite cements are the first and ubiquitous cements in the Upper Thanetian reefs (Plate 37/5). Geopetal peloidal micrite and crystal silt are common in larger interparticle and intraparticle pores (Plate 37/6). Micritic rims occur around grains that were first micritized and then overgrown by translucent rims that probably represent thin isopachous cement. Long-bladed to scalenohedral isopachous calcite overgrows the peloidal fills or, along the remaining open pore walls, the fibrous calcite cements (Plate 37/6). The last generation of cement is blocky calcite that does not completely fill the larger pores.

3.5 Eocene to Oligocene

Lower/mid-Ypresian to Bartonian shallow-water sediments on the platform top (Supersequence 4; Fig. 2) are mostly alveolinid grainstones and packstones (Bally, 1954; Sanders, 1994). Lower to Middle Eocene coral-algal reef sediments are only known from displaced boulders in a bed intercalated in the slope limestones of the same age (Moussavian & Vecsei, unpublished). They are probably derived from small reefs, which may have been similar to the Paleocene reefs.

During the Late Priabonian to Early Rupelian, a platform margin reef tract formed during a long phase of shelf flooding within a supersequence (and 2nd-order sea-level cycle) dated as Bartonian p.p. to Early Rupelian (Supersequence 5, Fig. 2; Vecsei et al., 1996a). Patch reefs started to grow along the upper slope in the Early Priabonian. The reefs coalesced in the Late Priabonian to Early Rupelian, forming a laterally extensive reef tract that prograded over the slope. Most of the reef sediments are as yet poorly investigated framestones, bindstones, and rudstones. Coral diversity appears high (23 taxa; originally attributed only to the Priabonian by Lombardini, 1921).

4 REEFS AND REEF ORGANISMS AFTER THE K/T BOUNDARY

The K/T boundary events caused a profound change in reef communities and reef types in all known occurrences, including the Maiella platform margin (cf. reviews in Kauffman, 1984, 1988; Sepkoski, 1981; Stanley, 1984; Moussavian, 1992; "events", in this context, may last up to several millions of years). Although this change is qualitatively well established, assessment of survival rates across the K/T boundary, of radiation thereafter, and of paleo-geographic distributions in the benthic community are as yet impossible owing to the scarcity of taxonomic data, and so do not yet permit detailed discussion (cf. Moussavian, 1992). This is also true for the scleractinian corals (see below) and for the algae, which were both of fundamental importance for reef construction during the Paleocene. In contrast, the disappearance of lineages of benthic foraminifera at the end of the Cretaceous and the evolution of new lineages during the course of the Paleocene (with appearance of larger hyaline forms during the Thanetian) is well documented (e.g., Hallock et al., 1991; Pignatti, 1994).

After an extinction, a time interval of ecological continuity typically begins with a time of recovery of reef biota, dominated by euryplastic survivor taxa that occupy vacant ecological niches; this is followed by radiation, and then a relatively long time of community stabilization (Fagerstrom, 1987). Our reconstruction of reefs and reef organisms on the Maiella platform after the disappearance of the rudists, the main constructional organisms, at the end of the Cretaceous is qualitatively well established and reveals changes that may have occurred at the beginning of such a radiation.

Scleractinian corals

Scleractinian corals were an essential reef constructing and binding element during the Late Cretaceous (Moussavian, 1992), and they mainly occupied the reef-crest and deeper fore-reef environments (Masse & Philip, 1981; Camoin et al., 1988). The number of coral genera may have been reduced from roughly 90 in the Late Cretaceous to less than 40 in the Paleocene, and it did not significantly increase until the Eocene (Newell, 1971). The data that have become available since Newell's (1971) paper suggest that 50 genera are still the same in the Paleocene; the data are nevertheless insufficient for a detailed assessment of the taxonomic change (cf. Rosen & Turnsek, 1989).

Despite their severe taxonomic reduction, corals did not disappear from reefs for a long period, if at all, around the K/T boundary: This is shown in the Upper Maastrichtian reefs of Sicily (Camoin et al., 1988), the Danian to Lower Thanetian reefs of the western Pyrenees (Pujalte et al., 1993), and the Paleocene corals from the Maiella platform margin. The groups that survived into the Paleocene, especially corals and modern red algae, already formed small reefs by the Danian to Early Thanetian.

We have identified 16 Paleocene coral taxa from the Maiella platform (Table 1). All these taxa are hermatypic, and we consider them to represent builders of smaller or larger patch reefs. Although the taxa probably do not represent the complete community, the Danian to Lower Thanetian and the Upper Thanetian associations (sampled in the redeposited blocks and boulders) consist of different taxa. The Danian to Lower Thanetian association resembles that of the Danian and Thanetian of Scandinavia, northern Italy, the Pyrenees, Slovenia, Croatia, Bosnia and Ucrainia. The Upper Thanetian association shows more similarities to Eocene coral faunas from France, England, the Czech Carpathians, and Mexico (cf. Drobne et al., 1988). Some species from the Maiella are known from the whole Paleocene and continue into the Eocene. Meaningful comparison with the Upper Eocene to Rupelian coral fauna is as yet impossible because of its obsolete taxonomy. Some of the Paleocene genera (e.g., *Actinacis* and *Polytremacis*) are known also from the Cretaceous outside the Maiella, but the species are different. Thus the Danian

Maiella coral species	World distribution
Danian to Lower Thanetian	
Rhabdophylliopsis alloiteaui (Alloiteau & Tissier, 1958)*	Danian; Spain
Dendrophyllia candelabrum Hennig, 1902* **	Danian; Denmark, Sweden, Greenland
Goniopora elegans (Leymerie, 1846)* **	Danian-Thanetian-Eocene; Slovenia, Ucraina, Bosnia, France
Actinacis cognata Oppenheim, 1901*	Danian-Thanetian-Eocene; Bosnia, Croatia, Italy, Slovenia, Ucraina, Czech Republic
?Porites sp.*	--
Stylocoenia montium (Oppenheim, 1912)*	Danian-Thanetian-?Eocene; Bosnia, Ucraina, Slovenia
Rhizangia sp.*	Danian; Slovenia
Agathiphyllia cf. blaviensis Chevalier, 1954* **	--
Placocoeniopsis katzi Kusmicheva, 1975* **	Danian; Crimea
Upper Thanetian	
Stylocoenia neutra Barta-Calmus, 1973 ° °°	Thanetian-Eocene; Slovenia, France
Actinacis barretti Wells, 1934 °	Eocene; Mexico, Jamaica
Cladocora sp. °	--
"Acropora" esperanza Frost & Langenheim, 1974 °	Eocene, Mexico
Alveopora sp. °°	--
Polytremacis bellardi (Haime, 1848) °°	Danian-Thanetian-Eocene; England, Italy, Ucraina, Hungary, Croatia, Czech Republic
Rhizangia padricensis Turnsek (in print) °	Thanetian; Italy

* from reef block at altitude 1135 m (Fig. 3); ** from reef block between sections Avella NW and Avella W (Fig. 3)

° from reef blocks in breccia bed in Scrima Cavallo section (Fig. 5); °° from reef block in the upper part of section Avella NW (Fig. 3)

Table 1. Coral taxa of Danian to Lower Thanetian and Late Thanetian reef sediments determined in the Maiella carbonate platform and their world distribution (det. D. Turnsek).

to Lower Thanetian coral fauna in the Maiella is distinct from both the older (Upper Cretaceous) and the younger (Upper Thanetian and Eocene) ones.

In a previously interpretation of the Paleocene coral associations we relied on the zoological significance of the determined taxa, and concluded that the differences between the Danian to Lower Thanetian coral fauna and both the older (Upper Cretaceous) and the younger (Upper Thanetian and Eocene) ones marks a distinct, albeit short, Danian-Lower Thanetian period in coral evolution (Vecsei et al., 1996b). Such a distinct Paleocene evolutionary period (distinct from the Late Cretaceous and the Eocene ones) has been recognized on a world-wide scale by Beauvais & Beauvais (1974). Schuster (1995) has found close affinities between Thanetian reef corals from Egypt and Eocene to Oligocene corals from the Caribbean, indicating that the reef corals of Thanetian age were indeed related to the younger Early Tertiary faunas. However, the zoological significance of the established taxonomy of Paleocene corals has recently been doubted on the grounds of a detailed study in corals from Austria and Slovakia (H. Tragelehn, pers. comm.). Considering these serious doubts, we now prefer not to propose a conclusion weather the differences between the Danian to Lower Thanetian and the Upper Thanetian coral associations from the Maiella platform margin have ecological or evolutionary causes. Thus the definitive evaluation of the significance of these coral associations should await the development and application of an improved taxonomy and of higher-resolution biostratigraphic and chronostratigraphic methods.

There is only a short Ypresian to Lutetian record of reef organisms in the Maiella. The relatively high number of determined coral taxa indicates that the reef corals significantly diversified by the Priabonian to Early Rupelian in the Maiella, in a similar way as elsewhere in Italy where the latest Eocene to Oligocene coral diversity is well documented (Frost, 1981, with 14 families including 73 hermatypic species; Bosellini & Russo, 1992). Available data are insufficient for a detailed discussion of Eocene to Oligocene reef evolution and its (certainly complex) controlling factors in the Maiella. For example, the effects of the second-order mass extinction event in the reef community at the Eocene/Oligocene boundary (that caused minor turn-over in the sleractinians on the family level but was rather inconsequential on the generic level; Fagerstrom, 1987) can not yet be discerned here.

Environmental stresses on the reef biota

Stresses due to environmental deterioration are cited by most authors as the main causes for mass extinction around the K/T boundary. In many reef-bearing sequences, as in the Maiella, the stress factors sea-level fluctuations and long-term climate change are easily deciphered using sequence stratigraphy, facies analysis, and diagenetic histories. In contrast, stratigraphic incompleteness of the sequences, and diagenetic overprint do not allow to demonstrate the effect of some other important parameters, i.e., short-term temperature change, ocean chemistry and nutrients (cf. Perch-Nielsen et al., 1982; Hsü et al., 1985; Zachos & Arthur, 1986; Hallock et al., 1991).

5 REEF EVOLUTION AND PLATFORM DEVELOPMENT

The Maiella platform margin during the Early Tertiary (Danian to Rupelian) offers the opportunity to explore the significance of reef evolution for platform growth style

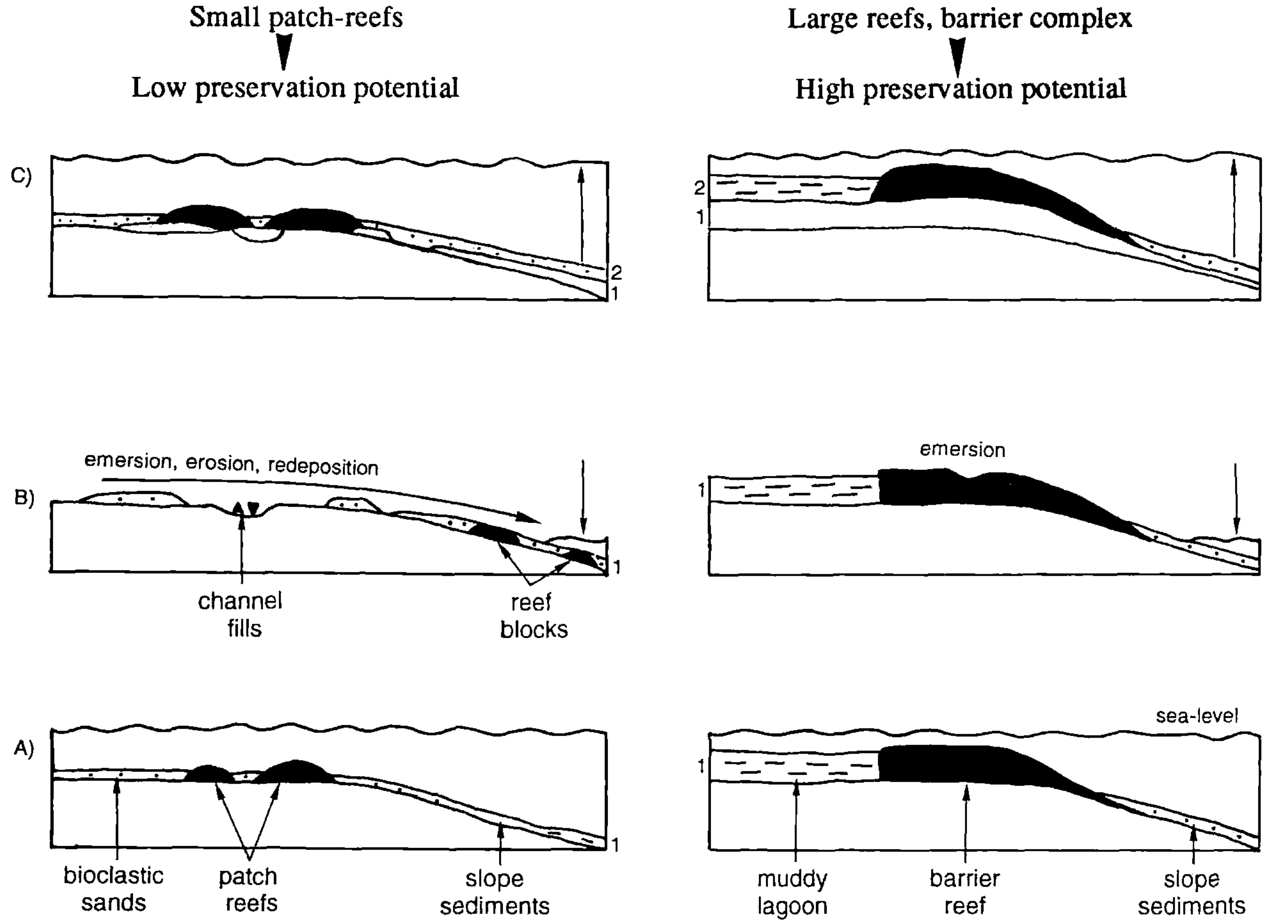

Fig. 6. Hypothesis on the influence of reef evolution on platform growth style. Small, isolated reefs (as in the Paleocene of the Maiella) result in low preservation potentials of the reefs and the platform top sediments. Areally extensive reef tracts and platform margin barriers (as in the Priabonian to Rupelian of the Maiella) have a higher preservation potential and protect the inner platform from erosion. A to C are successive phases.

during a long time interval. During this whole time, the platform had a similar shelf and slope morphology; thus we may assume that changes in reef type were a major influence on the growth style of the platform. Studying the platform in this way for the complete Cenomanian to Rupelian interval would probably not be justified because the platform margin during the Cenomanian to Maastrichtian had a different morphology (a bounding escarpment).

Considering the small total volume of the preserved Danian to Lower Thanetian coral-algal reefs on the Maiella platform, it appears improbable that they formed an outer shelf barrier. The inferred reef sediment volume increased in the Late Thanetian, and a small barrier may have formed, but the aggradation rate in the Maiella averaged over the whole Paleocene was evidently very low (close to zero). In contrast, the diverse Priabonian to Lower Rupelian coral-algal-dominated reef associations built a large reef tract along the platform margin (Fig. 6). The substantial aggradation (and progradation) of the Priabonian to Lower Rupelian reefs indicates that they largely resisted erosion by currents and erosion during subaerial exposure. Thus the small size of the Paleocene reefs, and the larger size of the Priabonian reefs that allowed the construction of a large reef tract, appear to have significantly influenced the contrasting styles of platform growth during the Early Tertiary.

During the Paleocene, platform aggradation may have been restricted by several factors. For example, favorable times for reef growth on the platform top may have been relatively short (due to the combined effects of the diverse environmental stresses dicussed above, including but not restricted to sea-level lowstands). Reduced carbonate production by the reef organisms is another factor that may theoretically explain reduced platform aggradation rates. The same major groups of organisms lived in the Paleocene reefs, however, as lived in reefs during the rest of the Cenozoic, so it appears improbable that the carbonate production potential of Paleocene reefs should have been significantly lower than that of later reefs. Indeed, Schlager (1981) and Bosscher & Schlager (1993) have shown that most Phanerozoic reefs and platforms, including those of Paleocene age, were able to keep pace with high rates of sea-level rise, owing to high accumulation rates in carbonate platforms with reef rims (about 80-270 m/m.y. for the Paleocene, data normalized by them for 1 m.y. intervals to correct for stratigraphic dating bias). Thus, Bosscher & Schlager (1993) concluded that the K/T boundary extinction of reef organisms may have been too short to cause a long-term drop in accumulation rate, in contrast to the periods following other mass extinctions where they can show a link between these parameters. However, the stratigraphic resolution obtained by the literature data they used appears to be insufficient to detect any short-term changes in accumulation rate that may have occurred during the Early Paleocene.

6 CONCLUSIONS

The Paleocene coral-algal reefs from the Maiella carbonate platform margin indicate that small, partly framework-supported reefs already existed in the Danian to Early Thanetian shortly after the K/T boundary, and that they were taxonomically relatively diverse. The existence of similar reef communities in several areas of the Tethys in the Early Paleocene may indicate the relatively high environmental tolerance of this new reef type and also increasing global extension of the warm surface water zone. The coral-algal reefs of the Maiella further increased in volume (and probably also in size) by the Late Thanetian. Concomitantly the coral associations changed and the algal and foraminiferal associations diversified. After an Early to mid-Eocene interval almost devoid of reefs, they diversified again in the Priabonian to Early Rupelian. These results support the current reassessment of reef evolution after the K/T boundary. Reef evolution may have been (at least locally) faster than generally assumed. The definitive evaluation of the significance of the Maiella coral associations should, however, await the application of an improved coral taxonomy and higher-resolution biostratigraphic and chronostratigraphic methods.

The details of the evolution of reef organisms around the K/T boundary remain uncertain, and leave questions of fundamental importance unanswered. For example, the only taxonomic changes in the reef organisms that were as yet quantified (to our knowledge) are the decline and disappearance of the rudists and (in the peri-reef) the larger hyaline foraminifera (e.g., orbitoids and lepidorbitoids) at the end of the Cretaceous, and the appearance of new foraminiferal lineages during the Thanetian (e.g., nummulitids, discocyclinids, and alveolinids). There are strong indications that the coral taxa were severely reduced in numbers and in taxa around the time of the K/T boundary, but it is not known exactly to what degree they and the other members of the reef community were in fact affected. Another question that remains unanswered is whether the Late Cretaceous ancestors of the Paleocene coral-algal reef taxa lived in association with the rudists in biostromes or in other reefs.

The environmental stress parameter that can most easily be demonstrated for the reefs on the Maiella platform margin is the repeated relative sea-level lowstands around the K/T boundary and during the Paleocene. Other important environmental parameters, i.e., short-term temperature reduction, ocean chemistry, and nutrients, were probably also of some significance, because of their apparent global character.

We hypothesize that the small size of reefs and the probable lack of an outer shelf barrier during the Paleocene of the Maiella platform margin promoted erosion and redeposition of the reefs and of the hydrodynamically unprotected platform interior sediments. In contrast, the larger size of the Priabonian to Rupelian reefs allowed the construction of a large reef tract that partly protected the inner shelf.

ACKNOWLEDGEMENTS

D. Turnsek determined and evaluated the coral faunas. L. Hottinger and J.S. Pignatti determined some benthic (especially alveolinid) foraminifera and their ages. J.C. Tipper, D. Bernoulli, L. Hottinger, and an anonymous reviewer critically reviewed several versions of the manuscript. H. Oberhänsli and U. Leppig made valuable suggestions. H. Tragelehn commented on the coral taxonomy. J.C. Tipper assisted with the English language. K.-H. Gräf, H. Mertel, and R. Schlenker provided technical assistance. The Deutsche Forschungsgemeinschaft supported this study within the Forschungsschwerpunkt "Riff-Evolution und Kreide-Sedimentation" (grant Ve 146/1-1 and 1-2). All this is gratefully acknowledged.

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Manuscript received August 23, 1996
Revised manuscript received December 12, 1996