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Palaeoenvironments on a Middle Eocene carbonate ramp in the Vértes Mountains, Hungary

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(with 5 figures and 3 plates)

Eocene sediments of the Hungarian Paleogene Basin – located on the Northern margin of the Tethys – unconformably overlie Mesozoic rocks, which were uplifted during Late Cretaceous to Early Eocene time. In the Vértes Mountains, there was a Bartonian, narrow, low-angle subtropical carbonate ramp with 40-50 m thick limestone (Szőc Limestone Formation) directly covering the karstic surface of Triassic limestone and dolomite. Ramp sediments were overlain basinward by Upper Lutetian - Bartonian brackish and normal marine deposits.

Seven facies were distinguished by semi-quantitative microfacies analysis of Szőc Limestone. The inner ramp is represented by four facies: (1) extraclast rudstone to extraclast-bioclast floatstone (basal beds of Szőc Limestone), (2) bioturbated foraminifer-mollusc-echinoderm packstone/grainstone (interpreted as sea-grass meadow), (3) skeletal grainstone (bioclastic sand shoals), and (4) *Nummulites perforatus* rudstone/packstone (*Nummulites* banks). On the mid-ramp, larger foraminiferal floatstone and red algal facies with 3 subfacies – coral-algal boundstone (small patch reefs), larger foraminiferal-red algal and larger foraminiferal-rhodolith floatstones – were recognized. The lower mid-ramp to upper outer ramp is characterized by glauconitic larger foraminiferal grainstone (bioclastic sand deposition effected by currents).

All facies record normal marine conditions. Main palaeoecological parameters influencing palaeoenvironments were hydrodynamic energy, depth, light conditions, substrate and nutrient availability.

Introduction

The notion *carbonate ramp* was first defined by AHR (1973). A standardized model for Tethyan Tertiary carbonate ramps with down-ramp distribution of biofacies was suggested by BUXTON & PEDLEY (1989). BURCHETTE & WRIGHT (1992) provided a review of the classification, tectonic setting, facies, sequence stratigraphy and diagenesis of carbonate ramp systems. Carbonate platform types from genetic approach, related to the carbonate-producing biota were introduced by POMAR (2001).

In the last fifteen years, several Eocene carbonate ramp models have been proposed. Larger foraminifera dominated carbonate ramp systems developed during early foreland basin subsidence in the Early Eocene in the SE Pyrenees (GILHAM & BRISTOW 1998) and in the Middle to Late Eocene in the French Alps (SINCLAIR et al. 1998). Coralline red algae dominated Late Eocene carbonate ramps were published from the Southern Alps, Northern Italy by BASSI (1998) and from Upper Austria by RASSER (2000). DARGA (1990) described a Late Eocene low-dipping carbonate ramp with isolated coral patch reefs in Bavaria, the Northern Calcareous Alps.

The Eocene rocks in Hungary have been studied for more than 150 years. In the 20th century, investigations focused on bauxite and coal on the basis of the Eocene successions and were mainly concerned with palaeontologic or stratigraphic aspects. There are only a few studies, that concentrate on carbonate environments and facies patterns (KECSKEMÉTI & VÖRÖS 1975, HAAS et al. 1984, KÁZMÉR 1985, 1993).

The aim of this paper is to describe the main facies types and to present a depositional model based on microfacies studies of the Middle Eocene carbonates in the Vértes Mountains.

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Stratigraphical setting and lithology

The Hungarian Paleogene Basin (HPB) was located on the northern margin of the Tethys. The Eocene sediments of the HPB unconformably overlie the Mesozoic rocks, which were uplifted during the Late Cretaceous to Early Eocene. In a long-lasting period of subaerial exposure, tropical karstification of the Mesozoic rocks and bauxite deposition in karstic depressions took place (MINDSZENTY ET AL. 1989, KAISER 1997). The subsidence of the HPB began in the Early Lutetian in the SW part of the basin, and it proceeded with a temporal shift to the NE (e.g. Vértes Mountains), (DUDICH AND KOPEK 1980, BÁLDI-BEKE AND BÁLDI 1991) (Fig. 1).

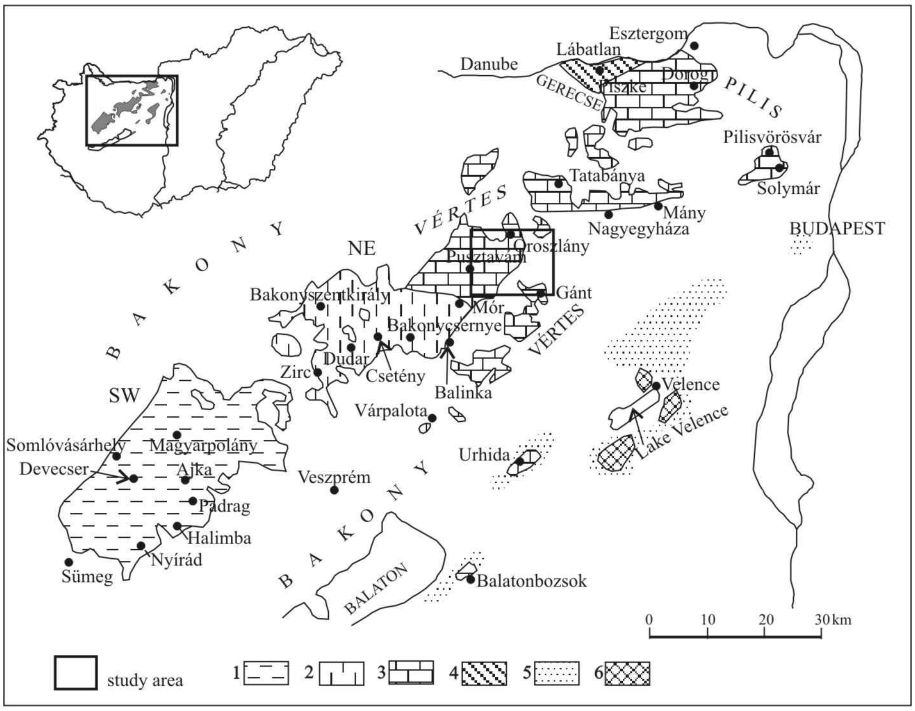

Fig. 1. Lutetian through Early Priabonian formations on the surface or near the surface in the Transdanubian Range, Hungary. Legend: 1. Early Lutetian to Early Priabonian sequence in the SW Bakony /shelf limestone, hemipelagic marl and turbidites/; 2. Late Lutetian to Early Priabonian sequence in the NE Bakony (coastal and terrigenous shelf sediments, hemipelagic marls); 3. Latest Lutetian or Bartonian to Early Priabonian shelf sediments; 4. Priabonian hemipelagic marl with olistostromes; 5. Stratovolcanic and sedimento-pyroclastic andesites; 6. Subvolcanic andesites. (After BÁLDI-BEKE & BÁLDI 1991).

Most of the Vértes Mountains is built up of Middle and Upper Triassic limestones and dolomites. The Eocene sediments are exposed in outcrops at the NW and SE margins of the Vértes Mountains, where they unconformably overlie the Upper Triassic Dachstein Limestone and Hauptdolomit Formations. In the Oroszlány Basin – NW of the Vértes Mts. – Eocene successions were explored by deep wells and they are exposed in coal mines, where they overlie Middle Cretaceous limestones and marls. At the end of the Eocene, the area was uplifted and eroded. The Eocene rocks are covered by Oligocene continental sands and clays (Fig. 2).

The Eocene formations show remarkable lateral and vertical diversity of sedimentary facies. In the Oroszlány Basin, the sediment deposition began in the Late Lutetian(?) (KOLLÁNYI et al. 2003). Alluvial siliciclastics and coal-bearing sediments (Dorog Formation) were accumulated in the depression of the Oroszlány Basin, whereas the paleohigh of the Vértes Mountains was still subaerially exposed. In the basin, the Dorog Formation was overlain by molluscan marls (Csernye Formation), with a rich fauna indicating brackish and normal marine lagoonal environments. Later on, larger foraminifera-bearing marls (Csolnok Formation) were deposited in a shallow marine basin. In the Bartonian (LESS, personal communication), on the margin of the basin, a narrow, low-angle carbonate ramp with 40–50 m thick limestone (Szőc Limestone Formation) developed on the karstic surface of the Triassic rocks, whereas in the basin it overlay the Csernye or Csolnok Formations (Fig. 3).

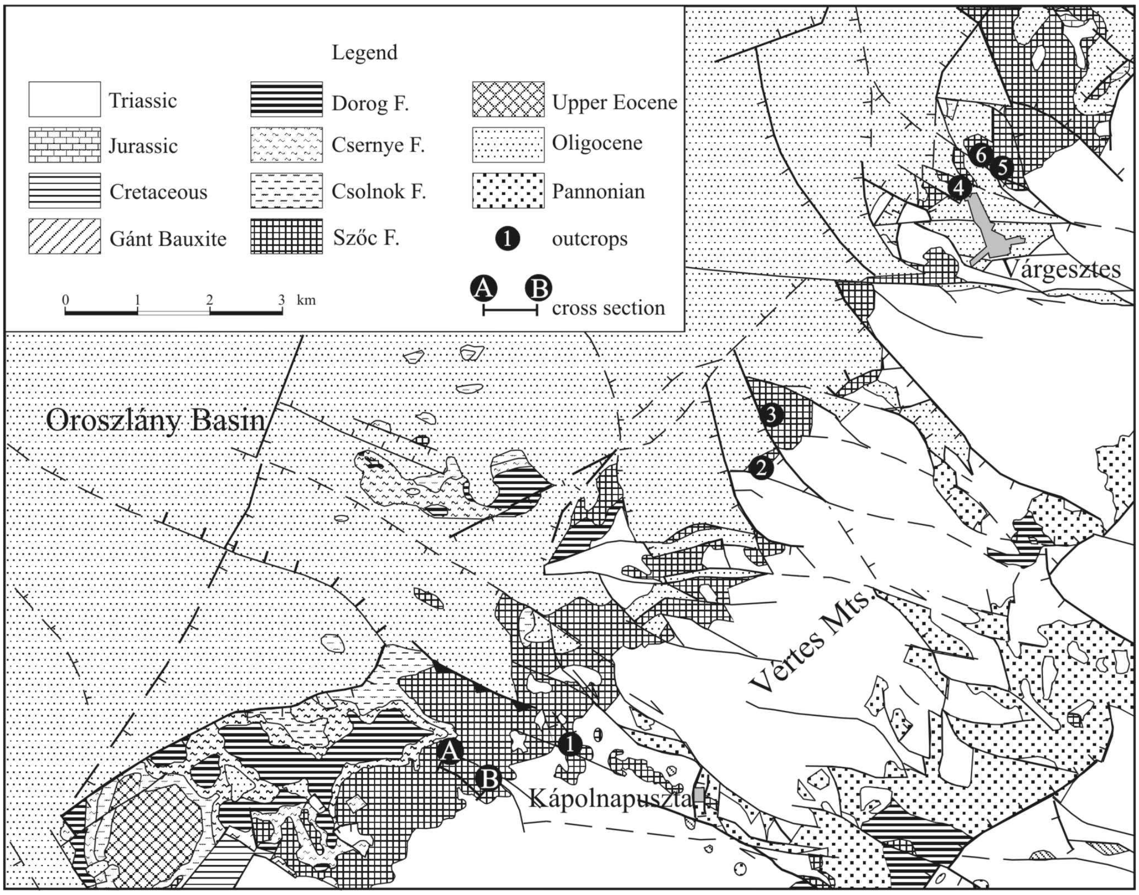

Fig. 2. Geological map of the Vértes Mts. without Quaternary sediments (after BUDAI et al. 2002) with the location of the measured sections and with the location of the cross section AB, that can be seen in Fig. 3. Legend: 1. Kápolnapuszta; 2. Csáki-vár; 3. Hosszú Hill; 4. Várgesztes 1; 5. Várgesztes 2; 6. Várgesztes 3.

The Middle Eocene carbonate sequences were studied in 6 outcrops located on the NW side of the Vértes Mountains (Fig. 2). Continuous successions can be studied in the 650 m long rocky wall at Várgesztes village (Várgesztes 2 and 3 profiles) and in the road cut at Hosszú Hill. We can find small outcrops in the road cut, north of Várgesztes (Várgesztes 1), and in a valley, NW of Kápolnapuszta. The contact of the Triassic and Eocene rocks can be observed in a small quarry at Csáki-vár.

In the studied profiles, 3 main facies types can be differentiated:

The lower part of the successions consists of massive, or poorly bedded biodetrital limestones, which occur in every outcrop, except in the road cut, north of Várgesztes. On the basis it contains bored extraclast pebbles and boulders of Triassic carbonates. In some layers we can find whole or fragmented echinoids and molluscs along with the macroscopically unrecognizable sand-sized bioclasts.

The biodetrital limestone is overlain by larger foraminifera limestones and nodular calcareous marls, which occur in every outcrop, except the Csáki-vár quarry. They have various clay content. At Hosszú Hill thin (10-20 cm) clay marl beds are intercalated in the calcareous marl. Sedimentary structures are often destroyed by bioturbation, but locally beds with erosional bases and cross stratification can be observed. The larger foraminifera tests are usually chaotically arranged, rarely they can be found imbricated, or oriented parallel with the bedding planes. In the road cut, north of Várgesztes, the larger foraminifera-bearing beds are alternating with coral and red-algae-bearing beds.

At Hosszú Hill well-bedded glauconitic limestone can be found upsection. It contains small *Nummulites* and *Discocyclina*, whole or fragmented echinoids and biogene detritus.

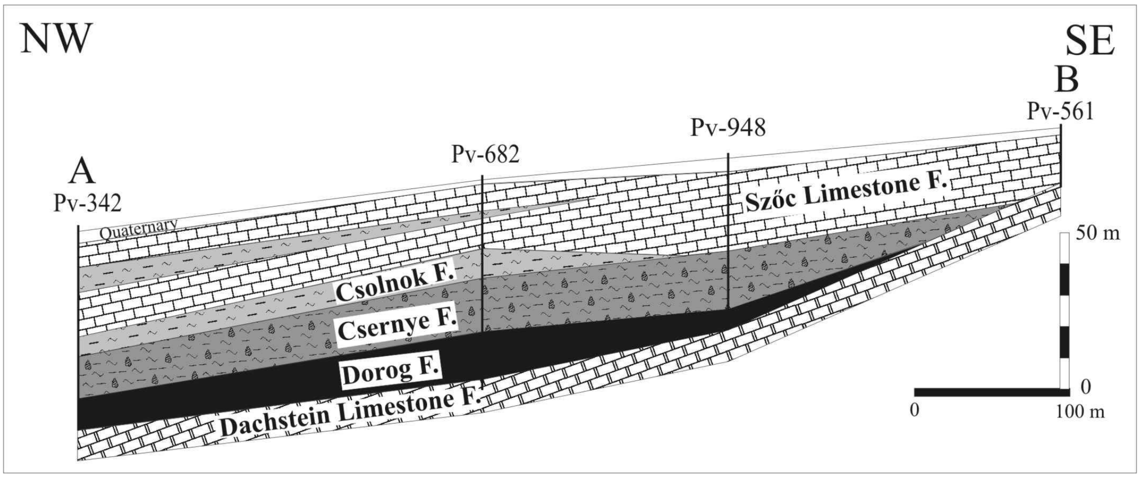

Fig. 3. Cross section of the carbonate ramp-basin transition, based on core data, with the stratigraphical setting of the Middle Eocene formations. See location of the cross section in Fig. 2.

Methods

100 thin sections and several polished slabs, cut perpendicular to bedding planes, were studied from 6 measured sections. Semiquantitative microfacies analysis was carried out by using BACCELLE and BOSELLINI's (1965) comparison charts. DUNHAM's (1962) and EMBRY and KLOVAN's (1972) microfacies nomenclature were applied. 7 microfacies types (A-G) of the Szőc Limestone could be differentiated. The results of the microfacies analysis with the lithostratigraphical columns of the studied profiles are shown in Fig. 4. a-f.

Facies types

Biodetrital limestone

A. *Extraclast rudstone to extraclast-bioclast floatstone* (Pl. 1, fig. 1-2). This echinoderm facies contains bored lithoclasts that are made of Triassic carbonates. Lithoclasts are unsorted, the arenitic ones are usually well-rounded to rounded. Bioclastic components are red algae detritus, *Asterigerina* and other small benthic foraminifera, echinoderm and mollusc fragments. Samples contain micrite in variable quantity. Components are cemented by sparry calcite. The boreholes have bioclastic packstone or wackestone infilling.

Occurence: This facies represents the basal beds of Szőc Limestone. It can be found in every outcrop, except Várgesztes/1.

B. *Bioturbated foraminiferal-molluscan-echinoiderm packstone/grainstone* (Pl. 1, fig. 3). This facies contains unrounded to rounded mollusc, echinoderm and red algae fragments, which are often slightly micritized. The dominant component is the mostly tube-like (cylindrical growth form, DARGA 1993) *Acervulina linearis* (Pl. 1, fig, 4). The foraminiferal tests are usually filled with sediment or sometimes they are filled with sparry calcite. Abundant foraminifera are *Asterigerina, Fabiania cassis* (Pl. 1, fig. 5), *Eorupertia*, *Haddonia heissigi*, miliolids and small benthic rotaliines, and *Orbitolites* also occurs sporadically. In some layers, Discocyclinidae can be observed as well.

Occurrence: It occurs in every outcrop, except Várgesztes 1. It overlays the Extraclast rudstone to extraclast-bioclast floatstone (A) facies (Várgesztes 2-3), or the Foraminiferal-red algal grainstone (C) facies (Káplnapuszta). At Hosszú-Hill it alternates with the C facies. It can be found in the greatest thickness at Várgesztes 2.

An *Ostrea* floatstone subfacies occurs in the outcrops at Várgesztes 2-3 and Kápolnapuszta in the upper part of the biodetrital limestone, where the previously described biota is accompanied by *Ostrea* shell fragments.

C. *Foraminiferal-red algal grainstone* (Pl. 1, fig. 6). This facies contains well-sorted, well-rounded bioclasts, frequently with micrite envelopes, cemented by sparry calcite. The main components are small benthic foraminifers and the fragments of red algae, *Acervulina*, echinoderm and mollusc shells. Two types can be differentiated: red algae dominated with few *Acervulina* and *Acervulina*-red algae dominated.

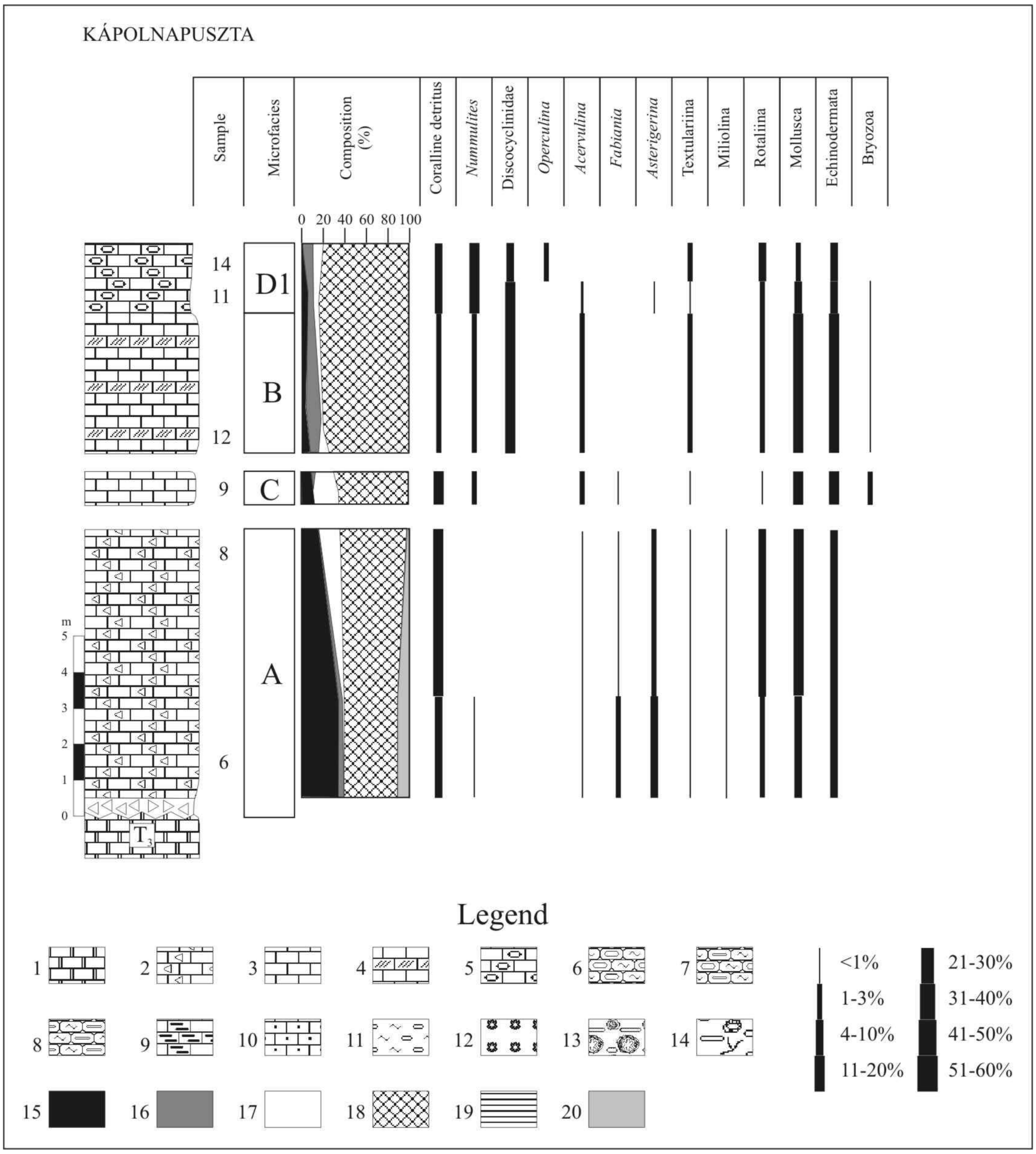

Fig. 4. a. Kápolnapuszta. Lithostratigraphic column and results of microfacies analysis. Legend: **1.** Dachstein Limestone; **2.** Extraclastic biodetrital limestone; **3.** Biodetrital limestone; **4.** Biodetrital limestone with *Ostrea* shells; **5.** *Nummulites perforatus* limestone; **6.** Calcareous marl with *N. perforatus*; **7.** Calcareous marl with *N. perforatus* and *N.* millecaput; **8.** Calcareous marl with *N. millecaput*; **9.** *Discocyclina* limestone; **10.** Glauconitic limestone; **11.** Larger foraminifera marl; **12.** Coral-bearing beds, **13.** Rhodolith-bearing beds; **14.** Red algae-bearing beds; **15.** Micrite; **16.** Microspar; **17.** Sparry calcite cement; **18.** Bioclast; 1**9.** Intraclast; **20.** Extraclast. Microfacies: **A:** Extraclast rudstone to extraclast-bioclast floatstone; **B:** Bioturbated foraminiferal-molluscan-echinoderm packstone/grainstone; **C:** Foraminiferal-red algal grainstone; **D1:** *Nummulites perforatus* rudstone/packstone; **D2:** Coral-*Nummulites* floatstone; **E:** Larger foraminiferal floatstone/rudstone; **F1:** Coral-red algal boundstone/floatstone; **F2:** Larger foraminiferal-rhodolith floatstone; **F3:** Larger foraminiferal-red algal floatstone; **G:** Glauconitic larger foraminiferal grainstone.

Occurence: This facies can be found with red algae dominance at Kápolnapuszta and Csáki-vár and with higher amount of *Acervulina* at Hosszú Hill.

Larger foraminifera limestone and calcareous marl

D. *Nummulites perforatus* rudstone/packstone (Pl. 2, fig. 1). The dominant component is *Nummulites perforatus*, accompanied by sand-sized bioclasts in micritic matrix. Both A and B form of *N. perforatus* can be observed in the different beds in various proportion. The tests frequently show edge-wise imbrications. Other bioclasts can be found only in small quantity. These are mollusc, echinoderm and red algae fragments, small benthic foraminifera, and few larger foraminifera, such as *Discocyclina*, *Alveolina*, *Acervulina,* *Fabiania* and *Eorupertia.* The proportion of *N. perforatus* to other bioclasts is slightly lower in Hosszú Hill, than in Várgesztes/2-3.

Occurrence: This facies overlies the biodetrital limestone in the successions. It doesn't occur at Csáki-vár and Várgesztes 1.

In the outcrop at Hosszú Hill, a Coral-*Nummulites* floatstone subfacies (Pl. 2, fig. 2) can be recognized, which alternates with *N. perforatus* rudsone/packstone facies. It contains fragments of corals, along with the previously described biota.

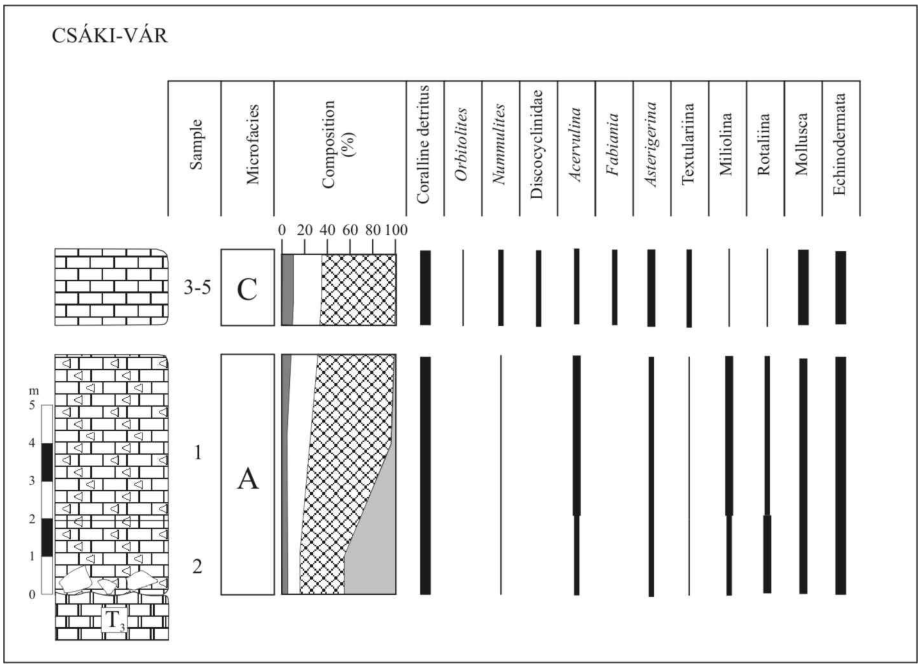

Fig. 4b. b) Csáki-vár. For legend see Fig. 4a.

E. *Larger foraminifera floatstone/rudstone* (Pl. 2, fig. 3-5). This facies is characterized by diverse assemblages of mostly unabraded larger foraminifera with sand-sized foraminifera detritus in micritic matrix. The foraminifera chambers are usually filled with micrite. Foraminifera taxons are *Nummulites perforatus* A and B, *N. millecaput* A and B, *Discocyclina, Operculina, Alveolina, Sphaerogypsina,* rarely *Fabiania* and *Eorupertia.* Other bioclasts are rare, they are mostly small benthic and planktic foraminifers, mollusc and red algae fragments. In Hosszú Hill a greater diversity can be observed than in Várgesztes 3. The foraminifera tests may be bored, or encrusted mainly by agglutinated foraminifera or serpulids. The densely packed texture is partly the consequence of compaction. Mechanical and chemical compactional features such as fractured foraminifera tests and pressure solution can be recognized (Pl. 2, fig 4-5).

Occurence: This facies can be found at Hosszú Hill and Várgesztes 3. At hosszú Hill the definite changing of the dominant larger foraminifera taxons can be observed in the succession: *Nummulites perforatus* → *Nummulites millecaput* → *Discocyclina*, *Operculina.* At Várgesztes the dominant species is *Nummulites perforatus*. The B-forms of *N. millecaput* occur in mass quantity only in a thin interbedding.

F. *Red algal facies.* This facies can be found only in one outcrop at Várgesztes/1, where it can be subdivided into 3 alternating subfacies:

1) *Coral-red algal boundstone/floatstone* (Pl. 3, fig. 1). This facies consists of encrusted, calcitized corals in wackestone matrix with fine calcarenite and calcilutite. The encrusting organisms are coralline red algae and rarely *Acervulina linearis*. Larger foraminifera, echinoderm and mollusc fragments occur sporadically. Corals are represented mostly by delicate branching and thin platy colonies, but there are encrusting forms mainly in the upper part of the section, as well. The corals are often paraautochtonous, not in life position, and the branching forms are often fragmented, but there are small *in situ* colonies, too.

2) *Larger foraminiferal-rhodolith floatstone* (Pl. 3, fig. 2–3). This facies contains 6–10 % rhodoliths, along with the similar fossil assemblage, as the Larger foraminifera floatstone/rudstone (E) facies. The rhodoliths are usually 1–3 cm large, ellipsoidal, or subspheroidal, with warty/lumpy growth forms, and dense internal arrangement (nomenclature after BOSENCE 1983a, WOELKERLING et al. 1993, BASSI 1998). The rhodoliths are often bored. Nuclei are usually coral or sometimes coralline fragments. Multispecific construction is typical. The preservation usually doesn't allow the precise identification of red algae in the

rhodolith crusts, but some taxons could be determined, such as *Sporolithon, Spongites,* and *Polystrata alba* (Peyssonneliaceae). Beside them, encrusting foraminifera, such as *Haddonia heissigi* and *Acervulina linearis* are also common. The internal crusts consist of Corallinaceae or *Sporolithon. Polystrata alba, Haddonia heissigi* and *Acervulina linearis* can be observed in the outer envelopes. Along with the rhodoliths, the similar red algae and encrusting foraminifera taxons can be found in thin crusts around *Nummulites* or coral fragments. Also few fragments of branches and crusts (mainly *Sporolithon*, Melobesioideae and *Lithoporella melobesioides*) occur.

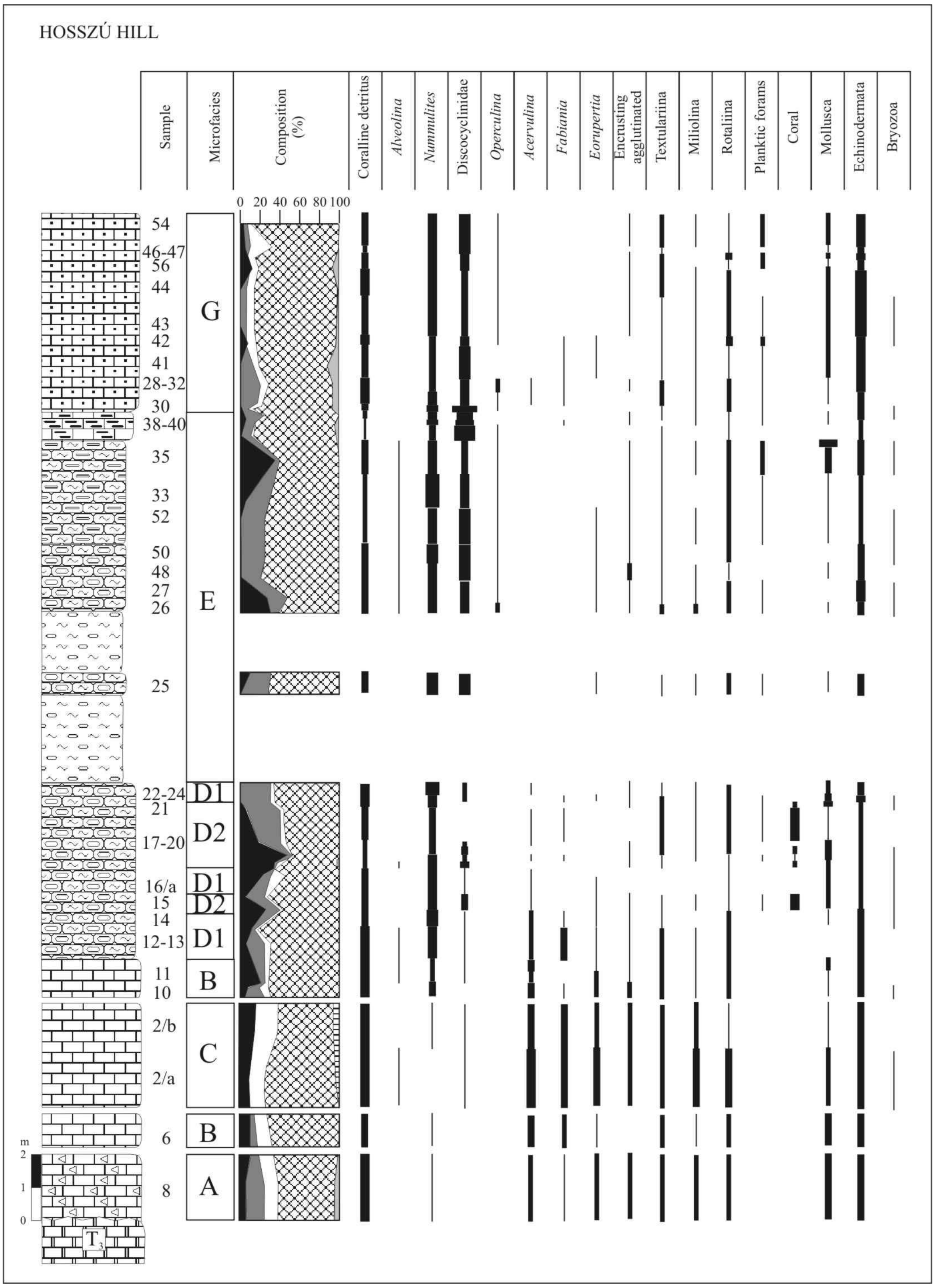

Fig. 4c. Hosszú Hill. For legend see Fig. 4a.

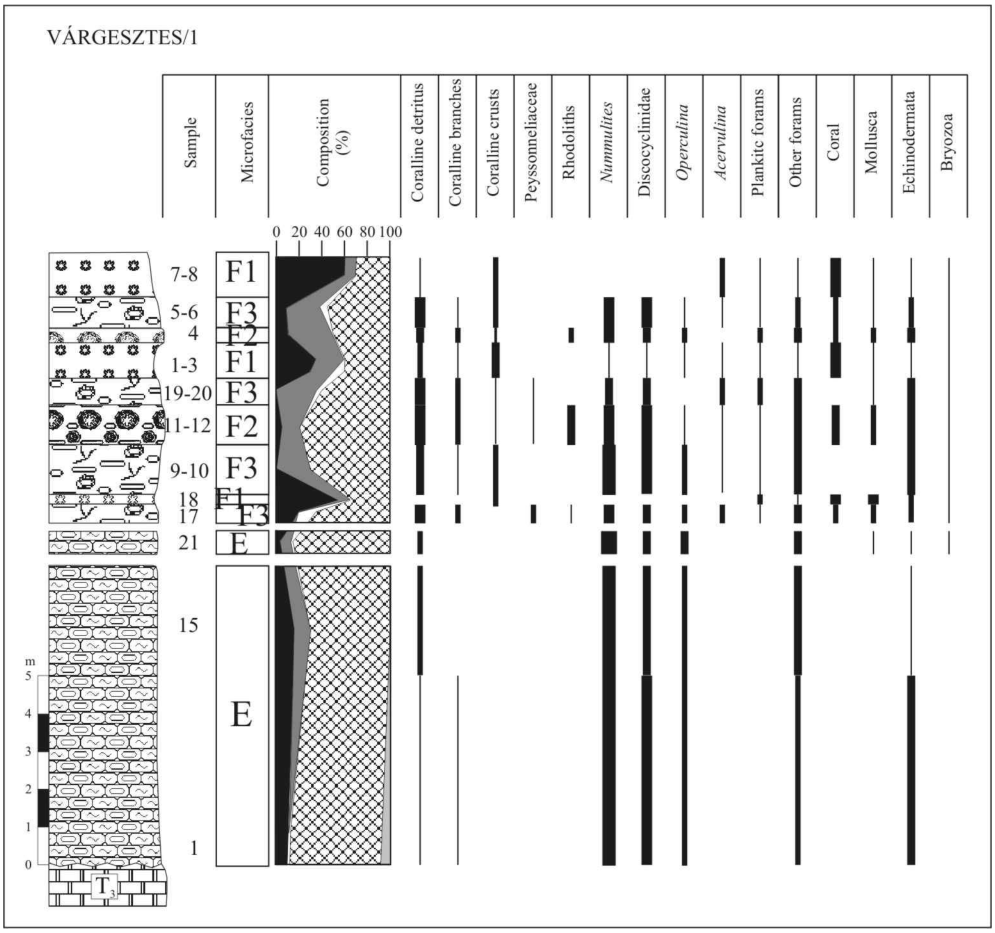

Fig. 4d. Várgesztes 1. For legend see Fig. 4a.

3) *Larger foraminiferal-red algal floatstone.* This facies contains, along with the foraminifers, the fragments of branching and crustose red algae of the same taxons as the F/2 facies, but here rhodoliths can't be found. The other bioclastic components and the rock fabric are similar to the previously described E facies.

Glauconitic limestone

G. *Glauconitic larger foraminiferal grainstone* (Pl.2, fig. 6). This facies contains bioclastic and extraclastic calcarenite, cemented by sparry calcite. Bioclasts are mostly reworked, fragmented and bored tests of *Discocyclina* and small *Nummulites* infilled with glaucony and accompanied by echinoderm and red algae detritus, small benthic and few planktic foraminifera.

Occurence: This facies can be found only at Hosszú Hill, where it overlies the larger foraminifera floatstone/rudstone (E) facies.

Facies interpretation

A. *Extraclast rudstone to extraclast-bioclast floatstone.* The great amount of bored extraclasts, which are of various size from well rounded sandy grains to half meter boulders, indicate, that sedimentation took place near the rocky coast that was made up of Triassic carbonates. Here the abrasion and/or synsedimentary tectonism could result in the fall of the rock fragments, which were redeposited together with the Eocene sediments (KERCSMÁR 2003). Well-rounded grains refer to wave agitation above fair weather wave base (FWWB), micrite could deposit in more protected environments, e. g. in boreholes.

B. *Bioturbated foraminiferal-molluscan-echinoiderm packstone/grainstone*. The echinoids, molluscs, miliolids and red algae, together with the hollow *Acervulina* and the occurrence of the typical sea-grass dweller *Orbitolites* can be interpreted as a sea-grass community (BRASIER 1975, BUXTON & PEDLEY 1989). *A. linearis* probably encrusted the rhizomes of the sea-grasses and after the death and decay of the plant it was filled by sediment or sparry calcite. (KÁZMÉR 1993). The sea-grasses usually live in depth less than 12 m and they play an important role in the accumulation because of their epibionts, their ability to baffle carbonate mud, and bind and stabilize the sediment (BRASIER 1975). This resulted in unsorted sediments, which were deposited under moderate to high energy, wave-agitated conditions.

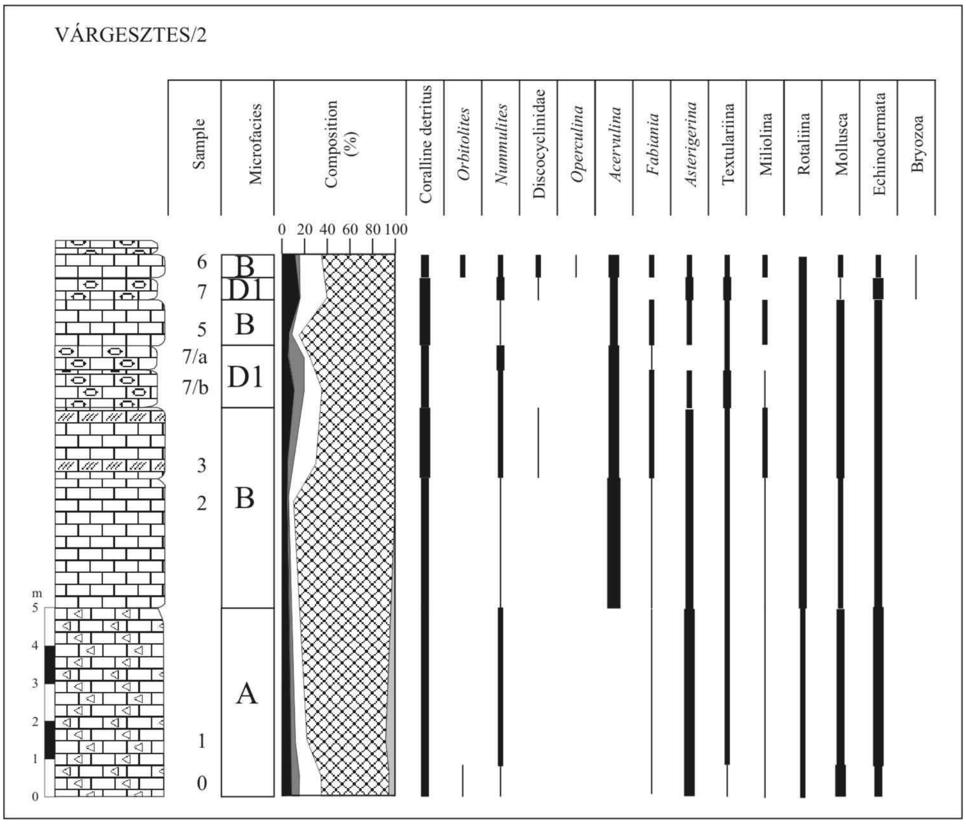

Fig. 4e. Várgesztes 2. For legend see Fig. 4a.

C. *Foraminiferal-red algal grainstone.* This facies contains the same fossil assemblage as the previously described facies, but here the bioclasts are always fragmented, well-sorted and well rounded. All these indicate reworked sediments, which were washed out from the surrounding areas. Grainstone texture refers to high-energy, permanently agitated shallow marine environment, with a mobile sandy substrate. Isolated localities of small outcrops don't allow the precise determination of the geometry and type of the mobile sand shoals and their relation to the neighbouring areas.

D. *Nummulites perforatus rudstone/packstone*. Sediment deposition took place around FWWB, where nummulitic tests were concentrated by *in situ* winnowing, but moderate energy conditions were not sufficient enough to remove all of the mud. The edge-wise imbrications of the foraminiferal shells were caused by wave motion (AIGNER 1983). The various ratio of A- and B-forms in different beds can be interpreted as (i) a consequence of the changing hydrodynamical conditions. This interpretation is supported by e. g. the imbrication of shells in the B-form dominated beds, where the light, smaller shells of A-forms could be partly washed out (AIGNER 1982, 1983, 1985). (ii) In other cases, it may be related to the reproductional cycle of the foraminifers and/or changes of some ecological factors (LEUTENEGGER 1977, WELLS 1986, HOTTINGER 2000). The paraautochtonous accumulations of shells could form *Nummulite* banks (Aigner 1983). Behind the banks, which might represent low relief, in more protected areas small coral colonies could develop (AIGNER 1983). They are recorded by Coral-*Nummulites* floatstone subfacies.

E. *Larger foraminifera floatstone/rudstone.* The accumulation of larger foraminifera tests with micrite infilling in micritic matrix refers to deposition under FWWB. The changes of the dominant taxons represent different paleodepths. The succession *Nummulites perforatus* → *Nummulites millecaput* → *Discocyclina*, *Operculina* indicates a deepening trend (HOTTINGER 1983b, HALLOCK & GLENN 1986). The chaotic arrangement of the shells may be the consequence of bioturbation. Boring activity was influenced by relatively low sedimentation rate, which might be the result of the lower carbonate production and probably the transportation of fine sediments by storm waves and currents (SEILACHER and AIGNER 1991). Occasional storm activity is indicated by local erosive surfaces and cross stratification (AIGNER 1985, SEILACHER and

AIGNER 1991). The bioclastic rudstones record residual assemblages by *in situ* winnowing (Aigner 1985).

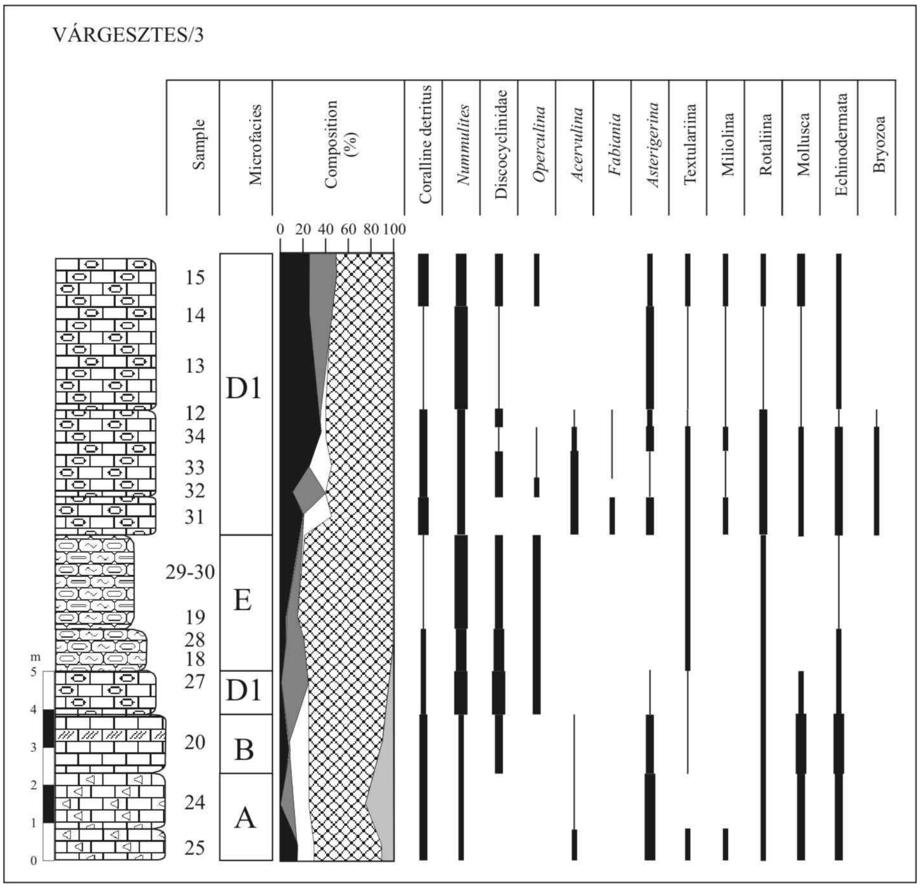

Fig. 4 f. Várgesztes 3. For legend see Fig. 4a.

F. Red algal facies

1) *Coral-red algal boundstone/floatsone*. The occurrance of this facies is restricted to a definite, small area, which is surrounded by larger foraminifera and red algae dominated sediments. Thin platy and branching corals and high mud content indicate relatively low energy conditions, under the FWWB. All these suggest a small patch reef with low relief. The paraautochtonous and often fragmented corals refer to storm reworking. Similar Eocene patch reefs in mid-ramp settings are described by BUXTON & PEDLEY (1989), DARGA (1990) and BASSI (1998). RIEGL & PILLER (1999) defined coral accumulations with low relief and without any distinct internal differentiation, as a "coral carpet".

2) *Larger foraminiferal-rhodolith floatstone.* Rhodolith formation needs unstable substrate, low sedimentation rate and certain hydrodynamic energy (HOTTINGER 1983a). Growth forms are influenced by the taxonomical composition and the frequency of turning (BOSELLINI & GINSBURG 1971). In high energy environments frequent movements produce laminar or densely branched rhodoliths, meanwhile low energy environments are characterized by open branched ones. (BOSELLINI & GINSBURG 1971, BOSENCE 1983b). The formation of small, dense rhodoliths with heavy nucleii requires more frequent and higher velocity bottom currents, than less dense, irregular, complex ones (BASSO & TOMASELLI 1994). MINNERY (1990) observed a general increase in nodule size (from 3-6 cm in 45-55 m to 10-20 cm in 70-80 m) and a decrease in density with depth. In the studied samples micritic matrix refers to deposition in lower energy environment. The occurrence of *Sporolithon, Polystrata alba* and Melobesioideae suggests relatively deep water and moderate illumination (ADEY & MACINTYRE 1973, BOSENCE 1983b, MINNERY 1990). The formation of 1-3 cm sized, warty or lumpy rhodoliths with relatively light nucleii composed of coral or coralline fragments (compared to heavy extraclast pebbles, BASSO & TOMASELLI 1994) probably needed less frequent turning and moderate hydrodynamic energy. All these can refer to deposition under the influence of storm waves and currents, between FWWB and SWB (storm wave base). Multispecific construction is rather the result of the increasing size and stability of the rhodolith, than the changing of the environment (BOSENCE 1983b, RASSER 2000).

G. *Glauconitic larger foraminiferal grainstone*. Grainstone texture refers to high energy conditions. Glauconitisation takes place near the sediment-sea water interface and it requires iron availability, low oxygenated environment and low sedimentation rate (ODIN & MATTER 1981, RASSER & PILLER 2001). The iron necessity of glaucony was supplied probably by terrigenous influx and volcanic activity. In the inner part of the bioclasts, a micro-environment existed which was characterized by reduced oxygen level. The reduced accumulation of deposits was provided by the winnowing affect of bottom currents. Today glaucony can be found in broad depth range between 60 and 500 m (ODIN & MATTER 1981).

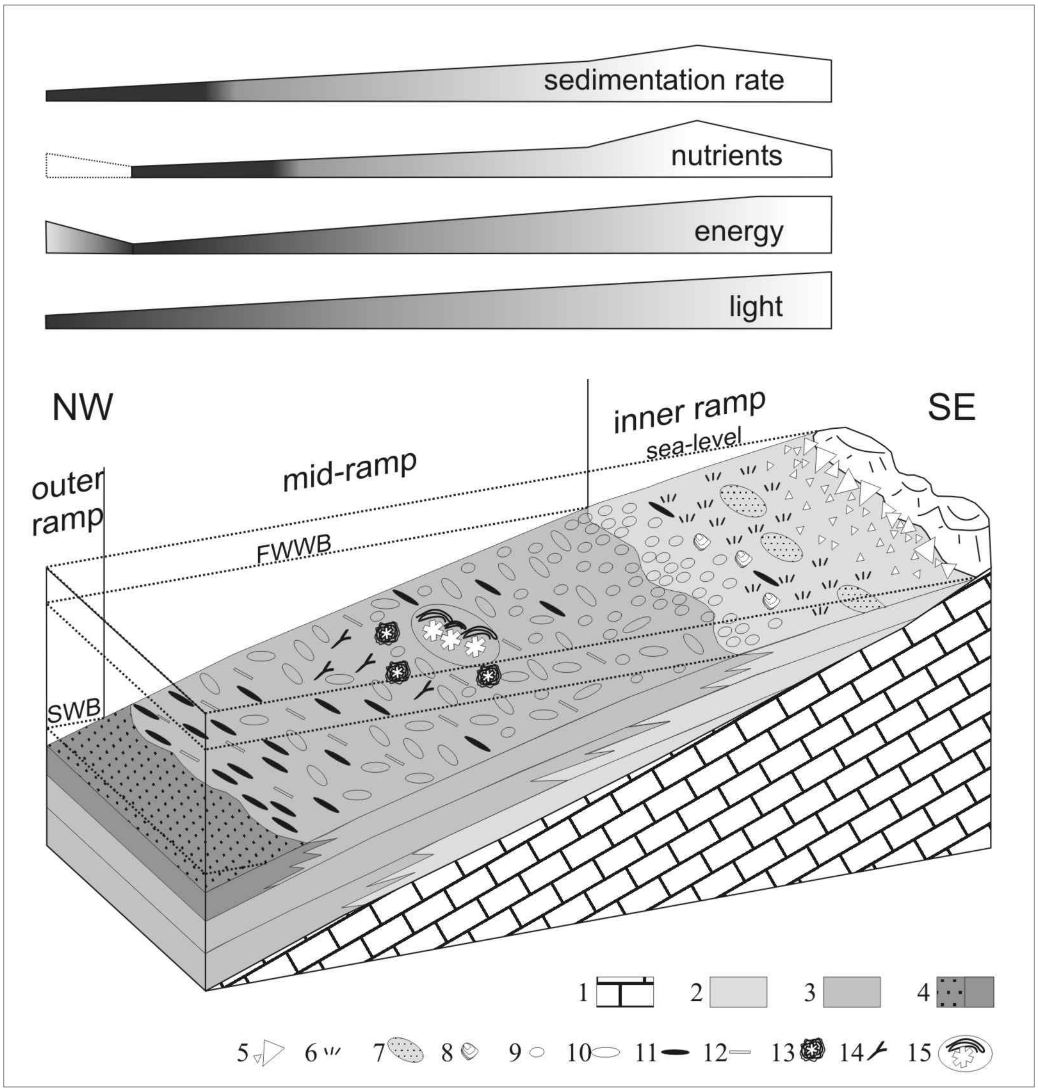

Fig. 5. Depositional model and palaeoecological interpretation of the Middle Eocene carbonate ramp in the Vértes Mountains. Legend: **1.** Dachstein Limestone; **2.** Inner ramp deposits; **3.** Mid-ramp deposits; **4.** Glauconitic limestone; **5.** Extraclasts; **6.** Sea-grass community; **7.** Sand shoal; **8.** *Ostrea*; **9.** *Nummulites perforatus*, **10.** *N. millecaput*; **11.** Discocyclinidae; **12.** *Operculina*, **13.** Rhodolith, **14.** Red algae branches; **15.** Coral-algal patch reef.

Carbonate ramp model

From core data (available in the Hungarian Geological Survey) some information can be obtained about the extension and geometry of the Eocene sediments (Fig. 2, 3). These indicate that the deposition of the Middle Eocene Szőc Limestone in the Vértes Mountains took place on a narrow, low-angle carbonate ramp (AHR 1973) (Fig. 5). The carbonate ramp model is supported by the lack of a barrier reef and a major break in slope along the margin of the inner shelf area and by the gradual transition between the studied facies.

Based on the microfacies analysis, the carbonate ramp could be subdivided into 3 parts (BURCHETTE & WRIGHT 1992): inner ramp above fair weather wave base (FWWB), mid-ramp between FWWB and storm wave base (SWB) and a lower mid-ramp to upper outer ramp under SWB.

On the inner ramp 4 microfacies types were recognised. Extraclast rudstone to extraclast-bioclast floatstone deposited in the vicinity of the rocky coast. Sea-grass meadows, represented by bioturbated

Foraminiferal-Molluscan-Echinoderm packstones/grainstones, were developed above FWWB. Foraminiferal-red algal grainstones were deposited under the highest energy conditions in wave or tide agitated bioclastic sand shoals. *Nummulites perforatus* rudstone/packstone records *Nummulite* banks which were accumulated around the FWWB.

The mid-ramp was characterized by larger foraminiferal floatstone and red algal facies which were deposited in gradually deepening water and decreasing illumination under the influence of occasional storms. Small, isolated coral-red algal patch reef, or coral carpet, surrounded by larger foraminifera-rhodolith floatstone deposits, could develop on the mid-ramp, as well.

The lower mid-ramp to upper outer ramp, represented by glauconitic larger foraminiferal grainstones, was characterized by sediment reworking and low sedimentation rate under high energy, current agitated conditions.

The studied sections don't represent the lowest facies of the carbonate ramp. The deposition of the larger foraminifera-bearing marls (Csolnok Formation) in the basin indicates a subtidal environment under the SWB and above the photic zone, and the core data don't refer to a steep slope towards the basin. This doesn't seem to be agreeing with POMAR's model (2001), in which he has suggested – despite poorly documented depositional geometries – a distally steepened ramp profile for the thick Tethyan nummulitic accumulations, related to a system dominated by coarse-grained skeletal carbonate production in the mesophotic zone. But more exact determination of the type of the studied carbonate ramp needs further examinations of deep well cores from the Oroszlány Basin.

According to the facies model, the measured sections represent transgressive successions: directly above the Triassic basement inner-ramp facies types can be found and these are overlain by mid-ramp facies types.

Palaeoecology

The studied fossile assemblages – with the dominance of larger foraminifera, red algae, echinoderms and corals - record normal marine, tropical/subtropical conditions in all facies. The most important palaeoecological factors were depth, light intensity, hydrodynamic energy, substrate, nutrient content and sedimentation rate (Fig. 5).

Inner ramp

The inner ramp above FWWB was characterized by generally high water turbulence. Along the rocky coast, the boulders and pebbles derived from Triassic carbonate rocks, contributed in great amount to Eocene bioclastic sediments and they served as hard substrate for boring and encrusting (such as red algae) organisms. In high energy conditions, instable, coarse-grained bottom were inhabited by ovoid to subspheroid, thick-walled foraminifers (HALLOCK and GLENN 1986). The strong light was unfavourable for the "giant" Nummulitidae (HOTTINGER 1983b). In somewhat quieter environment, the small, rather spheroid, trochospiral *Asterigerina* was abundant (HALLOCK and GLENN 1986).

The sea-grass community provided wide variety of habitats to the fauna and flora, and this resulted in the greatest diversity of biota and the highest carbonate production of the ramp (BRASIER 1975). As a result of the sediment baffling, trapping and binding activity (BRASIER 1975) sea-grass covered areas were the place of the highest accumulation on the carbonate ramp. The decomposition and the recycling of the leaves by the burrowing community fed a nutrient reservoir, which could provide the nutrients for the sea-grasses (HOTTINGER 1997). A barrier, formed by a film of rapidly growing R-strategist micoorganisms on the sediment surface, could prevent the dispersion of the nutrients in the free water (HOTTINGER 1997). Primary food producers (the benthic and epiphytic unicellular algae and bacteria) together with epizoans, substrate fauna, infauna and the sea-grasses and associated algae, created a complicated feeding circle (BRASIER 1975).

Along with miliolids and small trochospiral epiphytic rotaliines, the encrusting larger foraminifera *Acervulina* was the most abundant benthic foraminifera in the sea-grass communities, together with the sporadically occurring porcelaneous larger foraminifera *Orbitolites*. Other larger foraminifera, such as *Nummulites,* occured rarely in this facies, because the R-strategist benthic fauna (HOTTINGER 1982) probably became more successful in the space competition by the rapid reproduction and spreading in the nutrient-rich areas (HALLOCK & GLENN 1986).

Red algae were the other main encrusting organisms besides *Acervulina*. In the sea-grass community the very high percentage of *Acervulina,* compared to that of red algae (e.g. at Várgesztes 2-3), might be on the one hand a consequence of some ecological factors, which were less favourable for the red algae, e.g. the high sedimentation rate and the dominance of fleshy plants on soft sandy mud substrate. *Acervulina* could occupy the places, which were unsuitable for the Corallinaceae (DARGA 1993). On the other hand, the advantageous growth strategy of *Acervulina* could result, that they became the pioneeer encrusting organisms on the shells of other biota (HOTTINGER 1983a, MINNERY 1990, MOUSSAVIAN & HÖFLING 1993).

The mobile sand shoals represented the highest energy conditions of the carbonate ramp. The well-lit, but permanently agitated sandy substrate might be characterized by reduced colonization. The reworked bioclasts, derived from the neighbouring environments, such as the sea-grass communities, provided sediment supply for the shoals.

Mid-ramp

The mid-ramp was characterized by low nutrient content, which should have been favourable for the larger foraminifera (HALLOCK 1985, HALLOCK & GLENN 1986, HOTTINGER 1982, 1997). In opposition to R-mode of life - where the populations grow very quickly, use up all available resources, then disappear – the K-strategist larger foraminifera maintain their population density at a uniform level by growing slowly and producing large, complex shells and using lastingly their resources by three ways: seasonally asexual reproduction during algal blooms, housing of more storage products by enlarging the body size, and getting energy supply derived from symbionts (HOTTINGER 1982).

The symbionts of present day Nummulitidae are diatoms, which have the greatest adaptive light potential among the algal symbionts (LEUTENEGGER 1984). The high energy, well-lit areas around FWWB are inhabited by large, thick-walled lenticular-subsphaeroidal species (HALLOCK & GLENN 1986), such as *Nummulites perforatus.* In slightly deeper water, in more oligotrophic environment, with lower energy and light conditions giant, flat *Nummulites millecaput* became abundant (HALLOCK & GLENN 1986).

During asexual reproduction, the symbionts are transmitted directly from the parent individual to the megalospheric juveniles, after sexual reproduction the young microspheric individuals need the re-establishment of symbiosis (LEUTENEGGER 1984, HOTTINGER 2000). In many larger foraminifera, the frequency of the sexually reproduced microspheric B-forms is low, the asexual reproduction with the predominance of small megalospheric A-forms help to stabilize symbiosis (LEUTENEGGER 1984, Hottinger 2000). On the other hand, sexual reproduction maintain the genetic variability (HOTTINGER 2000). This dimorphism is advantageous in the adaptation to the environment.

According to HOTTINGER (2000), the two generations have different growth rates and life histories: small asexually reproduced A-forms with inherited symbionts are able to grow and to reproduce rapidly during seasonally high levels of food sources, during low levels, species can remain present as few, sexually reproduced, slowly growing and large sized B-forms, which are ready to reproduce asexually at the suitable moment. This idea supports, that the mass occurrence of giant microspheric B-forms of *N. millecaput* was due to marginal circumstances, e.g. low light and low nutrient content (HALLOCK and GLENN 1986, Boltovskoy et al. 1991).

In the deeper part of the mid-ramp in lower energy environment small, thin-walled, flat *Discocyclina* and *Operculina* were the dominant taxons. Light can easily penetrate through thin wall and the flat shell provides more wall surface for the symbionts (HALLOCK & GLENN 1986). The modern larger foraminifera *Operculina ammonoides* can tolerate a depth as deep as 130 m in Gulf of Aqaba (HOTTINGER 1983b). *Discocyclina* (which has no recent analogue) is supposed to have been able to live in even deeper, because of its special wall structure: Its ”crystalline cones” (FERRANDEZ-CAÑADELL & SERRA-KIEL 1992) probably could serve as light lenses.

Lower mid-ramp to upper outer ramp

The lower mid-ramp to upper outer ramp was characterized by mostly allochtonous fauna, which doesn't allow a precise palaeoecological interpretation of this area. But the formation of autochtonous glauconite suggests low sedimentation rate in deeper water, more than 60 m (ODIN & MATTER 1981), and the grainstone texture refers to high energy conditions provided by currents.

Conclusions

In the Middle Eocene carbonate deposition of the Vértes Mountains took place on a low angle carbonate ramp. Based on semiquantitative microfacies analysis 7 main facies type can be differentiated.

The inner ramp is represented by 4 microfacies types, which are mainly bioclastic packstones and grainstones composed of foraminifera, red algae, echinodem and mollusc fragments. Mid-ramp was characterized by the predominance of larger foraminifera under the influence of occasional storms. On the outer ramp glauconitic, larger foraminifera-bearing grainstones deposited in current agitated high energy conditions.

The main influencing palaeoecological factors were depth, light intensity, hydrodynamic energy, substrate, nutrient content, and sedimentation rates. The inner ramp was characterized by high energy well-lit conditions with the highest nutrient content and the highest sedimentation rate. The mid-ramp records oligotrophic environment with moderate/low energy and light conditions. Rhodolith-bearing deposits represent the lowest sedimentation rate on mobile soft substrate. The lower mid-ramp to upper outer ramp was characterized by high energy conditions and low sedimentation rate.

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Plate 1

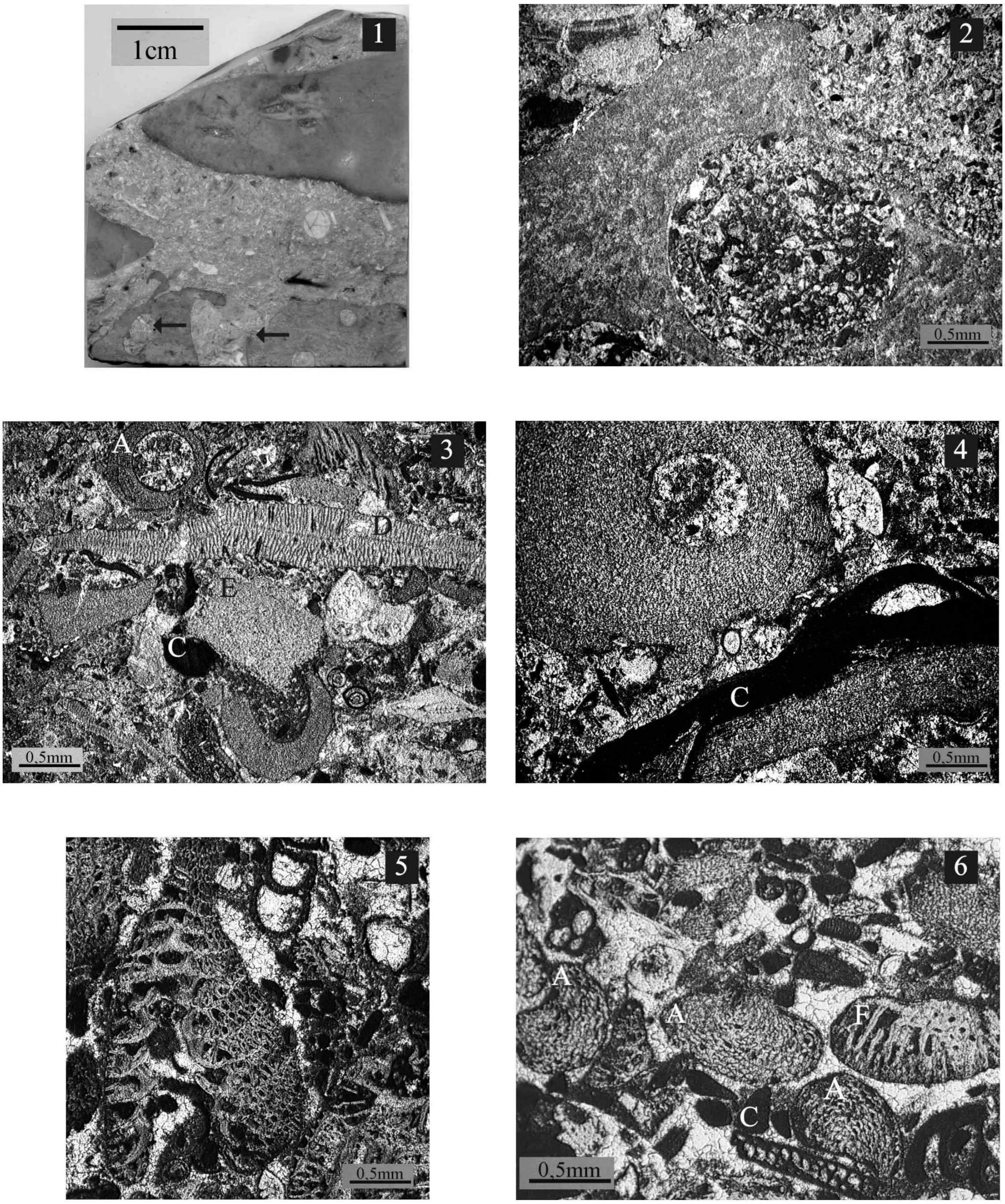

Fig. 1. Extraclast rudstone (A facies) with bored (arrow) Triassic limestone lithoclasts. Csáki-vár, sample 2.

Fig. 2. Borings in Triassic extraclast with bioclastic packstone infilling. Bioclasts are small benthic foraminifera, red algae, mollusc and echinoderm fragments. Csáki-vár, sample 2.

Fig. 3. Foraminiferal-Molluscan-Echinoderm packstone (B facies). A: *Acervulina linearis* (HANZAWA) with sediment infilling; C: Corallinaceae fragment; E: Echinoderm fragment; D: *Discocyclina*. Várgesztes 2, sample 6.

Fig. 4. Two *Acervulina linearis* (HANZAWA) with sediment infilling, the one in the right bottom is encrusted by Corallinaceae (C). Várgesztes/2, sample 6

Fig. 5. *Fabiania cassis* (OPPENHEIM), Hosszú Hill, sample 2b.

Fig. 6. Foraminiferal-red algal grainstone (C facies). A: *Acervulina*; F: *Fabiania cassis*; C: Corallinaceae fragment; Hosszú Hill, sample 2b.

Plate 2

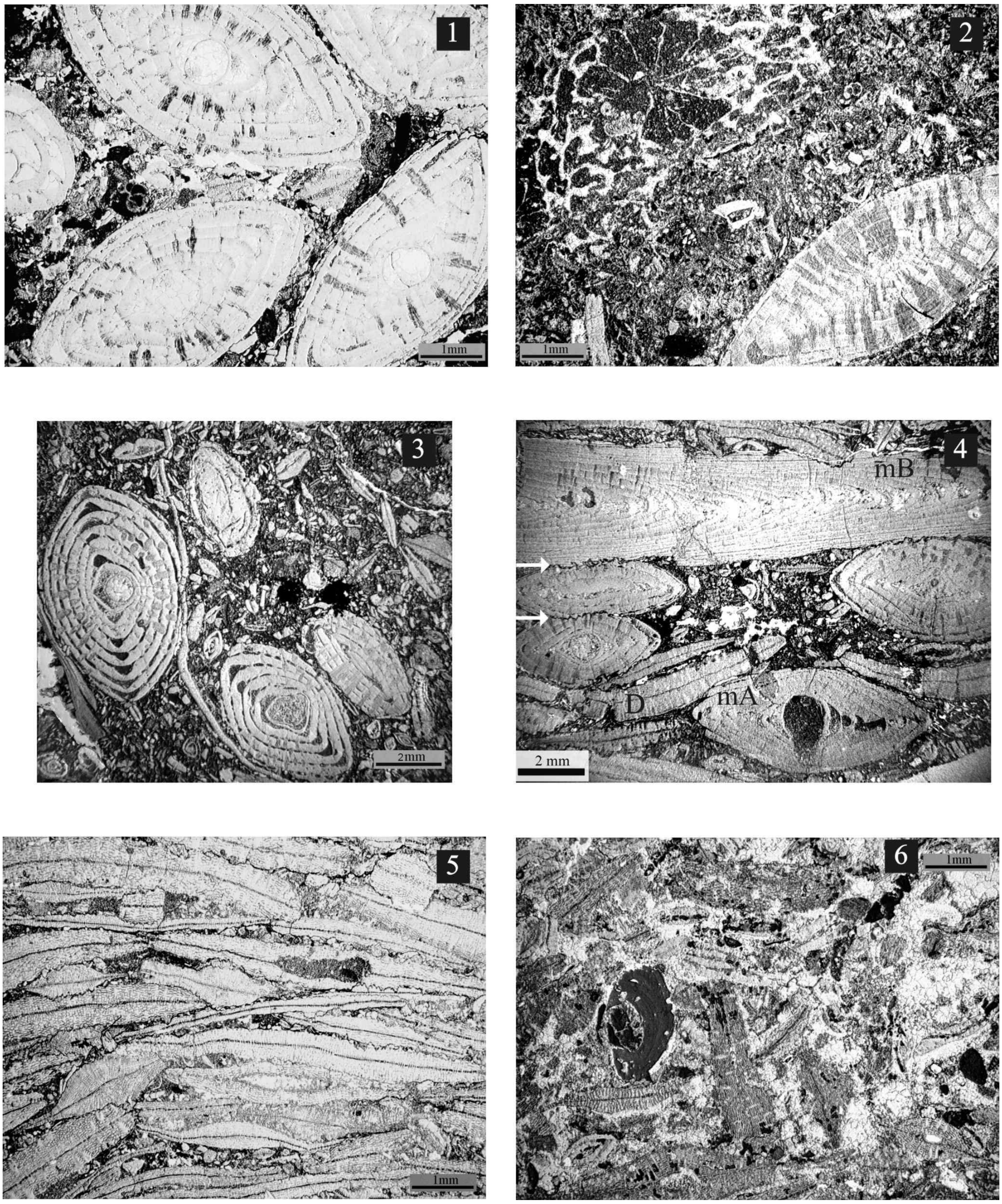

Fig. 1. *Nummulites perforatus* rudstone (D1 facies), with imbricated nummulitic tests. Hosszú Hill, sample 14.
Fig. 2. Coral-*Nummulites* floatstone (D2 facies). Hosszú Hill, sample 21.
Fig. 3. *Nummulites perforatus* floatstone (E facies). Várgesztes/3, sample 18.
Fig. 4. Larger foraminiferal rudstone (E facies), with mechanical and chemical compactional features. D: fractured *Discocyclina* test, arrow: microstylolitic contact between nummulitic tests. mA: *Nummulies millecaput* BOUBÉE A form; mB: *Nummulies millecaput* BOUBÉE B form. Várgesztes/3, sample 19.
Fig. 5. *Discocyclina* rudstone (E facies), with fitted fabric and microstylolitic contacts between *Discocyclina* tests. Hosszú Hill, sample 38.
Fig. 6. Glauconitic larger foraminifera grainstone (G facies) with glauconitized grains: larger foraminifera, echinoderm and red algae fragments. Hosszú Hill, sample 47.

Plate 3

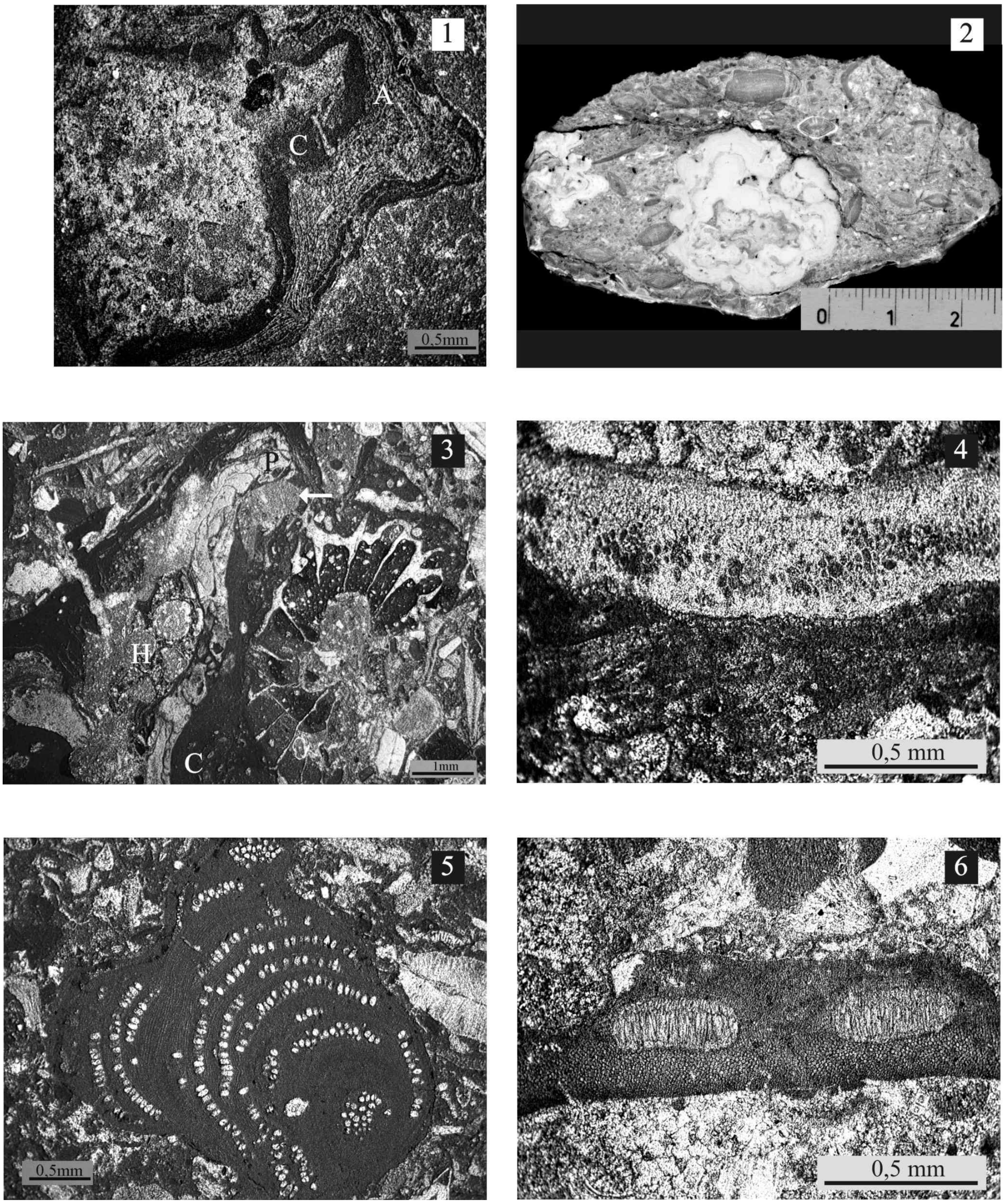

Fig. 1. Coral-red algal boundstone (F1 facies). C: Corallinaceae crust; A: *Acrevulina linearis* (HANZAWA). Várgesztes/1, sample 1.

Fig. 2. Larger foraminiferal-rhodolith floatstone (F2 facies), with warty rhodolith. Várgesztes/1, sample 4.

Fig. 3. Multispecific rhodolith with coral nucleus. P: *Polystrata alba* (PFENDER) DENIZOT; H: Haddonia heissigi HAGN; C: Corallinaceae. Várgesztes/1, sample 12.

Fig. 4. *Polystrata alba* (PFENDER) DENIZOT, (Peyssonneliaceae). Várgesztes 1, sample 17.

Fig. 5. *Sporolithon aschersoni* (SCHWAGER) MOUSSAVIAN & KUSS (Sporolithaceae); warty growth form with swollen protuberances, non-coaxial hypothallium and sporangial sori. Várgesztes/1, sample 19.

Fig. 6. *Lithothamnion* sp. (Melobesioideae); encrusting growth form, non-coaxial hypothallium and multiporate conceptacles. Várgesztes 1, sample 9b.