GEOLOGICA CARPATHICA, 50, 3, BRATISLAVA, JUNE 1999
241–256

LATE CRETACEOUS ISOLATED PLATFORM EVOLUTION IN THE BAKONY MOUNTAINS (HUNGARY)

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(Manuscript received July 3, 1998; accepted in revised form March 17, 1999)

Abstract: Upper Cretaceous rudist platform and slope deposits were studied in the Bakony Mountains. During the Turonian–Early Senonian tectogenesis an articulated basin came into being in the area of the Bakony; depressions and highs were formed roughly parallel with the structural strike of the mountain. Inundation of the highs led to the evolution of carbonate platforms. The studied platform was located in the inner part of the basin separating a southern and a northern sub-basin. Facies studies revealed that the architecture and evolution of the southern and the northern slope of the asymmetrical platform were fundamentally different. A steep erosional slope bounded the platform to the south with lithoclast accumulation at the toe of the slope, whereas a gentle accretional slope was developed northward. Evolution of the platform and the slopes was controlled mainly by two 3rd-order relative sea level changes on which higher order oscillation of the sea level was superimposed.

Key words: Transdanubian Range, Bakony Mountains, Upper Cretaceous, carbonate platform, foreslope, megabreccia, sea-level changes.

Introduction

During the Senonian, in the western part of the Transdanubian Range structural unit, a large basin came into being and was filled by continental and marine sediments. The mid-Cretaceous (Aptian–Early Albian) and Late Cretaceous (Turonian–Coniacian) tectogenetic events led to the formation of the rather complicated structural pattern of the basement of the basin (Császár & Haas 1984). As a net result of tectonic movements and subaerial erosion, highs and elongated depressions (subbasins) came into existence, roughly parallel with the structural strike of the unit. In addition to the tectonically-forced increase of accommodation, evolution of the basin was controlled for a long time by the initial topography (Haas 1983). Unequal subsidence of the structural unit led to transgression affecting the western part of the unit in the Santonian. Fluvial-lacustrine-paludal sedimentation was initiated in the depressions whereas the paleohighs were inundated only during a subsequent stage of the relative sea level rise in the Campanian, when carbonate platforms evolved on their top. Further relative sea level changes resulted in progradation and retrogradation of the carbonate platforms, before their final drowning in the Late Campanian.

In the Northern Bakony Mountains, outcrops, quarries, and boreholes exposed sequences deposited on platforms and basins as well as on slopes between platforms and basins. Studies of these slope sequences revealed that the northern and southern slopes of the paleohigh in the central part of the Senonian basin (it is referred in the present paper as the Ugod High or the Ugod platform) show significantly different development. The primary aim of the present paper is to describe the characteristic features of the slope facies and explain the cause of the differences mentioned above. Attempts were also made to understand the role of sea-level changes in the history of the evolution of the basin, also taking into account the fact that sea-level changes left traces in the foreslope and platform margin facies.

Geological setting

In the early part of the Alpine evolutionary stage, from the Late Paleozoic to the Early Tertiary, the structural units (terranes) making up the basement of the Pannonian Basin were located far from their present-day setting and far from each other. The Bakony Mountains as a part of the Transdanubian Range Unit was located somewhere between the Upper Austroalpine and the South Alpine realms (Kovács 1982; Kovács & Kázmér 1985; Haas et al. 1994). In the middle and Late Cretaceous, collisions of the Adriatic microplate and other microplates in the southern foreland of the European plate may have led to squeezing out of the Transdanubian Range Unit and the initiation of its large scale eastward displacement. The reconstructed paleogeographic setting of the study area in the Senonian is presented in Fig. 1 based on works of Ziegler (1988), Haas et al. (1990), Csontos et al. (1992), Dercourt et al. (1993), Wagreich & Faupl (1994).

Senonian formations hundreds of metres in thick occur in the western part of the Transdanubian Range Unit, i.e. in the Bakony Mountains and in the basement of the Kisalföld (Small Plain) and the North Zala Basin (Fig. 2). Late Cenomanian-Turonian collision (Pre-Gosau phase) led to uplift and intense erosion in the Transdanubian Range Unit. This was followed by subsidence from the Santonian to the next collision event in the Paleocene (Laramian phase), resulting in a typical tectonically-forced transgression–regression depositional cycle. The major lithostratigraphic units of the Senonian cycle and their stratigraphic position and relationships are shown in Fig. 3. Their basic features are described below.

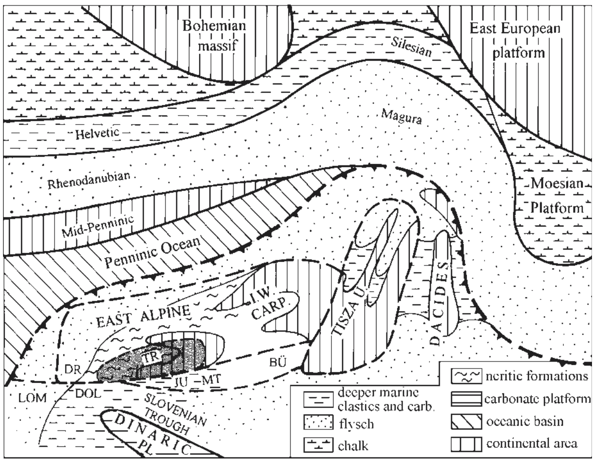


Fig. 1. Paleogeographic setting of the Transdanubian Range Unit in the Campanian. Abbreviations: LOM — Lombardy, DOL — Dolomites, DR — Drauzug, JU — Julian Alps, TR — Transdanubian Range, MT — Mid-Transdanubian Unit, BÜ — Bük Unit, I.W. CARP — Inner West Carpathians.

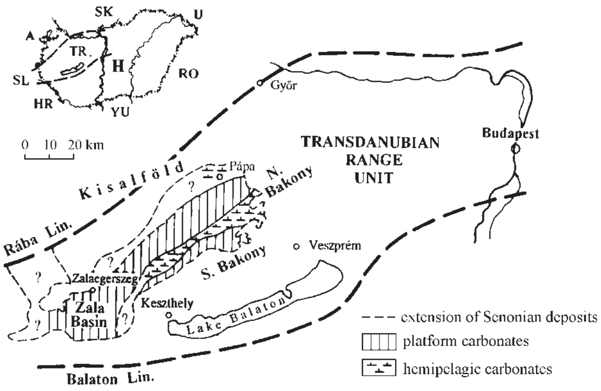


Fig. 2. Extension of the Senonian and distribution of the Campanian formations in the Transdanubian Range Unit.

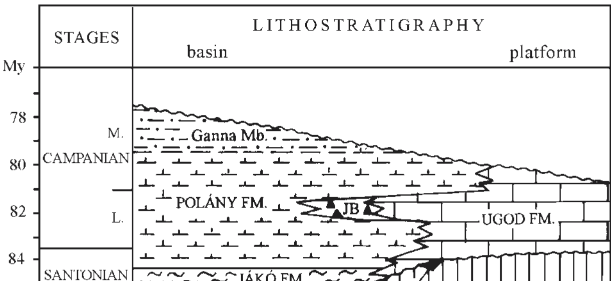


Fig. 3. Lithostratigraphic chart of the Senonian in the Transdanubian Range. Abbreviations: JB — Jákóhegyi Breccia, bx — bauxites.

Bauxites. In certain areas of the Bakony Mountains bauxitic sediments occur at the base of the Senonian cycle. Bauxites were deposited in karstic depressions of the bedrocks, under subaerial conditions, in some cases in fluviatile-lacustrine environments (Mindszenty et al. 1984; Haas 1984; Juhász 1990).

Csehbánya Formation. It is made up by an alternation of variegated clays, clay-marls, marls, silts, sands, and gravels and in minor quantities dark grey clays with thin coal seams. In some areas, the alternation of the lithofacies types shows definite meter-scale cyclicity (alluvial cycles). In the eastern part of the basin, the Csehbánya Formation directly overlies the pre-Senonian basement, or locally rests on bauxites. It exceeds 200 m in thickness. Proceeding to the west in the central depression, the Csehbánya Formation is about 100 m thick, overlying the Ajka Coal, and further to the west it pinches out. Channel and flood plain deposits of the Csehbánya Formation were deposited in fluvial and delta plain environments (Jocha-Edelényi 1988).

Ajka Coal Formation. It consists of an alternation of brown coal beds and dark grey to brownish-grey carbonaceous to argillaceous or lighter-shaded marly and silty lithofacies with mollusc coquina interlayers. The thickness of the formation may exceed 100 m. The Ajka Coal was formed in fresh- or brackish-water mangrove swamps. Coal-capped shallowing-upward cycles reflect a high-frequency sea-level oscillations (Góczán et al. 1986; Haas et al. 1992).

Jákó Marl Formation. It is constituted by grey marl and silty marl. Coquina layers are abundant and typical. The lower part of the unit (Csingervölgy Marl Member) is characterized by clay-marl to marl lithotypes and by storm coquinas of brackish-water molluscs and solitary corals. Marl, calcareous marl and silty marl rock-types prevail in the upper member of the formation, showing an upward increase in the carbonate content. Pycnodonta or Exogyra abound in some layers, though sequences poor in megafossils also occur. The thickness of the formation is usually 60 to 80 m but exceeds even 100 m in some places. The lower member has a uniform thickness of 10 to 20 m while the thickness of the upper member is much more variable. Deposition of the lower member took place in a shallow marine, locally slightly brackish-water lagoonal environment, whereas the upper member may have been deposited in a normal salinity neritic environment, showing an upward deepening trend (Haas 1983).

Ugod Limestone Formation. It is made up of light-coloured bioclastic limestones composed to a considerable extent of shell fragments of rudists. Calcarenites are the most common rock types but calcirudites are not infrequent either. Rudist bioherms or biostromes, locally with hermatypic corals, hydrozoans and red algae also occur. In some areas wackestones or mudstones poor in megafossils but locally rich in benthic foraminifers are known. The formation attains a maximum of 200 m in thickness in the Bakony (it may exceed 300 m in the Zala Basin). The Ugod Limestone was formed on carbonate platforms. Various rock types of the formation represent different shallow subtidal environments of the platforms (inner platform, platform margin, and proximal foreslope) (Haas 1979; Haas & Pálfalvi 1989).

Polány Marl Formation. It is made up of grey marl, sandy, silty marl, calcareous marl and argillaceous limestone lithofacies. The lower part of the formation is of higher carbonate content. Flaser bedding and bioturbation are characteristic features. In some areas, also in the lower part of the sequence, limestone bodies containing lithoclasts of the Ugod Limestone and also calcarenite interlayers are known to occur (Jákóhegy

Breccia Member — Nagy 1957). In the higher parts of the formation, the carbonate content decreases, the amount of clay and silt increases and sandstone interlayers appear (Ganna Siltstone Member). The maximum thickness of the formation may attain 800 m; the original thickness, however, is known nowhere due to subsequent erosion. The depositional environment of the Polány Marl extended from the toe-of-slope of the rudist platforms to the shallow bathyal basin as regards the lower member, and was a deep bathyal basin during the deposition of the upper member (Haas 1983).

In the present paper the platform (or trend of platforms) located on the central high in the north-eastern part of the basin is discussed. Extension of the Senonian formations, outcrops and locality of the most important borehole sections are displayed in Fig. 4. A conceptual cross-section running through the study area is shown in Fig. 5.

Stratigraphic correlation

Reconstruction of the evolution of the Ugod platform and its slopes requires exact stratigraphic correlation of the studied sections. Boreholes in the neighbourhood of Magyarpolány provided the best data for the southern sub-basin of the Senonian basin, the Mp-42 and Mp-38 cores were studied most comprehensively from a biostratigraphic point of view. Nannoplankton and palynologic investigations were carried out on both cores (Félegyházy 1985; Bodrogi & Fogarasi 1995; Bodrogi et al. 1998; Siegl-Farkas 1983; Siegl-Farkas & Wagreich 1996). According to the studies of Fogarasi on the Mp-42 core, the first nannofossils (represented by the species *Calculithes obscurus*) appear in the lower member of the Jákó Fm. *Lucinorhabdus cayeuxii* (ssp. B) appears at the top of the Jákó Fm. while the lower portion of the Polány Fm. is characterized by *Broinsonia parca constricta*. The first appearance of the species *Ceratolithoides aculeus* was found at the top of the Jákóhegy Mbr. The youngest part of the succession is characterized by *Quadrum gothicum* which appears near the top of the lower member of the Polány Fm. Nannoplankton investigations on the Mp-38 core were carried out by Bóna and Gál (in Haas 1981) about 20 years ago. According to the re-evaluation of their results by Fogarasi (pers. com.), *Calculithes obscurus* also appears in the lower member of the Jákó Marl, but together with *Lucinorhabdus cayeuxii*. However, nannofossil correlation of the higher part of the succession is rather uncertain.

On the basis of the palynological data (Bóna & Góczán in Haas 1981; Siegl-Farkas 1983) in both cores, the boundary of the palyno-zones D and E (for a definition of the zones see Góczán 1964) can be drawn within the Jákó Marl, practically at the boundary of the lower and upper members; the top of zone E is located at the top of the Jákó Fm. The boundary of zones E and G can be emplaced in the lower part of the Jákóhegy Mbr.

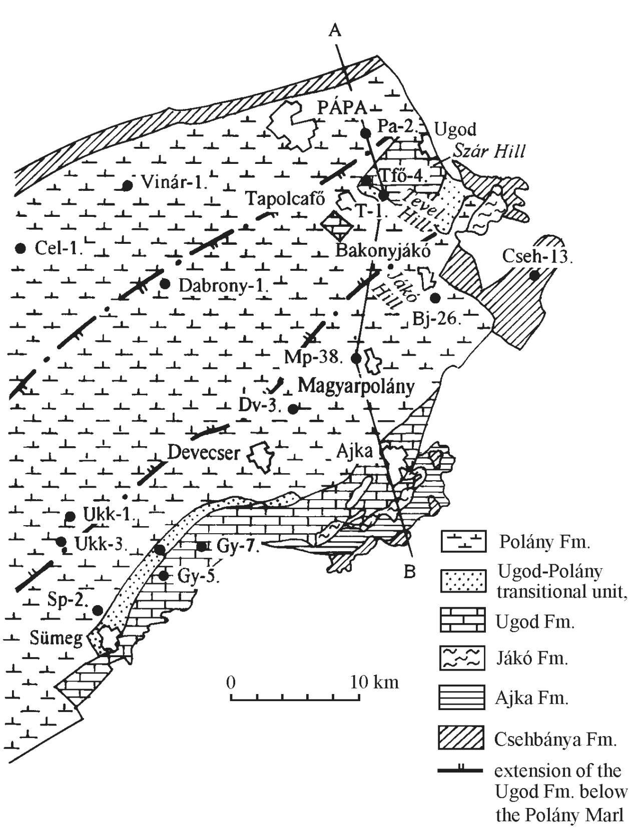


Fig. 4. Outcrops and subcrops of the Senonian formations and locality of the most important borehole-sections in the Bakony area.

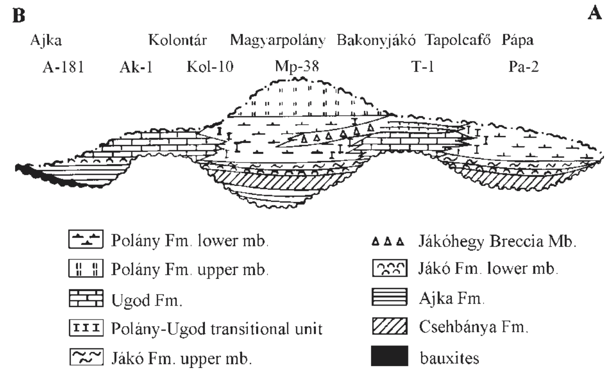


Fig. 5. N-S cross-section of the Senonian Basin in the Bakony areas. (For location of the section (A–B) see: Fig. 4).

In the northern sub-basin palynological investigations on the Pápa Pa-2 core carried out by Góczán (in Haas 1981) provided a basis for the biostratigraphic correlation between the two sub-basins. He found that the boundary of zones D and E is also within the Jákó Fm. and that the E/F boundary is located in the lower part of the Polány Fm., while zone G begins within the lower member of the Polány Fm., about 60 m above its base. These data constrain synchronous marine flooding in the two sub-basins in zone D. The inundation of the Ugod High may have begun at the end of zone E. This is also supported by recognition of the E zone at the base of the Ugod Limestone on Szár Hill at Ugod (Góczán in Haas 1981).

Based on nannofossils, Fogarasi (pers. com.) has drawn the Santonian/Campanian boundary at the appearance of *Broinsonia parca constricta*, that is, in the basal part of the Polány Fm. The chart of Haq et al. (1987) defines the boundary somewhat deeper, in the topmost part of the Lucianorhabdus cayeuxii

Zone. The higher part of the Polány Formation in the core Mp-42 can be emplaced in the Campanian.

Facies analysis

The Ugod platform

On Szár Hill (south of village Ugod — see Fig. 4), Upper Triassic carbonates are directly overlain by Campanian rudist limestones of carbonate platform facies. According to core data, a similar setting can be found in a 3–4 km wide zone under the Tevel Hill (south of Tapolcafő — see Fig. 4) and probably also even further in a south-west direction (Haas 1979). The thickness of the platform carbonates (Ugod Limestone) exceeds 100 m. This elongated carbonate platform (or platforms) trending southwest–northeast is referred to in the present paper as the Ugod platform.

A complete succession of the Ugod Limestone was exposed in the core Tapolcafő-1 (Fig. 6 — for detailed lithological descriptions and results of microfacies analysis see Haas 1979). The Senonian sequence begins with platform limestones, directly overlying the Upper Triassic Dachstein Limestone. A lag-layer only a few meters thick, containing clasts of the underlying formation was found at the base of the sequence (Haas 1979). In the platform sequence (facies-type A) the following microfacies sub-types were distinguished by Haas & Pálfalvi (1989):

— ostracode-miliolinid biopelmicrite, wackestone (facies-type A1);

— biomicrite, packstone with rudite, arenite and silt-sized bioclasts of rudists (A2);

— micritic biosparite, packstone-grainstone — poorly winnowed grainstone. Medium to coarse calcarenite with fragments of rudists, other molluscs, echinoderms, intraclasts and peloids (A3);

— foraminiferal biosparite, grainstone with large amount of benthic foraminifers (A4);

— biosparite, grainstone. Medium to coarse calcarenite-calcirudite. It consists mainly of rudist fragments (A5).

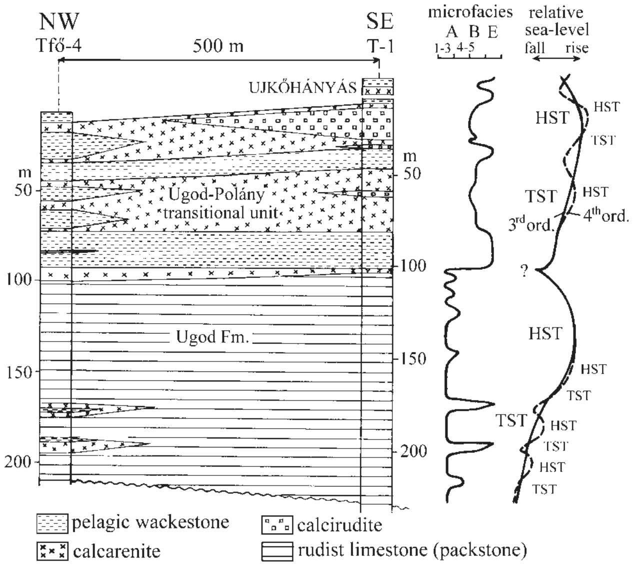


Fig. 6. Simplified lithofacies column of cores T-1 and Tfő-4 and their facies interpretation. Abbreviations: TST — transgressive systems tract; HST — highstand systems tract.

The northern slope of the Ugod platform (neighbourhood of Tapolcafő)

Sequences deposited on the northwestern slope of the Ugod platform can be studied in the quarries located northwest of Tevel Hill and in cores cut in the same area (Fig. 4).

The quarries and the upper part of core T-1 exposed rock types showing intermediate features between the Ugod and Polány Formations; to be precise the intertonguing zone of the two formations is exposed. The typical microfacies types of the transitional interval are as follows:

— Biomicrite (packstone) with arenite-sized rudist fragments and large amounts of calcisphaerulids (E1);

— Biomicrite (packstone) with predominantly silt-sized bioclasts. It is rich in calcisphaerulids and a few planktonic foraminifers also occur (E2).

Comparison of the Senonian sequence of the T-1 core with that of core Tfő-4 (see Fig. 6; description in Haas & Pálfalvi 1989), drilled at about 500 m distance from core T-1, roughly perpendicularly to the strike of the paleohigh, makes it possible to establish the following tendencies:

— the Ugod Limestone shows a definite trend of thinning northwestward i.e. moving away from the core of the platform;

— thin interlayers of foreslope facies appear in the lower part of the Ugod Limestone, in core Tfő-4.

— the thickness of the first thicker pelagic interval appearing above the Ugod Limestone is approximately equal in the two cores but upsection the proportion of the pelagic intervals is much higher in core Tfő-4.

— the calcirudite facies is completely missing in the transitional unit in core Tfő-4.

The Senonian sequence of the sub-basin north of the Ugod platform is known from the borehole Pápa Pa-2 (Figs. 4, 5), drilled about 5 km to the north of borehole T-1. In borehole Pa-2, overlying the Triassic formations, a typical basinal succession was exposed: the Csehbánya Formation (120 m) at the base is overlain by the Jákó Marl (60 m) which passes upward into the Polány Marl.

The southern slope of the Ugod platform (neighbourhood of Magyarpolány)

South of the Ugod platform, the Senonian formations are exposed by a few outcrops and cored wells near Magyarpolány. According to the core data, the Senonian sequences are underlain by Jurassic-Lower Cretaceous formations. At the base of the Senonian succession, overlying a few meter-thick terrestrial interval, the 50–100 m thick Ajka Coal Formation occurs. It is covered by the terrestrial Csehbánya Formation, 50–150 m in thickness. The transgressional marine sequence begins with the brackish lower member of the Jákó Formation which is followed by the normal saline upper member of the Jákó Formation. With an upward-increasing carbonate content, the Jákó Marl gradually progresses into the lower member of the Polány Marl, consisting mainly of calcareous marl. In the 300–350 m thick lower member, the Jákóhegy Breccia, a 30–100 m thick lithoclastic limestone intercalation appears. Upsection the lower member passes gradually up into the more argillaceous and silty upper member (Ganna Siltstone).

The Jákóhegy Breccia in the Magyarpolány-38 core

The first lithoclastic interlayer in the lower member of the Polány Marl appears at 406 m in core Mp-38 (for location see Fig. 4). Upsection the frequency of the lithoclastic layers and proportion and size of the clasts increase. The lower boundary of the Jákóhegy Member was drawn at the horizon where the lithoclasts begin to occur continuously (Fig. 7). The upper boundary of the member is sharp. Above 270 m the lithoclasts abruptly disappear. In the lithoclastic layers, the proportion of the clasts is 50–90 % (Pl. I: Figs. 2–3). Mud-supported texture characterizes the lithoclastic interlayers of the Polány Marl and the lower and uppermost part of the Jákóhegy Breccia, whereas grain-supported texture prevails in the middle part of the Jákóhegy Member. Microstylolitic grain contacts are common in the latter interval. The size of the lithoclasts is between 0.1 and 10 cm. The maximum grain size was also found in the middle part of the Jákóhegy Member. The roundness of the clasts is highly variable. Angular grains are predominant, but well-rounded ones occur as well. The petrographic data of the lithoclastic intervals are summarized in Fig. 8.

A detailed microscopic study was carried out on the lithoclastic layers to investigate the microfacies characteristics of the lithoclasts and their matrix. The diagenetic features of the

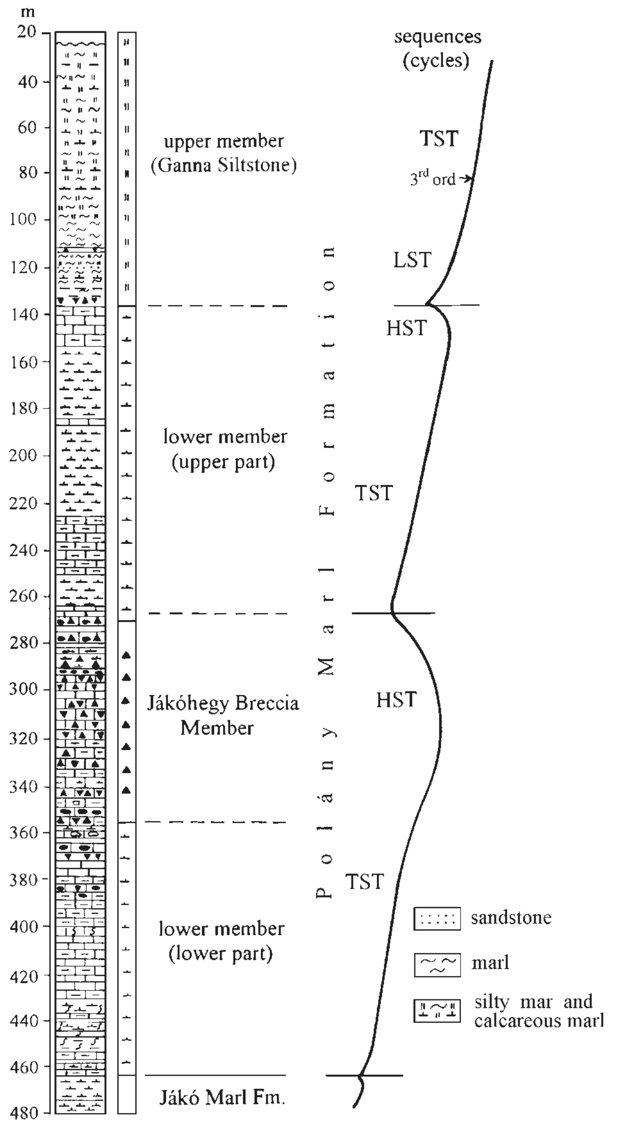


Fig. 7. Lithologic column, lithostratigraphy and relative sea-level curve of Core Mp-38. For legend see Fig. 9. Abbreviations: LST — lowstand systems tract, TST — transgressive systems tract; HST — highstand systems tract.

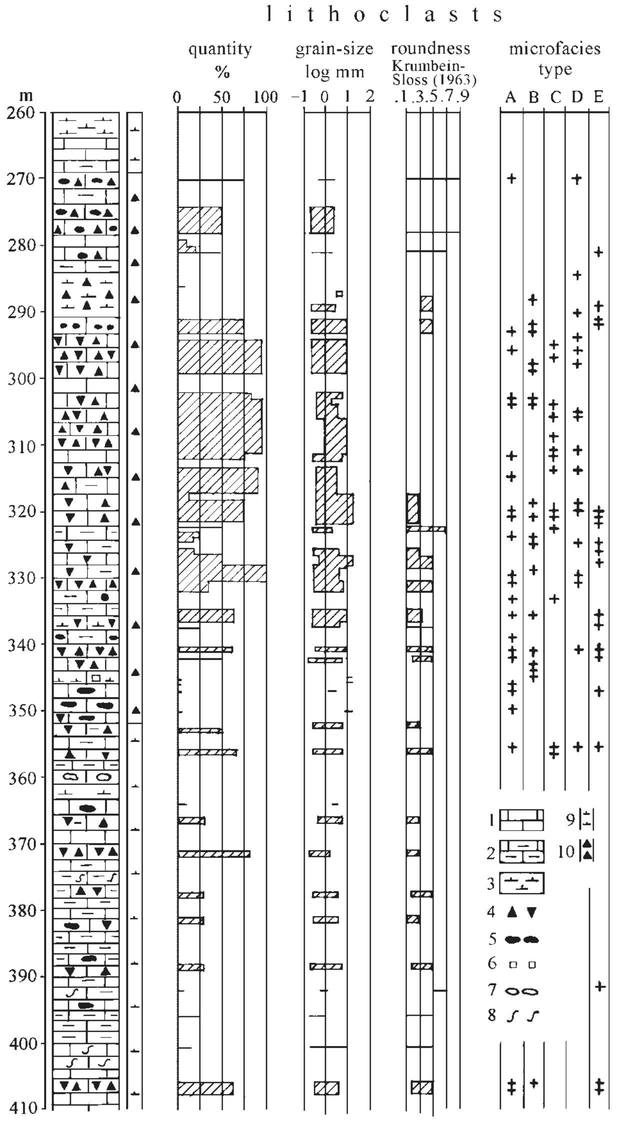


Fig. 8. Megascopic data, and microfacies-types of the lithoclasts in the lithoclastic interval of Core Mp-38. Legend (for Figs. 8, 9, 10): 1. limestone, 2. argillaceous limestone, 3. calcareous marl, 4. lithoclasts, 5. plastoclasts, 6. rudite-size bioclasts, 7. nodules, 8. bioturbation, 9. Polány Formation, 10. Jákóhegy Breccia Member.

PLATE I

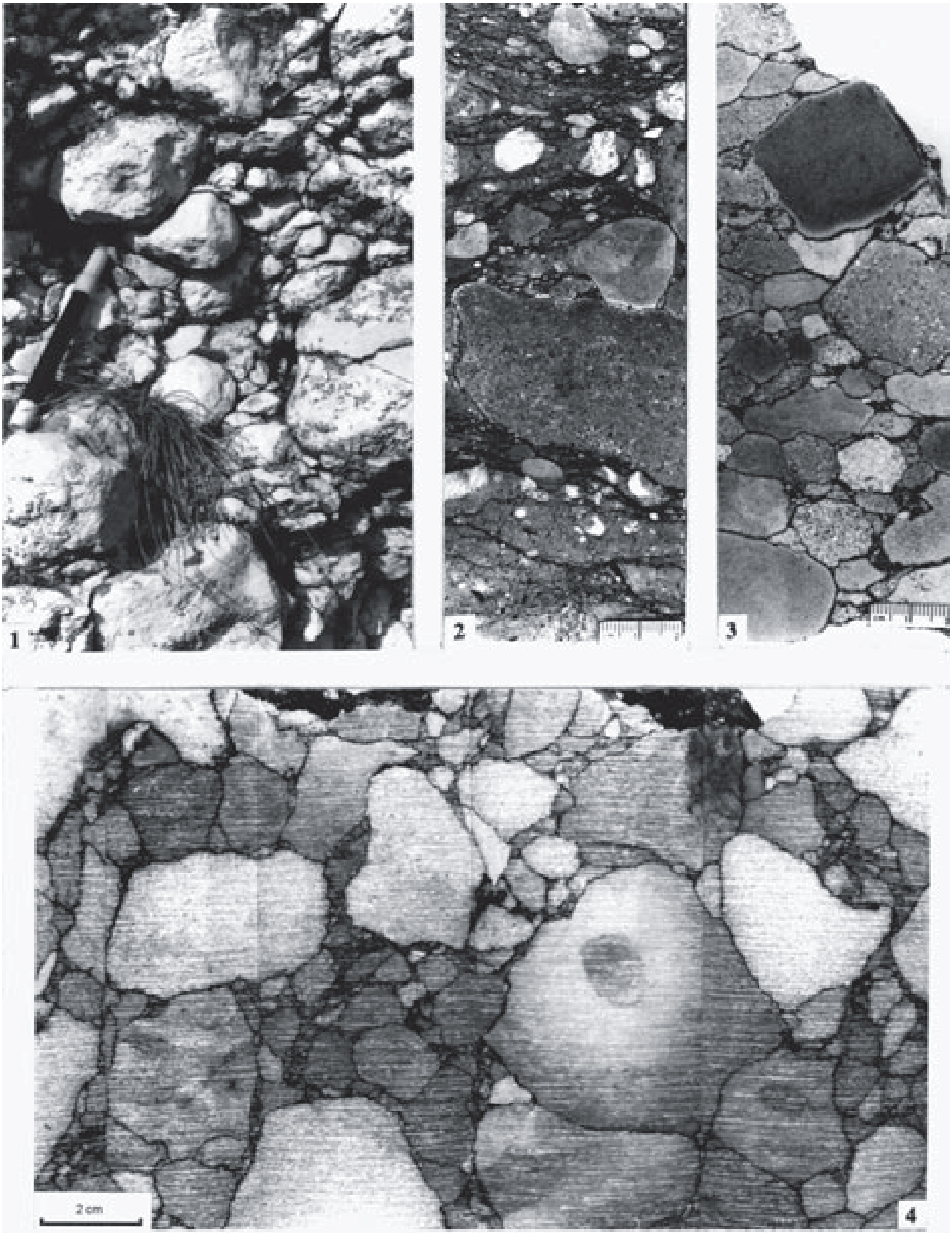
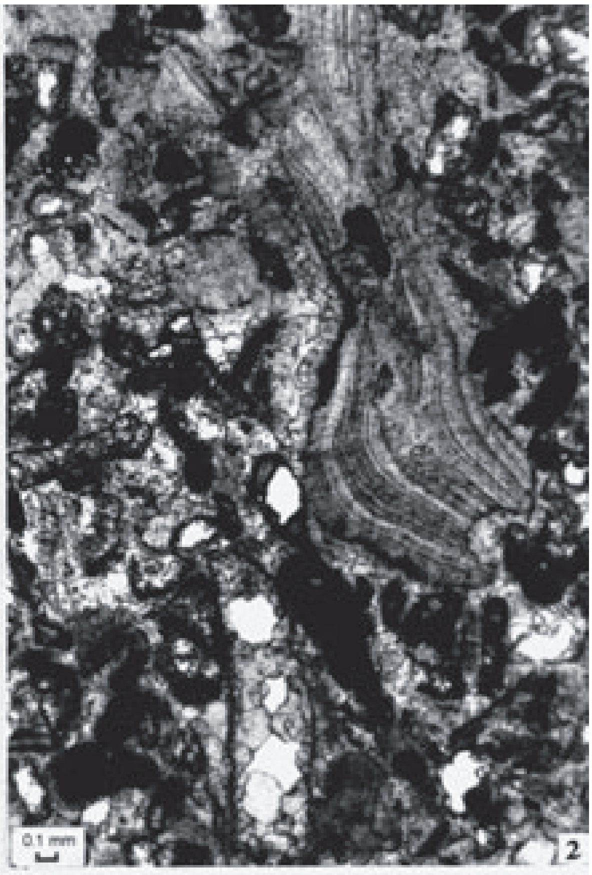


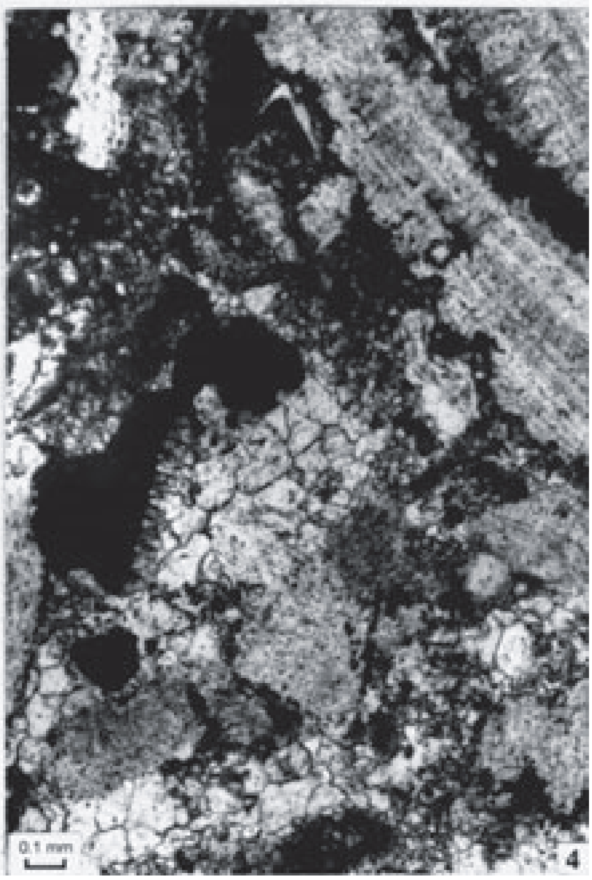
Plate I: Fig. 1. Outcrop of the Jákóhegy Breccia on the top of Jákó Hill (stratotype-section). **Fig. 2.** The Jákóhegy Breccia in core Mp-38, 329.3 m. **Fig. 3.** The Jákóhegy Breccia in core Mp-38, 308.3 m. **Fig. 4.** The Jákóhegy Breccia in core Dv-3, 629.5 m.

▶

Plate II: Microfacies type A (lithoclasts). **Fig. 1.** Rudist-bearing biomicrite (packstone) Core Mp-38, 315.0 m. **Fig. 2.** Biopelsparite (grainstone) Core Mp-38, 345.0 m. **Fig. 3.** Biointramicrite (packstone) Core Mp-38, 330.0 m. **Fig. 4.** Pore filling drusy sparite cement Core Mp-38, 330.0 m.

PLATE II





lithoclasts were also studied. The results are shown in Fig. 9. On the basis of this analysis microfacies-types were defined. Most of the types were recognized in both the matrix and the lithoclasts, but certain types appeared only in the matrix or in the lithoclasts.

The defined microfacies types are as follows:

A/ Packstone-grainstone with arenite-size particles (Pl. II: Figs.1-4). It contains a large amount of shell fragments of rudists and other thick-shelled molluscs and echinoderm fragments. Benthic foraminifers and occasionally algae (*Pieninia*) also occur. A few calcisphaerulids may also be present. This type was recognized only in lithoclasts.

B/ Wackestone, packstone, less frequently grainstone, calcarenite (Pl. III: Figs. 1-2). It is characterized by a predominance of mollusc shell fragments and echinoderm elements. Benthic foraminifers are generally present, but in a small quantity as a rule. This type is fairly common in the lithoclasts and it also occurs in the matrix, but rarely.

C/ Wackestone, packstone, less frequently grainstone, with arenite-size or locally silt-size particles (Pl. III: Fig. 3). Echinoderm fragments are predominant and benthic foraminifers are generally also present. It is frequent as material of lithoclasts, but infrequent in the matrix.

D/ Wackestone, packstone with silt-size particles, prevailingly of echinoderm origin (Pl. III: Fig. 4). A few calcisphaerulids are present as a rule. This type is common as both matrix and lithoclast.

E/ Packstone, wackestone with silt-size particles of mollusc and echinoderm origin (Pl. IV: Fig. 1). It is characterized by the large number of calcisphaerulids. This type is common in the lithoclasts (21 %), and the most frequent as matrix (64 %).

F/ Mudstone, wackestone (Pl. IV: Fig. 2). Planktonic foraminifers (including the globotruncanids) are common. Other fossil elements are scarce. This microfacies was not found in lithoclasts, and is also rare as matrix of lithoclasts. It is typical in the intervals where the lithoclasts are absent.

The relations of the microfacies of the lithoclasts and the matrix are shown on Table 1, on the basis of analysis of 118 thin sections. According to these data, microfacies A is the most frequent in the lithoclasts (31 %), while types B, C and E are present in about equal proportion (14-17 %). In the matrix, microfacies type E is definitely predominant (64 %), the frequency of type D is significant (22 %) while types B, C and F are poorly represented (4-6 %) (Pl. IV: Figs. 3-4, Pl. V: Figs. 1-4).

Table 1: Relationships between the microfacies types of the lithoclasts and the host-rocks (matrix) of the lithoclasts.

%	mf							
0	F	-	-	-	-	-	-	
21.2	E	-	2	-	2	19	2	
17.0	D	-	1	12	4	12	2	
14.4	C	-	1	2	9	4	1	
16.1	B	-	-	-	5	14	-	
31.3	A	-	1	2	6	26	2	
clast		A	B	C	D	E	F	mf
matrix		0	4.2	4.2	22.0	63.6	6.0	%

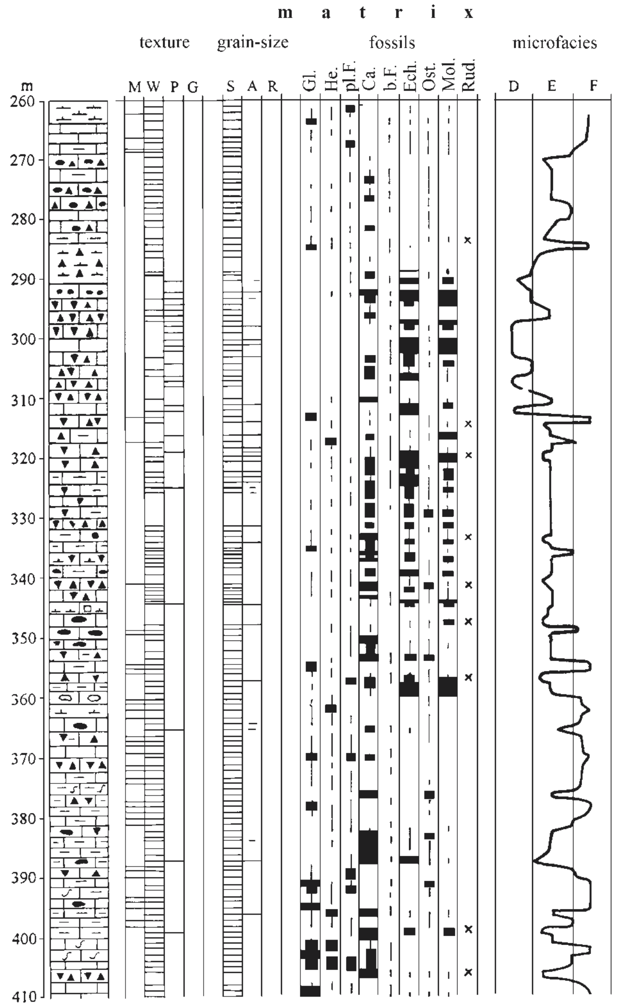
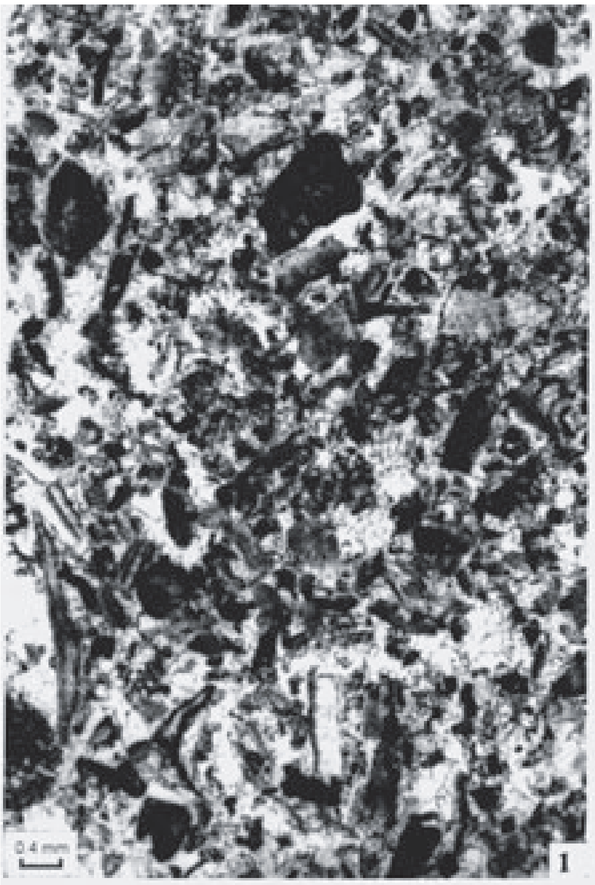


Fig. 9. Petrography, microfacies-types and facies interpretation of the matrix in the lithoclastic interval of Core Mp-38. For legend see: Fig. 8. Abbreviations: M — mudstone, W — wackestone, P — packstone, G — grainstone; S — silt-size, A — arenite-size, R — rudite-size; Gl — Globotruncana, He — Heterohelix, plF — other planktic forams, Ca — Calcisphaerulids, bF — benthic forams, Ech. —echinoderms, Ost. — ostracods, Mol. — molluscs, Rud.—rudists.

In many cases, signs of cementation and other early diagenetic features could be recognized in the lithoclasts, mainly in type A, but occasionally also in types B and C. The interparticle pores are filled with equant sparry calcite as a rule; drusy mosaic and syntaxial overgrowths are common. The biomolds are generally filled by coarse sparite. In two B-type lithoclasts, vug pores were observed. In two A-type lithoclasts, isopachous fibrous rims were visible around the grains; in another sample, fibrous sparite lined the biomoldic pores.

Plate III: Microfacies type B (lithoclasts). **Fig. 1.** Poorly winnowed biosparite with drusy mosaic cement, Core Mp-38, 292.8 m. **Fig. 2.** Biomicrite (packstone), Core Mp-38, 304.0 m. **Fig. 3.** Microfacies type C (matrix), fine calcarenite-calcisilt packstone, Core Mp-38, 304.0 m. **Fig. 4.** Microfacies type D (matrix), calcisilt packstone, Core Mp-38, 269.7 m.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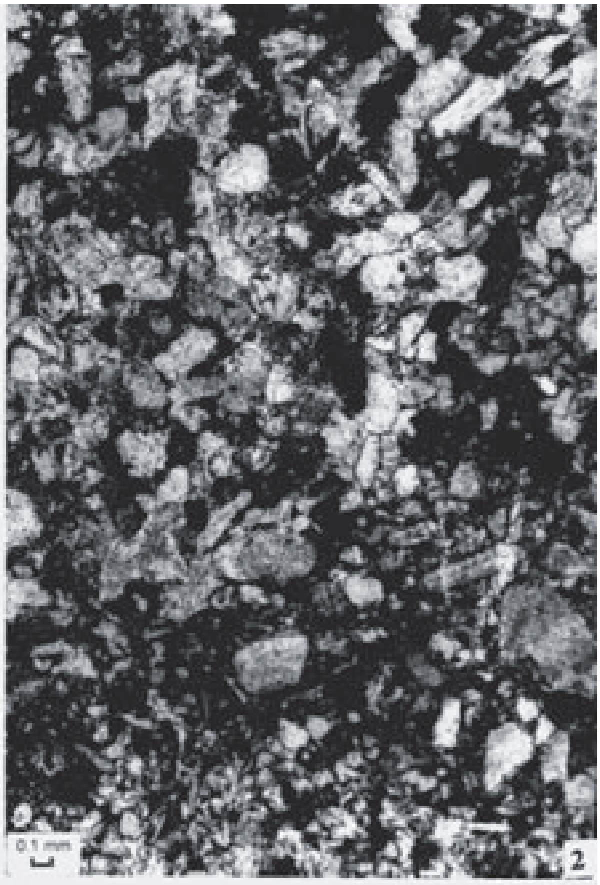
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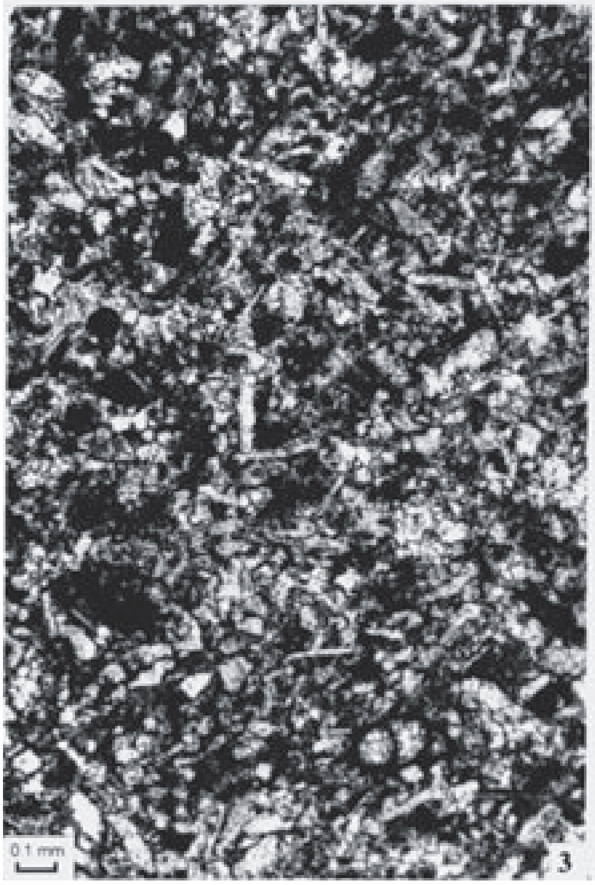
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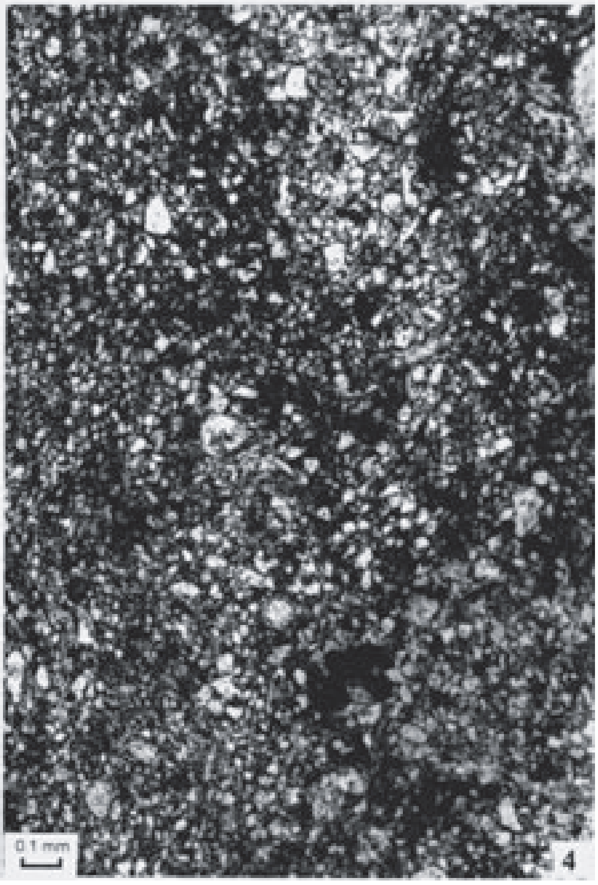
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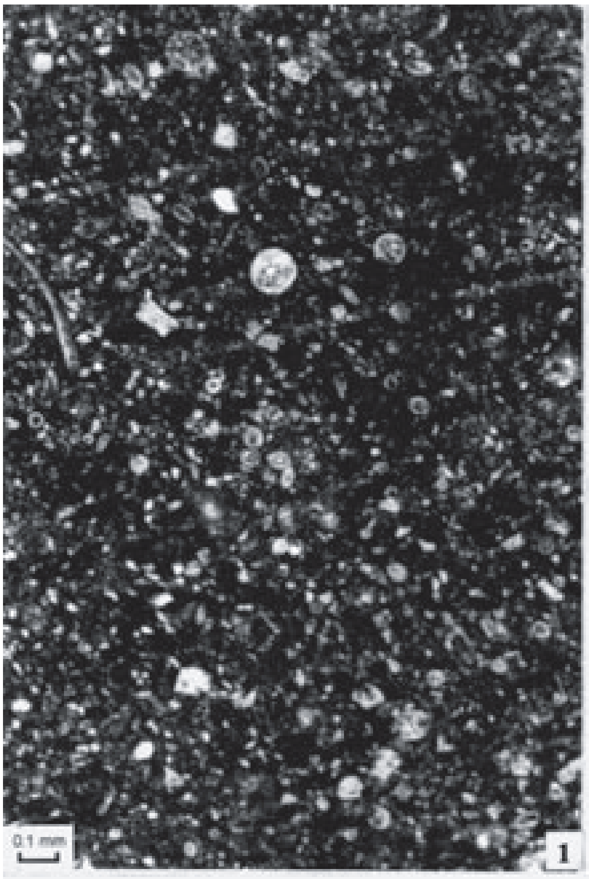
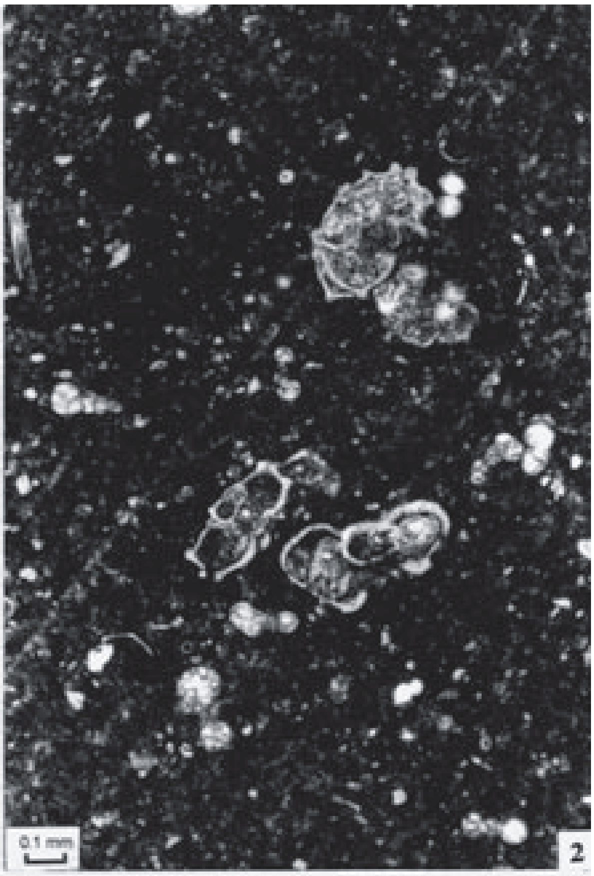
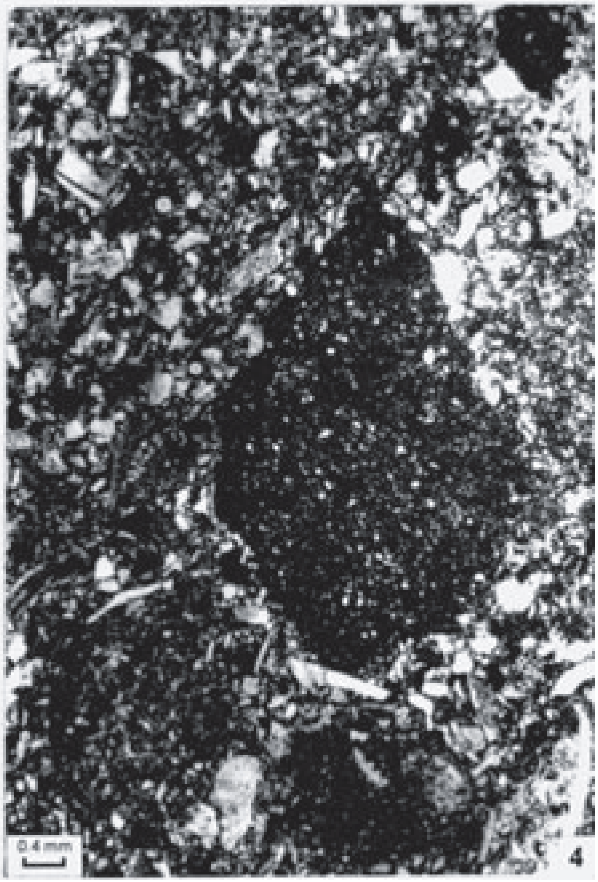
PLATE IV







Geometry of the Jákóhegy Breccia body

Outcrops of the Jákóhegy Breccia are known on Ség Hill, on Tevel Hill and on Jákó Hill west of Bakonyjákó (Fig. 4; Pl. I: Fig. 1). The Jákóhegy Member is also encountered in some boreholes in the neighbourhood of Magyarpolány and further SW in the core Devecser-3 (Fig. 4; Pl. I). The core data of the Magyarpolány area also provided some information on the geometry of the Jákóhegy Breccia. Figs. 10 and 11 show the features and thickness of the Polány Formation and within it the Jákóhegy Member as found in these cores. In the 3.5 km-long cross-section connecting the cores Mp-42–Mp-44–Mp-41 significant southeastward thinning of the Jákóhegy Member is clearly visible. In the north-south cross-section between the cores Mp-40 and Mp-44 marked thinning is also evident. These trends suggest the southward or southeastward dipping of the slope. The differences in the thickness of the member are much less along the profile between cores Mp-42 and Mp-38 (also in a north-south direction). It can be explained either by a change in the orientation of the paleoslope or by subsequent tectonic displacements.

General facies model

On the basis of the study of the surface exposures and cores in the neighbourhood of Tapolcafő and Magyarpolány a general facies model can be set up for the time when the transgression reached the top level of the paleohigh (Ugod High) between the southern and northern sub-basins (Fig. 12). The paleohigh was probably bordered by normal faults and it might have been slightly tilted to the north. Inundation of this high led to the formation of a 5–8 km wide isolated carbonate platform with a steep southern slope and a much gentler northern one. On the platform rudist limestones were formed, on the northern slope redeposited bioclasts of platform origin and at the foot of the southern slope lithoclastic sediments were deposited. The difference in the material of the foreslope deposits also indicates an intense lithification along the southern platform margin, which did not occur on the opposite margin. Based on the features of the cements, meteoric diagenesis can be assumed, which may have affected the more elevated southern rim during the high-frequency lowstand intervals.

Along an idealized north-south cross-section the following paleo-environments and sub-environments could be distinguished.

Low-angle accretional slope (microfacies E1, E2)

Along the northern margin of the Ugod platform a wide gentle slope (2–3^{o}) can be reconstructed. On the distal part of the slope, carbonate silt (E1) was deposited. The platform may have been the source of some part of the calcisilt. However, algae producing calcisphaeres (the other major component of the silt-sized carbonate) probably lived on the slope. In the proximal part of the slope arenite-sized bioclasts, mainly fragments of rudists (E2), were accumulated together with in-situ deposited calcisphaerulids.

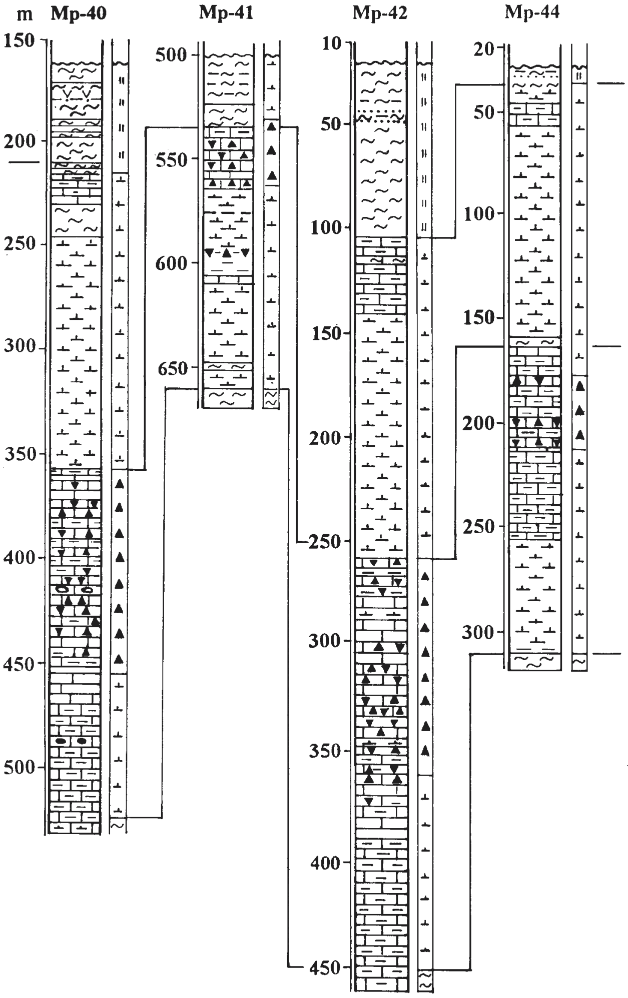


Fig. 10. The Jákóhegy Breccia in core-sections in the neighbourhood of Magyarpolány. For legend see: Fig. 8.

Rudist platform (microfacies A5-1 and A)

Within the rudist platform, the following environments could be reconstructed on the basis of the study of the cores at Tapolcafő:

Outer platform — high-energy carbonate sand shoal environment with accumulation of abraded fragments of rudists (A5) or benthic foraminifers (A4). The poorly winnowed grainstone microfacies type (A4) may have been deposited in the transitional zone between the outer and inner platform environments.

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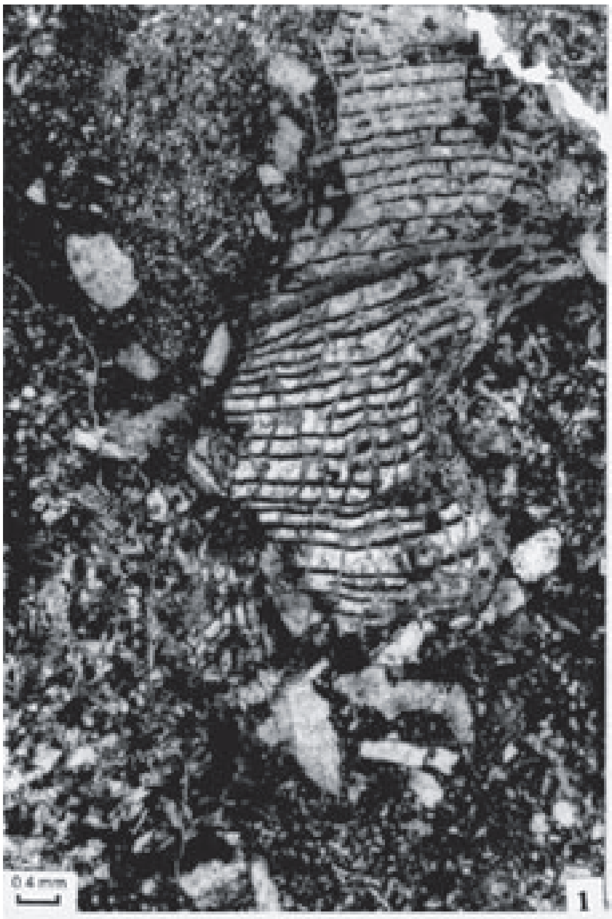
Plate IV: Fig. 1. Microfacies type E (matrix), wackestone with Calcisphaerulides, Core Mp-38, 383.0 m. **Fig. 2.** Microfacies type F (matrix), wackestone with planktic Foraminifera, Core Mp-38, 378.0 m. **Fig. 3.** Rudist shell fragment in F-type matrix, Core Mp-38, 283.0 m. **Fig. 4.** Lithoclast of type E in B-type matrix, Core Mp-38, 291.0 m.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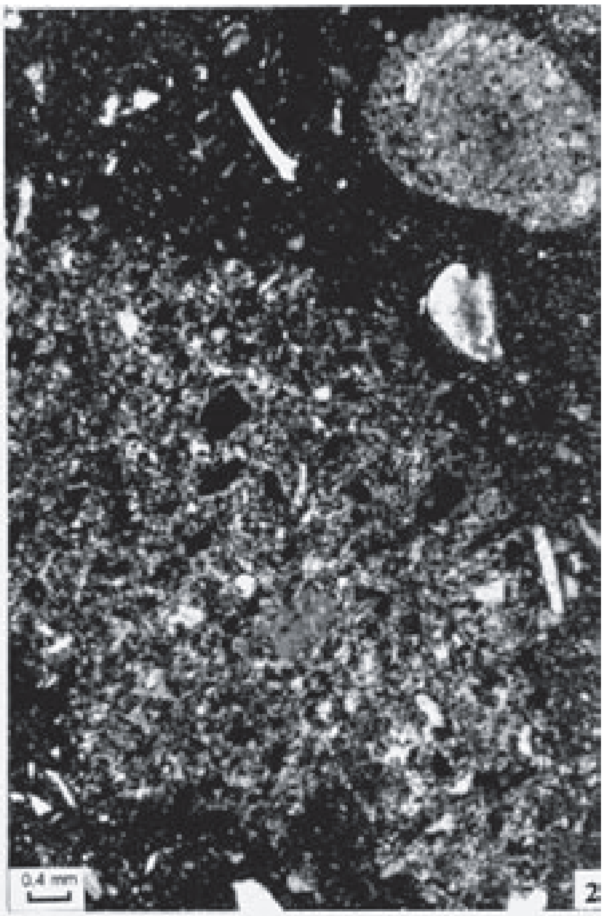
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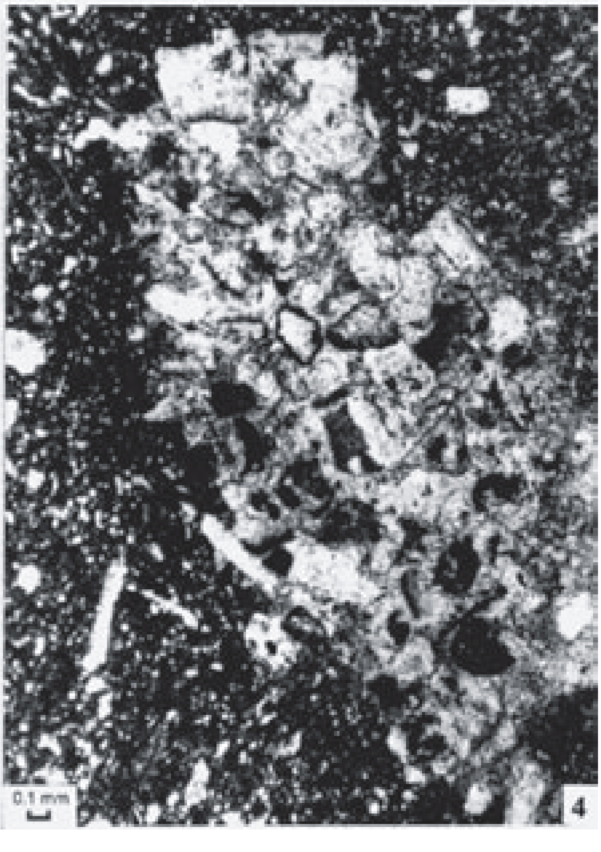
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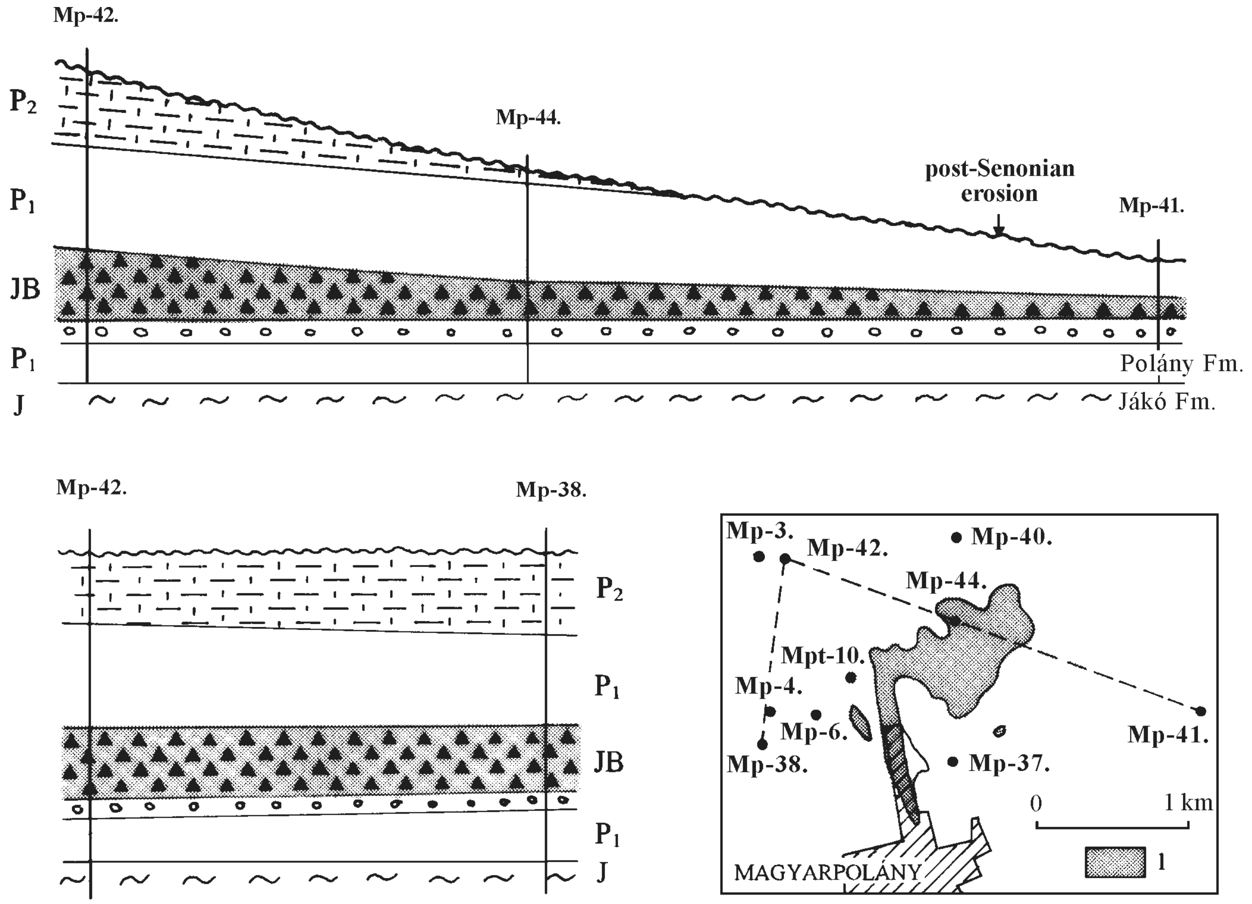

Fig. 11. Cross-sections through the core-sections which penetrated the Jákóhegy Breccia in the neighbourhood of Magyarpolány. Location of the section is shown on the insert-map. Legend of the map: 1. outcrops of the Polány Formation. Abbreviations: J — Jákó Fm., P — Polány Fm., JB — Jákóhegy Breccia.

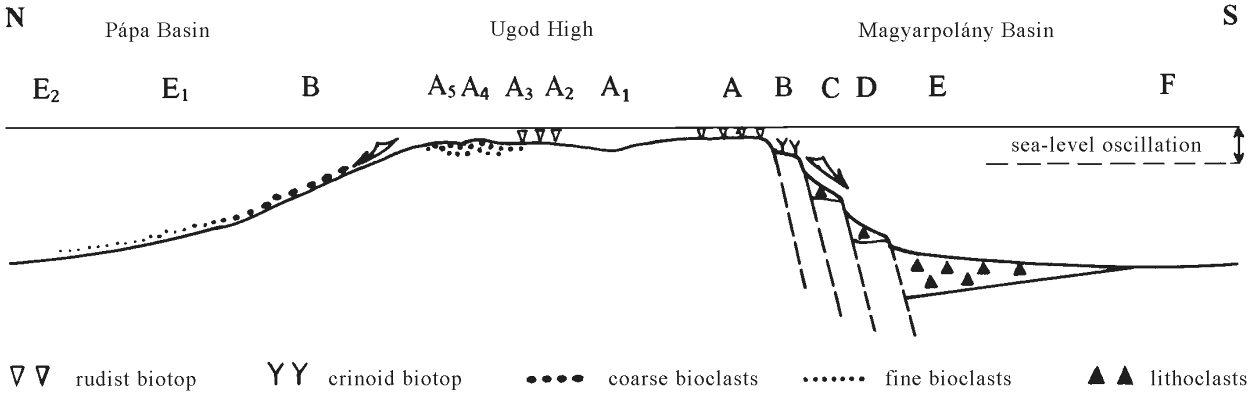

Fig. 12. General facies model for the Ugod High and the surrounding basins in the Campanian.

Inner platform — medium to low-energy environment (A2) with accumulation of fragments of rudists and other shallow marine biota. Bioerosion may have played an important role in the fragmentation of the skeletons.

Inner platform lagoon — very low-energy, protected environment (A1) with low-diversity biota.

For an environmental reconstruction of the southern part of the platform only the lithoclasts of the Jákóhegy Breccia provided data. In the marginal zone, a medium to high-energy carbonate sand shoal environment may have existed (microfacies A), similar to that on the northern margin. Meteoric cement in the lithoclasts indicates the early lithification of the carbonate

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Plate V: Fig. 1. Lithoclast of type A in E-type matrix, Core Mp-38, 303.0 m. **Fig. 2.** Lithoclast of type B in E-type matrix, Core Mp-38, 341.5 m. **Fig. 3.** Lithoclast of microfacies type A in D-type matrix, Core Mp-38, 324.0 m. **Fig. 4.** Lithoclast of type B in E-type matrix, Core Mp-38, 321.0 m.

sand, most probably during the short-term subaerial exposure intervals.

Steep erosional slope with depositional terraces (microfacies B–D)

An abundance of lithoclasts in the southern foreland of the Ugod platform indicates a steep erosional slope bounding the platform to the south. However, the fact that in addition to the platform facies (A) various microfacies types of the foreslope were also found in the lithoclasts suggests that as a result of the pre-depositional and syn-depositional tectonic activity, terraces could have formed on the slope where accumulation of sediments may have occurred. Consolidated or semi-consolidated sediments of these terraces may also have subject to clastification and reworking.

The echinoderm-mollusc calcarenite (microfacies B) and the echinoderm calcarenite-calcisilt (C) microfacies were probably deposited under shallow marine conditions, but below the euphotic zone. A certain part of the bioclasts was transported from the platform, but the other part (e.g. majority of the crinoids) may have lived on the slope terrace. The relatively elevated position of this environment is also indicated by the fact that this facies is fairly common in the lithoclasts.

At the toe of the slope a large amount of lithoclasts of varied origin were deposited mainly by rockfall. Periplatform taluses were formed. The intraparticle pores of the grain-supported breccia were filled mainly by echinoderm calcisilt mud (microfacies D) which may also have been deposited on the top of the taluses during quiet periods. This interpretation is also supported by the observation that this microfacies type is common both in the lithoclasts and in the matrix of the lithoclasts.

Debris was deposited in the more distal part of the toe-of-slope environment. Slump structures are also common. Mollusc-echinoderm silt with a large amount of calcisphaerulids (microfacies E) is the characteristic matrix. However, this microfacies-type also appears in the lithoclasts. This moderately deep, pelagic environment may have been very similar to that of the distal zone of the northern slope (E1).

Hemipelagic basin (microfacies F)

Relatively deep (shallow bathyal) hemipelagic basin. The pelagic nature of the depositional environment is indicated by the almost exclusively planktonic biota. Its distant location from the coeval platforms is also supported by the fact that bioclasts and lithoclasts of platform origin did not reach this environment as a rule. However, the high carbonate content of the deposited mud may have originated partly from the surrounding platforms.

Cyclicity

Cyclicity was recognized in the studied successions of both the northern and southern slopes. It was very obvious and easily recognizable in the cored sections at Tapolcafő. In the core T-1 the field observations already revealed the cyclic alternation of three basic lithotypes in the approximately 100 m-thick transitional unit above the typical Ugod Limestone (Haas 1979). It was also confirmed by the microfacies analysis: skeletal (rudist) calcirudite-coarse calcarenites (A5) and fine to medium rudist-echinoderm calcarenites (A3) alternate with calcisphaerulitic fine calcarenite-calcisilt layers (E1, E2).

In the Tfő-4 core, in the lower part of the Ugod Limestone the calcisphaere facies appeared in two horizons. Then, following a thick platform limestone interval, the microfacies types E1 and E2 prevail in the transitional unit (Haas & Pálfalvi 1989). They are punctuated by the intercalations of fine to medium calcarenites (A3). The facies successions and their relationships in the two cores together with the interpretation of their cyclicity are shown in Fig. 6.

On the basis of the facies analysis, two 3rd-order relative sea-level cycles, superimposed on 4th- and probably 5th-order ones, could be recognized in the studied successions. Sea-level rise at the beginning of the first 3rd-order cycle led to the inundation of the Ugod High, colonization of the platform biota and initiation of the carbonate factory on the top of the paleohigh. The early evolutionary stage of the platform was followed by a significant platform progradation during the highstand stage of the cycle. The low angle of the northern slope may have favoured rapid progradation. The first cycle may have ended with a sea-level drop which probably resulted in the subaerial exposure of the top of the platform and consequently reduced shedding and slope accretion.

The next sea-level rise led to the back stepping of the platform. It resulted in the appearance of the deeper slope facies above the platform and upper slope facies. It was followed by a highstand progradation, superimposed however on 4th- and 5th-order oscillations (retrogradations and progradations) prior to the final drowning.

In the Magyarpolány Mp-38 core, recognition of the cyclicity was more difficult. However, on the basis of the microfacies analysis the cyclic alternation of the depositional facies could be detected (Fig. 9). Within the lower member of the Polány Formation two 3rd-order cycles could also be interpreted. The first cycle was initiated by a sea-level rise, the same one which resulted in the establishment of the carbonate factory on the Ugod High. This event is probably reflected in the significant increase of the carbonate content in the deepening-upward basinal succession in the transitional interval between the Jákó and Polány Formations. Although both rises and falls of relative sea-level may result in megabreccia formation and according to the available data the lowstand periods were generally more favourable for the megabreccia accumulation (Spence & Tucker 1997), the Jákóhegy Breccia was probably formed in the highstand stage of the first cycle. Positive correlation between the amount of lithoclasts and the amount of sand-size bioclasts of platform origin appear to support this interpretation (see Fig. 9); since shedding of the platform bioclasts was probably more intense in the highstand periods when the platform was covered by shallow sea (Droxler & Schlager 1985). The first debris flow deposits may have formed during the early highstand. This was followed by basinward extension of the toe-of-slope megabreccia aprons (Jákóhegy Member) during the late highstand. The top of the Jákóhegy Breccia marks the end of the first 3rd-order cycle.

Traces of high-frequency cyclicity were also detectable. The intercalations of the pelagic facies F poor in particles of platform origin may indicate the short-term lowstand intervals whereas layers rich in platform derived bioclasts and also in lithoclasts correspond to the highstand stages.

The second 3rd-order cycle is made up of pelagic carbonates; rudite to arenite-sized grains are missing (Fig. 9). This means that due to retrogradation of the platform only the silt or lutite-sized carbonate mud may have reached the internal part of the intraplatform basins. However, the high carbonate content of the basin sediments indicates survival of the platforms in the immediate neighbourhood. The end of the second cycle is indicated by a significant change in the lithology, in the form of the remarkable increase in the clay and siliciclastic silt content (Fig. 9).

The 3rd-order cycles (sequences) recognized in the studied successions could also be applied for stratigraphic correlation of the basin, slope and platform sections. In the section of the Mp-38 core representing the southern slope of the platform, from the upper part of the Jákó Fm. (top of palyno-zone E) to the base of the Ganna Mbr., two sequences were recognized. Similarly, two sequences were found in the cores at Tapolcafő, representing the northern side of the platform and its northern foreslope, where deposition of the Ugod Fm. probably began in palyno-zone E.

Summary of platform and slope evolution

By the early Senonian, as a combined effect of the pre-Senonian structural evolution and denudation, a WSW–ENE trending elongated, asymmetrical high had come into being, leading to separation of a southern and a northern sub-basin within the Transdanubian Range Unit. The Ugod High may have been bounded by steep multiple faults to the south. In contrast, a gentle slope came into existence on the northern side of the Ugod High. The difference in the altitude of the top of the high and the bottom of the depression may have been about 120–150 m. Filling up of the basins may have commenced in the Santonian. In the first evolutionary stage, a fluvial environment came into being in the northern sub-basin (Csehbánya Formation) and fluvial, lacustrine and paludal deposition occurred in the southern one (Csehbánya and Ajka Formations). It was followed by an abrupt facies change in the second stage, at the end of the Santonian, which led to the inundation of the basin and the establishment of shallow neritic brackish-water conditions in both sub-basins (lower member of the Jákó Marl). At this evolutionary stage, the difference in the altitude of the top of the high and the bottom of the shallow sea may have been about 20–50 m. Subsequently, the relative sea level rise continued. It is clearly reflected in the fundamental change in the biota upsection in the Jákó Formation.

It is highly probable that the rising sea level reached the top of the Ugod High at the very end of the Santonian, when the transitional layers between the Jákó and the Polány Formations were deposited in the basin (Fig. 13). The definite trend of upward-increasing carbonate content within the Jákó Marl may indicate the initiation of the euphotic carbonate production on the surrounding platforms.

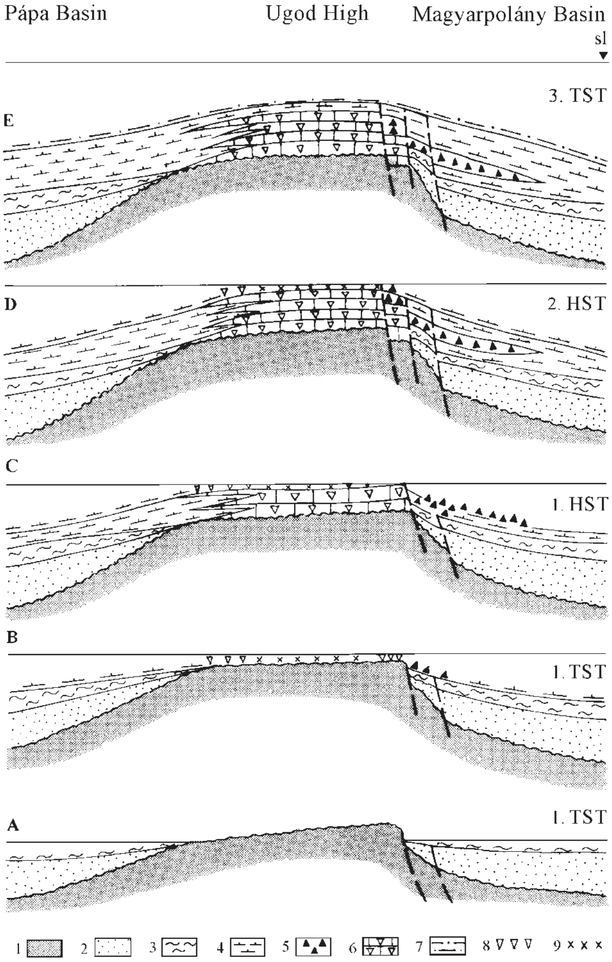

Fig. 13. Stages of evolution of the Ugod High and the surrounding basins during the Santonian–Campanian interval. Abbreviations: TST — transgressive systems tract; HST — highstand systems tract.

The tectonically pre-formed, steep but articulated southern slope was transformed into a steep erosional slope whereas on the more gentle northern side an accretional submarine slope came into being. At the toe of the steep slope, lithoclastic fans were formed, while on the low-angle slope, bioclasts (mainly of platform origin) were accumulated.

During the highstand of the next significant (3rd-order) sea level cycle a rapid progradation of the platform may have taken place on the northern slope, while the lithoclastic fans at the toe of the southern slope prograded toward the inner part of the southern sub-basin. Controlled by higher order sea level oscillations, however, the intensity of the bioclastic and lithoclastic influx from the platform fluctuated.

The transgression at the base of the next 3rd-order cycle led to a significant reduction in the extension of the platform. It is reflected in retrogradation and significant back stepping of the facies zones on the northern slope and cessation of the lithoclast and rudite to arenite-size bioclast accumulation at least in the inner part of the southern sub-basin.

The next sea level rise and the coeval increase of the fine terrigenous influx may have caused the final drowning of the Ugod platform and also of the other rudist platforms in the

Senonian basin of the Transdanubian Range, in the middle part of the Campanian.

Acknowledgments: The investigations providing the basis of the present paper were carried out by the author at the Hungarian Geological Institute. The work was also supported by the Hungarian Academy of Sciences. The author is indebted to Attila Fogarasi (Budapest) for the discussions on the biostratigraphy. J. Michalík, M. Wagreich, A. Galácz are gratefully acknowledged for comments and suggestions that improved the manuscript.

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