Upper Cretaceous

by

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To study the Upper Cretaceous sequence is of outstanding importance for the geological understanding of the Sümeg area. It is in this area that the best-exposed sequences of the Central Range Senonian are found, exposures enabling the student to determine the intricate space and time relations of the lithostratigraphic units and to detect the regularities, interrelations, involved.

In the course of our work the major problem to be solved was to find out the kind of regularity involved in the space and time range of the rock units observed while doing field surveys for the geological map and studying the sequence of a number of artifical exposures and to specify the paleoecological and geohistorical model responsible for the formations therein.

For the solution of these problems it was indispensable to develop a stratigraphic synthesis based on an up-to-date approach. The lithostratigraphic calibration was regarded as a particularly important task, as progress in this respect was believed to have lagged behind progress in biostratigraphic knowledge.

Exploration history

In his travelogue of Hungary, F. S. Beudant (1822) described *Hippurites-* and *Radiolites*-bearing limestones "from a hill to the east of the town, in its immediate vicinity" (supposedly from the Köves-domb) to which he referred as "Kalkstein von Sümeg" and which, with a reference to analogies with France, he classified as Jurassic limestones.

F. Hauer (1862) was the first to distinguish Cretaceous lithostratigraphic units of formation character in the Bakony Mts. He mentioned the Rudist limestone of Sümeg too and believed it to belong to the Zirc Beds.

A. Koch (1872) carried out the separation of the basic stratigraphic units of the Upper Cretaceous formations: "Gryphaea horizon" and "Rudist limestone" which up to latest times served as a basis for the mapping and description of the Cretaceous in the Sümeg area.

J. Böckh (1875) was the first to record on a map of 1:144,000 scale the Upper Cretaceous formations of Sümeg, distinguishing between "Hippurites limestone" and "Marly limestone" units.

In his review of the geology of the southern Bakony (1877) he described *Hippurites* species from the Upper Cretaceous limestone and brought the formation in connection with the Alpine "Gosau formation".

While studying the geology in the neighbourhood of Lake Balaton, L. Lóczy (1913) was the first to attempt at an all-round interpretation of the Upper Cretaceous of Sümeg. In his work he drew the following conclusions: "The Hippurites limestone of the Upper Cretaceous introduces the sequence at Sümeg with a thickness of 50 m or so. These strata are overlain, in 15 m thickness, by marly limestones and bluish-grey marls with enormous quantities of Gosau-type fossils and a thin coal seam. Then, as a third member of 100 m thickness, it is an Upper Senonian Inoceramus-bearing marly limestone that completes an Upper Cretaceous sequence which I venture to estimate at 160 to 170 m". In the light of our present-day knowledge the succession listed by L. Lóczy is not valid, but his description contains some correct observations of detail.

Gy. Rakusz (1935), relying on the results of a couple of days of observations, registered an opinion approximating our present-day knowledge. He identified the argillaceous marls with traces of coal with the coal-bearing formations of Ajka and then, as beds overlying these, he registered a Gryphaea marl—Hippurites marl—Inoceramus marl succession.

In the early 1930's the Hungarian State Collieries (MÁK) launched a coal exploration project during which several exploratory shafts and two boreholes were located. From 1929 on bauxite prospecting was conducted on the Bárdió-tag to the southeast of Sümeg.

In a paper devoted to the geological and paleontological conditions of the Upper Cretaceous at Sümeg, K. Barnabás (1937) listed a rich fauna from the Gerinc quarry and the Köves-domb.

On the basis of a fossil which was recovered from the limestone of the Vár-hegy and which he believed to be a Gryphaea fragment, he assigned the "Vár-hegy limestone" conditionally to the Senonian or, more precisely, he placed it above the Gryphaea limestone. Thus the overlying coal-bearing strata were placed by him, erroneously, beneath the Inoceramus marl.

The work of R. Hojnos (1943) did not enhance progress in the solution of stratigraphic problems of the Senonian; the less so, his assignment to the Senonian of the "silicified Cretaceous limestone" which already L. Lóczy (1913) correctly referred to as Tithonian was a retrogressive venture.

The activity of J. Noszky jr. was a connecting link between pre- and postwar history of geological research and exploration. He spent a lot of time, from 1943 to 1957, with repeated, very careful studies, mapping, of the Sümeg area.

In the Annual Report for 1944 of the Geological Institute he gave the following succession of Upper Cretaceous stratigraphic units:

1. grey carbonaceous clay sequence with corals and Gastropoda
2. argillaceous Gryphaea limestone
3. Hippurites limestone
4. calcareous marl with Gryphaea, then nodular, laminated marl with worm tracks and chert inclusions
5. Inoceramus marl.

In his report of 1957 he changed this opinion inasmuch as the "Cyclolites marl" quoted as the basal bed in his earlier works he did not consider anymore an independent stratigraphic horizon, but he took it to be a different, local facies of the Hippurites limestone.

Parallel to his detailed geological mapping in 1950 the detailed paleontological study of selected fossil groups was begun.

B. GÉCZY (1953) wrote a treatise on Cyclolites, G. KOLOSVÁRY (1954) on other hermatypical and ahermatypical corals. E. SZÖRÉNYI (1955) studied and monographed the Echinoidea fauna.

In 1957, under G. KOPEK's guidance, coal exploration was recommenced and in this context three boreholes had been put down by 1960 (Sp-1, -2, -3) to the north of Sümeg. These yielded important results contributing to the understanding of stratigraphy, as they had penetrated the most complete sequence ever observed in the study area. That the Rudista limestone cropping out at a number of sites fell out of the sequence to the north of Sümeg had become evident. The results of coal explorations were presented in a manuscript report by G. KOPEK (1959). Concerning the genetic circumstances of the coal seams, he pointed out, in his Ph.D. thesis (1961), that the Upper Cretaceous sequence in the Sümeg area was of more marine character than it was the case with Ajka and that this was due to a transgression from the south.

The exploratory activities gave a new impetus to scientific research and monographing. Paleontologist specialists carried out detailed studies of the rich mega- and microfossil collections from the boreholes and, at the same time, they re-studied the materials of surface exposures as well.

F. BARTHA studied (1962) the fossils recovered from the coal-bearing sequence of boreholes Sp-1 and -2 and, primarily on the basis of a paleoecological study of Pyrgulifera, he analyzed the process of its formation.

L. CZABALAY (1961–1982) devoted a number of publications to the biostratigraphic and facies characterization of the Mollusca fauna. The individual groups of strata were distinguished from one another on the basis of their Bivalvia and Gastropoda faunal assemblages. In more than two papers, he dealt with the Rudista fauna of the formations from the Sümeg area and she processed other molluscs of the Rudista limestone, too. She produced paleontological evidence to confirm the heteropical nature of the Hippurites limestone and the Gryphaea marl.

M. SIDÓ (1961–1980) carried out detailed foraminiferological study as well as biostratigraphic and facies evaluation of several boreholes from the Sümeg area. In her paper on the examination of the Foraminifera fauna of the Rudista limestone she presented the results obtained for several samples from Sümeg as well.

F. GÓCZÁN (1961–1971) studied in detail the sequences of the boreholes Sp-1 and Sp-2, establishing well-defined spore-pollen biozones and assigning the Senonian formations to the Santonian, Campanian and Maastrichtian substages. By examining samples from the Gerinc quarry, he confirmed that the "Hippurites limestone" and the "Gryphaea marl" are heteropical counterparts of each other.

In 1972 in our M. Sc. theses, we dealt in detail with the Upper Cretaceous formations and the stratigraphic, facies and paleogeographic characteritics of two subareas—the Köves-domb (J. HAAS) and the Hajnal-hegy (E. EDELÉNYI). Later we devoted several papers to discussing the stratigraphy and paleogeography of the Senonian in the Sümeg area (1977, 1979).

Extension, mode of superposition, stratigraphic subdivisions, local types

The Upper Cretaceous formations are common in the Sümeg area (Fig. 31). Usually denudation- or, in some places, tectonically controlled, the limit of their extension runs at about two kilometres to the southeast of the settlement. The Senonian sequence can be further traced to the northeast, towards Gyepükaján, as shown by drilling results. As regards the Várvölgy basin and the northwest foreland of the Keszthely Mts, the Upper Cretaceous record is just sporadical, so to the southeast of Sümeg both the extension of the Upper Cretaceous and its geological characteristics are quite obscure.

Composed of pelitic rocks, the Upper Cretaceous formations are seldom observable in outcrop, while the surface extension of the carbonate rock units is considerable. On the morphological bench

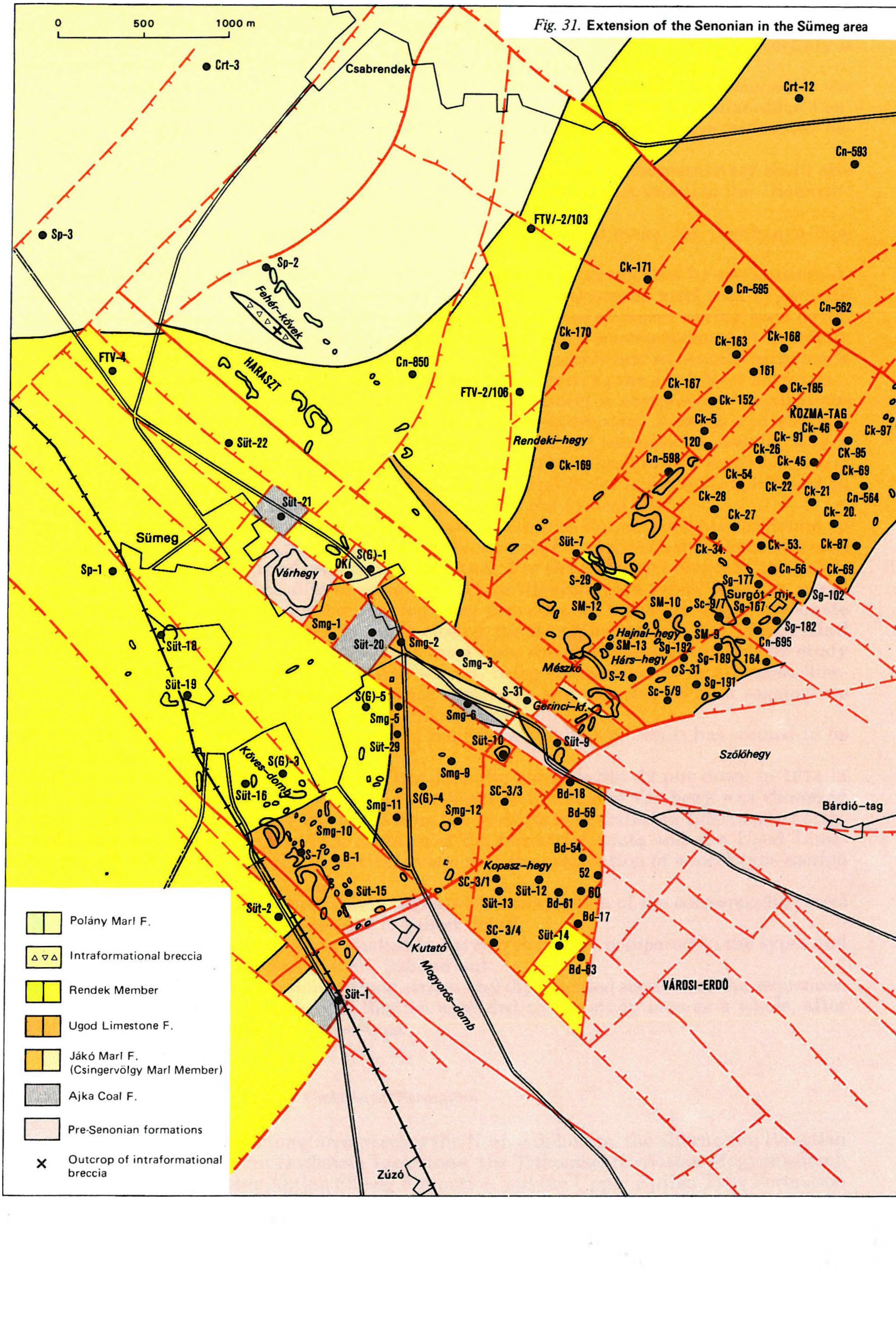


Fig. 31. **Extension of the Senonian in the Sümeg area**

reworked or in-situ rock debris or, in case of marly rocks, by a residual clay layer. The carbonate bottom, as a rule, is little karstified.

At the base of the Senonian sequence, in general, a terrestrial formation only a few metres thick is found, but the terrestrial detritus is sometimes totally absent, so that the beds of the Ajka, Jákó and Ugod Formations can be observed directly at the base of the Senonian sequence.

The common rock types of the Csehbánya Formation are rock debris, argillaceous carbonate detritus, pebbles, breccias, conglomerates, variegated, sandy clays, variegated marls, red clays, bauxitic clays, bauxite, green clays, grey clays, argillaceous marls, carbonaceous clays, freshwater marls, calcareous marls and limestones.

The most typical sequences of the base are shown in Fig. 32. The map shows the contours of the Csehbánya Formation and of the formations directly overlying the pre-Senonian substratum as well. By constructing it, we have tried to answer the question concerning the kind of relationship that may exist between the spatial distribution of the formations directly overlying the terrestrial formations and the geological features of these. To suppose such a relationship has been possible because it is the pattern of the one-time relief that is basically reflected in both geological features.

The terrestrial sediments or the pre-Senonian substratum is covered by various Senonian formations and the worm's eye view of the immediate overburden formations shows a zonal arrangement. (The individual zones are shown in Fig. 32 by the letters A, B and C.)

In the greater, northwest, part of the Senonian-covered area (shown as C) the Ajka Coal Formation is the immediate overburden. Farther southeast, the coal seams are pinching out and in a strip of 200 to 300 m width (shown as B), the overlying beds are constituted by shallow-water marls, calcareous marls, and argillaceous limestones assignable to the Jákó Formation, then farther southeast on, it is the Ugod Limestone Formation that rests directly on a pre-Senonian substratum. In other words, the older Senonian formations will pinch out one after the other in a southeasterly direction and so the younger ones in particular zones will extend beyond the older sediments.

An additional peculiar feature that can be read off the map is the northeast–southwest orientation of the afore-mentioned zones which is broken only at the western margin of the Gerinc range, turning to a north-south direction.

Examining the relationships between the arrangement pattern of the basal formations and the distribution of the terrestrial formations, we can register the following relationships:

1. In the outermost zone (see A in Fig. 32), beneath the Ugod Limestone Formation, no terrestrial formation can be usually found, rock debris of a small thickness and clay detritus (basal bed) being observable in rare cases.
2. Terrestrial formations of rather considerable thickness occur there, where the immediate overburden is represented by the Jákó (Zone B) and the Ajka Formation (Zone C).
3. In some zones—more or less normal to the limits of pinching out of the formation—the terrestrial formations are missing from zones B and C as well.

Regarding pre-Senonian paleogeographic and source area conditions, the most useful information is provided by the pebble-size grains occurring in the terrestrial basal beds. The grains widely vary in size and roundness, though the coarse, scarcely rounded detritus is most frequent. Being of local origin for the most part, each rock variety can be found in situ in the neighbourhood. Where the underlying rock is represented by Upper Triassic limestones or dolomites, there even the pebbles or the breccias are composed of such rock varieties (boreholes Cn-211, -563, -567, -598, Ck-95). In the borehole Ck-167, in addition to poorly rounded Triassic limestone debris accounting for abour 80% of the material, brown-coloured Jurassic chert debris have also been recovered. At the base of the borehole Sp-2 too, Mesozoic chert and limestone pebbles were observed. Where the underlying rock is Lower or Middle Cretaceous, there even the basal detritus, usually very reduced in thickness, is composed for the most part of these formations (boreholes Süt-15, -16, -17).

Beside the coarse-grained detritus, silts and pelites of different lithological character are also abundant in the terrigene sequences. Basically two types of them can be singled out: a green to greenish-grey and variegated, montmorillonite-containing clay on the one hand and kaoliniferous and bauxitiferous clay or bauxite on the other.

In the basal part of the Senonian sequence of the borehole Süt-15, above the debris of local origin of the Upper Barremian calcareous marl, 1.5 m of dark green clay can be found which consists, as shown by the DTA results of M. Földvári and the X-ray analyses of I. Viczián, of montmorillonite as essential mineral and montmorillonite-illite mixed-layer clay minerals as minor components to which some quartz, calcite and pyrite are added.

In the borehole Süt-18, the lowermost 7 metres of the sequence are represented by unfossiliferous, variegated sediments. The montmorillonite content of the dark green, ochre-yellow and purplish-red to purple sandy and silty clay was found to be remarkable (between 11 and 77%) in all of the 10 samples analyzed. (The X-ray diffraction analyses were performed by A. Szemethy.) It is worth mentioning

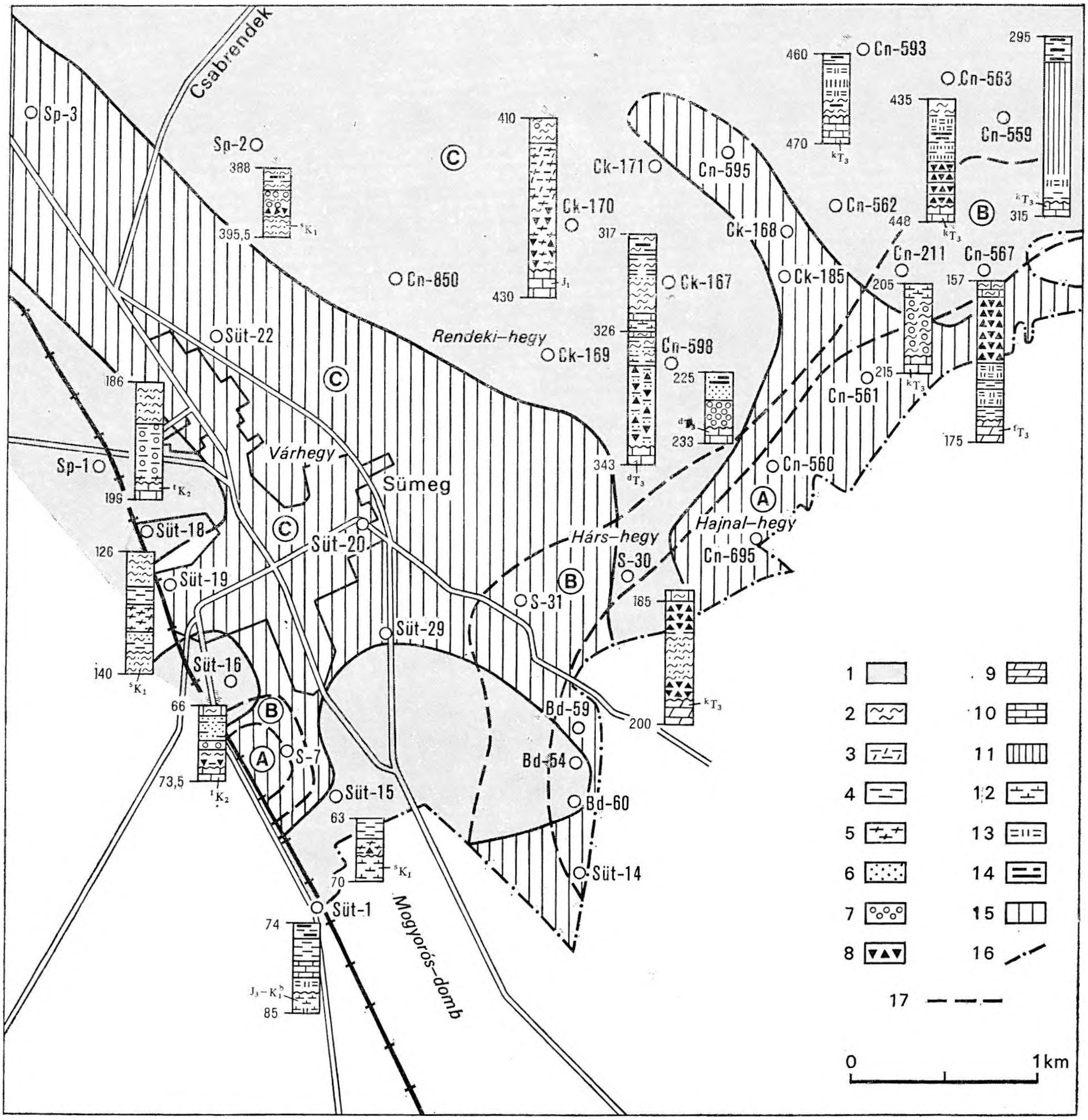


Fig. 32. Extension of the Csehbánya Formation and its geological features

1. Csehbánya Formation, 2. marl, 3. variegated marl, 4. clay, 5. variegated clay, 6. sand, 7. gravel, 8. detritus, 9. dolomite, 10. limestone, 11. bauxite, 12. calcareous marl, 13. bauxitic clay, 14. coal, 15. the Csehbánya Formation is missing from the Senonian sequence, 16. extension limit of the Senonian, 17. boundary of facies zones, facies zones *A-B-C*

that the montmorillonite content in the green rock varieties was 25 to 31%, that in one sample of purple colour it was 40%, in one ochre-yellow sample 58% and that the maximum, 77%, was observed in a sample of purplish-red colour. From among the clay minerals other than montmorillonite only a low amount of illite and mixed-layer illite-montmorillonite mineral could be registered.

From the variegated clay layer above the basal bed composed of detritus of foot-wall origin in the borehole Sp-1 40% mixed-layer illite-montmorillonite was detected by X-ray analysis (M. Melles). The heavy mineral spectrum of the rock material of this bed was shown to be poor by G. Noske-Fazekas, unlike it is the case with the underlying Lower to Mid-Cretaceous formations. Low quantities of zircon, garnet, epidote, tourmaline and chlorite could also be observed. The amount of dolomite grains, however, proved to share a considerable part of the mineralogical composition.

Our discussion of the bauxite rock types here will be quite brief, for their qualitative, genetic, etc. characteristics are to be dealt with under a separate heading. We shall restrict ourselves here to analyze the relations of the bauxites known from the base of the Senonian and other terrestrial formations and the relationships observed between the Senonian formations and the bauxite rock bodies.

Bauxitic rock types were exposed by some boreholes (Cn-593, -563, -559, -567) in the northeast part of the marginal zone, in a belt, where the Ajka Formation is heavily reduced in thickness or it may even be pinching out. That in two boreholes farther northwest (Cn-563, -593) carbonaceous clay interbeds beneath or between the bauxitic layers were observed, is worthy of mention. In three of the four boreholes the Senonian sequence is introduced not by bauxite, but by other terrestrial sediments such as breccias, clays or carbonaceous clays and marls. Thus it is obvious that the Upper-Cretaceous-covered bauxitiferous strata are products of a terrestrial accumulation taken place at the beginning of the Senonian sedimentation cycle, just like it is the case with the multitude of rock varieties listed in the foregoing. It is also worth mentioning that in the cases learned thus far the pre-Senonian basement is an Upper Triassic sequence (Rhaetian) composed of an alternation of limestones, dolomites and marls that cannot be regarded as liable to karstification. This fact suggests that in the cases analyzed here the site of deposition and the conditions of preservation of the bauxites and their isochronous facies counterparts were primarily controlled by the Senonian facies relations and that the lithology of the underlying rock types played only a quite subordinate role in this.

Chronostratigraphy

From the terrestrial formations no fossil has been recovered, their exact age being unknown. According to the results of paleontological studies by F. Góczán, the basal beds of the Ajka Formation are of Upper Santonian age (Oculopollis-, Complexipollis Zone). As supposed by M. Sidó (1969), however, they would be older than Lower Santonian, probably Coniacian.

The terrestrial sediments of the Csehbánya Formation may be regarded as nearly contemporaneous with the lower strata of the Ajka Formation. As already mentioned, as one proceeds from the northwest to the southeast, the older formations pinch out, being overlapped by the younger.

Consequently, a regular transgression cycle can be delineated, where the lowermost beds overlying the terrestrial layers tend to represent a marine facies of normal salinity. Taking one datum level, a configuration with a landward decrease in salinity may be supposed. Hence the hypothesis (otherwise valid to the transgressive cycle in general) suggesting that the formations of one and the same facies (rock type) tend to become younger (or in a boundary case, isochronous) as one proceeds toward the one-time shoreline.

Since the coal-bearing sequence encompassing a complete facies succession (freshwater to shoreline) is normally underlain by only a terrestrial suite of reduced thickness and since terrestrial sediments of greater thickness occur in the zone of thinning of the Ajka Coal Formation, where even the lowermost coal-bearing beds contain brackish-water fossils, we feel fully entitled to suppose that here a considerable part of the terrestrial sediments is contemporaneous with the older limnic beds of the Ajka Formation.

Since palynological results gave an Upper Santonian age for the beginning of the Ajka Formation, the Csehbánya Formation seems to correspond to the same time interval.

Ajka Coal Formation

The Ajka Coal Formation occurs in an area lying northwest of the Köves-domb–Hárs-hegy–Kozma-tag line. No outcrops of it are known. Only a thin Pliocene or Quaternary covers it in the territory of the tectonic blocks to the northwest and southeast of the Vár-hegy.

The formation is composed of rock types varying rapidly both laterally and vertically. High variability is a characteristic feature. Thus, along with the basic similarity, marked divergencies are also observed in the lithologic composition and paleontological pattern of the type sequence (borehole Süt-22) and the additional sections. The major common features are as follows: presence of carbonaceous rock varieties; dark-coloured (dark grey, brownish-grey) pelitic rock varieties of a high organic content; frequency of silty, pelitic sediments with sand lenses and bioclast lenses composed of ground fossil material and lumachelle beds, respectively a regular cyclic repetition of these. The formation may overlie directly the pre-Senonian (Triassic-Aptian) basement or the terrestrial formations. Its thickness varies from 0 to 110 m. Its overburden was in all the observed cases represented by the Csingervölgy Member.

Local type section

For local type of the formation the 101.0 to 162.7 m interval of the borehole Süt-22 (Fig. 33) has been designated.

The weathered surface of the Aptian Tata Limestone in the borehole sequence is directly overlain by the coal beds of the Ajka Formation.

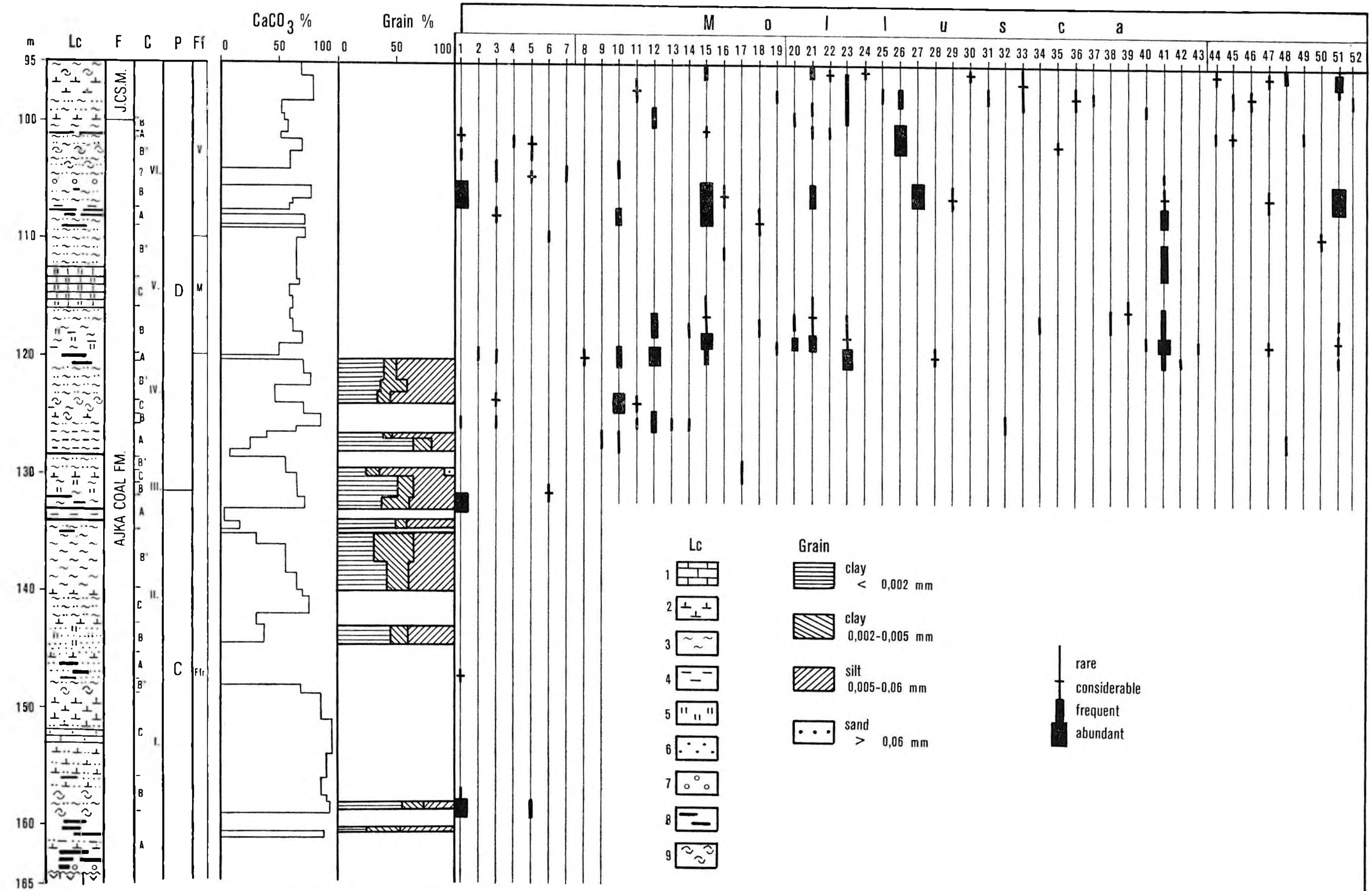


Fig. 33. Local type section of the Ajka Coal Formation: borehole Süt-22

Lithologic column (Lc): 1. limestone, 2. calcareous marl, 3. marl, 4. clay, 5. siltstone, 6. sand, 7. gravel, 8. coal, 9. lumachelle. — ***Formations*** (F): *J.Cs.M.* Csingervölgy Member of Jákó Marl Formation. — *C* cycles, *P* pollen zone, *Ff* Foraminifera: *M* Miliolina assemblage, *V* Vidalina assemblage, *Ffr* beds free from Foraminifera. — *Mollusca:* Brackishwater species: 1. Fragment of Pyrgulifera, 2. Potomia, 3. Corbicula, 4. Melania, 5. Hemisinus csingervallensis, 6. H. lignitarius, 7. Goniobasis (1—7. oligo—miohaline), 8. Anomia intercostata, 9. Astarte subcretacea, 10. Cyrena baconica, 11. C. solitaria, 12. Cardita, 13. Cypricardia, 14. Cardium sp., 15. C. ottoi, 16. Cytherea fragment, 17. Glauconia, 18. Cerithium, 19. Turritella sp. (8—19. plio-brachyhaline). Species enduring changes in salinity: 20. Nucula, 21. Limopsis, 22. Pecten sp., 23. P. laevis, 24. Plicatula, 25. Lima sp., 26. Ostrea sp., 27. Lopha sp., 28. Exogyra sp., 29. Modiolus, 30. Mytilus sp., 31. M. antrakopholus, 32. Crassatella galloprovincialis, 33. Dosinia, 34. Cytherea polimorpha, 35. Tanaliopsis, 36. Otostoma, 37. Tectus, 38. Pirenella sp., 39. P. münsteri, 40. Haustator sp., 41. Turritella decipiens repelini, 42. Cryptorhytis baccata, 43. Actaeonella. Marine species: 44. Arca inaequidentata, 45. Cucullaea, 46. Pectunculus, 47. Astarte similis, 48. Crassatella macrodonta var. sulcifera, 49. Tellina sp., 50. Corbula sp., 51. C. angustata, 52. Fusus

The thickness of the formation in the type sequence is 63 m. It is composed for the most part of sands and silty marls with bioclast lenses and, at the top, of dolomitic marls including thin layers of coal and/or marl, calcareous marl and limestone and also sandstone. The vertical variability of the sequence is also significant, changes in lithology having been recorded at an average of 1.5 m intervals in the megaloscopic description of the unit.

The rock types are generally of dark grey or brownish-grey colour, locally with lighter bands and patches.

A regularity, cyclicity, in the alternation of the rock types can be observed and this is followed by qualitative and quantitative changes in the molluscs the most characteristic fossil group. The general structure of the cycles is as follows:

Member A Dark grey carbonaceous clay, argillaceous coal, browncoal abounding with *Mollusca* shells.

Member B Grey to brownish-grey silty marl (less frequently, sandstone) with sand lenses, usually poor in fossils, but the shell fragments of *Mollusca* are locally enriched in thin laminae of cm thickness. Coalified plant remains are abundant.

Member C Light grey calcareous marl, dolomitic marl, limestone and dolomitic limestone (less frequently, siliceous limestone).

The next cycle member (*B'*) shows features that are identical with those of *B*. This is overlain again by carbonaceous beds representing Member *A* of a new cycle. So we have a clear idea of a symmetric cycle of which *C* is the central element. Its formula reads: ... $A_1B_1C_1B_1'A_2$ ... The cyclic changes of rock composition are described by the diagram representing the $CaCO_3$ content (Fig. 4), in the lower half of the cycle the carbonate content grows gradually, in the upper one it decreases.

As mentioned above, the abundances of the individual fossil elements are connected with particular cycle members. The correlation is even more clear if the relations between the quantitative distribution patterns of the successive cycles and the fossils indicative of different salinity are examined (Fig. 33). The incoming of brackish-water and normal salinity fossils in higher parts of the sequence and their predominance in Member *B* of the uppermost two cycles (V and VI) can be traced quite clearly.

Enduring freshwater or freshening environments, the Mollusca genera *Pyrgulifera, Hemisinus, Melania (Melania obeloides)*, *Goniobasis*, *Corbicula*, *Potomonya* and *Cyprina* are characteristic in the lower interval of the formation (up to 120 m), where they concur with *Munieria*-type green algal remains, and fructifications of *Chara*. In the coal-bearing cycle-member *A*, however, the aforementioned molluscs regularly recur up to the upper formation boundary. In the lower part of the sequence, Member *B* too is characterized by limnic fossils, but in its upper part is is this very cycle member in which regularly appear the brackish water *Glauconia* and *Turritella* species as well as *Astarte subcretacea* REPELIN, *Cyrena buconica* TAUSCH, *Cypricardita testacea* ZITTEL, *Cardium ottoi* GEINITZ, *Cardita granigera* GÜMB., *Anomia intercostata* ZITTEL, etc. and/or marine to brackish-water forms like *Crassatella gelloprovincialis* MALK., *Mytilus* sp., *Limopsis calvus* ZITTEL, etc. (see Plate XXIX). Similarly to Member *B* of Cycle V is bound the appearance of Foraminifera with the incoming of *Nummofallotia cretacea* (SCHLUMB.) (119.5 m), then with the Miliolidae–Cornuspira–Vidalina assemblage.

Members *C* and *B'* are again characterized by the predominance of fossils indicative of waters on the way of freshening.

In addition to the quite distinct cyclicity of the sequence a definite trend is felt in the paleontological features too: it is the marine fossil elements that become increasingly predominant in the successive cycles. Obviously, some difference is also manifested in the lithologic composition of the individual cycles, each showing some individual features. For example, Member *C* may happen to be absent or hardly observable.

Six or six and a half cycles can be traced in the sequence selected for type which varies in thickness between 6 and 16 m with an average of 10 m. The individual coal-bearing intervals are from 1 to 3 m thick. These are coal beds of a few cm thickness alternating with carbonaceous clays and clays.

Some samples of the type section representing Member *C* of particular cycles were analyzed in detail.

As shown by the results, the carbonate content in the Ajka Formation above Member *C* of Cycle II is associated, for the most part, (50–80%) with dolomite. The maximum of dolomite content was obersved in Cycle IV [49% $CaMg(CO_3)_2$ at 5% $CaCO_3$]. That, according to A. SZEMETHY's X-ray results, the $CaCO_3$ content in some cases is represented or a considerable part by aragonite is worthy of mention.

Of the clay minerals, kaolinite, illite and montmorillonite were present in varying amount, but jointly in almost all samples. Mixed-layer illite-montmorillonite minerals are considerable in quantity.

The quantitative and qualitative variation of the clay minerals throughout the section does not exhibit any regularity.

The allothigenic components of sand size are for the most part quartz grains (70–80%). Potash feldspar grains are present in 5 to 10%. Allothigenic heavy minerals are quite low in amount (0.05–0.7%). According to the results of A. LENKEI, garnet, muscovite, tourmaline, epidote, chlorite and hornblende occur in the lower section interval and garnet and augite at the top, their amount being comparatively high in both cases.

Above the Ajka Formation, with a transitional development, the Csingervölgy Member of the Jákó Formation follows. The transitional interval—including by and large the topmost 10 m of the Ajka Formation and the basal 10 m of the Csingervölgy Marl, respectively—is composed by dark grey to brownish-grey, sand-lensed marls and calcareous marls.

Mostly reduced to tiny debris, the calcareous fossils attain an extremely high, locally rock-forming, percentage.

Taking the whole sequence into consideration, the lithological variability attains its maximum in this interval.

The boundary between the two formations has been drawn by us at the level of the last coal stringers (101 m). At the boundary the Mollusca fauna itself exhibits a marked change, for the genera *Pyrgulifera*, *Hemisimus*, *Melania* and *Corbicula* fall out of the faunal assemblage definitively.

Geological features

The extension and thickness of the Ajka Coal Formation are illustrated in Fig. 34. In the figure 3 sections subperpendicular to the isopachs and crossing the most thoroughly studied exposures (Sections I, II and III) are shown.

By plotting the profiles we have pursued the aim to correlate the geological features observed in the individual drilling sections and to recognize the changes in thickness and geological features displayed by the formation in the direction of greatest thickness variation.

All these circumstances have made it advisable for us to select a geologically well-motivated horizon as a base of reference in dealing with the sequences involved. In the present case the Jákó Formation and the base of the Csingervölgy Member, respectively, were selected as such. This solution has been believed adequate because the low degree of variability of the facies characteristics of the Csingervölgy Marl (at least over the area of distribution of the Ajka Formation) seems to indicate that the deposition of its basal layers was taking place already on a rather level surface. Consequently, profiles that are plotted in this way will enable us to analyze even the morphological features that existed prior to or during the sedimentation of the Ajka Formation. Naturally, reference horizons do not delineate an isochronous level, for the formations may be supposed to tend to become, as a rule, gradually younger from the northwest to the southeast, owing to facies shifts in the course of transgression.

By analyzing the profiles (Fig. 34), we have attempted to draw conclusions as to the causes responsible for the thickness patterns presented too. Namely, it may be figured out that sequences of different thickness were formed during equal time intervals at varying sedimentation rates, but it is also possible that a low thickness reflects a shorter time of deposition.

Profile I (Fig. 35) has been drawn by starting from the Mogyorós-domb, traversing the Köves-domb and past the west side of Sümeg as far as Forrókút.

The easternmost exposure of the section is the borehole Süt-15 (Fig. 36) which intersected the formation in a thickness of 31 m. This is exactly the half of the thickness of the type sequence. The coal-bearing unit is underlain by one metre and a half of clay covering the Sümeg Marl. Above it, rock types standing close to the upper part of the type sequence can be found representing one complete cycle and a half *(A–B–C–B–A–B–C)* with two thin coal beds. Among the fossils no fresh-water species was found.

In the horizon of the lower coal bed the specimens of *Cardium ottoi* GEINITZ, species predominant throughout the sequence, already appear. *Nucula concinna* Sow., *Pecten laevis* NILSSON and *Astarte similis* MÜNSTER are frequent bivalves. The horizon of the upper coal bed is characterized by the incoming of *Glauconia* and *Pyrenella* forms and also *Lima* sp. and *Limopsis calvus* ZITTEL, each being a brackish-water form or one enduring a reduction in salinity (Plate XXIX).

Foraminifera in the lower, coal-bearing interval of the sequence are quite sporadical. It is *Ostracoda* that predominate in the microfaunal assemblage. In the uppermost metres, however, a Vidalina–Miliolina assemblage represented by a wealth of individuals was observed.

In the borehole S-7 (K-1) put down on the Köves-domb Barremian calcareous marls are overlain by about 10 cm of yellow or green clays and a 20-cm-thick bed with coal stringers. In its overburden limestone beds assigned to the Ugod Formation and containing debris of local origin deriving from the Sümeg and Tata Formations were exposed.

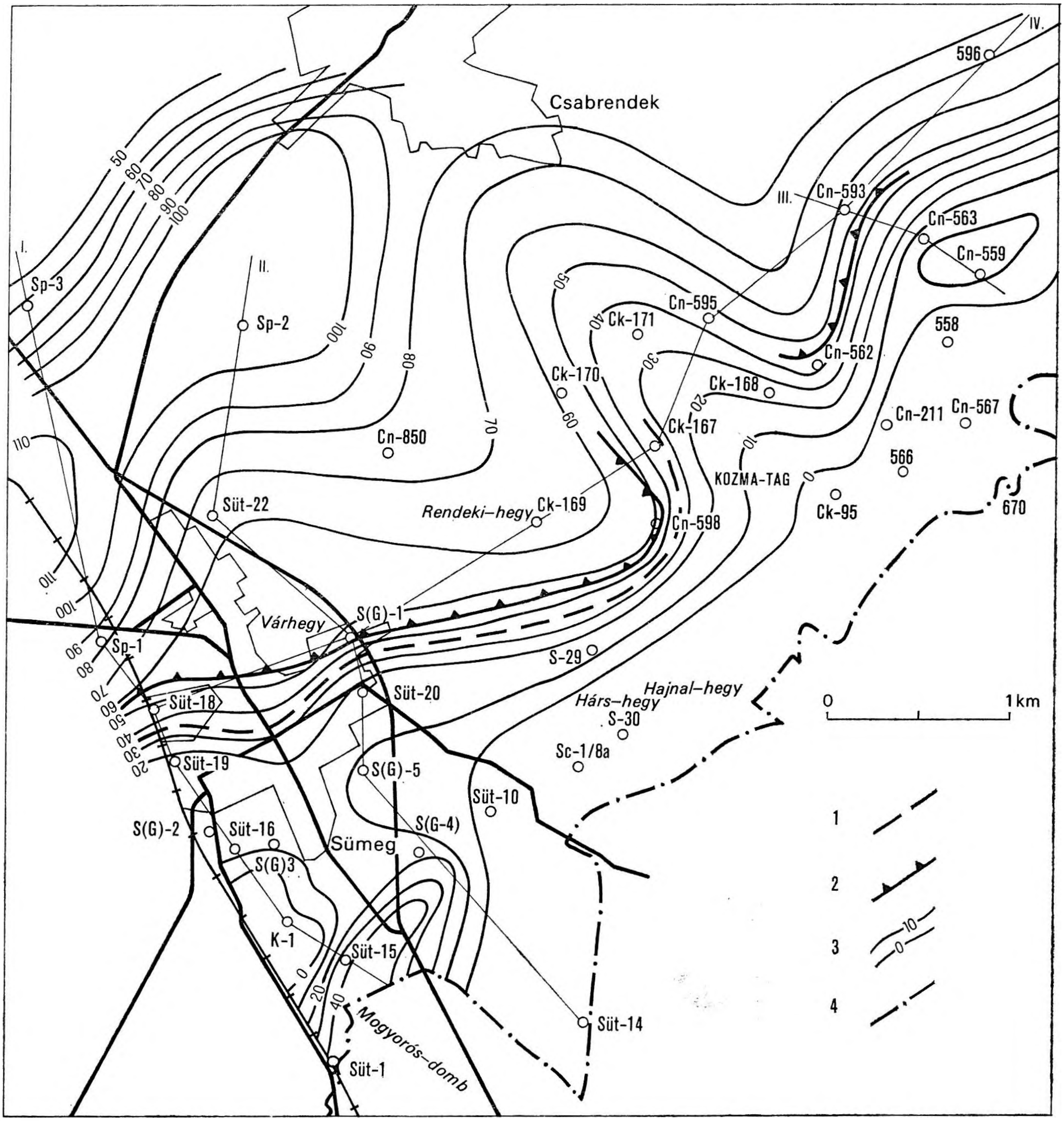


Fig. 34. Thickness of the Ajka Coal Formation

1. Boundary of extension of limnic facies based on the first appearance of Foraminifera, 2. number of coal-bearing cycles in the direction of the spines ≥7, 3. isopachs of the Ajka Coal Formation, 4. boundary of extension of the Senonian

In the Sintérlap quarry to the northwest of the borehole the coal-bearing beds are completely lacking and the Aptian crinoidal limestone is overlain by Hippurites limestone.

In the borehole Süt-16 put down on the northwest margin of the Köves-domb (Fig. 36) 12 m of rock characteristic of the Ajka Formation was observed: dark grey, sandy, sand-lensed argillaceous-marls, sandstones and lumachelle layers rich in coalified plant remains. No coal bed was cut by the drill.

The Mollusca fauna is characterized by a brackish-water assemblage: *Nucula concinna* Sow., *Pecten laevis* NILSSON, *Cardium ottoi* GEINITZ, *Corbula angustata* Sow.

Already at the base of the sequence do *Foraminifera* appear, being represented by the individuals of the brackish-water Vidalina–Nummofallotia–Miliolina assemblage.

The thickness of the formation is only 13 m in the borehole Süt-19 (Fig. 37) too, but a thin coal-bearing group of strata can already be observed. Above the first coal-bearing sequence (at only 1.5 m from the underlying bed) already a brackish-water fossil assemblage was found with the predominance of *Cardium ottoi* GEINITZ and great quantities of specimens of *Nucula*, *Cyrena* and *Pirenella* species.

Similarly to the brackish-water marine molluscs, the Cornuspira–Nummofallotia–Miliolina assemblage of Foraminifera (*Nummofallotia cretacea* SCHL., *Cornuspira senonica* DUN., *Quinqueloculina* div. sp., *Spiroloculina* div. sp., *Valvulineria asterigerinoides* PLUMMER) appears in the basal beds of the formation already. With a view to the cyclicity of the facies, it is not too surprising that, higher up the profile, again a supposedly limnobrackish interval devoid of Foraminifera will follow.

A radical change compared with the foregoing was registered in the sequence of the borehole Süt-18 (Fig. 37), though the exposure lies only 300 m away to the northwest of the borehole Süt-19.

The thickness of the sequences discussed in the foregoing is only a fraction of that observed in the borehole Süt-18 and though the rock types are similar, the coal-bearing beds increase in number. Essential difference is manifested in the distribution of fossils reflecting the environment of deposition. Whereas in the sequences hitherto analyzed the marine molluscs (*Cardium*, *Nucula*, *Corbula*, *Pecten*, *Lima*, etc.) and Foraminifera (*Nummofallotia*, *Vidalina*, *Cornuspira*, *Miliolides*, *Rotalia*, stc.) appeared for the most part at the base of the formation, in the exposure in question this was observed only about 40 m higher.

The section of the Ajka Formation studied in the borehole Süt-18 is close to that of the borehole Süt-22 designated as type both regarding its thickness and other features. A difference does exist, however, is that in this sequence (more precisely, in its lower interval) the carbonaceous cycles typical of the formation are not represented in such a regular development as it is the case with the type section and that even the number of the coal-bearing intervals is reduced compared with the type (a total of only 4).

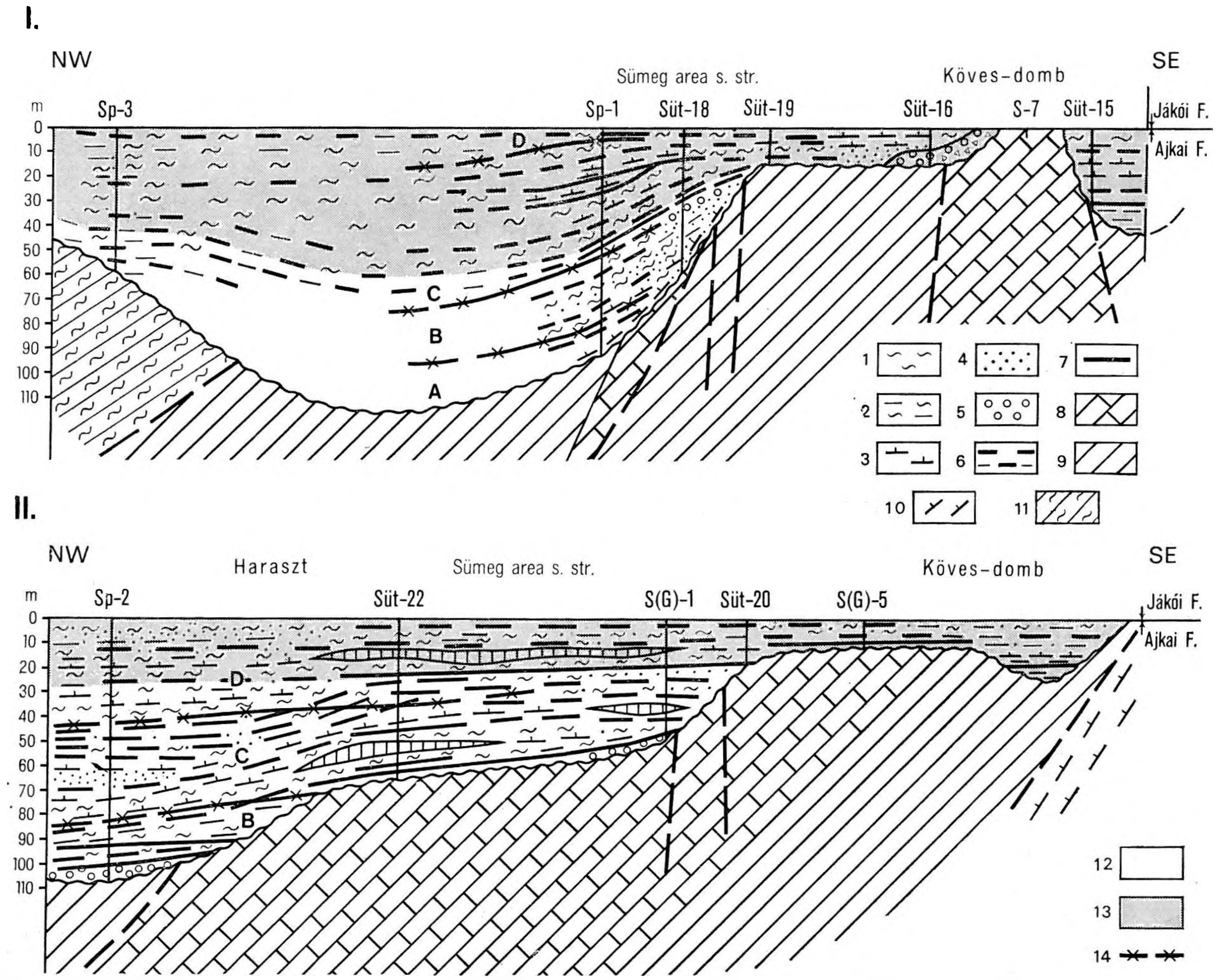


Fig. 35. Changes in the thickness and the lithological features of the Ajka Formation, along NW–SE profiles
1. Marl, 2. argillaceous marl, 3. calcareous marl, 4. sand, 5. gravel, 6. carbonaceous marl, 7. coal, 8. Tata Fm, 9. Sümeg Fm, 10. Mogyorós-domb Fm, 11. Kössen Fm, 12. freshwater facies, 13. brackish-water facies, 14. boundary of pollen zones, pollen zones *A-B-C-D*

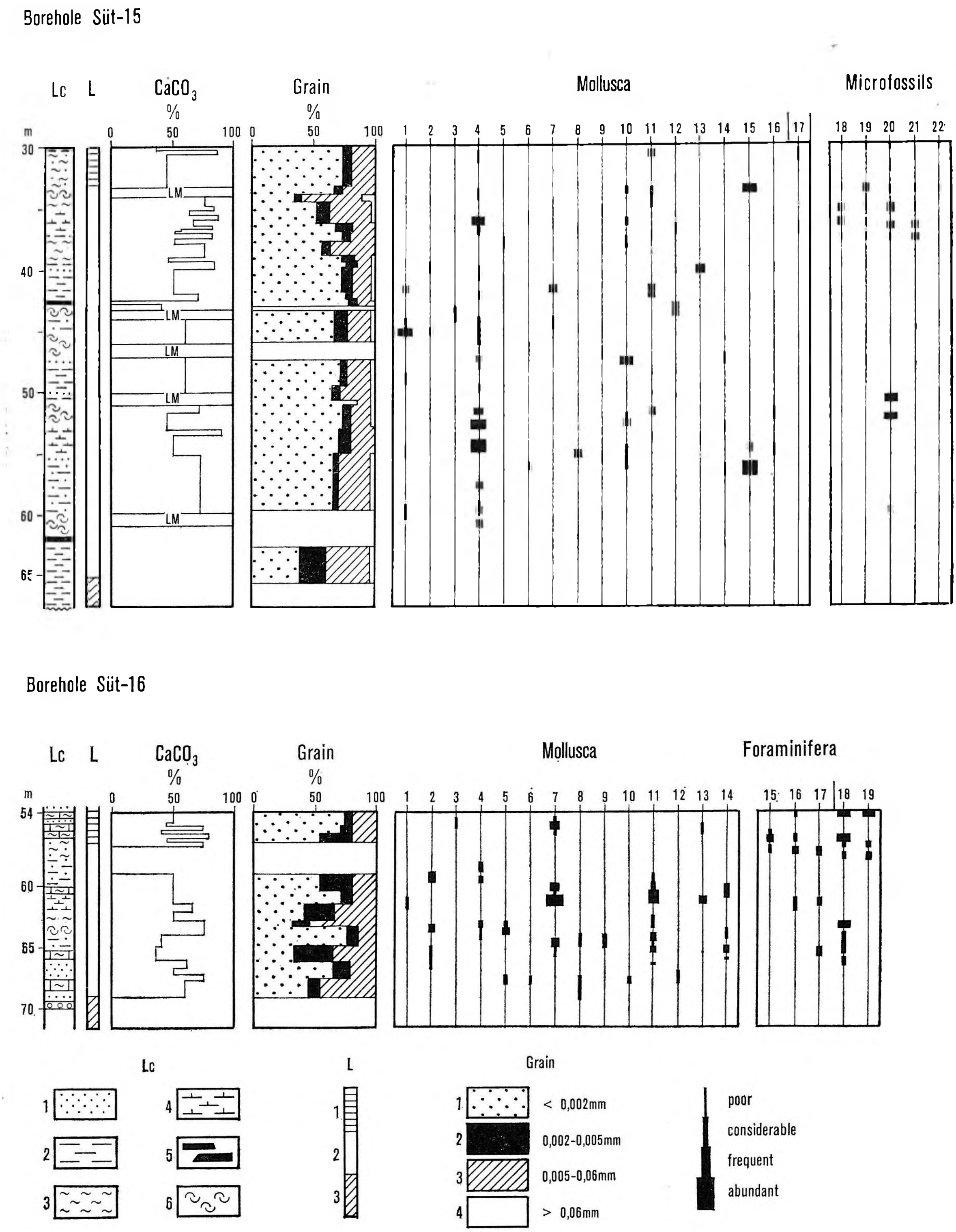


Fig. 36. The Ajka Formation interval of the boreholes Süt-15 and -16: lithologic column and analytical record

Lithologic column (Lc): 1. sand, 2. clay, 3. marl, 4. calcareous marl, 5. coal, 6. lumachelle. — *Lithostratigraphic units* (L): 1. Csingervölgy Member of the Jákó Marl Formation, 2. Ajka Fm., 3. Csehbánya Fm. — *LM* lumachelle bed. — *Grain:* 1—2. clay, 3. silt, 4. sand. — *Brackish-water facies of borehole Süt-15:* 1. Turritella, 2. Glauconia kefersteini, 3. G. obvoluta. 4. Cardium, 5. Cypricardia, 6. Cardita; euryhaline facies of the same borehole: 7. Pirenella, 8. Cerithium, 9. Bulbus, 10. Nucula, 11. Pecten, 12. Lima, 13. Limopsis; its marine facies: 14. Tellina, 15. Astarte, 16. Corbula; 17. Cyclolites, 18. Vidalina, 19. benthonic Foraminifera, 20. Mollusca, 21. Ostracoda, 22. Echinodermata. — Brackish-water facies of the *borehole Süt-16:* 1. Turritella, 2. Cardita; its euryhaline facies: 3. Haustator, 4. Nucula, 5. Mytilus, 6. Modiola, 7. Pecten, 8. Lima, 9. Limopsis, 10. Ostrea; its marine facies: 11. Corbula, 12. Dentalium, 13. Astarte, 14. Corbula; Foraminifera: 15. Vidalina, 16. Nummofallotia, 17. other benthonic Foraminifera. — 18. Ostracoda, 19. Echinodermata

Located in the vicinity of the lime-burning plant of Sümeg, the borehole Sp-1 (Fig. 38) is also characterized by a sequence similar to that of the type section, but the thickness of the formation is greater (83 m) and the coal-bearing intervals too are greater in number than it is the case with the type. In the lower part of the formation the *Foraminifera*-free interval already exceeds 50 m in thickness and, as shown by F. BARTHA's results, the brackish-water assemblage gains predominance only 45 m above the base of the formation.

The lower, freshwater interval is characterized by the predominance of *Pyrgulifera glabra* (HANTKEN) and the presence of the genera *Helix, Bulimus, Melania, Pachyostoma, Goniobasis* and *Cyrena. Pyrgulifera glabra* var. *suemegensis* and varieties of *P. inflata* (YEN) and also the species *Dejaneria bicarinata* STOL. occur in the brackish-water beds. *Foraminifera* appear for the first time in the sequence containing marine-brackish *Mollusca (Turritella, Cardita, Pecten).*

The borehole Sp-3 was put down at 2 km to the northwest of Sümeg and it penetrated the formation in a thickness of 56 m. The cycles are generally irregular, the lower interval being characterized, as a rule, by the disappearance of the sandy-pelitic member *(B)*, the upper one by that of the carbonate one *(C)*. The coal-bearing sequence is of modest thickness, being represented, for the most part, only by carbonaceous clay and carbonaceous marl rock types.

According to the results of studies on molluscs, the brackish-water faunal elements appear at 34 m from the base. Most frequent are *Cardium ottoi* GEINITZ, *Corbula angustata* SOW., *Limnopsis calvus* SOW., *Pecten laevis* NILSSON, *Odontostomia* sp., *Astarte similis* MÜNSTER and *Nucula* sp.

Plotted across the exposures between the Városi-erdő and the northwest side of the Rendeki-hegy, parallel to No I, Profile II (Fig. 35) provides a picture that is, in its basic features, similar to the former. From the sequence of the borehole Süt-14 representing the southeast end-point the formation is missing and in the borehole S(G)-5 it is yet only 9 m thick and of marine-brackish facies throughout this interval. In the boreholes S(G)-1 and Süt-22 by the Vár-hegy, however, it approximates or even reaches 50 m and, beneath the brackish-water interval, the limnic facies appears, too.

The borehole Sp-2 (Fig. 39) penetrated the thickest Ajka Formation of all boreholes ever put down in the Sümeg area (110 m). In the sequence, 6 cycles can be recognized, though there are cases when it is the coal-bearing member *(A)* of the cycles that is reduced in thickness (e.g. the base of Cycle II) or when it is interrupted by argillaceous marl, marl and sandstone layers. It is difficult to delineate the upper boundary of the formation, for after the disappearance of the coal beds the rock types characteristic of the formation persist and a gradual decrease in sand content and a parallel growth of the carbonate content lead uninterrupted into the overlying lithostratigraphic unit.

According to F. BARTHA's results, the Mollusca fauna of the formation is observed to be characterized, in the lower two-thirds of the sequence, by forms indicative of a freshwater environment *(Pyrgulifera glabra* HANTKEN, *Strophostoma, Megalostoma, Helix, Melanopsis, Bulimus, Cyrena* and *Corbicula)* and, in the upper third, by limno-brackish forms *(Pyrgulifera glabra* var. *suemegensis* BARTHA, *P. inflata* YEN, *Dejaneria bicarinata* STOL., *Melanopsis lignitarum)* as well as marine-brackish ones *(Cardita, Turritella, Glauconia, Ampullina).*

The appearance of Foraminifera too (*Nummofallotia cretacea* SCHLB., *Cornuspira senonica* DUNIKOVSKY, *Cornuspira* sp., *Vidalina hispanica* SCHLB., *Lamarckina ripleyensis* CUSH., *Rotalia cretacea* TEN DAM, *Rotalia* sp., *Epistomina subcretacea* TEN DAM) is bound to the third one-third of the sequence of the formation.

Judging by the thickness and the geological features of the Ajka Formation, 2 areas get laterally individualized in the sections shown. In the southeast, a low thickness and a reduced number of coal-bearing intervals are characteristic. That a marine (marine-brackish) faunal assemblage occurs already at the base of the formation and that in all boreholes but Süt-19, curiously one of boundary position, the representatives of *Pyrgulifera* are totally absent is an important feature. The total disappearance of the formation in the sequence of Sintérlap quarry on the Köves-domb calls attention to the particular conditions under which the sedimentation in the immediate neighbourhood of the exposure took place.

In the northwest (boreholes Süt-18, Sp-1, -2, -3), greater formation thickness and greater number and thickness of the coal beds are characteristic. Foraminifera and mollusca indicative of a marine influence appear only in the upper third of the sequences or at their top. In the deeper parts of the sequences, however, freshwater or limno-brackish molluscs are abundant with green algae of *Munieria* type and ostracods.

In the northwest the formation consists of two genetically different parts: a lower one of comparatively greater thickness, predominantly of freshwater or limnobrackish origin, with several coal beds and an upper, marine-brackish one. The transition between the two is continuous or, to be more precise, it manifests itself in such a way that in the upper part of the limnic interval the first manifestations of a brackish-water environment already appear and that, on the other hand, sediments still exhibiting freshwater characteristics can be found in the basal part of the overlying

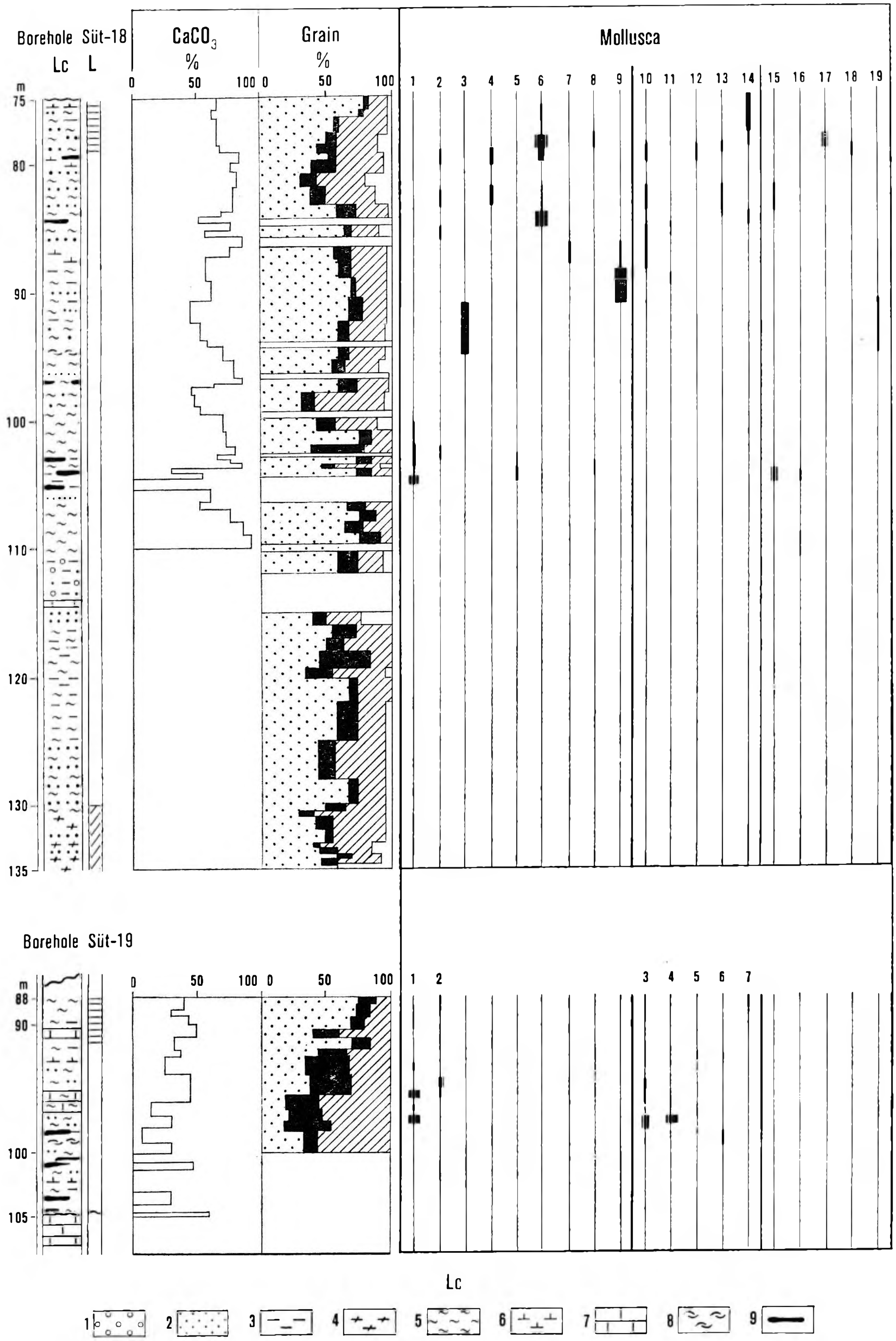


Fig. 37. The Ajka Formation interval of the boreholes Süt-18 and -19: lithologic column and analytical record

Lithologic column (Lc): 1. gravel, 2. sand, 3. clay, 4. variegated clay, 5. marl, 6. calcareous marl, 7. limestone, 8. lumachelle, 9. coal. — B r a c k i s h - w a t e r f a c i e s of the *borehole Süt-18:* 1. Pyrgulifera, 2. Hemisinus sp., 3. H. lignitarius, 4. Glauconia sp., 5. Melanopsis sp., 6. Cardium ottoi, 7. C. sp., 8. Cyrena solitaria, 9. Cyrena baconica; its e u r y h a l i n e f a c i e s : 10. Turritella difficilis repelini, 11. Cerithium sp., 12. Tectus sougrainensis, 13. Nucula concinna, 14. Pecten laevis; its m a r i n e f a c i e s : 15. Aporrhais sp., 16. Astarte similis, 17. Corbula angustata, 18. Crassatella macrocarinata, 19. Corbicula ajkaensis. — B r a c k i s h - w a t e r f a c i e s of the *borehole Süt-19:* 1. Cardium, 2. Cyrena solitaria; its e u r y h a l i n e f a c i e s : 3. Pirenella münsteri, 4. Nucula concinna, 5. Pecten, 6. Cyprina, 7. Lima. — (For the rest of explanations, see Fig. 36.)

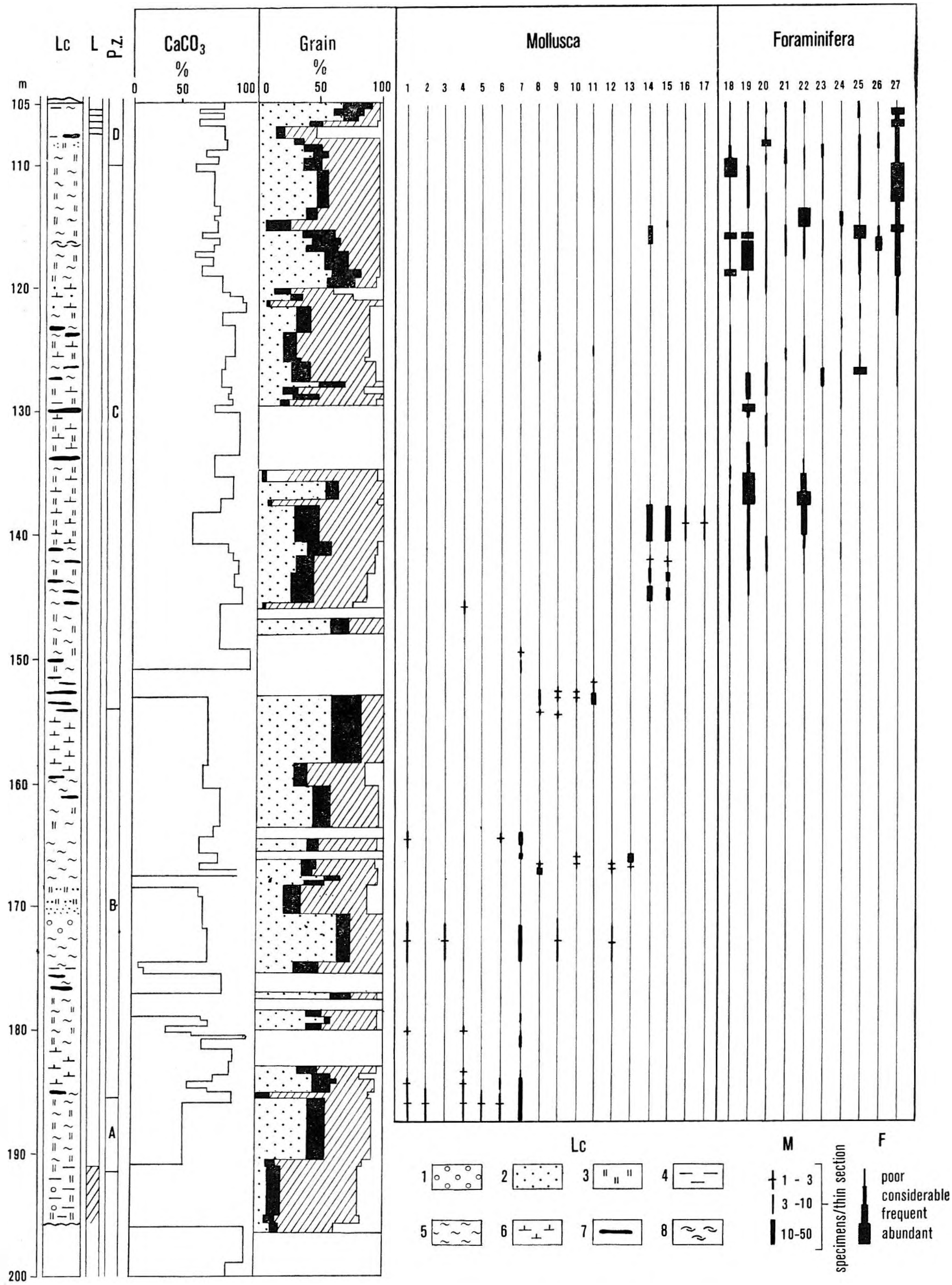
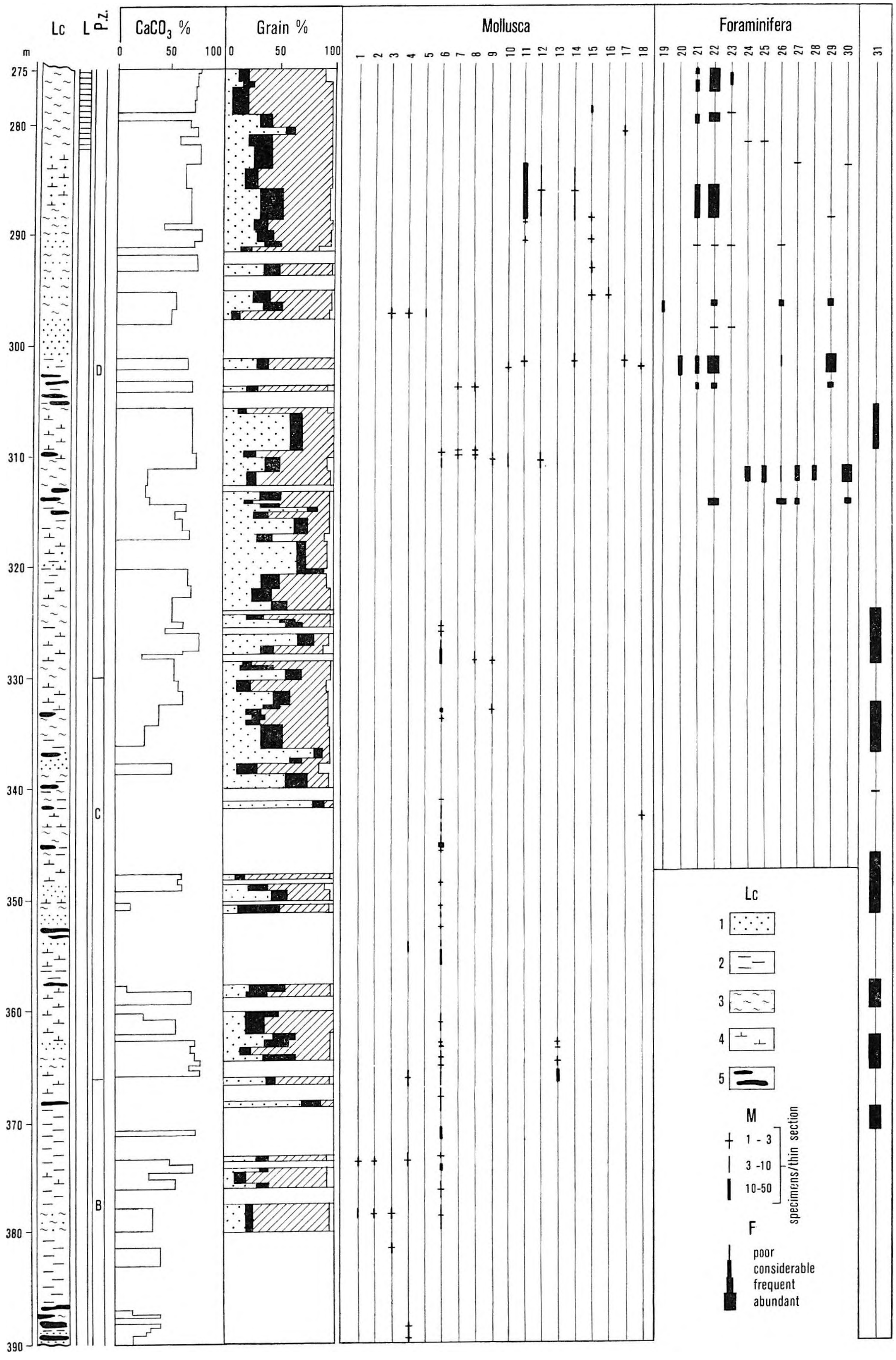


Fig. 38. The Ajka Formation interval of the borehole Sp-1: lithologic column and analytical record

Lithologic column (Lc): 1. gravel, 2. sand, 3. siltstone, 4. clay, 5. marl, 6. calcareous marl, 7. coal, 8. lumachelle. — ***Mollusca*** (after F. BARTHA): freshwater facies: 1. Helix sp., 2. Bulimus munieri, 3. Melania heberti, 4. Melania sp., 5. Goniobasis sp., 6. Cyrena baconica, 7. Pyrgulifera glabra; brackish-water facies: 8. Pyrgulifera glabra or suemegensis, 9. P. inflata, 10. P. inflata or impressa, 11. P. inflata or acutispira, 12. Dejaneria bicarinata, 13. Viviparus; marine facies: 14. Cardita sp., 15. Meretnia sp., 16. Turritella sp., 17. Pecten sp., ***Foraminifera*** (after M. SIDÓ): 18. Miliolidae, 19. Cornuspira, 20. Vidalina, 21. Nonionella, 22. Nummofallotia, 23. Lamarckina, 24. Rotalia, 25. Epistomina, 26. Cibicides, 27. Bryozoa. (For other explanations, see Fig. 36.)



Lc
L
P.z.
CaCO3 %
Grain %
Mollusca
Foraminifera
m
0 50 100
0 50 100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
19 20 21 22 23 24 25 26 27 28 29 30
31
275
280
290
300
310
320
330
340
350
360
370
380
390
D
C
B
Lc
1
2
3
4
5
M
1 - 3
3 -10
10-50
specimens/thin section
F
poor
considerable
frequent
abundant

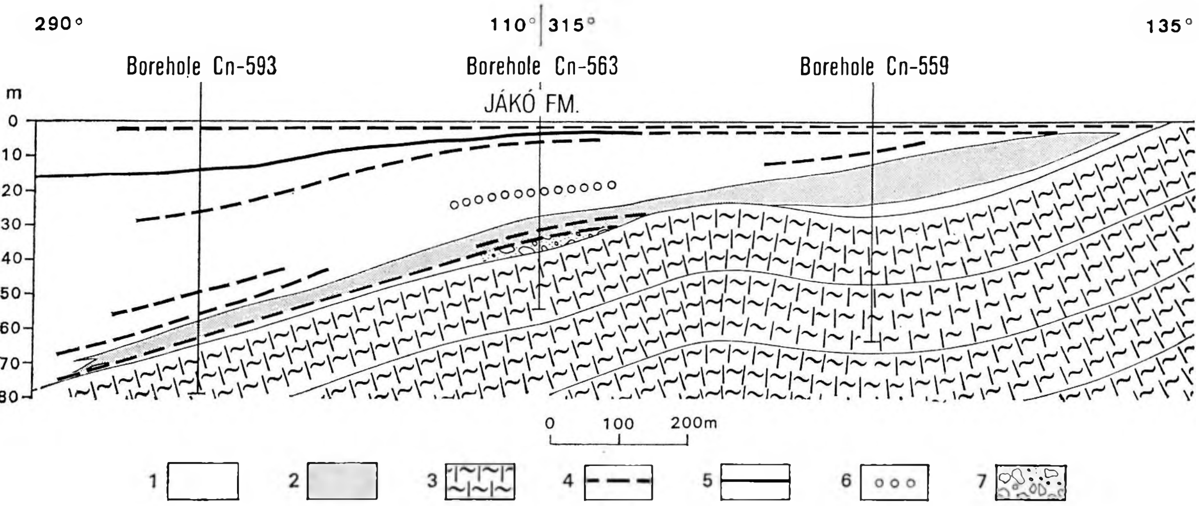


Fig. 40. Relationship of the Ajka, Csehbánya and Halimba Formations (Profile III)
1. Ajka Coal Formation, 2. Halimba Bauxite Fm., 3. Kössen Fm., 4. carbonaceous clay, 5. coal, 6. gravel, 7. detritus

brackish-water facies. The main difference between the two sections is manifested in the character of transition between the afore-mentioned two facies zones. Namely, the steepness of the pre-Senonian substratum as reflected by the changes in thickness in the two sections is different: the single, relatively steep transitional interval of Profile I is extended, in Profile II, into a gentle slope flanked by two, less steep transitional stretches.

The trace of Profile III (Fig. 40) extends east of Rendeki-hegy, to the southeast of Csabrendek settlement and it illustrates, in addition to the thickness and geological features of the Ajka Formation, the relation between the bauxite body here exposed and the coal-bearing beds as well.

In the borehole Cn-559 the Ajka Formation was only 12 m thick and 3 coal-bearing intervals could be observed. No information on fossils is given in the descriptions, so we are unable to give a biofacies interpretation.

At the base of the formation 14 m of grey bauxite has been intersected which overlies the Upper Triassic surface through the intermediary of a couple of metres of clay to variegated clay.

In the borehole Cn-563 the thickness of the coal-bearing strata was as low as 8 m, but underneath there followed 20 m of greyish-green, unfossiliferous marl, underlain, in turn, by red and grey argillaceous bauxite. In a field description by Z. Vörös carbonaceous clay layers interbedded with the bauxite are mentioned.

Nearly 60 m thick in the borehole Cn-593, the Ajka Formation includes, as reported by P. Farkas and P. Fülöp, 8 or possibly 9 coal-bearing intervals and even the cycles can be traced comparatively well. From the uppermost 10 m of the formation the genera *Nucula*, *Pecten* and *Corbula* and, beneath them, *Pyrgulifera*-containing beds were registered as a result of drilling works. At the base of the formation 4 m of red argillaceous bauxite, bauxite and, at the very base, again some carbonaceous marl and *Mollusca*-lumachelle were observed by the describers.

Profile III shows several features in common with the corresponding intervals of the previous two, the main trends being equal. The interval of reduced thickness in the southeast after the appearance of the formation's lower boundary and its growing thicker in a northwesterly direction are clearly noticeable. On the basis of the unfortunately scant fossil record the thicker sequence seems to be of brackish-water to limnic facies here too, while the more reduced thicknesses are composed of only a brackish-water facies.

According to the isopach map, the NE–SW orientation is modified by anomalies perpendicular

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Fig. 39. The Ajka Formation interval of the borehole Sp-2: lithologic column and analytical record
Lithologic column (Lc): 1. sand, 2. clay, 3. marl, 4. calcareous marl, 5. coal. — *P.z.* pollen zones. — *Mollusca:* terrestrial-freshwater: 1. Strophostoma cretacea, 2. Megalomastoma supracretacea, 3. Helix sp., 4. Cyrena baconica, 5. Corbicula ajkaensis, 6. Pyrgulifera glabra, 7. Unio sp.; brackish-water: oligo-miohaline: 8. Pyrgulifera glabra v. suemegensis, 9. P. inflata, 10. P. inflata v. acutispira, 11. Melania lignitarius, 12. Dejaneria bicarinata, plio-brachyhaline: 13. Cerithium sp., 14. Cyrena sp.; marine: 15. Cardita sp., 16. Turritella sp., 17. Ampullina sp., 18. Glauconia sp.; *Foraminifera:* 19. Haplophragmium, 20. Ammobaculites, 21. Miliolidae, 22. Cornuspira, 23. Vidalina, 24. Nonion, 25. Nonionella, 26. Nummofallotia, 27. Lamarckina, 28. Valvulineria, 29. Rotalia, 30. Epistomina; *alga:* 31. Munieria. (For other explanations, see Fig. 36.)

trend. This is evident from Profile IV which, perpendicularly to the former (Fig. 41), issues from the southern side of Sümeg and after crossing the hill range, extends as far as the southern part of Csabrendek. These parts of it can be singled out. Over the stretch encompassing the Sümeg area and the neighbourhood of Csabrendek the thickness conditions and the geological features are similar, but the middle stretch is characterized by a reduced thickness and a reduced number of coal beds.

At the beginning of the chapter the question concerning the kinds of changes in the characteristics of the formation with which the thickness variation trends shown in Fig. 34 are associated, was posed. On the basis of the interpretation of the profiles and considering the data of exposures outside the profile, the following trends of variation in characteristics of the various area-units could be registered:

1. In the northwest part of the area characterized by the presence of the formation, higher formation thicknesses and greater number and thickness of the coal beds are conspicuous. The formation can be split up into a lower freshwater interval in transition to the limno-brackish facies and an upper one characterized by the preeminence of a brackish-water facies tending to approximate the marine characteristics. Within the area-unit the total thickness of the formation increases northwestwards for about 2 km (up to 40–120 m), to show then again a marked decrease (Profile I).

The question whether the thickness pattern within the NW subarea is due to a change in the thickness of the freshwater or marine (brackish-water) facies group or maybe to a change of both combined, was also examined. For this reason, we were looking for a feature that might be observable in the greatest possible number of exposures and that is indicative of a change in salinity. The boundary between the *green algae–Ostracoda* (Foraminifera-free) and the *Foraminifera* (Vidalina–Nummofallotia) fossil assemblages, the horizon of the first appearance of Foraminifera, seemed to be best suited to that purpose.

This boundary divides the sequences into two parts and though it cannot be said that it divides exactly the rock types formed in a freshwater and a limno-brackish or marine-brackish environment, it is yet supposed to delineate a by and large isohaline horizon. If the exposures in the northwest subarea (Fig. 34) be evaluated in terms of this subdivision, the following observations will be experienced:

a) in the internal parts of the subarea the changes in the thickness of the upper, marine-brackish interval are poor, consequently, most of the remarkable differences in thickness are due to the thickness differences of the lower (freshwater to limno-brackish) interval (boreholes Sp-1, -2, Süt-22) and

b) to the south the thickness of the marine-brackish beds decreases (to 10–20 m),while that of the freshwater ones shows hardly any change, to pinch out eventually all of a sudden (within 100–200 m) (Profile I). The line of pinching out follows by and large the boundary of the southeast subarea, running parallel to the isopachs along the 20 m isopach. In the northwest the higher thickness of the unit is coupled with a greater number (6–9) of coal-bearing cycles. The thickest coal beds are found in the zone of maximal formation thickness (borehole Sp-2), at the base of the sequence, being shifted to the middle third of the formation farther southeast. The coal of highest quality (10,465 kg/Joule) is found in the upper marine-brackish interval of the formation.

2. In the southeast subarea of low formation thickness only marine-brackish facies are found even in the borehole Süt-15 that cut the thickest sequence. No uniform trend of thickness variation is recognizable within the subarea. The coal-bearing sequences are reduced in number (a maximum of three), the coal beds being thin and the coal itself of very low quality.

The external (SE) boundary line of the southeast subarea is subparallel to the isopachs (Fig. 34). To the southwest of the extension limit the Csingervölgy Marl directly overlies the pre-Senonian formations. The situation observable on the Köves-domb is somewhat different from the general trend (Profile I). Namely, in the northwestern part of the hill the Ajka Formation is lacking, being present around it (at least to the northwest and southeast and probably also to the northeast).

Bio- and chronostratigraphy

Based on various fossil groups, the biostratigraphy of the Sümeg area exposures of the Ajka Formation has been dealt with by several authors in recent years.

During his palynological study in key section detail of the boreholes Sp-1 and Sp-2, F. Góczán established the following abundance zones within the Ajka Formation (listed from the bottom to the top):

A — *Oculopollis–Complexipollis* Zone
B — *Trilobosporites* Zone
C — *Tetracolporopollenites (Brecoplites)–Oculopollis zaklinskalae* Zone
D — *Hungaropollis krutzschi* Zone.

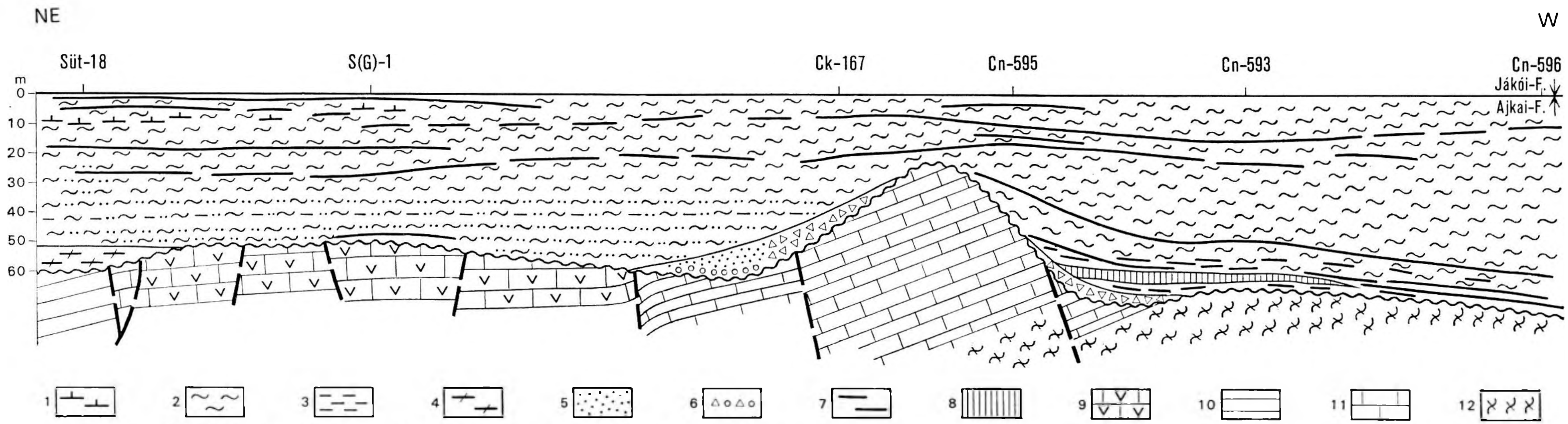


Fig. 41. Variation of the geological features of the Ajka Formation along a NE–SW profile between Sümeg and Csabrendek (Profile IV)
1. Calcareous marl, 2. marl, 3. clay, 4. variegated clay, 5. sand, 6. gravel, detritus, 7. coal, 8. bauxite, 9. Tata Fm., 10. Sümeg Fm., 11. Dachstein Fm., 12. Kössen Fm.

Zone A could be distinguished only at the bottom of the borehole Sp-1, Zone D extends into the Csingervölgy Member, too.

The palynological study of the local type section (borehole Süt-22) was carried out in 1974 by F. GÓCZÁN. Accordingly, the basal 30 metres of the formation (up to 133 m) can be assigned to Zone C, as suggested by the abundances of the *Oculopollis* species and the presence of the zonal index species *Brecoplites globus*. At the base of this interval the specimens of *Appendicisporites tricuspidatus* WEGL. et KRIEG are abundant. The upper interval of the formation (up to 96 m), based on the predominance of the genus *Hungaropollis*, is to be placed in Zone D. The *Occulopollis* species are only subdominant, while the representatives of *Krutzschipollis*, according to their abundances, are pushed back to the third place.

The absence of Zone A known from the borehole Sp-1 and of Zone B known from the boreholes Sp-1 and Sp-2 in the section in discussion is conspicuous. This may be due to the fact that the location of the borehole was a relatively elevated area in the beginning of the Senonian cycle and that sedimentation there did not begin until a little bit later. Similar causes may be ascribed to the fact that the thin coal bed from the borehole S-7 on the Köves-domb shows the pollen pattern of Zone D (F. GÓCZÁN 1973).

That the marked change of the palynoflora (zone boundaries) in the borehole Süt-22 coincides with the changes in facies is also worthy of attention. The end of Zone C is at the same time the end of the freshwater phase, while the top of Zone D roughly coincides with the top of the Ajka Formation. The causes responsible for this may be looked for in the close relationship between pollen predominance and environment of deposition.

Long-distance interregional correlations of biozones in freshwater to brackish-water facies are difficult to carry out which, of course, is a problem for the scientist seeking a more precise chronostratigraphic assignation. Exactly for this reason, it is the evaluation of the spore-pollen remains, spread over vast areas by the winds, of Senonian plants of particularly accelerated evolution, that appears to be most suitable for this purpose, even though, on account of what was said in the foregoing, the possibility of that the zones in some cases are bound to facies boundaries exists here too. The regional correlation of the spore-pollen zones was carried out by F. GÓCZÁN for a number of exposures from the Bakony–Zala facies area and, as experienced by him, the palynological zonation of different facies can be readily correlated.

Considering the zonal scale generally adopted by palynologists, F. GÓCZÁN (1964) assigned the rocks of the formation to the Santonian stage (Zones A and B) and the lower part of the Campanian (Zones C and D).

Based on the boreholes Sp-1 and -2, the foraminiferal zonation of (or biofacies) M. SIDÓ (1969) includes zones that are similarly based on abundances: Cornuspira-, Rotalia I-, Nummofallotia-, Epistomina-, Miliolidae-, Vidalina-, Rotalia II- and Nonionella zones as well as biofacies. These zones cannot be identified consistently in the coal-bearing beds of the Sümeg area boreholes. According to our experiences, the abundances of the individuals of some foraminiferal species depend primarily on the character of facies and thus they change, often cyclically, together with the lithologic features.

Very sensitive to environmental changes and being composed of species of not sufficiently short range, the foraminiferal fauna of the formation is unsuitable for an exact long-distance correlation and does not provide a handy tool for the delineation of stage boundaries. Even the most characteristic species [*Nummofallotia cretacea* SCHLUMBERGER, *Vidalina hispanica* (SCHLB.), etc.] are characterized by a relatively wide range, being present throughout the Senonian inasmuch as the environmental conditions are appropriate (M. SIDÓ 1969).

Among the Molluscs there are few forms of considerable lateral distribution, thus being generally of little interest from the viewpoint of interregional correlation. Some species appearing in the uppermost, brackish-water beds of the formation, e.g. *Turritella repelini decipiens* CZAB., *Astarte similis* MÜNSTER, *Limopsis calvus* ZITTEL, and *Pecten laevis* NILSSON, however, can be encountered in formations of similar facies in the wider neighbourhood (Yugoslavia, Austria, Romania) as well. According to the chronostratigraphic practice adopted by scientists dealing with these faunal elements, the afore-listed fossils are indicative of the Campanian (L. CZABALAY 1964e).

An important role in short-distance (local) time-correlation necessary for paleoenvironmental-geochronological reconstructions may be played by some lithologic features and one-time organisms sensitive to changes in environment (Foraminiferae, molluscs).

A prerequisite for a time correlation based on ecologically sensitive fossils and sediments is a morphologically levelled topography. This was not the case with the study area as a whole. Facies shifts in time must be reckoned with. In other words, it is quite plausible that in case of transgression the land tracts of deeper topographic position (being closer, as a rule to the marine sedimentary basin) provided the conditions for the deposition of sediments of some type and for the spread and proliferation of certain fossils somewhat earlier than it may have been the case with a relatively more elevated terrain. Within particular morphological subunits, however, it is possible to carry out both lithostratigraphic correlations and time correlations based on facies-dependent fossils.

On the basis of bio- and lithostratigraphic analyses, the Ajka Formation in the Sümeg area seems to span the Santonian to Lower Campanian time interval. To be more accurate, the formation of the freshwater sediments in the northwest subarea began as early as Santonian time, while the marine-brackish beds in the southeast unit seem to have formed as late as the Campanian.

Paleoenvironment

The Ajka Formation must have been generated in an initially lacustrine and eventually coastal swamp zone that evolved in a direct or indirect connection with the transgression of the sea and persisted for a comparatively long time with the stabilization of some of the environmental factors.

Relatively constant factors during the birth of the formation may have been the overall pattern of the relief, the amount and quality of the sediment introduced into the basin and the climate.

The relief, as suggested by the profiles presented, tended to rise slightly in a southeasterly direction. The nature of the introduced sediment suggests that the extended neighbourhood was represented by a dolomite karst terrain of a likewise gentle morphology.

The accumulation of the weathering products of sand, silt and clay size introduced into the basin kept pace with the subsidence throughout the history of the formation. Nevertheless, the rate of accumulation may from time to time have lagged behind the subsidence, thus producing the sedimentary cycles.

A good deal of the introduced material is composed of dolomite silt deriving from the immediate neighbourhood which seems to have flowed in as a result of sheetwash. The sand-size quartz and feldspar grains, furthermore, some of the clay minerals of different type were probably redeposited from older Cretaceous formations (as suggested by the presence of redeposited remains of *Radiolaria* and *Spongia*), the rest, however, may have come from comparatively remote magmatic to metamorphic sources.

Information on the climatic circumstances is provided by the floral spectrum that can be inferred from the results of palyonological investigations. According to a climatic analysis by F. Góczán (1961, 1973), the study area at the time of coal generation belonged to a tropical-subtropical zone with one precipitation maximum.

From among the largely varying parameters, the variation of salinity and water depth may be quoted.

There is a clear unidirectional trend in the variation of salinity—a transition from a freshwater environment into a marine one. In the northwest subarea of the formation a freshwater to lacustrine environment is indicated in its the lower part by terrestrial and freshwater gastropods and bivalves (*Helix, Strophotoma cretacea, Megalomastoma supracretacea, Pyrgulifera glabra, Melania, Pachyostoma, Goniobasis, Corbicula, Bulimus, Cyprina*, etc.) that can be encountered in great abundance, in the upper part, by the similarly abundant remains of Munieria algae (*Munieria grambasti* Bistr.) and *Chara* as well as by the total absence of fossils of explicitely marine type such as *Foraminifera, Bryozoa, corals* and *Echinodermata.*

In the upper part of the formation an increase in salinity, as indicated by fossils of higher salinity demand, can be readily traced on the diagram of the borehole Süt-22 (Fig. 33). The steady growth of salinity is indicative of a marine communication becoming gradually more pronounced, suggesting that the coastal freshwater lake and swamp system developed into a littoral saltwater swamp.

Although the water depth within the swamp system did change a little bit, this minor change led to substantial differences in sedimentation. During the migration of facies provoked by periodical changes in water depth a distinct cyclicity evolved which allows us to deduce, in terms of the facies rule, some conclusions as to the characteristics of the juxtaposed facies as well.

Judging by the composition of the cycles studied in detail in the borehole Süt-22 and by the succession of the cycle-members, the following environments as producers of peculiar types of sediments are believed to have developed on the one-time seaside terrain:

1. *Lake or littoral swamp* (Cycle-member *A*). The coastal-swamp environment was characterized —as suggested by the pollen spectrum—by a rich mangrove vegetation (F. Góczán 1961). The gastropods feeding on plants that are observable in the rock may have lived partly in situ, but their preservation state suggests that most of the shells were emplaced after the organism had died. A permanent water-coverage, but only a few dm of water depth, can be supposed. The decay of a lot of organic matter resulted in a strongly reductive environment of acidic chemistry.

In the light of coal petrographic results obtained for the material of the borehole Sp-2, I. Elek, in 1961, identified shallow- and deepswamp facies and a transitional "zone of currents" between the two. According to the results of facies analysis, the coal beds from the borehole Sp-2 were deposited for the most part in the agitated transitional zone.

2. *Somewhat deeper parts of a lake or lagoon (generally the more internal parts)* (Cycle-member *B*). The bottom was floored by sandy-muddy sediments. Because of the relatively deep water a dense swamp vegetation could not settle in it anymore; the oxygen and the nutrients for the rich Ostracoda and Gastropoda fauna having been supplied by calcareous algae and probably by higher aquatic plants. The presence of lumachelle beds containing a lot of tide-mixed fossil detritus suggests that these bottom tracts got from time to time in the zone of wave action. A water agitation somewhat weaker than this is indicated by the sand and bioclast lenses particularly characteristic of the facies in question, being often bioturbated, i.e. laced by worm tracks. The water depth is estimated at 1 m or so.

3. *The deepest part of the lake or lagoon (its centre)* (Cycle-member *C*). A light-coloured calcareous mud, with a rich green algal flora (Munieria) in the freshwater interval, is characteristic. The water depth may have been a few metres. A relationship between the periodical changes in water level and the salinity can be registered, too. According to the salinity variation diagram of the borehole Süt-22, the marine organisms appeared for the first time in a high water level period (brackish-water fauna), i.e. it was at that time that a communication with the transgressing sea was established. In the subsequent accumulation period again a trend towards the establishment of a freshwater regime may be supposed and then, as evidenced by the subsequent cycles, the process was repeated several times.

Jákó Marl Formation

Extension, mode of superposition, stratigraphic subdivisions

In the Sümeg area the Jákó Marl Formation is common. The only exception to the rule is a marginal zone and the surroundings of the Aptian crinoidal limestone outcrop of Köves-domb. The outcrops of the formation, however, are confined to two places: near the well (Hárs-kút) on the south side of the Köves-domb and in the Gerinc quarry. Within the formation three units of member rank can be singled out, two of which being essentially of equal extension, while the third one is developed quite apart, in the marginal zone (Fig. 42).

The individual members, as a rule, are lithologically uniform, a rather marked variability being noticeable only in the lower one, the Csingervölgy Marl Member, which is represented in the northwest by calcareous marls with a southeastward growth of the pelite content, but which is constituted farther south by sandy rock varieties. The lower member abounds with Mollusca (first of all *Bivalvia*) and with ahermatypical corals.

In the upper member it is uniformly siltstones, silstone-marls and, in subordinate quantities, argillaceous marls are found. Megafossils, if any, are quite sporadical. Selected as a type section, the borehole Süt-22 exhibits the two basin-facies members of the formation.

The member developed in the marginal zone represents a transition towards the Ugod Formation. It is composed of rock types of higher carbonate content such as silty marl, calcareous-nodular marl and sandy, argillaceous limestone. As type exposure the sequence of Gerinc quarry has been selected, its upper part being exposed in the quarry face, its lower part in the borehole Sc-1/8 put down in the quarry-yard.

The problem of the lithostratigraphic calibration of the rock types belonging to the formation came primarily during the scientific exploration of the study area (key section drilling) into the fore. What is now regarded as the lower member of the formation was earlier discussed either independently under the name of "corals- and molluscs-bearing argillaceous marl group" (with the possible separation of the so-called "Lima marl" at its base) distinctly separated from the overlying "Gryphaea marl" or was referred to, combined with the former, as "clay-marl group with corals, molluscs, Gryphaea and crab claws", resp. as "lower clay-marl". The separation of the two units was practised primarily in paleontological studies. The upper part of the upper member, in turn, was often quoted as "calcareous marl with worm tracks".

The Jákó Marl is underlain for the most part by the Ajka Formation; on the margins, however, it transgresses beyond this, overlying terrestrial sediments of the pre-Senonian basement. The thickness of the formation varies between 0 and 110 m, the isopachs running subparallel to those of the Ajka Formation (Fig. 42). A substantial deviation can be found only in the northwest part of the area. The marginal, more carbonate member is found in the zone between the 0 and 30 m isopachs. The formation in its larger, northern subarea is overlain by the Polány Formation, in the south by the Ugod Formation with which it is laterally intertongued.

Local type section: borehole Süt-22

As local type section the 38.5 to 101.0 m interval of the borehole Süt-22 has been selected. The lithologic features of the formation and the results of its examination are presented in Fig. 43. In the type sequence the two members are lithologically quite distinct. The lower 31-m-thick member

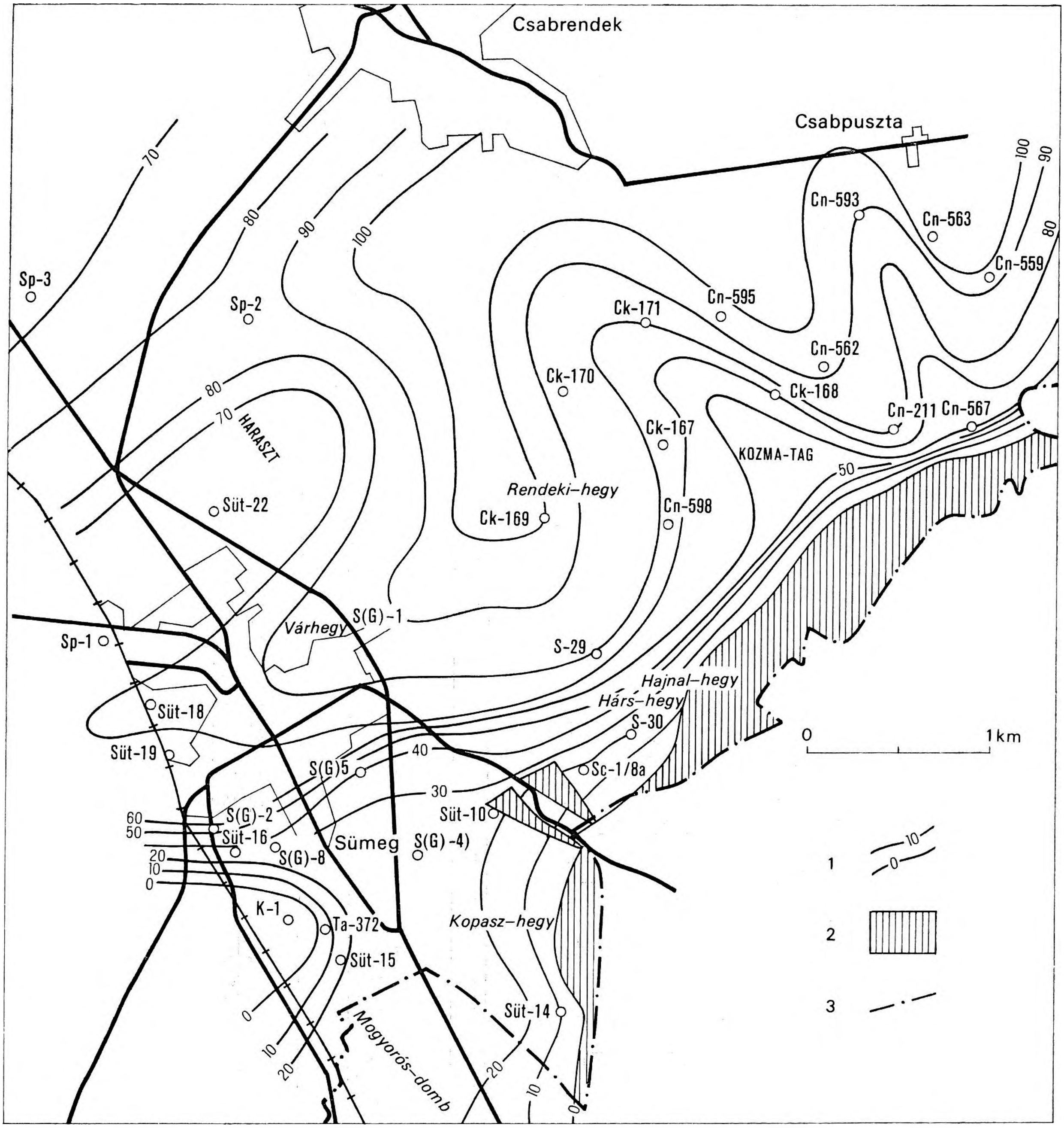


Fig. 42. Extension and thickness of the Jákó Marl Formation

1. Isopachs of the Jákó Marl Formation, 2. the Jákó Marl Fm. is absent within the Senonian area, 3. boundary of extension of the Senonian

is of great diversity and its lower half is of cyclic composition, similarly to the case of the Ajka Formation, being still characterized by a comparatively high dolomite content (up to even 10%). In the upper part of the member the cycles cannot be identified anymore, the individual rock types alternate in a great frequency, though irregularly. The upper member is lithologically uniform (69.2 to 42.6 m), being constituted for the most part by silstone-marls. The dolomite content drops to a few per cent.

The lower boundary of the Jákó Formation is drawn above the coal-stringered, sandy marl regarded as the topmost layer of the Ajka Formation and actually representing the initial *(A)* member of the only regular and complete cycle of the Csingervölgy Member. 7.1 m thick, the cycle shows the *A–B–C–B′–A* cyclicity pattern already presented in the discussion of the Ajka Formation. A half cycle more can be traced above it. Naturally, no coal-bearing beds are found in *Member A*

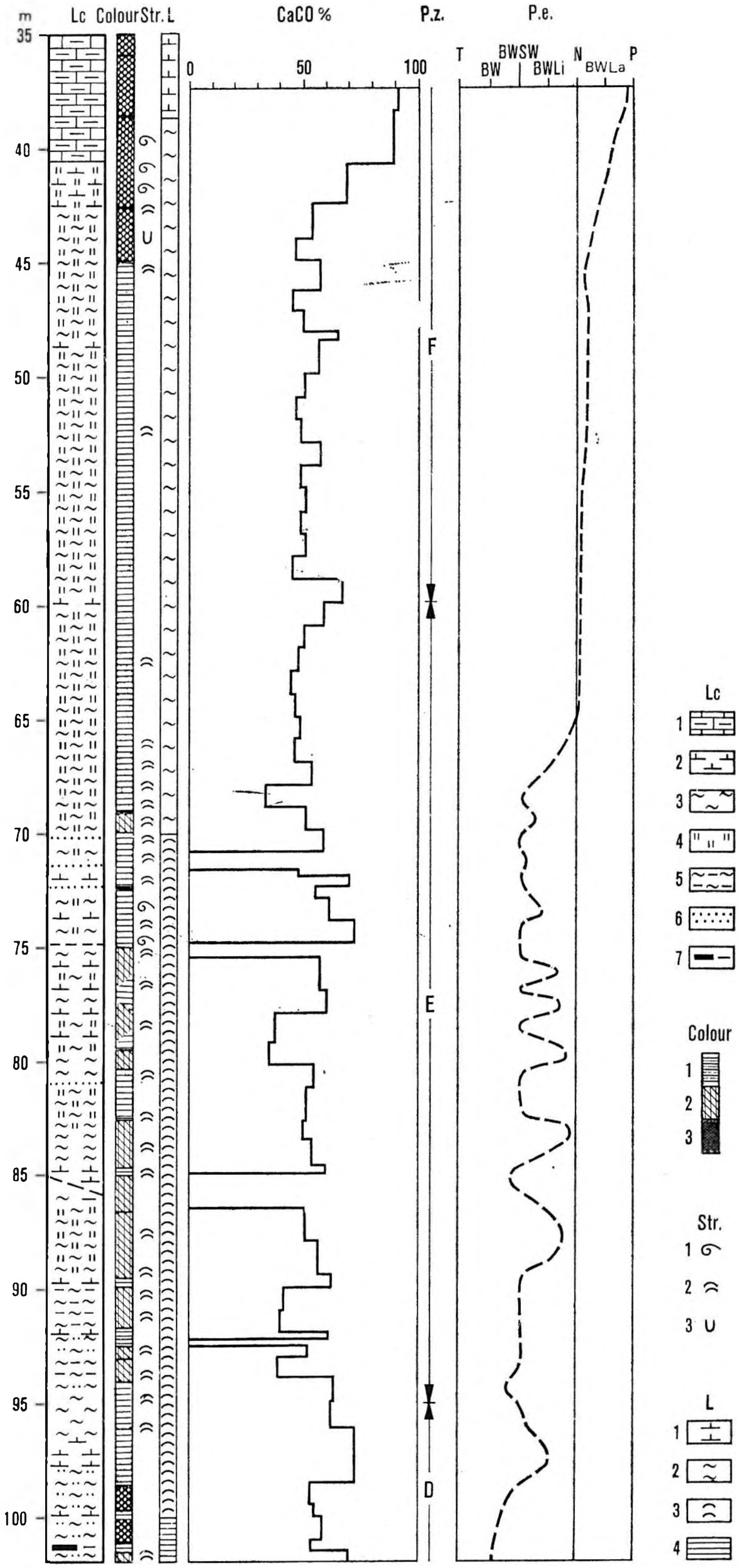


Fig. 43. The Jákó Marl interval of the borehole Sümeg Süt-22: lithologic column and petrographic and palynological record and paleoenvironmental interpretation

Lithologic column (Lc): 1. argillaceous limestone. 2. calcareous marl, 3. marl, 4. siltstone, 5. argillaceous marl, 6. sand, 7. carbonaceous clay. — *Colours:* 1. light grey, 2. dark grey, 3. brownish-grey. — *Structure* (Str.): 1. Exogyra-Pycnodonta lumachelle, 2. other mollusc lumachelle, 3. worm tracks. — *Lithostratigraphic unit* (L): 1. Polány Marl Fm., lower member, 2. Jákó Marl Fm., upper member, 3. Jákó Marl Fm., lower member, 4. Ajka Coal Fm. — *P.z.* palynological zones. — *Paleoenvironment* (P.e.): *T* terrestrial, *BWSw* brackish-water-swamp, *BWLi* brackish-water-littoral, *BWLa* brackish-water-lagoonal, *N* normal salinity-neritic, *P* pelagic basin anymore, being replaced by a dark grey argillaceous marl rock type. A 10-m-thick bed above the cyclic part represents a transition to the overlying member.

The 2.5-m-thick *Member B* of the cycle is represented by grey to brownish-grey, heavily sandy, sand-lensed marls. Its fossil content is generally poor, small mollusc shell fragments being encountered in great quantities associated with the sand lenses. Most of the identifiable faunal elements are euryhaline or marine-brackish forms (*Nucula concinna* Sow., *Pecten laevis* NILSSON, and *Cardita granigera* GÜMBEL, respectively).

Member C is represented by a grey dolomitic, calcareous marl containing a lot of fossil detritus composed of a few Bivalvia and Gastropoda indicative of normal salinity (*Cantharus* sp., *Fusus tritonium* ZEKKELI, *Arca* sp., *Pectunculus* sp.) as well as of euryhaline forms (many *Ostrea* sp., and fairly numerous *Haustator* sp., *Turritella* sp., *Pecten laevis* NILSSON and *Cyrena* sp.). It is here that the first ahermatypical corals appear.

Member B' of the cycle is constituted by marls and sandy marls (2.1 m thick). It contains a great quantity of smaller Bivalvia. In its lower part the marine species are also frequent (*Corbula angustata* Sow., *Crassatella* sp., *Arca inaequidentata* ZITTEL, *Astarte similis* MÜNSTER), being followed, higher up the profile, by an assemblage of forms enduring changes in salinity or brackish-water species (*Cardium ottoi* GEINITZ). The traces of *Cliona vestifica* VOLTZ. on mollusc shells were observed by L. CZABALAY.

Member A of the next cycle (0.90 m) is composed of dark grey argillaceous marls. Its fauna consists of sporadically freshwater (*Cyprina* sp.), predominantly marine-brackish (*Cardium ottoi* GEINITZ, *Cyrena solitaria* ZITTEL) and euryhaline forms (*Limopsis calvus* ZITTEL, *Pecten laevis* NILSSON, *Nucula concinna* Sow.).

Member B is represented by sandy and siltstone-bearing marls and argillaceousmarls. The fauna is composed of euryhaline forms (*Nucula concinna* Sow., *Limopsis calvus* ZITTEL) and forms indicative of normal salinity (*Corbula angustata* Sow.); higher up the profile the latter become gradually predominant. In the lower interval the traces of *Cliona vestifica* VOLTZ. are still frequent. In the upper part the ahermatypical corals become ever more frequent.

The last identifiable *cycle-member (C)* is a grey dolomitic calcareous marl. Its fauna is represented almost exclusively by forms of normal salinity environments (*Tellina stoliczkaiae* ZITTEL). The fossils are often enriched in particular lenses.

In the upper acyclical part of the lower member (84.7–69.2 m) three beds can be singled out on the basis of the lithological features. In the lower third there is a dark grey, argillaceous-marl with rare sand lenses and few fossils. Above it follows, in 7 m thickness, a sandy, marly siltstone or pure silstone unit densely interrupted by thin calcareous marl and argillaceous marl interbeddings of great diversity. The upper few metres are more uniform in lithology, being represented by silty marls and argillaceous marls.

This upper part of the sequence contains fossils in fair to low quantities, its megafossil assemblage consisting for the most part of forms indicative of waters of normal salinity and, in subordinate quantity, of euryhaline Molluscs (*Astarte similis* MÜNSTER, *Tellina stoliczkaiae* ZITTEL or *Dosinia cretacea* ZITTEL, respectively).

During the study of the megafossils of the lower member, L. CZABALAY distinguished two intervals, each with a typical fossil assemblage: *Members B* and *C* of the lower cycle being characterized by a Gastropoda–Pecten–Cardium assemblage, *Members B* and *C* of the next cycle by an Astarte–Nucula–Corbula assemblage.

As shown by the results of analysis of the microfauna (the decanted material was studied by M. SIDÓ), the lower interval of the member is represented by a Miliolidae–Cornuspira–Vidalina assemblage, the upper part by the appearance of *Goupillaudina lecointrei* MARIE, the representatives of *Gavellina* and, eventually, of *Nonionella* and the planktonic forms.

On the basis of the palynological analysis (F. GÓCZÁN), the member is characterized by the abundance of *Hungaropollis oculus* GÓCZÁN, *H. auritus* GÓCZÁN, *H. longianulus* GÓCZÁN, resp. *Krutzschipollis spatiosus* GÓCZÁN, *K. crassus* GÓCZÁN and *Sümegipollis triangularis* GÓCZÁN.

The upper member of the Jákó Marl (its thickness–27 m) evolves continuously from that underlying it, showing a gradual reduction in grains, a considerable decrease in the amount of fossils and a change of forms. The lithology of the member is uniform. Predominant rock types are silty marl and marly siltstone interrupted, in rarest cases, by thin interbedded layers of marl. (With minor deviations, the $CaCO_3$ content is around 50%). Megafossils are poor. Fish scales, Echinoidea detritus, coalified plant remains, though sporadical, are observable throughout the member.

From among the molluscs, the thin-shelled, well-preserved *Bivalvia* are characteristic. Typical species are: *Crassatella macrodonta* var. *sulcifera* ZITTEL, *Tellina stoliczkai* ZITTEL, *Pholadomya granulosa* ZITTEL, all being euryhaline forms. *Scaphopoda* are encountered rather frequently. At the upper boundary of the member the representatives of *Exogyra* show a marked enrichment.

The foraminiferal assemblage is composed of rich planktonic and peculiar benthonic species:

Vaginulina cretacea PLUMBER, *V. taylorana* CUSHMAN, *V.* sp., *Gavelinella* sp., *Goupillaudina* sp., *Hedbergella cretacea* (D'ORB.), *Globotruncana marginata* (REUSS).

Peculiar and even quantitatively important species from the association of sporomorphs are *Hungaropollis krutzschi* GÓCZÁN, *H. brevis* GÓCZÁN, *H. oculus* GÓCZÁN, *Krutzschipollis crassus* GÓCZÁN, *K. longanulus* GÓCZÁN, *K. spatiosus* GÓCZÁN, *Longanulipollis bajtayi* GÓCZÁN, *L. longianulus* GÓCZÁN, *L. lenneri* GÓCZÁN.

A good deal of the carbonate content in the formation is associated with dolomite minerals (as shown by A. SZEMETHY's X-ray diffraction results). The amount of dolomite decreases gradually upwards in the lower member. Over a short interval above the member-boundary the two minerals occur in equal quantity, then a marked prevalence of calcite is observed. Likewise in the vicinity of the member boundary, a few per cent ankerite can be registered too. In some samples a good deal of the carbonate is connected with aragonite.

The clay minerals are represented by kaolinite, illite and montmorillonite, their percentage decreases gradually as one proceeds upwards, attaining a marked reduction in the upper part of the member. Montmorillonite is totally absent at the top. The behaviour of illite is opposed to the former. A low percentage of the sand-size constituents is allothigenic mineral. Quarts is predominant among the light minerals. The most frequent allothigenic heavy mineral is augite. A low quantity of epidote, colourless garnet, magnetite, chlorite, muscovite, hornblende and hypersthene is also present (as shown by A. LENKEI).

The u p p e r b o u n d a r y of the formation and, consequently, that of the formation itself is delineated by a marked growth of the $CaCO_3$ content and the appearance of a nodular, bioturbated rock structure. Near the boundary a remarkable change takes place in the Foraminifera content, as *Vaginulina* disappear and a number of planktonic species make their appearance: *Heterohelix*, *Pseudotextularia*, *Globigerinelloides*. Planktonic microfossils of the *Calcisphaerulidae* group and the representatives of *Stomiosphaera* and *Pithonella* appear too.

Geological features

Similarly to the case of the Ajka Formation the basic features of the formation in question are outlined along profiles plotted in the direction of greatest change in thickness (Fig. 43). The boundary between the two members of the formation has been selected as a reference horizon for plotting the sections. With a view to the uniform development of the upper member throughout the area in question, it may be supposed that the sedimentary basin was least differentiated during the deposition of this formation member. Profile I (Fig. 44), issuing from the borehole Sp-3, runs in a southeasterly direction, to cross the Köves-domb along the west side of Sümeg. In the borehole Sp-3, rocks belonging to the Jákó Marl are exposed in 66.9 m thickness between 153.1 and 220.0 m.

The two members of the formation are distinctly individualized. Unlike the cyclicity observable in the type section, here even the deeper part of the lower member is homogeneous.

Attaining a thickness of 28.6 m (between 220.0 and 191.4 m) the l o w e r m e m b e r is composed of grey to dark grey marls and clay marls. In its lower part there are local occurrences of sands and, quite exceptionally, even thin sandstone interbeds are found. The upper part is silty. The fossils are often enriched so as to form lumachelle accumulations. They show an increase in quantity upwards. In the lower interval the ahermatypical corals and coalified plant detritus are still abundant.

As shown by L. CZABALAY, *Pecten laevis* NILSSON, *Astarte similis* MÜNSTER and *Cyclas ambliqua* appear in greatest number of individuals in the Mollusca assemblage. Specimens of *Nucula concinna* SOW., *Cyrena* sp., *Limopsis* sp., *Gervilleia solinoides* DEFR. are frequent, those of *Pecten* sp., *Cardium ottoi* GEINITZ and *Haustator* sp. are less so.

The u p p e r m e m b e r is constituted for the most part (between 191.4 and 153.1 m) by grey marls, silty marls with interbedded calcareous marl layers getting gradually more frequent up in the section. The fauna is scant, as a rule, containing primarily fish scales, fish teeth and fragments of crab claws with subordinate shell fragments of molluscs. In the lower part the typical species of the lower member are still present. Faunal elements appearing in the upper member are *Fusus* sp., *Aporrhais* sp. and *Dentalium* sp.

Located in the vicinity of the profile line (and taken into consideration in profile-plotting), the borehole Sp-2 intersected the Jákó Marl in a thickness of 86 m (190.4 to 276.4 m). The borehole is one of the key sections exemplifying the biostratigraphic zonal scale of the Senonian in the Bakony Mountains.

The l o w e r m e m b e r is 34 m thick, the lowermost 7 m of which form a regular cycle. Above this a sequence of low variability follows. A few metres of silty calcareous marl are overlain, in greater thickness, by a sequence of alternating calcareous marls and silty calcareous marls, the top of the member being predominated by silty marls and calcareous siltstones.

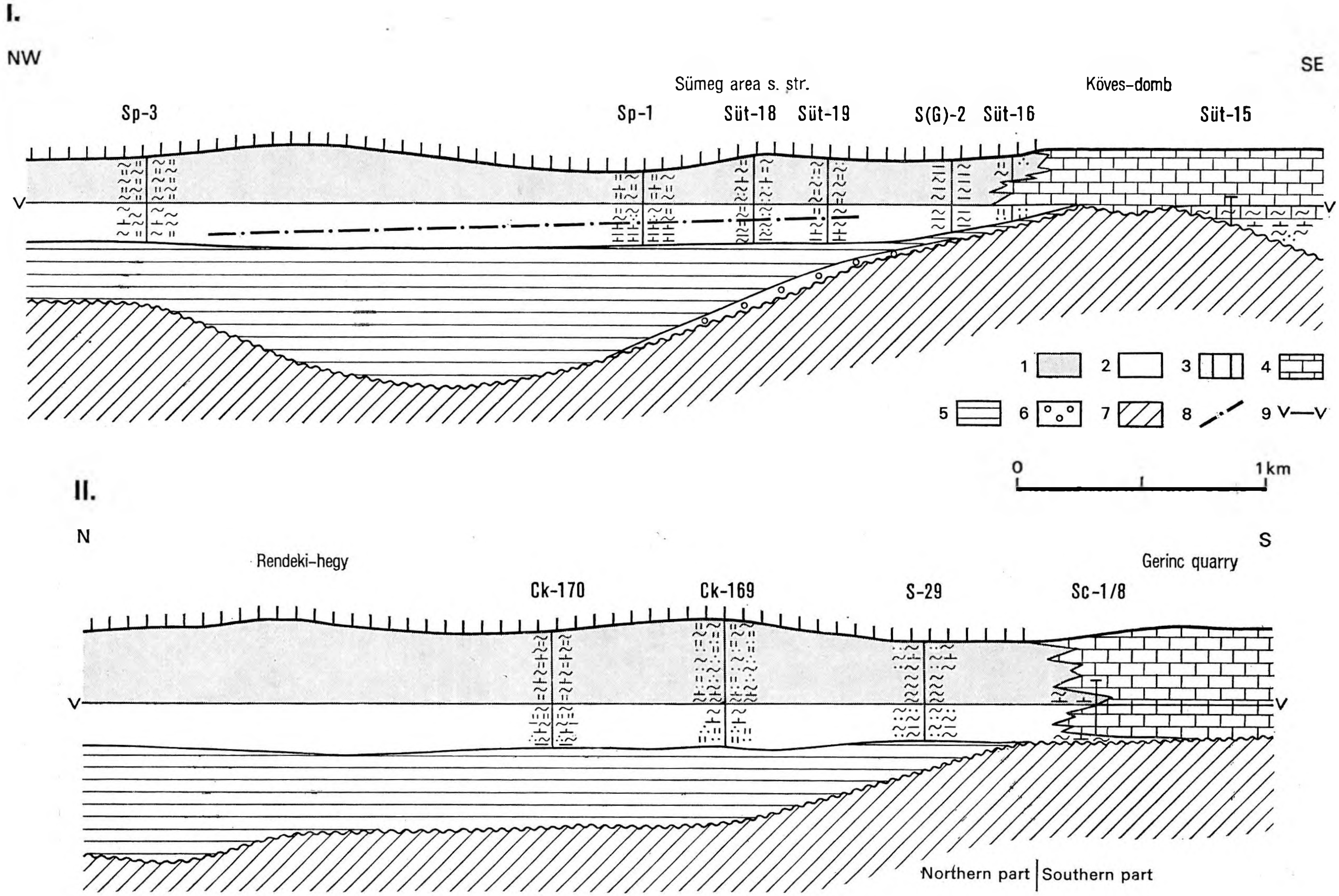
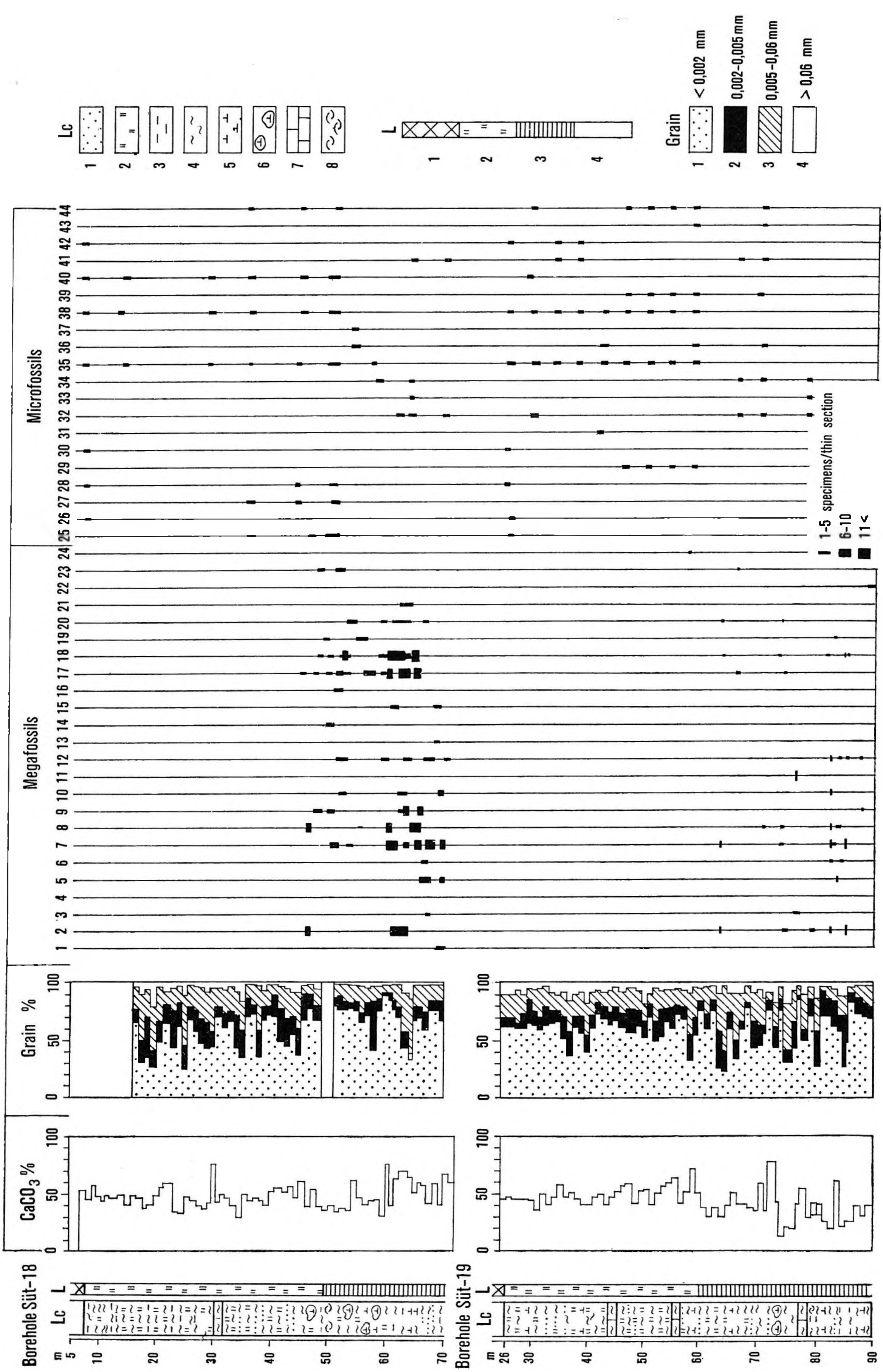


Fig. 44. Transversal profiles across the area of the Csingervölgy Marl Member

1. Upper member, 2. lower member, 3. Polány Fm., 4. Ugod Fm., 5. Ajka Fm., 6. Csehbánya Fm., 7. pre-Senonian basement, 8. upper limit of cyclicity, 9. reference level — boundary of lower and upper members



Lc
L
Grain
< 0,002 mm
0,002–0,005 mm
0,005–0,06 mm
> 0,06 mm
Microfossils
Megafossils
1-5 specimens/thin section
6-10
11<
Grain %
CaCO3 %
Borehole Süt-18
Borehole Süt-19
m

On the basis of her examination of the megafossils, L. CZABALAY showed the presence in the cyclic lower interval of the lower member of a "Gastropoda–Pecten–Cardium–Corals" biofacies, while in its upper interval she identified a "Nucula–Corbula–Corals" biofacies.

Among the representatives of Foraminifera it is *Miliolina* and *Vidalina* that are characteristic. A sharp change is observed at the upper member-boundary, *Miliolidae* and *Vidalina* disappearing and only *Nonionella* reaching a little bit above the member-boundary.

Constituted by silty marls and calcareous marls, the upper member is exposed by the drill (242.3–190.4 m) in a thickness of 51.9 m.

The Mollusca assemblage in the lower part of the member is still represented by a "Nucula–Corbula–Corals" biofacies, but in the upper part it is by a "Clavagella" and a "Dentalium" one.

The microfauna content shows the following distribution: in 10 m thickness above the lower boundary an interval containing exclusively *Nonionella* (otherwise free from Foraminifera) will follow and eventually there appear *Vaginulina*, *Epistomina* and *Globotruncana* and, in the upper part of the member, *Gavelinella* as well.

In the borehole Sp-1 the thickness of the formation is 54.9 m (51.6–106.5 m). Having a thickness of 32 m, the member is composed grey marls, silty marls or nodular marls and calcareous marls alternating with varying frequency, gradually decreasing upwards. The megaloscopic description by M. PAPAJCSIK–GERECS suggests a sequence of cyclic nature with three to four cycles distinguishable. (This number exceeds the figure observed in the borehole Süt-22.) Member *C* of the last identifiable cycle falls at the boundary between two members of the formation.

According to the results of analysis of the megafossils, *Astarte similis* MÜNSTER and *Corbula angustata* SOW., both species indicative of a sea water of normal salinity, are predominant. Frequent forms are: *Ostrea* sp., *Tellina stoliczkai* ZITTEL, *Pholadomya granulosa* MÜNSTER; from among the gastropods a few specimens of *Turritella fittoniana* MÜNSTER were encountered. *Cyclolites* are present in fair quantities. Similarly to the case of the borehole Sp-2, the lower part of the "Gastropoda–Pecten–Cardium–Corals" and "Nucula–Corbula–Corals" biofacies can be identified within the member.

According to the results of the analyses of microfossils a Miliolina–Vidalina–Nummofallotia assemblage is characteristic in the lower part of the member, *Nonionella* being encountered throughout the member.

The upper member is 23 m thick (74.5—51.6 m). Lithologically, it is an extremely homogeneous, grey silty marl interrupted very rarely by single marl beds.

The amount of the megafossils decreases markedly, no new species presenting itself. It is the forms known from the lower member that are persisting. L. CZABALAY assigned the member as a whole to the "Nucula–Corbula–Corals" biofacies. The "Clavagella" and "Dentalium" horizon in this exposure could not be identified. Upon their disappearance it is the "Exogyra" horizon that follows immediately. The microfossil assemblage is significantly different from that of the lower member. After an interval of a couple of metres above the member-boundary it is *Vaginulina*, *Bulimina* and *Epistomina* rather than *Globotruncana cretacea* that appear.

The borehole Süt-18 (Fig. 45) exposed the Jákó Formation in a thickness of 70.4 m (7.7–78.1 m), 29.6 m of which is the thickness of the lower member. A peculiar feature of the sequence is the cyclic development traceable throughout the lower member.

The lower part of the member is characterized by regular cycles (3 of them). In the upper one the development is not completely regular anymore, the regularity being confined to an alternation of more calcareous and more detrital beds with ones of higher pelite and silt content and then, in the uppermost 12 metres of the member, this alternation becomes faded, too. In the lower half of the basal cycle the brackish-water faunal assemblage typical of the upper part of the formation is gradually replaced by species enduring the variation of salinity (*Pecten laevis* NILSSON, *Gervilleia solenoides* DEFR., *Corbula angustata* SOW., *Nucula concinna* SOW.).

←

Fig. 45. The Jákó Marl interval of the boreholes Süt-18 and -19: lithologic column and analytical record

Lithologic column (Lc): 1. sand, 2. siltstone, 3. clay, 4. marl, 5. calcareous marl, 6. nodular limestone, 7. limestone, 8. lumachelle. — ***Lithostratigraphic units*** (L): 1. Polány Formation, 2. Jákó Fm., upper member, 3. Jákó Fm., Csingervölgy Member, 4. Ajka Fm. — ***Grain:*** 1—2. clay, 3. silt, 4. sand. — ***Megafossils: Facies:*** tending to get desalinized: 1. Pyrgulifera sp.; brackish-water: 2. Cardium ottoi, 3. Cyrena solitaria, 4. Cardium sp.; fossils enduring changes in salinity: 5. Turritella difficilis, 6. Haustator sp., 7. Pecten laevis, 8. Nucula concinna, 9. Lima marticensis, 10. Limopsis calvus, 11. Exogyra, 12. Gervilleia solenoides?, 13. Cryptorhytis baccata; marine: 14. Dentalium sp., 15. Cantharulus gosauicus, 16. Acropagia sp., 17. Astarte similis, 18. Corbula angustata, 19. Pectunculus sp., 20. Crassatella macrocarinata, 21. Tellina stoliczkai, 22. Pirenella münsteri, 23. corals, 24. fish scales. — ***Microfossils:*** 25. Globotruncana concavata, 26. Gl. marginata, 27. Gl. globigerinoides, 28. Gl. sp., 29. Globigerinelloides sp., 30. Hedbergella cretacea, 31. Heterohelix striata, 32. Miliolidae, 33. Vidalina hispanica, 34. Cornuspira sp., 35. Vaginulina sp., 36. Nonionella sp., 37. N. cretacea, 38. Gavelinella sp., 39. Valvulineria sp., 40. Epistomina, 41. Nummofallotia cretacea, 42. Goupillaudina lecointrei, 43. Rotalia sp., 44. other benthos

The n e x t i n t e r v a l is characterized by the predominance of euryhaline species, though marine forms *(Echinidea, Cirripedia* and a few *Corals)* are also encountered sporadically in the regularly cyclic sequence of the member. In that part characterized by an alternation of more pelitic rock varieties with more calcareous ones the faunal assemblage is already marine.

In the lithologically distinguishable u p p e r m o s t i n t e r v a l of the lower member the species enduring a decrease in salinity already disappear. The microfossil assemblage shows the characteristic pattern of the lower member.

The u p p e r m e m b e r is represented in a thickness of 40.8 m by marly siltstone, silty marl, argillaceous marl and, less frequently, marly limestone. Its mega- and microfossil assemblages agree with those observed in the sections already discussed.

The borehole Süt-19 (Fig. 45) exposed the formation in 64.6 m thickness. It is from 60.2 to 91.0 m that the Csingervölgy Member could be identified, being conspicuous with its comprising a number of cycles greater than is the case with the sequences exposed farther north.

The b a s a l 16 m o f t h e m e m b e r are composed of six regular cycles, above this, along the member-boundary, marls and silty-sandy marls alternate with thin interbeds of nodular, calcareous marl and, less frequently, of marly limestone with lots of megafossils. As interpreted by L. Czabalay, three megafossil-based intervals can be singled out: at the base of the member (in the lower one cycle and a half) a brackish-water assemblage fairly tolerant of changes in salinity (*Pirenella, Cardium, Cyrena, Nucula* species) appears. Within a short interval above the former, similarly to the case of the borehole Süt-18, it is marine (*Gervilleia solenoides* Defr., *Corbula* sp.) or euryhaline (*Pecten laevis* Nilsson, *Nucula* sp.) species that predominate and the traces of borer-sponge *Clionia*, are abundant. Single brackish-water species (*Limopsis calvus* Zittel) are encountered too. A difference compared with the sequence of the borehole Süt-18 is that there this interval appears already above the cyclic sequence. The third macrofossil-based interval has yielded a marine fossil assemblage in which, in addition to *Bivalvia* and *Gastropoda*, the representatives of *ahermatypical corals* appear too.

In the microfossil assemblage of the member such forms as *Nummofallotia cretacea* Schlumb., *Vidalina hispanica* Schl., *Cornuspira* sp. and *Miliolideae* are abundant, to disappear then a few metres beneath the member-boundary. The uppermost few metres contain *Nonionella* exclusively.

The u p p e r m e m b e r is lithologically similar to the local stratotype and the fossil assemblage is also akin to that of the type section.

The Jákó Formation can be divided into a lower and an upper member in the section of the borehole Süt-16 too, but a thin limestone bed showing the characteristics of the Ugod Formation is indented between the two.

In 12 m thickness beneath the Ugod Limestone (44.9–56.4 m) the Csingervölgy Member was cut by the drill. This part of the sequence is constituted by a sevenfold alternation of dark grey siltstone and marly limestone of varying sand content and marly limestone and pure limestone. The only cycle of regular development is that one the *A*-member of which is composed of a little sandy, argillaceous marl with traces of coal. Its megafauna is poor, consisting, similarly to what has been previously discussed, of euryhaline and purely marine forms. (The latter are predominant in the limestone beds.) Brackish-water species are subordinate. In the uppermost part *Scaphopoda* and *fish scales* characteristic already of the upper member are found.

Its microfaunal assemblage agrees with the characteristic species of the cyclic part of the lower member, forms disappearing all but *Nummofallotia cretacea* Schl. with the appearance of the Ugod Limestone.

Above the Ugod Limestone of about 17 m thickness the u p p e r m e m b e r is 19.1 m thick (10.1–29.2 m). Its is constituted by dark grey, locally somewhat sandy siltstone with rare interbeddings of sandy and marly limestone with fossils typical of the member.

The borehole S-7 of Köves-domb did not hit the Jákó Marl, the pre-Senonian basement being overlain, with a thin argillaceous and carbonaceous basal bed, by the Ugod Formation.

Located to the southeast of the borehole S-7, the borehole Süt-15 (Fig. 46) exposed, beneath extraclastic limestone beds of the Ugod Formation, 17 m of the lower member of the Jákó Marl. The geological features are similar to the case of the lower member exposed in the borehole Süt-16. being composed of alternating dark grey argillaceous marls, sandy silty marls and grey calcareous marls.

Both rock types contain a good deal of megafossils among which the euryhaline forms (*Pecten laevis* Nilsson, *Plicatula aspera* Sow.) predominate. In the more calcareous intervals marine forms prevail (*Astarte similis* Münster), the heavily argillaceous beds abounding with brackish-water forms (*Cardium ottoi* Geinitz).

In the southernmost part of the Köves-domb, in the immediate proximity of the roofed well (Hárskút), the extremely fossiliferous beds of the lower member of the formation that have altered ochre-yellow owing to oxidation are present in outcrop as well. The outcrop is a well-known locality, where Upper Cretaceous molluscs and ahermatypical corals have been sampled for a long time. From

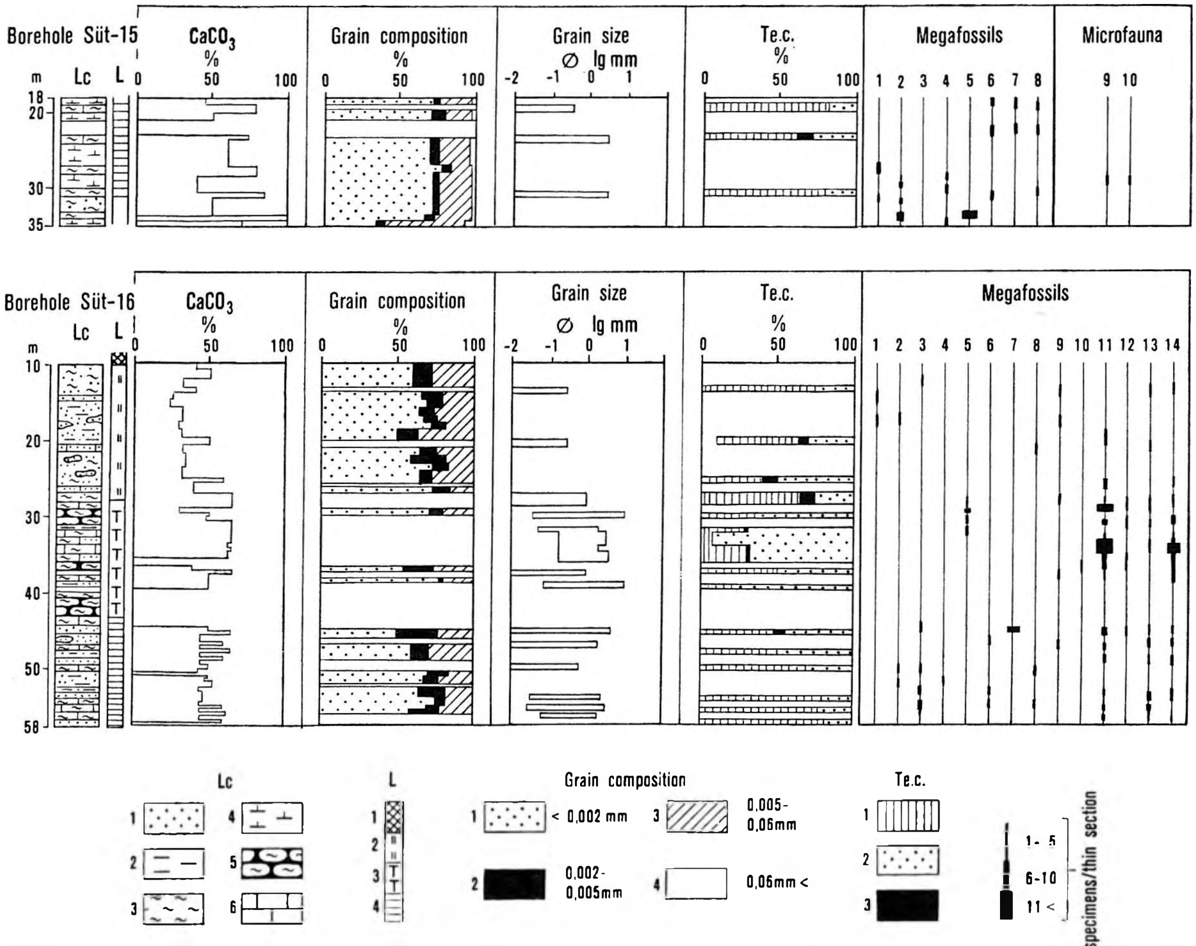


Fig. 46. The Jákó Formation interval of the borehole Süt-15 and -16: lithologic column and analytical record

Lithologic column (Lc): 1. sand, 2. clay, 3. marl, 4. calcareous marl, 5. nodular marl, 6. limestone. — ***Lithostratigraphic units*** (L): 1. Polány Marl Fm., 2. Jákó Fm., upper member, 3. Ugod Fm., 4. Jákó Fm., Csingervölgy Member. — ***Grain composition:*** 1—2. clay, 3. silt, 4. sand. — ***Textural composition*** (Te.c.): 1. micrite, 2. fossils, 3. pellets. — Megafossils from the ***borehole Süt-15:*** 1. Cyclolites, 2. Pecten, 3. Plicatula, 4. Cardium, 5. Astarte, 6. Rudist detritus, 7. Ostrea sp., 8. Echinodermata; microfossils: 9. Vidalina, 10. benthonic Foraminifera. — Megafossils from the ***borehole Süt-16:*** 1. Dentalium, 2. Nucula, 3. Inoceramus, 4. Limopsis, 5. Exogyra, 6. Astarte, 7. Rudista group, 8. Haustator, 9. fish scales, 10. Serpula, 11. Mollusca detritus, 12. Rudista detritus, 13. Ostracoda, 14. Echinodermata

among the ahermatypical corals *Cyclolites* are represented by the highest number of species and individuals. B. GÉCZY (1953, 1954) devoted a special study to their description. The most frequent species are *C. macrostoma* REUSS, *C. orbigny homoiomacrostoma* GÉCZY, *C. reussi* FROMENTEL and *C. semisubcircularis* GÉCZY.

As shown by G. KOLOSVÁRY (1954), other ahermatypical corals include forms of the genus *Phyllosmilia*, while the representatives of the genera *Montlivaultia*, *Placosmilia* and *Trochosmilia* occur just sporadically. Colonies of *Bryozoa* and worm tubes were observed to be attached by overgrowth to coral skeletons (GÉCZY 1954).

As shown by L. CZABALAY (1961), the Mollusca fauna represents a Gastropoda–Pecten–Cardium assemblage characteristic of the lower part of the lower member. Within it she identified a biofacies containing, for the most part, Glauconia and just a few bivalves (*Cyrena* and *Corbula* species) and one constituted by Cerithium. In the Glauconia facies the following species are abundant: *Glauconia renauxiana* D'ORB., *G. coquiandiana* D'ORB. var. *G. kefersteini* MÜNSTER (Gastropods) and *Cardium ottoi* GEINITZ, *Limopsis calvus* ZITTEL, *Plicatula aspera* ZITTEL, *Cyrena solitaria* ZITTEL *Corbula angustata* SOW. (Bivalvs).

Typical Gastropods of the Cerithium biofacies are *Pirenella, Haustator, Desmieria, Aptyxiella, Rostellaria* and *Fusus* sp. Most frequent Bivalves are *Corbula angustata* SOW., *Tellina stoliczkai* ZITTEL, *Nucula concinna* SOW., *Astarte similis* MÜNSTER and *Lima* sp.

During her study of the Foraminifera fauna, M. SIDÓ (1961) found *Operculina baconica* to be present in largest number of specimens in a decanted material sampled from the exposure. (According to M. SIDÓ 1963, the species is a synonym of *Goupillaudina lecointrei* MARIE.) In addition, specimens of *Nummufallotia cretacea* HANTK., *Cornuspira cretacea* RSS., *Nonionella cretacea* (CUSH.) and Haplophragmoides occur in smaller numbers.

S u m m a r i z i n g the above, let us conclude that, as shown by an analysis of the exposures of Profile I (Fig. 44), the Csingervölgy Member evolves continuously above the Ajka Formation throughout the section, save for a rather shorts tretch of the Köves-domb; moreover, that its peculiar cyclic development can be traced farther over an interval of varying length within the lower member as well. The number of cycles increases from zero in the northwest to six in the southeast up to that point of the section, where a rapid decrease in formation thickness is observable. Before reaching that point, however, no change in the thickness of the lower member is observed. The differences in thickness within the upper member are remarkable.

Changes in fossil content as bound to lithological cycles are generally recognizable, but, in addition, there is a general trend consisting in that the brackish-water forms tend to be replaced up in the sequence by an euryhaline marine assemblage. The two members get individualized in terms of both their mega- and microfossil contents. Near the member-boundary a microfossil-free interval, consistently a few m thick, occurs.

A transition between the northwestern and southeastern stretches of the section is represented by the borehole Süt-16 in which, though two members get individualized, but the thickness of either is reduced. In the northern part of the Köves-domb the Jákó Formation is not developed; to the south of it, in turn, only its lower member covered by the beds of the Ugod Formation can be found.

Normal to the strike of the sedimentary basin (Fig. 44), Profile II starts from the northern side of the Rendeki-hegy and, extending southwards, it crosses the Hárs-hegy and ends in the Gerinc quarry.

The northernmost exposure is the borehole Ck-170 which, in 89.5 m thickness above the Ajka Formation (259.5–349.0 m), exposed the Csingervölgy Marl Formation (Fig. 47).

The lithology of the l o w e r m e m b e r is characterized in the lower half of the unit by alternating marls, sandy marls, siltstones and calcareous marls and calcareous sandstones, in the upper half by that of argillaceous marls, marls and limestones. Nodular structure is frequent. The rock contains a considerable amount of macrofossils consisting for the most part of corals and molluscs.

The u p p e r m e m b e r somewhat differs in lithology from the sequences that we came to know in Profile I, its rock varieties being characterized, as a rule, by a higher carbonate content such as calcareous marl, marl and, subordinately, limestone, siltstone and, less frequently, argillaceous marl. The abundance of *Exogyra* in the fossil assemblage is conspicuous. The appearance of *Scaphopoda* and fish scale and crab remains is a feature corresponding to the development of the local type section. In the overburden, after a transition of a few metres, the Polány Formation (Rendeki Member) is that which follows.

In the borehole Ck-169 the geological features of the formation are similar to those from the borehole Ck-170.

The Jákó Marl sequence of the borehole S-29 (Fig. 47) put down on the Hárs-hegy is composed of rock varieties having a lower carbonate content compared with the case of the previous boreholes. The lower member is constituted by argillaceous marls and sandy marls, the upper member by marls, argillaceous marls and sandy-silty marls. The fossil assemblage is similar to the case of the type section.

The southeast end-point of Profile II is the Gerinc quarry. In the lower, abandoned quarry-yard here, more precisely in the borehole Sc-8 and Sc-8a put down there (Fig. 47), a Jákó Formation member of marginal facies could be studied.

At the entrance to the quarry a few metres of light brown, ochre-yellow and light grey marl and argillaceous limestone are exposed. (The sequence was penetrated by the boreholes Sc-8 and Sc-8a as well.) It is overlain, both in the quarry and the boreholes, by the Ugod Formation in 20 to 30 m thickness. It is after this that the marl lens left unextracted in the lower quarry-yard (owing to its being unsuitable for lime-burning) can be observed. The borehole Sc-8a penetrated it between 8.5 and 30.0 m.

The marl member is composed of light grey to ochre-yellow, nodular, mottled calcareous marls, marls and argillaceous marls. *Ahermatypical corals* and *Bivalvia* are present in considerable quantities in the megafaunal assemblage.

The rich *Cyclolites* fauna recovered during earlier samplings of paleontological aim was processed in detail by B. Géczy (1954). In his work he quotes the following species: *Cyclolites robusta* Quenstedt, *C. macrostoma* Reuss, *C. polymorpha* Goldfuss, *C. discoidea* Goldfuss. Other ahermatypical corals are frequent in the rock too. G. Kolosváry (1954) identified *Stephanosmilia polydectes* Kolosváry, *Coelosmilia niobe* Kolosváry, *Phyllosmilia* sp. and *Ph. sümegensis* Kolosváry.

From among the Vivalvia, small-sized *Chlamys* species and *Pycnodonta* are frequent. K. Barnabás, in his Ph. D. thesis (1937), reported *Gryphaea vesicularis* Lam., *Janira (Vola) quadricostata* Sow., *Lima marticensis* Math. and *Actaeonella* sp.

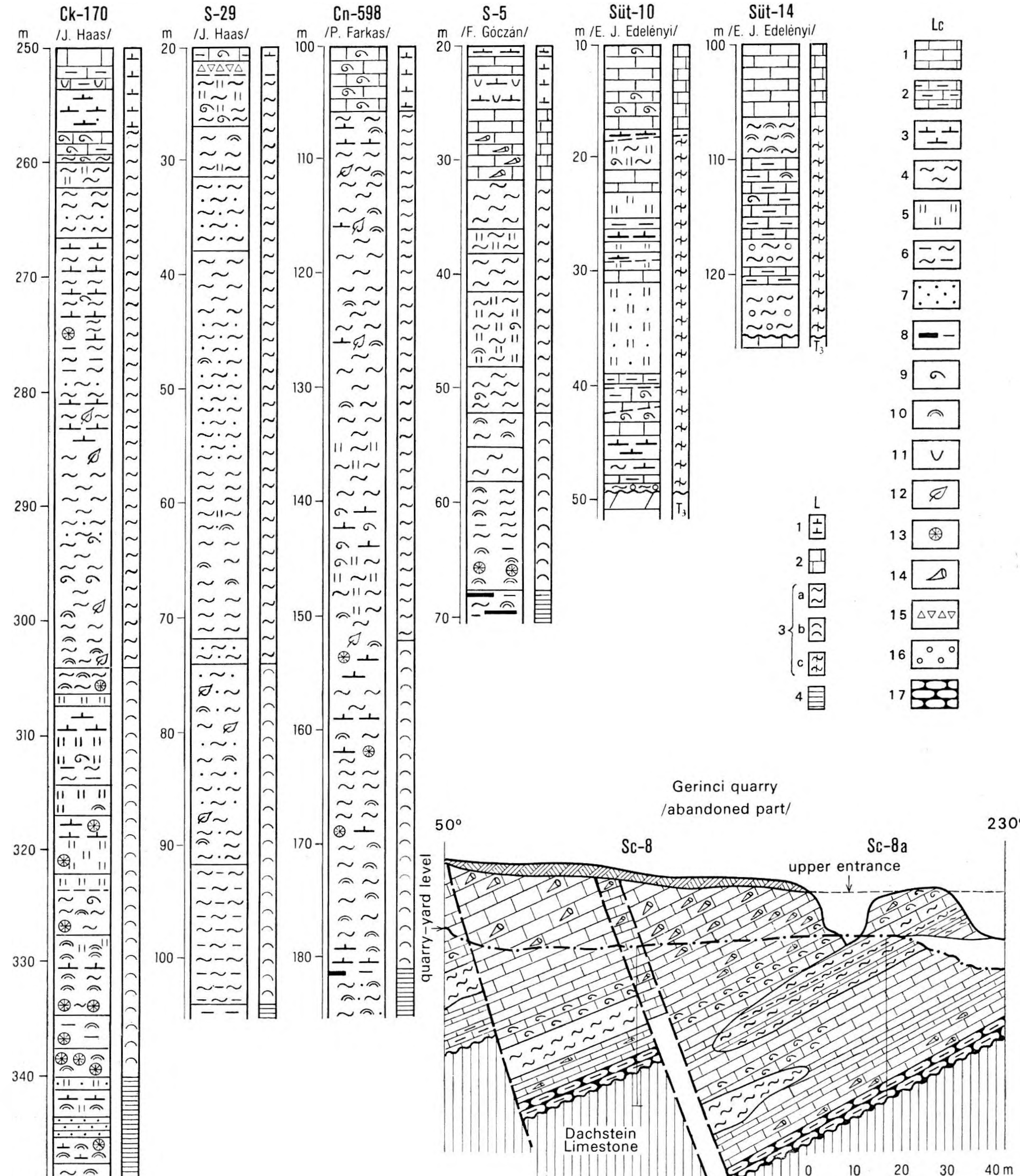


Fig. 47. Characteristic drill logs of the Jákó Marl Formation in the Sümeg area and its lenticular occurrence within the section exposed in the Gerinc quarry

Lithologic column **(Lc): 1. limestone, 2. argillaceous limestone, 3. calcareous marl, 4. marl, 5. silt, 6. argillaceous marl, 7. sand, 8. carbonaceous clay, 9. Exogyra, Pycnodonta lumachelle, 10. mollusc lumachelle, 11. worm tracks, 12. coalified plant remain, 13. ahermatypical coral, 14. rudist valves, 15. intrabreccia, 16. gravel, 17. nodular structure. —** ***Lithostratigraphic units*** **(L): 1. Polány Marl Fm., lower member, 2. Ugod Limestone Fm., 3. Jákó Marl Fm.:** ***a)*** **upper member,** ***b)*** **lower member,** ***c)*** **marginal facies, 4. Ajka Coal Fm.**

It is probably from this lens that the Echinoidea—the determination of which is given in the summarizing work of E. SZÖRÉNYI (1955)—derive: *Botriopygus nauclasi* COQUAND, *Echinobrissus pannonicus* SZÖRÉNYI and *Hungaresia hungarica* SZÖRÉNYI.

As shown by M. SIDÓ (1961), its rich Foraminifera fauna in the upper part can be found in a great number of individuals: *Goupillaudina lecointrei* MARIE, *Nonionella cretacea* CUSH., *N. extensa* (BROTZ.) and a few *Haplophragmoides* sp. and *Bulimina ovulum* RSS. In the lower part of the unit the species *Nummofallotia cretacea* SCHLUMB., *Cornuspira cretacea* RSS. and *C. senonica* DUN. predominate.

According to microscopic results, fossil debris account for 30 to 50% of the rock, sand-size quartz grains varying between 5 and 15%. Foraminifera are present in a considerable number in the lower interval of the section too, locally accounting for 5% of the rock volume.

The immediate cover of the marl beds is constituted by brownish-red argillaceous limestones with Exogyra; higher up the profile, the typical, rudist-bearing Ugod Limestone appears too.

Accordingly, similarly to the case of Profile I, two stretches can be distinguished in Profile II as well. The greatest thickness values occur at the end and in the middle part of the northern stretch of the section, followed then by a marked reduction in thickness within a short distance and there appears a unit consisting of rock varieties of higher carbonate content showing a transition towards the Ugod Limestone and intertonguing with it. The thickness differences, in this profile too, are due to changes in the values of the upper member. In the exposures of Profile line II plotted to the northeast of Profile I the formation is lithologically (rock varieties of higher carbonate content) somewhat different from what could be observed in the exposures representing the west side of the area studied. A difference in the fossil assemblage is represented by the massive occurrence of *Exogyra* in the upper member—a feature otherwise common in the upper part of the Jákó Formation in other areas of the Bakony.

The transition between the Jákó and Ugod Limestone was exposed by the boreholes Süt-10 and -14 falling outside the profile traces.

Located on a limestone outcrop on the northern slope of the Kopasz-domb, the borehole Süt-10 (Fig. 47) exposed the transitional member in a thickness of 25 m above Triassic dolomites.

On the basis of the fossil assemblage the lower 19 m can be correlated with the lower member, this being overlain by beds showing characteristics of the upper member. An intertonguing with the Ugod Formation is observable throughout the section. In the lower interval there appear still just a few, 1- to 2-m-thick interbedded layers of marly limestone and limestone, then higher up the section the Ugod Limestone features gain predominance, to become exclusive in the end.

The rocks assignable to the Jákó Formation, as a rule, are of a high carbonate content. The lower interval is constituted by dark grey marly siltstone, light grey sandy, marly siltstone, siltstone and ochre-yellow argillaceous marl. The megafauna is available in a fair quantity with *Exogyra* sp. and *Pecten* sp. as predominant forms, small fragments of *Mollusca*, skeletal elements of *Echinoidea* and the remains of crabs and, in the lower interval, of *algae* being quite frequent.

The upper interval consists of dark grey siltstones and sandy siltstones, a microlamination being frequently observable in the sandy parts. The fossil content is composed of usually small mollusc shell fragments present in low to fair amounts, scattered and poorly preserved external moulds of Bivalvia, pyrite-filled *Nucula* and *Avellana* valves, minor gastropods (*Voluta torasa* ZEKKEL), corals, crab claw fragments, echinoderm elements and fish scales.

The borehole Süt-14 put down in the Városi-erdő intersected the transitional unit in 10 m thickness, overlying coarse-detrital basal formations with a marine fauna (Fig. 56).

The formation is composed of brownish-grey to grey nodular limestones with a few interbedded layers of pelitic sediment. The carbonate content shows a strong fluctuation in the lower half of the unit (35–95%), tending to increase above it. The fossil content is represented for the most part by bivalves *(Chlamys, Pecten, Lima)* and ahermatypical corals; a few small-sized *Rudista* occur, too. In the upper part of the unit the fossil content gets heavily enriched, the rock turns darker in colour and coalified vegetal remains are quite frequent. Among Foraminifera *Nodellum velascoense* is characteristic.

The Csingervölgy Marl is overlain by an Ugod Formation of typical development.

On the basis of the sequences and/or profiles presented and in terms of the dissimilar geological features, the study areas can be split up into the following subareas:

1. In the marginal zone the pre-Senonian basement is directly overlain by the transitional member of the formation the characteristics of which are determined primarily by the intertonguing with the Ugod Limestone, its lithological development being characterized throughout the unit by the high carbonate content. In its lower part it contains the typical microfossil assemblage of the lower member (Csingervölgy Marl), in the upper part that of the upper member.

2. In the western part of the area, the immediate vicinity of Sümeg, the peculiarity of the formation consists in its cyclic development transient from the Ajka Formation.

The megafauna is characterized by a marine brackish-water assemblage and by the fact that forms attached to normal salinity environments become predominant as one proceeds upwards, respectively. In this subarea, the upper member is of monotonous siltstone facies, poor in fossils. There appears no significant change in its characteristics either in the vertical or the lateral sense.

3. In the northern part of the area the characteristics of both members differ somewhat from those in the western part. The lower member is of modest thickness, less than even 10 m in a belt almost 1 km wide. Compared with the rest of the area no remarkable change in thickness of the upper member could be observed. Both members are composed of argillaceous marls, calcareous marls and—subordinately—marly limestones with a preponderance of the more calcareous rock varieties in the upper member. The fossil content of the member is similar to the case of the type section, the only difference being that the upper member generally contains a larger number of *Exogyra* and *Pycnodonta*.

The general conclusion that can be deduced from the spatial changes in formation thickness (Fig. 42) is as follows:

The configuration of the isopachs on the map corresponds by and large to the case of the Ajka Formation. The basic orientation remains northeast–southwest and the direct connection between the thickness values of the two formations is apparent. A resemblance is indicated by the NW-SE trending re-entrants of the isopachs and by the turning of the strike to a north-south direction, as observed to the south of Sümeg.

There is a difference concerning the position of the thickness maximum. Namely in the case of the Jákó Formation the formation is observed to grow thicker to the east of the Rendeki-hegy in a NE-SW trending strip of 1 to 1.5 km width which at the foot of the Rendeki-hegy turns to a southerly direction and is reduced in width to 0.5–1 km only. Less significant divergency is observed on the west side of the area, where a zone of reduced thickness, trending northeast–southwest, 2 km long and 1 km wide, can be observed.

Since the two members of the formation represent two more or less different development stages of the Senonian sedimentary basin, to prepare a separate isopach map for the lower one has been regarded as useful (Fig. 48).

The low variability of the thickness values of the lower member is conspicuous. The thickness maximum is 34 m. Observable in the eastern part, the northeast-southwest orientation of the isopachs turns north-south in the western part in this case, too. The traces of the northeast-southwest strip of reduced thickness on the western side already appear in the lower member.

Bio- and chronostratigraphy

On the basis of a palynological study of the boreholes Sp-1 and Sp-2, F. Góczán identified, the following abundance zones in the Jákó Formation:

D — *Hungaropollis krutzschi* Zone

E — *Sümegipollis triangularis* / *Krutzschipollis spatiosus* Zone

F — *Longanullipollis lenneri* / *L. bajthayi* Zone

In the borehole Sp-1, the boundaries of Zone E extend a little bit even beyond the lower and upper boundaries of the formation.

The study of the borehole Sp-2 produced results that deviate to some extent from this. In that exposure, the lower member of the formation falls completely in Zone D, while from its upper member only the lower part does so. In higher parts of the upper member of the Jákó Marl the characteristic forms of palynological zone E could be identified.

In the local type section of the formation the lower member and the lower half of the upper member belong—as shown by F. Góczán's studies in 1974—to Zone E. The genera *Krutzschipollis* predominate and the eponymous zonal species can be found throughout the interval. *Hungaropollis* and—primarily in the upper part—the species of the genus *Longanullipollis* are quite frequent. The lower boundary of the zone coincides approximately with the lower boundary of the formation.

In the upper part of the upper member it is the species of *Longanullipollis* that predominate, the genera predominant in the deeper parts being here subordinate. Consequently, the presence of Zone F here is likely.

Analyses of materials from the marl beds in the Gerinc quarry (transitional member) showed the probable presence of the upper part of Zone E and the basal one of Zone F. These results are in accordance with the opinion suggesting the member to have formed in the marginal, more elevated zone, i.e. in that strip of land that was later reached by the transgression.

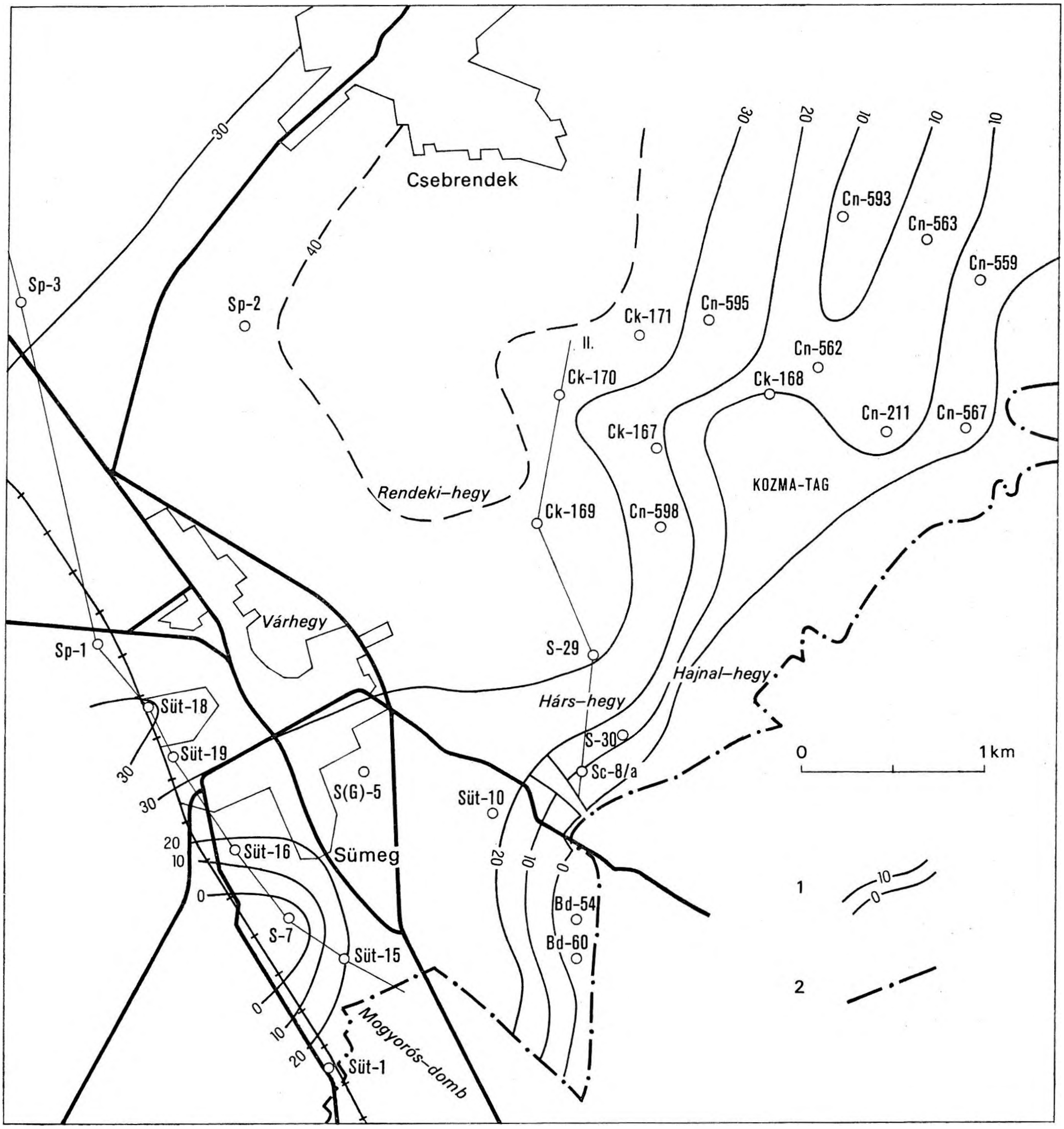


Fig. 48. Thickness of the Csingervölgy Marl Member

1. Thickness of the Csingervölgy Marl Member, 2. boundary of extension of the Senonian

Consequently, in the light of palynological results, it is the upper part of Zone D and the whole Zone E that can be identified in the Csingervölgy Member of the Jákó Marl, while in the upper member of it, Zone E and the lower part of Zone F can be registered. On the basis of these results, F. GÓCZÁN believes that the age of the lower member in the nortwest basin-centre area corresponds to the upper Lower Campanian and the lower Upper Campanian and that the age of the upper member and that of the transitional unit known from the Gerinci quarry can be fixed in the Upper Campanian.

As a result of her foraminiferological study of the boreholes Sp-1 and Sp-2, M. SIDÓ (1969) distinguished in the Jákó Marl Formation the following abundance zones: "Vidalina Zone; Rotalia Zone (II); Nonionella Zone; Operculina Zone; Globigerina Zone; Epistomina Zone; Bulimina Zone and Vaginulina Zone".

All these zones but the "Operculina Zone" cannot be distinguished in a consistent way even in the relatively small Sümeg area, being even less suited to interregional long-distance correlation purposes.

So much can be pointed out anyway that *Cornuspira senonica* DUNIKOVSZKY, *Vidalina hispanica* SCHLUMBERGER and *Nummofallotia cretacea* (SCHLUMBERGER) are typical in the lower part of the Csingervölgy Member and that the species of the genus *Goupillaudina* are so in the upper part of the member.

Characteristic forms of the upper member are the representatives of *Vidalina* and *Gavelinella.*

As shown by the latest results of M. SIDÓ, it is at the boundary of the two members that the planktonic species with the zonal index fossil *Globotruncana concavata*—ranging, according to the international literature (F. T. BARR 1972, E. A. PESSAGNO 1962, J. PREMOLI-SILVA and H. M. BOLLI 1973) from the Upper Coniacian up to the latest Santonian—appear.

During her analysis of the formation for megafossils, relying on the elaboration of key sections Sp.-1,-2,-3, L. CZABALAY distinguished the following four—or, in the local stratotype, three—zones or biofacies, respectively:

"Gastropoda–Pecten–Cardium–Corals"
"Astarte–Nucula–Corbula"
"Clavagella" } and/or "Pecten"
"Dentalium" }

The "Gastropoda–Pecten Zone" is situated within the lower member of the formation, the second zone extends from the lower member well into the upper one, the "Clavagella" and "Dentalium" and the "Pecten" biozones, respectively, representing the upper member.

The Mollusca fauna of the formation is composed predominantly of facies-indicating species, though forms of a wider lateral distribution can be encountered, too. The two lower biozones contain in the first place species of more restricted lateral distribution, being known from localities in southern Greece, Yugoslavia, and Romania. In the upper zones the species of wider lateral distribution tend to play an ever increasing role (forms known from India, the Caucasus and the Crimea).

A good deal of the Glauconia species typical of the lowermost biozone are characteristic of the Campanian stage, similarly to the case of *Desmieria zekeliana* (STOL.) and *D. goldfussi* (MÜNSTER). *Aptyxiella (Acroptyxis) flexuosa* (SOW.) and *A. gracilis* (MÜNSTER) occur solely in the Campanian. *Tanaliopsis spiniger* (ZEKELI), *Rostellaria granulata* SOW. and *Ampullospira bulbiformis* (SOW.) are known Upper Santonian to Lower Campanian sediments.

The "Astarte–Nucula–Corbula" biozone is composed partly of Lower Campanian or older species [*Astarte similis* MÜNSTER, *Lopha semiplana* (LAMARCK), *Pecten laevis* NILSSON], partly of forms reaching their predominance in the upper part of the Campanian [*Pholadomya granulosa* ZITTEL, *Modiola sphaenoides* DEFR.). The typical forms of the upper biozone or biozones, *Dentalium hexapleura* ZITTEL and *D. rudum* ZITTEL, are characteristic of the Upper Campanian.

The *Cyclolites* fauna of the formation consists of forms of considerable lateral extension, but these have not yet been evaluated biostratigraphically.

In the light of foraminiferological studies the lower member of the Jákó Formation can be assigned to the Santonian, its upper member to the Lower Campanian. According to palynological results, F. GÓCZÁN places the lower member in the Lower Campanian, the upper one in the Upper Campanian. As suggested by L. CZABALAY, the Mollusca assemblage of the lower member is composed of Santonian-Campanian, that of the upper one, of Campanian forms.

Naturally, in the case of this formation, we must reckon with a time-shift of the unit and its individual members owing to shifts in facies. It is probable that in synchrony with the formation of the lower member of the internal zone the marginal zone was still witnessing the brackish-water deposition of the higher part of the Ajka Formation and that when in the marginal zones the formation of the lower member began the basin's interior was already undergoing the deposition of the upper member.

Depositional environment

The formation of the Jákó Marl took place in a littoral or sublittoral to neritic environment that gradually replaced the lacustrine or coastal swamp environment of the Ajka Coal Formation, still carrying on itself for varying lengths of time a number of features inherited from the former. Within this environmental unit the differences in environmental parameters led to the disintegration of three typical environmental units which resulted in the formation of three distinct sedimentation types—the three formation-members.

The traces of the cyclic changes in parameters characteristic of the depositional environment of the Ajka Formation are still recognizable in the lower part of the Csingervölgy Member, in spite of the fact that with the decline of swamps and with the more and more pronounced marine communication the environment has changed radically. However, since the amplitude of variation of the individual parameters has been reduced, the differences in the sediment material become less pronounced too.

The minor environmental units within the major types of environment are difficult to assess in the course of analyzing the lithofacies types, because both the sediment and the fossil content were removed from their original site, to be redeposited in a partly mixed form, often heaped into lenses by wave action—a phenomenon observable first of all in the lower member.

In the initial phase of deposition of the lower member the two facies of the depositional environment were still quite distinct. The one facies was characterized by muddy, subordinately muddy-sandy, the other one by muddy-sandy, sandy, periodically sandy-pebbly sedimentation. Between the facies there existed differences in salinity, water depth and the distance to the shoreline.

1. In the subarea of mud—sand, sand and pebble sedimentation—the south and southeast parts of the study area—mainly marine-brackish (*Cardita granigera* GÜMBEL, *Cardium ottoi* GEINITZ) and euryhaline (*Nucula concinna* Sow., *Pecten laevis* NILSSON) faunal elements can be found. However, the freshwater forms are also frequent (*Cyprina* sp.). All these circumstances suggest a mixing of the fossils by wave action. The fossils are commonly crushed which, when taken together with their accumulation into lenses, is indicative of a heavy agitation, i.e. a deposition in the zone of surfs or the tidal zone, respectively. The water depth may have attained a maximum of a few metres.

2. In the environmental unit marked by muddy sedimentation—the northwest part of the study area—the fauna consists predominantly of forms of normal salinity demand (*Cantharus* sp., *Fusus tritonium* ZEKKELI, *Pectunculus* sp., etc.); it is here that *Cyclolites* appear, and the forms tolerant of salinity changes are subordinate, being gradually superseded. The water depth may have varied from a few m to about twenty m. From the anomalies of growth of Cyclolites, B. GÉCZY (1954) inferred a comparatively rapid sedimentation of varying rate (Plate XXXI).

The relative abundance of mollusc shells, often preserved quite intact, and *Bryozoans* and borer-bivalves anchored on Cyclolites skeletons on the one hand and the superposition of various organisms are indicative of a depositional environment that was generally quiet or just periodically agitated, i.e. a zone immediately beneath the zone of wave action.

The sediment was deposited in a well- or fairly light-penetrated (photic) zone. The bottom was partly covered by a lush vegetation as suggested by a fauna composed of tiny *Gastropoda*, further, of *Ostracoda* and *Foraminifera*.

Some of the fossils were represented by forms of high oxygen demand (*Pecten laevis* NILSSON and *Cardium ottoi* GEINITZ), the rest by less oxygen-exigent ones (*Nucula concinna* Sow.). A reductive environment under the water—mud interface is suggested by the presence of pyrite filling the interior of the foraminiferal chambers and scattered elsewhere in the sediment.

Indirect information on water temperature is furnished by the *Cyclolites* fauna that was shown by B. GÉCZY to indicate a temperature range of 20 to 26 °C. A direct evidence was yielded by the C and O-isotope methods of paleotemperature measurements carried out by the Institute of Mining Research that gave a water temperature of 22 °C (transitional member, Gerinc quarry).

The upper member of the formation indicates a depositional environment that differs in several respects from the former case. Sedimentation was rather pelitic and calcareous. Represented by montmorillonite and illite, respectively, the clay mineral composition suggests, on the one hand, a source area made up of basic magmatic rocks and, on the other hand, a deposition in a deeper, more open sea environment farther offshore (E. NEMECZ 1973). The rest of the material introduced into the basin derived from the immediate neighbourhood. The upward decrease of the dolomite content and the almost total lack of sand-size grains are indicative of a depositional environment that must have lain comparatively far away from the shoreline, too.

The composition of the megafossils is suggestive of a seawater of normal salinity [*Tellina stoliczkai* ZITTEL, *Corbula angustata* Sow., *Haustator rigida* (SOW.) etc.]. The good preservation state of the thin-shelled forms of Bivalvia, the scattered distribution of the fauna and the large number of *Scaphopoda* that lived burrowed in the mud make a quiet depositional environment probable, environment that was scarcely agitated or not agitated at all. The marked pyrite content of the sediment is indicative of reductive conditions that have prevailed beneath the water-sediment interface.

The very low amount of the benthonic fauna and the disappearance of forms of high oxygen demand that were typical beforehand suggest that the oxygen content of the water was very low above the water-sediment interface as well, which is probably due to the decline of water plants and so essentially to an increasing water depth and a decrease in light penetration.

A reduction of the oxygen content seems to have caused the extinction of the microfossil assemblage at the boundary between the two members and to have produced sedimentary strata almost free of microfossils.

On the basis of the reconstructable environmental parameters the water depth may be estimated at 20 to 100 m.

Representing a transition between the Jákó and Ugod Formations, the member is obviously transitional even in terms of genetic conditions. In other words, the sedimentation was probably taking place in that part of the neritic zone which lay close to the shallow-water carbonate platform. The ecological features of the fauna correspond to those of the Csingervölgy Member.

Ugod Limestone Formation

Extension, mode of superposition, stratigraphic subdivisions

Composed of an extraordinary variety of limestones of primarily biogenic type, the stratigraphic unit of the Ugod Formation is exposed on a level, barren landscape lying to the south of Sümeg and in the Hajnal-hegy–Hárshegy–Kozma-tag zone traceable along the hill range. These rock variants serving as an excellent raw material for lime burning have been extracted for a long time in several quarries of varying size.

To register the mode of superposition of the Ugod Formation and to analyze it stratigraphically is rendered rather difficult by the fact that a sequence with immediately overlying beds showing a continuous sedimentation can seldom be exposed. In the zone, where the Ugod Formation once developed, the rocks composing it are exposed even at present or they are covered by post-Senonian formations, the extent of their erosion being poorly known. All that can be determined is that the rock thickness lost to erosion in the Eocene-covered areas was by 50 to 100 m less than it was the case in those parts covered by post-Eocene sediments. In the subarea (farther northwest), however, where younger Senonian formations are known too, the Ugod Formation is missing from the sequences, owing obviously to its not having been developed there at all.

In attempts at interpreting the results gained during the study of the Ugod Formation the methods used in the case of the older formations usually do not work. For instance, no help of any virtual use is provided by the isopach maps (Fig. 49), as these do not reflect the original conditions. We have had to refrain from plotting profiles with reference to the base level of the overlying formation, too. On the other hand, a base to start from for reconstructing the paleoenvironment was provided by the fact that we had already had some knowledge of the main features of the one-time morphology, of the sea to land relation, of the position of the shoreline and the general trend of its course.

In addition to the biofacies analysis, an approach used also heretofore in paleoenvironmental interpretation, we could well rely on the results of analysis of the structure and texture of carbonate rocks.

The exposures of the Ugod Formation show—because of the extraordinary variability of the unit—sequences that are rather difficult to correlate either by litho- or by biostratigraphic methods. This has been so remarkable that it has seemed meaningless to designate a type section. As for the solution of the correlation problem, a task of fundamental significance for paleonenvironmental interpretation, we have attempted to approach it in two steps. First we carried out the correlation of sequences exposed along profiles designated parallel to the main strike of the presumed one-time shoreline, because the least pronounced variability and the simplest way of parallelization were supposed to coincide with that direction. Then, as a second step, we attempted at a correlation in a direction normal to the one-time shoreline, first within the formation itself and then with the heteropical formations as well.

On the basis of the analysis we have managed to delineate three distinct facies zones exhibiting different geological features (*A*, *B* and *C* in Fig. 58). Each of these zones is characterized by different mode of superposition of the Ugod Formation.

Geological features

1. Köves-domb

On the barren surface of the Köves-domb the various rock types of the Ugod Formation, particularly suitable for a detailed paleoecological and petrographic study, can be investigated in a comparatively large and coherent area. In addition to several minor pits there are two large quarries giving an excellent insight into subsurface conditions. Orientation is helped by a number of boreholes as well.

In 1971 a map on a scale of 1:5,000 was prepared from this area, during which efforts were made to represent cartographically even minor units within the Ugod Limestone, i.e. rock bodies of only local importance. The map which is informative of the location of boreholes and exposures that are essential for the present work, is shown in Fig. 50.

On the Köves-domb the most complete Ugod Limestone sequence was exposed by the borehole S-7 (K-1) put down in 1962 a few metres to the northeast of the Kecskevári quarry (Fig. 51a–b).

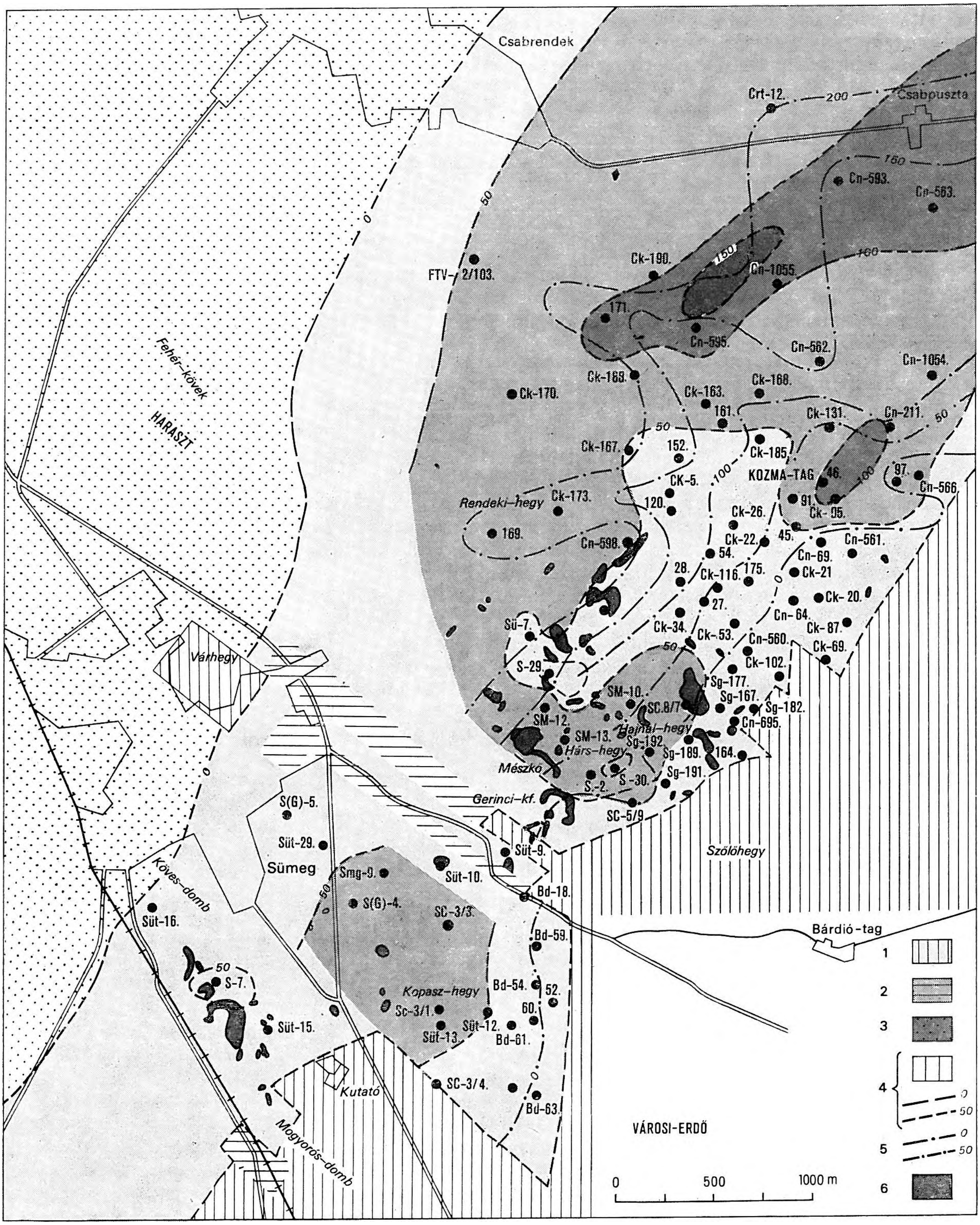


Fig. 49. Thickness of the Ugod Formation and of the Upper Cretaceous underlying it

1. The Upper Cretaceous is absent in the study area owing to erosion, 2. the Ugod Limestone is absent in the study area owing to erosion, 3. the Ugod Limestone Formation is absent because of non-deposition, 4. thickness of the Ugod Limestone, 5. thickness of the Upper Cretaceous underlying the Ugod Limestone, 6. Ugod Limestone in outcrop

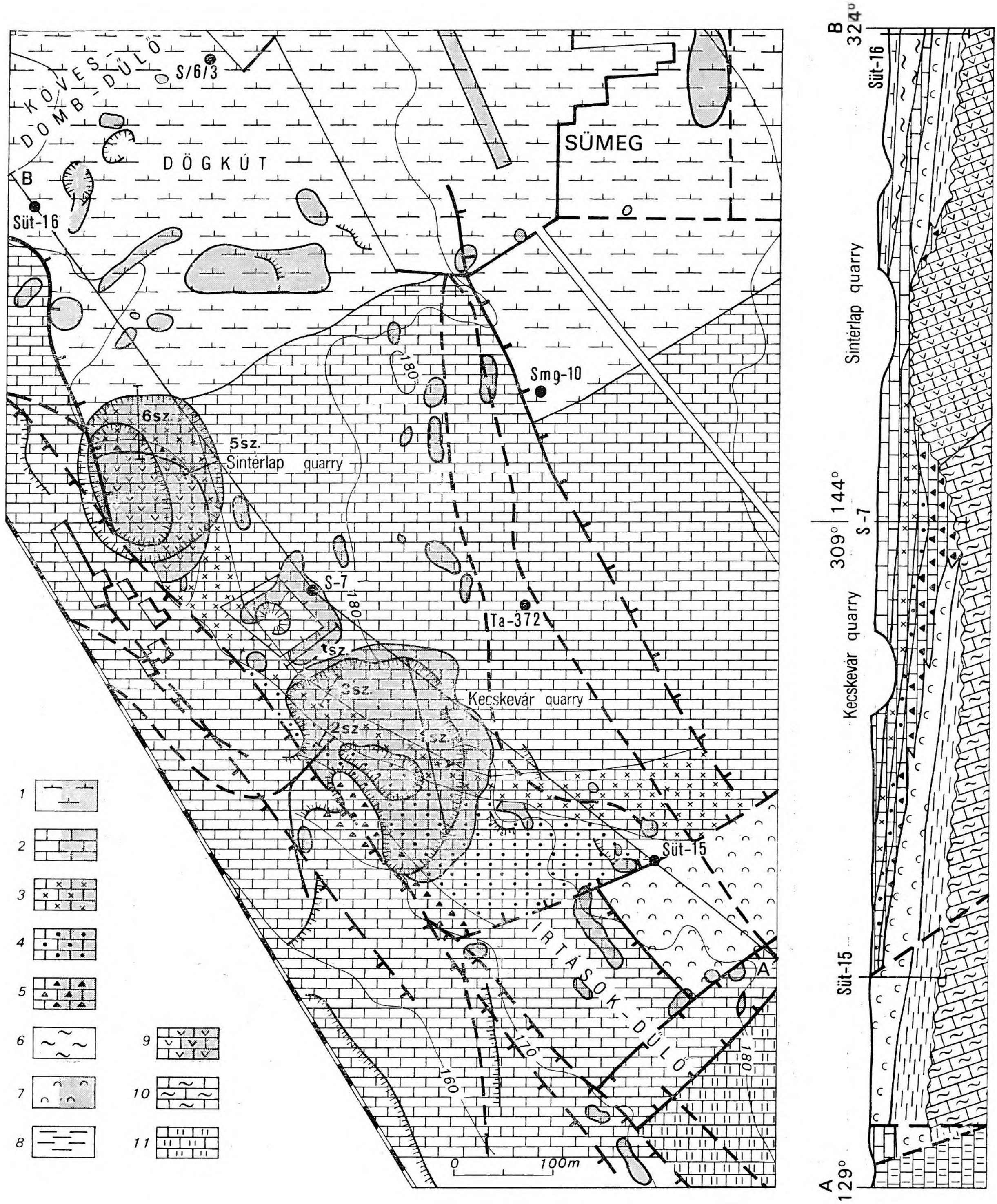


Fig. 50. Geological map chart of the Köves Domb's Mesozoic with the Tertiary and younger rocks peeled off and a detailed subdivision of the Ugod Formation (as of the knowledge of 1971)

1. Polány Fm., Rendek Member, 2. Hippurites-bearing bioclastic limestone, 3. red and light grey, biocalcarenitic limestone, 4. aphaneritic limestone, 5. extraclastic limestone (2—5. Ugod Fm.), 6. Jákó Fm., 7. Csingervölgy Fm., 8. Ajka Fm., 9. Tata Fm. (Aptian), 10. Sümeg Fm., 11. Hárskút Fm. (Lower Cretaceous). Red patches indicaet autcrops. — 1—6. Profiles

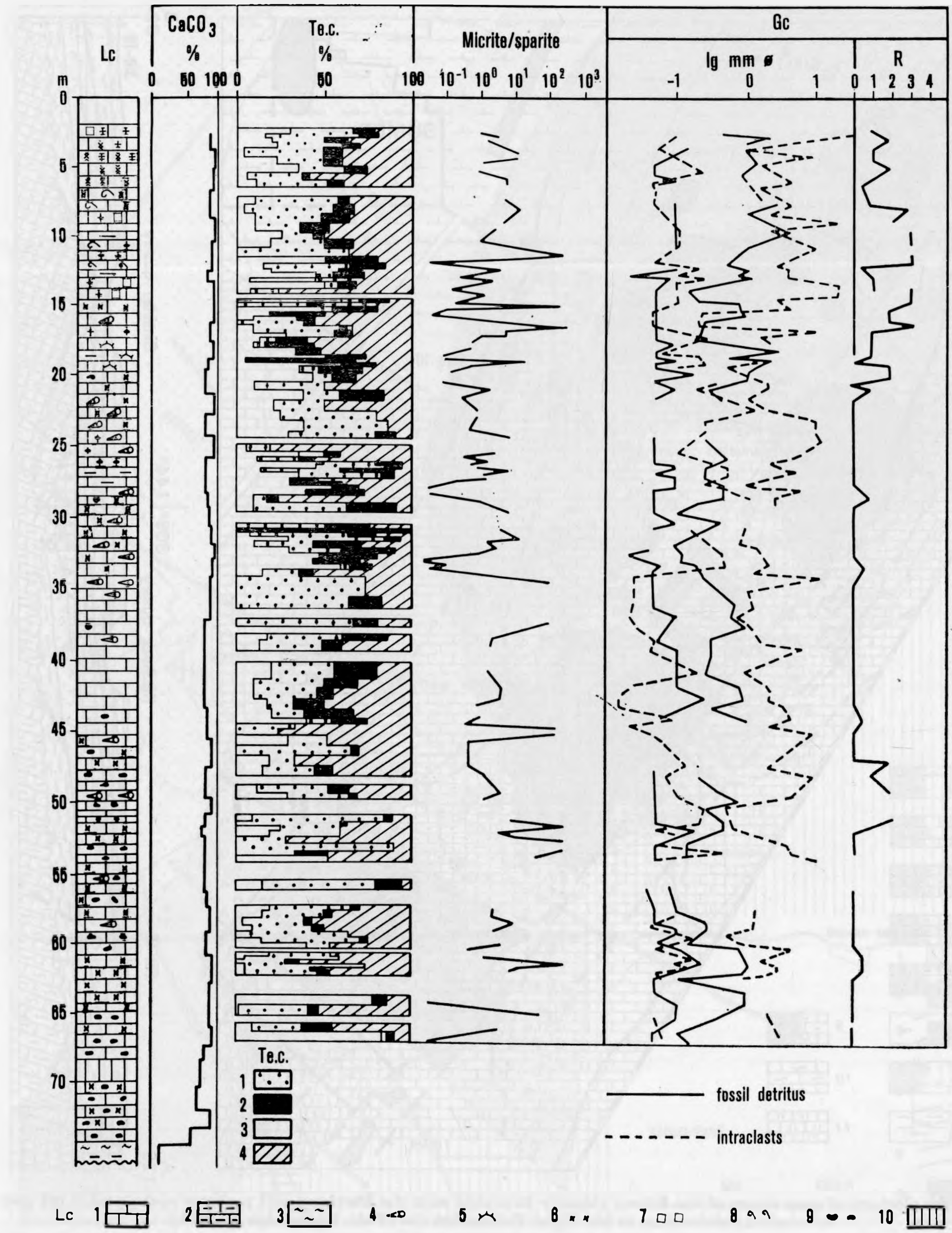


Fig. 51a—b. Lithologic column and analytical record of the borehole S-7 (K-1)

Lithologic column **(Lc): 1. limestone, 2. argillaceous limestone, 3. marl, 4. with rudists, 5. with echinoids, 6. calcarenitic, 7. calciruditic, 8. with Exogyra, 9. intraclastic, 10. no core. — *Textural composition* (Te.c.): 1. micrite, microsparite, 2. intraclast, 3. sparite, 4. fossils. — *Grain composition* (Gc): size, roundness (R). — *Rudist orientation* (O). — *Fossils:* 1. red algae, 2. hermatypical coral, 3. Exogyra, 4. Ostrea, 5. Rudista indet., 6. Praeradiolites, 7. Biradiolites, 8. Orbignya, 9. Nerinea, 10. Actaeonella, 11. Trochactaeon, 12. Echinoidea, 13. alga indet., 14. red algae, 15. Miliolidae, 16. Textulariidae, Nodosariidae, 17. Dicyclina, Cuneolina, 18. Hydrozoa, 19. corals, 20. Mollusca detr., 21. Ostracoda, 22. Bryozoa, 23. Echinodermata. — *Paleoenvironment* (P.e.): *BL* backreef, *Ds* drifting sand, *F* front-reef**

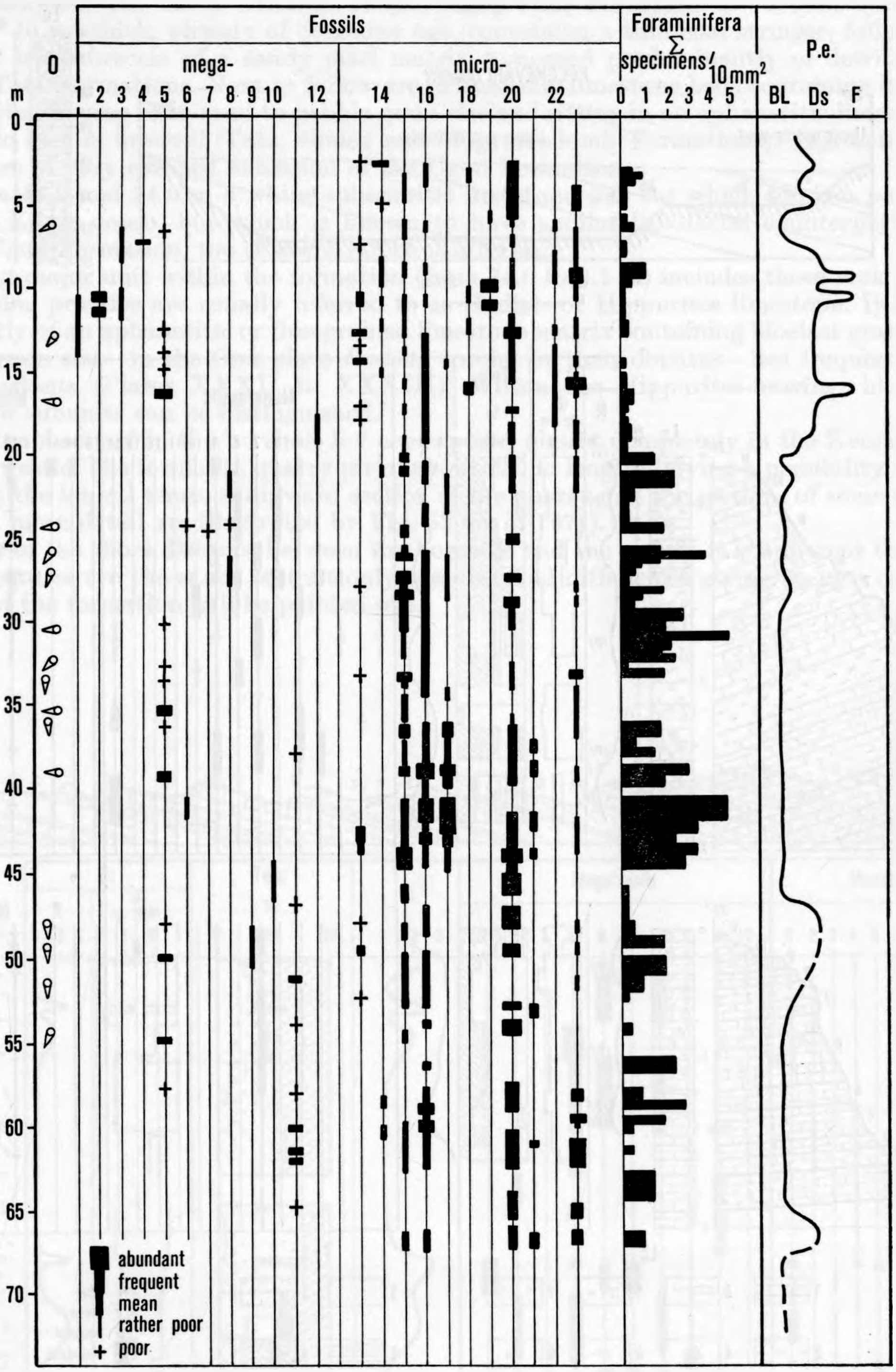

Fossils
mega-
micro-
O
m
Foraminifera
Σ specimens/10 mm²
P.e.
BL
Ds
F
abundant
frequent
mean
rather poor
poor

Fig. 51b

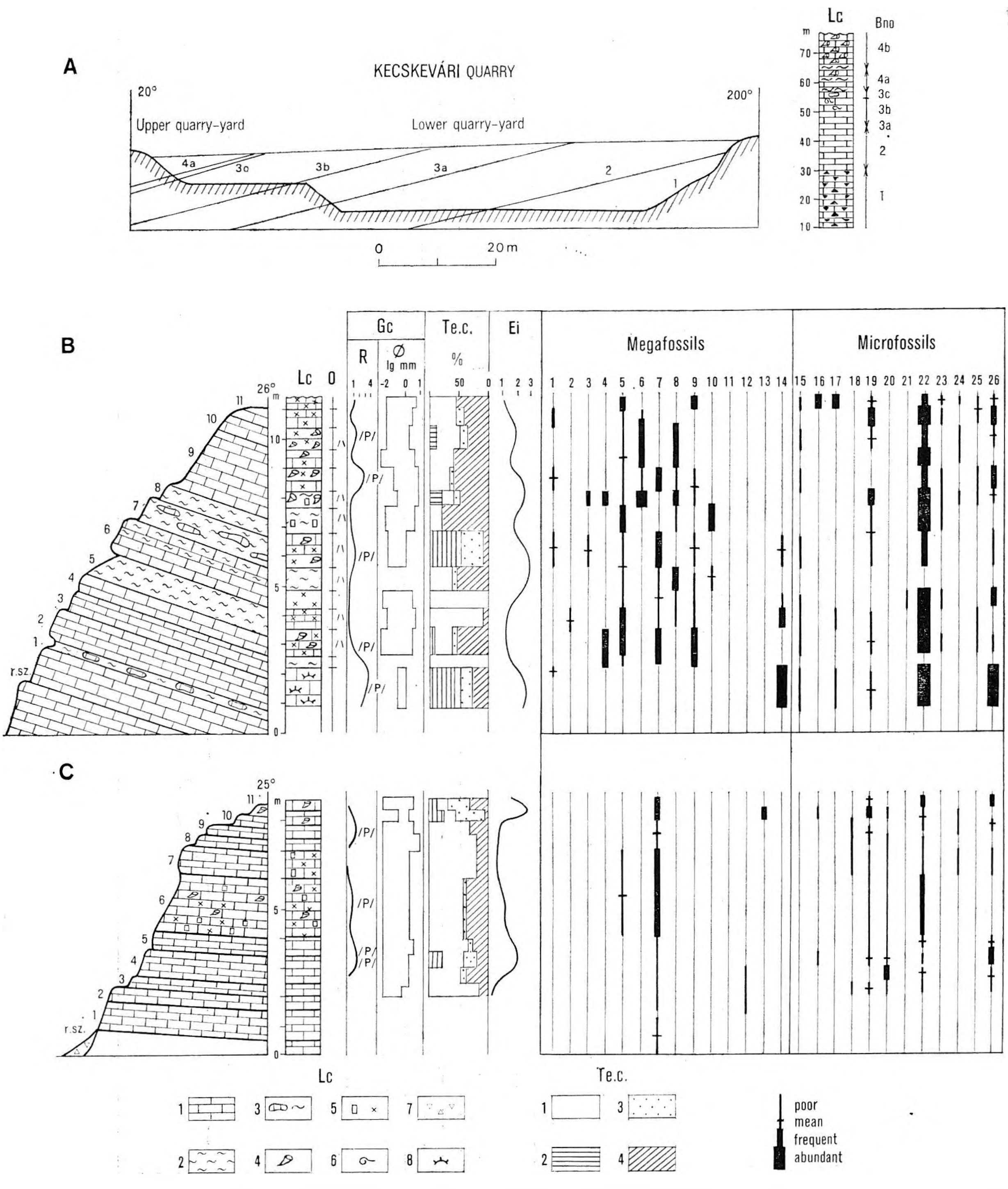


Fig. 52. The sequence of the Kecskevár quarry: analytical results

Lithologic column (Lc): 1. limestone, 2. marl, 3. nodular marl, 4. Rudista, intact, 5. Rudista, fragmentary (calcirudite and calcarenite), 6. Pycnodonta, Exogyra, 7. extraclasts, 8. Echinoidea; *number of bed* (Bno) — *Orientation* (O) — *Grain composition* (Gc): *R* roundness (*P* = pseudoöid): size. — *Textural composition* (Te.c.): 1. micrite, 2. sparite, 3. lump, 4. fossil. — *Energy index* (Ei). — *Megafossils:* 1. red algae, 2. Cyclolites, 3. hermatypical coral, 4. Serpula, 5. Mollusca detr., 6. Rudista detr., 7. smaller Rudista, 8. larger Rudista, 9. Exogyra, 10. Ostrea, 11. Gastropoda, 12. Nerinea, 13. crab's nippers, 14. Echinoidea. — *Microfossils:* 15. alga, 16. green algae, 17. red algae, 18. Calcis, 19. benthonic Foraminifera, 20. larger Foraminifera, 21. Bryozoa, 22. Mollusca detr., 23. Rudista detr., 24. Ostracoda, 25. Crinoidea, 26. Echinoidea

In the borehole the marly siltstone of the Sümeg Marl Formation is covered by a terrestrial layer hardly 40 cm thick, already of Senonian age, containing a thin coal stringer, followed in turn by 5.8 m of basal breccia of a sandy marl matrix composed predominantly of detritus from the Sümeg and Tata Formations. Next to follow are extraclastic limestone beds containing debris of pre-Senonian rocks varying from sand to pebble grain size and sitting in an aphaneritic limestone matrix in the 70.0 to 44.0 m interval (Tata, Sümeg and Mogyorósdomb Formations). This unit is a special representative of very reduced extension of the Ugod Formation.

Between 44.0 and 34.0 m a white aphaneritic limestone was cut which too is a peculiar facies type of the Köves-domb, but which is known to have similar lithofacies counterparts elsewhere within the Ugod Formation, too (Plate XXXII, XXXIII).

The next major unit within the formation (from 34.0 to 0.1 m) includes those rock types which in the mapping practice are usually referred to as Rudist- or Hippurites limestone. It is composed predominantly of an aphaneritic or fine-grained limestone matrix containing bioclast grains of arenite and rudite grain size—in the first place *Rudista* species or their detritus—less frequently of marly limestone variants (Plates XXXII to XXXIII). Within the Hippurites-bearing, bioclastic unit further minor subunits can be distinguished.

The units observed in the borehole S-7 are exposed almost completely in the Kecskevár quarry to the southwest of the former (a quarry pit of about 250 m length), giving a possibility for checking variations in the lateral sense. A dipward section of the quarry and the sections of some quarry faces examined in more detail are illustrated by Fig. 52 (as of 1971).

Because of the short distance between the borehole and the quarry it is apparent that the basic geological features are the same, so that only the observed differences giving an idea on the lateral variability of the formation will be pointed out.

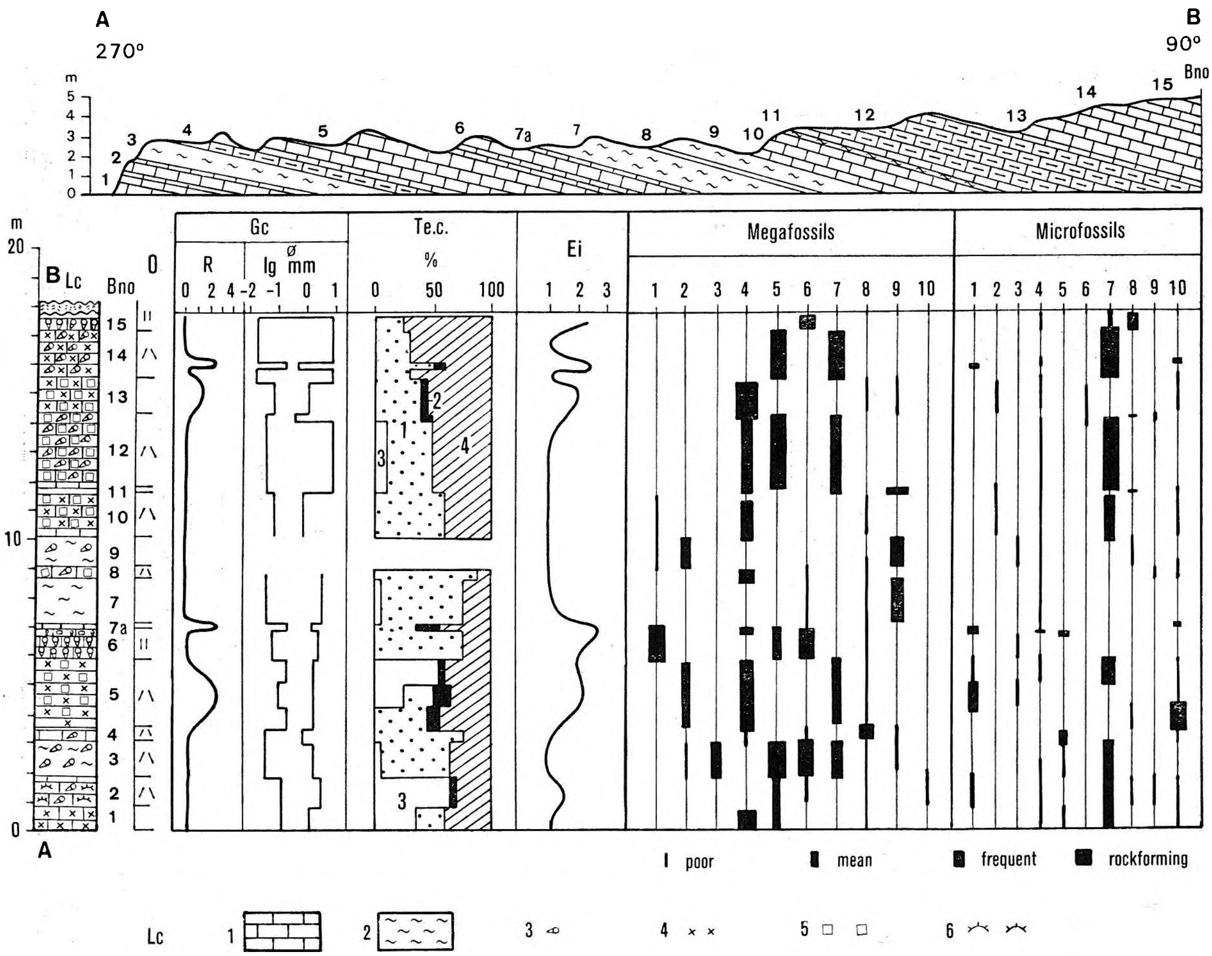


Fig. 53. Sequence exposed along the explosives depository of the Kecskevár quarry and its analytical record

Lithologic column (Lc): 1. limestone, 2. marl, 3. with rudists, 4. calcarenitic, 5. calciruditic, 6. with echinoids. — *Number of bed* (Bno). — *Orientation of rudist valves* (O). — *Grain composition* (Gc): roundness (R); size. — *Textural composition* (Te.c.): 1. micrite, microsparite, 2. intraclast, 3. sparite, 4. fossils. — *Energy index* (Ei). — *Megafossils:* 1. red algae, 2. coral, 3. Serpula, 4. Mollusca detr., 5. Rudista detr., 6. smaller rudist shell, 7. larger rudist shell, 8. Exogyra, 9. Ostrea, 10. Echinoidea. — *Microfossils:* 1. algae, 2. green algae, 3. red algae, 4. Foraminifera, 5. Hydrozoa, 6. coral, 7. Mollusca detr., 8. Rudista detr., 9. Ostracoda, 10. Echinodermata

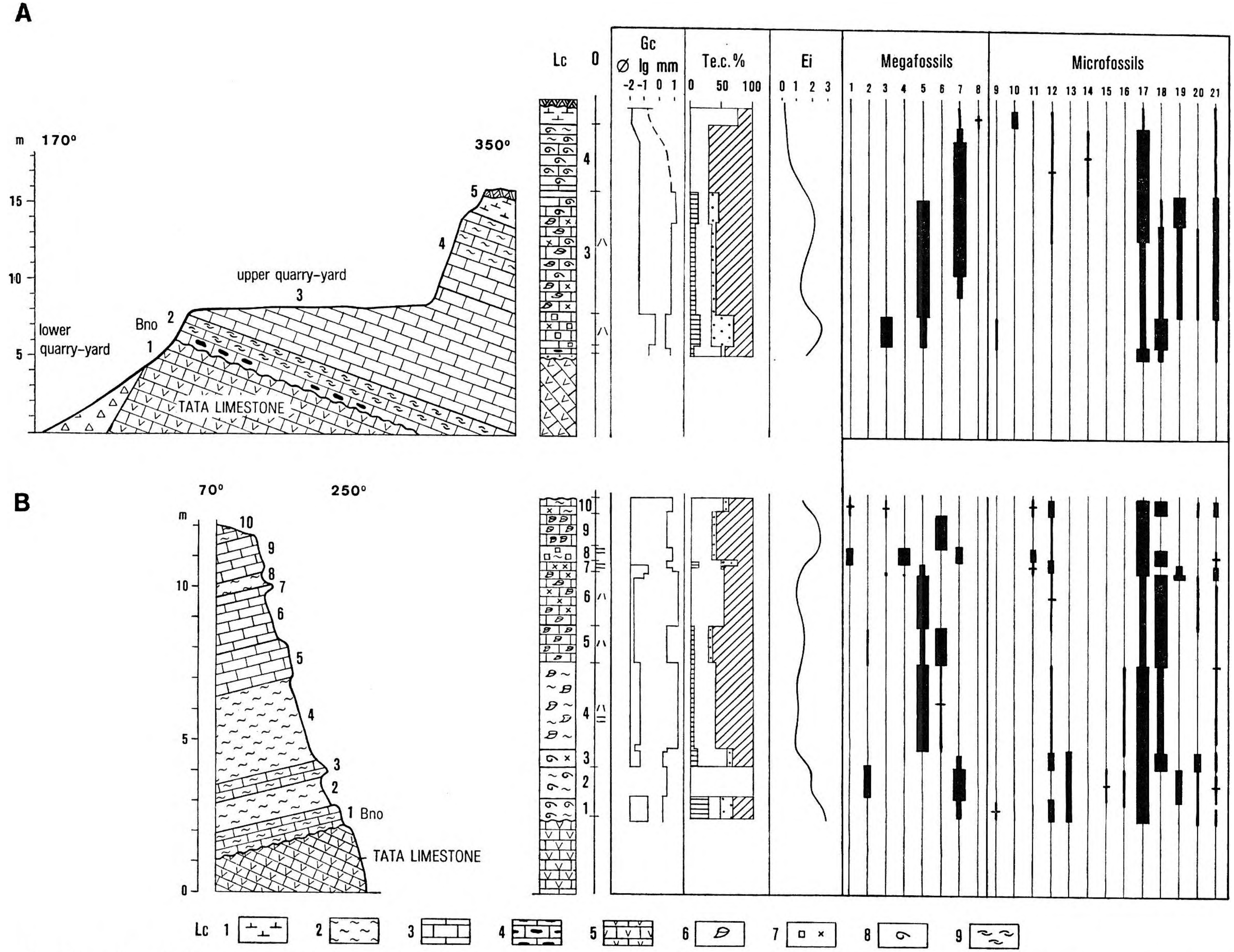


Fig. 54. Lithologic log and analytical record of the sequence exposed in the Sintérlap quarry [*A*) northern quarry face, *B*) eastern quarry face, section in the direction of dip]

Lithologic column (Lc): 1. calcareous marl, 2. marl, 3. limestone, 4. gravelly limestone, 5. crinoidal limestone, 6. Rudista, intact, 7. Rudista, fragmentary (calcirudite and calcarenite), 8. Pycnodonta, Exogyra, 9. Mollusca detr. — ***Megafossils:*** 1. red algae, 2. corals, 3. Mollusca detr., 4. Rudista detr., 5. smaller rudist, 6. larger rudist, 7. Exogyra, 8. Ammonites. — ***Microfossils:*** 9. algae, 10. Calcisphaerulidae, 11. red algae, 12. benthonic Foraminifera, 13. Nummofallotia sp., 14. larger Foraminifera, 15. Hydrozoa, 16. corals, 17. Mollusca detr., 18. Rudista detr., 19. Exogyra, 20. Ostracoda, 21. Echinodermata. (For other symbols, see Fig. 52.)

In Profile *A* from Fig. 52 the sequence of the quarry can be seen. That the aphaneritic limestone in the quarry is by several metres thicker than that observed in the boreholes S-7 is worthy of attention.

In 1971, in the lower quarry-yard the aphaneritic limestone was excellently exposed (Profile *C* of Fig. 52). Similarly to the corresponding part of the borehole S-7, the texture is biomicrite and micrite, but higher up the profile the amount of intraclasts increases significantly.

The northern face of the upper quarry-yard of Kecskevári quarry exposes the Hippurites-bearing, bioclastic limestone beds, from the upper part of the limestone of medium to fine calcarenite grain size and light grey colour up to the yellowish-brown Hippurites limestone beds of medium- to coarse grain size (Plates XXXIV and XXXV). The dipward section (26/15°), the columnar section and the diagram showing the lithological parameters and genetic features are given in Profile *B* of Fig. 52.

To the north of the Kecskevári quarry, around the explosives deposit of the mine, trenches have exposed the upper subunits of the Hippurites limestone member. The plan of these exposures, the individual profiles and diagrams are given in Fig. 53.

Naturally, the sequence of strata is similar to the upper part of the borehole S-7, as it started with the topmost exposed bed of the section. That marl layers of several metres thickness with sporadical valves of *Rudista* are interbedded with the bioclastic limestones is worthy of mention—a peculiarity not observed either in the Kecskevári quarry or in the borehole S-7.

As evident from a comparison of the profiles presented, the individual beds are laterally so variable that in certain cases a lenticular structure can be spoken of.

The Sintérlapi quarry on the northwest side of the Köves-domb provides an excellent exposure of the Hippurites-bearing, bioclastic limestone overlying the rough surface of the Aptian Tata Limestone.

The west and south sides of the quarry have exposed a Tata Limestone dipping at 310/50°. On the south side of the quarry mining activities in recent years have rendered visible even the extraclastic limestone overlying the Aptian.

The section of dipward orientation taken from the middle part of the south side of the quarry (as of 1971) and the results of its examination are presented in Profile *B* of Fig. 54. The rough surface of the Tata Limestone is overlain by 5 metres of Exogyra-bearing, bioclastic limestone and marls with tiny *Rudista* valves, then above the bioclastic limestones a bed containing tightly intergrown *Hippurites*, forming bunch-like agglomerates resulting from the fact that the animals were buried in their living positions.

The exposures from the north part of the quarry are shown in Profile *A* of Fig. 54. The Ugod Formation in this section is already represented by only a Hippurites-bearing, bioclastic limestone sequence of extremely reduced thickness (10 m) resting on a pre-Senonian basement. It is overlain by a few metres of Exogyra beds that are covered by a peculiar, worm-track-bearing calcareous marl facies of the Polány Formation.

It was considered very probable that beneath the "worm-track"-marl-covered surface of the northern part of the Köves-domb the Ugod Formation was even more reduced in thickness, to pinch out finally, or that it intertongued with other formations representing heteropical facies. It was these hypotheses that we wished to verify by the survey borehole Süt-16 drilled in 1971 (Fig. 46) which we located at a distance of 200 m to the north of the Sintérlapi quarry.

In the borehole, above the middle member, composed mainly of siltstone marls, of the Csinger-völgy Marl there evolves—without any break in sedimentation and with a gradual growth of the $CaCO_3$ content of the rock, and an increasing abundance of valve fragments of *Rudista*—a limestone of only 11 m thickness assignable to the Ugod Formation (46.5–35.5 m).

Above the rocks assignable to the Ugod Formation—in contact with a surface of slide seamingly responsible for a slight displacement only—the borehole sequence includes a marly siltstone layer, then there follows an interval of a few metres in which the interbedded layers of Exogyra lumachelles abound. Next to follow is a siltstone-marl exhibiting features of the upper member of the Jákó Formation and the sequence is closed by the basal beds of the Polány Formation.

A sequence somewhat similar to the above was intersected by the borehole, S(G)-3 put down in 1967, at a distance of 200 m to the northeast of this borehole. However, F. Góczán, who described this borehole, does not mention any limestone with *Rudist* detritus.

In the boreholes that have penetrated the Senonian to the northwest of the borehole Süt-16 there is no trace of Ugod Formation rock types, even though the nearest borehole, S(G)-2, was put down at a distance as little as 180 m away.

The Ugod Limestone Formation of the Köves-domb, a quite peculiar formation as it is, shows, all in all, the following geological and mode-of-superposition characteristics (profile from Fig. 50):

In the middle part of the Sintérlap quarry the Ugod Limestone overlies, practically immediately, the pre-Senonian basement. Above the Aptian Tata Limestone about 10 m of bioclastic limestone

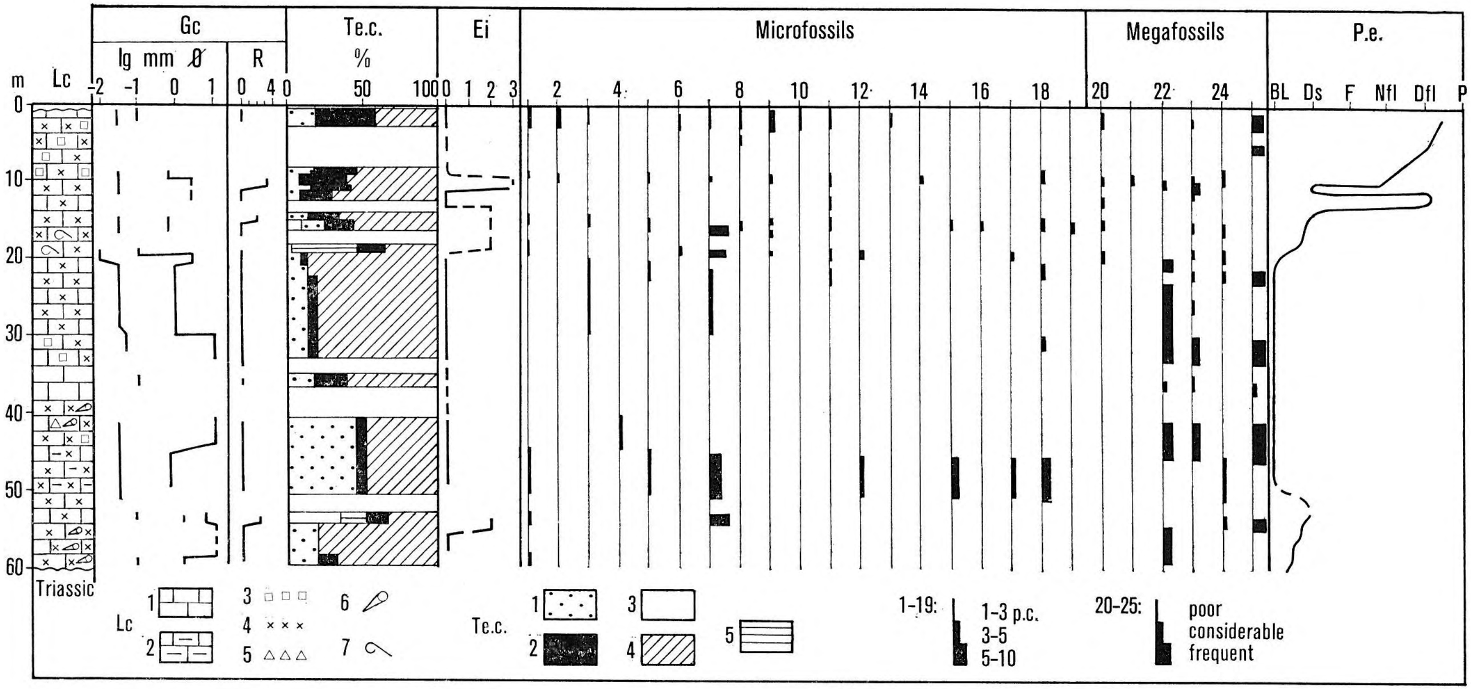


Fig. 55. Lithologic log and analytical record of the borehole Sg-192

Lithologic column (Lc): 1. limestone, 2. argillaceous limestone, 3. calcirudite, 4. calcarenite, 5. authigenic (intraformational) breccia, 6. rudist shell, 7. Exogyra shell. — *Grain composition* (Gc): size, roundness (R). — *Textural composition* (Te.c.): 1. micrite, microsparite, 2. intraclast, 3. sparite, 4. fossils, 5. pellets. — *Energy index* (Ei) — *Fossils:* 1. Textulariidae, 2. Spiroplectammina, 3. Dorothia, 4. Orbitolinidae, 5. Dicyclina, 6. Cuneolina, 7. Miliolidae, 8. Spiroloculina, 9. Nodosariidae, 10. Lenticulinae (Robulus) 11. Bulimina, 12. Rotaliidae, 13. Gyroidina, 14. Gavelinella, 15. Stensiöina, 16. Nummofallotia, 17. Orbitoides, 18. Monolepidorbis, 19. Accordiella conica, 20. Stomiosphaera, 21. Cadosina, 22. Rudista detr., 23. Mollusca detr., 24. Ostracoda, 25. Echinoidea. — *Paleoenvironment* (P.e.): *BL* backreef, *Ds* drifting sand, *F* front-reef, *Nfl* near by foreland, *Dfl* distant foreland, *P* pelagic basin with interbedded marl layers can be observed, containing, at its top, *Rudist* specimens grown closely alongside and enclosed in the burying sediment in their living position. In addition, hermatypical, reef-building organisms are also contained in the upper part of the limestone *(corals, Hydrozoans, red algae)*. These strata are traceable on the surface farther south. Beneath them, as evidenced by the sequence of the borehole S-7 and the Kecskevár quarry, the Ugod Formation grows considerably thicker (to about 70 m). Already the Hippurites-bearing, bioclastic limestone itself is thicker and this is followed farther downwards by an aphaneritic limestone and then by an extraclastic one. This latter surrounds as a southward-extending blanket the one-time cliff composed of Aptian crinoidal limestones and covered by only a few metres of bioclastic limestone. Becoming again thinner farther south, the Ugod Limestone overlies there the Csingervölgy Marl (borehole Süt-15).

2. *Városi-erdő–Surgó-tag–Kozma-tag (Facies Zone "A")*

On the margin of the Városi-erdő and farther northeast, in the Bárdió-tag, then in the Surgó-tag and Kozma-tag subareas, a number of bauxite-exploratory boreholes have exposed the Ugod Formation. Unfortunately, most of these boreholes give but little information for a more exact analysis, since for the most part they did not penetrate a Senonian sequence of considerable thickness or since they did not furnish core samples that should be suitable for appropriate studies. At any rate, so much can be pointed out that in the outermost belt known at present the pre-Senonian (upper-Triassic) basement is overlain directly or with a very thin basal layer of marl-cemented breccia or pebble or marl to calcareous marl in between, by a *Rudist*-bearing limestone.

As an example of this facies unit, let us present here the profile of the borehole Sg-192 drilled in 1974 near the Surgó-tag subarea and an evaluation of the results of its examination (Fig. 55). In the borehole the dolomite is overlain by a light brownish-grey, fine-crystalline limestone consisting of bioclastic grains of calcarenite to calcirudite grain size.

A similar sequence was exposed, as suggested by the descriptions, by the boreholes put down earlier in the Surgó-tag subarea and by a number of bauxite exploratory boreholes drilled in the southern Kozma-tag and also by the boreholes Bd-18, -52, -60, -61 and -63 in the Bárdió-tag subarea.

Drilled for cement raw material exploration purposes, the borehole Sc-9/7 was put down in 1974 on the southwest slope of the Hajnal-hegy. It penetrated the Ugod Limestone in a thickness of more than 70 m, but it did not reach the underlying formation. The sequence is composed of beds consisting of coarse biocalcarenite to calcirudite grains with thin limestone and marl layers interbedded in the deeper part (below 40 m) in which the shell fragments of *Exogyra* and other minute molluscs are enriched. The rock texture is generally an intraclastic biomicrite. Interestingly enough, the grains are for the most part well rounded, being often coated by a micrite film.

Although in this borehole the nature of superposition to the pre-Senonian basement is unknown, in the light of the spatial position and the geological features of the drilled sequence an assignment to the Facies Zone "*A*" seems to be justified.

3. *Northern side of Városi-erdő–Hárs-hegy–Hajnal-hegy (Facies Zone "B")*

Drilled in the northwest margin of the Városi-erdő, the borehole Süt-14 exposed a very thick Ugod Limestone sequence preserved in smaller, down-faulted tectonic blocks. The columnar section of the borehole, its stratigraphic subdivisions and lithological and paleoenvironmental parameters are summarized in Fig. 56.

Overlying the Triassic limestones in the basal 9 m, the extraclastic marls and the limestones with detritus of *Rudista* may already be assigned to the Ugod Formation.

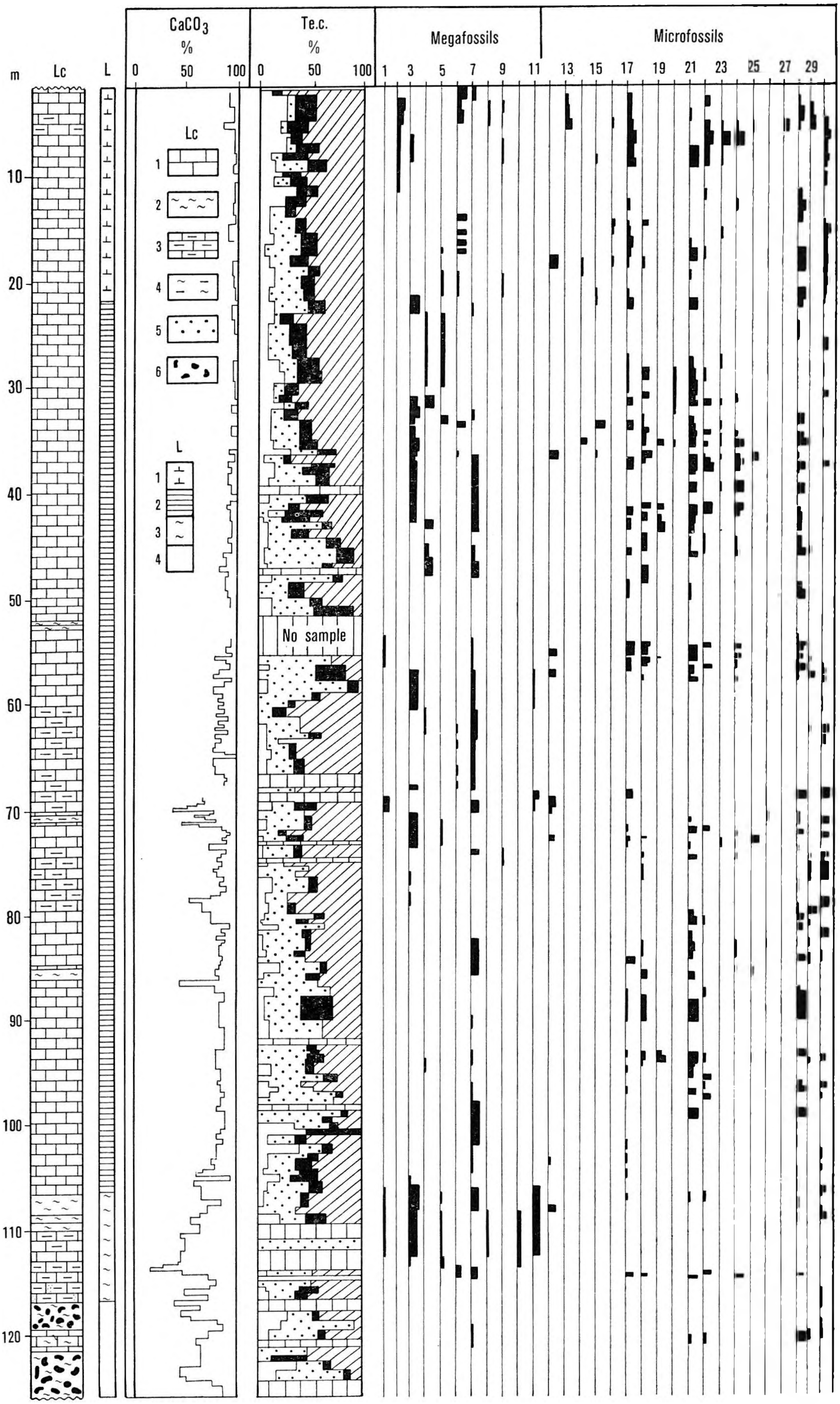
The next 10 metres of marl and calcareous marl represent a transitional member of the Jákó Formation intertonguing with the Ugod Formation.

The 80-m-thick typical Ugod Limestone can be subdivided into 3 subunits: the lower one is characterized by an aphaneritic limestone (similar to the aphaneritic limestone facies of Köves-domb), the middle one is represented by a fine calcarenite with interbedded marl layers, the upper one by fine- to medium-grained calcarenites of uniform lithological character. The last two subunits are close to the Hippurites-bearing, bioclastic limestone of Köves-domb.

The uppermost subunit of the sequence shows the features of the basal interval of the Polány Formation.

A good opportunity for studying the Ugod Formation constituting the Hárs-hegy is provided by the Gerinc limestone quarry. A NNE–SSW oriented profile of the quarry is presented in Fig. 47, complemented with the columnar sections of the cement-exploratory boreholes drilled in 1974 (Sc-8, -8a).

The Ugod Limestone Formation overlies the rough surface of an alternating Upper Triassic limestone and dolomite sequence; the basal layer is 5 to 10 cm thick, ochre-yellow siltstone-marl, in other places, marly limestone containing detritus deriving from the underlying formation. It is followed, higher in the profile, by 4 to 6 metres of light grey, brown, ochre-yellow marly limestone



m
Lc
L
CaCO3 %
0 50 100
Te.c. %
0 50 100
Megafossils
Microfossils
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29
10
20
30
40
50
60
70
80
90
100
110
120
Lc
1
2
3
4
5
6
L
1
2
3
4
No sample

with limestone nodules and calcareous marls—a subunit with plenty of shell detritus of *Rudista* and other *Mollusca* and skeletal detritus of *Echinoidea*. Some beds of it contain large quantities of *Rudists* of small size (5 to 6 cm long and 3 to 4 cm in diameter), less frequently the representatives of *Exogyra* are encountered, too.

The next distinct unit is a 18- to 20-m-thick (tectonically reduced in thickness in the borehole Sc-8) light brown to light grey limestone with a large quantity of bioclasts, of fine- to medium size and locally recrystallized. Valves or detritus of *Rudista* in a lying position are extremely abundant. In addition, there are a few internal moulds of *Actaeonella;* in the lower part of the unit, a few *Pycnodonta* can also be encountered, gradually increasing in number as one proceeds higher in the profile. Above this a more pelitic rock body of lower $CaCO_3$ content follows which is nothing else than the intertonguing part of the lower member of the Csingervölgy Marl. The borehole Sc-8 bore witness to that idea—formulated in his report of 1958 already by Noszky Jr.—that the grey argillaceous marl with interbedded layers of ochre-yellow, nodular marl is part of a lenticular rock body of modest spatial extension.

Its lithological and paleontological data were given in discussing the Jákó Formation. Its thickness in the Gerinc quarry is 8 to 9 m.

It is overlain by a unit composed again of limestone beds, 32 to 35 m of which exposed in the middle and upper quarry-yards. (The borehole Sc-8 penetrated 11 m of the formation.) Its rock varieties are of high carbonate content. At the very base there lie 6 m of light brownish-grey, thin-bedded, a little marly, argillaceous limestone containing single valves of *Exogyra* grouped in nests. In its upper part, sporadical specimens of *Rudista* can be observed, too.

The next unit of this interval of high carbonate content is composed of yellowish-grey to brownish-grey, for the most part thin-bedded or, less frequently, thick-bedded limestones of a $CaCO_3$ content of 93 to 96% and characterized by a fine or, just sporadically, coarse crystal size. Frequent forms are the small to medium-size specimens of *Rudista* which are often perpendicular to stratification, particularly so in the lower interval. A considerable part of the rock is built up of *Rudista* shell detritus fragmented to tiny particles and of shell fragments of other molluscs.

On the basis of the quarry section and the supplementary borehole sections, the following general conclusions as to the sequence of the Gerinc quarry can be drawn: 1. in this area the Triassic is overlain directly by *Rudist*-bearing marly limestones; 2. in the lower interval a lens exhibiting characteristics typical of the Csingervölgy Marl is enclosed in the carbonate sequence; 3. up in the profile, rock varieties of increasingly higher carbonate content are characteristic.

The topmost beds of the Ugod Limestone at present are not exposed in the Gerinc limestone quarry. To study them has become possible as a result of the drilling of the borehole S-30 at a distance of 200 m to the northeast of the quarry. The borehole, after intersecting Eocene formations, penetrated Senonian beds in a thickness of 140.4 m. The rocks of the Ugod Formation are in a tectonic contact with the Triassic dolomite, but the dislocation is probably insignificant.

The lower interval of the borehole exhibits features similar to the sequence of the Gerinc quarry. Above the intertonguing beds of a few metres thickness of the Csingervölgy Marl, there are 20 metres of a uniform limestone of coarse biocalcarenite to fine calcirudite grain size representing the Ugod Formation and similar in geological features to the rocks exposed in the upper quarry-yard of Gerinc. Next to follow is a subunit characterizable by an aphaneritic, finely bioclastic limestone with planktonic microfossils interbedded with thin calcareous marl and marl layers; and then the uppermost 30 m are again represented by homogeneous, fine- to medium-grained biocalcarenite limestones.

Located at a distance of 300 m to the southeast of the borehole S-30, the borehole Sc-5/9 exposed a sequence that is a transition between the the unit of Facies "A" and that of Facies "B". Beneath the Ugod Limestone the transitional member of the Jákó Marl is though present, but it is extremely reduced in thickness (4 m). The lower part of the limestone interval is a coarse-grained calcarenite with shell detritus of *Rudista;* higher upwards the grain size slightly decreases.

The northern side of the Hajnal-hegy, as shown by extrapolation of the results, belongs to this zone too, but in this area no borehole penetrating a full sequence was drilled. From among the boreholes in the Kozma-tag subarea it is the sequence penetrated by the borehole Ck-95 that can be assigned to this facies unit.

←

Fig. 56. Lithologic log and analytical record of the borehole Süt-14

Lithologic column (Lc): 1. limestone, 2. marl, 3. argillaceous limestone, 4. argillaceous marl, 5. sand, 6. gravel. — *Lithostratigraphic units* (L): 1. Polány Marl Fm., lower member, 2. Ugod Limestone Fm., 3. Jákó Marl Fm., 4. lower interval of the Ugod Limestone Fm. — *Megafossils:* 1. corals, 2. worm tracks, 3. Mollusca, 4. Gastropoda, 5. Bivalvia, 6. Pycnodonta, 7. Rudista, 8. Decapoda pincers, 9. Echinodermata, 10. fish scale, 11. vegetal detritus. —*Microfossils:* 12. algae, 13. Stomiosphaera, 14. Ammodiscus, 15. Lituola, 16. Siderolites, 17. Textulariidae, 18. Orbitolinidae, 19. Dicyclina, 20. Cuneolina, 21. Miliolidae, 22. Nodosariidae, 23. Bulimina, 24. Rotaliidae, 25. Anomalinidae, 26. Nummofallotia, 27. Orbitoides, 28. other benthonic Foraminifera, 29. Ostracoda, 30. Echinodermata. (For other symbols, see Fig. 55.)

Facies Zone "*B*" is characterized as a whole by *Rudist*-bearing carbonate beds directly overlying a Triassic basement, beds surrounding a Csingervölgy Marl interbed present in a lenticular form or jutting in as a tongue. In the middle interval, it is poorly rounded biocalcarenite to calcirudite beds of micritic matrix with *Rudista* and larger benthonic *Foraminifera* that alternate with micrite-cemented sediments of very minute grain size composed of bioclasts and containing planktonic Foraminifera as well, beds already exhibiting the characteristic features of the Polány Formation.

As evidenced by the borehole S-30, the uppermost interval—for the most part lost to erosion in the study area—is represented by a biocalcarenite already free from planktonic fossils; consequently, unlike the lower-situated, intertonguing, transitional subunits, it is composed of a typical, homogeneous Ugod Limestone.

4. Southern side of the Rendeki-hegy (Facies Zone "C")

The northwest facies zone of the Ugod Formation is presented by the example of the sequence exposed by the bauxite-exploratory borehole Ck-168 (Fig. 57).

In the borehole the Ugod Formation overlies the clay-filmed nodular upper subunit of the Rendeki Member of the Polány Formation. At the boundary between the two formations there is a striking change in both the megaloscopic and microscopic characteristics. The light brown, aphaneritic to fine-crystalline limestone is replaced by a white, fine-grained calcarenite. In the bioclast material of sand grain size there occur debris of *Rudists*, too. The typical foraminiferal assemblage of the Rendeki Member of the Polány Formation is replaced, after an interval extremely poor in *Foraminifera*, by a Miliolidae–Nodosariidae–Textulariidae assemblage. *Calcisphaerulidae* show a marked decrease in number.

On the basis of the lithological characteristics of the Ugod Formation the following subunits can be singled out:

At the b a s e (131–160 m) a white, small or, less frequently, medium-grained calcarenite with fine-crystalline matrix is characteristic. The rock texture is of biosparite to biomicrosparite composition.

The middle subunit of the sequence (120–131 m) is composed of a pink, fine-crystalline or aphaneritic limestone. Minute shells of *Rudista* are quite unfrequent in it. The texture is biopelmicrite or biopelmicrosparite, respectively. The number of foraminiferal individuals is considerable. Larger *Miliolidae* or, in the higher beds, *Dycyclina* are predominant.

In the u p p e r p a r t of the sequence (79–120 m) there is a yellowish-white, aphaneritic limestone containing a considerable quantity of bioclasts of arenite and rudite texture. Valves of smaller *Rudista* (in the first place, *Agria*) are abundant in the rock. Accordingly, in the borehole Ck-168 chosen as type, three subunits of the Ugod Limestone overlying the Rendeki Member can be distinguished: 1. finely biocalcarenitic limestone; 2. middle subunit represented by an aphaneritic limestone with few Rudista; and 3. an upper subunit composed of coarse bioarenitic to ruditic limestone.

According to the authors' observations, limestone beds of similar lithological composition and mode of superposition were exposed by the bauxite-exploratory boreholes Ck-167, -169, -170 and -171 and also by the quarry to the northwest of the Kozma-tag and the outcrops in the southern foreland of the Rendeki-hegy. On the basis of the descriptions and the results of analyses, the sequence penetrated by the borehole Cn-598 and probably the Ugod Limestone penetrated by the boreholes Cn-211, -563, -593 and -596 can also be assigned to this facies zone, although in the latter case the descriptions suggest that the textural characteristics could not be determined in an exact way.

All in all, Facies Zone "*C*" is characterized by an aphaneritic to fine-crystalline lithofacies of fine calcarenite grain size, generally unrounded or very poorly rounded, with rudite grains that are usually scarce, but locally considerably enriched sitting in a predominantly micritic matrix.

Spatial relations between the individual facies zones or formations

The spatial relations between the listed facies zones and the relationship of the Ugod Limestone with the under- and overlying beds and heteropical formations were analyzed by studying geological sections parallel and perpendicular to the strike of the facies zones. In Fig. 58, profiles of northwest-southeast direction plotted by taking the top of the underlying formations to be a reference horizon are presented.

The upper profile from Fig. 58 shows that the outermost facies zone, Zone "*A*" in the southeast, characterized by coarse biodetritus and hermatypically intergrown *Hippurites* locally buried in living position coincides with the zone of total pinching out of the Jákó Formation. Attached to the marginal facies zone of the Jákó Formation is the zone "*B*" in which an intertonguing with the Csingervölgy Marl in the deeper part and with the Polány Formation in the middle stretch (borehole S-30) was observed.

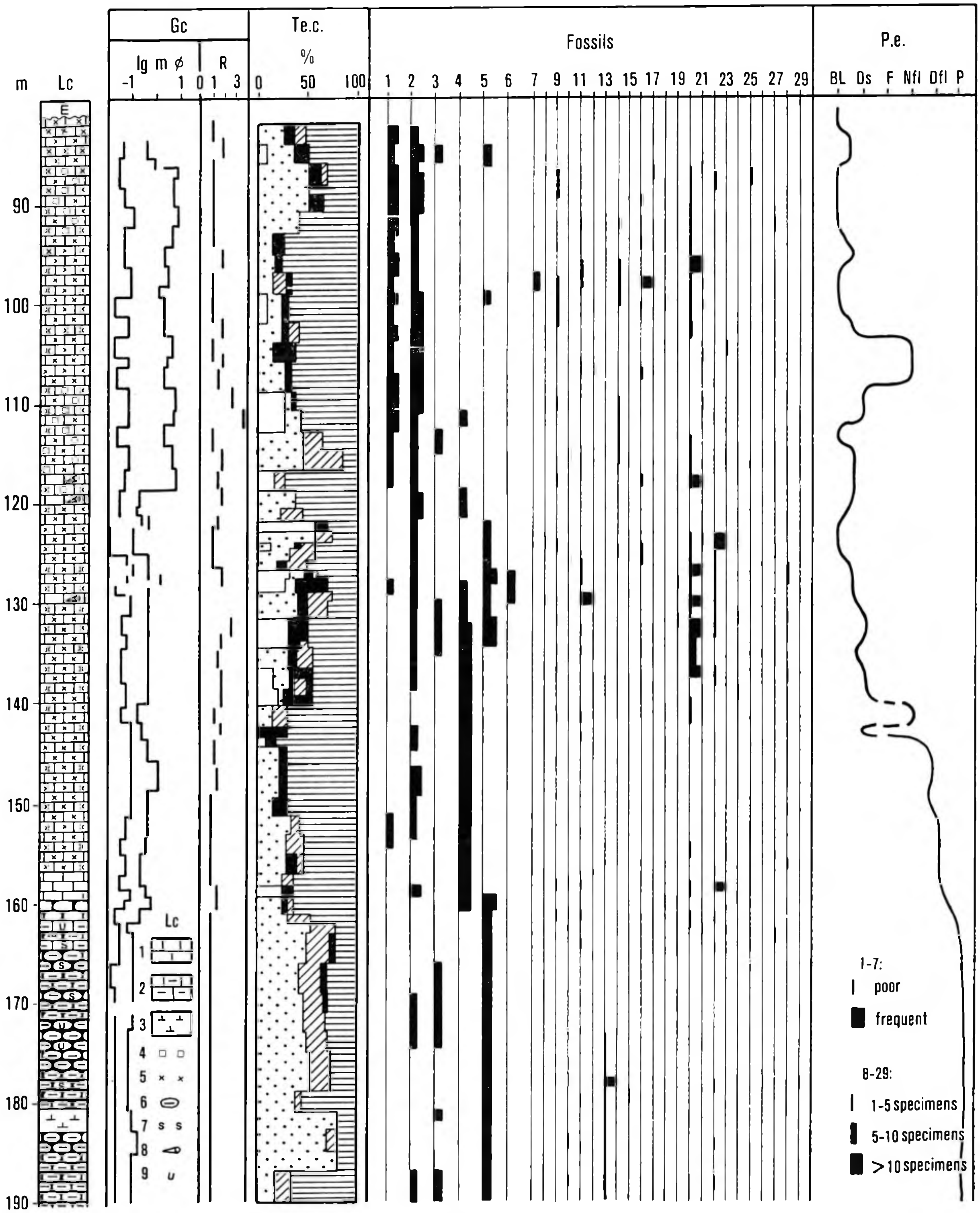


Fig. 57. Lithologic log and analytical record of the borehole Csabrendek Ck-168

Lithologic column (Lc): 1. limestone, 2. argillaceous limestone, 3. calcareous marl, 4. calcirudite, 5. calcarenite, 6. nodular structure, 7. bioturbation, 8. rudist shell, 9. worm track. — *Fossils:* 1. Rudista detr., 2. Mollusca detr., 3. Ostracoda, 4. Crinoidea, 5. Echinodermata, 6. Holothuroidea, 7. Globochaete. *Foraminifera:* 8. Lituola, 9. Spiroplectammina, 10. Textularia, 11. Dorothia, 12. Ataxophragmium, 13. Bulimina, 14. Cuneolina, 15. Accordiella, 16. Dicyclina, 17. Valvulineria, 18. Valvulammina, 19. Meandrospira, 20. Miliolidae, 21. Rhapydionina, 22. Nodosaria, 23. Lenticulina, 24. Orbitoides, 25. Gyroidina, 26. Stensiöina, 27. Rotaliidae, 28. Nummofallotia, 29. Goupillaudina. (For other symbols, see Fig. 55.)

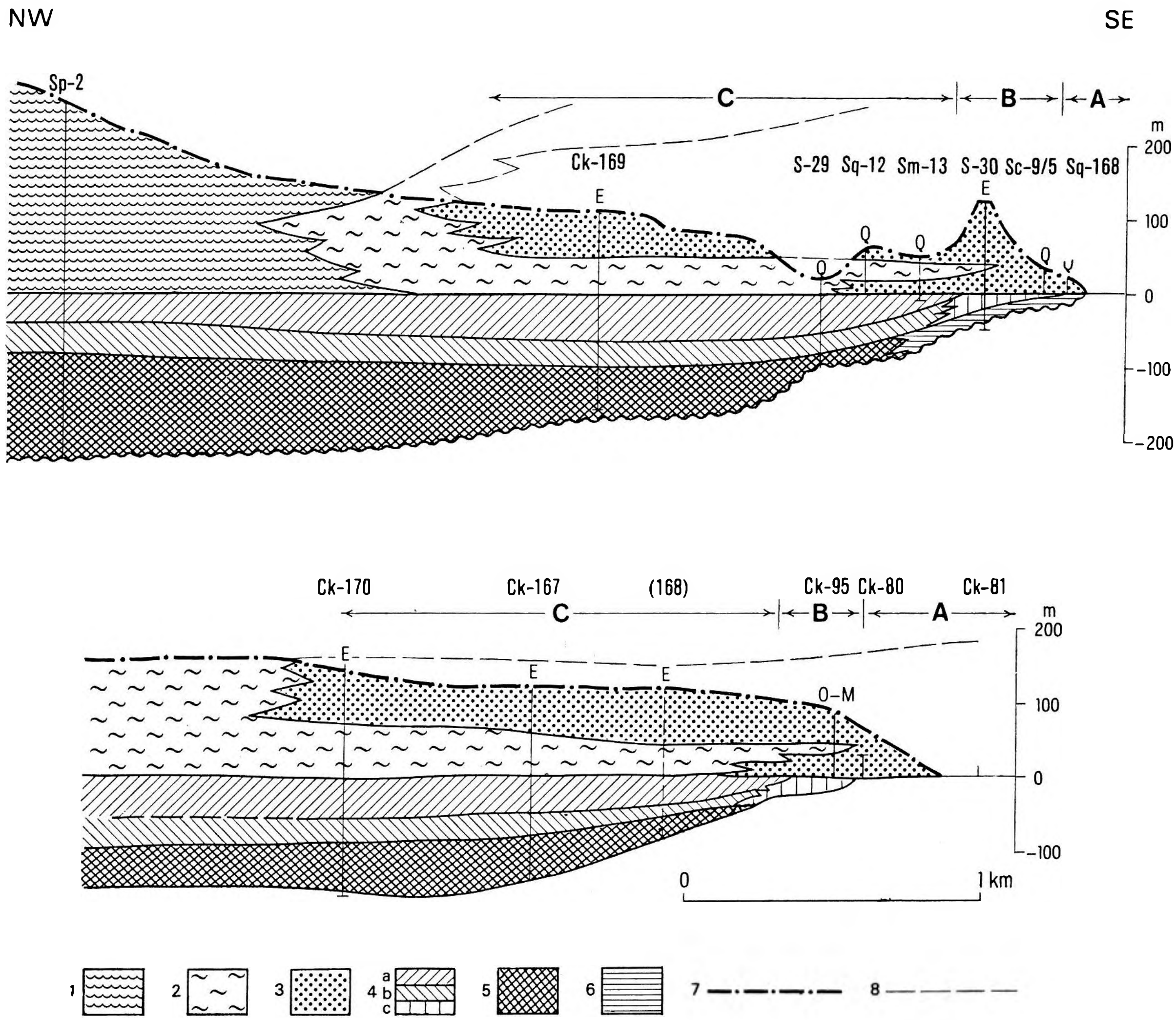


Fig. 58. NW—SE oriented profiles showing the relations between the Senonian formations with reference to the top level of the Jákó Marl

1. Polány Formation, 2. Rendek Member, 3. Ugod Fm., 4. Jákó Fm.: *a)* upper member, *b)* lower member (Csingervölgy Marl), *c)* marginal facies, 5. Ajka Fm., 6. Csehbánya Fm., 7. present-day denudation surface, 8. supposed original formation boundaries. — *E, O-M, Q* symbol of formation overlying the Senonian; *A—B—C* facies zone

It is by and large in the zone of typical, two-member development of the Jákó Formation and appearance of the Ajka Formation, that the characteristic features of Facies Zone "*C*" present themselves in the sequence. An essentially similar arrangement can be seen in the lower profile of Fig. 58 as well.

The lower interval of the Polány Formation is thus intertonguing approximately in the Gerinc quarry–Kozma-tag line with the Ugod Limestone, its upper interval being so at the foot of the Rendeki-hegy. In other words, the area of the Ugod Limestone is shifted by about one kilometre and a half to the northwest, towards the one-time basin. The subsequent trends of potential shifting cannot be traced owing to the loss of formation due to erosion.

Bio- and chronostratigraphy

To single out biostratigraphic units within the Ugod Formation is rather difficult, for the fossil assemblage is composed of reef-dwelling organisms and these excel with their ecological sensitivity rather than with a characteristic, narrow stratigraphic range. In many cases even a radical change in the composition of the fossil assemblage reflects but a slight change in environment, thus having little to do with the range of a species. That the palynological zoning, readily applicable to pelitic formations, can play only a subordinate role in a limestone facies poses another problem.

On the basis of the above, it is obvious that in addition to direct biostratigraphic evidence needed for a chronostratigraphic assignment, the use of indirect methods based on observation of the intertonguing of heteropical facies, the consideration of the chronostratigraphic evidence of the under- and overlying formations and the evaluation of facies relations and facies shifts cannot be dispensed with.

The most peculiar fossil group of the Ugod Formation is represented by *Rudista*. Both *Hippurites* and *Radiolites* are present in a relatively large number of species and an extremely large number of individuals in the Sümeg area. The ranges of the particular index fossils are shown, as compiled by L. Czabalay (1982), in Table 5.

The individual elements of the faunal assemblage can be traced in the northern part of the one-time Tethys from southern France across the Alps-Carpathians-Dinarics range as far as Asia Minor, being bound consistently to facies similar to the Ugod Formation. Their stratigraphic range is comparatively narrow, some of them being restricted to the Upper Santonian and the Lower Campanian, others to the Lower and Upper Campanian intervals, though a few forms spanning the Upper Campanian or the Lower Maastrichtian, respectively, have also been encountered.

Thus, in terms of the *Rudists*, the lower subunit of the Ugod Formation cropping out on the Köves-domb and near the Kozma-tag and represented by hippuritic, bioclastic limestones and the lower rudist-bearing beds of the Gerinc quarry sequence may be assigned to the Lower Campanian, the rocks exposed in the upper part of the borehole Süt-14 and also the upper subunit exposed in the Gerinc quarry, to the Upper Campanian.

In the light of evidence concerning the spatial position of the Ugod and Polány Formations it is not surprising that the *Rudists* encounterable on the Köves-domb suggest an older age and those known from the Hajnal-hegy and Hárs-hegy outcrops are indicative of a younger one. In fact, these data confirm our view about the spatial relations of the formations involved.

The same point is corroborated by the fossil material recovered from the transitional argillaceous beds between the Polány and Ugod Formations on the slope of the valley in the northern part of the Hárs-hegy. From this material, L. Czabalay identified the following fossils which she believed to be characteristic of the Upper Campanian: *Inoceramus capitosus vengarteni* Czabalay, *I.* cf. *striatoconcentricus* Gümbel, *Cucullaea (Trigonarca) austriaca* Zittel, *Biradiolites* sp., *Pycnodonta* sp., *Ostrea canaliculata* (Sow.).

From the interbedded limestone layers and the limestones overlying the formation on the plateau above the valley, limestones abounding with *Rudist* shells, the following fossils have been recovered:

Agriopleura cf. *moroi* (Vidal)
Praeradiolites cf. *subtoucasi* Toucas
Lapeirouseia zitteli Douville
Hippurites (H.) mestrei Vidal
Hippurites exaratus Zittel
Hippurites lapeirousei Goldfuss
Hippurites castroi Vidal
Hippurites nabresinensis Futterer
Biradiolites aff. *stoppanianus* (Pirona)
Radiolites angeiodes (Picot de Lap.)
Ceratostreon matheronianum (d'Orb.)
Janira sp.
Neithaea sp.
Arca (Cucullaea) sp.

L. Czabalay suggests that this faunal assemblage is similar to that recovered from beds dated as Campanian to Maastrichtian in Austria (Gosau) and southern France.

In the Sintérlapi quarry and the extraclastic limestone exposed at the base of the Senonian in the borehole S-7 the following gastropodal assemblage can be found: *Itruria cycloidea* Pcelincev, *I. goldfussi* (d'Orbigny), *I. lamarcki brandenbergensis* Kollmann, *Trochactaeon giganteus subglobosus* (Muenster), *Actaeonella caucasica styriaca* Kollmann. According to L. Czabalay (1975), the afore-listed forms are typical of the Lower Campanian, but some of them appear already in the Santonian.

As shown by L. Czabalay (1964e), the rich fauna of *Bivalvia* from the beds above the hippuritic and bioclastic limestone of Köves-domb (Kecskevár quarry) can be assigned to the Campanian, though assignment of higher precision is impossible.

From among the larger Foraminifera occurring in the upper part of the Ugod Limestone, *Monolepidorbis* is typical of the Campanian, *Orbitoides* and *Siderolites* are characteristic of the Upper Campanian–Maastrichtian. *Cuneolina* and *(Dicyclina)* are known already in the Middle Cretaceous. The range of *Rhipidionina liburnica* (Stache) extends from the Cenomanian up to the Lutetian. *Accordiella conica* Farinacci is characteristic of the Campanian.

Table 5.

Stratigraphic range of the Rudista fauna of the Ugod Limestone
after L. CZABALAY (1982)

Species	Santonian	Campanian		Maastrichtian	
	Upper	Lower	Upper	Lower	Upper
Plagioptychus aguilloni (D'ORBIGNY)	—	—	—		
Vaccinites sulcatus (DEFRANCE)	—	—	—	—	
Vaccinites praesulcatus (DOUVILLÉ)		—	—		
Vaccinites vredenburgi (KÜHN)		—	—	—	
Vaccinites vesiculosus (WOODWARD)		—	—		
Vaccinites inaequicostatus (MÜNSTER)	—	—	—		
Vaccinites gosaviensis (DOUVILLÉ)		—	—	—	
Vaccinites braciensis (SLADIĆ-TRIFUNOVIĆ)	—	—	—	—	
Vaccinites atheniensis (KTENAS)	—	—	—	—	
Vaccinites cornuvaccinum gaudryi (MUN.-CHALM.)		—	—		
Vaccinites taburni GUISCARDI	—	—	—		
Vaccinites chalmasi (DOUVILLÉ)	—	—	—		
Vaccinites archiaci (MUNIER-CHALMAS)			—		
Vaccinites carinthiacus (REDLICH)	—	—	—		
Vaccinites oppeli santoniensis (KÜHN)	—	—	—		
Vaccinites oppeli (DOUVILLÉ)	—	—	—		
Vaccinites giganteus (D'HOMBRES-FIRMAS)	—	—	—		
Vaccinites fortisi (CATULLO)		—	—		
Vaccinites boehmi (DOUVILLÉ)	—	—	—		
Hippurites heberti MUNIER-CHALMAS		—	—		
Hippurites sulcatoides DOUVILLÉ		—	—		
Hippurites crassicostatus DOUVILLÉ		—	—		
Hippurites heritschi KÜHN		—	—	—	
Hippurites nabresinensis FUTTERER	—	—	—		
Hippurites colliciatus WOODWARD	—	—	—		
Hippurites lapeirousei GOLDFUSS		—	—	—	
Hippurites variabilis MUNIER-CHALMAS		—	—		
Hippurites bioculatus LAMARCK		—	—		
Hippurites socialis DOUVILLÉ	—	—	—		
Agriopleura moroi (VIDAL)		—	—		
Agriopleura cf. *garumnica* (ALIBERT)			—	—	
Radiolites spongicola ASTRE			—	—	
Radiolites angeiodes (PICOT DE LAPEIROUSE)	—	—	—	—	
Radiolites albonensis TOUCAS			—	—	
Radiolites aurigerensis MUNIER-CHALMAS	—	—	—		
Radiolites gastaldianus PIRONA	—	—	—		
Radiolites radiosus D'ORBIGNY	—	—	—	—	
Radiolites subradiosus TOUCAS	—	—	—		
Radiolites squamosus D'ORBIGNY	—	—	—		
Radiolites nouleti (BAYLE)		—	—		
Radiolites styriacus (ZITTEL)		—	—		
Radiolites pannonicus BARNABÁS		—			
Radiolites galloprovincialis MATHERON	—	—	—		
Neoradiolites matheroni (TOUCAS)	—	—	—		
Praeradiolites subtoucasi TOUCAS	—	—	—	—	
Praeradiolites aristidis (MUNIER-CHALMAS)	—	—	—		
Praeradiolites hoeninghausi (DES MOULINS)		—	—	—	
Praeradiolites maximus ASTRE			—	—	
Praeradiolites saemanni (BAYLE)			—	—	
Praeradiolites plicatus desmoulinianus (MATHERON)		—	—		
Laperiouseia jouanneti (DES MOULINS)			—	—	—
Laperiouseia zitteli DOUVILLÉ		—	—		
Lapeirouseia pervinquieri (TOUCAS)	—	—	—		
Osculigera kuehni LUPU	—	—	—		

Noteworthy from the viewpoint of local correlation is the occurrence of *Nummofallotia cretacea* Schlumb. and of forms from the genus *Goupilladina*, as these forms are encountered in the heteropical Jákó Formation and the Polány Formation, respectively, as well. *Nummofallotia* was observed for example in the lower part of the borehole S-7, the basal beds in the Sintérlap quarry, the lower part of the borehole Süt-14 and in the Ugod Limestone of the boreholes Sg-192, S-30 and Ck-167 and -168.

In the basin centre boreholes, the upper limit of occurrence of *Nummofallotia* lies somewhere around the upper boundary of the lower member of the Jákó Marl, coinciding with palynological Zone E.

The sea urchin fauna occurring in the Echinoidea beds of the Köves-domb and the Gerinc quarry is believed by E. Szörényi (1955) to be of Coniacian to Lower Santonian age as suggested by the presence of *Pyrina ovolum* (Lamarck), *Botriopygus toucasianus* Orbigny, *B. nanclosi* Coquand and *Micraster corbaricus* Lambert.

F. Góczán (1964), on the basis of his palynological investigations, assigned the Hippurites-bearing limestones in the upper quarry-yard of the Gerinc quarry to the upper part of the Upper Campanian. From the grey nodular, pelitic basal beds of the Ugod Formation exposed in the borehole Sc-5/9 (Facies Unit "B") at the foot of the Hárs-hegy, F. Góczán listed species assignable to Zone D, i.e. the upper part of the Lower Campanian.

From marls with tiny rudists interbedded with the hippuritic-bioclastic limestones of the Sintérlap quarry on the Köves-domb, a typical Zone E assemblage was recovered, while from the basal beds of the borehole S-7, a typical assemblage of Zone D came into the fore (F. Góczán 1973).

The observations that have served as a basis for an indirect chronostratigraphic evaluation are discussed in the context of the geological features of the Jákó, Polány and Ugod Formations. In brief, the results involved have led to the following conclusions:

1. According to observations carried out in the northwest foreland of the Köves-domb (borehole Süt-16), the limestone beds made up for the most part of *Rudist* debris extend well between the lower and upper members of the Jákó Marl. This means that in the immediate vicinity the genesis of the Ugod Formation started already in Late Santonian to Early Campanian time.
2. On the Köves-domb and in the Városi-erdő, the Ugod Limestone is overlain by the Upper Campanian beds of the Polány Formation.
3. On the Hárs-hegy, the Hajnal-hegy and in the northern part of the Kozma-tag subarea, beds exhibiting the characteristics of the Rendek Member of the Polány Formation are overlain by an Ugod Formation composed of *Rudist* detritus which was formed at the end of the Campanian or possibly already at the beginning of the Maastrichtian.
4. During the study of the Polány Formation some samples were observed to contain minute debris of rudists. Of greatest chronostratigraphic value is the middle interval of the borehole Sc-4/2, where, in addition to *Globotruncana arca* (Cushm.), *G. linneiana* (d'Orb.), i.e. Foraminifera, *Rudist* shell fragments were observed in beds assigned to palynological Zone F.

S u m m a r i z i n g the results of direct and indirect analyses, we may conclude that the Ugod Limestone now known from the Köves-domb, i.e. not lost to erosion, is of Upper Santonian (?) to Lower Campanian age. The beds overlying the Rendek Member of the Polány Formation on the Hajnal-hegy and in the vicinity of the Rendeki-hegy were formed in the latest Campanian and maybe in earliest Maastrichtian time. In the marginal zones (*A* and *B*), similarly to the case of the Köves-domb, the birth of the Ugod Formation may have begun in Late Santonian or Early Campanian time and interrupted by deeperwater facies in Facies Zone "*B*", but uninterrupted in Facies Zone "*A*", it seems to have lasted up to the base of the Maastrichtian.

Depositional environment

In outlining the depositional environment of the Ugod Formation we may start from analyzing the rock structure and texture, the ecological conditions of the biogenic components present in rockforming quantities and from their postmortal changes. Much help in constructing the paleo-environment, however, may be provided by an analysis of the thickness and facies characteristics of the formations underlying the Senonian and by evaluating the relevant profiles with a view to reconstructing the original spatial relations of the Ugod Limestone.

Because of the marked spatial variability of the sequences involved we were, already in discussing the geological observations concerning the Ugod Formation, compelled to delineate facies areas and to examine, first of all in these selected areas, the features that are in common or different and then to proceed to analyzing the discrepancies between the facies. This system is that which we follow during our analysis of the depositional environment, too, discussing in the first place the Köves-domb subarea which is of relatively small size and thus studied in most detail, being considered a relatively independent unit.

Köves-domb

The analysis of the depositional environment of the Ajka and Jákó Formation gave information also on what the topography around the Köves-domb and prior to the birth of the Ugod Formation was like. We have pointed out that the comparatively steep slope on the northern side of the Köves-domb (a morphological bench) resulted in a zone of environmental change at the time of birth of the Ajka and Jákó Formations. Consequently, the area of the Köves-domb as a whole was relatively elevated (as compared to the areas to the northwest).

On the northwest side of the Köves-domb the Ugod Formation rests directly on the denuded surface of the Aptian Tata Formation and it does it with a considerable angular unconformity (Sintérlap quarry). This suggests that the Tata Limestone block cropping out on the northwest side of the Köves-domb had already got elevated during the pre-Senonian movements and that the present condition reflects the preservation of a pre-Senonian tectonic pattern.

The closer neighbourhood of the Sintérlap quarry may be interpreted as a rock cliff that emerged —a little bit—above sea level. By this model a number of characteristic, particular and, for the most part, spatially restricted environmental units of the Köves-domb can be explained.

It is this model that renders the genetics of the extraclastic limestone beds with marine fossils from the borehole S-7 intelligible. It is by this means that we understand the data of the diagram from Fig. 51a–b and the trends therein (a pebble material deriving from the immediate vicinity, an upward shift towards a monomictic composition, a decrease in grain size and an increase in roundness).

In the light of the observations listed in the descriptive chapter and shown in Fig. 51a–b, the circumstances of formation of the rocks involved may be reconstructed as follows.

The block built up of Aptian crinoidal limestones, tectonically heavily disturbed and thereby fragmented in particular parts, got in the course of transgression into the zone of intensive abrasion. Attached by the surfs, the rock cliff was supplying sizeable quantities of detritus, of which the predominantly crinoidal limestone clasts may be the result. That rock materials other than this one occur in the lower part of the unit too (rocks available in the basement of the Köves-domb and the Mogyorós-domb, respectively) indicates that at the outset of the abrasion process a considerable part of the one-time Köves-domb–Mogyorós-domb plateau belonged to the abrasion zone. It was a subsequent overall rise in water level that was responsible for the situation that the greater part of these areas was occupied by the zone of wave action and that then it was already only the emergent cliffs that supplied some detritus.

On the leeward side behind the emerging cliffs not affected by wave action, lime mud was being deposited in which a lush vegetation developed. The living organisms that populated this environment must have largely outnumbered the rather poor fossil assemblage presently available, for the predominant fossils, *Trochactaeon*, were feeding on carrion.

At definite time intervals (e.g. whenever the abrasion reached a particular, heavily crushed zone, thus producing a kind of stone-fall), large amounts of unsorted detritus gushed upon the muddy bottom. Of course, the debris that thus penetrated into the sediment could not be rounded on, once deposited in the back-reef, leeward environment not affected by wave action. This explains the poor roundness of the detritus.

The particular stone-falls of such an intensity would bury and kill the living organisms dwelling there. *Trochactaeon*, extremely thick-shelled as they were, may be supposed to have been able to invade and conquere durably that harsh environment, however adverse to life it was, for the simple reason that they did survive the critical periods. In the quiet periods the bottom would be re-populated and even the representatives of *Rudista* would reappear.

The introduction of extraclasts into the sediment ceased then, when an intensively abraded cliff got definitively under the sea level and, having become an area of accumulation, it was buried with sediments. This process manifests itself in the fact that the detrital material tends to decrease continuously (Fig. 51a–b: borehole S-7, 43.0–50.0 m).

On the basis of the profiles, the extraclastic limestone leaning against the Aptian crinoidal limestone block intertongues with the carbonaceous formations of Köves-domb (penetrated by the borehole Süt-15) and with the lower member of original facies of the Jákó Formation.

Upon cessation of abrasional activities the environment-modelling function of the rock-cliff environment was not lost. When its surface got durably into the tidal zone, the condition for the development in this area of a Hippurites–algae–corals community materialized.

As can be seen on the NW–SE oriented profile of the Köves-domb (Fig. 50), to the southeast of the one-time reef, i.e. the Sintérlap quarry, rock types of different facies are enclosed between the pre-Senonian basement on the one hand and the hippuritic and bioclastic unit representing the upper part of the Senonian sequence on the other. From the genetic viewpoint, a characteristic feature of the sequence is the upward increase of the value of environmental energy—a fact established by means of texture studies.

The environment of formation of the units distinguished in the descriptive part is interpreted as follows:

1. The *aphaneritic limestone unit* is characterized by a texture type composed of micrite grains of 0.1 to 0.5 m diameter (pellets, lumps) or of microcrystalline calcite, respectively. The grains of a few microns size may have been deposited on a quiet sea bottom free from currents or surfs. The beds of intrabiomicrite texture are indicative of a permanently or periodically poorly agitated depositional environment.

It follows from the above that in the areas, where the beds in question occur, the environment during their deposition was free from water movement. Protection against agitation must have been provided by the one-time rock cliff and it was in the leeward side behind the cliff that the conditions, that may be observed at present in the well-protected lagoons behind coral reefs, were provided.

The bios of the non-agitated lagoon was certainly more scant than that of the hippuritic facies complex, oxygen- and nutrient-rich and supplied with fresh seawater. That the lagoon was not poor in organisms, after all, is quite probable. *Foraminifera* leading a benthonic way of life, particularly the larger *Dicyclina* and *Cuneolina* genera, are very frequent. Tiny *Rudista* (primarily *Praeradiolites* and *Agria*), gastropods (*Actaeonella* sp., *Nerinea*), *ostracods* and *echinoderms* are abundant. This faunal assemblage under such closed circumstances can be supported by a rich vegetation only which alone provides it with both oxygen and nutrients (a few green algal debris could be observed even during studies with the microscope). Even between the back-reef lagoons of present-day coral reefs does a type with a lush vegetation occur. The one-time environment in which the aphaneritic limestone unit was formed may have been similar to this.

Judging by the distribution of green algae and the composition of the fauna, the water depth may be estimated at 5 to 10 m. Sunlight must have penetrated as deep as the sea bottom. The presence of stenohaline marine organisms *(Rudista)* is indicative of normal salinity. In the closed, quiet lagoons the water seems to have been strongly warmed up under the tropical to subtropical climate—a circumstance suggested by the presence of organisms with an extremely thick skeleton: *Rudista*, *Gastropoda*, giant-sized *Miliolina*, very large *Dicyclina* species.

2. The *hippuritic, bioclastic facies* on the Köves-domb covers the aphaneritic limestone beds, transgressing beyond these (e.g. Sintérlap quarry).

The occurrence of rock types with a biomicrite to biosparite texture containing grains of arenite and rudite grain size is indicative of a depositional environment affected by comparatively heavy agitation which, however, varied in intensity.

The marked enrichment of bioclasts suggests sedimentation in a shallow-water environment that was a warm water rich in carbonate. In this environment reef-like structures were being built continuously serving as a permanent source of biogenic carbonate detritus.

Within the hippuritic, bioclastic unit various lithofacies of varying spatial extension showing somewhat different geological features can be found. The aphaneritic unit in the borehole S-7 is overlain by a sequence consisting of alternating beds of red, coarse to medium-grained limestones of biosparite and micrite texture. Similar rock varieties can be observed in the Kecskevár quarry and the outcrops in the north of the Köves-domb.

The micritic biosparite texture in a periodically poorly agitated environment can be brought about in such a way that the lime mud settling in the interstices of the grains in the quiet periods is winnowed by the water in periods of agitation. A part of the lime mud, however, may be preserved in the well-protected voids between the grains. The hypothesis suggesting such a poorly agitated environment is corroborated by the roundness of the grains, their being sorted and by the abundance of coated grains and calcareous pellets or lumps.

Thus the sedimentary environment must have been alternately agitated or non-agitated, i.e. quiet and, accordingly, the bottom itself must have been of calcarenitic or lime mud character, respectively. The alternations of the substratum and agitation were followed by corresponding changes in the fauna and flora, too. An example to illustrate this is the growth of the amount of the Foraminifera fauna parallel to the increase in micrite content.

Similar environmental conditions are reflected by the light grey, pink-mottled limestones of micrite and biosparite to biomicrite texture that follow above the afore-discussed beds in the borehole S-7 (and also in the Kecskevár quarry and the southeastern part of the Sintérlap quarry). Water agitation, oxygen content and availability of food seem to have been too poor and the water depth too large to enhance the mass proliferation of the *Rudists*, though solitary forms of smaller size are locally abundant. So it was mainly *Exogyra*, forms less sensitive to environmental effects, that would swarm the muddy, lime-muddy bottom.

The reddish-brown echinoid-bearing limestone beds overlying the above-discussed strata in several exposures (borehole S-7, Kecskevár quarry, outcrops in the southeast part of the Köves-domb) represent a quite peculiar facies.

For the most part, the rock is composed of *Echinoidea* skeletons, their detritus and a biosparite matrix. The orientation of the skeletons is indicative of postmortal redeposition, but given the large quantity of intact skeletons, just a very short-distance transport seems to have been involved. Consequently, the data that can be gained from the way of life of the sea urchin fauna feature the conditions that existed in the immediate vicinity of rock generation. *Botryopygus*, the predominant forms, are, in E. Szörényi's opinion (1955), organisms enclosed in the sediment that lived in a shallow, clean seawater. The other genera are inhabitants of shallow-water seas with a calcareous mud bottom, too. Thus the sea urchins, with the advent of ecological conditions favourable for their life, must have populated the muddy bottom in enormous quantities. As a result of revival of water movement at times, the skeletons were transported away to short distances and accumulated there.

The topmost interval of the Köves-domb sequence (the upper 15 m of the borehole S-7, the topmost beds exposed in the Kecskevár and Sintérlap quarries) is composed of micritic biosparite-textured limestone, marly limestone and silty marl beds. Both the petrographic character of the limestone (biosparite texture, grain roundness, pseudooölite pattern) and the composition and morphology of the fossil assemblage (giant-sized, cemented specimens of *Hippurites* enclosed in situ or integrown hermatypically or in a "bunch-like" pattern, larger *Alectryonia*, globular *coral colonies*, *red algal* nodules, etc.) are suggestive of a depositional environment affected by heavy or periodically heavy agitation which may have been a littoral surf-affected zone.

The beds in question (mainly the upper ones) are characterized by larger or smaller, but hermatypically intergrown rudists which, on account of their enormous nutrient- and energy demand, require a clean, warm and oxygen-rich water abounding with planktonic organisms (O. Kühn 1967). O. Kühn supposed unicellular *Zooxantella* green algae to have supplied the oxygen that was needed to satisfy the high oxygen demand of the giant forms of *Hippurites*. Lime-secreting, green algae could be observed even directly in thin sections. The listed prerequisites for meeting the light demand of the green algae and the other conditions for the mass occurrence of Rudists were assured, in addition to the heavy agitation, by the low water depth.

The water on a quite shallow-water platform may grow quite warm. By analogy with the present-day environments, a water temperature of even 30 to 32 °C is conceivable. Paleotemperature measurements by O and C isotopes of rock samples and Hippurites, Radiolites and Alectryonia from the Köves-domb (I. Cornides et al. 1979) gave values between 30 and 35 °C.

It is a continuous fracturing of fossil skeletons and shells accumulating in abundance that accounts for the scarcity of both *Rudist* valves superimposed on one another in a vertical position and of the formation of genuine reef structures. Fracturing and fragmentation seem to have been caused by the mechanical and chemical effects of etching and borer organisms (traces of etching-sponges and, less frequently, borer-bivalves can be observed on the fossils), the more so by mechanical destruction as a result of wave action. Much of the mud and the finer fraction of detritus from the voids between the skeletal fragments was washed out by the water and was then deposited in the less agitated water of the lagoon. The coarse detritus was accumulated—for the most part—at the place of its birth.

Interbedded marl layers, lenses or just coatings are suggestive of changes of varying duration such as greater water depth, poorer agitation or a temporarily more heavy influx of sediment. In such cases the communities of *Rudista*, initially quite prolific, would dwindle and thin, so that the corresponding beds are now characterized by the remains of *Exogyra*, *Ostrea*, smaller Rudista and calcareous dwelling-tubes of worms.

In conclusion, the circumstances of formation of the uppermost beds may be summarized as follows:

1. The sedimentary environment was predominated, as a rule, by heavy agitation, circumstances under which calcarenite and calcirudite sediments were formed due to the fracturing and fragmentation of biogenic structures. Sometimes, pelitic sedimentation was coupled with the reduction of agitation. Because of intensive bioerosion the formation of bioclasts did not cease even in such cases.
2. The water depth was generally quite low (1 to 10 m), sunlight penetrated down to the bottom. The water may have grown quite warm.
3. Because of the constant agitation of the water its aeration was quite efficient, being well supplied with both oxygen and nutrients. The high quantity of dissolved CO_2 in the water was advantageous for the growth and proliferation of large-sized, calcareous organisms.

On the basis of the ecological analysis of the sequence, two major sedimentation rhythms can be observed to have followed the formation of the extraclastic sediments. The first one took place then, when the emergent block facing the open sea (or possibly a series blocks) was still efficient in screening the effect of wave action, and when in the background fine calcareous mud was being deposited, but the accumulation of coarse rock detritus had already ceased. That may have been the time when the rock cliff got below the wave base level of the sea, so that its desctruction did not continue anymore, though hardly any sediment could escape removal on its surface.

The assumption that during the submergence of the cliff it was on this morphological high that the formation of hermatypical communities of Rudista, algae and Hydrozoans could set in seems to be realistic.

The second rhythm began when the morphological differences in the Köves-domb subarea had been eliminated. The cliff had been reduced by erosion and sediment of reduced thickness was deposited on its surface, while the depression in the back-cliff area was filled with lime mud. It was on the resulting platform, now already quite level, that the reef-like environment came into existence which was populated by Rudist communities of varying size, and smaller coral and hydrozoan colonies and which served as a source for the large-scale production and accumulation of arenite and rudite grains spread as a level blanket on the surface. Composed of bioclast grains rounded as a result of the mechanical action of the waves, the resulting sediment is often characterized by a good sorting. This reef-like environment differed in many respects from the present-day coral reefs. A barrier-reef that might have served as a braker seems to have been absent, so a leeward lagoon could not develop either.

Facies Zones A, B, C

Distinguished in the descriptive part, Facies Zones A, B and C represent a shallow-water carbonate platform and its sloped foreset. The position and orientation of the slope are adjusted to the earlier morphological pattern.

In the following discussion the genetic conditions are interpreted by facies zones. The lithofacies types similar to those of Köves-domb are simply referred to. Emphasis is placed on pointing out the differences and explaining them.

Facies Zone A. On the basis of structural and textural characteristics, the facies zone may be interpreted as the immediate foreland of the platform facies. It follows from the interpretation of lithological analyses that bioclastic sedimentation took place near the lower boundary of the zone of wave action, but mostly below it (unsorted or two-fraction grain composition, micrite or sparry micrite matrix). The *Hippurites* of vertical position intergrown in a bunch-like pattern observable in the Kozma-tag subarea suggest that the area in question belonged—at least temporarily—to the platform already. This feature has not been observed elsewhere either in outcrop or in boreholes. Therefore we presume that the paleoenvironment of the bioherms with Rudists may have lain even farther southeast, i.e. at the top of the slope assumed earlier or on its less steep stretch. This facies now generally lost to erosion may be supposed to be analogous with the Rudist platform of Köves-domb.

Facies Zone B. As far as the facies characteristics of the borehole Süt-14 representing the southwest part of Zone B are concerned, these represent actually a transition between the Köves-domb pattern and the sequences of Hajnal-hegy–Hárs-hegy.

Enclosed in marine sediments and composed of scarcely rounded limestone- and dolomite breccia grains of local origin, the basal beds seem to have been formed similarly to the case of the extraclastic limestone of Köves-domb, being interpretable as submarine talus debris. The next lithofacies showing features of transition between the Csingervölgy Marl and the Ugod Limestone (the zone of pinching-out of the Jákó Formation) was obviously formed in an environment characterized by features representing an intermediate position between the two typical paleoenvironments.

The rock varieties of the typical Ugod Formation are basically similar to their counterparts known from the Köves-domb, but here the individual lithofacies are not pronounced so sharply; the calcareous mud and the bioclastic sediment not being completely separable. Consequently, the genetic conditions appear to have been similar to the case of the Köves-domb, but the presence of a barrier reef crucial for a distinct differentiation of the facies cannot be reckoned with here. The basic trends observed during the investigation of the Köves-domb, however, are recognizable here too. The lower aphaneritic facies is indicative, here also, of a comparatively quiet lagoonal environment protected against wave action, and then, with the filling up of this lagoon, a Rudist-breeding carbonate platform habitat invaded by the surfs or a little bit beneath the zone of wave action developed. Curiously enough, the subsequent feature to be observed here is again the presence of a lower energy level, then the level of environmental energy shows again an increase, to re-decrease eventually as late as the setting in of the deposition of the Polány Formation. It is also remarkable that in the exposures in the immediate vicinity of the borehole Süt-14 (boreholes labelled Bd) the rock types occurring at the base of the sequence are completely different. This discrepancy reflects considerable morphological differences that once existed to the east of the present-day location of the borehole Süt-14.

The Ugod Limestone sequences exposed in the Gerinc quarry and the borehole S-30—in terms of environmental interpretation—differ in important features from the Köves-domb occurrence and, in lesser measure, from that of Városi-erdő, too. Namely, in the Hárs-hegy sequences there is no purely micritic or pelmicritic rock type and there is hardly any rock type composed of well-sorted, rounded and coated grains of sparry matrix; instead of these, biomicrite rocks composed of poorly rounded or unrounded grains or a rock type composed of bioclasts in 80 to 90% amount containing hardly any matrix, are characteristic.

This means that instead of the surfy platform and cliff environment or the lagoon environment protected against wave action known from the Köves-domb, the zone of Hárs-hegy is considered to have witnessed a sedimentation taken place for a considerable length of time beneath the level of wave action. The reduction in grain size of bioclasts as compared to Zone A suggests that the deposition of the sediments took place on a slope that lay farther away from the shallow-water carbonate platform which was the source of the detrital material deposited. This is also reflected by the fact that in the middle part of the sequence beds with planktonic *Foraminifera* exhibiting lithological features typical of the Rendek Member are interbedded. At the time of deposition of the lower interval which got into the zone of formation of the Rendek Member, the depth of the bottom may periodically have reached even the 50 to 80 m value, but during the formation of the Rudist-bearing, bioclastic beds its seems to have been somewhat shallower.

The micritic or, less frequently, sparite-cemented calcarenite and calcirudite rock types in the upper interval of the sequence seem to have been formed immediately beneath the zone of wave action in a periodically agitated environment.

Facies Zone C. The northwest facies zone shows a mode a superposition markedly different from the features hitherto discussed. The Ugod Formation in this zone overlies the thick sequences of the Ajka- and Jákó- and even the Polány Formations (Rendek Member). Consequently, this subarea must have been a sedimentary basin already in an earlier period of the Senonian cycle.

The appearance of the Ugod Limestone apparently indicates a bottom that was becoming gradually shallower—a trend already referred to in our analysis of Zone B.

The predominant biomicrite rock type indicates that the beds were generally deposited beneath the wave base. The appearance of a well-rounded sparite-cemented microfacies, however, indicates that the bottom must have from time to time got into the tidal zone. A very low water depth, good penetration of sunlight and high water temperature are indicated by the abundance of coated grains (algal activities), the presence of oncoid grains (blue-green algae) and the frequency of *Miliolina*, *Dicyclina*, *Cuneolina* and *Rhapidionina*, i.e. genera of larger Foraminifera. The depth of the sea bottom tends to have decreased as one proceeds up in the profile.

On the basis of the ecological analysis of the facies zones two stages of development during the formation of the Ugod Limestone can be distinguished. The earlier stage is characterized by a steeper slope and a more pronounced difference in morphology between the platform and the basin, the second stage by an equilibration of the differences and the extension of the biogenic detrital facies to the pelagic facies area.

Polány Marl Formation

The Polány Marl Formation includes the calcareous marl and limestone beds on which the larger part of the city of Sümeg has been built and which locally crop out even from below the pavement of the streets and which are exposed, day in day out, when house foundations are excavated or wells or trenches are dug. To the northeast of the town, in the Haraszt subarea and on the hillside of the Rendeki-hegy a lot of quarries have exposed the formation.

In the Sümeg area the lower member of the Polány Formation typically composed of grey thin-bedded, laminated calcareous marls and silty calcareous marls is known. In the vicinity of the Ugod Limestone, partly intertongued with it, carbonate rock types of transitional facies occur. This transitional unit is proposed to be distinguished under the name of Rendek Member. The choice of name is justified by the occurrence of a lot of good exposures of the unit on the hillside of the Rendeki-hegy.

Local type section: borehole Sp-2

The features of the Polány Formation or, more precisely, of the lower member observable in the Sümeg area are exhibited most completely by the boreholes Sp-2 and -3. In Sp-2 (Fig. 59), on the basis of the lithological characteristics, two intervals can be singled out:

The l o w e r i n t e r v a l (93–190 m) shows the following basic features: argillaceous lime-

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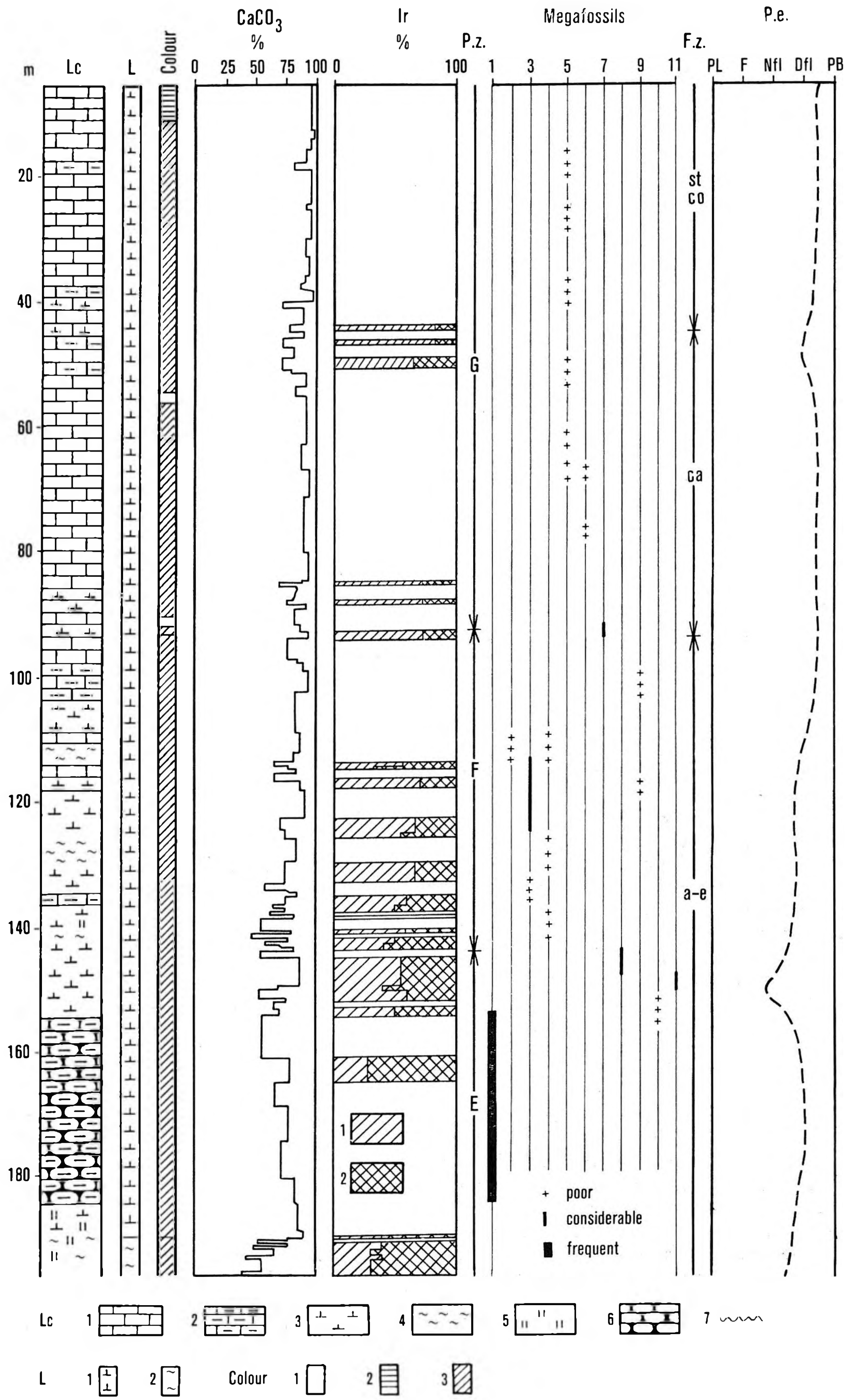
Fig. 59. The Polány Formation interval of the borehole Sp-2: lithologic log and analytical record

Lithologic column **(Lc): 1. limestone, 2. argillaceous limestone, 3. calcareous marl, 4. marl, 5. silt, siltstone, 6. clay structure, 7. wavy clay-filmed bedding surface. —** ***Lithostratigraphic units*** **(L): 1. Polány Marl Fm., lower member, 2. Jákó Marl Fm., upper member. —** ***Colour:*** **1. white, 2. dark brown, 3. light grey. —** ***Grain composition of insoluble residue*** **(Ir): 1. clay, 2. silt. —** ***Palynological zones*** **(P.z.) —** ***Megafossils:*** **1. Aptyxiella flexuosa, 2. Pectunculus sp., 3. Ostrea sp., 4. Pycnodonta vesicularis, 5. Inoceramus regularis, 6. I. balticus, 7. Corbula sp., 8. Limopsis sp., 9. Tellina stoliczkai, 10. Cucullacea austrica, 11. Gervilleia solenoides. —** ***Foraminiferal zones*** **(Fz):** ***st-co*** **Globotruncana stuarti — G. conica Zone;** ***ca*** **Calcarata Zone;** ***a—e*** **G. arca — G. elevata Zone. —** ***Paleoenvironment*** **(P.e.):** ***PL*** **carbonate platform,** ***F*** **front-reef (platform margin),** ***Nfl*** **nearby foreland slope,** ***Dfl*** **distant foreland slope,** ***PB*** **pelagic basin**



m
Lc
L
Colour
CaCO3 %
0 25 50 75 100
Ir %
0 100
P.z.
Megafossils
1 3 5 7 9 11
F.z.
P.e.
PL F Nfl Dfl PB
20
40
60
80
100
120
140
160
180
G
F
E
st co
ca
a-e
1
2
+ poor
considerable
frequent
Lc 1 2 3 4 5 6 7
L 1 2
Colour 1 2 3

stones, calcareous marls, silty calcareous marls and, less frequently, limestone and marl beds alternate in it ($CaCO_3$ content 60 to 95%, the noncarbonate fraction is constituted, in about 50%, by pelites, in 50% by detritus of silt size).

In the more carbonate parts of the sequence a thin-bedded structure (with beds of 0.1–1.2 m thickness) is characteristic. The beds of argillaceous limestone or limestone are separated by uneven bedding planes covered by argillaceous marl or by clay layers of a few cm thickness. The calcareous marl rock type is characterized by laminated, the marl by foliated, jointing. Layers of bioturbated structure and traces of worm tracks, a few cm long and 0.2 to 0.8 cm in diameter, usually parallel to the bedding planes, are quite frequent and conspicuous. A structure due to mud cracking in a plastic state (plast-dotted pattern), mud creep features and nodularity are typical of the lower 20 to 40 metres of the sequence composed of argillaceous limestones, but they can be observed, in a reduced proportion, even higher up the profile.

The rock colour is generally light grey or, locally, because of subsequent oxidation of the dispersed pyrite content, light brown.

The rock texture is predominantly biomicrite with a fossil content of about 30%. Pelletal, intraclastic rock textures do also occur. The matrix consists for the most part of the detritus of microfossils (*Calcisphaerulidae*, planktonic *Foraminifera*) and skeletons of nannofossils. Tiny detritus of mollusc and echinoderm skeletons and valves of *Ostracoda* are usually abundant.

The foraminiferal fauna is characterized by the joint presence of both planktonic *(Hedbergella, Globotruncana, Globigerinelloides, Heterohelix)* and benthonic *(Arenobulimina, Gavellinella, Stensiöina* and *Goupillaudina)* forms and their nearly equal amounts.

In the u p p e r p a r t of the sequence (6–93 m) the lithofacies is represented by limestone and argillaceous limestone ($CaCO_3$ 90–95%), only in the 44.0 to 51.5 m interval does the carbonate content drop below 75%.

The rock is of light grey colour with a darker shade in the more pelitic interval.

The rock structure is characterized by beds separated by a thin clay film and by slightly wavy bedding surfaces, less frequently the beds are covered by a thin dark grey clay film. Bioturbation, as a rule, is poorly manifested. In rare cases, even microlamination may be observed. Structures of a plast-dotted pattern resulting from mud cracking and mud sagging are common. Some horizons abound with traces of narrow (0.3 to 0.8 cm in diameter) worm tracks.

The texture is micrite with a low quantity of tiny mollusc and echinoderm debris and planktonic microfossils. The biogenic grains show a modest decrease upwards. The matrix-micrite is constituted primarily by the tests of nannofossils. Of the noncarbonate mineralogical components it is pyrite that may be mentioned, partly filling the cavities of microfossils, partly showing a scattered distribution independent of the former or, less frequently, forming large lumps.

Megafossils are seldom found in the rock. In addition to poorly preserved *Echinoidea* remains, some well-preserved *Inoceramus* specimens were found (Fig. 59). Fish scales and tiny coalified vegetal detritus occur sporadically too, The microfossils attain a considerable quantity. From among the Foraminifera it is the planktonic forms *(Globotruncana, Herohelix Hedbergella)* that predominate, though benthonic forms are also frequent, being primarily represented by arenaceous ones *(Spiroplectammina, Textularia, Verneuilina, Tritaxia, Gaudrina, Clavulina, Arenobulimina, Marssonella, Dorothia, Ataxophragmium)*. From among the calcispherulid microfossils the representatives of *Stomiosphaera* and *Pithonella* are very frequent.

In the borehole Sp-3 to the northwest of the borehole Sp-2, i.e. in the direction of the one-time basin, the formation is more pelitic throughout its vertical extent as compared to the case of the borehole Sp-2, the subunits distinguished over there being unidentifiable here. Outcrops of rocks identifiable with the lower part of the Polány Marl intersected in the borehole Sp-2 are known to us on the Haraszt-legelő and on the southwest side of the Rendeki-hegy. In the Haraszt subarea near the boundary between the lower and upper subunits, authigenic breccia beds or rocks containing sporadical debris deriving from the fine calcarenites of the Ugod Limestone can also be observed to crop out. The grains vary in size between 0.5 and 30 cm, being unrounded or just very poorly rounded. The grading in the exposure shown by X in Fig. 31 can be observed, too. The lenticular rock body is a few m in thickness. As suggested by the description, this rock body was intersected by the borehole Sp-2 between 54.0 and 55.5 m.

The strata in the abandoned quarries on the northwest side of the Rendeki-hegy can be identified with the upper part of the Sp-2 borehole sequence (this being exposed there in about 10 to 15 m thickness). The rock exposed by the quarries is generally represented by argillaceous limestones and calcareous marls, locally with single, thicker (a maximum of 1 m) carbonate interbeds. From among the megafossils only the sporadical representatives of Inoceramus and Echinoidea may be mentioned.

Rendek Member

The Rendek Member is characterized by finely crystalline, argillaceous limestone or pure limestone which is of grey or yellowish-brown to brown colour owing to post-sedimentary oxidation. The sedimentary structural characteristics are similar to the case of the lower part of the Polány Formation as exposed in the borehole Sp-2, the only difference consisting primarily in the higher carbonate content. The nodular and plast-dotted features are conspicuous, worm tracks and bioturbated structures abound. In rare cases detrital grains from the Ugod Limestone and, in some beds, even rudist detritus can also be observed.

At the lower member boundary, as a rule, an *Exogyra–Pycnodonta* lumachelle layer is observable.

The characteristic texture is biomicrite and biopelmicrite. The fossil debris are generally 20 to 60 μm in size, grains over 100 μm being quite sporadical.

In the microfauna it is benthonic Foraminifera, primarily *Bulimina*, *Nodosaria* and *Textularia*, that predominate. In the lowermost subunit the representatives of *Goupillaudina* are frequent. Bioclasts consisting of *Mollusca*, *Ostracoda* and *Echinodermata* remains are common.

As local type section of the member, the profile of the borehole Ck-168 is presented (Fig. 57). Beds of similar nature are exposed in the boreholes Ck-167, Cn-598, S-29, Süt-14, -16, -19, -22 and S(G)-5 as well, though the mode of superposition of the member may vary from section to section. Outcrops are known to us from the Városi-erdő, the northern part of the Köves-domb, in the western part of Sümeg in an abandoned quarry and also to the northeast of the Vár-hegy.

Relation of the Formation to the neighbouring units

In judging the spatial relations of the Polány Formation the following observations may be relied on:

1. In the northernmost boreholes (Sp-2) it is the Jákó Formation that underlies the Polány Formation, the Ugod Limestone being obviously absent in these areas.

To the south of here, by and large in the municipal area of Sümeg, the boreholes have not exposed beds belonging to the Ugod Limestone either, but the essential difference compared to the previous case is that here the Polány Formation, is for the most part, lost to erosion. Namely, it may be presumed that the Ugod Limestone's beds used to extend like tongues between beds of the Polány Formation. This is suggested by the exposures at the east foot of the Vár-hegy in which limestone beds with rudist detritus and Exogyra are observed between laminated calcareous marls with worm tracks as well as by the tiny rudist detritus observed in the 9 to 20 m interval of the borehole Sc-4/2 and the borehole Süt-18 and on the hillside of the Rendeki-hegy.

2. On the hill range to the east of Sümeg, in the zone Hajnal-hegy–Hárs-hegy–Kozma-tag N, boreholes (S-29, Cn-589, Ck-167, -168, -169, -170 and -171) exposed the Rendek Member of the Polány Formation as underlying the Ugod Limestone.

Although no conclusive evidence is available to us, it may be supposed that above the eroded upper parts of the Ugod Formation rocks exhibiting features of the Rendek Member lie again.

3. As observable in the vicinity of the Köves-domb and in the borehole Süt-14 on the margin of the Városi-erdő, the Ugod Limestone overlies directly the marginal facies of the Rendek Member or it rests directly on the pre-Senonian basement without an Ugod Limestone in-between. On the other hand, the rocks of the Rendek Member are found to overlie the Ugod Limestone. The superposition in the northwest part of the Köves-domb is traceable even on the surface, being quite distinct in the northwestern face of the Sintérlap quarry as well (Fig. 54).

In the uppermost 25 m of the Senonian sequence (as preserved in a minor fault block), exposed by the borehole Süt-14 too, it is above rocks assignable to the Ugod Formation that rock types characteristic of the Rendek Member are encountered (Fig. 56). This subunit stands close in character to the rocks exposed in the topmost part of the borehole S-29 on the hillside of the Hárs-hegy.

Because of denudation that took place repeatedly in post-Senonian time it cannot be found out whether additional rudist-bearing limestone bodies, lenses or possibly bioclastite tongues jutting in may exist, or not, above the beds assignable to the Polány Formation. The only thing we can do in this connection is to admit that the one-time existence of such bodies cannot be precluded. Moreover, an extrapolation of the profiles from Fig. 58 seems to corroborate such a possibility.

4. In the southeast belt of the Senonian-covered part of the hill range no Polány Formation rock can be encountered. Rocks of this kind were not formed at all prior to the birth of the Ugod Formation, while those that may have existed as overlying this formation have been probably lost to erosion together with the higher parts of the Ugod Formation (exposures in the southern part of the Surgo-tag and Kozma-tag).

Bio- and chronostratigraphy

In the general description of the formation we have mentioned that, at its lower boundary, the change in the lithological features is coupled with parallel changes in the nature and composition of the fossil assemblage. The remains of planktonic organisms become significant and the benthonic assemblage, in turn, is characterized by the total absence of euryhaline forms.

Particularly important from the viewpoint of long-distance stratigraphic correlation is the occurrence of cosmopolitan species and the presence of fossils of a wide lateral distribution and short stratigraphic range. Beside the few Ammonite remains it is primarily spores and pollen grains, Foraminifera and bivalves that may come into account for time correlation.

The spore-pollen material of the borehole Sp-2 was studied by F. Góczán (1964) (Fig. 59). He assigned the rock of the lower part of the sequence to Zone E characterized by the predominance of *Krutzschipollis* and *Suemegipollis* and to Zone F with the predominance of species of the genus *Longanulipollis*. In the upper part, Zone G showing the predominance of *Pseudopapillopollis* div. sp. and *Semioculopollis minimus* could be identified.

In the borehole Sp-1 too, Zones E and F were identified by F. Góczán, but the boundary between the two zones here fell close to the lower formation boundary and in the uppermost samples already a spore-pollen assemblage indicative of Zone G could be observed.

In the borehole Süt-22 J. Bóna determined a *Longanulipollis–Krutzschipollis* assemblage characteristic of Zone F. The uppermost sample belongs, as suggested by the predominance of *Pseudopapillopollis praesubherzynicus*, already to Zone G.

Thus, in terms of palynostratigraphy, the rocks of that part of the Polány Formation exposed at Sümeg may be assigned to the Upper Campanian (Zones E and F) and the Lower Maastrichtian (Zone G), respectively.

According to foraminiferal results (M. Sidó 1961, 1980), the lower part of the formation in the borehole Sp-2 can be shown to include a *Globotruncana arca–G. elevata* assemblage zone. It is at about 100 m above the lower formation boundary that specimens of *Globotruncana calcarata* appear (between 45 and 94 m). Above this, forms belonging to the *Globotruncana stuarti–G. conica* assemblage zone could be observed. If we accept, on the basis of the international literature (H. Bolli 1960, E. A. Pessagno 1962, I. Sigal 1977, Van Hinte 1976), that the range of *Globotruncana calcarata* spans the uppermost part of the Campanian, so *that* part of the Polány Formation exposed in the borehole is of Upper Campanian to Lower Maastrichtian age.

In the lower part of the formation peculiar benthonic assemblages are observable. This is of primary importance for local correlation, as over a large part of the territory only the basal beds of the formation are preserved. The top of the Vaginulina Zone distinguished by M. Sidó during her study of the borehole Sp-2 (1961) coincides with the lower boundary of the formation, while the Gavellinella Zone can be recognized in the basal part of the formation.

In corresponding intervals of other boreholes studied from the northwest subarea (Sp-1, Süt-22, -18, -19, -16 and Sc-4/2, similar trends of change in the foraminiferal assemblage can be observed and the zones singled out at the base of the formation in the borehole Sp-2 can be relatively well identified. Based on M. Sidó's and R. Kopek-Nyírő's determinations from a decanted material and on our thin section analyses, the following general trends are recognized: near the lower formation boundary the species of *Vaginulina* heretofore present in a very significant amount, will disappear or become greatly reduced in quantity (upper boundary of the Vaginulina Zone). As for the genus *Goupillaudina*, also present in a considerable quantity, its vanishing occurs only higher up the profile, at 10 to 20 m above the lower formation boundary. *Stensiöina* reach the maximum of their quantity in the same interval. The representatives of *Gavellina*, however, remain quite frequent even after the disappearance of *Vaginulina*, *Goupillaudina* and *Stensiöina*. Consequently, we have all reason to identify the interval immediately overlying the lower formation boundary in the boreholes just listed with the Gavellina biozone designated in the borehole Sp-2. It is in this interval that *Bulimina* and *Lenticulina* and some arenaceous forms such as *Tritaxia*, *Dorothia* and *Globigerinelloides* grow abundant. The amount of planktonic forms increases as one proceeds upwards.

On the basis of *Bivalvia* and *Gastropoda* from Sp-2, L. Czabalay (1961) distinguished an Exogyra horizon at the lower boundary of the Polány Formation and Aptyxiella-, Gervilleia- and Ostrea horizons higher up the sequence. Actually, the horizons are a result of the succession of fossil assemblages varying with changes in sedimentation. Since the assemblage of benthonic organisms on the sea bottom may often change even within a short distance, it is not surprising that the succession typical of the type section does not repeat itself in an unchanged form in exposures that lie very close to one another. An exception to the rule seems to be the Exogyra horizon, for, as already mentioned, the presence of lots of *Ceratostreon matheronianum* (d'Orb.), a form earlier referred to as *Exogyra matheroniana*, at the formation base is common.

As far as the Aptyxiella horizon is concerned, it is no longer present in either the borehole Sp-1 and -3 or Süt-22 and -18. The predominance of *Gervilleia solenoides* Defr. too is restricted to the above-outlined position in the borehole Sp-2 only. In the borehole Sp-3 it shows an increased abundance partly in the Exogyra horizon, partly underneath, while in the borehole Sp-1 it has not been observed at all. Another difference consists in the fact that in the borehole Sp-2 it occurs in association with *Pycnodonta vesicularis* (LAM.), while in the boreholes Sp-1 and Sp-3 it is dissociated. Similar is the case with the predominance of *Ostrea* typical of the next horizon. In the boreholes Sp-2 and -3 *Inoceramus balticus* could be shown to occur in the upper part of the formation and *I. regularis* D'ORB. higher up the sequence.

L. CZABALAY pointed out that, in France, Yugoslavia, the Crimea and the Caucasus, *Ceratostreon matheronianum* (D'ORB.) reached its quantitative maximum in the Upper Campanian and that *Pycnodonta vesicularis* (LAM.) did it in the Maastrichtian. As shown by Soviet and German authors, *Pholadomya granulosa* ZITTEL and *Gervilleia solenoides* DEFR. are characteristic of the Upper Campanian. The occurrence of *Inoceramus regularis* D'ORB. is suggestive of the lower part of the Lower Maastrichtian.

Based on a material recovered from the quarries of Haraszt, the *Echinoidea* of the formation were monographed by E. SZÖRÉNYI (1955). Species identified: *Conulus albogalerus* KLEIN, *C. globulus* KLEIN, *C. raulini* (D'ORB.), *C. subsonicus* (D'ORB), *Echinocorys sulcatus vulgaris* BREYNIUS and *Micraster (Gibbaster) fastigatus* KLEIN.

Ammonites are scarce. Beside a few *Scaphites*, one specimen of *Pachydiscus neubergicus* SCHLOTH. sampled by J. NOSZKY Jr. from the Városi quarry in the Haraszt subarea is known. In terms of the Ammonite chronozonation, this species is the zonal index fossil of the Maastrichtian Stage. Since the borehole Sc-4/2 was spudded in the yard of this quarry, an exact interregional correlation is possible. A comparison of the sequences suggests that the recovered specimen may have derived from the upper part of the lower interval of the Polány Formation.

Let us summarize our fossil-based interregional correlation considerations by saying that the chronostratigraphic content of the Polány Formation spans the interval from the Upper Campanian up to the lower part of the Maastrichtian. In most exposures, however, only the lower part of the formation, i.e. that assignable to the Campanian, can be observed, because, in part, the higher horizons are occupied by the Ugod Formation as a heteropical counterpart and, in part, the uppermost, younger beds have been lost to erosion.

Paleoenvironment

In analyzing the paleoenvironment, we may start from our paleoecological knowledge derived from the structural and textural features and from the fossils available. The peculiar biomicrite texture and the fact that a sparry matrix cannot be observed to cement the grains at all, are suggestive of a sedimentation on a sea bottom not affected by wave action. The frequency of mud creep and sagging phenomena and the so-called plast-dotted structure suggest that the sediment still unconsolidated or not completely consolidated after its primary deposition may have undergone a little bit of downslope movement and thus been rearranged. In the light of data concerning the phenomena of movement of modern sea bottom sediments of similar grain size, we need not think of a slope of considerable steepness, for slumping may start on a slope of a few degrees already.

With a view to the foregoing, it may be suggested that the lower part of the formation, or the Rendek Member in which the above features are common, was formed on a slope of low steepness beneath the zone of wave action. As regards the dip conditions of the slope, we may have some idea based on the ecological analysis of older formation, but we cannot prove this, nor can we estimate the absolute depth on the basis of fossils.

Generally predominant in the study area at the lower formation boundary, the representatives of *Ceratostreon (=Exogyra)* are epibenthonic organisms that lived in the infralittoral region. The fact that specimens of this genus are common even in the more pelitic sediments between the Rudist-bearing limestone beds of the Ugod Formation and also that at the lithological contact between the Ugod and Polány Formations they tend to grow consistently enriched suggests that these organisms must have well endured ecological conditions similar to the case of the *Rudista* communities extremely sensitive to changes in environmental parameters and bound to quite shallow waters. However, the fact is that they were very far from reacting so sensibly to changes in ecological factors as it was the case with the *Rudists*. It appears that *Ceratostreon (Exogyra)* forms were the first to invade quite systematically the ecological niches that had been becoming unfavourable for the *Rudists* (primarily *Hippurites*). (The disadvantageous conditions may have included the growth of the rate of deposition of pelitic, silty sediments, the worsening of oxygen supply and the increase in water depth.) Since the Hippurites community seems to have dominated the 1 to 10 m depth range, the statement that the predominance of Ceratostreon was confined to the 10 to 30 m water depth interval seems to be acceptable.

As we have seen, the upper member of the Jákó Formation was deposited on a terrain that had been by and large planated and that was sloping gently northwards. Thus the marked increase in

$CaCO_3$ content indicative of the formation boundary and the horizon of enrichment of Ceratostreon seem to have been brought about at approximately the same time over the area of distribution of the formation and the bottom on which these processes took place seems to have been an invariably very gently sloping one. Eventually, the steepness of the slope would increase, for the Rendek Member on the landward side is covered by Rudist-bearing limestone beds suggestive of an even more shallow environment (even though these are of slope-deposited bioclast origin rather than deriving from the reef body), while in the basinward tracts, an overall trend of increase in pelagicity and a probably parallel trend of increase in depth is suggested by several factors, first of all, by the *Foraminifera.*

Analyzing the composition of the foraminiferal fauna, we observe that the planktonic forms tend to increase in number as one proceeds northwestwards and, in the northwest subarea, from the bottom to the top of the sequences. The amount of planktonic microfossils of *Calcispherulidae* type grows similarly. This must suggest an increase in pelagicity in the given directions.

From among the benthonic Foraminifera the arenaceous forms in the southwest subarea are scarce, but in the northwest they are quite abundant in some horizons of the upper interval. The appearance in larger quantity of arenaceous forms suggests such a bottom water from which the precipitation of carbonate shells requires high energy, consequently, a sea bottom covered by comparatively cold water beneath the photic zone.

On the southeast margin *Orbitoides* specimens absent in the material of the northwest exposures can be observed in the Rendek Member. These forms of larger size in the Tethyan realm occur always in the immediate vicinity of Rudist reef environments. It is very probable that, similarly to the case of the Foraminifera (Elphidium, Ammonia, etc.), the segregation of carbonate needed for building the large shells was accomplished by means of a symbiosis with algae. In this case their confinement to the photic zone readily penetrated by sunlight is apparent. All these circumstances suggest that the scene of deposition of rocks constituting the Rendek Member was that part of the one-time submarine slope lying below the wave base, but still falling in the zone well-penetrated by sunlight (i.e. appr. depth of 10 to 30 m). The northwest, deeper, part of the slope in turn lay deeper than the photic zone. Taking the one-time depth in the line of the borehole S-29 to have been 40 m and reckoning with a slope angle of 3° (slump-affected slopes dip generally at 2 to 4°), the depth of sea bottom in the area between the boreholes Sp-2 and Sp-3 is estimated at 160 m. This depth does not contradict the value that can be estimated on the basis of the ecological evaluation of *Foraminifera* and *Mollusca.*

In those sequences of the northwestern subarea which have exposed the Polány Formation (boreholes Sp-2 and -3) the fossil assemblage indicates a continuous pelagic paleoenvironment. This is suggested by the basically nannoplanktonogenic fraction of the rockforming micrite matrix, the predominance of the planktonic microfossil assemblage and the nektonic organic remains.

The pelagic environment did not imply any considerable distance off the coastline—a fact indicated by the composition of the pollen flora of the formation.

In the context of water depth the following conclusions can be drawn: the textural features, and the lack of green algae and presumably of animals in symbiosis with green algae are suggestive of a paleoenvironment that lay below the zone of wave action and the photic zone.

The relative frequency and specific diversity of benthonic fossils, however, makes it probable that the water depth may not have exceeded the depth of shelf seas (about 200 m).

Because of large-scale oxygen production by the wealthy nannoplankton the upper water layers may have been rich in oxygen. The deeper-situated water layers and primarily the interstitial water of the mud grains being deposited, seem, on account of the large-scale decomposition of organic matter, to have represented a reductive environment—a hypothesis corroborated by the disseminated pyrite content observable throughout the respective sediments.

The wealth of organic matter in the mud is suggested by traces of suspension-feeding, burrowing organisms.

The alternation of an undisturbed microlamination suggestive of quiet sedimentation with intervals carrying features of slumping in the upper part of the sequences of the Polány Formation exposed in the Sümeg area suggests a very gentle slope of the bottom attaining just a few degrees with phenomena of periodical movement confined to the uppermost mud layers.

An episodical intensification of slope-generated sediment movement may have been responsible for the lenticular accumulations of lithoclasts in the Haraszt sequence which appears to coincide with the formation of the thick breccious rock body (the Jákóhegy Breccia Member) observed in the northern Bakony exposures and also in boreholes at Magyarpolány and Devecser that may be indicative of a revival of tectonic movements.

Let us sum up the facts above: The scene of formation of the Rendek Member was the deeper-situated, rather gently dipping part of the slope that connected the relatively elevated platform zone of the southwest subarea and the deeper-situated northwest basin portion. In the deeper northwest basin portion (the lower member of the Polány Marl showing the most typical features of the formation) sedimentation took place on an externally neritic, limemud-covered sea bottom of 100 to 200 m depth and of a gentle slope. Pelagicity and water depth are supposed to have gradually increased with the progress of time.

Paleomorphological reconstruction

In the light of the facies and thickness conditions of the Upper Cretaceous formations of Sümeg we have attempted at analyzing in more detail the morphological conditions that existed at the beginning of the Senonian sedimentary cycle—an analysis providing the basis for the reconstruction of the geohistorical process.

In outlining the paleomorphological image we may first refer to the charts showing the distribution and extension of the individual formations which were presented in their discussion (Fig. 32, 34, 42 and 48). Comparing these, we can see very well that the younger formations tending to acquire an increasingly more marine facies form regular belts transgressing beyond the older ones. Taken in itself, this very image is apt to suggest that two basical morphological provinces, a deeper, northwest one and a relatively higher-situated, southeast one, may have existed for a very long time—at least from the deposition of the terrestrial sediments up to the formation of the rudist-bearing limestones—in the study area and that the contemporaneous slope that lay between the two provinces is marked

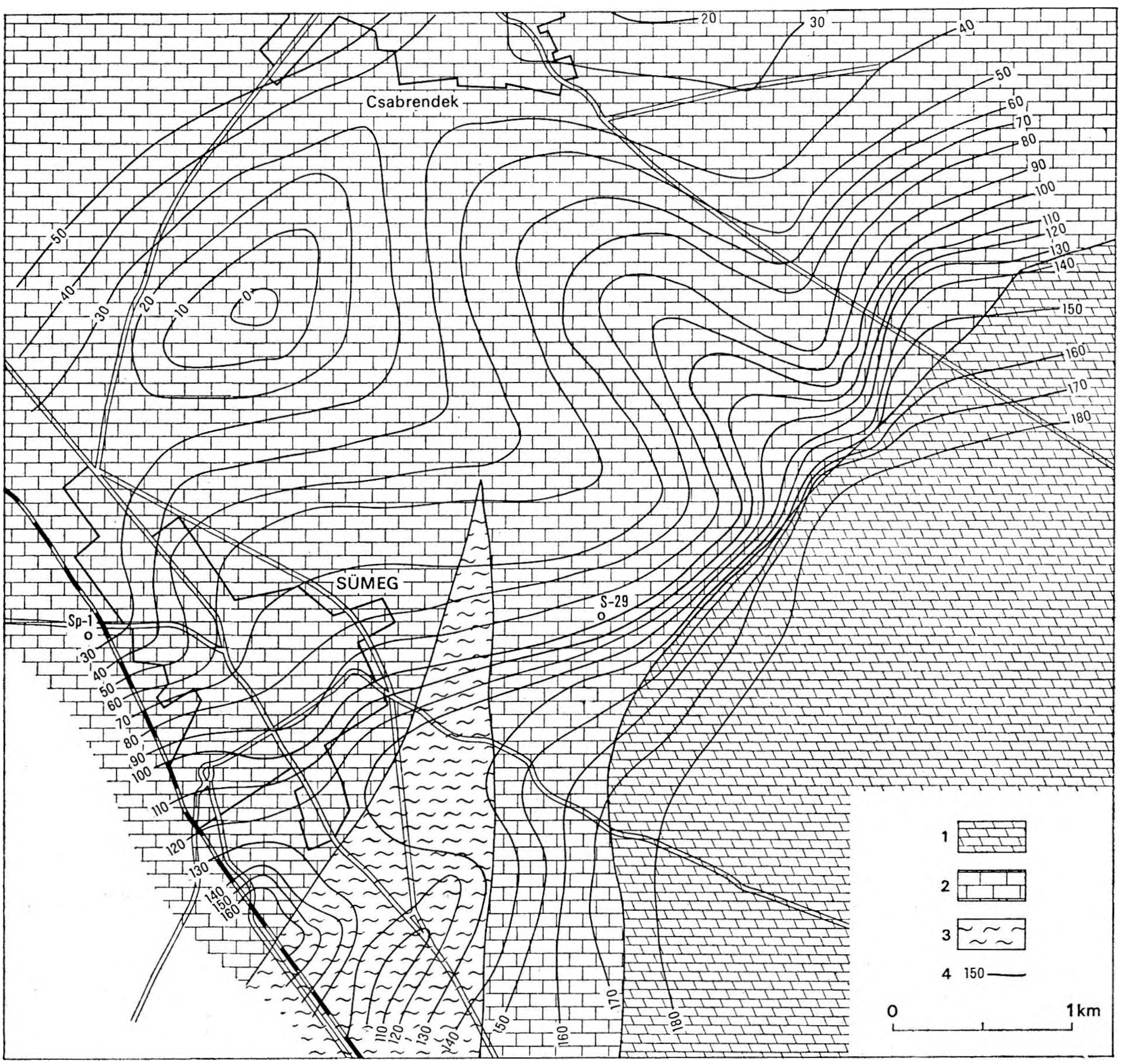


Fig. 60. Paleogeographic and paleomorphologic reconstruction
1. Dolomite, 2. limestone, 3. marl, calcareous marl, 4. supposed contour lines of paleorelief

by parallel, northeast-southwest trending zones of modest width resulting from the overlap of the successive formations.

Such an image is corroborated and new details are shed light upon by the isopach map of the Ajka Formation (Fig. 60) with isopachs distinctly parallel with the marginal boundary line of the formation. As shown in discussing the profiles, the integrate area of distribution of the formation can be divided, on the basis of the characteristics of the sequences, into a northwest and a southeast subarea, the latter being overlapped only by the marine-brackish beds of higher stratigraphic position. The limit of extension of the freshwater (Foraminifera-free) sediments is parallel to the outer boundary of extension of the Ajka and Jákó Formations, too. All in all, the simplest way to illustrate the situation is to design a model according to which an area of mild relief showing a gentle overall rise from the northwest to the southeast becomes gradually inundated, probably in the course of a regional subsidence. If we accept this, then the boundaries of pinching-out of the afore-listed formations and also the facies boundaries (limno-brackish–marine-brackish), and even the isopachs of the Ajka Formation and the Jákó Formation or the Csingervölgy Member, respectively, may be taken to represent almost a kind of contours, for all these indicate, by and large, the one-time line of intersection of water level and relief. The advancing transgression will quasi fathom the one-time relief and preserve it by the protective cover of its sediment. The geomorphological map shown in Fig. 60 is based on this assumption, too. In plotting it, we have started from such basic features as the boundary lines of extension of the formations and the isopachs and facies characteristics of the sediments overlying the substratum. Namely, if a simple subsidence is the case, the difference in altitude between the individual points of the pre-Senonian basement can be assessed. The outer boundary of the Ajka Formation will give the line of intersection of water level and relief at the start of formation of the Csingervölgy Member, and if the estimated water depth for each particular point and the thickness of the Ajka Formation are substracted, the land surface prior to subsidence and accumulation will be restored. When plotting the paleomorphological map, we used, for the case of areas beyond the boundary of the Ajka Formation, the thickness data of the overlapping Csingervölgy Marl.

Naturally, the real picture may have been more or less different, more complicated, compared to our model. For example, it would be easy to imagine that during the long time span of transgression the rates of subsidence varied from subarea to subarea even within this comparatively small area, distorting our model from the reality. Nevertheless, in the light of the observations quoted, we believed that this very simple model would give a good approximation.

On the basis of our model the following geomorphological image for the date of start of Senonian sedimentation may be reconstructed (Fig. 60): the highest-situated part of the area lay to the southeast of the Városi-erdő–Surgo-tag–Kozma-tag line; it was connected by a northwest-southeast trending slope with an almost level, horizontal subarea that was slightly inclined to the northwest. Nearly normal to the NW–SW main direction extended morphological elements of second-order importance such as minor elevations and depressions. The most significant of these may have been a flat ridge of about 50 m relative height which now extends beneath the Rendeki-hegy and which seems to have been comparatively narrow. A ridge of similar orientation, but by far less elevated, is supposed to have existed in that part of the Sümeg area, where the terrestrial deposits are missing (Fig. 32).

To the west of the present-day Hárs-hegy the steepness of the slope separating the principal morphological elements was more reduced and its orientation seems to have turned N–S. The original configuration is difficult to decipher owing to possible subsequent tectonic deformation.

On the geological map (Fig. 3) of the rocks underlying the Senonian, giving a portrayal of pre-Senonian paleogeology, there appears a feature that seems to support our image of the one-time morphology.

Bringing the Norian Hauptdolomit and the Rhaetian formations into contact with each other, the tectonic line extending through the Surgo-tag–Kozma-tag subareas has a position and orientation very well coinciding with the position and strike of the one-time elevation reconstructed. It is obviously no accident either, that the slope of a rough morphology has been formed exactly on the surface of the Rhaetian marl and limestone sequence less resistant to weathering.

In fact, minor faults parallel to this distinct structural line may have been involved in the process responsible for the above paleomorphological image, too. These tectonic lines, however, are difficult to detect in a direct form, because they are not responsible for the juxtaposition of dissimilar lithological types.

On the basis of this model it is expected, and can even be verified by tests, that on the benches of gradually higher position—as one proceeds from the northwest to the southeast—the formations of identical facies (lacustrine, marine) will appear gradually later. Within the individual benches the particular facies may be regarded as geologically isochronous.

The effect of the initial morphology upon Senonian sedimentation and the course of the inundation process are discussed in the chapter "A geohistorical summary".

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