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# SULPHUR-, GYPSUM- AND ALGINITE-BEARING STRATA IN THE ZSÁMBÉK BASIN

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## INTRODUCTION

The Zsámbék Basin is the easternmost member of a series of smaller-larger Tertiary subsidences in the NE part of Transdanubia parallel to the NE-SW range of the Gerecse Mts. The basin is bordered by Triassic, Oligocene and Miocene sediments, and filled by Tertiary sediments. Its deepest point probably lies south of Budajenő *(Fig. 1)*.

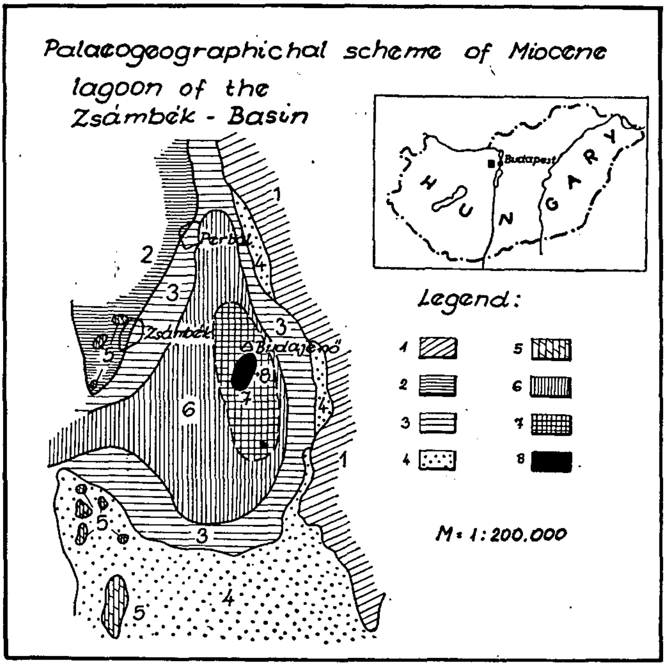



*Fig. 1.* Legend: 1. Area of Mesozoic limestone and dolomite of Buda Mt.; 2. Oligocene rocks; 3. Sarmatian littoral oolitic limestone overlaid by Lower Pannonian rocks; 4. Oolitic limestone overlaid by Pleistocene formation; 5. Triassic dolomite outcrops of Gőböljárás-puszta and Strázsa-hill; 6. Supposed area of the alginite bearing formations; 7. Supposed area of the deep-sitting evaporitic and alginitic formations; 8. Area of the native sulphur and gypsum bearing Miocene formations limited by boreholes No. Bő-2, 3, 4, 5, and 6.

In 1974 a borehole, Bő-2, was drilled near Budajenő to provide data about the structural conditions, hydrology and stratigraphy of the basin. This borehole intersected native sulphur- and gypsum-bearing evaporites, of Miocene age, as well as alginites in the Lower Pannonian [A. JÁMBOR, 1976, 1977, A. JÁMBOR *et al.*, 1976, Cs. RAVASZ, 1978].

In 1977 four more diamond boreholes, 400 m deep each, were drilled around the Bő-2 to collect detailed informations about the reserves and geology of the potential economic raw materials. Two of them (Bő-3, Bő-5) were sited in the supposed NNE-SSW strike of the evaporites in 2 km distance from each other. The other two boreholes were drilled in perpendicular direction, at 1 km distances (Bő-4, Bő-6).

The thorough investigation fo the cores of these five holes, along with the reinterpretation of the previous geological exploraticns [S. JASKÓ, 1943; A. JÁMBOR, 1969, 1971] has given the opportunity to summarize the geological and mineralogical data about these notable mineral indications.

## THE GEOLOGY OF THE BASIN

The basement of the basin is consisted of Upper Ladinian dolomites [J. ORAVECZ, 1976], with 15—20° dip. The Bő-2 has reached this formation at 766.2 m depth, and has not cut through until the 1200.5 m depth bottom of the hole. The dolomite is covered by about 40 m thick dolomite breccia, dolomite-debris (Nagyegyháza Dolomite-breccia) of possibly Eocene age based on lithological analcgy. The younger Paleogene is represented by alternating marine argillaceous and arenaceous sediments of Oligocene age with a dip of 12 to 5° in about 230 m thickness (Mány Formation). Paleontological evidences [T. BÁLDI, M. BÁLDI—BEKE and L. RÁKOSI, 1976] have placed its age in the Upper Oligocene (Egerian), however, its litho-stratigraphic character suggests that it might span through the whole Oligocene period [A. JÁMBOR, L. KORPÁS, 1976].

The Oligocene is unconformably overlain by the lowermost part of the Neogene complex, the Middle Rhyolitic Tuff Member of Lower Badenian age. The unconformity is obvious not only from the different bedding directions (0—5° angular unconformity), but also from the different colouring, oxidation, of the uppermost 40 m of the Oligocene as a result of pre-Miocene terrestrial weathering.

The formation begins with a pebbly argillaceous siltstone. It is unsorted, the pebbles are of different grade of rounding and of different materials like rhyolitic tuff, calcareous concretions, Oligocene siltstone, quartzite. It can be considered as terrestrial stream-sediment. The representativ rock-type of the formation is a light grey-grey vitroclastic plagioclase rhyolitic tuff. It consists of 20 per cent of crystal fragments, andesine, quartz, less K-feldspar and biotite and 80 per cent of altered, devitrified glass-shards and pumice. At its base it is introduced by sandy tuffites, while its top shows a transition towards a calcareous argillaceous tuffite. The scarce fossil content of these volcanogenic sediments (Echinodermata spines, Mollusca fragments) indicate subaquatic deposition. The widely diffeiing coloring of the strata as well as the modular parting of the rocks, however, suggest a dry, oxidizing environment for diagenesis.

The uppermost part of the Lower Badenian is represented by the Zsámbék Member. This is composed of alternating strata of two rock types. The first one is a greyish-yellow to yellow argillaceous silty sand and sandstone. The other variety is a pale green, yellow and grey clayey siltstone. In the series there are several thin pebble-

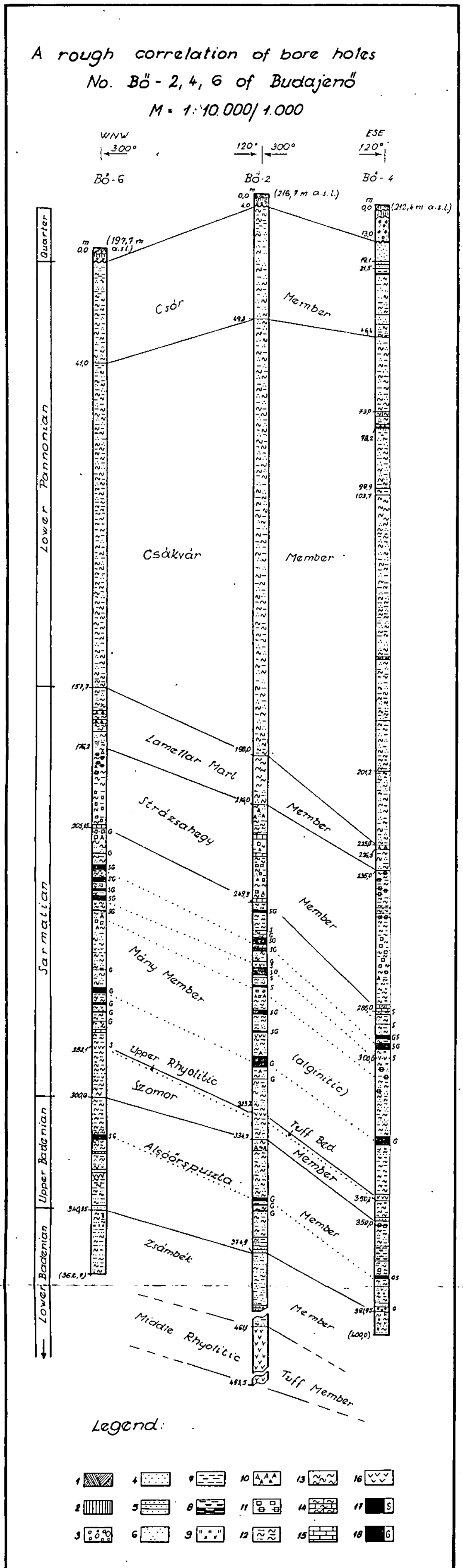



Fig. 2

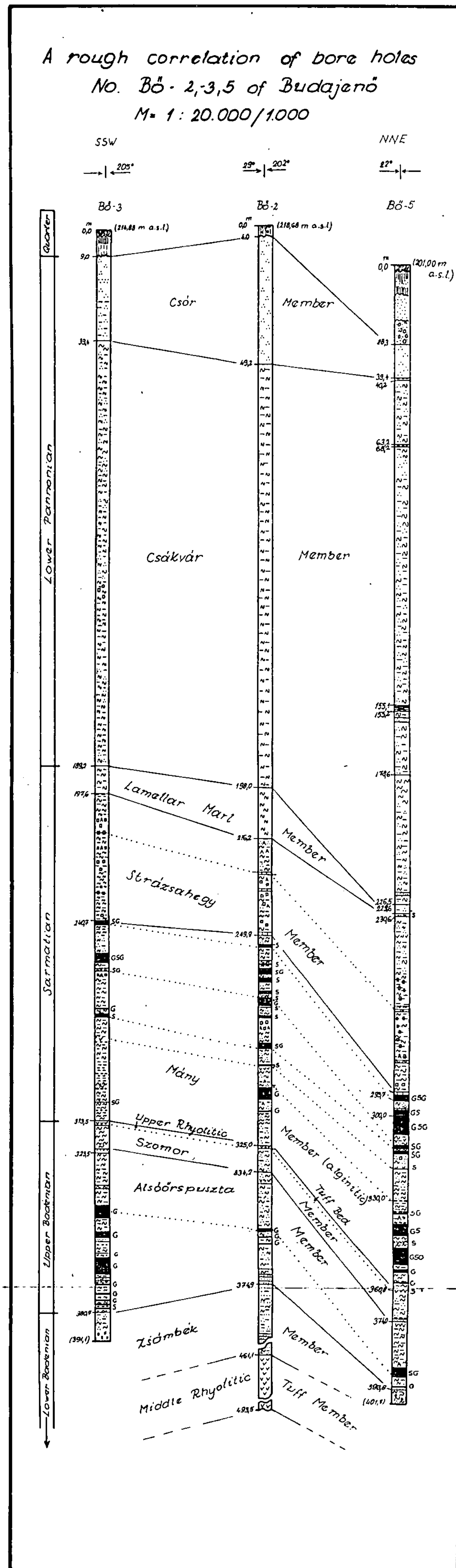



Fig. 3

*Fig. 2.* and *3.* Legend: 1. Soil; 2. Loess; 3. Gravel, pebble and conglomerate; 4. Sand; 5. Sandstone; 6. Silt, siltstone; 7. Clay; 8. Carbonaceous clay; 9. Variegated clay; 10. Alginite; 11. Diatomite, diatomaceous shale; 12. Clayey marl; 13. Marl; 14. Argillaceous limestone; 15. Limestone; 16. Tuff (acidic), tuffite; 17. Native sulphur (layer, seam etc.); 18. Gypsum (bed, layer etc.).

rich intercalations and beds rich in fossilized carbonaceous plant-fragments. Variegated clay has been developed on the top of the formation. Bő-2 has intersected the uppermost horizons of the Middle Rhyolitic Tuff at 409.0 m depth *(Figs 2* and *3)*. Due to lack of molluscs; paleontological investigations have been restricted to Foraminifera. The genera *Rotalia, Borelis* and *Peneroplis,* and *Rotalia, Elphidium, Gyroidina, Spiroplectammina* and *Eponides* were identified from the Bő-2 and Bő-3 holes, respectively. These fossils indicate a shallow-marine, hyperhaline envircnment of deposition [I. KORECZ-LAKY, 1978]. On the whole the basin can be considered a near-shore belt, with repeated uplifting on its edges, associated by short-duration terrestrial stream sedimentation which resulted in the accumulation of coarse grained detritus.

The Alsóörspuszta Member represents the Uper Badenian. Clay with sand and silt forms the base in the central parts, which gradually gives place to clayey-sandy siltstone. In the other parts a more abrupt facies change is recorded with argillaceous conglomerate, pebbly sandstone, and pebbly clay-marl. Upwards these are overlain by light grey, finely laminated, rather homogeneous clay-marl. The monotony of these strata, however, is interrupted by occasional intraformation brecciation, slumping, and intercalations of beds enriched in carbonaceous plant fragments, or tuffites and lumachelles.

It was the Alsóörspuszta Member, where the environmental conditions necessary for the formation of evaporites, like gypsum and native sulphur, became predominant. The number of gypsum- or sulphur-rich intersections in the boreholes varies between 17 and 2. The structure of these deposits is also variable, from the randomly disseminated "porphyric" form to chaotic folded laminae. Native sulphur frequently forms fine-grained crystal aggregates, or the crystals are evenly disseminated, always in a gypsum matrix. Dolomite, dolomitic marl, maıl and calcareous marl are found interbedded with the evaporites.

The types, number of species and individuals of Foraminifera and molluscs have clearly indicated both the Upper Badenian age, and the evolutionary facies changes, of the Member. Sedimentation took place in waters of normal salinity along the shorelines of a lagoon. The decrease of the amount of fauna and its disappearance are bi-directional and due mainly to two factors: shallowing, which is indicated by the presence of *Pirenella* and *Hydrobia* and enrichment of carbonaceous fossilized plant fragments, and the increasing degree of salinity, evidenced by evaporation. A continuity of sedimentation, though abrupt changes in lithology, called the Szomor Member, marks the beginning of the Sarmatian stage. The rocks are light grey poorly bedded, occasionally laminated brittle marls, less clay-marls, calcareous marls. This horizon is easily traceable in every borehole. A rather thin (0.2—1.0 m) intercalation of crystalloclastic glassy rhyolitic tuff with low sulphur content is found in the upper levels of the Member. Radiometric age determination was made in a sample from Bö-3 (313.8—314.0 m), with a result of $13.2 \pm 1$ m. y. This age corresponds to the Lower Sarmatian "upper rhyolitic tuff" horizon according both to the recommendations of the RCMNS Congress [1975] and the Paratethys standard proposed by BAGDASARIAN, VASS and SLAVIK [1975]. It is also well fit into the local stratigraphic pattern.

According to the rich Foraminifera fauna, and the bivalves, which are represented by few genera, but in high amounts *(Cardium transcarpaticum* GRISK., *Abra reflexa* [EICHW.]*)*, and a number of external moulds of gastropods, the sediments belong to the Kozárdi substage. The depositional environment was still the same, not agitated, lagoonal. Beds essentially free of marine fauna, i. e. of molluscs, indicate hyper-salinity during sedimentation.

The Mány Member (with alginites and evaporites) is predominant one in the Sarmatian stage. This gives the bulk of the sulphur and gypsun mineralization in the area. The Member is slightly thickening towards the centre of the Budajenő Basin. The individual evaporite strata have greater thickness, the rocks have lower Ca-content in this Member than either in the underlying or the overlying ones. It is also characterized by the predominance of silty clay-marls. The proportion of pelites — especially in the higher parts of the Member — is also increased by the high amount of oil-shales and diatomites.

20—30 native sulphur and gypsum deposites have been recorded in the Member, which can be arranged in three groups. The lowermost one has developed in the lower first quarter of the Member, and seems to thin out SE-wards. It consists mainly of gypsum.

The middle group contains the highest enrichments of native sulphur in the basin. This occupies the lower (No. Bő-2) or the upper middle parts of the Member.

A small number of gypsum- and sulphur-rich strata comprise the upper group, near the top of the formation. The individual beds are generally discontinuous, but the groups can well be correlated by the help of characteristic intercalations (like rhyolitic tuffite, carbonaceous clay). Concerning the evaporites, the native sulphur forms either separate beds or occurs in disseminated, patchy form, thin laminae. The bulk of gypsum is finely crystalline, laminar, but at the beginning of the evaporation it tended to be arranged in "porphyric" disseminations. The decrease in the amount of gangue minerals is coupled with a decrease in grain-size and crystallinity of evaporite minerals.

Mineralogical analysis of evaporites revealed the existence of celestite and trace amounts of barite in several samples.

Laminated limestone, dolomite, dolmitic marl and calcareous marl are the most frequent barren intercalations. Clay, clay-marl and clay-marl with felsic volcanogenic material are also present in lesser amounts. In general the Member is characterized by a low carbonate content. This is in apparent contradiction with the frequency of barren limestone-dolomite intercalations in the evaporites. The contradiction can probably be solved by assuming the epigenetic alteration of evaporites to produce carbonates.

Based on the mollusc fauna, the lower one-third of the Member belongs to the Kozárd substage, while the upper two-thirds occupies the lower *Cardium latisulcum* zone of the Tinnye substage.

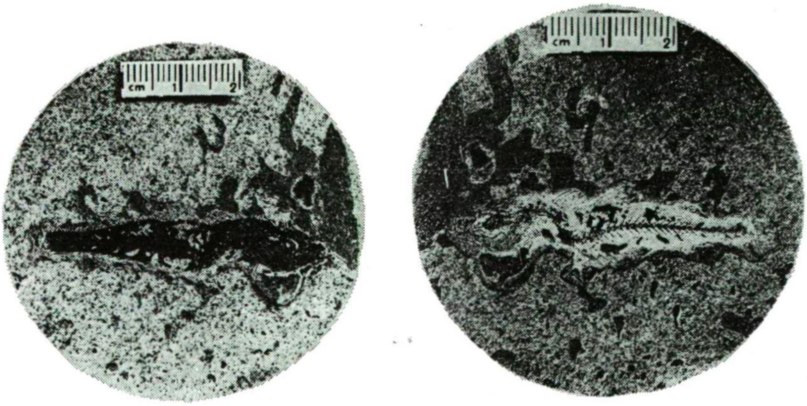
Sedimentation began in a shallow water not agitated marine environment. The landlocking of the lagoon, the shallowing associated with it and, as a consequence, the interruption of evaporation are marked by the development of *Hydrobia*-containing lumachelles and carbonaceous clay beds. Following these processes, the lagoon gradually subsided, as proved by the reappearance of rich fauna, Diatomas, Foraminiferas. Finally, the increasing rate of evaporation and salinity as well as contemporaneous precipitation of evaporites resulted in the development of unfavourable conditions for marine life. Thus rocks, almost free of fauna were formed.

The youngest Miocene sequence in the area is the Strázsahegy Member. This was continuously formed on the overlying rocks, sepaiated from those only by a 0.5 m thick marl-bed. Slump structures, allotigenic brecciation and the lack of evaporite minerals are the main characteristics fo this intercalation. The main lithology of the series is a clay-marl, which frequently contains alginitic clay marl and diatomites (diatomite-earth, microbedded diatomite, laminated diatomite, *Fig. 4*). The rocks are predominantly pelitic, with varying Ca-content.

Compared to the Mány Member (alginites and evaporites) these strata are characterized by more abundant diatom flora and a mollusc fauna, but a poorer foraminiferal assemblage. Among the frequent bivalvae remnants *Cardium vindobonense* Partsch is predominant indicating the upper level of the Tinnye substage as well

*Fig. 4.* Microlaminated oil shale built up of alternating diatomite and alginite lamellae. — Borehole No. Bő-5, 252 m.

as the completeness of Sarmation stratigraphy. The boundary with Pannonian has been drawn on a paleontological basis with a view to the decrease in size of *C. vindobonense* individuals, the flattening of its ribs, the extincticn of most other Sarmatian species, and the appearance of larger ostracods and sparsely fish remnants *(Fig. 5)*.



a b

*Fig. 5.* Positive (a) and negative (b) print of Gadus sp. (?) in Sarmatian oil shale. — Borehole No. Bő-5, 252 m.

The Strázsahegy Member shows a gradual transition towards the Laminated Marl Member of the Lower Pannonian Formation. These latter differ from the Miocene lithologies mainly by their well-formed laminated structure. Lamination is due to alternation of laminae with different materials and colours in 2—20 mm thicknesses. The different stain is reflected by different tones of grey, material differences are manifested in the variation of the silt and $CaCO_3$ content. The rocks of this formation show a quite uniform grain-size distribution, no arenaceous members have been encountered in this series. The argillaceous fraction makes 47.0 to 48.9 per cent ot weight, which largely differs from that of Strázsahegy Member (max. 29.7% weighf per cent) and of Csákvár Member (36.0%).

In the Laminated Marl Member alginitic clay-marl intercalations were recorded in the Budajenő Bő-4 and Bő-6 holes. This proves the transition of alginites to the Lower Pannonian. The oil-shale, which was found in 10—20 cm thicknesses, exhibits interlamination of light-green and greyish green diatomite and alginite in 0.1 mm laminae. Cleavage is well-developed along bedding. Characteristic "oil-shale" odour is felt on the fresh cores immediately after their being pulled out of the hole.

Upwards in the sequence the alginites gradually disappear. A possible explanation of this phenomenon could be the intense subsidence of the basin and its environment during this period.

Although deposition continued on the Sarmatian-Pannonian boundary, it is marked by the decrease of relief energy of the neighbouring terrestrial areas as well as the diminution of salinity of the depositional media. This fact brought about an abrupt change in fauna, however, the Pannonian still contains several intercalations with a marine fauna.

In the lower horizons of the Lower Pannonian Formation the *Limnocardium praeponticum* and the *Planorbis praeponticus* Horizons have been recognized. Except for undeterminable fragments no Congeria has been found.

The mollusc fauna is represented by only a few species. The fossils are brownish-yellow coloured, well-preserved, lying always conformably with the depositional bedding. Complete individuals or shell-pairs are very rare.

Their biostratigraphical separation from the Sarmatian is indicated by the extinction of *Cardium vindobonense, Irus gregarius, Acteocina lajonkairena.*

The rich Sarmatian foraminiferal assemblage gradually disappears at the top of the Sarmatian, though 5 m above the boundary a *Milliammina sp.* was found, which otherwise was limited to the Sarmatian. Like in Tököl-1 and Tp-63 at Perbál the extension of Foraminiferas beyond the boundary of the Sarmatian and Lower Pannonian was suggested by I. Korecz-Laky.

Ostracods are locally abundant in several strata of the Laminated Marl Member, as double or single shells, parallel with bedding. They mostly belong to the form-species *Pectinaria Ostracopannonicus* Jámbor—Radócz.

The microfloral assemblage also allows to trace the Sarmatian-Pannonian boundary. All Sarmatian species disappear at this boundary, and three other species appear: *Colonias placentula* Ehr. var. *enghyptia* (Ehr.) Cl. *Melisina praeislandica* Jousé, and *Chrisostomum sphaericum* Hajós.

In the diatom assemblage of the alginitic clay marls (oil-shales) the *Penneatae* forms are predominant. These mostly epiphytic species often comprise continuous colonies. The diatoms existed and were subsequently deposited in such shallow lakes (up to several meters deep) which were substantially lower in salinity than the Sarmatian sea.

Local enrichment of fossilized plant fragments of 2—10 mm width and 1—8 cm length, partly replaced by spherical bacterio-pyrite are abundant in the rocks of this formation, so are the Y-shaped fossil traces.

The thin rhyolitic tuff intercalations characteristic as they are of the Lower Pannonian Formation elsewhere [A. Jámbor, M. Korpás-Hódi, 1971] could not be identified in the Budajenő drill-holes in spite of careful logging.

Slow, continuous subsidence caused an increase of water-depth, and diminished the effects of swelling. Dessication cracks, which are quite abundant elsewhere in the series, are absent here. The whole sequence becomes more monotonous. Further dilution of water is probably due to the higher humidity of climate.

Middle part of the Lower Pannonian of the Zsámbék Basin is the Csákvár Member. This shows a more marked monotony and greater thickness than either the underlying Laminated Marl or the overlying Csór Member. Its lithology differs from the adjacent older formation by the lack of laminated clay-marls and marls. The results of geophysical logging of the drill-holes is in good accordance with this fact. Its thickness considerably varies throughout the basin, due to the uneven subsidence of the latter.

The gradual changes of lime-content and stain allows only poor subdivision of the monotonous, pale-grey to greyish-green coloured pelitic, mostly clayey-siltstone sedimentary sequence. Besides this main lithology, clay, carbonaceous clay, diatomaceous clay-marls, limestones, and bentonites also occur occasionally.

Upwards in the formation the ratio of the silt fraction increases from 30 to 60—70 per cent at the expense of the argillaceous fraction. At the top of the sequence the finer-grained fraction is increasing marking a gradual transition towards the Csór Beds. The carbonate content of the rocks drops to 20—30%, with the appearance of dolomite. A peculiar rock type of the Member is a silty clay, of dark-grey or greenish-grey colour, intense lamination, low lime content, and pelitic huminite stain. According its fossil content, it represents the typical facies of the Pannonian inland sea, though its huminite content indicates greater depth of deposition.

The trace element enrichment of the Pannonian sediments is only one half of the respective Miocene average values. This is probably due to the initial low trace element content of the terrestrial source areas, or the lack of that enrichment process, which is usually linked with the evaporation of sea-water [Á. Jámbor, 1976].

Constant variation of water depth and salinity (0,5—1,0%) can be suggested for the Lower Pannonian Formation according to the analyses of its rich diatom flora. The species-poor assemblage shows the predominance of mesohaline-oligohaline species. Marine forms, if any, are considered to be allochtonous.

Considering Mollusca, it is the disappearance of *Limnocardium praeponticum* and the introduction and gradually larger abundance of *Didacna subdeserta, Limnocardium triangulocostatum, Monodacna viennensis, Orygoceras* that marks the Csákvár Member.

The *Melanopsis* gain their virulence at the base of the upper part of the Csákvár Member, and so the *Paradacna,* which may also become locally abundant. Besides the Paradacna, the larger forms of *Limnocardium, Congeria partschi* and *Pisidium sp*. are also common fossils. The accessorial species of this bio-stratigraphical horizon are *Limnocardium huminicostatum, L. conjugens, L. schedelianum, Monodacna viennensis.* The top of this formation is marked by *Parvidacna laevicostata, Pontalmyra tinnyeana, Limnocardium carnuntium, L. schedelianum, L. winkleri* and *Congeria czjzeki* assemblage delineates the *Congeria banatica* Horizon of the Lower Pannonian Formation.

It is worth to notice that while the whole series is lithologically unseparable, the mollusc fauna allows a subdivision of the series into four identifiable horizons, separated by fossil-free sections.

The youngest member of the Lower Pannonian is the Csór Member. In spite of its great thickness the series is uncomplete. The erosion at the begginning of the Pleistocene has removed a part of these beds and all the overlying later Pannonian strata.

The NE part of the basin was affected most intensely by this erosion.

In lithology the lower boundary of this formation is drawn with a marked increase of the silt and fine-sand fraction. The lithology is broadly similar to that of Csákvár Member, except for this change in grain-size distribution. The most abundant rock type is a clayey, marly siltstone. The carbonate content is again decreasing by 50 per cent compared to the former formation.

Pectinaria tubes are common and abundant in siltstones [A. JÁMBOR, M. KORPÁS-HÓDI, 1971].

In the Csór Member the *Congeria sp. dff. czjzeki* Horizon contains remnants of *Congeria czjzeki*, a non-typical variety of *C. czjzeki*, in great numbers. *Micromelania sp., Planorbis cf. tenuistriatus, P. cf. okrugici, Monodacna cf. viennensis, Pisidium krembergi, Limnocardium rogenhoferi, L. cf. secans, L. cf. off. triangulocostatum, L. hoffmani, L. cf. winkleri, L. riegeli* are also characteristic species.

A pebble bed has deposited unconformably on the eroded surface of the Lower Pannonian Formation rocks. It consists of poorly sorted, weakly rounded pebbles with 0.2—5.0 cm size, of Triassic dolomite, limestone, less quartzite and lydite. This is overlain by sandy silts, silty clays and Würmian loess under the Holocene soil cover.

Looking at the Miocene paleogeography of the area, a gradual infilling of a periodically isolated lagoon can be assumed as environment of deposition. A barrier on the SW side of this lagoon controlled the rate of water inflow. According to dynamic balance between the rate of inflow and evaporation, the shore zone seems to have shallowed the basin, to have split up into several subbasins or even to have reached the stage necessary for the development of evaporites. The oscillation of the water level was probably due to an alternating local uplifting and subsidence of the bottom as well as larger, regional processes like transgression and regression. The shifting of the shore-line — especially in the Sarmatian — is well shown not only by lithology (carbonate-content, grain-size variation) but in the change of the faunal and floral assemblage, like appearance, alteration and mass-extinction of different species. The extreme increase of salinity is demonstrated by the precipitation and accumulation of evaporites: calcite, dolomite, gypsum, native sulphur, barite, celestite.

The age determination of the sequence could be satisfactorily carried out both by lithostratigraphy and biostratigraphy. The difference between the two methods is in most places negligible, and even where it is larger, like in the case of the Sarmatian-Pannonian boundary, it is unessential for exploration.

Taking the lithology into consideration, the formation of gypsum already began sporadically in the Lower Badenian Middle Rhyolitic Tuff and continued through the Zsámbék Member. Its first appearance in individual beds occurs in the Upper Badenian Alsóörspuszta Member, in association with the first alginites and native sulphur bed. Above the Upper Rhyolitic Tuff, in the Sarmatian native sulphur and gypsum with alginites were formed, thus the Mány Member represents the most favourable paleogeographic and geological conditions for the formation of evaporites.

Most of the gypsum deposits and associated minerals are considered to be of sedimentary origin. The bulk of native sulphur was formed epigenetically after gypsum, the proportion of syngenetic precipitations is subordinate.

Several test results and analyses give evidences for the process of reduction of sulphates as well as the existence of hydrocarbons. There is also evidence for the subsequent oxidation process of the sulphur deposits: secondary formation of gypsum and carbonatization. The results of petrological investigations, the geology and geochemistry of evaporites and alginites have already been published previously [A. JÁMBOR, G. SOLTI, 1975; CS. RAVASZ, 1976, 1978], so are not discussed here in detail.

If the age of the sulphur- and gypsum deposits of the Zsámbék Basin and those of the Carpathian Foreland are correlated by biostratigraphy, the Zsámbék Member and the Middle Rhyolitic Tuff correspond with the Moravian, the Alsóörspuszta Member with the Wielician, the upper one with the Cosovian, respectively. The Sarmatian deposits comprise a special type, as no similar deposits of similar age have been found in the Carpathian area. As a consequence, it can be said that the other, less-explored intramontane basins in the Transdanubian Central Mountains are promising for sulphur, gypsum and alginite explorations.

Sedimentation was not interrupted on the Sarmatian-Pannonian boundary, though there was marked decrease of the environmental relief energy and of the salinity of sea-water. As a consequence of this latter effect, the faunal assemblage showed a quite abrupt change, however, marine element still persist locally. By the help of its relatively rich Mollusca fauna, the clay-marl, marl, sandy silstone sequence of the Lower Pannonian Formation can well be subdivided into distinct stages. The Marl Member corresponds with the *Limnocardium praeponticum* Horizon. The Csákvár Member consists of four biostratigraphical horizons — as it was previously discussed. Its lower part is characterized by *Monodacna viennensis* and *Orygoceras* species. The upper part consists of three different horizons with the predominance of *Melanopsis, Limnocardium* and *Pervidacna.*

As one proceeds upwards in the sequence, the Ca-content decreases. The reduction of $CaCO_3$ content is coupled with a slight dolomitization. According to the microfloral assemblage no geographical or ecological change of considerable value could take place during the Lower Pannonian sedimentation. Shallow water, gradual subsidence of the basin and constant oscillation of water-level seem to be characteristic features of these sediments, coupled with a decrease of salinity. The freshening of the water indicates a more humid climate, together with the huminitic clays, which are indicative of nearby swampy areas. The monotonity of the Lower Pannonian sedimentation indicates the low relief values the environment must have had and a pelitic transport by lake-currents from NE towards SW.

The Upper Pannonian, which has been preserved in other places, like in the Buda Mts., might also reach considerable thickness in this area, but along with the upper part of the Lower Pannonian, it has been eroded away in the early Pleistocene. This deflation, and/or erosion might have been a very significant process, as the pebble beds deposited on Lower Pannonian surface.

100—200 m of the sequence was removed and the base level further dropped by 35—25 m: an anomalously high value for Transdanubian Central Mts. With these facts in mind a conclusion arises that following the Early Styrian movements an intense uplift must have taken place.

## Evaporites

In the Budajenő area these deposits are of sedimentary stratified type. With strike parallel with the N-S trending longer axis of the basin they dip to ENE at 2—5° angle.

The pattern becomes more complex in the case of identification of individual evaporite strata. The number of these varies between 47 and 24 in the drill-holes. Several horizons tend to diversify or be merging, or pinch out in the area. This brings about large variations in thickness, structure and composition even of the otherwise correlable deposits.

The immediate footwall and hanging wall of the evaporites, as well as the intercalations, except for tuffs, are high-carbonate, low-porosity rocks, marl, calcareous marl, limestone and dolomite. These are essentially primary evaporites or secondary alteration products with the oxidation of sulphur. The host rock in a general sense is a silty clay-marl, which is the most abundant rock type of the basin.

The precipitation of evaporites decreased or even ceased with decreasing water depth as indicated by the appearance of sandy clays with carbonaceous plant fossils, tuffites and diatoms, alginites. This proves that an increase of grain-size due to the shifting of shore-line and the decrease of pH and Eh created unfavourable environmental conditions for the formation of evaporites. On the other hand, the accumulation of organic materials was a necessary factor for the process of reduction of sulphates. The deposits themselves and pelitic rocks of the immediate footwall and hanging wall have in fact a relatively high bitumoid-content *(Fig. 11)*. Deeper in the underlying sequence the high organic content is due to the enrichment of carbonaceous plant fossil fragments in the clays and siltstones. These observations are in accordance with the analysis of cores of the Bő-2, 3, and 4 boreholes by the Fischer-extraction method for alginites, by the tar and bitumoid determination of chloroformic and fluorescent bitumoid solutions or $C_{org}$-analysis of other rock types, which have given reliable quantitative results.

Concerning the most indicative component, the organic C-content, the following results have been obtained:

| | |
|---|---|
| alginites | 3.5 —7.6 wt% |
| diatoms | 2.0 —3.3 wt% |
| carbonaceous clay and clay-marl | 1.7 —2.4 wt% |
| gypsum-containing marl | 0.25—0.45 wt% |
| sulphur and gypsum-containing marl | 1.8 —3.8 wt% |

The pH seems to be the major controlling factor for the precipitation of gypsum, while for sulphur the Eh values were more important. Thus gypsum still contains carbonaceous clay, but in tuff hosts only sulphur occurs. This indicates a sublittoral lagoonal facies of high salinity (20%), high pH (8—9) and Eh (between 0.0 and +0,01) values for the formation of gypsum. The native sulphur precipitated from poorly aerated waters of lower pH and Eh near to the bottom of the basin.

Structural deformation is well-developed in several parts of the deposit groups, mostly on their middle and top levels. This is exhibited in the intense fracturing and shearing of the originally flat and subparallel gypsum and sulphur beds as well as the development of chaotic folding *(Figs 6, 7)* subsequent fracturing and displacement of strata, and the formation of convolute structures *(Figs 8, 9)*.

These structures have resulted from primary diagenetic processes, like subaquatic slumping in a still plastic state, and the contractive stresses affecting the subconsolidated incompetent gypsum rocks. Anhydrite-gypsum alteration is excluded from the causes of deformation foι mineralogical reasons.

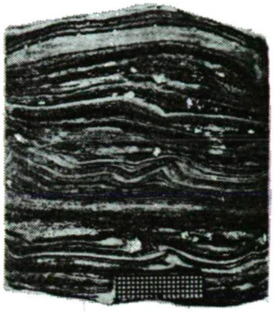


Fig. 6

Fig. 7

*Fig. 6.* Folded gypsum (grey, black) and dolomitic marl lamella-fascicles (white, light grey), and native sulphur (white lentils, spots). — Borehole No. Bő-3, 255.0—255.2 m.

*Fig. 7.* Flow folding of lamellar gypsum. Contorted, fragmented gypsum laminae (white, dirty white), and intercalating argillaceous marl (grey). — Bore hole No. Bő-3, 354.8—352.9 m.

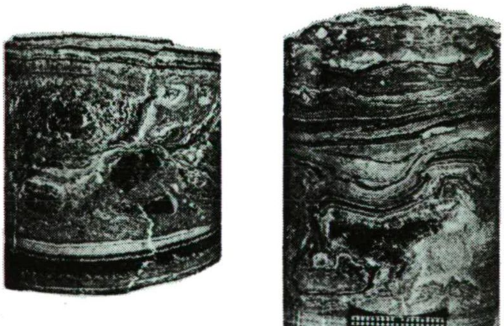


*Fig. 8.* Composite bedding and micro-faulting. Paralell-lamellar and convolute structure of a gypsum seam. Gypsum (black), argillaceous marl (middle- and light grey), and magnesian limestone (white). — Borehole No. Bő-4, 378.6—378.8 m.

The two main economic minerals, native sulphur and gypsum, may occur separately or form assemblages. The pure sulphur deposits are generally thinner than the gypsum deposits. The average thickness of the deposits is 0.5 m, their sulphur content is 12.5 wt%, the gypsum content is about 30 wt%. The sulphur-rich deposits have 30—38 wt% S content, while the gypsum deposits contain 75—83% of the economic mineral. The thickest known deposit is 3.3 m.

Preliminary results of the mineralogical-petrological analysis of evaporites in the Bő-2 intersections have already been published [Ravasz, 1978]. The mineralogy of the evaporites from other holcs, Bő-3, 4, 5 and 6 are in correspondence with these previous data. Therefore only generalized conclusions are given here in detail, complemented with a few interesting data.

Evaporites are more or less well-crystallized. Native sulphur is usually fine-grained, subhedral. Gypsum exhibits variable crystallinity from fine-grained to porphyric (up to 2.5 cm). The largest crystals of sulphur are found in sulphur-rich strata. Euhedral porphyric gypsum has developed usually in a large amount of barren matrix.

Sulphur occurs in thin laminae or beds, associated with gypsum and carbonates, and forms nodules or patches several mm in size *(Fig. 10)*. Crystal aggıegates of sulphur have occasionally precipitated in clays and rhyolitic tuffs.

Fig. 9

Fig. 10

*Fig. 9.* Bent-lamellar and flat-lenticular gypsum lamellae and layers (black, dark grey) with marl intercalations. — Borehole No. Bő-4, 379.3—379.5 m.

*Fig. 10.* Native sulphur and gypsum seams of different crystallinity and bedding. Native sulphur layer and lamellae (at the bottom and the middle of the uppermost member of the core), lenses, spots (tiny, white area in the same part). Porphyric gypsum crsytals (at the top and the lower thirds part of the core), gypsum layers and lenses composed of middle- and fine grained crystals and interbedded argillaceous marl. — Borehole No. Bő-3, 252.0—252.4 m.

Both the habits of crystals and their combination, and their accumulation-types show greater variation in the case of gypsum than in that of sulphur. Several drill-holes have intersected — within the evaporite complexes — thin beds of fibrous gypsum and hemihydrate (identified by XRD). The matrix of the Upper Badenian basal conglomerate in the Bő-4 is a gypsum-bearing sandstone. Here the gypsum is fibrous, mostly altered to hemihydrate, porphyric grains are rare.

Accessory minerals are celestite, barite, thenardite, and the "gangue" minerals: nalcite, dolomite, aragonite, ankerite, rodochrosite, pyrite and other opaque micerals.

Celestite and barite, usually embedded in gypsum, form small patches, semi-continuous stringers, less frequently disseminations of separate crystals. From the 85 samples analysed so far (Bő-2, 3, 4, 6 holes) fifteen samples contain celestite in higher amounts (up to 17%), 31 samples have an average celestite content characteristic of evaporites, and 39 samples have celestite in amounts less than the average. 23 samples contained some barite up to the evaporite average, while 62 samples had a barite content equal to more than the sedimentary average (max. 0.75%).

Siderite, ankerite, rhodochrosite have been identified from the Upper Badenian sequence of Bő-3 and the Sarmatian from the Bő-4 boreholes. These minerals are of only genetic importance. So does the thenardite, which appears to be formed on the core surfaces after several weeks of exposure. Though this is clearly secondary, it may give information about the salinity of the original media of sedimentation.

### Oil-shales

Oil-shales were discovered at Pula (Balaton Highlands) and Gérce (Vas county) in 1973 [Á. Jámbor, G. Solti, 1975]. The careful investigations of their genetics have opened up ways for the perspectives of oil-shale explorations in Hungary. Two alternatives have been provided for us to determine the future exploration targets. The first was the prospecting and exploration of maar-like tuff-rings like those of Pula and Gérce. The other one was to find sediments which have developed in the same facies as oil-shales discovered. Certain specific paleogeographical and sedimentological conditions are known to be indicative of the formation of oil-shales, as shown by several examples, like Green River (USA), Estonia etc. The proportion of these factors, their predominant or exclusive appearance controls whether a pelite may be altered to oil-shale or not.

Field evidences have been obtained for the important controlling nature of the association of volcanic tuff material, which independently of its acidity (silica-content), provided a suitable environment, biotop, for the growth of oil-producing algae.

The shallow depth of the basin, as well as the lack of detritus coarser than silt-grade are other charcateristic features. Lamination is mainly due to the seasonal changes (precipitation, temperature) causing rhythmic sedimentation. The greenish colours and low density of alginites can be attributed to the high organic content. Finally, the so-called oil-shale odour, is a unique feature of these rocks in a freshly exposed, still wet state. According to our investigations only the slightly diagenised Neogene or younger alginites may have represent an economic potential for oil-shale explorations in Hungary. This consideration has drawn our attention to the Neogene basins in the forelands of the Transdanubian Central Mountains. The first of these occurrences was discovered in the Öcs — Kapolcs Basin, and therefore it is being referred to as Kapolcs-type. The alginites of the Zsámbék Basin are of similar type. Based on these two occurrences, paleogeographic and lithological features were analyzed in detail for determining the future perspectives of oil-shale explorations in Transdanubia [Cs. RAVASZ, 1977].

The existence of alginites in the sequence of the Zsámbék Basin has been convincingly proven by exploratory drilling.

The lack of enclosement and the varying subsidence of the basement brought about variations in the relief-energy and water depth during the Badenian. These factors prevented a continuous undisturbed sedimentation.

Close to the Sarmatian-Badenian boundary, the Parathetys Basin was isolated, the water of the newly formed inner sea was gradually diluted, and changes in sedimentation took place. The early members of the Sarmatian were still affected by synorogenic movements. This period was followed by a relatively undisturbed sedimentation during the middle and upper stages of the Sarmatian in what is now the Zsámbék basin.

Sedimentation is characterized not only by evaporites but the abundance of diatoms and algae as well. At the time of the sedimentation of the Mány Member and the Strázsahegy Member the Zsámbék Basin had limited communications in SW direction only with the Mány basin. This environment has created suitable conditions for the specific sedimentation, with the accumulation of evaporites, planktonogenic, organic-rich pelites. The products of the distant felsic volcanic activity have reached the basin and provided favourable conditions for the rapid growth of planktonic organisms.

In dry seasons dead planktonic organisms fell onto the dull bottom of the basin, accumulating under anaerobic condition. Subsequent wet seasons brought about the formation of organic-poor pelites in thin beds.

The landlocked lagoon was recharged with water from the south-west, where a morphological barrier may also have existed, preventing the more saline dull bottom waters to recycle into the open sea.

It should be noted that two rock types may contain alginites. These are the clay-marl-siltstones and the aleuritic clay-marls. Both are exclusively laminated or finaly bedded, grey of greenish-grey coloured. This intimate bedding is reflecting the alternations in the proportion of clay to silt grain size fractions, and also in the alginite and lime content, producing 1 to 100 mm thick individual beds.

The laminated sediments are nearly always free of macrofossils, and greyish-green coloured. The poorly bedded types generally enclose a rich mollusc fauna, and show light-grey or grey colours. The alginites are preferentially abundant in the first type.

The disappearance of mollusc fossils is in connection with the formation of highly organic — therefore oil-shale like — sediments.

Alginites are common throughout the Zsámbék Basin. This has been proven not only by the five Budajenő drillholes, but the geological log of the water-exploratory well drilled in 1975 between Zsámbék and Bő-2, too *(Fig. 1)*.

It can be established that while the most favourable conditions for oil-shale sedimentation existed in the Mány and Strázsahegy Members during the Sarmatian, the richly algal rock-types in the lower part of the Lower Pannonian Formation, in the Laminated Marls indicate only a less favourable environment.

Detailed investigations were carried out on the alginitic clay-marl samples of Bő-2 borehole to determine the qualitative features and nature of oil-shales.

# Fischer-analysis data of Sarmatian boundary of the bore hole No. Bő-2 (Budajenő)

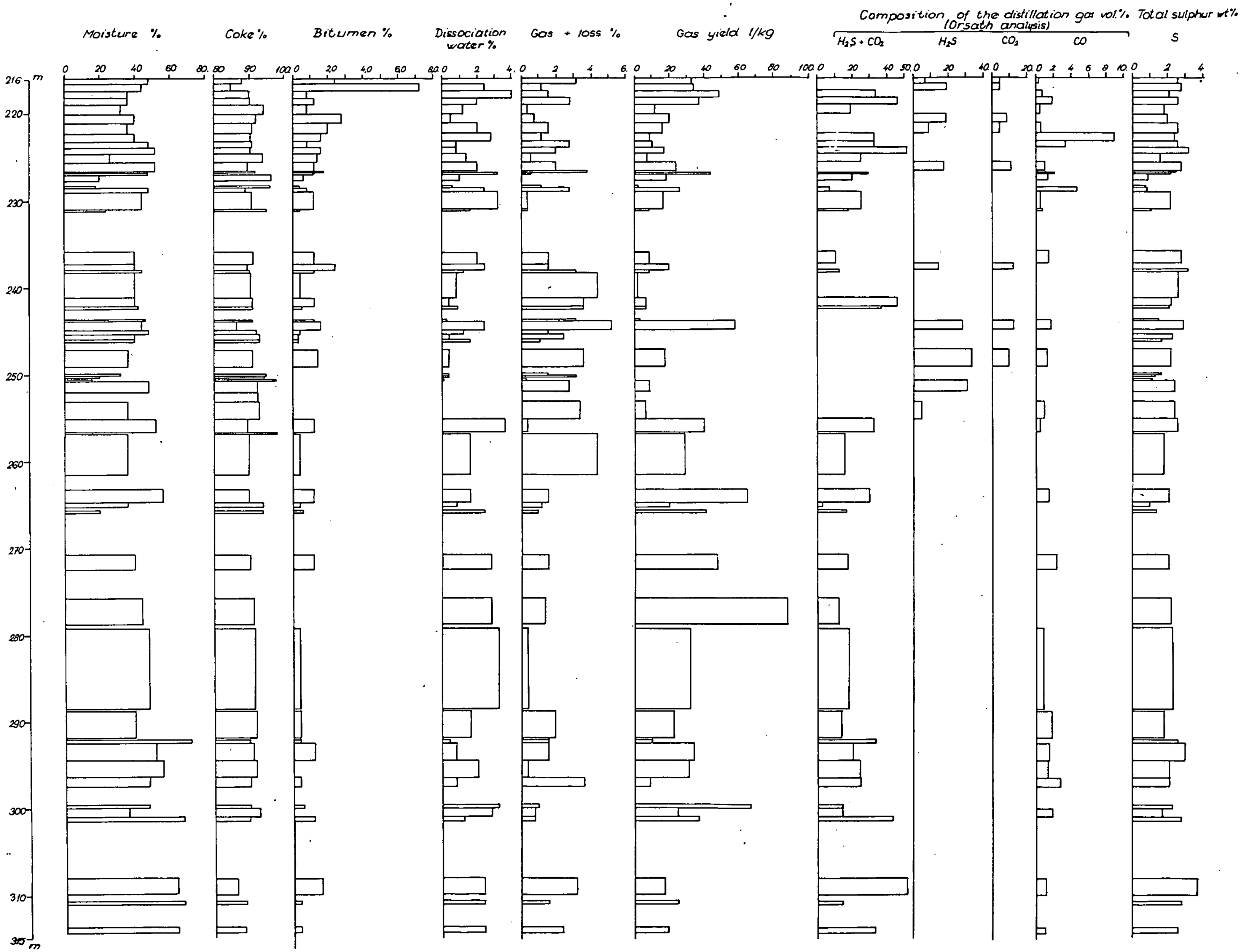



Fig. 11

Analytical results are given in *Fig. 11.*

According to our previous practice, the organic content of alginitic rocks has been determined by differential thermal analysis (DTA).

The lower clay-marl beds of the Laminated Marls in the Lower Pannonian Formation contain 8—9 wt% of organic material. This value abruptly rises to more than 20 wt% in the Sarmatian Strázsahegy Member.

This average value peristst in the 216.0—228.5 m section of the hole, with a range between 17—22%. An exception is the clay-marl siltstone in the 221.1—222.3 m interval with more than 32 wt% organic content. Upwards in the sequence only one test gave more than 24 wt% value, the average was 15—17 wt%, ranging from 12 to 24%.

A further decrease of organic content is observed in the Csákvár Member, with few anomalous values over 27—28 wt% (261.7—261.85 m). The decrease in the average value is mainly attributed to the increasing abundance of evaporites in the middle part of the sequence.

At the base of Mány Member the organic content is 7—8 wt% — like on the Sarmatian-Pannonian boundary — i. e. abruptly reduced from 14—15 wt% of the silty clay-marl of Szomor Member.

Only sparse control analyses were made on the materials of Bö-2 to 6 boreholes. The results provided evidences of the existence of organic-rich alginites. An important find was the high organic content (5—29%) of the alginitic clay-marls of the Laminated Marls in the Lower Pannonian.

The tar content by the Fischer-method gives the best image abbut the distillable oil content of the alginites. Similarly to the previously detailed results of the DTA, this method showed the upper horizons of the Strázsahegy Member to have a higher tar content. 7.2 wt% maximum values were analyzed in the 216.6—217.4 m interval. Down to 237.9 m depth, 4 intersections with 3.5 m overall thickness have reached the lower limit of the öil-shale economic cut-off grade by API-standards (more than 2%) [K E. Stanfield *et al.*, 1951]. Between 216.0 and 244.8 m only 9 beds from the 27 contained less than 0.4 wt% of tar. This nearly 30 m thick interval has an average of 1.5 wt% tar content.

The tar content of the lower parts of the Strázsahegy Member as well as the Csákvár Member is lower than 1.0 wt%, though 1.4—1.6 wt% maxima were also recorded.

The distillation refinery gas yield of alginites, oil-shales, in Bő-2 borehole have also been investigated. The rocks of higher than 2 wt% tar content produced 14.5—34.0 l/kg values, with calorific values ranging between 316.6—890.6 kgcal/m$^3$. The high $H_2S$ content of gas (6.75—19.2 vol%) is rather due to the high pyrite concentration. The 2.0—3.0 vol% total sulphur content of the gas is unfavourably high.

Summarizing the analytical test results of the Budajenő oil-shales the following conclusions can be drawn. The organic content of the rocks is very high, though intensely varying between 3 and 32%. The ash-content is averaged at 90.9%, with 88.0 and 98.0 wt% minimum and maximum values, respectively. Their oil and gas yield is low. The tar content by Fischer's method is ranging between 7.2 wt% and zero, with 0.85% average value. Gas yield provided values from 0 up to 88.0 m$^3$/t. The high sulphur content (2.26% average, 0.8—3.7 wt% range) is also unfavourable.

The DTA and Fischer analysis of samples from Budajenő has supported the earlier observations about the broad correlation of the tar content and the thermically analysed organic content (as determined by DTA) of the oil-shales. This correlation, however, should be treated with great caution, with consideration of all other factors.

In the oil-shale at Pula 30% organic content was accompanied by 4—8% tar content, 35—75% organics were coupled with 13—25% tar. At Gérce the oil-shales with 25% organics yielded only 1.2—5.5% tar. At Budajenő 20% average organic content produced 0.4—7.2% tar (average is 0.85%) in dry samples.

The alginites and diatomites of the Strázsahegy and Csákvár Members in Bő-3 showed fluorescent bitumoid content in 0.01—0.015 wt%. This value is twice as much as the bitumoid content of the Badenian rock types deeper in the section. An anomalously high value of 0.14 wt% was recorded in the diatomite-silty clay marl in the 307.0—307.2 m interval of the Bő-4 borehole as resin-asphalthene type bitumoid.

## CONCLUSIONS

In the Zsámbék Basin such paleogeographical environment and specific sedimentation processes prevailed from the beginning of the Miocene to the Early Pannonian, which were sufficient for the fast and extensive growth of "oil-producing" algae. These algae, accumulated in the sediments and diagenized produced oil-shales. However, taking their low tar content into consideration, only few samples reach economically important grades, and only one sample can be classified as low-grade oil-shale.

Their poor quality does not allow economic evaluation. One considerable depth is also an unfavorable factor.

Despite these discouraging economic value, this exploration has largely contributed to our knowledge of the genesis of oil-shales in the Carpathian basin. The detailed evaluation of the genesis of basin facies as oil-shales has provided further possibilities for future explorations.

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