Magyarhoni Földtani Társulat
Földtani Közlöny
Hungarian Geological Society

143/2, 145–156., Budapest, 2013

Study of the Middle Miocene (Badenian and Sarmatian) formations in the Várpalota Neogene Basin

József KÓKAY

Budapest, H–1212 Széchenyi u. 49.

A várpalotai neogén medence középső-miocén (badeni, szarmata) képződményeinek vizsgálata

Összefoglalás

Jelen munkában a szerző a terület középső-miocén földtani képződményeinek vizsgálatával foglalkozik rétegtani egységenként földtani, rétegtani és őslénytani szempontból, felszíni, mélyfúrási és bányászati adatok alapján. A feldolgozás a szerző korábbi, a várpalotai alsó-miocénnel foglalkozó OTKA kutatási témájának (T 026440) folytatása, amelyben már jelezte, hogy a kárpáti emelet üledéksorára a medence ÉNy-i részén (Bántapuszta) a legidősebb badeni (M4a) meszes–durvatörmelékes összlet diszkordánsan települ, gazdag ősmaradvány együttessel. A kutatófúrásokban sikerült az M4a szintet az egész medencében azonosítani. A szerző Bántapusztáról leírta a Lajtai Mészkő Formáció „Öskü Tagozatát", míg a D-i medencéből a Pusztamiskei Formáció „Berhidai Tagozatát". A alsó-badeni (M4b) felső része erős diszkordanciával következik az alatta lévőre. A szerző elvégezte a középső- és felső-badeni képződmények vizsgálatát is, és feldolgozta a szarmata rétegsor kifejlődési viszonyait és gazdag faunáját.

Tárgyszavak: alsó-badeni alsó része, M4a, Öskü Tagozat, Berhidai Tagozat, alsó-badeni felső része, M4b, középső-badeni, M4c, felső-badeni, M4d, szarmata, kozárdi alemelet, tinnyei alemelet

Abstract

This study records some observations from the author's investigations into the Middle Miocene geological formations of the Várpalota Neogene Basin. Special attention was given to each stratigraphic unit with respect to geological, stratigraphic and palaeontological features. The findings are based on data derived from surficial investigations, boreholes and mining activity. The present work is a continuation of the author's previous study on Lower Miocene, which was supported by OTKA (Hungarian Scientific Research Fund) grant T 026440 and in which the author suggested that in the north-western part of the basin (i.e. Bántapuszta sub-basin) the Karpatian succession is unconformably overlain by the lowermost Badenian (M4a) calcareous-coarse-clastic sequence. The latter has a rich fossil assemblage. In the boreholes, the M4a horizon can be identified in the entire basin. In this study, from Bántapuszta the author describes the "Öskü Member" of the Lajta Limestone Formation and, from the Southern sub-basin, details of the "Berhida Member" of the Pusztamiske Formation are given. The younger lower Badenian (M4b) covers the underlying sediments with an unconformity. An examination of Middle and Upper Badenian sediments, as well as of the facies conditions and the rich fauna of the Sarmatian was also carried out by the author.

Keywords: lower part of the Lower Badenian, M4a, Öskü Member, Berhida Member, upper part of the Lower Badenian, M4b, middle Badenian, M4c, Upper Badenian, M4d, Sarmatian, Kozárdian substage, Tinnyeian substage

Introduction

The present study on the Middle Miocene formations of the Várpalota Neogene Basin — summarizing for the first time the geological, stratigraphic, tectonic and palaeontological data — is of special importance, since this area is unique, not only within the Paratethys but also within the entire Mediterranean region. There are a plenty of data derived from related exposures and boreholes and this enables a detailed examination of these formations to be carried out, together with their respective fossil records. Thus, this study also aims to fill a gap in the geological literature.

A large number of samples — collected from exposures and from borehole cores — and geological documentation were already available prior to the present study. With regular collecting work from exposures, excavation trenches and shafts, as well as from drilling core repositories, the author was able to add to the existing data. In order to make an accurate geological-stratigraphic interpretation, the investigation focused on fossils, and among these predominantly mollusc fauna. Nevertheless, the author has been studying the Middle Miocene formations of the Várpalota Basin for more than half a century and the evaluation of samples has yielded many new results.

From a palaeogeographic point of view the Várpalota Basin consists of the following areas or sub-basins (Figure 1):

— Bántapuszta sub-basin: in its western, approximately 2 km^2-large area Ottnangian, Karpatian and the oldest lower Badenian marine sediments can be found. Rocks represent mainly calcareous and coarse-grained clastic lithofacies.

— Sárrét sub-basin: it is located South of the Bántapuszta sub-basin in a West–East direction between Várpalota and the village Ősi, and is divided by the Várpalota major fault from the Bántapuszta sub-basin.

— The North-South oriented 'Southern sub-basin' which is located between the villages of Ősi and Küngös.

In recent years the author has studied the following Miocene stratigraphic units of the Várpalota Neogene Basin:

— Lower Miocene (previous work, see KÓKAY 2008, OTKA T 026440),

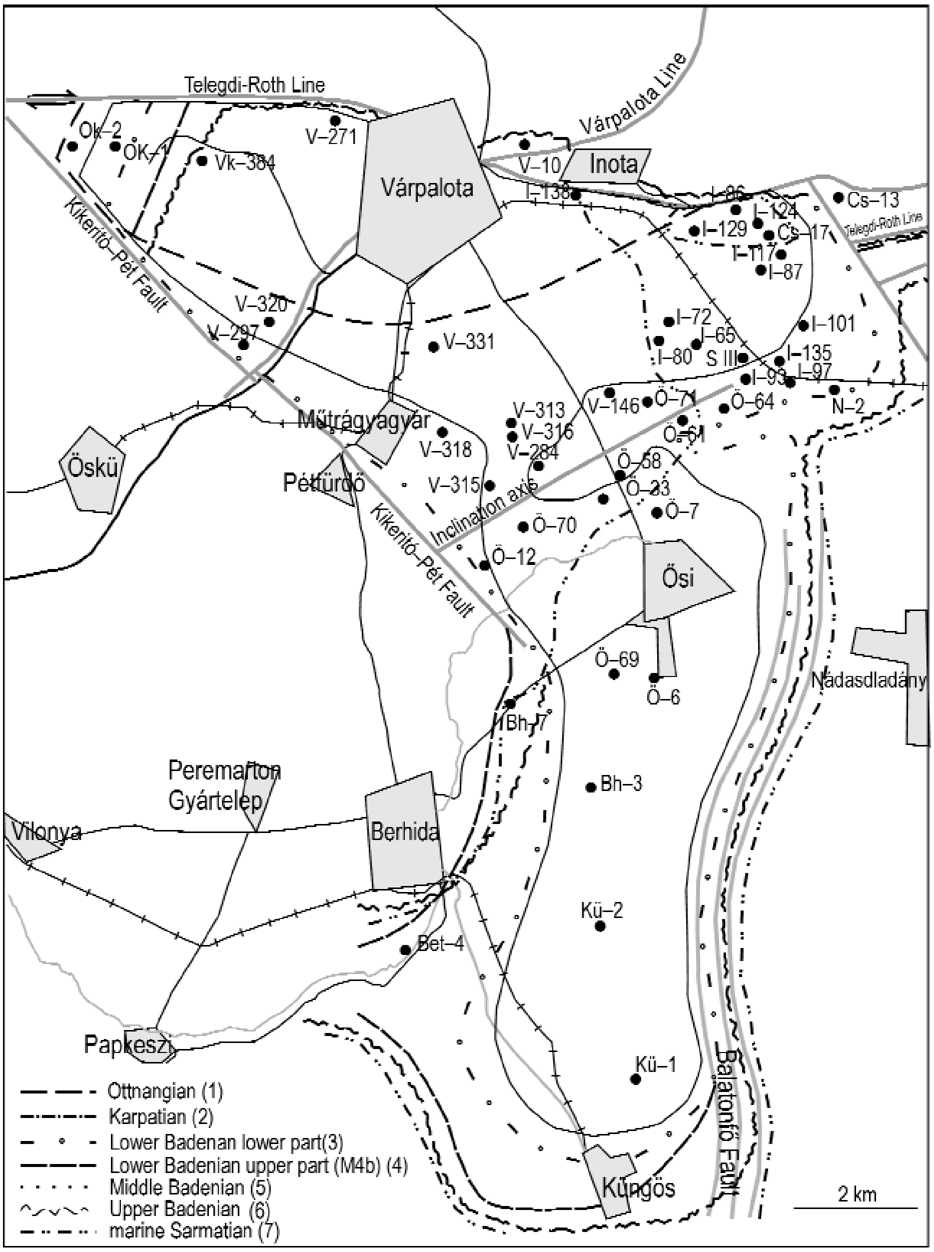

Figure 1. Sketch map of the Várpalota Basin

1. ábra. *A Várpalotai-medence vázlatos helyszínrajza*

A rétegtani egységek elterjedése: 1 – ottnangi, 2 – kárpáti, 3 – legalsó-badeni, 4 – alsó- badeni felső része (M4b) 5 - középső-badeni (M4c), 5 – felső-badeni (M4d), – tengeri szarmata, line = vonal, fault = törés, Inclination axis = Inklinációs tengely

— Middle Miocene: lowermost Badenian (M4a), younger Lower Badenian (M4b), Middle Badenian (M4c), Upper Badenian (M4d) and Sarmatian (M5) successions.

The Sarmatian succession of this area was classified into the older Kozárdian substage and the younger Tinnyeian substage (BODA 1971, 1974).

Middle Miocene formations of the Várpalota Basin

Badenian

Lowermost Badenian (M4a)

The Karpatian bryozoan–Balanus-bearing conglomerate succession — which is exposed in the excavation trenches that reveal the Lower Miocene and Middle Miocene (i.e. Karpatian-Badenian) boundary — is not directly overlain by the (marine) lowermost Badenian (M4a), but by a 2.5m-thick fluvial pebble and sand succession. This fact certainly indicates that, at the time of the stratigraphic boundary, regression took place on the basin margins; namely, a small orogenic movement occurred at this time. This fossil-free pebbly succession has its origins in the southern neighbourhood of the area and can be considered as the basal gravel of the transgrading M4a sea.

The author stated in the final report (KÓKAY 2008) of an earlier piece of research focusing on the Lower Miocene formations, that he found the upper boundary of the succession belonging to the Karpatian to be the most problematic. Formerly the author believed in the seemingly plausible concept that the Karpatian – Lower Badenian boundary coincides with STILLE's "Main Styrian Phase". This significant tectonic event — accompanied by considerable denudation, the incision of river valleys, the oxidization of the surface of the Karpatian sediments and the accumulation of terrigenous deposits — has been known for a long time by the author (KÓKAY 1985a). About 20 years ago the author found a *Borelis melo* (FICHTEL et MOLL) foraminifer specimen in the echinoid–Anomia-mollusc-bearing limestone which overlies the Karpatian. This raised the question whether the succession belonged to the Karpatian, since — according to international opinion — this foraminifer appears in the "Langhiano" which correlates with the Lower Badenian substage in the Paratethys. The author considered the "Styrian Tectonic Phase" concept too "strong" for the area; therefore he decided to make detailed examinations concerning the above-mentioned succession including the basinal sediments, the palaeontological record and the lower and upper boundaries.

The thickness of the Lower Badenian calcareous-coarse-clastic and sandy succession in Bántapuszta is about 27 m. From a lithostratigraphic point of view this can be classified as a new member — i.e. the *Öskü Member of the Lajta Limestone Formation* ("Leithakalk") — given that the settlement of Bántapuszta belongs to the village of Öskü (Figure 2).

Further samples have been collected by the author from the outcrops of the succession above-mentioned and from research pits and trenches which had been dug for the author. The pebble content of the succession increases in the vicinity of the "Pét–Kikeritó" transverse fault. This bounds the area on the South–West. Dacite dust tuff boulders with the burrows of boring clams can also be found. The boulders may have been derived from the upper beds of the underlying succession which is of Karpatian age (see the description of the Berhida Member). The most important elements of the distinguishable fossils are represented by the large foraminifers *Hetero-*

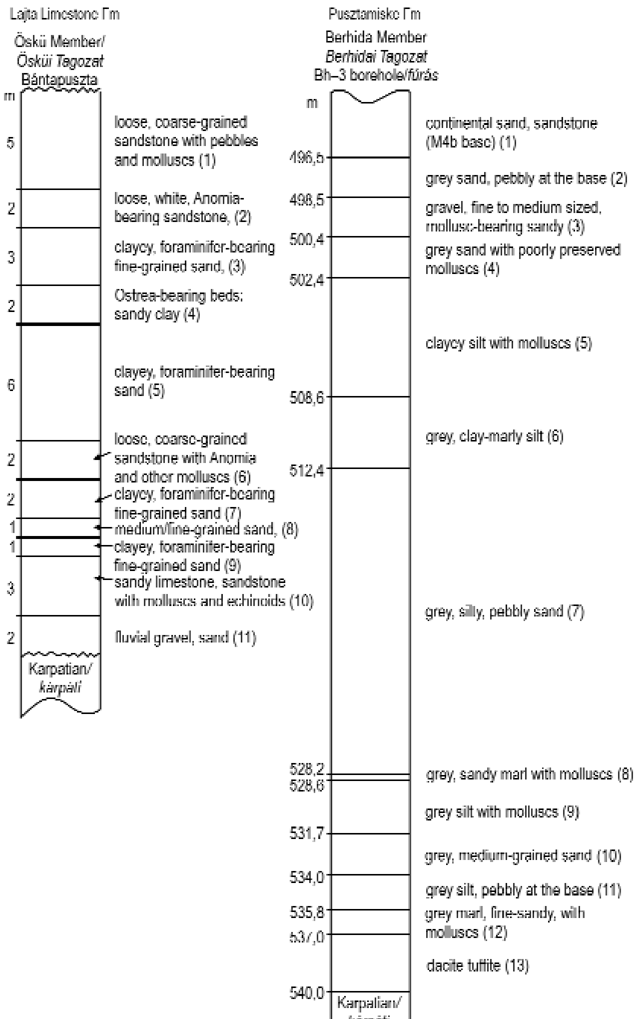

Figure 2. Lowermost Badenian key sections in the Várpalota Basin, Lajta Limestone Formation ("Leithakalk"), and Pusztamiske Fm

2. ábra. *Legalsó badeni (M4a) alapszelvények a Várpalotai-medencében (Lajtai Mészkő Formáció és Pusztamiskei Formácó)*

A bal oldali rétegoszlop jelkulcsa: *1 – laza, durva kavicsos és molluszkás homokkő, 2 – laza, fehér, anomiás homokkő, 3 – agyagos, foraminiferás finomhomok, 4 – osztreás összlet agyagos homokban, 5 – agyagos, foraminiferás homok, 6 – anomiás-molluszkás laza, durva homokkő, 7 –agyagos, foraminiferás finomhomok, 8 – aprószemű homokkő, 9 – agyagos, foraminiferás finomhomok, 10 – molluszkás, echinoideás, homokos mészkő, homokkő, 11 – folyóvízi kavics, homok*

A jobb oldali rétegoszlop jelkulcsa: *1 – szárazföldi homok, homokkő M4b bázisán, 2 – homok, szürke, alul kavicsos, 3 – homokos, aprókavicsos molluszkás, 4 – homokos, szürke, porló molluszkás, 5 – aleurit, szürke, agyagos, molluszkás, 6 – aleurit, szürke, agyagmárgás, 7 – homok, szürke aleuritos, kavicsos, 8 – márga, szürke, homokos, molluszkás, 9 – aleurit, szürke, molluszkás, 10 – homok, szürke közepes szemű, 11 – aleurit, szürke, alul kavicsos, 12 –márga, szürke, finomhomokos, molluszkás, 13 – dácittufit* *stegina* (lately *Planostegina*) *granulatatesta* PAPP-KÜPPER, *H. politatesta* PAPP-KÜPPER and, *H. costata* (D'ORB.). The first two species appear in the Early Badenian, whereas the third could have much earlier origins. Nevertheless, its most common occurrence is certainly a characteristic of the Early Badenian. The sand beds are rich in other benthic foraminifers of bay facies (KÓKAY 1967c).

The sediments contain plenty of fossil molluscs; the aragonite-shelled specimens have usually remained as impressions. However, in the lowermost mollusc–echinoid limestone beds specimens with shells are also found — especially among the genus *Cardita.* Approximately 250 mollusc taxa were identified in the Bántapuszta succession. The most common taxon is the newly-described *Ostrea (Alectrionia) karpatica,* hitherto known only in this stratigraphic horizon of the Várpalota Basin in the Paratethys realm. Mollusc fauna of the Öskü Member contain many taxa which up until now have been recognized only in the Lower Miocene (or have been described from occurrences in North Italy, or from the Lower Miocene or lower art of the Middle Miocene of the west of France).

The most significant and characteristic mollusc taxa of the Lajta Formation Öskü Member are the following:

Bivalvia: *Arca taurocostulata* SACCO, *Anadara girondica* MAYER, *Barbatia candidaidae* FUCINI, *B. subhelbingli varuabilis (*MAYER*), Bathyarca pectunculoides* SACCO, *Striarca lactea gaimardi* PEYROT, *Pecten cristatocostatus* SACCO, *P. subarcuatus* TOURN., *P. dunkeri* MAYER, *Flabellipecten larteti* TOURN., *F. almerai* DEP. et ROMAN, *Aequipecten catalaunica* ALM. et BOF., *Anomia ephippium* L., *Monia tauraculeata* SACCO, *Exogyra miotaurinensis* SACCO, *Ostrea saccellus* DUJ., *O. (Alectryonia) karpatica* KÓKAY, *Cubittostrea frondosa caudata* MÜNST., *C. frondosa delboisi* MAYER, *Spondylus concentricus* BRONN, *S. crassicosta rarostellum* LAMK., *Modiolus aphaneus (*ROV.*), Mytilus galloprovincialis mioherculea* SCHAFFER, *Astarte incrassata sallomacensis* C. et P., *A. burtini (*LAJON.*), Crassatella producta (*ROV.*), Pteria studeri* MAYER, *P. phalaenagea (*LAMK.*), Cardium sallomacense* C. et P., *C. andreae* DUJ., *Bucardium burdigalinum (*BAST.*), Cerastoderma michelottii* DESH., *Laevicardium polycolpatum* C. et P., *L. multicostatum mioangulatum* SACCO, *Dosinia basteroti (*AG.*), Clausinella basteroti taurorudis* SACCO, *Chione (Ventricola) erasa* C. et P., *Mactra miocaenica* DOLLF. et DAUTZ., *M. (Pseudoxyperas) oblonga* MILLET, *Gastrana peregrina* BAST., *Psammobia ellipsoidalis* C. et P., *Macoma leognanensis* C. et P., *Gari affinis megalomorpha* C. et P., *Panopea faujasi* MÉM., *Lutraria angusta* DESH.

Gastropoda: *Bolma taurinatus percarinatus* SACC., *Turritella vermicularis planatula* SACCO, *T. tricarinata* BROCC., *Protoma carniolica (*STACHE*), Natica angyglossa* C. et P., *Zonarina subelongata* D'ORB., *Z. tauroporcella* SACCO, *Columbella (Alia) curta pseudospirata* SACCO, *Mitra protense* BELL., *M. subangulata* BELL., *M. lactea* BELL.

Further detailed studies may expand the list of taxa. From a stratigraphic point of view the *Aturia aturi* (BAST.) *(Nautilidae)* specimen is not significant; however, it indicates strong circulation in the water of the bay which protruded far into the land. The shell of the cephalopod — which lived in the pelagic region — was drifted into the bay. *Aequipecten scabrellus lomnickii* (HILBER), *Turritella vermicularis planatula* SACCO, *Fusus lamellosus palatinus* STRAUSZ and some other species appeared in the lower Badenian formations of the Paratethys.

A part of the boreholes (e.g. Várpalota V–313, –137 and V–140) that were deepened at the western margin of the basin also revealed the Öskü Member with similar faunal assemblages. In the clayey, fauna-rich sediments of borehole Várpalota V–318 *Ostrea (Alectrionia) karpatica* and bryozoan branches were predominant. *Heterostegina granulatatesta* PAPP–KÜPPER, *H. politatesta* PAPP–KÜPPER and *Alabamina armellae* POPESCU were also frequent. The latter foraminifer is also characteristic of the Lower Badenian. In the calcareous deposits of the Öskü Member echinids are frequent; *Scutella* (4–5 species), *Clypeaster* (8–10 forms), *Brissopsis* and other taxa can also be found.

On the basis of borehole data, the beds of the Öskü Member tilted eastwards due to tectonic movements; the earliest Badenian (M4a) sea receded and deep valleys were incised into the uplifted area (KÓKAY 1985a). The surface was oxidized, resulting in brown and red colouration. (SW–NE oriented erosional valleys ran into the foredeep of the Telegdi-Roth Line which was a river bed at that time.) Formerly this event was interpreted by the author as a phenomenon which occurred at the Karpatian – Lower Badenian boundary. Now it is obvious that this event took place within the Early Badenian, at the boundary of biozones "Lower Lagenid Zone" (M4a) and "Upper Lagenid Zone" (M4b). This has been internationally accepted with respect to the division of the Paratethys. Subsequent to the strong orogenic movement and the following denudation, epirogenic subsidence and transgression commenced over a large area. As a result of this, during the time of the M4b biozone the sea occupied the basin and — on the bases of data derived from boreholes — the incised valleys became filled up with sedimentary successions and these are thicker than those overlying the weathered-out ridges.

During the process of the present study, there was one particular question which emerged — what is the heteropic (basinal) facies of the Öskü Member? Based on the documentation of many (mainly coal-exploration) drillings, 40 boreholes were found to be suitable for the analysis of the M4a basinal facies; among these boreholes 28 were suitable for examining fossils.

The thickness of the oldest Badenian succession ranges from 5 to 40 m. It is made up predominantly of grey sand, sandstone, silt, marl, clay marl and — subordinately — gravel. Furthermore, it comprises the angular clasts of a quartzite dyke of the Lovas Slate. The sandy deposits also include the fine debris of the slate in large quantities. The M4a succession is generally thicker in the Southern subbasin than in the Sárrét sub-basin. The inclination axis runs between these two sub-basins; from a geomechanical point of view, it was analysed in detail during the tectonic summarization of the Várpalota Basin (KÓKAY 1996). The Karpatian sea penetrated through this pseudo-anticline into the Southern sub-basin in two places: at the western end of the axis along the Kikeritó–Pét Fault, and South–West of the S-III. Shaft (East of the first place). The other areas of the inclination axis remained dry; these areas — except a small patch in the middle (borehole Ősi Ő–14) — were flooded by the sea only during the earliest Badenian. The area of borehole Ő–14 stood out from the sea as an island until the latter part of the Early Badenian transgression.

The earliest Badenian basinal succession can be classified into the *Berhida Member of the Pusztamiske Formation.* Boreholes which penetrated this succession demonstrated the presence of sand, silt, clay, clay marl, marl and sandstone in the Sárrét sub-basin and the Southern sub-basin. The key section of this member is in borehole Berhida Bh–3 (Figure 2). The M4a sedimentary succession has its maximum thickness (40.5m) in the latter borehole.

In this key section, the borehole shows that the lowermost Badenian marine succession overlies a 3m-thick dacite tuffite bed. (According to the analyses of PENTELÉNYI [2000]), the corresponding tuff layer in the nearby Küngös Kü–1 borehole can rather be considered as rhyodacite.) Due to its marginal proximity, the Kü–1 borehole penetrated this tuffitic-bentonitic succession to an even greater thickness. Its close proximity to the margins is also indicated by the fact that the tuffitic succession is directly overlain by fluvial pebbly sand and terrigenous clay. These latter beds are covered with the deposits of the earliest Badenian (M4a) transgression. In borehole Ősi Ő–26 — drilled on the inclination axis, SW of the S-III. Shaft — the M4a succession is underlain not by the Permian red sandstone (as indicated in earlier documentation) but by the Karpatian sandstone and clay marl succession. The upper part of this succession was oxidized to a red colour and under these layers, in the grey deposits, coalified plant remains and fossil molluscs can be found. Thus the higher part of the area along the inclination axis became exposed on the surface at the end of the Karpatian (such as those beds of the Öskü Member in Bántapuszta or as in borehole Küngös Kü–1). In the Sárrét sub-basin the several dm-thick tuffitic-bentonitic intercalation at the Karpatian – lowermost Badenian boundary can be found only in the eastern areas. Borehole Várpalota V–133 — which was deepened at the south-western border of the town — yielded only disseminated biotite crystals in the sandstone covering the Karpatian stage. It can be stated that where tuffitic-bentonitic deposits are present, marine sedimentation was continuous or only oscillation took place.

Due to the erosional and oxidational processes which took place subsequent to the huge uplift, the upper boundary of the lowermost Badenian succession can be defined with high accuracy. In other parts of the Várpalota Basin different types of terrigenous sediments accumulated unevenly during this regressive period. Borehole Csákvár Cs–17 (S of the Inota Aluminium Smelter) penetrated a 16 metre-thick fluvial sand succession in this "boundary horizon". This stratigraphic boundary has been penetrated by a vivid green-coloured, fine-grained sand of a thickness of 1–6m, especially in the eastern part of the Sárrét sub-basin. It contains loose, cylindrical carbonate encrustations (rhizoliths). It can be assumed that the study area was savannah grassland at that time. At the M4a-M4b boundary, borehole Berhida Bh–3 has been penetrated by a 10.5 metre-thick terrigenous, predominantly reddish-brown clayey and sandy succession. In several research pits and trenches the boundary is indicated by 1–5 metre-thick grey, greasy clay, sometimes with carbonate nodules. There are places where the boundary is difficult to define because of the lack of terrigenous sedimentation. Such a place was the trench for water pipes along the west side of the access road in Bántapuszta, in the western area of the open-pit mine. Here, the strongly eroded yellow sand (which belongs to the M4a succession) is also overlain by yellow sand; the latter belongs to the M4b zone, and in its upper section it contains a rich, well-preserved mollusc fauna, (80 species), characteristic of the Szabó sand pit. However, the stratigraphic boundary cannot be identified; sediments at the boundary were reworked by the invading late Early Badenian sea.

Boreholes in the Sárrét sub-basin and the Southern sub-basin — which represent the above member — revealed sand, silt, clay, clay marl, marl and sandstone, usually with rich fossil assemblages. The foraminifer assemblages of a few samples were examined, but they were not suitable for determining age boundaries. The mollusc fauna was poorly preserved and disintegrated easily. In spite of this it was possible to determine 300 species. It can be stated that — apart from those species that are also present in the Szabó sand pit in Várpalota — the fauna is different. Similar to the fauna of the Öskü Member, it is rather characteristic of the Lower Miocene that it contains several species already known from North Italy and the west of France; up until now there has been no evidence of these in the Paratethys. From a single layer (507.3–510.3m) of borehole Küngös Kü–1, 102 taxa were determined. The fauna was equally rich in borehole Inota I–93.

The most important taxa of the *Pusztamiske Formation Berhida Member* are the following:

Anadara girondica MAY., *A. turoniensis aquitanica* C. et P., *Barbatia (Soldania) gallica* MAY., *Nuculana westendorpi* NYST, *N. sublaevis* BELL., *N. bonellii* BELL., *Flabellipecten larteti* TOURN., *F. pasinii* MEN., *Aequipecten genton* FONT., *Chlamys costai* FONT., *Pallioum (Lissopecten)* cf. *hyalinum* POLI, *Ostrea karpatica* KÓKAY, *O. frondosa percaudata* SACCO, *Monia tauraculeata* SACCO, *Carditopsis chavani* GLIB., *Astarte solidula taurolevis* SACCO, *Beguina rusticana* MAY., *Cerastoderma basteroti* DESH., *Acanthocardia impar* (ZHIZH.), *A. girondica* MAY., *A.* cf. *saucatsensis* MAY., *Bornia taurinensis* SACCO, *Montacuta exigua* COSSM., *Rochefortia duvergieri* C. et P., *Sportella degrangei* C. et P., *Spaniorinus* cf. *burdigalensis* COSSM., *S. neuvillei* C. et P., *Diploldonta (Felaniella) brevifulcra* C. et P., *D. (Felaniella) biali* C. et P., *Phacoides michelottii* MAY., *Ventricola tauralternans* SACCO, *Circomphalus plicata rotundior* KAUT., *Paphia taurelliptica* SACCO, *Grateloupia* *irregularis* BAST., *Abra degrangei* COSSM., *A. stricta* BROCC., *Macoma cumana tauroparva* SACCO, *Gastrana fragilis persinuosa* C. et P., *Solenocurtus antiquatus miocaenicus* C. et P., *Gari (Macropsammus) biali* C. et P., *Thracia degrangei* C. et P., *Corbula carinata hoernesi* BEN., *Gibbula subscalata* BOETTG., *G.* cf. *proturbinoides* BOETTG., *Turritella vermicularis planatula* SACCO, *T. communis subuliformis* BOETTG., *Protoma carniolica* STACHE, *Bittium subgranosum evolutum* C. et P., *B.* cf. *laevielegans* SACCO, *Scala (Clathrus) kostejana* BOETTG., *Subuluscala lagusensis* DE BOURY, *Pyrgolampros miosulculatus* SACCO, *P. taurotransiens* SACCO, *Pyrgostelis varpalotensis* n. sp., *Cingula (Parvisetia) pupina* C. et P., *Polinices arsenae* BOETTG., *P. kostejana* BOETTG., *P. catena varians* DUJ., *Actaeon striatellus parvula* C. et P., *Retusa truncatula clavata* SACCO.

Among the taxa of the list, *Anadara girondica* MAYER, *Nuculana westendorpi* NYST, *Ostrea karpatica* KÓKAY and *Acanthocardia impar* (ZHIZH.) are the most frequent species; 21 species of the small-sized Erycinidae and Leptonidae families are also present. *Gastrana fragilis persinuosa* C. et P. is also frequent and characteristic of the Lower Miocene. (It is described from the younger fauna of the Szabó sand pit incorrectly as *G. fragilis persinuosa*, but here the *tumida* subspecies is present.) *Turritella vermicularis planatula,* which was found in numerous specimens in the Öskü Member, is also present in the Berhida Member; however, *Protoma carniolica* is more frequent in the Berhida Member. A unique form is represented by a small-sized *Cardium* species, i.e. the *Acanthocardia impar* (ZHIZH.), which dwelt in the Chokrakian formations of the Eastern Paratethys and probably migrated to the East from here.

Upper Lower Badenian (M4b)

The orogenic uplift was followed by epirogenic movements, and the sea invaded the earliest Badenian (formerly considered as Karpatian) surface again. The latter was strongly dissected by erosional valleys in the north-western part of the study area. A succession was deposited, made up predominantly of sandy and pelitic sediments. Here, sandstone is a subordinate feature (it is rather typical in the western part); pebbles, conglomerates and Leithakalk are much less frequent. The upper part of Early Badenian succession has its maximum thickness usually in the foredeep of the Telegdi-Roth Line; in borehole Inota I–87, which was drilled South of the Inota Power Station, its thickness is 50m and is made up of clay, silt and sand. The neighbouring borehole Csákvár Cs–17 penetrated a 33 metre-thick clay succession. However, the thickest — i.e. the 100 metre-thick clayey-sandy succession — was penetrated by borehole Várpalota V–10 (drilled in the 1920s near the railway station); it contains a fossil assemblage similar to that of the Szabó sand pit. In the Southern sub-basin the upper part of Lower Badenian was the thickest in borehole Berhida Bh–3, where a 22 metre-thick succession was revealed; it is made up of silt, sand and — subordinately — gravel. In the Bántapuszta sub-basin the thickness of this succession ranges from 3 to 25m depending on the depth of the erosional valleys that had been formed previous to the M4b transgression. In this area sandstone is more frequent. The M4b horizon was revealed by TELEGDI-ROTH (1924) in the lower part of the open-pit coal mine near the eastern outskirts of the town. SZALAI (1926) collected well-preserved fossil molluscs from the sand in the "Unio sand pit" located in the south-western rim of the town. The sand pit represents a horizon close to the Upper Badenian coal seam.

The abandoned Szabó sand pit in the western part of the town came into being in the 1930s. A rich and well-preserved bivalve fauna was described from here by SZALAI (1926) and later STRAUSZ (1943). Details concerning the gastropod fauna were published by STRAUSZ (1954), whereas a description of the foraminifer fauna had been presented earlier by MAJZON (1943). Further molluscs were described by KECSKEMÉTI-KÖRMENDI (1962), and —concerning the foraminifer fauna — further data were provided by LAKY (in KECSKEMÉTI-KÖRMENDY 1962, p. 82). The sand pit yielded about 400 mollusc species and 100 foraminifer species. In the "Proposal for new lithostratigraphic units of Hungary" (GYALOG, BUDAI eds 2004), it has been classified into the *Szabóbánya Member of the Pusztamiske Formation.* In the lowermost part of the protected exposure homogenous sand can be seen. It is overlain by fauna-rich, grey, cross-bedded sand of wave-agitated environment. The fauna also comprises freshwater and brackish-water taxa (*Brotia escheri* BRONG., *Theodoxus grateloupianus* FÉR., *Nematurella scholli* SCHLICK.) which were transported into the sea by rivers. Terrestrial gastropods (*Melampus, Pedipes, Stolidoma*) are indicative of mangrove habitats. A new research pit in the vicinity of the Szabó sand pit yielded a similar fauna (KATONA et al. 2011).

Middle Badenian (M4c)

Subsequent to the regression of the Early Badenian sea, this substage is represented exclusively by continental, fresh-water sediments in the Várpalota Basin. This period — i.e. from the retreat of the sea until the tectonic collapse of the basin, which resulted in the deposition of coal — is characterised by continental sediments of uneven thicknesses. In some parts of the basin and in patches, the Lower Badenian marine formations are directly overlain by the coal seam or the coaly clay bed that is found under the coal seam; the Middle Badenian succession is missing. The Middle Badenian sediments are present in a considerable thickness, especially in the Sárrét sub-basin and predominantly in its northern areas in the foredeep of the Telegdi-Roth Line. It reaches its maximum thickness (i.e. 44m) in borehole Inota I–86, which is located South of the Inota Thermal Power Station. This succession is made up of greenish-grey, clayey silt with carbonate nodules and Helicidae fragments and intercalations composed of dolomite pebbles and Eocene clasts. In borehole Csákvár Cs–17 — located south-west of borehole Inota I–86 — the lower part of the 18 metre-thick succession is undoubtedly of lacustrine facies; its leading taxon is *Brotia escheri* BRONGT. Much further south in borehole Inota I–135, in the 2.7 metre-thick clayey silt between the lower and upper Badenian beds, the author found a specimen of *Planorbarius sansaniensis* BOURG., whereas in borehole Berhida Bh–3 — in the same stratigraphic position — a *Brotia escheri* BRONG. specimen. In the washed residues of samples derived from boreholes Inota I–124 and I–129 (drilled in the southern foreland of the Power Station) only terrestrial molluscs were found. The foreland of the above-mentioned great, compressive tectonic line was characterised by fluvial debris cones with small ponds between them.

19 mollusc species were determined by the author from the Middle Badenian sediments (KÓKAY 2006).

Upper Badenian (M4d)

On the basis of foraminifer biozonation, this is the — internationally accepted — uppermost stratigraphic "section" of the Badenian stage in the Paratethys realm. During the Late Badenian, the Várpalota Basin had no connections with the sea. However, the lack of the connection with the sea did not affect the crustal movements, which triggered transgression and regression. Nevertheless, at the boundary of the Middle and Late Badenian a strong orogenic activity started. This, which was called the "New Styrian Phase" by STILLE, and the "Leitha Phase" by HÁMOR (1985). However, this area was also affected by the orogenic movements that had occurred in the Paratethys area — i.e. the entire basin collapsed (KÓKAY 1996). Subsidence resulted in the development of a marshland and the accumulation of plant material; this led to the formation of the Várpalota lignite (Várpalota Lignite Member of the Hidas Lignite Formation). In the Bántapuszta and Sárrét sub-basins the accumulation of plant material started in a forested wetland facies characterised by the predominance of cypresses (the relatives of Taxodium and Sequioa). The lower, half-metre-thick layer of the coal seam is made up of compressed tree trunks of a visibly woody structure (xylith). On the basis of coal petrographic analyses of borehole Berhida Bh–3 of the Southern sub-basin (ELEK 1987), it can be stated that the accumulation of organic material in that area took place in deep marsh facies and was characterised by clayey intercalations; this resulted in a higher ash content. Subsequent to the deposition of the xylith bed, the formation of coal continued in a huminitic marsh facies in the Bántapuszta and Sárrét sub-basins. Fusitic parts (i.e. fossil charcoal) are clearly visible in the layer. It is mainly in the western part of the Sárrét sub-basin that the coal seam — characterised by an average thickness of 5m — overlies light grey dacite tuff of uneven thicknesses (0.5–3m); it is capriciously bentonitized. In the central and north-western areas of the Sárrét sub-basin the huminitic succession is covered with a 2 cm-thick, more or less bentonitized biotitic dacite tuff layer (in the mining language "central strip"). Above this the xylithic facies returns, thus indicating that orogenic movements resulted in the uplift of the basement and forested wetland became widespread again; it is indicative of less shallow water. Tectonic movements were accompanied by volcanism somewhere in the wider vicinity which yielded the "central strip" as a primary fallen volcanic ash (KÓKAY 1967a). Due to its marginal position and the terrigenous transportation, this layer occurs in different thicknesses in the Bántapuszta open-pit mine; in some places its thickness may reach 2–3m. Due to the deepening of water — subsequent to the accumulation of the upper, fibrous coal seam — the huminitic marsh facies returned. Throughout this time the formation of the xylithic lithotype took place, as can be seen in the Bántapuszta open pit mine. The thickest coal seams can be found in the fore-deep of the Telegdi-Roth Line; in some places it may reach 8–10m (boreholes Inota I–44 and I–61). In borehole Inota I–129 the thickness would have been 14m. However, as a result of the rapid subsidence of the foreland, lacustrine calcareous mud interbeddings were formed. Borehole Berhida Bh–3 in the Southern sub-basin penetrated the coal seam to a thickness of 8m. In its lower part clayey intercalations occur. The coal seam is overlain by the "gastropod-bearing" overburden, which contains *Congeria boeckhi* WENZ, *Theodoxus crenulatus varpalotensis* BARTHA, and *Ferebithinia vadaszi* (WENZ) species in large quantities. These indicate that in the course of deepening the marsh became a pond. The territory of the marsh was about 80 km^2. After the formation of the coal and the deposition of the overlying mollusc-bearing beds, subsidence continued and the area of the lake increased, eventually covering an area of about 90 km^2.

The depth of the sedimentary basin was so considerable, especially in the Sárrét and Bántapuszta sub-basins, that the substratum was situated under the wave base. Mollusc fauna of shallow-water habitats could live only in the coastal areas, whereas in the deeper and calm zone rhythmic sedimentation took place. Layering was caused by seasonal differences: in the dry and warm summers paper-thin carbonate laminae were formed, whereas in the cool and rainy winter seasons thin silt layers were deposited due to terrigenous input. Therefore a rhythmically-layered succession continued to be built until the basement became uplifted by a new orogenic movement. This triggered volcanism in the surroundings and the depositing dacite tuffite resulted in a characteristic lithostatic pressure (KÓKAY 1973).

In the course of the subsequent sediment accumulation microlaminated sediments were not formed. However, the water was not shallow enough for the mollusc fauna to return from the marginal biotopes. The author found the *Congeria* limestone of coastal-shallow lake facies in several places, such as on the eastern side of the Kálvária Hill in Inota, in borehole Ősi Ő–67, and West of Pétfürdő on a forested hill South of the road to Graz and the railway crossing; here the Triassic is overlain by *Congeria* and *Theodoxus*-bearing white limestone. At the foot of the Kálvária Hill the author noticed the outcrop of the *Ferebithinia* and *Theodoxus*-bearing limestone. In borehole Berhida Bet–4 the succession belonging to the M4b zone and the Sarmatian succession contains *Congeria*-bearing sand with poorly-preserved shells; these fossil *Congeria*s does not belong to the *C. boeckhi* WENZ species but to a much larger form. In the north-western foreground of the onetime open-pit mine in Bántapuszta, in the road cut, laminated calcareous marl beds were exposed in the course of the roadworks. These beds represent the heteropic facies of the clay marl succession which overlies the coal seam. The calcareous marl was underlain by the weathered coal seam to a thickness of 10cm, indicating the rim of the former marsh. Material was transported into the sedimentary basin from two directions. On the basis of boreholes Berhida Bh–3, Küngös Kü–2., Berhida Bet–4 and Ősi Ő–69, it is evident that the sediment transport from the South was predominant, because sandy intercalations and coastal septarian features increase southwards. The other main sediment transport occurred from the area located North of the section of the Telegdi-Roth Line, which lies between Inota and the Aluminium Smelter. The accumulation took place mainly in the foredeep and Eocene material was also redeposited (e.g. in borehole Inota I–86, KÓKAY 2006).

The "alginite" succession which overlies the coal is characterised by the excessive accumulation of Botryococcus algae, and therefore the practical use of this organic-rich material was also tested (SOLTI 1980). The succession represents a complete sedimentary cycle: it is capped by a thin coal seam of poor quality. The alginite succession thickens northwards, i.e. towards the foredeep of the Telegdi-Roth Line. Its thickness ranges from 20 to 30m in the southern part of the Sárrét sub-basin, whereas it exceeds 100m in the foredeep. The Upper Badenian — including the coal seam — has its maximum thickness (155.3m) in borehole Várpalota V–271 in the northern part of the Bántapuszta sub-basin; the basal coal seam is 6.3m thick, whereas the upper, clayey coal layer at the top is 2.1m. The considerable subsidence of the fault's foredeep indicates synsedimentary movements (KÓKAY 1996). The alginite succession which overlies the coal seam represents the Loncsos Alginite Member of the Hidas Lignite Formation (GYALOG, BUDAI eds 2004).

Formerly the author considered the fossil assemblage of the upper Badenian succession as a brachyhaline association (KÓKAY 1967b), assuming subterranean salt water infiltration. This hypothesis was confirmed by the data of KUBOVICS (personal communication), i.e. traces of boron in the alginite. However, later the author collected further fossils for his monograph on nonmarine molluscs (KÓKAY 2006). Altogether 33 taxa have been found; 23 of them lived in water; the faunal composition indicates a fresh-water environment, albeit these fresh-water taxa could tolerate salinity up to 3‰. Besides the molluscs, fish taxa have also been found; this record was published by GAUDANT (2005). A new fish species, i.e. *Eomorone kokayi* (described by GAUDANT), is predominant here. Its existing relatives live in the Indo-Pacific region in coastal lakes and lagoons. Other fossil vertebrate remains, which indicate a Badenian age (e.g. *Deinotherium bavaricum* von MEYER), can also be found in the collections (KORDOS 1985). On the basis of RÁKOSI's studies, an extremely rich fossil pollen record can be found, mostly in the upper third of the alginite succession. Therefore some parts of it could be referred to as "polleninite" (as suggested by L. RÁKOSI in a personal communication).

Leaf remains have also been found in the succession; *Cinnamomum* leaves are the most frequent. RÁKOSI determined a hydrophytic plant, i.e. the *Potamogeton schenkii* KIRCHENHEIMER, in the upper part of the sequence (L. RÁKOSI personal communication). It is also important to mention that some species of the genus may live in alkali lakes, too. Thus they are plants with a moderate degree of salinity tolerance. HAJÓS (in SOLTI 1980) described fresh-water and halophytic diatoms and thus, in accordance with GAUDANT, she assumed a low-salinity facies. A direct connection (inlet) cannot be presumed; in this case there would be changes in the faunal composition towards the inlet. The fauna is similar all over the basin, except at (i) the western rim of the Sárrét sub-basin, which is characterised by the frequency of the fresh-water taxa *Anisus rousianus* (NOULET), *Planorbarius cornu cornu* (BRONGT.), *Radix dilatata* (NOULET) and *Brotia escheri turrita* (KLEIN), and (ii) borehole Fehérvárcsurgó–5, in which *Anisus* cf. *rousianus* (NOULET) and *Radix dilatata* (NOULET) are frequent. Therefore, only subterranean infiltration of salt water can be assumed. The weak point of the hypothesis is that the closest Upper Badenian marine sediments are known 15–20km far from the Várpalota Basin. This infiltration under a barrier can be presumed somewhere East of Csákvár. This is at the rim of the Bicske sedimentary basin, via the northern foredeep of the Velence Hills and Fehérvárcsurgó, towards the Várpalota Neogene Basin. Its geomechanical explanation was given earlier by the author (KÓKAY 1996). This marine connection (inlet) was obvious during the Ottnangian, Karpatian and Early Badenian. A karst water-monitoring well, i.e. borehole Csákvár Cs–1, penetrated laminated alginite (similar to that in the Várpalota Basin) in the section between the Triassic basement and the Pannonian (Upper Miocene) succession. Unfortunately, owing to the discontinuous core recovery, only one sample was derived from the alginite succession. However, this represents the lagoonal continuation of the former inlet.

According to the experience of mining operations, due to subsequent silicification processes, chalcedony precipitation occurs along the joints and on the small fault planes. On the basis of decrepitation tests carried out in the laboratory of the National Ore and Mineral Mines (OÉÁ), the relative temperature of the formation was 275 °C (J. CSILLAG, personal communication). It is in connection either with Sarmatian faults or with the main fault which was formed during the Pontian (Upper Miocene).

Sarmatian (M5)

The author's first scientific contribution was the description of the Sarmatian in Várpalota (KÓKAY 1954), based on data available at that time. Boreholes which have been drilled since that time (especially in the Southern sub-basin) have yielded data of considerable value with respect to the geological build-up of the Sarmatian succession in the Várpalota Basin.

Subsequent to the deposition of the Upper Badenian beds, an intensive orogenic movement occurred. It resulted in the uplift of the Palaeo-Bakony hinterland. The increase of relief energy led to a sudden increase in the volume of denudation material. Continental deposits (Gyulafirátót Formation) can be found in some exposures in the western and north-western parts of the basin and in the northern part of the Sárrét sub-basin. However, these deposits can also be observed in boreholes all over the Várpalota Basin.

The terrestrial succession continues north-westwards, towards Öskü and Gyulafirátót, from where a small river carried its load through the foredeep of the Telegdi-Roth Line into the basin. The terrigenous succession is built up of well-rounded pebbles of different sizes, and sand; the succession is characterised by carbonate nodules and — being bentonitic — it feels greasy and soap-like to the touch. Grain size increases towards the West and North-West. According to BUBICS (personal communication) the pebbles are made up of the following rocks: 1. siliceous Palaeozoic sandstone, 2. quartz porphyry, 3. subvolcanic quartz porphyry, 4. the acidic dyke rock of leucocratic granite, 5. Jaspery quartzite from an Early Palaeozoic (originally volcano-sedimentary) sequence, 6. Palaeozoic breccia cemented by silica, 7. Palaeozoic sandstone-quartzite, 8. Palaeozoic sandstone-quartzite and amorphous silica, 9. chert, 10. fine-grained, siliceous red sandstone, 11. Early Palaeozoic gneiss, 12. Siliceous bauxite, 13. fragments of silicified tree trunks (Platanus, Quercus), 14. Pegmatitic quartz, 15. Gabbroic rock, 16. cherty Mizzia limestone, 17. tourmalinated quartz porphyry, and 18. Permian red sandstone. On the basis of their material, it would appear that only some of the pebbles may have been derived from the Oligocene "Csatka Gravel". The Telegdi-Roth Line and its foredeep can be traced through the Bakony Mts up to the village of Adásztevel (KÓKAY 1996). This indicates that the sediments arrived into the Várpalota Basin somewhere from the West.

The second terrigenous transportation occurred from the North into the Sárrét sub-basin with a basically different composition, and it was deposited predominantly in the foredeep of the fault. Its material is made up prevailingly of Triassic dolomite; the erosional material from Eocene rocks (clay marl, limestone) and redeposited Eocene fossils increase towards the East. According to official documentation this material in the boreholes — located South of the eastern edge of the Aluminium Smelter — belongs to the Eocene, although it is made up of the material that was redeposited in the Sarmatian or in the Late Badenian.

The third sediment transport (of a smaller amount) occurred from the South or South-East into the basin containing the material of the Lovas Slate, together with clasts of dyke quartzite. The first sediment transport (i.e. that of the material derived from the North–West, from the Öskü–Gyulafirátót area) was predominant. However, the thickest accumulation occurred in the foredeep between Inota and the Aluminium Smelter. For example, the thickest Sarmatian accumulation, i.e. 181m, is found in borehole Inota I–42, whereas in borehole Inota I–86 its thickness is 176m. Nevertheless, the sediments derived from the three places of origin belong to the Gyulafirátót Formation which becomes thinner south-eastwards. Its minimum thickness, i.e. 18m, is encountered in borehole Küngös Kü–1 where it overlies the Upper Badenian.

In contrast to earlier transgressions the Sarmatian sea invaded the basin from the South. The most complete Sarmatian marine succession is represented by the Küngös Kü–1 borehole, which is a key section borehole with good core recovery.

The total thickness of the Sarmatian in this borehole is 95.5m. The succession comprises the 18.7 m-thick Gyulafirátót Formation which covers the Upper Badenian. Only a small part seems to be missing from the Sarmatian inland-sea succession (exposed in a thickness of 75.2m by the drilling). The latter ranges from the top of the Gyulafirátót Formation up to the base of the Lower Pannonian (Figure 3).

From a chronostratigraphic point of view the Hungarian Sarmatian can be divided into two stratigraphic units (BODA 1971, 1974). The lower corresponds to the Volchynian substage in the Eastern Paratethys. It was denominated as the Kozárdian substage by BODA, and it is characterised by the presence of several *Mohrensternia* species (which belong to the Rissoidae family) and several other taxa, such as *Terebralia bidentata* DEFR., *Microloripes dentatus* DEFR., *Cerastoderma pseudoplicata* FRIEDB. and *Nassarius coloratus sarmaticus* LASK. etc. At the end of the Kozárdian substage an orogenic movement took place again in the area of the Carpathian Basin and the Vienna Basin; in some places — such as in the Várpalota area — this movement may have been strong, as is indicated by a 0.4 metre-thick, fluvial gravel interbedding in borehole Küngös Kü–1 (KÓKAY 1996 — Figure 12). The subsequent epeirogenic subsidence was followed by the expansion of the Tinnyeian substage. The spatial overstep of the Sarmatian inland sea indicates a decrease in salinity at the same time. It resulted in the disappearance of several mollusc and foraminifer species. Coevally, several Badenian relict species, which had survived in some bays of the Carpathian Basin and Vienna Basin, were "washed out" from their habitats during the end-Kozárdian regression. Furthermore, due to the following Tinnyeian transgression, they appeared in new areas. In the international literature this "event" is explained as being a result of the rejuvenation of the connection with the Mediterranean; however, the author thinks this hypothesis is not correct.

It is worth mentioning that *Thericium obliquistoma* SERR. — which was found by the author in the borehole samples of the Southern sub-basin — had formerly been unknown from the Sarmatian sediments of the Paratethys. The author collected this taxon for the first time from the Kozárdian beds which had been exposed in the eastern inclined shaft in Mány. Several specimens of this species have also been found in three boreholes of the Southern sub-basin of the Várpalota Basin, in sediments belonging to the Tinnyeian substage. (The Tinnyeian is coeval with the early Bessarabian in the Eastern Paratethys region.) In the lower Tinnyeian succession — in the S-III Shaft — a 20 cm-thick bed

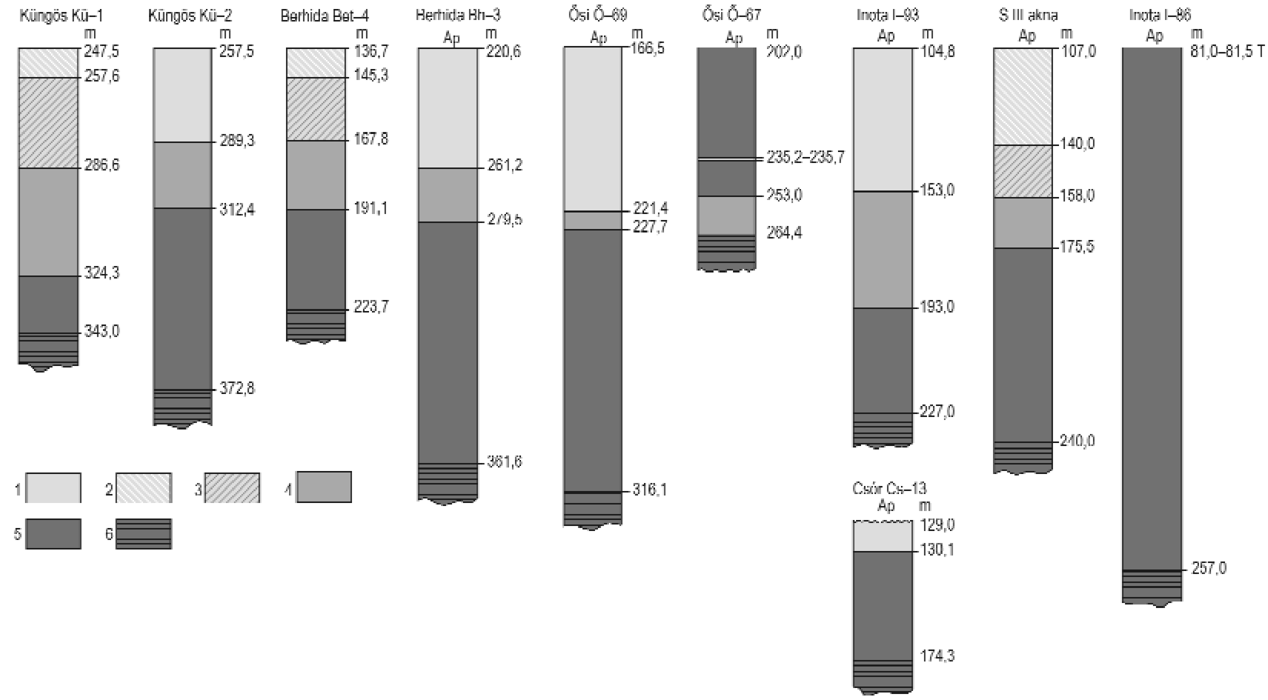

Figure 3. Sarmatian successions in the Várpalota Basin

1 – Tinnyeian substage, 2 – upper part of Tinnyeian substage, 3 – lower part of Tinnye substage, 4 – Kozárdian substage, 5 – Gyulafirátót Formation, 6 – Upper Badenian, Kü-2 = sign and number of the borehole, Ap = Lower Pannonian

***3. ábra**. Szarmata rétegsorok a Várpalotai-medencében*

1 – tinnyei alemelet, 2 – a tinnyei alemelet felső része, 3 – a tinnyei alemelet alsó része, 4 – kozárdi alemelet, 5 – Gyulafirátóti Formáció, 6 – felső-badeni, Kü-2 = a fúrás jele, Ap = alsó-pannóniai

made up of the dense aggregations of *Ostrea gingensis sarmatica* FUCHS is present. The foraminifer *Borelis melo* (FICHTEL et MOLL) is present in borehole Ősi Ő–6 from beds of the same age. In accordance with BODA (1971, 1974) the Kozárdian fauna is usually much richer; subsequent to the decrease in salinity at the time of the Kozárdian-Tinnyeian boundary some taxa have become extinct. The juvenile specimens of some species, such as *Abra reflexa* (EICHW.) and *Mohrensternia inflata* HÖRN. occur even in the lower part of the Tinnyeian substage. This is in accordance with the author's experience acquired during the investigation of the successions. The size of several species, such as of *Agapilia picta* (FÉR.), *Mitrella scripta* BELL., *Clavatula doderleini* (M. HÖRN.), *Ocinebrina sublavata* (BAST.) and *Microloripes dujardini* (DESH.) decreases; furthermore, they disappear during the Tinnyeian.

However, the later Sarmatian was characterised by the rapid evolution of *Cardium* species, similarly to those in the Eastern Paratethys. *C. plicatofittoni* SINZ. and *C latisulcum* MÜNST. are worth mentioning, and these are also frequent in the Várpalota Basin. The Tinnyeian formations usually significantly overlap the Kozárdian sediments. The Sarmatian succession of Várpalota has been divided into biozones. From bottom to top it is the following: Mohrensternia, Cerithium, Modiola, Trochus–Mactra and Melanopsis impressa biozones (KÓKAY 1954). This classification is still valid, and the faunal content of each zone is similar to that in the Vienna Basin. Parallel to the increasing transgression, the younger "horizons" can be observed in the northernmost areas. The change was the most striking at the Kozárdian-Tinnyeian boundary. The "Cerithium biozone" corresponds with the lower Tinnyeian.

The author has found taxa — passing from the Badenian into the Sarmatian — which up until now have been unknown from the Carpathian and Vienna Basins. These are the following: *Setia laevigata* EICHW., *Nematurella scholli* SCHLICK (frequent), *Thericium obliquistoma* SERR. (frequent), *Eulimella nitidissima* MONT., *Musculus tarchanensis* GATUEV, *Lepton mionitida* KAUT. (frequent), and *Laseina inequilateralis* COSSM. It is worth mentioning that the further westwards one goes, the more Badenian relict taxa can be found in the Sarmatian fossil record of the Paratethys. This is in accordance with the author's assertion (KÓKAY 1985b) that in the Late Badenian the marine connection with the Mediterranean existed at the south-eastern foot of the Alps. Similar assertions can be made for other geological periods, too. Badenian relict species are also referred to in earlier literature, such as *Potamides hartbergensis extortus* KÓKAY and *Vulgocerithium palatinum* KÓKAY (see the latter two species in KÓKAY 1954), *Borelis melo* (FICHTEL et MOLL) (foraminifer), as well as *Nassarius pupaeformis palatinus* STR. and *Clavatula doderleini curta* BODA (the latter two species were described by BODA (1959).

The author has described a considerably rich, nonmarine mollusc fauna (134 taxa) from the Sarmatian succession (KÓKAY 2006).

Salinity problems of the Sarmatian sea

In recent decades in Hungary and in some other countries, it is a commonly held perception that the Sarmatian inland sea was hypersaline — i.e. its salinity was higher than 40‰. This was due to the recent ooid formation that emerged in sea water which had salinity conditions of at least 40‰. However, it can be supposed that this is a misconception, since in the best-studied area of this type — i.e. in the Great Bahama Bank — an intense ooid formation occurs in normal salinity conditions (BALOGH 1991, p. 513). The explanation for this is that in the coastal region the cold, $CaCO_3$- and CO_2-rich sea water arrived from the North and mixed with the warm water of the Caribbean Sea; therefore, a significant part of the carbonic acid could no longer be dissolved in the water, so the calcium carbonate did not remain in solution and was precipitated in the form of ooids. Similar circumstances can be assumed in the Sarmatian, especially during the time of the (upper) Tinnyeian substage (i.e. the upper part of the Hungarian Sarmatian [BODA 1971, 1974]). In the latter, sedimentation took place over a larger area than in the earlier Sarmatian: the cold sea water which arrived from the NE and was rich in dissolved carbonate mixed with the warm water of the Central Paratethys. This resulted in the commencement of intensive ooid formation in many places, and the process did not need even a "normal" salinity environment.

In the literature there is another argument for the existence of the hypersaline Sarmatian sea — i.e. in certain bays such as the Mány, Bicske and Zsámbék, evaporites (gypsum and elementary sulphur) occur in some boreholes. It is the same in the Southern sub-basin of the Várpalota Basin; here, thin gypsum laminae were found in the Kozárdian successions (i.e. the lower part of the Hungarian Sarmatian [BODA 1971, 1974]), in boreholes Küngös Kü–1 and –2. Moreover, in the second borehole a 5-cm-thick gypsum layer is present. It should be noted that in this period a considerably strong tectonism affected the area and the entire Hungarian Range moved east–south-eastwards. Meanwhile, the entrances of some bays were periodically blocked, and saline lagoons came into being where evaporite formation occurred. This is also indicated by the fact that the Sarmatian successions of certain bays — which protrude into the land — do not contain evaporites (e.g. the Budapest bay, Balaton Uplands bays, Nyirád bay and Pusztamiske bay). It is obvious that evaporites are present in tectonically mobile areas; however, hyper-salinity is not generally characteristic. The Kara Bogaz Bay of the brackish-water in the Caspian Sea is characterised by considerable evaporite formation under the conditions of an arid, temperate climate.

However, the fossil record does not support the hyper-saline Sarmatian sea water hypothesis, since molluscs — which could tolerate even hyposaline conditions — dwelt in the Sarmatian brachyhaline sea water in large numbers. Such fossils are the *Hydrobia* or *Valvata* species and, for example, *H. stagnalis* BAST. can be found in hyposaline waters (1–1.9‰ salinity). Species which can tolerate low-salinity water were widespread in the Sarmatian near-shore or bay facies; in some samples they are represented by several species. However, they cannot survive in upper brachyhaline or "normal" salinity sea water.

The topmost bed of the Sarmatian succession is a 0.3–4.0 m-thick minor succession made up of clay, marl, calcareous mud and calcareous marl; it also contains *Melanopsis impressa* KRAUSS. It is very expansive and overlaps the Gyulafirátót Formation. This bed (or minor succession) was found in borehole Inota I–86 (where it overlies the Gyulafirátót Formation) and in the road-cut near the Bántapuszta open-cut mine (where a 30 cm-thick biotitic-tuffitic clay bed is exposed). This layer contained small *Modiolus incrassatus* (D'ORB.) and the mollusc *Replidacna*, and is also accompanied by *Ammonia beccarii* L. It is also overlain by continental deposits which already belonged to the lower Pannonian (Ősi Formation). Austrian geologists have already classified it in the Pannonian as the Pannon "A" zone, so in the present paper this "mini stage" is not dealt with in detail. (In the Várpalota Basin this strati-graphic zone is considerably rich in fossils and contains significant fossil assemblages; nevertheless, it is not directly related to the topic of the present study.)

Conclusion

The fossil-rich, lowermost Badenian succession (M4a) — which had been previously recognized by the author in the North-West part of the study area (i.e. Bántapuszta) — can be identified all over the Várpalota Neogene Basin. It uncon-formably overlies the Karpatian. The lowermost Badenian sediments are classified into two new lithostratigraphic units by the author: i.e. the Öskü Member of the Lajta Limestone Formation ("Leithakalk") and the Berhida Member of the Pusztamiske Formation. These sediments are unconformably overlain by the younger Lower Badenian succession (M4b). The Middle Badenian substage is represented by continental-fluvial deposits. During the Late Badenian the area had no direct connection with the sea, and only the subterranean infiltration of normal-salinity sea water can be presumed. The subsidence — triggered by the tectonic collapse of the basin — led to the formation of the "Várpalota coal" and the alginite succession in the Late Badenian.

The orogenic movement subsequent to the Late Badeni-an sedimentation resulted in the uplift and, as a consequ-ence, the denudation of the hinterland and the accumulation of a continental-fluvial succession in the Várpalota Basin. The Sarmatian sea invaded the area from the South. Fossils, indicating hyposaline environmental conditions, prove the brackish character of the sea in this period. In the Paratethys, the Badenian relict fossils become more frequent towards the West; this indicates a connection with the Mediterranean towards Slovenia.

References — Irodalom

BALOGH K. szerk. 1991: *Szedimentológia, I.* — Akadémiai Kiadó, Budapest, 547 p.

BODA J. 1959: A magyarországi szarmata emelet és gerinctelen faunája. — *A Magyar Állami Földtani Intézet Évkönyve* **47/3,** 567–862.

BODA J. 1971: A magyarországi szarmata emelet taglalása a gerinctelen fauna alapján. — *Földtani Közlöny* **101/2–3,** 107–113.

BODA J. 1974: A magyarországi szarmata emelet rétegtana. — *Földtani Közlöny* **102/3,** 249–260.

ELEK I. 1987: A Berhida–3. sz. fúrás szénkőzettani vizsgálatának eredményei. — *Kézirat,* Magyar Állami Földtani, Geofizikai és Bányászati Adattár, Budapest.

GAUDANT, J. 2005: A várpalotai diatomitos felső-bádeni halfaunája és annak paleoökológiai jelentősége. — *Földtani Közlöny* **135/1,** 21–30.

GYALOG, L., BUDAI, T. szerk. 2004: Javaslatok Magyarország földtani képződményeinek litosztratigráfiai tagolására. (Proposal for new lithostratigraphic units of Hungary.) — *A Magyar Állami Földtani Intézet Évi Jelentése 2002-ről,* 195–232.

KATONA L. T., KÓKAY J., BERTA T. 2011: A várpalotai Faller utcai badeni korú üledék molluszka faunája (Badenian mollusc fauna from Várpalota, Faller street). — *Földtani Közlöny* **141/1,** 3–14.

KECSKEMÉTINÉ KÖRMENDI A. 1962: Új Molluszka-fajok a várpalotai középsőmiocénből. I. Gastropoda; II. Lamellibranchiata. — *Földtani Közlöny* **92,** 81–99; 217–229.

KÓKAY J.: 1954: Várpalotai szarmata. — *Földtani Közlöny* **84,** 29–38.

KÓKAY J. 1967a: A Bakony-hegység felsőtortonai képződményei. — *Földtani Közlöny* **97/1,** 74–90.

KÓKAY J. 1967b: Sótartalomra vonatkozó őskörnyezettani vizsgálatok a bakonyi középső-miocén cerithiumos faunákon. — *Őslénytani Viták* **8,** 6 p.

KÓKAY, J.: 1967c: Stratigraphie des Oberhelvets („Karpatien") von Várpalota (Ungarn) — *Palaeontographia Italica* **63** (33), 76–111, tav. V–IX e 3 figure nel testo

KÓKAY J. 1985a: Tektonikai-geomechanikai vizsgálatok a Bántapusztai-medence területén (Várpalota). — *A Magyar Állami Földtani Intézet Évi Jelentése 1983-ról,* 43–50.

KÓKAY, J. 1985: Central and Eastern Paratethyan Interrelations in the Light of Late Badenian Salinity Conditions. — *Geologica Hungarica series Palaeontologica* **48,** 7–95.

KÓKAY J. 1996: A várpalotai neogén medence tektonikai összefoglalója (Tectonic description of the Neogene Várpalota basin (Bakony Mts, W Hungary). — *Földtani Közlöny* **126/4,** 417–445.

KÓKAY, J. 2006: Nonmarine mollusc fauna from the Lower and Middle Miocene, Bakony Mts., W Hungary. — *Geologica Hungarica series Palaeontologica* **56,** 196 p.

KÓKAY J. 2008: A várpalotai neogén medence középső-miocén képződményeinek vizsgálata. Study of the Middle Miocene of the Várpalota Neogene basin. — OTKA T 026440 http://nyilvanos.otka-palyazat.hu/index.php?menuid=930&num=46178&lang=EN

KÓKAY J. & RAINCSÁK GY. 1983: Földtani leírás a Várpalota és Hajmáskér (Lőtér) jelű 20 000-es földtani térképek területéhez. — *Kézirat,* Magyar Állami Földtani, Geofizikai és Bányászati Adattár, Budapest.

KORDOS L. 1985: A magyarországi eggenburgi–szarmata képződmények szárazföldi gerinces maradványai, biozonációja és rétegtani korrelációja. — *A Magyar Állami Földtani Intézet Évi Jelentése 1983-ról,* 157–165.

PENTELÉNYI L. 2000: Rövid ismertetés a Csór–17., Inota–138., Küngös–2. és Polgárdi–2. sz. fúrások miocén tufa-tufit betelepüléseiről. — *Kézirat,* Magyar Állami Földtani, Geofizikai és Bányászati Adattár, Budapest.

SOLTI G. 1980: A várpalotai bádenien korú diatomás agyagmárga összlet olajpala-földtani vizsgálata. — *Kézirat,* Egyetemi doktori értekezés, ELTE, Budapest.

SZALAI T. 1926: A várpalotai középmiocén faunája. — *Annales Historico-Naturales Musei Nationalis Hungarici* **24,** 331–347.

TELEGDI-ROTH L. 1924: A várpalotai lignitterület. — *Földtani Közlöny* **54,** 38–45.

Kézirat beérkezett: 2012. 04. 27.