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Diachronous deposits of Lake Pannon in the Kisalföld Basin reflect basin and mollusc evolution

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Pannonischer See
Kleine Ungarische Tiefebene
Burgenland
Slowakei
Beckenanalyse
Mollusken-Evolution

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Contents

Diachrone Ablagerungen des Pannonischen Sees in der Kleinen Ungarischen Tiefebene als Zeugen der Beckenentwicklung und der Molluskenevolution

Zusammenfassung

Das jungtertiäre Becken der Kleinen Ungarischen Tiefebene (Kisalföld) bildet einen Teilabschnitt des mitteleuropäischen Pannonischen Beckens und umfaßt Gebiete in der südwestlichen Slowakei, im östlichen Österreich sowie im nordwestlichen Ungarn. Littorale Sedimente des spätmiozänen Pannonischen Sees sind sowohl an dessen Westrand im Burgenland aufgeschlossen, als auch an dessen Ostrand im Transdanubischen Mittelgebirge. Reflexionsseismische Profile bezeugen, daß die Sedimentfüllung der Kleinen Ungarischen Tiefebene von NW nach SE progradierte. Als Folge dessen stellen die littoralen Sedimente des Burgenlands und des Transdanubischen Mittelgebirges nicht gegenüberliegende Küstenbildungen der Kleinen Ungarischen Tiefebene dar, sondern wurden entlang der gleichen progradierten nordwestlichen Küstenlinie des Pannonischen Sees, jedoch zu jeweils anderer Zeit, abgelagert. Die Molluskenfauna der westlichen Aufschlüsse ist einförmig ausgebildet und wird hier als "Fauna des Burgenlands" bezeichnet. Gleichermaßen ist auch die Fauna der östlichen Aufschlüsse recht einförmig ausgebildet und wird hier als "Fauna des Transdanubischen Mittelgebirges" bezeichnet. Aufgrund der Ähnlichkeiten zwischen diesen beiden Faunen, kann wohl davon ausgegangen werden, daß ihre Lebensräume im littoralen Bereich des Pannonischen Sees sehr ähnlich ausgebildet waren. Mehrere Bivalvenarten zeigen jedoch deutliche morphologische Unterschiede in den beiden Faunengebieten, die auf evolutive Ursachen zurückgeführt werden. Der Unterschied zwischen der Fauna des Burgenlands und der Fauna des Transdanubischen Mittelgebirges hat biostratigraphische Bedeutung, wodurch die Grenze zwischen der *Lymnocardium conjungens* Zone (Burgenland) und der *Lymnocardium ponticum* Zone (Transdanubisches Mittelgebirge) definiert wird. Magnetostratigraphische Daten legen nahe, daß mit einem Zeitunterschied im Bereich von etwa 500.000 Jahren zu rechnen sein dürfte.

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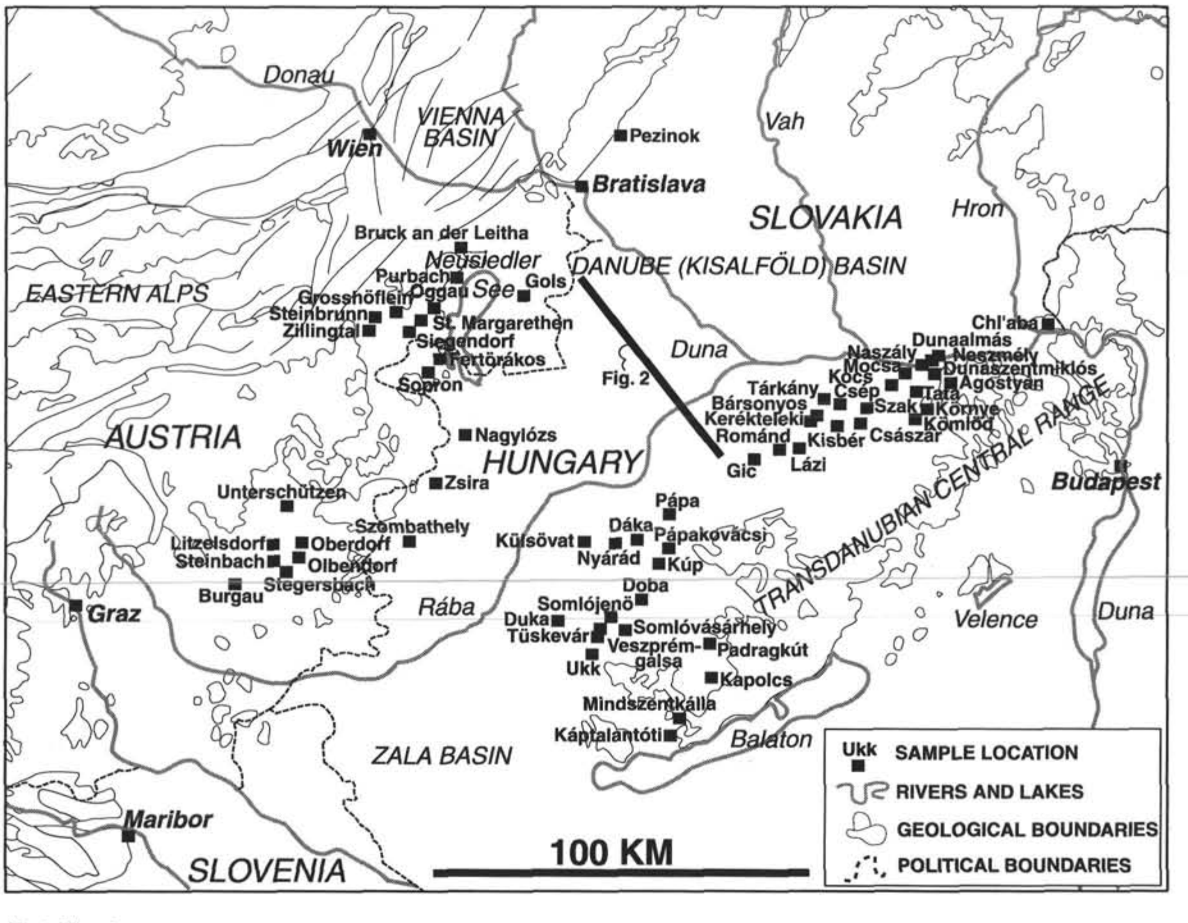
Abstract

The Neogene Kisalföld Basin is a subunit of the Central European Pannonian Basin. It includes southwestern Slovakia, the easternmost part of Austria, and northwestern Hungary. Littoral sediments of the Late Miocene Lake Pannon outcrop along the western (Burgenland) and eastern (Transdanubian Central Range, TCR) margins of the basin. Seismic reflection profiles across the Kisalföld Basin indicate that the basin was filled with sediments via progradation from the NW to the SE. Consequently, the littoral sediments of Burgenland and the Transdanubian Central Range do not represent opposite shores of the Kisalföld Basin; instead, they were deposited on the same prograding northwestern shoreline of Lake Pannon during two different time intervals. The mollusc fauna of the western outcrops is uniform (referred to here as the Burgenland fauna). Similarly, the eastern outcrops yield a uniform fauna (the TCR fauna). Similarity between the Burgenland and the TCR faunas allows us to establish that they lived in similar environments in the littoral zone of Lake Pannon. There are, however, consistent morphological differences between Burgenland and TCR forms in several bivalve species, which are thus interpreted as evolutionary change. The difference between the Burgenland and TCR faunas is useful for biostratigraphy; it defines the boundary between the *Lymnocardium conjungens* Zone (Burgenland) and *Lymnocardium ponticum* Zone (TCR). Magnetostratigraphic data suggest that the time difference involved is on the order of a half million years.

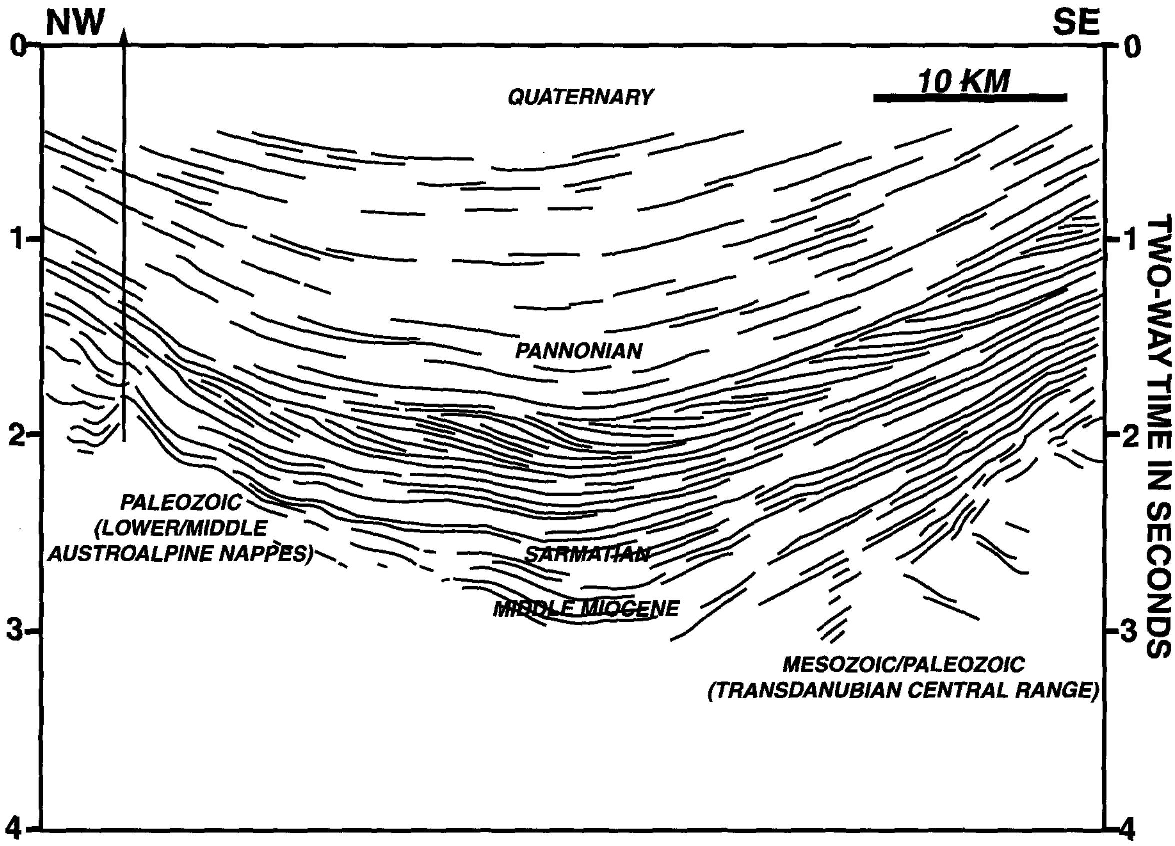
1. Geological setting

The Kisalföld ("Danube") Basin is a subbasin of the Neogene Pannonian Basin of Central Europe. Its area is shared by Austria, Slovakia, and Hungary (Text-Fig.1). The geology of the Kisalföld basin has recently been treated by Kőrössy (1987), Keith et al. (1994), Tari (1994, 1996), Horváth et al. (1995a), Mattick et al. (1996), Hrušecký et al. (1996), and Kováč & Baráth (1996). The Kisalföld Neogene Basin is superimposed on the Alpine thrust-fold belts of the Eastern Alps and Western Carpathians. Following an Early to Middle Miocene, partly terrestrial, partly marine synrift stage, the bulk of the Neogene sedimentary formations were deposited in the Late Miocene brackish Lake Pannon, which flooded the area due to a widespread post-rift (thermal) subsidence. Seismic reflectors show that the Kisalföld Basin was filled with sediments prevailingly from the NW, implying that the littoral zone of Lake Pannnon shifted from the NW towards the SE (Text-Fig. 2). Seismic profiles also suggest that at this time the Transdanubian Central Range (TCR) was a submerged sill, or a series of islands at best.

Due to Pliocene-Quaternary tectonic inversion, the sedimentary formations of Lake Pannon became exposed and eroded along the western and eastern edges of the basin, while the central part underwent continued subsidence, and was covered by Pliocene and Quaternary terrestrial sediments (Horváth et al., 1995b). Along the western edge of the basin, the littoral sediments of Lake Pannon outcrop in a number of fossiliferous localities in Burgenland and adjacent areas of Slovakia and Hungary, from Pezinok in the north to Stegersbach in the south. Similar sediments outcrop at the eastern boundary of the basin, along the western foot of the TCR, from Chl'aba in the north to Ukk in the south (Text-Fig. 1).



Text–Fig. 1.
The Kisalföld Basin with locations referred to in the text and in the Appendix.



Text–Fig. 2.
Line drawing interpretation of a seismic profile illustrating progradation from the northwest towards the southeast across the Kisalföld Basin. For location see Fig. 1. Vertical exaggeration is ten-fold at 2000 m/s velocity. For the original seismic profile see TARI (1994) and HORVÁTH et al. (1995b).

We observed that the littoral bivalve fauna from the western margin of the basin ("Burgenland fauna") is uniform in the sense that it represents a particular evolutionary stage in each lineage. We found that the same is true for the eastern margin as well; apart from slight facies differences, any member of this "TCR fauna" is represented by the same evolutionary stage in the outcrops throughout the entire length of the TCR. There are striking similarities between these uniform western and eastern faunas, suggesting that their paleoenvironments were very similar. In a number of bivalve species, however, there are relatively slight, but consistent morphological differences between the two faunas, reflecting evolutionary changes through time. These differences in most cases are easily recognizable, and make the two faunas distinguishable.

2. Materials and methods

In this study, we included only fossils that we have seen ourselves or that were depicted in publications. We did not use reports or determinations that we have not had the opportunity to check. We utilized the following museum and private collections (the list of fossils that formed the basis for this study is given in the Appendix):

BL: Collection of the Burgenland Museum (Eisenstadt, Austria)
DHG: Collection of DANA H. GEARY (Madison, USA) (Stegersbach material is courtesy of FRANZ SAUERZOPF)
FS: Collection of Franz Sauerzopf (Rust, Austria)
HPM: Collection of the Croatian Natural History Museum (Zagreb, Croatia)
JPL: Collection of JOSEF PAUL LUEGER (St. Leonhard am Forst, Austria)
MÁFI: Collection of the Hungarian Geological Institute (Budapest, Hungary)
MM: Collection of PÁL MÜLLER and IMRE MAGYAR (Budapest, Hungary)
NHMW: Collection of the Vienna Natural History Museum (Vienna, Austria)
TTM: Collection of the Hungarian Natural History Museum (Budapest, Hungary)
UV: Collection of the University of Vienna (Vienna, Austria)

The fossils were collected from littoral sandy or gravely deposits. Even in the case of museum specimens, we were able to identify the original embedding rock because we knew the outcrop from which the specimens came, the description of the outcrop was available, or because sand grains attached to the shells indicated the sandy environment. These sand layers are either amalgamated, forming thick sandy sequences, or they are thin intercalations in sublittoral silt sequences.

In Burgenland as well as adjacent areas of Slovakia and Hungary, the littoral deposits of Lake Pannon are of various ages. In this study we included the youngest and most widespread littoral deposits only, omitting older formations (*Congeria ornithopsis* and *Congeria hoernesi* Zones, or B and C Zones of PAPP, 1951) which outcrop in more restricted areas (e. g. in several localities around Sopron [PAPP, 1951, VITÁLIS, 1951], and in the Styrian Basin [EBNER & SACHSENHOFER, 1995]). These older formations are missing at the eastern margin of the basin.

Our objective here is not to compile a comprehensive list of bivalve species for each locality; instead, we want to complete earlier published information with unpublished data coming from different collections, in order to demonstrate similarities and differences among bivalve faunas. We omitted some relatively rare, or less studied dreissenid and cardiid species, and the sporadically appearing *Pisidium*. On the other hand, we included species that rarely occur in the given fauna if they are common on the opposite side of the basin (e. g. *Congeria ungulacaprae* is common in the TCR fauna, so we included its occurrences in Sopron and Pezinok; or *"Didacna" deserta* is very common in the Burgenland fauna, so we included its single known occurrence in the TCR area).

3. Comparison of the Burgenland and TCR faunas

3.1 Similarities

Many identical or very closely related species occur in the Burgenland and TCR faunas. Some of these common species are rare in other parts of the Pannonian basin, thus enhancing the impression that the Burgenland and TCR faunas are closely related. Some of our new findings confirm a close relationship between the two faunas: we found *Euxinicardium schreteri*, a species that had been known from the TCR only, in Burgenland. We also found two "typical" Burgenland species, *Lymnocardium tucani* and *"Monodacna" viennensis,* in the TCR.

Species that occur in both faunas include: *Congeria ungulacaprae, Dreissena bipartita, Lymnocardium hantkeni, L. tucani, Caladacna steindachneri, Euxinicardium schreteri, "Monodacna" viennensis, "Didacna" deserta*, and *Parvidacna* sp. Ancestor – descendant pairs in the two faunas are (with the older, Burgenland form first): *Unio atavus-U. mihanovici, Congeria gitneri-Dreissena auricularis, Lymnocardium schedelianum-L. variocostatum, L. conjungens-L. penslii,* and *L. edlaueri-L. ponticum.*

3.2. Differences

Some of the differences between the Burgenland fauna and the TCR fauna are conspicuous. The TCR fauna lacks shouldered *Melanopsis (M. vindobonensis, M. fossilis),* certain large *Congeria* species *(C. pancici, C. spathulata),* and some cardiid species *(L. brunnense, L. danicici, L. carnuntinum, L. stoosi),* whereas the Burgenland fauna lacks *Dreissenomya unioides, "Lymnocardium" priscae,* and *L. apertum.* Significant differences in the frequency of certain species exist as well. *"Didacna" deserta* is very common in Burgenland, but we know only a single intact specimen from the TCR. *Congeria ungulacaprae*, on the other hand, is one of the most common species in the TCR, but it is much less common in Burgenland.

Aside from these conspicuous taxonomic differences, slight but consistent morphological differences characterize the ancestor (Burgenland) – descendant (TCR) species pairs in some bivalves. Traditionally, the ancestral and the derived forms were described as different species, although the morphological difference between them is sometimes very slight, and can be appreciated only when larger samples are compared.

In Burgenland specimens of *Unio atavus,* the position of the beak in relation to the anterior margin is variable, but typically quite distant. In its descendant, *U. mihanovici,* however, it is invariably terminal, very close to the anterior margin. In addition, the beak is always above the dorsal margin in *U. atavus,* whereas it is in much lower position in *U. mihanovici* (MÜLLER, 1990; Plate 1, Fig. A, A').

According to PAPP (1950), the Vienna Basin and Burgenland fossil record shows that *Congeria* lost its apophyse (a tiny plate where the adductor muscle attached) in at least two independent lineages. *Congeria* has a well-developed apophyse, whereas the lack of it is a diagnostic feature of *Dreissena,* where both the anterior adductor and retractor attach to the same septum. One of these morphological changes is reflected in the Burgenland/TCR material. *Congeria gitneri* (= *"D. minima"* in LUEGER, 1980) in Stegersbach and Großhöflein (Burgenland) has a rudimentary apophyse (Plate 1, Fig. B, C, D). In *Dreissena auricularis* (TCR), however, there is no trace of the apophyse left (Plate 1, Figs. B', C', D'). (We know a sample from Pezinok [MÁFI Pl. 6091] where there is no apophyse, although this locality yielded Burgenland fauna.)

The Burgenland *Lymnocardium schedelianum* is a large cockle with relatively wide and rounded ribs, which are always separated by intercostal space (Plate 1, Fig. E). The only difference between this form and its descendant from the TCR, *L. variocostatum,* is that the ribs of the latter are completely flat and tightly spaced; intercostal space is present only on the very anterior slope of the shell (Plate 1, Fig. E').

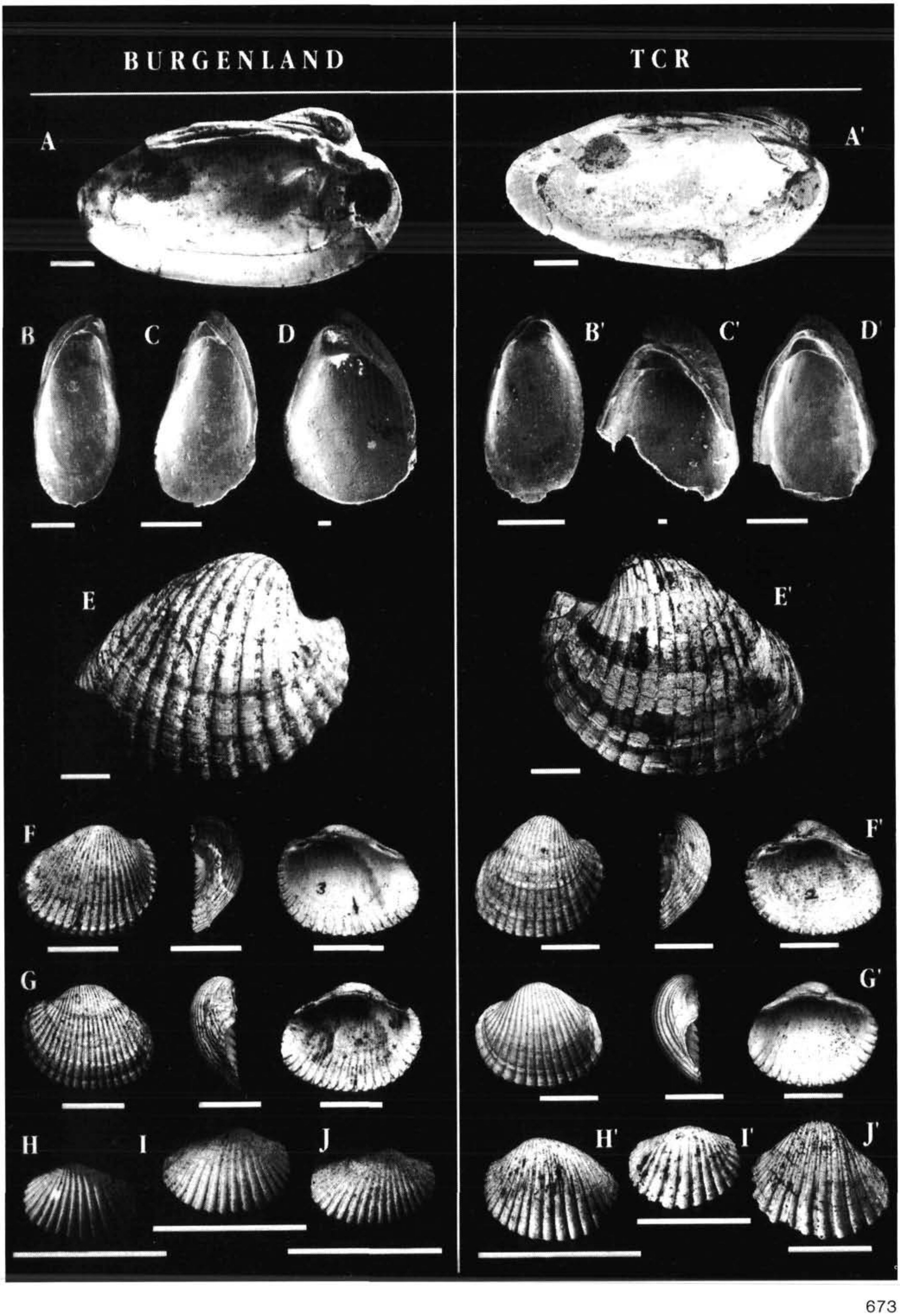
Lymnocardium conjungens (Burgenland; Plate 1, Fig. F, G) is similar to the early form of *L. penslii* (TCR). The latter is generally larger, and with different proportions in being higher, and having a wider posterior gape (Plate 1, Fig. F', G'). The umbo above the hinge is also higher. LUEGER (1980) reported the common occurrence of *L. conjungens* and *L. penslii* from Großhöflein, Burgenland. Indeed, his *"L. penslii"* specimens are unusually large for *L. conjungens,* but they

Plate 1

Ancestor – descendant pairs in bivalves from the western (Burgenland) and eastern (TCR) margins of the Kisalföld Basin.

Fig.-A:	*Unio atavus* Hörnes, Großhöflein.
Fig.-A':	*Unio mihanovici* BRUSINA, Dáka;
Fig.-B, C, D:	*Congeria gitneri* BRUSINA, B, C: Stegersbach, D: Großhöflein.
Fig.-B', C', D':	*Dreissena auricularis* (FUCHS), B': Lázi, C': Szák, D': Neszmély.
Fig.-E:	*Lymnocardium schedelianum* (PARTSCH) (authorship and taxonomic status needs revision), Oggau.
Fig.-E':	*Lymnocardium variocostatum* VITÁLIS, Dáka.
Fig.-F, G:	*Lymnocardium conjungens* (HÖRNES), Stegersbach.
Fig.-F', G':	*Lymnocardium penslii* (FUCHS), F': Ukk, G': Tüskevár.
Fig.-H, I, J:	*Lymnocardium edlaueri* PAPP, H: Pezinok, I, J: Stegersbach.
Fig.-H', I', J':	*Lymnocardium ponticum* HALAVÁTS, H': Pápa, I': Nyárád, J': Dáka.

Scale bars indicate 1 cm, except Fig.-B, C, B', D', where it is 1 mm, and Fig.-D and C', where it is 100 µm.


BURGENLAND
TCR
A
A'
B
C
D
B'
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E
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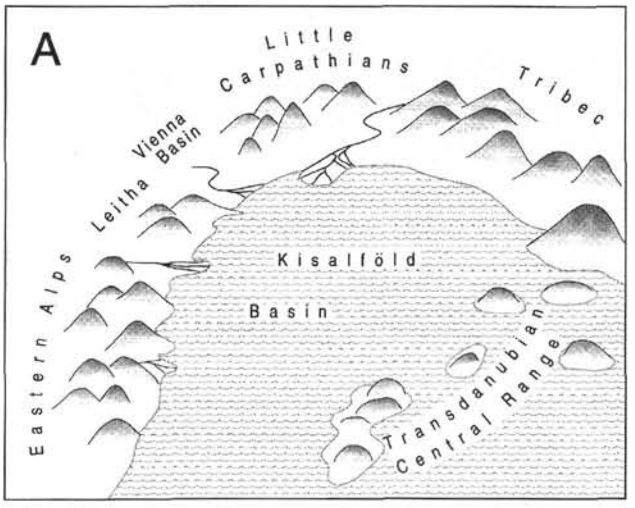
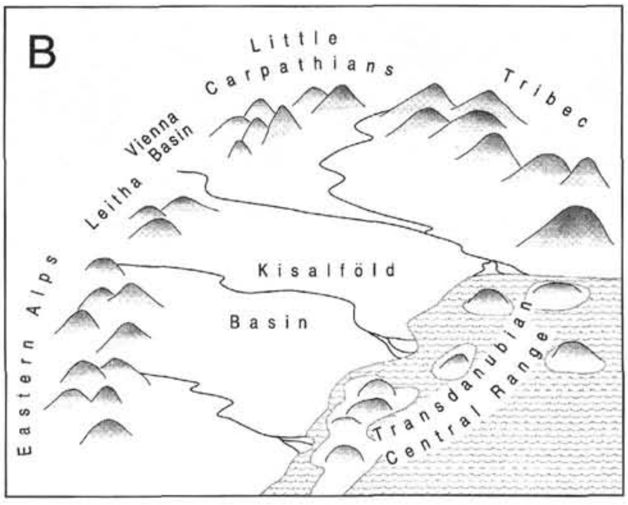
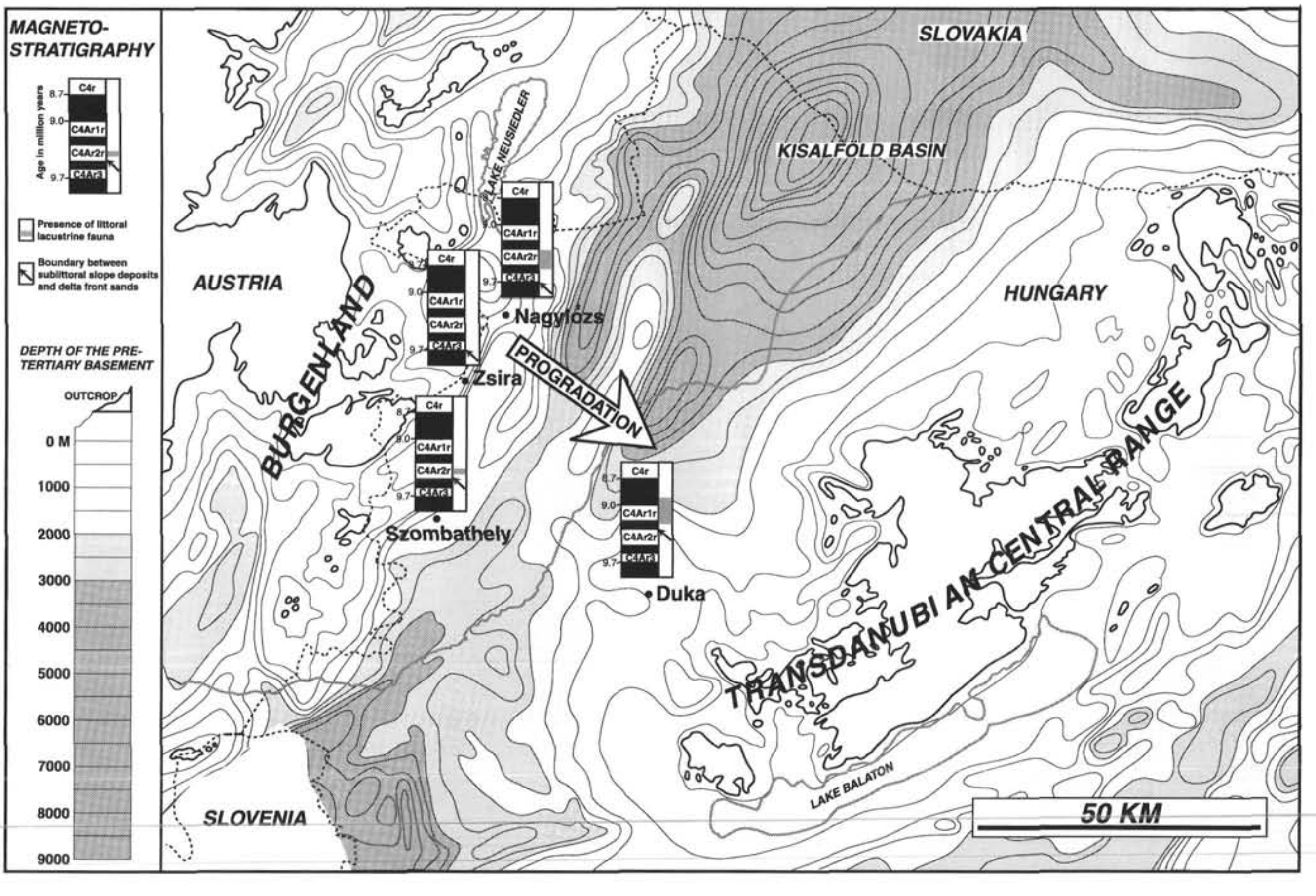




Text–Fig. 3.
Generalized cartoon representing the paleogeographic evolution of the Kisalföld Basin between the time of the "Burgenland fauna" (*Lymnocardium conjungens* Biochron; Fig. A) and the time of the "TCR fauna" (*Lymnocardium ponticum* Biochron; Fig. B).



Text–Fig. 4.
Assessment of the age of the Burgenland and TCR faunas by means of magnetostratigraphy. Along the western margin of the Kisalföld Basin, the boundary between fine-grained, sublittoral slope deposits and delta front sands were correlated to the top of C5n (Nagylózs-1, Zsira-1) and to the base of C4Ar2r (Szombathely-II). These correspond to ca. 9.7 and 9.5 Ma, respectively, according to BERGGREN et al. (1995). The littoral lacustrine fauna appears both in the Nagylózs-1 and Szombathely-II boreholes in C4Ar2r. At the eastern margin of the basin, in the Duka-II borehole, the base of the delta front deposits correlates to C4Ar1n (ca. 9.3 Ma), and the littoral fauna occurs from C4Ar1n to C4n. (Correlation of the actual polarity record of each borehole to the standard scale was carried out by Lantos, using the long normal C5n as tie-point in the western boreholes, and utilizing seismic profiles to connect the Duka section with Szombathely; see also MAGYAR et al., 1999.)

are injured and fragmentary thus cannot be subject to morphometric analysis.

Lymnocardium edlaueri is a common, but small bivalve in Burgenland (Plate 1, Fig. H, I, J) that is very similar to *L. ponticum* (TCR; Plate 1, Fig. H', I', J'). *L. edlaueri* tends to be more elongate antero-posteriorly; *L. ponticum* usually grows bigger, and in larger specimens the umbo is high above the hinge.

In two additional cases, the significance of the morphological differences between the Burgenland and the TCR specimens is unclear because we have so few specimens from the TCR. *Lymnocardium tucani* from Burgenland usually has more than 30 ribs. The TCR specimens, however, have only 23 to 26. Apart from this difference, the shells from the two regions look very much alike. The only known full TCR specimen of *"Didacna" deserta* significantly differs from the Burgenland specimens in having a longer posterior margin, and consequently, a smaller angle between the posterior and posterodorsal margins. The ventralmost point of the valve is in the posterior part, instead of being in central position (see MILAN et al., 1974).

4. Discussion

The only alternative to an evolutionary explanation for the morphological differences observed between Burgenland and TCR bivalves is that these differences reflect geographic variation. This hypothesis would require the presence of a paleogeographic barrier between the western and eastern margins of the Kisalföld Basin, such as, for instance, a profoundal lacustrine zone in the axis of the basin. Seismic evidence, however, indicates that although the Burgenland outcrops and the TCR outcrops are presently situated on the opposite margins of the Kisalföld Basin, historically they represent the same (NW) shoreline of Lake Pannon at two different times in the evolution of the lake (Text-Fig. 3).

The morphological and temporal differences between the Burgenland fauna and the TCR fauna provide the basis for the distinction of the *Lymnocardium conjungens* Zone (Burgenland) and *L. ponticum* Zone (TCR). Our paleogeographic model implies that between the Burgenland and TCR faunas there must be a continuous littoral fossil record buried beneath Pliocene and Quaternary sediments in the central part of the Kisalföld Basin.

Our progradational model has further predictions/consequences. It implies that 1) the youngest lacustrine fauna in the Vienna Basin is older than the Burgenland fauna; and 2) the littoral fauna southeast of the TCR is younger than the TCR fauna. The second prediction is met by the presence of the *Lymnocardium decorum* Zone (with Tihany- and Rădmăneşti-type faunas; see MÜLLER, 1990 and MARINESCU, 1990) south and east of the TCR. Data relevant to the first prediction are more ambiguous. Austrian, Czech, and Slovak stratigraphers traditionally assign the uppermost lacustrine fauna of the Vienna Basin as well as that of Burgenland to Zones D and E of PAPP (1951), and do not recognize an age difference between the faunas of the Vienna Basin and Burgenland (see, for instance, PAPP, 1951; SAUERZOPF, 1952; LUEGER, 1980; JIŘÍČEK, 1985; FORDINÁL, 1997). At this time, we cannot provide convincing paleontological evidence that the Vienna Basin littoral faunas are older than those from Burgenland, however we know of no evidence that argues against this interpretation.

According to this progradational model, the TCR lacustrine fauna cannot occur in Burgenland, because the latter area was transformed into alluvial plains by the time the TCR fauna evolved. The Burgenland fauna, however, could live in the TCR region, in littoral zones around islands. Indeed, we know one such occurrence from the southernmost part of the TCR. The Kálla Gravel and Sand Formation (JÁMBOR, 1980) contains typical "Burgenland" molluscs: *Unio atavus, Congeria* sp. ex group *C. subglobosa-pancici, Lymnocardium* cf. *soproniense* (or *schedelianum*?), and *Melanopsis fossilis* (see MAGYAR, 1988).

There are no radioisotopic ages from the Kisalföld Basin to determine the age of the respective faunas. We must rely on magnetostratigraphic analyses from the Nagylózs-1, Zsira-1, Szombathely-II, and Duka-II boreholes. Interpretation of these polarity profiles by LANTOS (in LANTOS & ELSTON, 1995 and pers. comm.) is anchored to the long-lasting Chron 5 normal. In the Nagylózs and Szombathely boreholes, which lie close to the western margin of the Kisalföld Basin, the interval with the littoral lacustrine fauna was correlated to C4Ar2r (MAGYAR et al., 1999; cf. KORPÁS-HÓDI, 1992 and LANTOS & ELSTON, 1995). On the opposite (eastern) side of the basin, in the Duka-II borehole, however, the littoral fauna correlates to C4Ar1r (MAGYAR et al., 1999; identification of molluscs in all three boreholes was carried out by KORPÁS-HÓDI; Text-Fig. 4). If we accept this correlation, then the age of the Burgenland fauna is somewhat older than 9.5 mys (because the Burgenland outcrops lie westward from these boreholes), whereas the age of the TCR fauna is slightly younger than 9.3 mys. The age difference between the western and eastern littoral faunas of the Kisalföld Basin is thus on the order of 0.5 million years.

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References

ANDRUSOV, N.: Fossile und lebende Dreissensidae Eurasiens. – Travaux de la Société des Naturalistes de St.-Petersbourg. Section de Géologie et de Minéralogie, 25, 1–683, avec un atlas de vingt planches, Sankt Petersburg 1897.

BARTHA, F.: Lázi felső-pannóniai korú faunájának biosztratigráfiai vizsgálata (Dépouillement biostratigraphique de la faune pannonienne supérieure de la localité Lázi). – Annual Report of the Hungarian Geological Institute of 1960, 265–283, Budapest 1963.

BERGGREN, W.A., KENT, D.V., SWISHER, C.C., & AUBRY, M-P.: A revised Cenozoic geochronology and chronostratigraphy. – In: BERGGREN, W.A., KENT, D.V., AUBRY, M-P. & HARDENBOL, J. (Eds): Geochronology time scales and global stratigraphic correlation, SEPM Special Publication, 54, 129–212, 1995.

BRUSINA, S.: Iconographia molluscorum fossilium in tellure Tertiaria Hungariae, Croatiae, Slavoniae, Dalmatiae, Bosniae, Herzegovinae, Serbiae et Bulgariae inventorum. Atlas II, Plates 1–30, Zagreb 1902.

EBNER, F. & SACHSENHOFER, R.F.: Paleogeography, subsidence and thermal history of the Neogene Styrian Basin (Pannonian Basin system, Austria). – Tectonophysics, 242, 133–150, Amsterdam 1995.

FORDINÁL, K.: *Congeria doderleini* Brusina from Pannonian sediments in a loam pit of the brick plant at Pezinok. – Západ. Karpaty, Sér. Paleont., 15, 71–77, Bratislava 1991.

FORDINÁL, K.: Representatives of genus *Parvidacna* (Bivalvia) in Pannonian sediments of the Bratislava area. – Západ. Karpaty, Sér. Paleont., 17, 71–79, Bratislava 1993.
FORDINÁL, K.: Bivalvia (Dreissenidae, Cardiidae) from Upper Miocene sediments in Bratislava. – Geol. Práce, 100, 27–36, Bratislava 1995.
FORDINÁL, K.: Molluscs (gastropoda, bivalvia) from the Pannonian deposits of the western part of Danube Basin (Pezinok-clay pit). – Slovak Geological Magazine 3-4, 263–283, Bratislava 1997.
FUCHS, Th.: Beiträge zur Kenntnis fossiler Binnenfaunen 4 und 5: Die Fauna der Congerienschichten von Tihany am Plattensee und Kúp bei Pápa in Ungarn. – Jahrbuch k. k. Geol. Reichsanstalt, 20, 531–548, Wien 1870.
HORVÁTH, F., TARI, G. & BOKOR, Cs. (Eds.) (a): Hungary: Extensional collapse of the Alpine orogene and hydrocarbon prospects in the basement and basin fill of the western Pannonian Basin. – AAPG International Conference and Exhibition, Field Trip Notes 6, 1–204, Nice 1995.
HORVÁTH, F., CLOETINGH, S. & TARI, G. (b): Stress-induced late stage subsidence anomalies of the Pannonian Basin. – In: HORVÁTH, F., TARI, G. & BOKOR, Cs. (Eds.): Hungary: Extensional collapse of the Alpine orogene and hydrocarbon prospects in the basement and basin fill of the western Pannonian Basin. AAPG International Conference and Exhibition, Field Trip Notes 6, 47–60, Nice 1995.
HRUŠECKÝ, I., ŠEFARA, J., MASARYK, P. & LINTNEROVÁ, O.: The structural and facies development and exploration potential of the Slovak part of the Danube Basin. – In: WESSELY, G. & LIEBL, W. (Eds.): Oil and gas in Alpidic thrustbelts and basins of Central and Eastern Europe. EAGE (European Association of Geoscientists and Engineers) Special Publication 5, 417–429, Geological Society Publishing House, Bath 1996.
JÁMBOR, Á.: A Dunántúli-középhegység pannóniai képződményei (Pannonian in the Transdanubian Central Mountains). – Annals of the Hungarian Geological Institute, 62, 1–259, Budapest 1980.
JIŘÍČEK, R.: Die slowakische Donautiefebene. – In: PAPP, A., JÁMBOR, Á. & STEININGER, F.F. (Eds.): Chronostratigraphie und Neostratotypen. Miozän der Zentralen Paratethys VII, M6, Pannonien, 276–339, Akadémiai Kiadó, Budapest 1985.
KEITH, J.F., VASS, D. & KOVÁČ, M.: The Danube lowland basin. – ESRI Occasional Publication, New Series No. 11A-B, 63–87, Columbia 1994.
KŐRÖSSY, L.: A kisalföldi kőolaj-és földgázkutatás földtani eredményei (Hydrocarbon geology of the Little Plain in Hungary). – Általános Földtani Szemle, 22, 99–174, Budapest 1987.
KORPÁS-HÓDI, M.: Palaeoecology and biostratigraphy of the Pannonian Mollusca fauna in the northern foreland of the Transdanubian Central Range. – Annals of the Hungarian Geological Institute, 66, 1–163, Budapest 1983.
KORPÁS-HÓDI, M.: A Szombathely II. sz. fúrás pannóniai (s. l.) molluscái (The Pannonian (s. l.) molluscs of borehole section Szombathely II). – Annual Report of the Hungarian Geological Institute of 1990, 505–525, Budapest 1992.
KOVÁČ, M. & BARÁTH, I.: Tektonicko-sedimentárny vývoj alpsko-karpatsko-panónskej styčnej zóny počas miocénu (Tectono-sedimentary development of the Alpine-Carpathian-Pannonian junction zone during the Miocene). – Mineralia Slovaca, 28, 1–11, Bratislava 1996.
LANTOS, M. & ELSTON, D.P.: Low- to high-amplitude oscillations and secular variation in a 1.2 km late Miocene inclination record. – Physics of the Earth and Planetary Interiors, 90, 37–53, Amsterdam 1995.
LUEGER, J. P.: Die Molluskenfauna aus dem Pannon (Obermiozän) des Fölligberges (Eisenstädter Bucht) im Burgenland (Österreich). – Mitteilungen der österreichischen geologischen Gesellschaft, 73, 95–134, Wien 1980.
MAGYAR, I.: Mollusc fauna and flora of the Pannonian quartz sandstone at Mindszentkálla, Hungary. – Annales Universitatis Scientiarum Budapestinensis de Rolando Eotvos nominatae, sectio geologica, 28, 209–222, Budapest 1988.
MAGYAR, I., GEARY, D.H., SÜTŐ-SZENTAI, M., LANTOS, M. & MÜLLER, P.: Integrated biostratigraphic, magnetostratigraphic and chronostratigraphic correlations of the Late Miocene Lake Pannon deposits. – Acta Geologica Hungarica, 42, 5–31, Budapest 1999.
MARINESCU, Fl.: Le faciostratotype de Rădmăneşti (Banat roumain). – In: STEVANOVIĆ, P.M., NEVESSKAJA, L.A., MARINESCU, Fl., SOKAĆ, A. & JÁMBOR, Á. (Eds.): Chronostratigraphie und Neostratotypen. Neogen der Westlichen ("Zentrale") Paratethys VIII, Pl1, Pontien, 436-439. JAZU and SANU, Zagreb-Beograd 1990.
MATTICK, R.E., TELEKI, P.G., PHILLIPS, R.L., CLAYTON, J.L., DÁVID, Gy., POGÁCSÁS, Gy., BARDÓCZ, B. & SIMON, E.: Structure, stratigraphy, and petroleum geology of the Little Plain basin, northwestern Hungary. – American Association of Petroleum Geologists, Bulletin, 80, 1780–1800, Tulsa 1996.
MILAN, A., SAKAĆ, K. & ŽAGAR-SAKAĆ, A.: Katalog der im Geologisch-paläontologischen Museum in Zagreb aufbewahrten Originale von Artentypen. – Geologisch-paläontologisches Museum in Zagreb, Zagreb 1974.
MÜLLER, P.: Revised and other species of malacofauna from Tihany (Fehérpart) in Hungary. – In: STEVANOVIĆ, P.M., NEVESSKAJA, L.A., MARINESCU, Fl., SOKAĆ, A. & JÁMBOR, Á. (Eds.): Chronostratigraphie und Neostratotypen. Neogen der Westlichen ("Zentrale") Paratethys VIII, Pl1, Pontien, 558–581. JAZU and SANU, Zagreb-Beograd 1990.
PAPP, A.: Übergangsformen von *Congeria* zu *Dreissena* aus dem Pannon des Wiener Beckens. – Annalen des Naturh. Museums Wien, Wien 1950.
PAPP, A.: Das Pannon des Wiener Beckens. – Mitteilungen der Geologischen Gesellschaft in Wien, 39–41, 99–193, Wien 1951.
PAPP, A.: Die Molluskenfauna des Pannon im Wiener Becken. – Mitteilungen der Geologischen Gesellschaft in Wien, 44, 85-222, Wien 1953.
PAPP, A.: Gastropoda (Neritidae, Viviparidae, Valvatidae, Hydrobiidae, Stenothyridae, Truncatellidae, Bulimidae, Micromelaniidae, Thiaridae) und Bivalvia (Dreissenidae, Limnocardiidae, Unionidae) des Pannonien. – In: PAPP, A., JAMBOR, Á. & STEININGER, F.F. (Eds.): Chronostratigraphie und Neostratotypen. Miozän der Zentralen Paratethys VII, M6, Pannonien, 276–339, Akadémiai Kiadó, Budapest 1985.
SAUERZOPF, F.: Beitrag zur Entwicklungsgeschichte des südburgenländischen Pannons. – Burgenländische Heimatblätter, 14, 1–16, Eisenstadt 1952.
STOLIZCKA, F.: Kenntniss der Molluskenfauna der Cerithien- und Inzersdorfer Schichten des ungarischen Tertiärbeckens. – Verhandlungen der k. k. zoologisch-botanischen Gesellschaft in Wien, 7–10, Wien 1862.
STRAUSZ, L.: Das Pannon des mittleren Westungarns. – Annales Historico-Naturales Musei Nationalis Hungarici, pars Mineralogica, Geologica et Palaeontologica, 5, 1–102, Budapest 1942.
SZILAJ, R., SZÓNOKY, M., MÜLLER, P., GEARY, D.H. & MAGYAR, I.: Stratigraphy, paleoecology, and paleogeography of the "*Congeria ungulacaprae* beds" (= *Lymnocardium ponticum* Zone) in NW Hungary: study of the Dáka outcrop. – Acta Geologica Hungarica, 42, 33–55, Budapest 1999.
TARI, G.: Alpine Tectonics of the Pannonian Basin. – Unpublished Ph.D. thesis, Rice University, 501 p., Houston 1994.
TARI, G.: Neoalpine tectonics of the Danube Basin (NW Pannonian Basin, Hungary). – In: ZIEGLER, P.A. & HORVÁTH, F. (Eds.), Peri-Tethys Memoir 2: Structure and Prospects of Alpine Basins and Forelands. Mémoires du Muséum national d'Histoire naturelle, 170, 439–454 +enclosures 1–3, Paris 1996.
VITÁLIS, I.: A *Limnocardium vario-costatum* n. sp. – Mathematischer und Naturwissenschaftlicher Anzeiger der Ungarischen Akademie der Wissenschaften, 51, 696–704, Budapest 1934.
VITÁLIS, I.: Sopron környékének szarmáciai és pannóniai-pontusi üledékei és kövületei (Les sedimentes et fossils sarmatiens et panno-no-pontiens des environs de Sopron). – Annals of the Hungarian Geological Institute, 40, 3–75, Budapest 1951.

APPENDIX

In the Appendix we give known occurrences of characteristic bivalves of sandy, littoral deposits of Lake Pannon from Burgenland and the Transdanubian Central Range, respectively. Species names given by the collector or author of paper are given in brackets where they do not correspond to our identification. Key to the collections is given in the Materials and methods section. Materials from outcrops in the vicinity of Müllendorf and Großhöflein (Föllig or Fölick) are united under the name "Großhöflein".

Because most of the MÁFI collection was obtained before 1920 by field geologists of the Royal Hungarian Geological Institute, this material is originally labelled and registered according to old Hungarian settlement names. In order to facilitate identification, we give these names in parenthesis after their Slovak and German counterparts at the end of the Appendix.

The Burgenland fauna

Unio atavus

Großhöflein:	LUEGER, 1980 [*Psilunio atavus*]; JPL; FS; MÁFI
Stegersbach:	SAUERZOPF, 1952 [*Psilunio stegersbachensis*]; DHG
Olbendorf:	SAUERZOPF, 1952 [*Psilunio stegersbachensis*]

Litzelsdorf: FS [*Psilunio litzelsdorfensis*]
Oberdorf: Sauerzopf, 1952 [*Psilunio stegersbachensis*]; FS; MÁFI
Pezinok: MÁFI

Congeria spathulata
Großhöflein: Lueger, 1980; JPL; FS
Stegersbach: DHG; FS
Oberdorf: FS

Congeria ungulacaprae
Pezinok: Fordinál, 1997; MM
Sopron: Andrusov, 1897 [*Congeria hoernesi*]; Papp, 1953, 1985 [*Congeria hoernesi*]; MÁFI

Congeria pancici
Großhöflein: Lueger, 1980; JPL; FS
Stegersbach: Sauerzopf, 1952 [*Congeria pancici longiconcha*]; Papp, 1953, 1985; FS; DHG; MÁFI; BL
Steinbach: MÁFI
Siegendorf: MÁFI; FS
St. Margarethen im Burgenland: MÁFI

Congeria praebalatonica
Großhöflein: Lueger, 1980 [*Congeria balatonica*]; JPL; FS
Stegersbach: Sauerzopf, 1952 [*Congeria spathulata praebalatonica*]; Papp, 1953 [*Congeria spathulata praebalatonica*]
Litzelsdorf: Sauerzopf, 1952 [*Congeria spathulata praebalatonica*]

Congeria doderleini
Stegersbach: Papp, 1953, 1985; DHG
Pezinok: Fordinál, 1991, 1997
St. Margarethen im Burgenland: FS

Congeria gitneri
Großhöflein: Lueger, 1980 [*Dreissena minima*]; DHG
Stegersbach: DHG

Dreissena bipartita
Pezinok: Fordinál, 1997

Lymnocardium schedelianum
Großhöflein: Lueger, 1980; JPL; FS
Bratislava: Fordinál, 1995
Stegersbach: DHG; FS
St. Margarethen im Burgenland: MÁFI; FS
Zillingtal: MÁFI
Oggau: FS

Lymnocardium brunnense
Großhöflein: JPL
Sopron: TTM
St. Margarethen im Burgenland: MÁFI; FS
Bratislava: Fordinál, 1995

Lymnocardium conjungens
Großhöflein: Lueger, 1980; JPL; MÁFI
Stegersbach: FS; DHG; MÁFI; TTM
Steinbach: MÁFI
Sopron: TTM
Gols: JPL
St. Margarethen im Burgenland: MÁFI; FS
Pezinok: Fordinál, 1997; MÁFI; MM
Siegendorf: NHMW
Fertőrákos: TTM
Bratislava: Fordinál, 1995
Purbach am Neusiedlersee: FS
Oggau: FS

Lymnocardium hantkeni
Stegersbach: NHMW; FS [*Lymnocardium stegersbachensis* n. sp.]
Großhöflein: Lueger, 1980; JPL

Lymnocardium edlaueri
Großhöflein: JPL
Stegersbach: FS; DHG
Pezinok: MÁFI [*Limnocardium vicinum*]; MM
St. Margarethen im Burgenland: FS
Gols: JPL

Lymnocardium tucani
Großhöflein: Lueger, 1980; JPL; DHG; MÁFI; FS
Stegersbach: FS; DHG; MÁFI
(?) Sopron: TTM

Lymnocardium subdiprosopum
Großhöflein: Lueger, 1980 [*L. diprosopum*]; JPL; FS

"Lymnocardium" carnuntinum
Großhöflein: DHG
Steinbrunn: MÁFI [*Limnocardium pseudosuessi*]
Zillingtal: MÁFI

"Lymnocardium" danicici
Großhöflein: Lueger, 1980; JPL; MÁFI; DHG; FS
Sopron: TTM [*Limnocardium galeatum*]

"Lymnocardium" stojadinovici
Unterschützen: MÁFI
Stegersbach: MÁFI

"Lymnocardium" stoosi, late form
St. Margarethen im Burgenland: MÁFI
Bratislava: Fordinál, 1995 [*Pseudocatillus simplex*]
Stegersbach: MÁFI, DHG
Großhöflein: Lueger, 1980 [*Pseudocatillus simplex*]; DHG; FS
Siegendorf: FS
Burgau: FS

Caladacna steindachneri
Großhöflein: JPL
Sopron: TTM
Bratislava: Fordinál, 1995 [*Caladacna ornata bisepta*]

Euxinicardium schreteri
Stegersbach: FS; DHG; MÁFI

"Didacna" deserta
Siegendorf: MÁFI
Großhöflein: Lueger, 1980; JPL
Stegersbach: Stoliczka, 1862 [*Cardium desertum*]; Papp, 1953, 1985; FS; DHG; MÁFI
Steinbach: MÁFI
Sopron: TTM
Siegendorf: JPL
Bruck an der Leitha: MÁFI
Bratislava: Fordinál, 1995
St. Margarethen im Burgenland: FS

"Monodacna" viennensis
Großhöflein: JPL
Stegersbach: MÁFI

Parvidacna petkovici
Stegersbach: FS [*Parvidacna loerentheyi*]; Papp, 1953, 1985; NHMW
Bratislava: Fordinál, 1993
Großhöflein: Lueger, 1980

The TCR fauna

Unio mihanovici
Dáka: Szilaj et al., 1999; MM
Pápa: MÁFI
Kocs: MÁFI
Románd: UV
Ukk: MÁFI
Veszprémgalsa: MÁFI
Kerékteleki: MÁFI

Congeria aff. *simulans turgida*
Neszmély: Andrusov, 1897 [*Congeria turgida*]
Dáka: Szilaj et al., 1999; MM; MÁFI
Pápa: MÁFI
Ukk: MÁFI

Congeria ungulacaprae
Kup: Fuchs, 1870 [*Congeria balatonica* var. *crassitesta*]; MÁFI
Mocsa: Korpás-Hódi, 1983
Tata: Korpás-Hódi, 1983
Chl'aba: MÁFI
Somlóvásárhely: Andrusov, 1897; MÁFI
Doba: MÁFI
Gic: MÁFI
Kapolcs: MÁFI
Neszmély: MÁFI
Kocs: MÁFI

Kömlőd:	MÁFI
Környe:	MÁFI
Kisbér:	MÁFI
Csép:	MÁFI
Császár:	MÁFI
Agostyán:	MÁFI
Kerékteleki:	MÁFI
Románd:	UV; MÁFI
Pápa:	MÁFI
Padragkút:	MÁFI
Káptalantóti:	MÁFI

Dreissenomya unioides

Lázi:	BARTHA, 1963; MÁFI
Dáka:	SZILAJ et al., 1999; MM; MÁFI
Szák:	MM

Dreissena auricularis

Kup:	FUCHS, 1870; MÁFI
Dáka:	SZILAJ et al., 1999; MM; MÁFI
Pápa:	MÁFI
Lázi:	BARTHA, 1963; MÁFI
Naszály:	KORPÁS-HÓDI, 1983
Dunaszentmiklós:	KORPÁS-HÓDI, 1983
Szák:	MM
Somlójenő:	UV
Veszprémgalsa:	MÁFI

Dreissena bipartita

Kup:	ANDRUSOV, 1897; BRUSINA, 1902; HPM
Dáka:	SZILAJ et al., 1999; MM

Lymnocardium variocostatum

Lázi:	BARTHA, 1963, MÁFI
Dáka:	SZILAJ et al., 1999; MM; MÁFI; TTM;
Kocs:	VITÁLIS, 1934; MÁFI
Kup:	MÁFI
Pápa:	MÁFI; UV
Tárkány:	MÁFI
Somlójenő:	UV; MÁFI
Románd:	UV
Tüskevár:	TTM
Gic:	MÁFI
Külsővat:	MÁFI
Veszprémgalsa:	MÁFI

Lymnocardium apertum

Lázi:	MÁFI
Dáka:	SZILAJ et al., 1999; MM; MÁFI; TTM
Szák:	MM
Dunaalmás:	KORPÁS-HÓDI, 1983
Pápa:	MÁFI
Veszprémgalsa:	MÁFI

Lymnocardium penslii

Lázi:	BARTHA, 1963; MÁFI
Dáka:	SZILAJ et al., 1999; MM; MÁFI; TTM;
Kocs:	KORPÁS-HÓDI, 1983; MÁFI
Szák:	MM
Pápa:	MÁFI
Veszprémgalsa:	MÁFI
Ukk:	MÁFI
Somlójenő:	MÁFI; UV
Kup:	NHMW; MÁFI
Románd:	UV
Tüskevér:	TTM; MÁFI [*Limnocardium banaticum*]
Neszmély:	TTM; MÁFI
Dunaalmás:	TTM
Bársonyos:	MÁFI
Tárkány:	MÁFI
Gic:	MÁFI
Kapolcs:	MÁFI
Kerékteleki:	MÁFI
Pápakovácsi:	MÁFI

Lymnocardium hantkeni

Kup:	FUCHS, 1870; MÁFI
Szák:	MM; MÁFI
Dáka:	SZILAJ et al., 1999; MM
Pápa:	MÁFI
Somlójenő:	STRAUSZ, 1942
Tüskevár:	MÁFI

Lymnocardium ponticum

Dáka:	SZILAJ et al., 1999; MM
Nyárád:	MM
Naszály:	KORPÁS-HÓDI, 1983 [*Limnocardium trifkovici, L. decorum*]
Kocs:	KORPÁS-HÓDI, 1983
Pápa:	MÁFI
Kup:	NHMW [*Cardium decorum*]; BRUSINA, 1902 [*Limnocardium trifkovici*]; HPM

Lymnocardium tucani

Pápa:	STRAUSZ, 1942 [*Limnocardium banaticum* var.]
Lázi:	MÁFI [*Limnocardium* sp.]
Tüskevár:	MÁFI

"Lymnocardium" priscae

Pápa:	STRAUSZ, 1942; MÁFI
Lázi:	MÁFI
Tüskevár:	STRAUSZ, 1942
(?) Kocs:	KORPÁS-HÓDI, 1983
Kup:	HPM

"Lymnocardium" cf. *wurmbi*

Dáka:	SZILAJ et al., 1999; MM; MÁFI
Pápa:	TTM

Caladacna steindachneri

Dáka:	STRAUSZ, 1942; SZILAJ et al., 1999; MM; TTM
Szák:	MM
Pápa:	STRAUSZ, 1942; MÁFI
Dunaalmás:	KORPÁS-HÓDI, 1983
Tüskevár:	MÁFI

Euxinicardium schreteri

Dáka:	SZILAJ et al., 1999; MM; MÁFI
Lázi:	MÁFI
Szák:	MM
Pápa:	MÁFI
Somlójenő:	STRAUSZ, 1942
Tüskevár:	MÁFI

"Didacna" deserta

Kup:	MILAN et al., 1974 [*Didacna chyzeri*]; HPM
(?) Neszmély:	MÁFI

"Monodacna" viennensis

Dáka:	MM
Lázi:	MÁFI

Parvidacna sp.

Lázi:	BARTHA, 1963; MÁFI
Neszmély:	KORPÁS-HÓDI, 1983 [*Parvidacna planicostata*]
Kocs:	KORPÁS-HÓDI, 1983 [*Parvidacna planicostata*]
Dunaalmás:	KORPÁS-HÓDI, 1983 [*Parvidacna planicostata*]
Pápa:	MÁFI
Dáka:	MM
Kup:	HPM

Hungarian settlement names from Austria and Slovakia in the MÁFI collection (in parenthesis)

Bruck an der Leitha (Bruk)
Chľaba (Helemba)
Gols (Gálos)
Großhöflein (Nagyhöflány)
Litzelsdorf (Lődös)
Oberdorf (Őrállás)
Olbendorf (Óbér)
Pezinok (Bazin)
St. Margarethen im Burgenland (Szentmargitbánya)
Siegendorf (Cinfalva)
Stegersbach (Szentelek)
Steinbach (Kőpatak)
Steinbrunn (Büdöskút)
Unterschützen (Alsólövő)
Zillingtal (Völgyfalu)