

Marsh-type agglutinated foraminifera from Upper Miocene sediments of the Danube Basin

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ABSTRACT: Upper Miocene (lower Tortonian) foraminifers are a little-known group of organisms in the Pannonian Basin System of the Central Paratethyan realm. The scarcity of the mostly endemic species in the sedimentary record is caused by changes in ecological conditions at the end of the Miocene epoch when the paleogeographical evolution of the area resulted in the striking changes in seawater chemistry. Nevertheless, they may exceptionally form a significant component of microfossil assemblages. The most abundant species within all studied samples (*Trochammina kibleri* Venglinisky 1961, *Miliammina velatina* Venglinisky 1961 and *Miliammina subvelatina* Venglinisky 1975) are here investigated in detail and compared with previously published data from localities across the entire Central Paratethys area. The co-occurrence of other taxa, as well as sedimentological and isotopic data allow us to better constrain their environmental requirements and the sedimentary environment in marginal facies of the Late Miocene Pannonian Basin System. These results confirm the ecologically constrained conditions during the deposition of the upper Sarmatian to lower Pannonian sediments.

Key words: Central Paratethys, Upper Miocene, Foraminifera, *Trochammina*, *Miliammina*

INTRODUCTION

The Late Miocene Tortonian interval (Pannonian regional Paratethyan stage; ~11.6–10.0 Ma; Kováč et al. 2017), represents a time interval of disconnection of the Pannonian Basin embayments from the open sea. Sediments of the Danube Basin show a rapid facies change, from marine conditions in the Badenian (Middle Miocene) to hypersaline or brackish conditions in the Sarmatian, and finally to oligohaline in the Pannonian (Kováč et al. 2017). In this realm, nearly all genera of foraminifers became extinct at the Sarmatian/Pannonian boundary due to the unfavourable ecological conditions (SPEE event; Harzhauser and Piller 2007). *Trochammina*, *Saccammina*, *Miliammina* and *Nonion* were the only foraminiferal taxa able to withstand changes in salinity from marine to oligohaline, and changes in oxygenation from dysoxic to even episodic anoxic conditions (Venglinisky 1961, 1975; Széles 1980; Jámboer et al. 1985; Fuchs and Schreiber 1988; Jiříček 1972, 1974, 1985; Jámboer et al. 1985; Kováč et al. 2008).

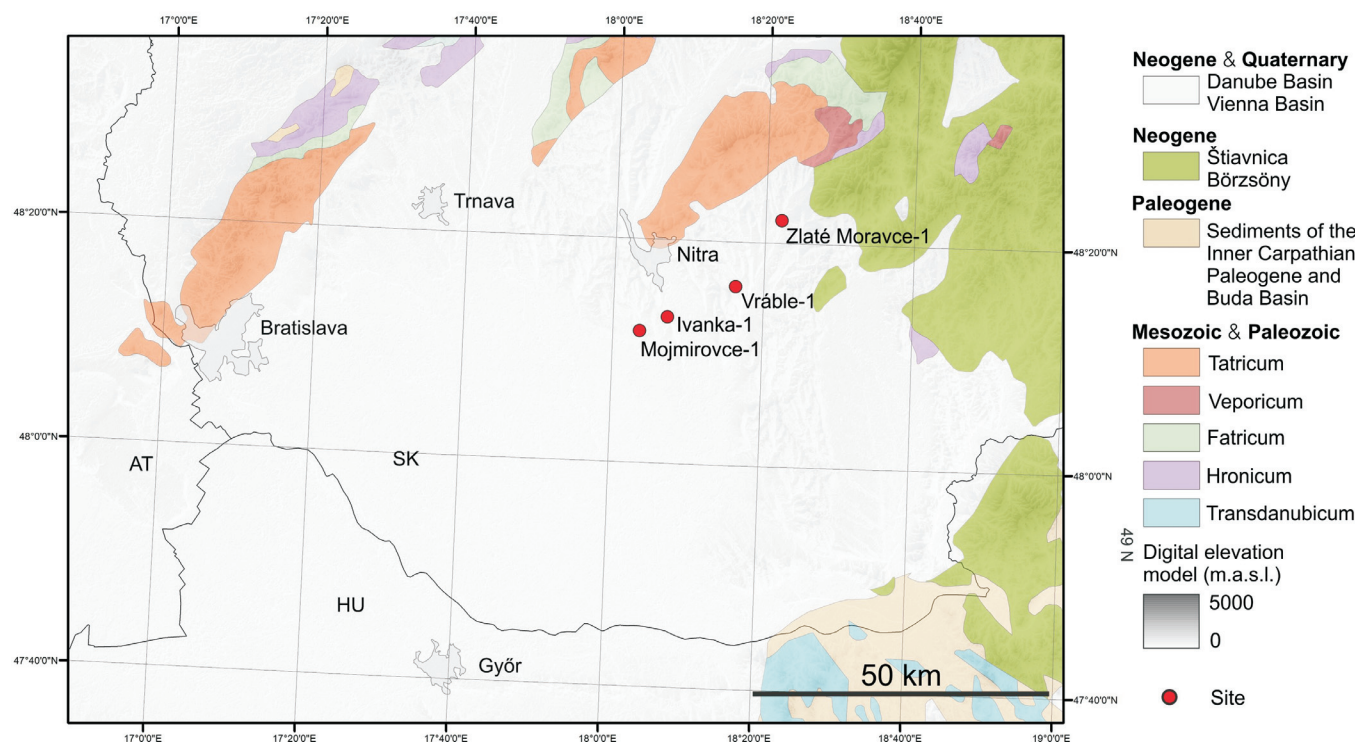
The studied samples were collected from the Komjatice depression of the Danube Basin where foraminiferal associations contain specimens with agglutinated tests belonging mainly to the species *Trochammina kibleri*, *Miliammina velatina* and *M. subvelatina*. Abundant specimens allow us to compare the taxonomical features of these rare endemic Paratethyan species with previously published descriptions. Sedimentological and isotopic data as well as the co-occurrence of other taxa allowed us to better specify their environmental requirements. The study also provides insight into the character of sedimentary environment of salty to brackish marshes during the early Pannonian in the basins of the Western Carpathians.

GEOLOGICAL SETTING

Upper Miocene sediments are widely distributed across the Neogene depocenters of the Pannonian Basin System (e.g., Danube-Kisalföld Basin and Vienna Basin; text-fig. 1). One of the largest depocenters is represented by the Danube-Kisalföld Basin which covers the area lying in three countries - Slovakia, Hungary, and Austria. In Slovakia, the southwestern part of the Danube Basin is characterized by a thick packet of Pannonian sediments unequally distributed over its partial depocenters (Blatné, Rišňovce, Komjatice and Želiezovce depressions). The Pannonian sediments from the studied wells (Mojmírovce-1, Ivanka-1, Vrable-1 and Zlaté Moravce-1) belong to the Komjatice Depression, situated on the northeastern margin of the Danube Basin.

MATERIAL AND METHODS

The analysis of the Komjatice Depression is based on a study of the available literature, including original well protocols containing lithological descriptions and lists of fauna (Gaža 1968, 1970; Čermák 1972; Biela 1978). The data are supplemented by investigation of well cores provided by the NAFTA oil company. Samples were taken from the Mojmirovce-1 (MOJ-1), Ivanka-1 (IV-1), Vrable-1 (VR-1) and Zlaté Moravce-1 (ZM-1) wells (text-fig. 1, Appendix 1). Foraminifers were obtained from 100 g of sediment, which was disaggregated using hydrogen peroxide and wet sieved (0.071 and 1 mm). Obtained residues were split to parts to receive approximately 300 specimens (when possible). A binocular stereoscopic microscope (Olympus SZ75) and a biological polarizing microscope were used for determination of foraminifers, and a scanning electron microscope QUANTA FEG 250 was used for imaging at the Institute of Electrical Engineering, SAS. Determination of foraminifers



TEXT-FIGURE 1

Localization of the studied sites. Geological map adapted from Hók et al. 2014. Red circle – studied sites (Mojmírovce-1 (MOJ-1), Ivanka-1 (IV-1), Vrábce-1 (VR-1) and Zlaté Moravce-1 (ZM-1) wells).

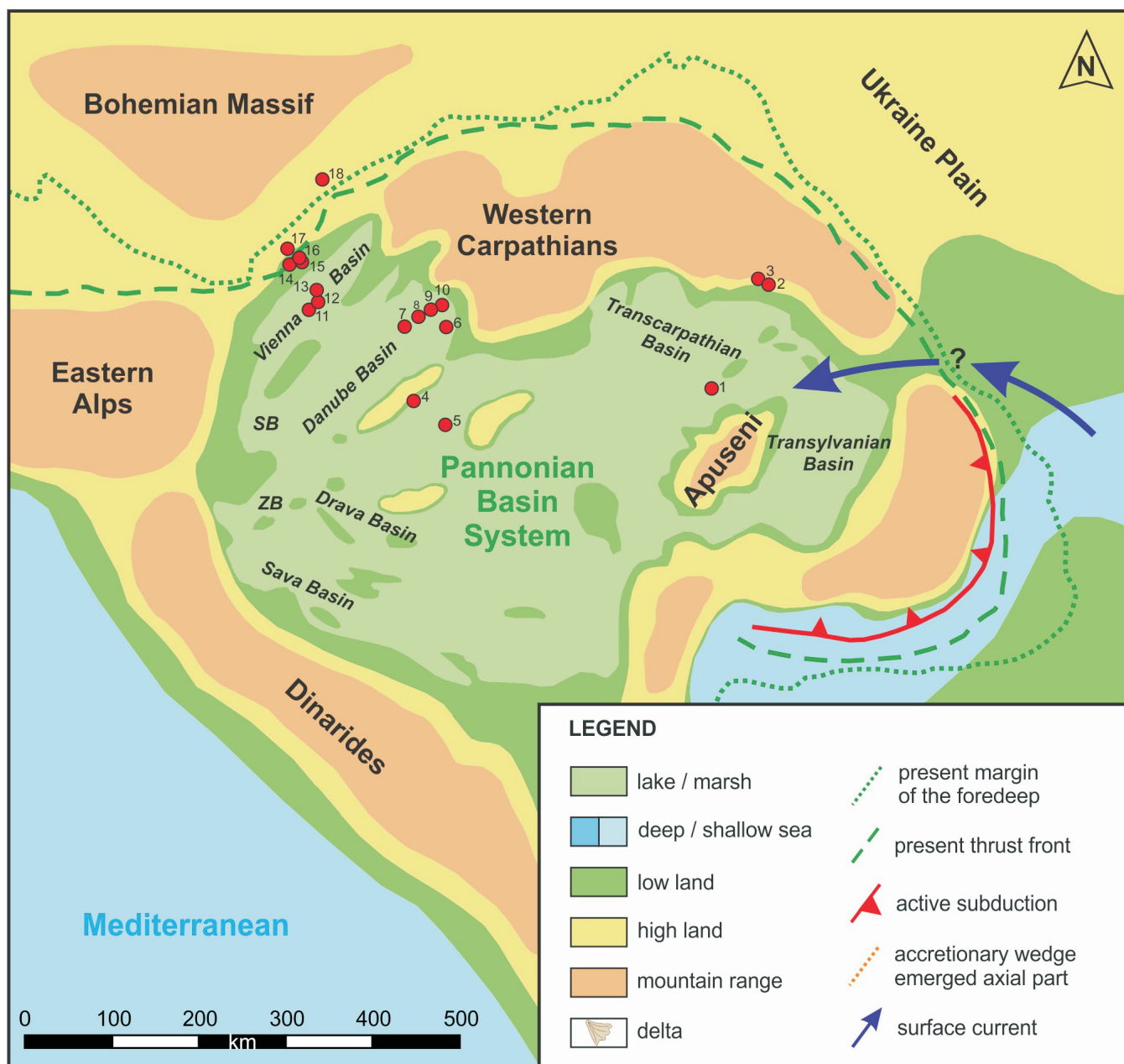
was based on Venglínský (1961; 1975), Čichá et al. (1998), Luczkowska (1974) and Holbourn et al. (2013). Due to the poor preservation of the foraminiferal tests, some specimens remain in open nomenclature. The length and width (maximum and minimum diameter) of the stratigraphically important species (*Trochammina kibleri*, *Miliammina velatina* and *M. subvelatina*) were measured, and selected specimens were drawn. The presence of carbonate content of the wall grain material was tested by using HCl (3%). Statistical evaluation was done using the PAST software (Hammer et al. 2001). Stratigraphically unimportant foraminifers listed in the appendix 1 were not included into the systematic part.

Isotope analyses of foraminiferal tests were performed on a MAT 253 mass spectrometer coupled to an automated Kiel IV preparation device through a dual-inlet interface. Samples of individuals or pooled tests weighing 20–30 micrograms were evacuated in borosilicate vials and reacted with 103% H₃PO₄ at 70°C following the method of McCrea (1950). After cryogenic purification the obtained CO₂ was measured for stable C and O isotopes. Values are reported as per mil vs. PDB and are calibrated using international reference material NBS18 with $\delta^{13}\text{C} = 5.01\text{‰}$, $\delta^{18}\text{O} = -23.2\text{‰}$ and two working standards with $\delta^{13}\text{C} = +2.48\text{‰}$, $\delta^{18}\text{O} = -2.40\text{‰}$ and $\delta^{13}\text{C} = -9.30\text{‰}$, $\delta^{18}\text{O} = -15.30\text{‰}$, respectively. The typical precision of measurement is 0.04‰ for carbon and 0.06‰ for oxygen.

Biostratigraphy

A detailed biostratigraphy of the studied wells was published by Šarinová et al. (2018). The Pannonian sediments of the

Ivanka-1 (IV-1) well contained the autochthonous nannofossil *Reticulofenestra tegulata* and the dinocysts *Virgodinium asymmetricum*, *Spiniferites bentori pannonicus* at a depth of 1603–1612 m. Such an association enriched by *Impagidinium spongianum*, *Achomosphaera* sp., and *Pontiadinium pecsvaradensis* was observed at a depth of 1506–1509 m. In the Vrábce-1 (VR-1) well, basal the Pannonian interval (depth 1149–1154 m) yielded an acme of the foraminiferal species *Trochammina kibleri*, *Miliammina velatina* and *M. subvelatina*, together with the calcareous nannoplankton acme event of *Isolithus semenenko*. The foraminifers *Miliammina* sp. and *Dogielina* sp. together with *Isolithus semenenko* were also present at a depth of 1103–1108 m. Well diversified dinoflagellates were observed in the interval between 1000–1108 m, while the association found between 950 and 955 m was characterized by the absence of dinocysts, the presence of terrestrial and freshwater elements (*Zygnema*, *Nuphar*) together with reworked dinoflagellates (*Deflandrea*). Shallower core intervals contained *Virgodinium asymmetricum*, *V. transformis*, *Impagidinium spongianum*, *Spiniferites bentori pannonicus*, *S. bentori oblongus*, *Achomosphaera* sp., *Chytroeisphaeridia cariacensis* (750–755 m); *Virgodinium asymmetricum*, *V. transformis*, *Pontiadinium pecsvaradense*, *Impagidinium spongianum*, *Chytroeisphaeridia cariacensis* (703–707 m) and *V. asymmetricum*, *P. pecsvaradense* (603–607 m). Pannonian sediments of the ZM-1 well contained mostly dinoflagellate species *Spiniferites bentori pannonicus* (653–658 m), which occurred together with *Impagidinium spongianum*, also present at a depth of 599–604 m. *Impagidinium spongianum* and *Spirogyra* were found at a depth of 551–556 m.



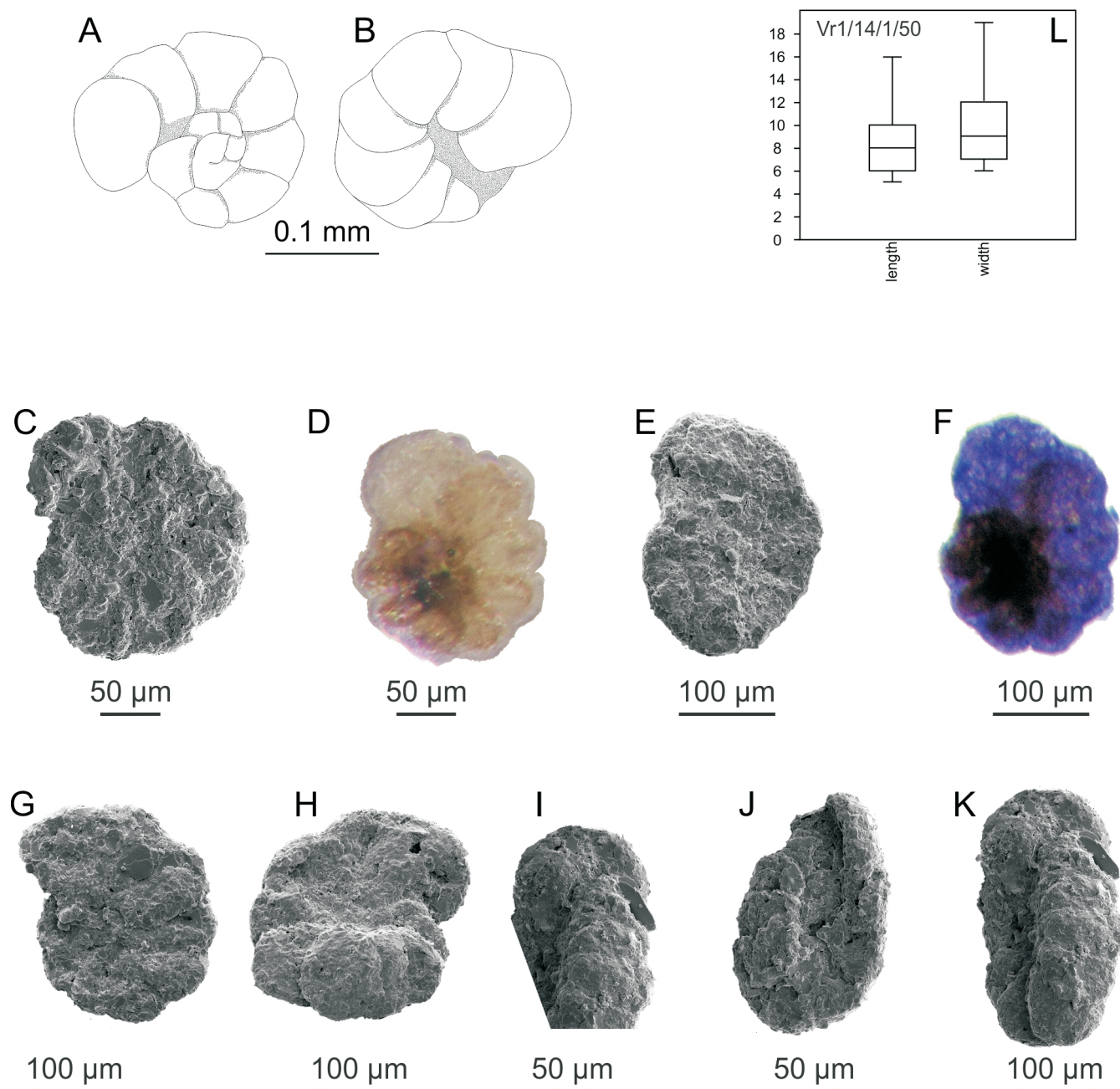
TEXT-FIGURE 2

Paleogeography of the Pannonian Basin System during the Pannonian (adapted from Kováč et al. 2017) showing sites containing assemblages dominated by *Trochammina kibleri* and *Miliammina* sp. div.: 1. Padurea Craiului-20 site; 2. Velijatin; 3. Vyškovo; 4. Lajoskomárom; 5. Tengelic-2; 6. Budajeno; 7. Mojmirovce-1; 8. Ivanka-1; 9. Vráble-1; 10. Zlaté Moravce-1; 11. Pamhagen; 12. Tadtén; 13. Halbtun; 14. Wienerherberg; 15. Mannsdorf; 16. Mariaellend; 17. Kágrán-9; 18. Čejč. (Adopted from: 1. Filipescu et al. (1999); 2,3 Venglínsky (1961, 1975); 4,5 Jámboř (1985), Korecz Laky (1982); 6–9 this work; 10–15 Fuchs and Schreiber (1988); 16–17 Jiříček (1972).

RESULTS

A total of 32 samples were taken from well cores. They cover Sarmatian and Pannonian intervals of the Mojmirovce-1 (MOJ-1), Ivanka-1 (IV-1), Vráble-1 (VR-1) and Zlaté Moravce-1 (ZM-1) wells. The residues contain undissolved bulk sediment, quartz grains, mica, pyrite, accessory mineral grains, coal, and microfossils: diatoms, floral parts, seeds, foraminifers, radiolarians, poriferan spicules, mollusk shells,

ostracod valves, fish scales and teeth. The tests of calcareous foraminifera are generally poorly preserved. Miliolids show signs of dissolution. Agglutinated forms are compressed. Re-worked planktic taxa are also observed. In the non-barren samples, the associations are dominated by *Trochammina*, *Saccammina*, *Miliammina* and *Nonion*. Overall, 25 foraminiferal taxa were determined, but to due their poor preservation some remain in open nomenclature (Appendix 1).

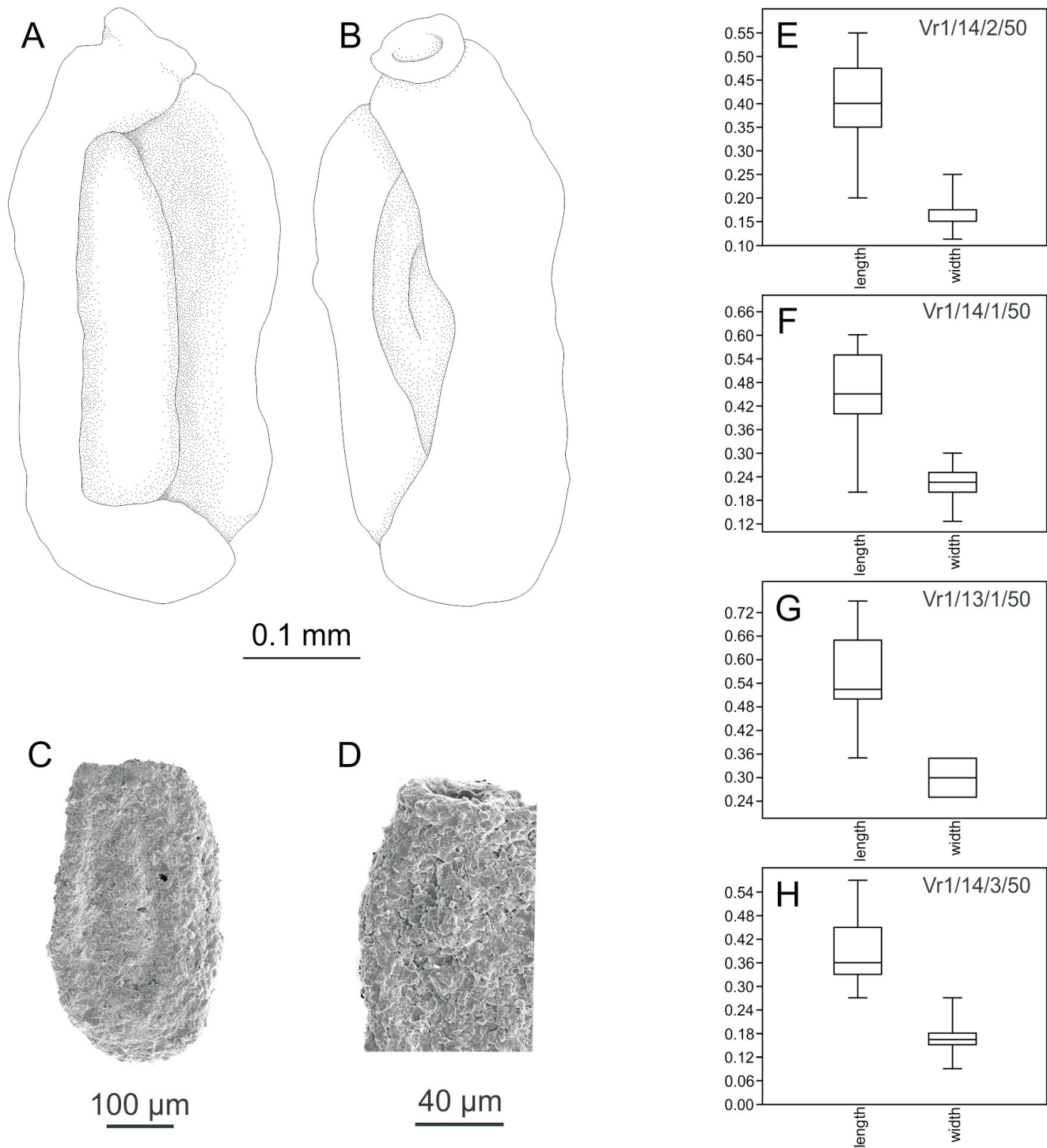


TEXT-FIGURE 3

Trochammina kibleri Venglinisky 1961. A. spiral side, B. umbilical side (VR1/14/2/50); C–D. *T. kibleri*, spiral side, SEM photograph; D. spiral side of the same specimen in immersion oil (VR1/13/2/50). E–F. *T. kibleri*, umbilical side, SEM photograph; F. umbilical side of identical specimen, colored by methylene blue, in water (VR1/14/3/50). G. *T. kibleri* umbilical side, SEM photograph (VR1/13/2/50); *T. kibleri*, apertural slit (VR1/13/2/50); I. *T. kibleri* detail of apertural slit (VR1/14/1/50); J, K. *T. kibleri* compressed specimens (VR1/14/1/50); L. box diagram of the length and width values of the measured *T. kibleri* (VR1/14/1/50).

From the upper part of MOJ-1 well (intervals 2090–2093 m, 2040–2045 m, 1956–1961 m, 1758–1763 m, 1603–1602 m, 1506–1509 m, 1298–1303 m), 12 samples were studied. Washed residues from the uppermost samples are almost barren, but extremely rare specimens of *Miliammina velatina* from the samples of the section between 1298–1303 m were determined. Sediments of the interval between 1956 and 1961 m yielded an association containing *Bolivina sarmatica*, *Bolivina*

spp. *Porosonion* ex. gr. *granosum*, with a lot of organic matter, fish bones and scales. In the Ivanka 1 well (IV-1) 10 samples from the intervals 1956–1961 m, 1758–1763 m, and 1506–1509 m were studied. In the lowermost interval, *Miliammina subvelatina*, *Ammonia tepida*, *Nonion* spp., *Bolivina sarmatica*, *Bolivina* spp. *Porosonion* ex. gr. *granosum* were found, while sediment above was barren of foraminifera. Ten studied samples from the Vrable-1 well (VR-1) yielded associations of almost

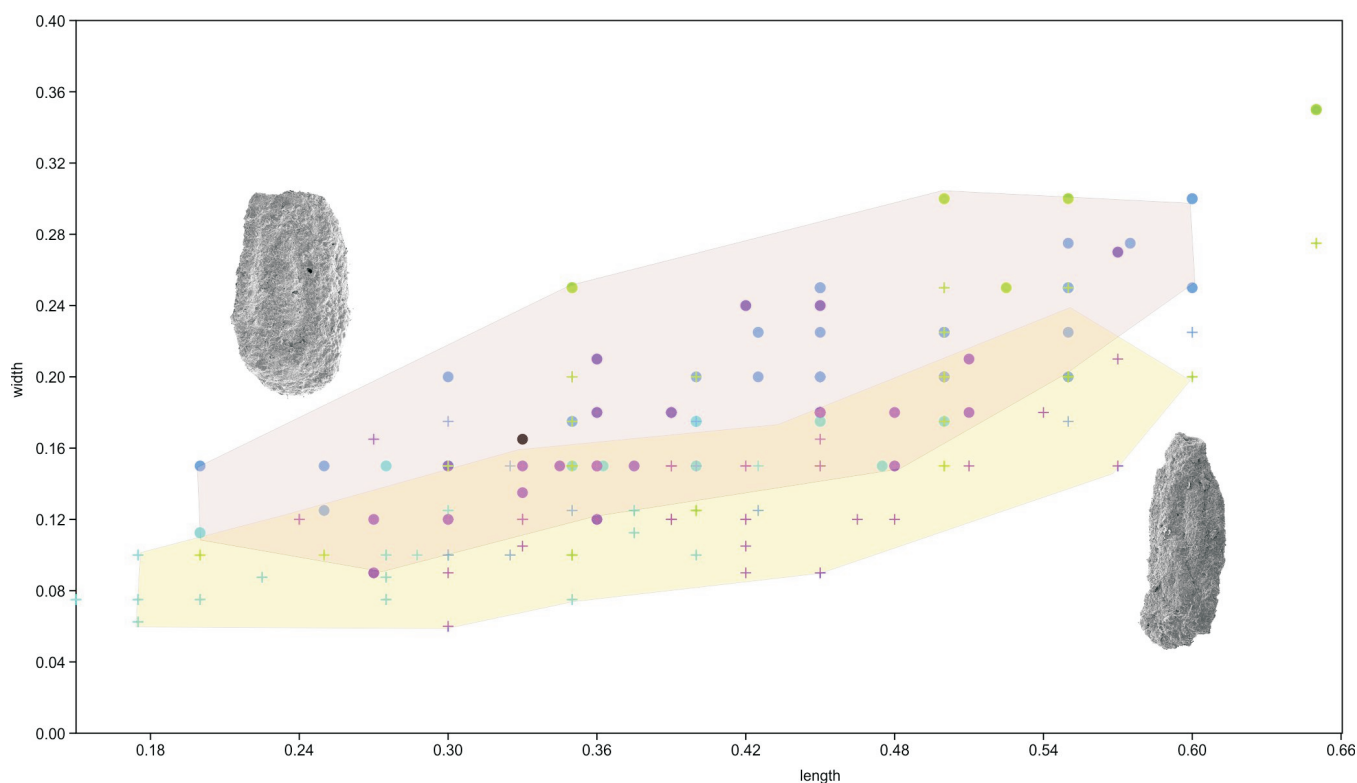


TEXT-FIGURE 4

Miliammina velatina Venglinisky 1961. A. spiral side, B. apertural side (VR1/14/2/50); C,D. *M. velatina* SEM photograph spiral side; D. aperture of identical specimen (VR1/13/2/50); E–H box diagram of the length and width values of the measured *M. velatina* from samples, where more than 50 specimens were observed.

monospecific *Trochammina kibleri* from the interval between 1149 and 1154 m, up to association overburden with *Miliammina velatina*, *M. subvelatina*, *M. fusca*, *M. obliqua*, *Ammoscalaria runiana* and *Ammobaculites* sp. cf. *exiguus*,

(1103–1108 m) together with ostracod valves, shark teeth and fish remains. In the uppermost studied part of the well (1000–1005 m to 802–807 m), foraminifers were not present (text-fig. 2).



TEXT-FIGURE 5

Length and width values of all measured specimens of *Miliammina*, dots show *M. velatina*, marked by red shaded area; plus symbol show *M. subvelatina*, marked by yellow shaded area. Upper left - *M. velatina* (VR1/13/2/50); lower right - *M. subvelatina* (VR1/13/3/50).

SYSTEMATICS

The higher rank classification follows Pawlowski et al. (2013), whereas the lower rank classification follows Kaminski (2014).

Class GLOBOTHALAMEA Pawlowski, Holzmann and Tyszka 2013

Order LITUOLIDA Lankester 1885

Family TROCHAMMINIDAE Schwager 1877

Trochammina Parker and Jones 1859

Trochammina kibleri Venglinisky

Text-fig. 3A-K

Trochammina kibleri sp. nov. VENGLINSKY 1961, p. 94, pl. 7, figs. 2a-v, 3a-v. – VENGLINSKY 1975, p. 94, pl. 2, figs. 1a-v, 2a-v.

– FUCHS and SCHREIBER 1988, p. 65, pl. 2, figs. 1-3, 5-6.

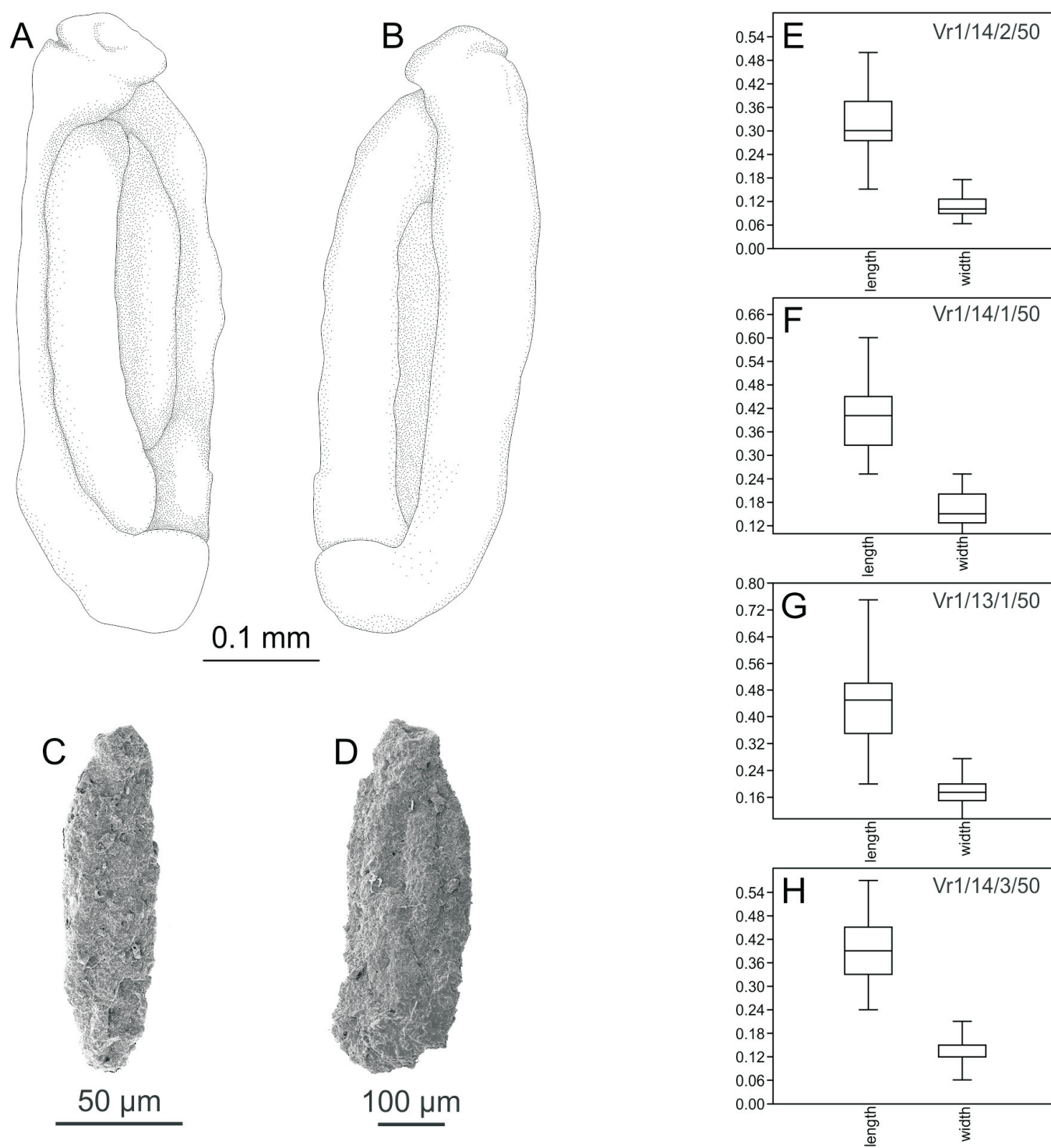
?*Trochammina kibleri* Venglinisky. – CICHA et al. Eds. 1998, p. 132, pl. 7, figs. 1-3.

Description: Test is of medium size, almost round, flattened, composed by 2.5–3.5 whorls. The last whorl consists of 7–11 slowly growing inflated chambers. Chambers are quadrilateral to trapezoidal on the spiral side, triangular on the umbilical side. Sutures are narrow, significantly depressed, a bit curved to the initial stadium, more visible in the younger part of test. Umbilical area is weakly concave. Periphery is round and lobate. Aperture is a slit on the umbilical side of the test, at the base of the last chamber. Fine grained wall is of brown–yellowish color. The type of grains was impossible to determine due to an iron oxide coat. Surface is smooth, matt to slightly glossy.

Dimensions: 0.6 to 0.2 mm; high not measured, average length/width ratio is 1.17.

Remarks: Specimens from the Carpathian Foredeep localities of the Ukraine have some consistent characters with the *Trochammina inflata* (Montagu) var. *macrescens* (Brady 1870), accepted now as *Entzia macrescens* (Brady 1870), from the brackish waters of the British Isles, but differs in possessing more chambers in the last whorl, narrower sutures, and a more oval outline. Our studied forms are smaller than the Ukrainian specimens. Their average dimensions are similar to *T. inflata* var. *macrescens* but possesses more chambers in the last whorl (6–9) and a slotted aperture - not round like in the genus *Entzia* as published by Filipescu and Kaminski (2008). Cicha et al. (1998) mentioned the uncertain generic position of the species due to a very low trochospiral coiling what appears to be a nearly pseudoplanispiral test. In our studied material, tests of *Trochammina kibleri* are extremely flattened, but the trochospire is visible. It implies that these tests were flexible due to organic cement, which suffered by bacterial decay on the sea floor, leading to the collapse of the agglutinated wall. Flexible agglutinated tests are frequently compressed or destroyed in fossil assemblages (e.g., Goldstein and Barker 1988; Loeblich and Tappan 1989).

Occurrence: Abundant at the middle Sarmatian/lower Pannonian boundary of the Ukraine Carpathian Foredeep (Vyškovo, Velijatin), and in the lower Pannonian of the Danube and Vienna basins (text-fig. 2).



TEXT-FIGURE 6

Miliammina subvelatina Venglinisky 1975. A. apertural side B. spiral side (VR1/14/2/50); C. *M. subvelatina* spiral side SEM photograph (VR1/13/2/50); D. *M. subvelatina* SEM photograph; D. aperture of the identical specimen (VR1/14/3/50); E–H. box diagram of the length and width values of the measured *M. subvelatina* from samples, where more than 50 specimens were observed.

Order SCHLUMBERGERINIDA Mikhalevich 1980
Suborder SCHLUMBERGERININA Mikhalevich 1980
Family MILIAMMINIDAE Saidova 1981
Miliammina Heron-Allen and Earland 1930

Miliammina velatina Venglinisky
Text-fig. 4A-D

Miliammina velatina VENGLINSKY 1961, p. 93, tab. 1, figs. 1a,b, 2a,b,v, 4a,b. – VENGLINSKY 1975, p. 150, tab. 8, figs. 1a,b, 5a-v, 6, 7. – FUCHS and STRADTNER 1988, p. 64, tab. 1, figs. 1, 3-7.

Description: Test is elongate, oval, compressed from the both longer sides, widely rounded in its basal part. Chambers are tubular, weakly arcuate bended, planispiral in the initial stage, in the younger part it becomes to be irregularly triloculine or quinqueloculine. Length/width ratio is about 1.4–2.0. Periphery is rounded. Sutures are slightly impressed, often hardly visible. Aperture is small, round or oval, situated at the end of the sharply cut end of the last chamber. Test wall is fine grained, often of brown to red color. According to Venglinisky (1961) the grain material consists of carbonates, chalcedony, biotite, spar, and irregular forms of iron hydroxides.

Almost all tests from our material are coated by iron hydroxides. All are deformed with strongly flattened chambers and tests.

Dimensions: Average length is 0.43 mm (0.2–0.75 mm); average width is 0.21 mm (0.1–0.35 mm).

Remarks: Specimens from the Carpathian Foredeep localities of Ukraine have some consistent characters with the *Quinqueloculina foeda* Reuss (referred as *Sigmoilopsis foeda* (Reuss) in Luczkowka (1974) from the Miocene of Wieliczka, but they differ in more straight tubular chambers. End of the last chamber possessing the aperture is sharply cut-off. It makes the last chamber shorter than the penultimate. Our specimens differ from the original described by Venglinisky (1961) in their smaller dimensions, more elongate narrower forms and more rectangular shape of the tests (text-fig. 5).

Occurrence: Abundant in the Sarmatian of Romania, in the middle Sarmatian to Pannonian of the Ukraine Carpathian Foredeep (Vyškovo, Velijatin), Sarmatian and Pannonian of the Danube and Vienna basins (text-fig. 2).

Miliammina subvelatina Venglinisky 1975
Text-fig. 6A-D

Miliammina subvelatina VENGLINSKY 1975, p. 150, tab. 8, figs. 1a,b, 5a-v, 6, 7. – STRADTNER and FUCHS 1985, p. 271, pl. 29, figs. 6-8. *Miliammina* sp. – FUCHS and SCHREIBER 1988, p. 64, pl. 1, figs. 2, 8-9.

Description: Test is elongated, oval, compressed from the both sides, widely rounded in its basal part, sometimes acute. Length/width ratio is between 2 and 2.7. Periphery is significantly acute. Chambers are extended, tubular, weakly arcuate bent, coiled in quinqueloculine or triloculine manner. On the outer side 4 to 5 chambers are visible. Often narrow sutures are slightly depressed. Aperture is simple, round or oval, situated at the tapering end of the last chamber. The margin of the aperture is perpendicular or diagonal to the long axis of the test. Test wall is agglutinated of clay to very fine silt grains.

Dimensions: Average length is 0.38 mm (0.15–0.75); average width is 0.14 mm (0.06–0.25 mm).

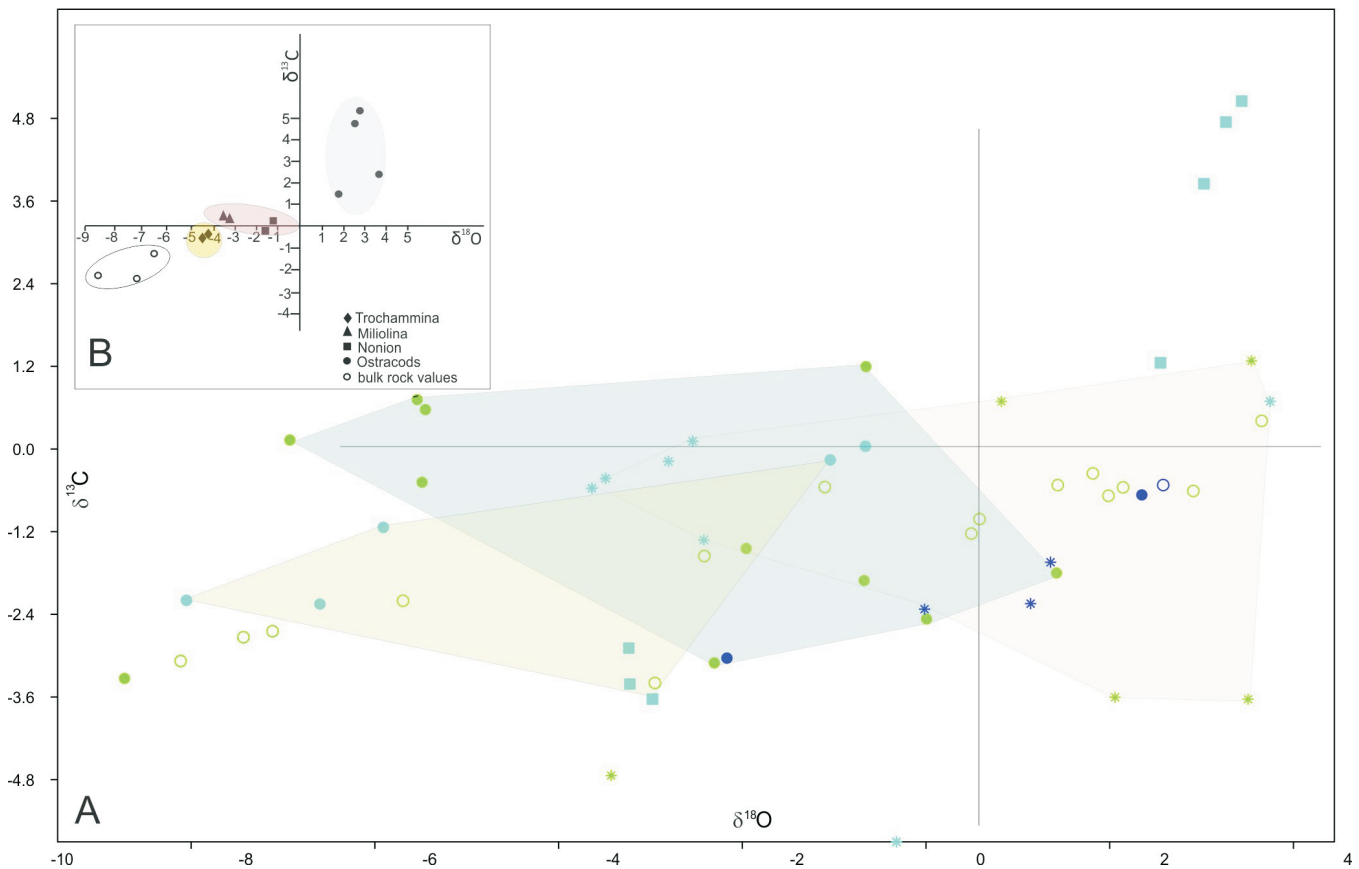
Remarks: Ukrainian specimens have some consistent characters with *Miliammina velatina* from the middle Sarmatian of Zakarpacie, but they differ in their smaller dimensions, thinner test wall, longer axis, and tapering apertural end. Our specimens are inconsistent in dimensions. They are smaller than *M. subvelatina* from the Sarmatian sediments of Zakarpacie, in shape more resembling the *M. subvelatina* from the Kagan-9 well (core 910–916 m; Schreiber and Fuchs 1985). Length/width ratio is similar to that measured in *M. velatina* from our material, in the partly overlapping values (text-fig. 5). Our specimens are sometimes very narrow, even twisted, often with an aperture on the neck.

Occurrence: Very abundant in the blue-gray marly clays of the lower Pannonian of the Ukraine Carpathian Foredeep (Vyškovo, Velijatin; Venglinisky 1975), in the Vienna Basin sediments around the Sarmatian/Pannonian boundary (Jiříček 1972), and very abundant in the lowermost Pannonian of the Danube Basin (text-fig. 2).

DISCUSSION

Marsh type associations dominated by agglutinated species from the Central Carpathian basins are sparsely documented (see Venglinisky 1961, 1975; Jiříček 1972, 1974; Jámboř et al. 1985; Korecz-Laky 1985; Schreiber and Fuchs 1985; Fuchs and Schreiber 1988). From the northern part of the Vienna Basin, the Badenian *Trochammina–Ammotium* assemblage is reported by Bartakovics (2007). An agglutinated association from the Moravian part of the Vienna Basin (Poddvorov) was documented by Ruman et al. (2013). Pannonian *Trochammina* assemblages documented by Jiříček (1972) from the Moravian part of the northern Vienna Basin (Čejč) do not fit well to the marginal marine environment proposed by Kováč et al. (2017). This can be caused by the inaccurate stratigraphical range or it can represent a marsh sedimentation distant from the coast, as documented from modern European saline soils (Balík and Bubík 2004; Filipescu and Kaminski 2008). From the South Morava region, the recent saline soil in the Nesyt site (Balík and Bubík 2004) yields a well described subrecent marsh foraminiferal association composed solely of *Haplophragmoides manilaensis*.

Associations dominated by *Miliammina velatina*, *M. subvelatina* and *Trochammina kibleri* are documented from the Sarmatian sediments of the eastern part of the Paratethys region (Ukrainian Foredeep; Venglinisky 1961, 1975, and the Padurea Craiului mountains in Romania; Filipescu et al. 1999). Associations with *Miliammina velatina* and *M. fusca* are known from Sarmatian sediments of the Central Paratethys from the Vienna Basin (Hudáčková and Zlinská 2010) and the Danube Basin (Šarinová et al. 2018). These types of foraminiferal assemblages are assumed to be a shallow water, brackish, or hypersaline (Bartakovics 2007; Ruman et al. 2013; Venglinisky 1961, 1975; Filipescu et al. 1999; Hudáčková and Zlinská 2010; Šarinová et al. 2018). Assemblages obtained from Pannonian sediments from the northern part of the Komjatice Depression (Danube Basin) are strongly dominated by *M. velatina* or *M. subvelatina*, and according to the isotope signal, a normal marine environment is proposed (text-fig. 7 A,B). An assemblage of marine dinoflagellate species (*Pontiadinium pecsvaradense*, *Impagidinium spongianum*, *Chytroeisphaeridia cariacensis*)



TEXT-FIGURE 7

Isotope analysis of the measured samples. A. Sarmatian (green) – Pannonian (blue) samples. Symbols: filled dots – autochthonous fossils (*Miliolina*, *Nonion*, *Trochammina*); asterisk – reworked (*Globigerina* sp. div.); empty circle – *Bolivina variabilis*; filled rectangle Ostracoda valves; B. Pannonian samples.

in samples dominated by *M. velatina* (Šarinová et al. 2018) confirms our results.

In the Central Paratethyan region, at the base of the Upper Miocene sedimentary record of the Pannonian Basin the *Trochammina*–*Miliammina* associations are found in pelitic deposits (Turnovsky 1958; Széles 1980; Jámboř et al. 1985; Fuchs and Schreiber 1988). In the Danube Basin and Vienna Basin Upper Miocene sediments (Jiríček 1972, 1974, 1985; Jámboř et al. 1985; Kováč et al. 2008) the associations are dominated by *Miliammina velatina* and *Trochammina kibleri* (text-fig. 2).

Isotopic analyses provided on our material has been performed on different microfaunal components from different habitats and on the bulk sediment samples (Fig. 7 A,B). Probably due to vital effects the oxygen and carbon isotopes of ostracods yield a positive values. Such positive offset of $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in ostracods points to disequilibrium in isotopic fractionation (Caporaletti 2011). Normal marine species such as *Nonion* and *Miliolina* provide an isotopic values around 0‰ $\delta^{13}\text{C}$ with a slight lightening in oxygen isotopes (–3.4 ‰ $\delta^{18}\text{O}$). Isotopic values of *Trochammina* tests show a more evident shift of $\delta^{18}\text{O}$ probably due to fresh water input to brackish marsh-type envi-

ronments. Bulk rock analyses give the most negative values due to lightening of carbon isotopes from organic matter and oxygen isotopes from fresh water. Unlike most agglutinated tests, *Trochammina kibleri* contain a carbonate component (Venglínský 1961). Its isotopic composition is close to values of calcareous benthic foraminifers, implying no significant influence by diagenesis. Carbonate formation in trochamminid tests might be related to anaerobic oxidation and methanogenesis of organic matter, producing CO_2 in pore waters with dissolved Ca (Pitman 1996). This is also indicated by the slight lightening of oxygen and carbon isotopes in trochamminid tests. Due to the probably authigenic origin of carbonates their values have also been plotted in isotopic diagram of the foraminiferal association. The agglutinated species *Enzia macrescens* and *T. inflata* occurring in high numbers in the salt marshes are positively correlated to elevation and muddy substrate, and negatively correlate to pH (Hawkes et al. 2010; Engelhart et al. 2013; Fatela et al. 2014; Hayward et al. 2011; Hayward 2014). They are associated with marsh plants, specifically *E. macrescens* flourishes epiphytically on decaying *Carex*-leaf debris (Alve and Murray 1999). If we assume very similar environmental limits of *T. kibleri* with *E. macrescens*, assemblages dominated by *T. kibleri* in the Central Paratethys area probably point to the environment

of the high salt marsh. According to above mentioned, sediments containing assemblages dominated by *T. kibleri* can be used as an indicator of the Pannonian paleo-shoreline (text-fig. 2). Association compositional change from *T. kibleri* mono-association, via *T. kibleri*–*M. velatina* with *M. subvelatina* to *Miliammina* sp. div. mono-association suggest an environmental shift from the salt marsh of the Pannonian Sea to the deeper marine environment, as well documented in the VR-1 well. The small-sized *Ammodiscus*–*Trochammina* assemblages occurred in the environment where benthic biota would have been stressed by periods with moderate hypoxia combined with lowered salinity (Nagy et al. 2010). This can serve as an environmental outline for our small sized *Trochammina*–*Miliammina*–*Saccammina* assemblages. Hypoxia in the sediments is also supported by the high content of authigenic pyrite in the studied sediments. Studied tests of *T. kibleri*, *M. velatina* and *M. subvelatina* from the Pannonian sediments of the Danube Basin are extremely flattened. It implies that these tests were flexible due to organic cement, which suffered from bacterial decay on the sea floor, leading to collapse of agglutinated walls. Such flexible agglutinated tests are frequently compressed or destroyed in fossil assemblages (Goldstein and Barker 1988; Loeblich and Tappan 1989). The features listed above suggest that the assemblages were adapted to restricted conditions in unstable environments (clearly divergent from those of a normal marine shelf), where the main limiting factors were low salinity and reduced amount of dissolved oxygen. In Pannonian sediments the agglutinated forms prevail probably due to limited carbonate availability, because such marsh-type environments with higher precipitation resulted in a higher acidity (low pH) and lower salinity. In these conditions the agglutinated foraminifers became dominant (Scott et al. 1990).

CONCLUSIONS

Detailed description of three endemic foraminiferal species (*Trochammina kibleri* Venglsky 1961; *Miliammina velatina* Venglsky 1961 and *Miliammina subvelatina* Venglsky 1975) from the Central Paratethys was performed. Morphometric analysis revealed a shift towards smaller sizes in individuals from the Komjatice depression (Danube Basin) samples compared to those studied previously.

The presence of *Nonion* and *Miliolina* with $\delta^{13}\text{C}$ isotopic values around 0‰ with a slight lightening in oxygen isotopes document normal marine (tidal plane) and middle to high marsh environment in the upper Sarmatian to lower Pannonian sediments, as suggested based on *Trochammina* tests with a more evident shift of $\delta^{18}\text{O}$. The shoreline of the lowermost Pannonian Sea is detected at the base of the *Trochammina kibleri* associations.

Our study confirms the ecologically constrained conditions (low salinity and oxygen depletion) during the deposition of the Upper Miocene sediments of the Danube Basin.

ACKNOWLEDGMENTS

This research was supported by the Slovak Research and Development Agency under the contracts No. APVV-16-0121, APVV-15-0575, APVV 14-0118 and VEGA 2/0034/16. The authors wish to express their gratitude to the Management of the NAFTA oil company and to Dr. Sliva for allowing access to the well-core repository, and to Dr. Kostič for assistance with the QUANTA FEG 250. Our gratitude goes to Michael A. Kaminski and Miroslav Bubík for insightful comments.

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APPENDIX 1

List of foraminifers from the samples containing more than 100 specimens per two standardized residua loads. Explanatory notes: x - 1-10 specimens; xx - 10-20 specimens; xxx - 20-50 specimens; xxxx - 100-200 specimens.

species	MOJ1/28/3/30	IV1/14/1/50	IV1/12/1/50	Vr1/13/1/50	Vr1/14/3/50	Vr1/14/3/50	Vr1/14/2/50	Vr1/14/1/50
<i>Ammobaculites agglutinans</i> (d'Orbigny, 1846)							x	
<i>Ammobaculites exiguus</i> Cushman & Brönnimann, 1948					x	x	x	
<i>Ammobaculites</i> sp.							x	x
<i>Ammonia tepida</i> (Cushman, 1926)			x					
<i>Ammoscalaria runiana</i> (Heron-Allen & Earland, 1916)				x	x	x	x	x
<i>Articulina</i> sp.	x							
<i>Asterigerina</i> sp.		x						
<i>Bolivina sarmatica</i> Didkovskiy, 1959	x	x	x					
<i>Bolivina</i> sp.		x	x					
<i>Dogielina</i> sp.	x		x					
<i>Elphidium</i> sp.	x	x	x					
<i>Lagenammina</i> sp.				x				
<i>Miliammina fusca</i> (Brady, 1870)	x	x		x	x	x	x	
<i>Miliammina obliqua</i> Heron-Allen & Earland, 1930								
<i>Miliammina subvelatina</i> Venglinisky 1975				xx	x	xxx	xxxx	xxx
<i>Miliammina velatina</i> Venglinisky 1961				x	x	x	xx	xxx
<i>Miliolinella</i> sp.	x	x	x	x		x		
<i>Nonion</i> sp.		x	x				x	
<i>Nubecularia crustaformis</i> Bogdanovich, 1952		x						
<i>Porosononion granosum</i> (d'Orbigny, 1846)	x			x				
<i>Quinqueloculina seminula</i> (Linnaeus, 1758)	x							
<i>Saccammina</i> sp.				x	xx	x		
<i>Trochammina kibleri</i> Venglinisky, 1961					xxx	xx	x	
<i>Trochammina</i> sp.				x			x	x

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