A new evidence of *Vexillum* (Gastropoda: Costellariidae) from the middle Miocene (Serravallian) of the Vienna Basin (Slovakia)

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Abstract: In this study, a new evidence of Neogastropods of the family Costellariidae MacDonald, 1860 from the Miocene of Central Paratethys is presented. The finds of fossil shells of the genus *Vexillum* Röding, 1798 derives from the middle Miocene (Serravallian) marine deposits from the eastern margin of the Vienna Basin (Western Carpathians, Slovakia), which belongs to the north-west Central Paratethys realm. The studied gastropods were discovered at the locality Rohožník – Konopiská, in the basinal pelitic facies and organodetritic corallinacean marls of the Studienka Formation of late Badenian age (*Bulimina-Bolivina* Biozone). The material studied here includes two new species: *Vexillum svagrovskyi* sp. nov. and *Vexillum pseudoschafferi* sp. nov. The affinity and comparison of both species with other similar costellariids from the Neogene of European Eastern Atlantic, Proto-Mediterranean and Paratethyan regions are discussed. From a paleoecological point of view, the results suggest that *V. svagrovskyi* was adapted to a moderately deep, circalittoral environment with occasional worsening of the paleoecological conditions (low bottom water oxygenation), whereas species *V. pseudoschafferi* preferred a shallow-water infralittoral environment.

Key words: *Vexillum*, Costellariidae, Gastropoda, Miocene, Badenian, Vienna Basin, Slovakia

1. INTRODUCTION

Vexillum Röding, 1798, one of the most common genera of the tropical marine gastropods of the family Costellariidae MacDonald, 1860, includes a wide spectrum of diversified fossil and modern species. Present-day representatives of *Vexillum* are distributed in the Indo-Pacific, they occur from intertidal to bathyal depths, on sand, mud, coral rubble, or reefs (Fedosov et al., 2017).

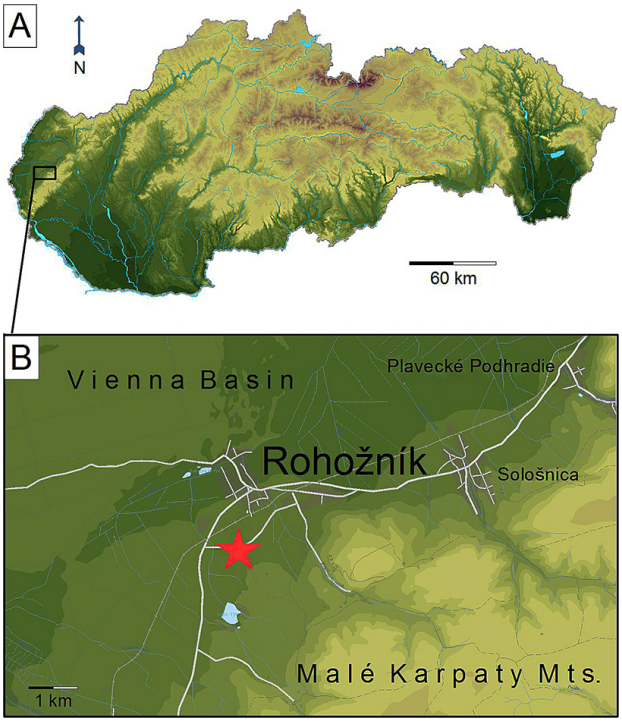

Fig. 1. Geographic position of the locality Konopiská at Rohožník. A – location in the territory of Slovakia; B – red star indicates locality in the area surrounding the Rohožník (modified from the ŠGÚDŠ site of Digital Elevation Model).

During the early to middle Miocene, the genus *Vexillum* was a carnivorous epifaunal component in the molluscan assemblages of the Central Paratethys Sea. From this realm, they are known from many Miocene localities (e.g. Hörnes, 1852; Hoernes & Auinger, 1880; Schaffer, 1897; Boettger, 1896, 1906; Friedberg, 1911, 1928; Csepreghy-Meznerics, 1954, 1956; Sieber, 1958; Kojumdgieva, 1960; Strausz, 1966; Hinculov, 1968; Krach, 1981; Bałuk, 1997). In Slovakia, their occurrence in the Miocene strata of the Vienna Basin, Danube Basin and East Slovakian Basin has been documented several times (see Schaffer, 1897; Hano, 1950; Seneš, 1955; Švagrovský, 1981, 1982; Tomašových, 1998; Ruman & Hudáčková, 2015).

The herein discussed costellariids were found in the upper Badenian sediments in the abandoned clay pit at the locality Konopiská near Rohožník (Vienna Basin). The deposits represent the Studienka Formation and are correlated with the *Bulimina-Bolivina* Biozone (e.g. Kučerová, 1986; Hladilová, 1991; Lambert et al., 2008).

2. GEOLOGICAL AND PALEONTOLOGICAL SETTING

2.1 Geographic position, geological setting and stratigraphy

The locality Konopiská comprises an old clay pit and its vicinity. It is located 1 km south of the Rohožník railway station (Fig. 1, GPS coordinates: 48°26'39" N, 17°09'53" E), on the eastern margin of the Slovak part of the Vienna Basin, at the western edge of the Malé Karpaty Mts. The pre-Neogene basement is

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composed of the Triassic megabreccia of Wetterstein-type limestones that belong to the uppermost tectonic units of the Northern Calcareous Alps (Kováč et al., 1991; Hladilová et al., 1998). The Neogene strata are represented by clays, sandy clays and sands of middle- to late Miocene age (Langhian to Tortonian) that correspond to the Paratethyan middle Badenian, upper Badenian, lower Sarmatian and Pannonian stages (e.g. Čierna, 1973). The locality Konopiská is a faulted deposit. The tectonic borders suggest block faulting of the subjacent Neogene group of beds in this area (see Čierna, 1973). A dislocated deposit has been revealed in the northern part of former clay pit – the Badenian and Sarmatian sediments were situated together and on the same level, which has probably been caused by the tectonic lowering of one of the nearby tectonic block (Holec et al., 2007).

The clay pit was exploited between 1976 and 1998, later abandoned, completely revitalized and flooded by water. The sediments have been assigned to the Central Paratethyan Badenian and Sarmatian stages (Kučerová, 1986; Hladilová, 1991; Kováč et al., 1991). Fordinál et al. (2012) confirmed the designation of these layers as the upper Badenian Studienka Formation and lower Sarmatian Holíč Formation, which is supported by the foraminiferal assemblages (Čierna, 1973) and ostracods (Kučerová, 1986). Additional data of the stratigraphic age based on the molluscan fauna were reported by Švagrovský (1971), Hladilová (1991) and Ruman & Hudáčková (2015).

2.2 Synopsis of previous research and paleoecology

Since the 60's of the 20th century, the fossil remnants of a wide spectrum of marine organisms have been studied by many authors from this locality. Fossils were initially obtained from drilling cores, later they were collected in an exposed clay pit. The middle Miocene marine strata have yielded rich associations of foraminifers (Čierna, 1973), diversified molluscan assemblages (e.g. Švagrovský, 1971; Hladilová, 1991; Fuksi et al., 2011; Fuksi 2015a, 2015b; Biskupič, 2013, 2014, 2016; Ruman & Hudáčková, 2015), ostracod crustaceans (Kučerová, 1986), decapod crustaceans (Fuksi et al., 2011; Hyžný & Gašparič, 2014) and serpulid polychaetes (Biskupič, 2017). Pek et al. (1997) has studied the boring ichnofossils in molluscan shells, stable isotopes from molluscs fossils and sediments from Rohožník were summarized by Hladilová et al. (1998). Brief description of lithology and faunal assemblages of the late Badenian strata has been presented by Biskupič (2018). Remains of fishes (Holec, 1973, 1975), rare cetaceans (Holec, 1987; Lambert et al., 2008) and unique examples of artiodactyl mammals (Holec et al., 2007) have been also found at the locality.

According to Fordinál et al. (2012), sedimentation during the late Badenian took place in the eastern part of the Vienna Basin under marine conditions in water depth up to 150 m with lowered levels of oxygen near to the sea-floor. Similarly, the assemblages of marine invertebrate faunas obtained from the basinal pelitic facies of the locality Konopiská at Rohožník bear witness of occasional deterioration of paleoenvironmental conditions near to the bottom. Episodic dysoxic events and low water dynamics are assumed by Hladilová (1991), Hladilová et al. (1998) and Lambert et al. (2008). According to Fuksi (2015b), sedimentation took place in a shallow subtidal, relatively protected environment (below storm wave base) with the stratified water column. Based on the analysis of Badenian ostracod assemblages, Kučerová (1986) suggests marine conditions with normal salinity, in depths of the sublittoral zone, with conditions of subtropical climate. According to Čierna (1973), paleoecological analysis of the upper Badenian foraminiferal associations indicates slow sedimentation nearby coast in depths of shallow- to deep sublittoral, in clear, well-aerated, but not turbulent waters, with a temperature of 20 – 30 °C and normal salinity of water above 30 ‰.

2.3 Lithology and fauna of the upper Badenian strata

The studied succession of the clay pit Konopiská attains a total thickness of about 20 m. The upper Badenian deposits of the Studienka Formation are mostly composed of basinal pelitic facies. To a small extent, the Badenian sediments were represented by allochthonous intercalations of organodetritic marls, limestones, sands and gravels of the Sandberg Member. The upper Badenian complex of strata is moderately sloping towards the basin, general direction of the angle of bedding is 20° northward. Based on the lithology and faunistic composition, these strata have been classified into several different deep- to shallow-water facies.

The lowermost part of the pelitic section has been composed of homogenous grey calcareous clays with bioturbation characterized by the occurrence of helical trace fossils, preliminarily identified as ichnogenus *Gyrolithes* de Saporta, 1884. Relatively diversified association of molluscs (gastropods, bivalves, scaphopods) is dominated by *Neopycnodonte navicularis* (Brocchi, 1814) and *Euspira helicina* (Brocchi, 1814), and was accompanied by numerous taxa of foraminifers, polychaetes, bryozoans, ahermatypic corals, echinoids, cirripeds, decapods, sharks and fishes. *Vexillum svagrovskyi* sp. nov. was documented exclusively from these strata.

The sequence continues with grey to green-grey calcareous clays with a typical molluscan assemblages characterized by *Corbula gibba* (Olivi, 1792) and *Tritia illovensis* (Hoernes & Auinger, 1882). During sedimentation of these layers, deterioration of paleoenvironmental conditions – e.g. sluggish circulation and lowered bottom-water oxygenation were assumed by Hladilová (1991), Hladilová et al. (1998) and Lambert et al. (2008). Beds of brownish-yellow to greyish-yellow clays rich in *Corbula gibba* (Olivi, 1792) and *Tritia illovensis* (Hoernes & Auinger, 1882) form the upper part of the section. The last two mentioned facies are characterized by species-poor, more or less monotypic associations of gastropods and bivalves. Other groups of marine organisms were represented by foraminifers, polychaetes, bryozoans, scaphopods, echinoids, decapods, fishes and rare cirripeds and ahermatypic corals.

Basinal pelites bear the finger-like layers and intercalations of marginal infralittoral facies of the Sandberg Member. These deposits were represented by allochthonous coarse-grained biodetritic marls, sands and gravels, rich in diversified shallow-water communities of the marine micro- and macrofauna (foraminifers, bryozoans, brachiopods, scleractinian corals, molluscs, polychaetes, decapods, cirripeds, echinoids, ophiuroids, sharks and fishes). Various facies belonging to the Sandberg Member were identified. Single layer of grey organodetritic marl characterized

by association of *Ditrupa cornea* (Linnaeus, 1767) and *Fissidentalium mutabile* (Hörnes, 1856) with thickness of 20–30 cm, as well as several longitudinal interbeds of grey and brown-yellow carbonate organodetritic corallinacean marls and limestones of variable thickness (10–80 cm) with significant prevalence of *Petaloconchus intortus* (Lamarck, 1818) and *Bittium reticulatum* (da Costa, 1778) were revealed in the lowermost to middle parts of the basinal pelitic section. In the upper part of pelites, an elongated lens-like body of pale-grey to yellow organodetritic marls characterized by *Petaloconchus intortus* (Lamarck, 1818) and *Tricolia eichwaldi* (Hörnes, 1855) was documented. Above these deposits, discontinuous intercalations of pale to ocherous sands with gravels and fragments of corallinacean limestones mixed with fragmented molluscan shells dominated by *Amalda glandiformis* (Lamarck, 1810) and turritellids, up to 150 cm in thickness, occur.

3. MATERIAL AND METHODS

The studied specimens of *Vexillum svagrovskyi* sp. nov. (19 shells) were collected in a former clay pit by the author in the period 1994 – 2004, most of the material has been found during recultivation works in 2001 – 2004. One shell was obtained during fieldworks by the staff of the Department of Geology and Palaeontology, Comenius University in Bratislava (Slovakia) in the 80's, and another specimen was found by amateur palaeontologist Štefan Meszároš (Bratislava). The examined material includes altogether 21 specimens. The shells are moderately preserved; only few specimens are well preserved with minimal signs of breakage. Small shells of *Vexillum pseudoschafferi* sp. nov. have been collected from the layers of organodetritic corallinacean marls. Clayey sediment was dissolved in the water, washed in a sieve, and after drying, the shells were subsequently separated from the samples. Material includes 15 specimens, with 11 juvenile and 4 adult shells.

All studied specimens are now stored in the institutional collection of the Natural History Museum of Slovak National Museum, Bratislava, Slovakia (SNM-PM) under the inventory numers Z 40040 – Z 40060, Z 40033 – Z 40036 and Z 40073 – Z 40083.

4. SYSTEMATIC PALEONTOLOGY

The higher gastropod systematics of Bouchet et al. (2017) is followed here, taking into account recent modifications regarding a new taxonomic interpretation of the family Costellariidae MacDonald, 1860. Following Fedosov et al. (2017), Bouchet et al. (2017) and MolluscaBase (2020), the Costellariidae are integrated into the superfamily Turbinelloidea Rafinesque, 1815.

Suggested by Cernohorsky (1980) and Turner (2001), the subgenus *Uromitra* Bellardi, 1887 is considered as a synonym of *Costellaria* Swainson, 1840. The costellariid gastropods, including the *Costellaria* Swainson, 1840 and *Vexillum* Röding, 1798, were revised by Fedosov et al. (2017) and *Costellaria* was shown to be a junior synonym of the *Vexillum* based on molecular data. Therefore, the here studied costellariids are placed within the genus *Vexillum*.

Class Gastropoda Cuvier, 1795
Subclass Caenogastropoda Cox, 1960
Order Neogastropoda Wenz, 1938
Superfamily Turbinelloidea, Rafinesque, 1815
Family Costellariidae MacDonald, 1860

Genus *Vexillum* Röding, 1798
Type species: *Vexillum plicatum* Röding, 1798 (= *Voluta plicarium* Linnaeus, 1758), by subsequent designation (Woodring, 1928). Recent of Indo-Pacific.

***Vexillum svagrovskyi* sp. nov.**
Figs. 2 – 5

Type material: Holotype: Z 40040, height: 29.2 mm, width: 9.6 mm (Fig. 2, A – B); **Paratype 1:** Z 40041, height: 28.5 mm, width: 9.1 mm (Fig. 2, C – D); **Paratype 2:** Z 40042, height: 33.1 mm, width: 10.3 mm (Fig. 2, E – F); **Paratype 3:** Z 40043, height: 33.4 mm, width: 10.4 mm (Fig. 2, G – H); **Paratype 4:** Z 40044, height: 33.3 mm, width: 10.0 mm (Fig. 3, A – B); **Paratype 5:** Z 40045, height: 40.2 mm, width: 12.5 mm (Fig. 3, C – D); **Paratype 6:** Z 40046, height: 30.3 mm, width: 10.4 mm (Fig. 3, E – F) (donation of the Department of Geology and Palaeontology, Comenius University, Bratislava, Slovakia); **Paratype 7:** Z 40047, height: 31.3 mm, width: 10.4 mm (Fig. 3, G – H) (donation of Štefan Meszároš, Bratislava, Slovakia).

Additional material: Maximum height: 38.1 mm. Z 40048, Z 40049, Z 40050, Z 40051, Z 40052, Z 40053, Z 40054, Z 40055, Z 40056, Z 40057, Z 40058, Z 40059, Z 40060.

Derivation of name: In memory of Prof. Jozef Švagrovský (1921 – 1985), Slovak palaeontologist, geologist, university professor, the prominent researcher of the Miocene molluscan assemblages of Slovakia.

Type locality: Konopiská clay pit near Rohožník, Vienna Basin, Slovakia.

Stratum typicum: Grey bioturbated calcareous clays of the Studienka Formation, middle Miocene, upper Badenian (= lower Serravallian), *Bulimina-Bolivina* Biozone.

Diagnosis: A medium-sized costellariid, shell fusiform, slender, with 8 – 11 almost flat-side up-to slightly convex teleoconch whorls, spiral whorls slightly scalariform, with smoothed opisthocline axial ribs and incised spiral grooves, weakening abapically, subsutural band prominent, wide and intermittent by 3 – 6 spiral furrows and striae, subsutural groove well-defined, the ornamentation on the body whorl attenuated, aperture elongated, siphonal canal long, four strong columellar folds.

Description: Slender, fusiform, medium-sized shell for the genus, reaching between 28 – 40 mm in length and 9 – 12 mm in width (based on 18 adult specimens). Spire outline generally straight. Protoconch missing in all specimens. Teleoconch consists of 8 – 11 almost flat-side whorls, last teleoconch whorl reach 59 – 64 % of total height. Spire whorls rather gradate with a moderate angular outline, separated by well developed and canaliculated suture. Last adult whorl elongated, convex, rounded

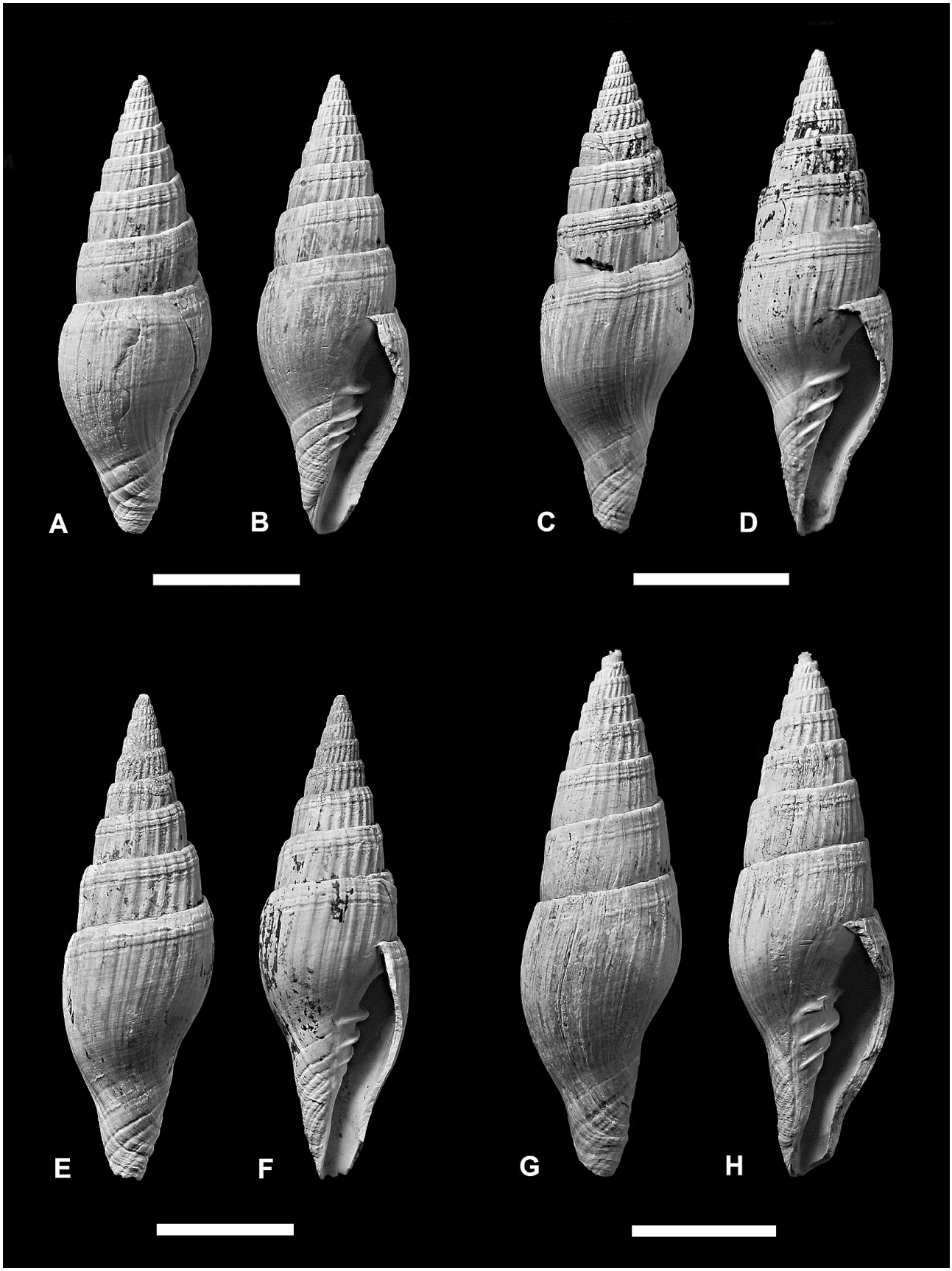

Fig. 2. *Vexillum svagrovskyi* sp. nov., Rohožník – Konopiská (clay pit). **A – B:** Holotype, Z 40040, A – abapertural view, B – apertural view; **C – D:** Paratype 1, Z 40041, C – abapertural view, D – apertural view; **E – F:** Paratype 2, Z 40042, E – abapertural view, F – apertural view; **G – H:** Paratype 3, Z 40043, G – abapertural view, H – apertural view. Scale bar = 1 cm.

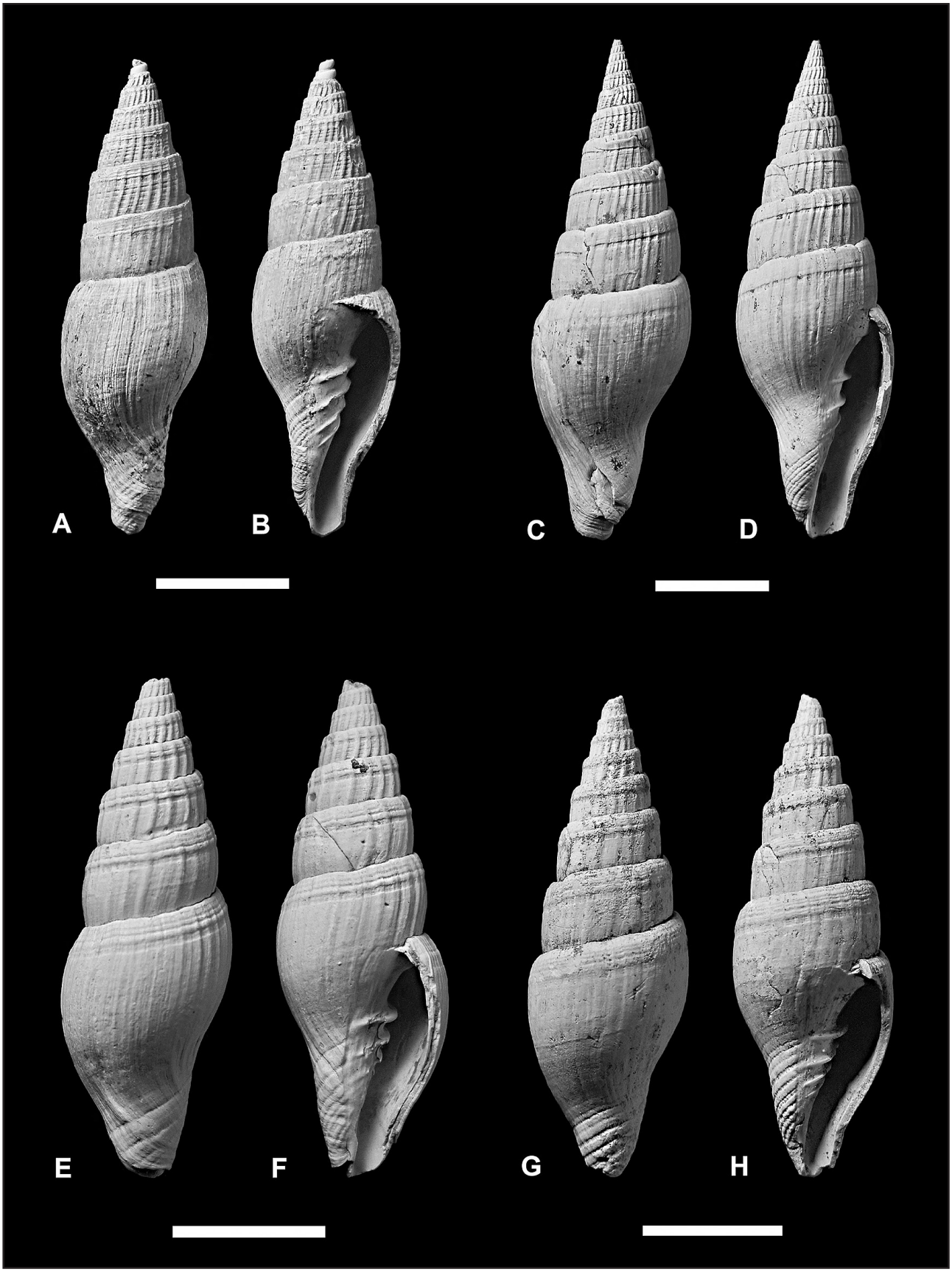

Fig. 3. *Vexillum svagrovskyi* sp. nov., Rohožník – Konopiská (clay pit). **A – B:** Paratype 4, Z 40044, A – abapertural view, B – apertural view; **C – D:** Paratype 5, Z 40045, C – abapertural view, D – apertural view; **E – F:** Paratype 6, Z 40046, E – abapertural view, F – apertural view; **G – H:** Paratype 7, Z 40047, G – abapertural view, H – apertural view. Scale bar = 1 cm.

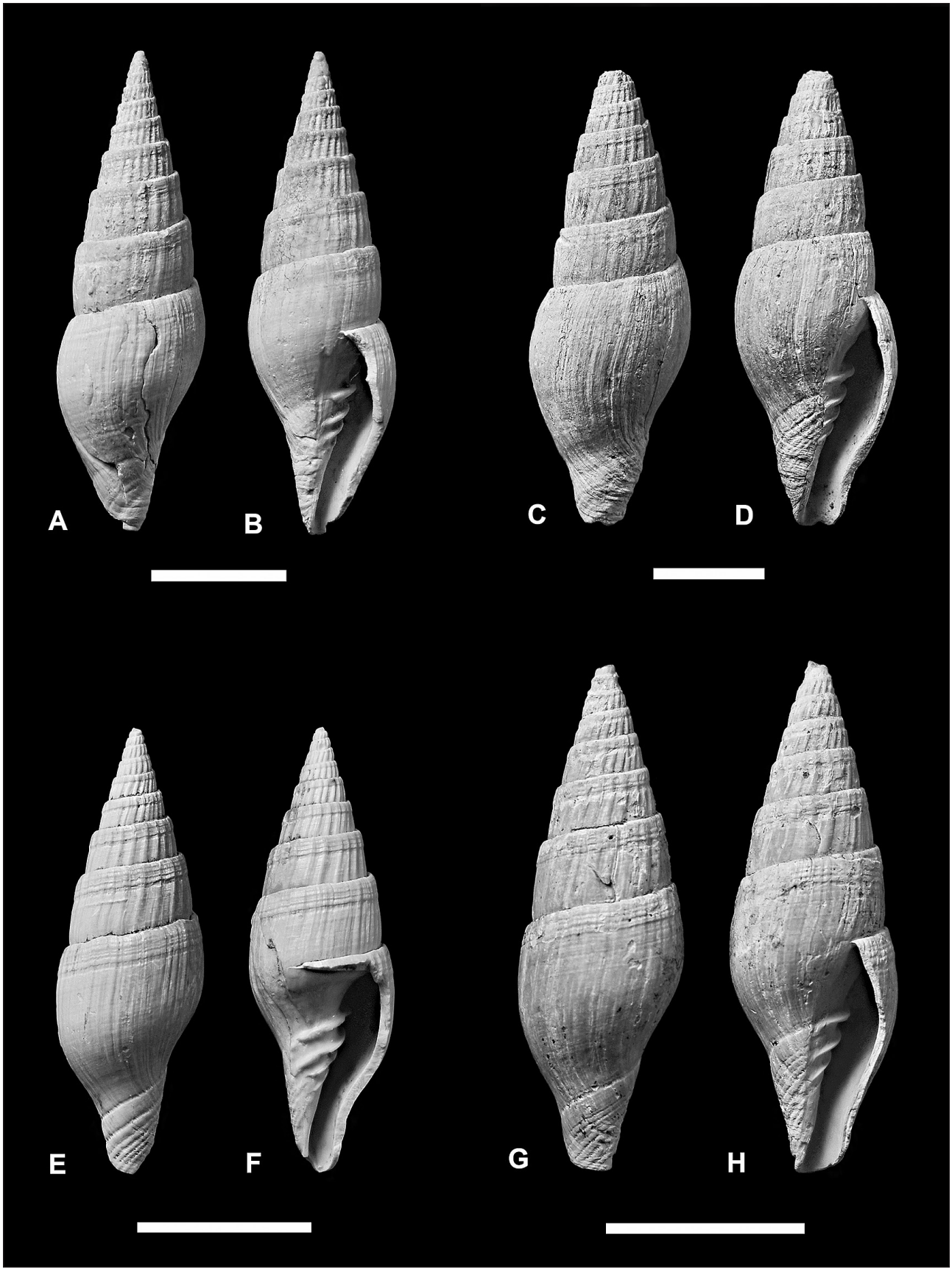

Fig. 4. *Vexillum svagrovskyi* sp. nov., Rohožník – Konopiská (clay pit).
A – B: Z 40049, A – abapertural view, B – apertural view; **C – D:** Z 40051, C – abapertural view, D – apertural view; **E – F:** Z 40052, E – abapertural view, F – apertural view; **G – H:** Z 40053, G – abapertural view, H – apertural view. Scale bar = 1 cm.

at the shoulder. Shell decorated by axial ribs, spiral grooves and cords, the sculpture of the first whorls is coarser than on last adult whorl. Axial sculpture composed of pronounced 17 – 30 smooth opisthocline axial ribs on first whorls, increasing to 23 to 43 ribs on penultimate whorl. Axial ribs are separated by equally wide interspaces with 2 – 6 incised spiral grooves. Subsutural area of the whorls bears conspicuous subsutural band, on the lower margin well delimited by a subsutural groove. The subsutural band occupying one-third of the high of the whorl, furcated to 3 – 6 spiral cords that are separated by narrow spiral furrows. Number and thickness of cords is relatively variable, the lowermost spiral cord is usually broader and more flattened than other cords. Axial sculpture of the body whorl is strongly reduced, it bears about 28 – 31 less pronounced and weakening opisthocline axial ribs. The sculpture on the last adult whorl becomes attenuated, generally composed of weakly sinuous and fine opisthocline growth lines and striae. The spiral sculpture consists of delicate and indistinct, slightly developed spiral lines and striae, subsutural band and subsutural groove obvious. Aperture elongate, more or less narrow. Anal canal indistinct, poorly developed, siphonal canal conspicuous, long and open. Outer lip simple and smooth. Columella bears well-defined four strong oblique folds, decreasing in size abapically. Siphonal fasciole with 6 – 11 spiral cords, of which upper 1 – 2 cords are flat and broad, other lower 4 – 10 spiral cords are rounded and narrower.

Remarks: The species has characteristic medium-sized, slender, fusiform shells, with teleoconch whorls decorated by axial ribs and spiral grooves, long siphonal canal, elongated aperture and columella with four strong folds, which is identical with morphological features of the genus *Vexillum* given by Fedosov et al. (2017).

Vexillum species are characterized by a high intraspecific variability of shell shape and sculpture, which is also seen in Miocene species, e.g. Hörnes (1852), Chirli (2002) and Chirli & Richard (2008) for *V. cupressinum* (Brocchi, 1814), Glibert (1952) for *V. aciculum* (Nyst, 1861), Janssen (1984) for *V. gliberti* Anderson, 1964. Similarly, also *Vexillum svagrovskyi* sp. nov. has evident intraspecific morphological variability, which is demonstrated by the variable shape of whorls and shell, as well as high variation of sculptural elements. Some specimens tend to have an axial and spiral sculpture developed only on the first whorls, on the penultimate up to last adult whorl – the axial ribs become faint to obsolete, whereas for other specimens a coarser sculpture composed of axial ribs developed on all whorls including body whorl. Moreover, the spiral sculpture is comparatively variable concerning a different number of spiral grooves, and a variable number of spiral cords on the subsutural band.

Only two costellariid species have been documented exclusively from the middle Miocene of Slovakia, both from Vienna Basin: *Vexillum neudorfense* (Schaffer, 1897) and *Vexillum nitidum* (Schaffer, 1897). The new species from Rohožník is closely similar to *V. neudorfense*, in shell size, sculpture, shape of a shell and stepped whorls. Under the name *Mitra neudorfensis*, this enigmatic gastropod species was originally described by Schaffer (1897) from the Badenian calcareous clays exposed in the late 19th century in the old clay pit (Brickyard) at Devínska Nová Ves (formerly Theben – Neudorf, Dévény – Ujfalu), district of Bratislava. However, the shell described and illustrated by Schaffer (1897; 542, fig. 5) differs from *Vexillum svagrovskyi* sp. nov. in having five columellar folds, a more elongated spire and coarser spiral cords on the subsutural band. From the same locality, Schaffer (1897; 541, fig. 4) described *Mitra nitida*. This costellariid differs from *V. svagrovskyi* in its smaller size, equally spaced axial ribs, stronger subsutural band and in developing five columellar folds.

Several Miocene species of *Vexillum* are known from the North Sea Basin (see Kautsky, 1925; Glibert, 1952; Anderson, 1964; Wienrich, 2007). Three closely similar species were discovered in Belgium, Germany and Denmark: *Vexillum aciculum* (Nyst, 1861), *Vexillum boreocinctum* (Kautsky, 1925) and *Vexillum gliberti* Anderson, 1964. *Vexillum aciculum* (Nyst, 1861) is comparatively similar to *V. svagrovskyi*, but differs in its smaller shell, less numerous axial ribs, considerably reduced sculpture, weak and unequally spaced axial ribs and spiral furrows, and simple and smooth subsutural band. *Vexillum boreocinctum* (Kautsky, 1925), from the Miocene of Germany, differs from the Slovakian costellariid primarily by its smaller size; measurements of specimens described by Kautsky (1925) reaches maximally 20 mm in length. Similarly, according to Wienrich (2007), the largest adult shell from the Lüllingen locality (Germany) reaches only 20.9 mm in length. At first sight, this species is reminiscent of *V. svagrovskyi* in its shell outline and sculpture (see specimens figured by Wienrich, 2007; tab. 136, figs. 6a – 6b, 7a – 7b), nevertheless, it differs in less numerous and coarser axial ribs on the first whorls, less inclined axial ribs, moderately convex shape of whorls, which is visible especially on the spire whorls and in bearing only three spiral cords on the subsutural band. Other Miocene North Sea Basin species, *Vexillum gliberti* Anderson, 1964 is comparable with *Vexillum svagrovskyi* sp. nov. mainly in its shell shape and sculpture. However, shells of this gastropod differ from the new species in smaller size and having a shorter body whorl, equally spaced axial ribs developed on all whorls and less pronounced subsutural band.

Many costellariid species are known from the Neogene of Italy (see Bellardi, 1850, 1887, 1888; Robba, 1968; Ferrero Mortara et al., 1984), three of them are relatively similar to the new one: *Vexillum borsoni* (Bellardi, 1850), *Vexillum antecedens* (Bellardi, 1887) and *Vexillum recurvatum* (Bellardi, 1887). *V. borsoni* differs from the Slovakian species mainly in its coarser sculpture, lower number of widely spaced axial ribs and slightly convex whorl sides. Similarly, the Miocene Italian species *V. antecedens* and *V. recurvatum* have conspicuously more elongated shells with moderately rounded whorls. Both species have distinctive, coarser ornamented shells: less numerous and equally spaced axial ribs are more pronounced, interspaces between axial ribs are wider, spiral furrows are well-defined on all whorls, and columellar folds get a form of almost sharp-crested cords that are developed on the siphonal fasciole.

Another, superficially similar species is the well-known Neogene *Vexillum cupressinum* (Brocchi, 1814) widespread in the European Atlanto–Proto-Mediterranean and Paratethyan regions (see Brocchi, 1814; Kojumgdieva, 1960; Strausz, 1966; Schultz, 1998; Chirli, 2002; Chirli & Richard, 2008; Landau et al., 2013). This costellariid differs from *Vexillum svagrovskyi* sp. nov. in its more slender shell; its spire, last adult whorl and siphonal canal

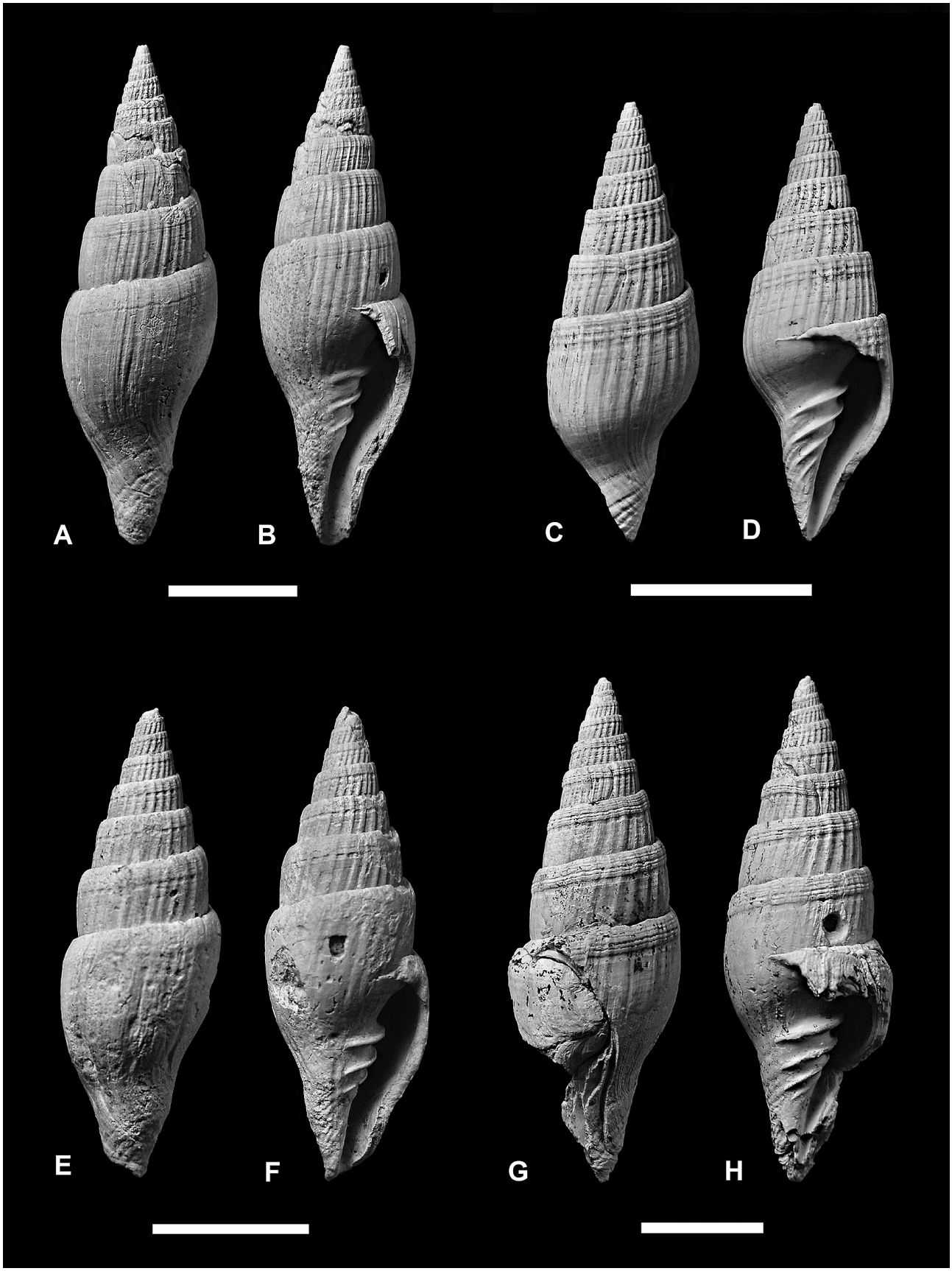

Fig. 5. *Vexillum svagrovskyi* sp. nov., Rohožník – Konopiská (clay pit).
A – B: Z 40048, A – abapertural view, B – apertural view; **C – D:** Z 40054, C – abapertural view, D – apertural view; **E – F:** Z 40060, E – abapertural view, F – apertural view; **G – H:** Z 40050, G – abapertural view, H – apertural view. Scale bar = 1 cm.

are markedly more elongated. Shells of this species have a coarser sculpture of nearly quadratic-reticulate structure composed of axial ribs crossed by spiral furrows and cords. Furthermore, some shells of *V. cupressinum* from the middle Miocene of the Vienna Basin differ in bearing five columellar folds (see Landau et al., 2013) instead of four in the new species.

Distribution: Only known from the middle Miocene (upper Badenian) of the locality Rohožník – Konopiská (Slovakia) (this paper).

***Vexillum pseudoschafferi* sp. nov.**
Figs. 6 – 7

Type material: Holotype: Z 40033, height: 11.7 mm, width: 4.4 mm (Fig. 6, A – B); **Paratype 1:** Z 40034, height: 6.8 mm, width: 2.7 mm (juvenile) (Fig. 6, C – D); **Paratype 2:** Z 40035, height: 6.3 mm, width: 2.6 mm (juvenile) (Fig. 6, E); **Paratype 3:** Z 40036, height: 5.7 mm, width: 2.4 mm, diameter protoconch: 670 µm, height protoconch: 750 µm (juvenile) (Fig. 7, A – B); **Paratype 4:** Z 40073, height: 5.9 mm, width: 2.3 mm, diameter protoconch: 700 µm, height protoconch: 840 µm (juvenile) (Fig. 7, C – D); **Paratype 5:** Z 40074, height: 5.3 mm, width: 2.1 mm, diameter protoconch: 650 µm, height protoconch: 800 µm (juvenile) (Fig. 7, E – F).

Additional material: Maximum height: 11.3 mm. Z 40075,

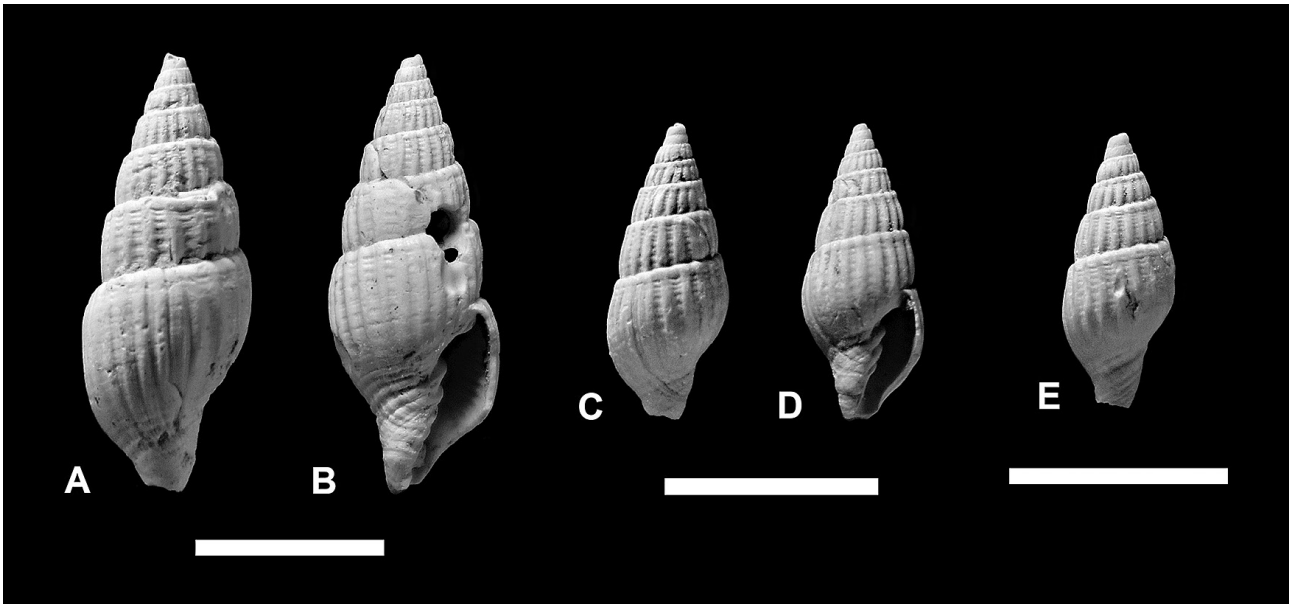

Fig. 6. ***Vexillum pseudoschafferi*** **sp. nov., Rohožník – Konopiská (clay pit).**
A – B: Holotype, Z 40033, A – abapertural view, B – apertural view; C – D: Paratype 1, Z 40034, C – abapertural view, D – apertural view (juvenile); E: Paratype 2, Z 40035, E – abapertural view (juvenile). Scale bar = 5 mm.

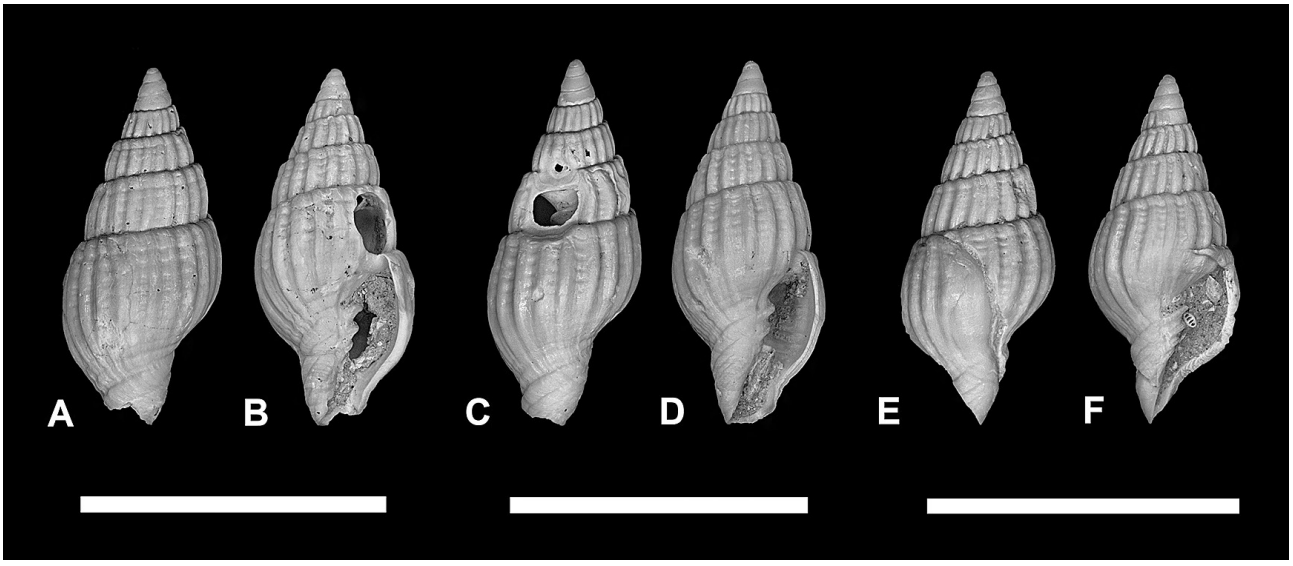

Fig. 7. ***Vexillum pseudoschafferi*** **sp. nov., Rohožník – Konopiská (clay pit).**
A – B: Paratype 3, Z 40036, A – abapertural view, B – apertural view (juvenile); C – D: Paratype 4, Z 40073, C – abapertural view, D – apertural view (juvenile); E – F: Paratype 5, Z 40074, E – abapertural view, F – apertural view (juvenile). Scale bar = 5 mm.

Z 40076, Z 40077, Z 40078, Z 40079, Z 40080, Z 40081, Z 40082, Z 40083.

Derivation of name: Combination of Greek *pseudis* (ψευδής) = false and *schafferi* = the name of the most closely similar species *Vexillum schafferi* (Meznerics, 1933).

Type locality: Konopiská clay pit near Rohožník, Vienna Basin, Slovakia.

Stratum typicum: Brown-yellow carbonate organodetritic corallinacean marls and limestones of the Studienka Formation, middle Miocene, upper Badenian (= lower Serravallian), *Bulimina-Bolivina* Biozone.

Diagnosis: *Vexillum* species of small size, shell fusiform, with 6 – 7 moderately convex teleoconch whorls, smooth multispiral protoconch of 3.5 – 4 whorls, spiral whorls slightly scalariform, with smoothed prosocline axial ribs and incised spiral grooves, subsutural band simple, small tubercles developed on the intersections of axial ribs, subsutural groove weak, aperture ovate, outer lip lirate within, siphonal canal short, four strong columellar folds.

Description: The species is characterized by its fusiform, elongated, small-sized shell for the genus, reaches maximally 11.7 mm in length. Protoconch conical, multispiral, smooth, composed of 3.5 – 4 whorls, with a medium-sized nucleus. The shell of adult specimens composed of 6 – 7 teleoconch whorls separated by well-defined suture. Teleoconch whorls are slightly convex, with a moderately stepped outline. The axial sculpture consists of strong prosocline ribs, well developed on all whorls. Smooth-surfaced axial ribs are separated by equally wide interspaces wherein are developed 4 – 7 fine spiral cords well delimited by spiral grooves. Spire whorls bears 16 – 20 axial ribs, their number increase to 20 – 22 on the body whorl. The subsutural area bears simple subsutural band, smooth or intermittent by a single fine narrow spiral furrow, crossed by axial ribs, producing small nodules developed at intersections; subsutural groove is weak. The last adult whorl is short, convex, rounded at the shoulder, and the subsutural band is weakened. Aperture is ovate, small, outer lip is lirate within, lirae extending shallow within the aperture. Anal canal is weakly developed, columella is straight, bearing four oblique folds weakening abapically. Siphonal canal is open, short in length, siphonal fasciole shows 6 – 9 spiral cords.

Remarks: The species is placed in *Vexillum* based on overall morphology typical for the genus sensu Fedosov et al. (2017).

Three congenerous middle Miocene Paratethyan Costellariidae species are comparable this new species: *Vexillum schafferi* (Meznerics, 1933), *Vexillum nitidum* (Schaffer, 1897) and *Vexillum brevior* (Friedberg, 1911). The new species is highly reminiscent of small-shelled *Vexillum schafferi* (Meznerics, 1933), also occurring in the Vienna Basin (see Hörnes, 1852; Hoernes & Auinger, 1880; Meznerics, 1933). All specimens of *V. schafferi* figured in the publications come from the Badenian locality Steinebrunn (Austria). At first sight, the morphological features of adult specimens of *Vexillum pseudoschafferi* sp. nov. are similar to the shell illustrated by Meznerics (1933; p. 343, pl. 14, fig. 6 a, b). However, this costellariid differs from the Slovakian species in its slightly slimmer shell, less convex whorls, the subsutural band is strongly suppressed. The specimen figured by Hörnes (1852; pl. 10, fig. 31 a, b, c) under the name *Mitra recticosta* Bell. has a slightly higher and slimmer shell, with more numerous whorls, its subsutural band is weakly developed, barely visible. Similarly, the specimen illustrated by Hoernes & Auinger (1880; pl. 10, fig. 9 a, b, c) as *Mitra (Costellaria) Borsoni* Bell. is rather taller, the shape of its shell is slender, teleoconch whorls are higher, the last adult whorl and siphonal canal are shorter and the subsutural band is poorly developed. *Vexillum nitidum* (Schaffer, 1897), only known from the Badenian (Miocene) calcareous clays of Devínska Nová Ves – brickyard (Vienna Basin, Slovakia), is relatively similar small-sized Paratethyan costellariid. This species differs from *V. pseudoschafferi* primarily by its much larger size, prominent and stronger subsutural band and in developing five columellar folds. *Vexillum brevior* (Friedberg, 1911), originally described by Friedberg (1911; 24, tab. 1, fig. 17) under the name *Turricula recticosta* Bell. var. *brevior* from the middle Miocene of Poland, is also a closely similar species, especially in its shell size and sculpture. However, this Polish congener has a different shape of shell, spire and last adult whorl. *V. brevior* is characterized by its slightly orthoconoid or acuminate spire; the last adult whorl is broader and more convex. Furthermore, according to Friedberg's illustration of the shell, it seems that axial ribs are crossed by spiral furrows and cords, whereas *V. pseudoschafferi* has smooth axial ribs.

From the Miocene of Europe, several similar small-sized costellariid species were also described (e.g. Bellardi, 1850, 1887, 1888; Peyrot, 1928; Hinsch, 1952; Rasmussen, 1956; Robba, 1968; Ferrero Mortara et al., 1984; Janssen, 1984; Lozouet et al. 2001; Wienrich, 2007). *Vexillum miocenicum* (Peyrot, 1928) and *Vexillum pyrenaicum* (Peyrot, 1928), from the Aquitanian of France, have more elongated shell, shorter last adult whorl and coarser axial sculpture than *Vexillum pseudoschafferi* sp. nov. The Proto-Mediterranean and Paratethyan *Vexillum borsoni* (Bellardi, 1850) differs in having a larger shell, elongated last adult whorl, longer siphonal canal and stronger axial ribs. *Vexillum cimbricum* (Oppenheim in Kautsky, 1925), known from the Miocene North Sea Basin of Germany, Denmark and Belgium, has stronger developed transverse sculptural elements, equally spaced axial ribs are more pronounced and massive, subsutural band is coarser, the outline of whorls is more stepped and angulated. Also, the Miocene North Sea Basin costellariid *Vexillum gliberti* Anderson, 1964 has longer body whorl and siphonal canal. *Vexillum jasperi* Wienrich, 2007, described from Germany, is characterized by its tall and slender shell, with short body whorl and siphonal canal, which suggests close similarities with *V. pseudoschafferi*. Nevertheless, this species has nearly flat-sided whorls, and coarser and less numerous opisthocline axial ribs. The Italian *Vexillum soror* (Bellardi, 1887) and *Vexillum crebricostatum* (Bellardi, 1887) are reminiscent of *V. pseudoschafferi* in their shape of shell and whorls, as well as in axial and spiral sculpture. However, both species differ in their more elongated body whorl and siphonal canal. In addition, *V. crebricostatum* has only three columellar folds.

Distribution: Only known from the middle Miocene (upper Badenian) of the locality Rohožník – Konopiská (Slovakia) (this paper).

5. DISCUSSION

From the various marine shallow- to deep sublittoral deposits of the upper Badenian Studienka Formation exposed at the locality Konopiská at Rohožník, seven species of the family Costellariidae were identified: *Pusia leucozona* (Andrzejowski, 1830), *Pusia transsylvanica* (Boettger, 1902), *Pusia paraleucozona* (Boettger, 1906), *Pusia cognatum* (Bellardi, 1887), *Vexillum svagrovskyi* sp. nov., *Vexillum pseudoschafferi* sp. nov. and *Thala partschi* (Hörnes, 1852). Most of the costellariids occurred in the shallow-water sands and marls with coralline algae, representing infralittoral facies, only *V. svagrovskyi* was found in the circalittoral pelitic deposits deposited in low-energy habitats below a storm wave base.

The facies distribution of the two *Vexillum* species indicates that they differed in their habitat preferences. *Vexillum svagrovskyi* sp. nov. occurs exclusively in massive or thick-bedded grey calcareous clays with bioturbation. This occurrence suggests that its distribution was restricted to the circalittoral pelitic facies, which probably formed in a relatively deep, low-energy marine depositional environment with soft-bottom conditions. Stenohaline organisms (e.g. ahermatypic corals, pectinid bivalves, scaphopods, echinoids, ophiuroids) that co-occur with *V. svagrovskyi* point to a normal seawater salinity. However, co-occurrences of the abundant opportunistic bivalve *Corbula gibba* (Olivi, 1792) indicates some stress that temporarily affected benthic communities, such as seasonal hypoxia or repeated sediment disturbance near the bottom (cf. Hyžný et al., 2012; Fuksi, 2015a, 2015b). Similar deep-water habitats on the eastern part of the Vienna Basin during the late Badenian were proposed by Tomašových (1998) and Fordinál et al. (2012); according to them, sedimentation took place in deeper marine settings with permanently (e.g., laminated benthos-free clays at Devinska Nová Ves) or temporarily-reduced levels of oxygen near the sea-floor (e.g., bioturbated clays with *Corbula* in the upper parts of the succession at Devínska Nová Ves – brickyard). *Vexillum svagrovskyi* sp. nov. is missing in the middle to upper part of the section at Konopiská, represented by calcareous clays. These strata are characterized by a different taxonomic composition of the benthic macrofauna, with monotypic but specimen-rich molluscan assemblages. The molluscan association is dominated by huge populations of the opportunistic bivalve *Corbula gibba* (Olivi, 1792), by the scavenger nassariid gastropod *Tritia illovensis* (Hoernes & Auinger, 1882) and by the carnivorous naticid gastropod *Euspira helicina* (Brocchi, 1814). The dominant bivalve *C. gibba* indicates recurring dysoxic conditions near the sea-floor, which correspond to the results of Hladilová (1991), Hladilová et al. (1998), Lambert et al. (2008) and Fuksi (2015a, 2015b). *Corbula gibba* is well adapted to habitats under unstable environmental conditions (Aleffi & Bettoso, 2000; Mandic & Harzhauser, 2003; Hrs-Brenko, 2006) and tolerates temporary hypoxia (Aleffi & Bettoso, 2000; Hrs-Brenko, 2006; Zuschin et al., 2007). This species thus belongs to few species that thrives in habitats (Mandic & Harzhauser, 2003; Fuksi et al., 2018). The presence of species-poor association of benthic invertebrates thus indicates that the paleoenvironmental conditions were unfavourable and oxygen-depleted in the middle and upper parts of the section. Thus, although *V. svagrovskyi* was adapted to deeper habitats with some degree of oxygen depletion, it did not tolerate conditions with higher frequency or magnitude of hypoxic events.

Almost all specimens of *Vexillum pseudoschafferi* sp. nov., were found in the infralittoral, shallow-water marginal facies of the Sandberg Member – in the layers and longitudinal interbeds formed by alternation of allochthonous coarse-grained bioclastic marls and limestones; only a single specimen was found in the basinal pelitic facies. Bioclastic algal marls and limestones represent an episodic redeposition of infralittoral facies by storm currents, bioclasts are probably derived from the adjacent platforms formed by coralline algae along the Malé Karpaty Mts. (Lambert et al., 2008). Towards the basin, these sediments form variously thick intercalations and lens-like bodies in the basinal pelitic facies (Hladilová et al., 1998). Poor sorting and coarse-grained debris with a large percentage of rhodoliths indicate that these layers were deposited in the proximal environments not far from their source environment (Ruman & Hudáčková, 2015). The presence of *V. pseudoschafferi* in these sediments suggests that this species inhabited shallow marine, infralittoral nearshore environments. This inference is supported by co-occurrence of typical shallow-water macrofaunal assemblages and by the dominance of coralline algae. The prevalence of abundant and species-rich sessile suspension-feeding epifauna (serpulid polychaetes, bryozoans, brachiopods, vermetid gastropods, cemented and epibyssate bivalves) indicates that sedimentation took place in well-aerated, nutrient-rich and higher energy environment, with normal salinity (occurrence of stenohaline taxa). The mass occurrences of chitons and herbivorous taxa of gastropods (e.g. *Gibbula, Jujubinus, Tricolia, Bittium, Cingula, Alvania, Rissoina*) suggests an algae-dominated habitat.

6. CONCLUSIONS

Two new species, *Vexillum svagrovskyi* sp. nov. and *Vexillum pseudoschafferi* sp. nov., belonging to middle Miocene costellariids are described here. They come from the upper Badenian clayey marine deposits of the Studienka Formation from the locality Konopiská near Rohožník (Vienna Basin, Slovakia).

A medium-sized costellariid gastropod *Vexillum svagrovskyi* sp. nov. occurred exclusively in massive to thick-bedded grey calcareous clays with bioturbation that formed the lowermost part of the pelitic section exposed in the former clay pit. The species belong to a morphological group, which is represented during the Miocene by closely allied species such as *Vexillum neudorfense* (Schaffer, 1897) and *Vexillum boreocinctum* (Kautsky, 1925). This medium-sized costellariid was adapted to the soft muddy bottom in the moderately deep (circalittoral) zone of the Vienna Basin. Normal salinity and occasional oxygen depletion are assumed as the habitat.

Vexillum pseudoschafferi sp. nov. is related to the small-sized morphological group inculding *Vexillum schafferi* (Meznerics, 1933) and *Vexillum brevior* (Friedberg, 1911). The species is relatively rare and occurred in the intercalations of corallinacean debris deriving from the nearby corallinacean shoals. An accompanied typically shallow-water assemblages of organisms

suggests shallow marine nearshore environment as preferred habitat.

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