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LARGE DEEP BURROWING BIVALVES IN MIDDLE MIOCENE (BADENIAN) OF CENTRAL PARATETHYS; EXAMPLES FROM NORTHERN CROATIA

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Key words: Badenian, Central Paratethys, Middle Miocene, *Panopea*, *Pholadomya*

Abstract: Bivalve genera *Panopea* and *Pholadomya* represent rarely documented large deep burrowers found within Miocene coralline algal facies of Northern Croatia. Two localities are investigated, situated in marginal part of the Medvednica Mt. and in the Zrinska Gora Mt. Both genera, *Pholadomya* and *Panopea*, represent infaunal, siphonate, suspension-feeding, relative immobile deep burrowing bivalves, with similar palaeoecological demands, sharing their habitats during the Miocene epoch. The aim of this study is to document the presence of bivalve genera *Pholadomya* and *Panopea* in their life position in the Middle Miocene (Badenian) sediments of the Medvednica Mt. and finding of the largest found specimen of *Pholadomya* bivalve in the Zrinska Gora Mt. This study provides an insight to the findings of these infaunal bivalves in Croatia and worldwide, their palaeoecological features and their similarities and differences regarding their reproductive activity and abundance in Miocene and recent sediments.

INTRODUCTION

Badenian (Middle Miocene) deposits in Northern Croatia outcrop at many localities along the marginal belts of the Medvednica Mt. and in the Zrinska Gora Mt. (Ćurčić, 1898; Kochansky-Devidé, 1944; Pavelić, 2001; Vrsaljko, 2003; Vrsaljko et al., 2006; Pezelj, 2006; Pezelj & Sremac, 2007; Basso et al., 2008; Mikša, 2009). Palaeogeographically, these deposits belong to the western part of the Central Paratethys area (Fig. 1). Geotectonically this area was part of the Miocene Pannonian Basin System (Pavelić, 2001).

Badenian time in western part of the Central Paratethys was characterized by a variety of paleoenvironments, from sea-shores with land flora to marine conditions with common shallow-marine and high-energy shallow-water environments in which lower to higher energy sediments can be distinguished. Among many different shallow-marine facies in the Badenian of Croatia, most common are associations of biocalcarenites and algal biocalcirudites. Coralline algal facies is usually characterized by the predominance of red calcareous algae (corallines) and rich association of invertebrate organisms: bivalves, echinoids, bryozoa, corals, gastropods and foraminifera. Bivalves and echinoids found in these sediments (e.g., *Chlamys*, *Ostrea*, *Pycnodonta*, *Clypeaster*, *Parascutella*), often large and with massive calcite shells, reveal a highly agitated and/or nutrient rich environment.

During the sampling in the western Medvednica Mt. and Zrinska Gora Mt., numerous internal and external moulds of deep burrowing bivalves *Panopea*, and less common *Pholadomya* were found. Findings of *Panopea* in Northern Croatia are usually connected to the coralline algal facies, and have only been mentioned by Vrsaljko (2003), Dželalija (2007) and recently described by Šoić (2011).

Classification, shell morphology, geological history and distribution of *Pholadomya*

Phylum Mollusca
Class Bivalvia
Subclass Anomalodesmata Dall, 1889
Family Pholadomyidae Gray, 1847
Genus *Pholadomya* G. B. Sowerby, 1823
Type species: *Pholadomya candida* G. B. Sowerby, 1823; recent, British Virgin Islands.

Genus *Pholadomya* belongs to the burrowing group of heterodont bivalves, with passive deep burrowing habit. These bivalves possess a wide siphonal gape at the posterior end and large pallial sinus. Anterior margin is rounded. Large siphons (inhalant and exhalant) cannot be completely

retracted to the shell. Their shells are equivalve, each posteriorly elongated, with strong radial ribbing and hinge with no functional teeth. They live in sublitoral sandy or muddy substrates in protected areas (Runnegar, 1972; Lazo, 2007).

Detailed systematic palaeontological overview and diagnosis of the Subclass Anomalodesmata is given in Ruppert & Barnes (1994) and Family Pholadomyidae, Gray, 1847 in Moore (Ed. 1969). Bivalves from the Family Pholadomyidae had a wide distribution in the geological history, and can be found from Early Carboniferous till today. Shells which resemble *P. candida*, but without radial ribs, appear in the Middle Paleozoic (Runnegar, 1972). Findings of *Pholadomya* worldwide are most often connected to Mesozoic sediments, especially Jurassic and Cretaceous (e.g., Moesch, 1874, 1875; Jankičević et al., 1983; Campbell & Grant-Mackie, 1995; Delvene, 2003; Fürsich & Padney, 2003; Armella et al., 2007; Carpentier et al., 2007; Hudson & Clements, 2007; Lazo, 2007). Most of the *Pholadomya* species occur in poorly sorted fine to medium sandstone and are found as closed individuals indicating burial in the life position. The broad distribution of *Pholadomya* in Early Cretaceous is connected to the warm tropical and temperate subtropical settings of the Tethyan Realm, especially Mediterranean area, where environmental conditions were favourable (Lazo, 2007 and references within).

The Jurassic and Cretaceous forms did not have the unusual accessory musculature like the living species, which probably appeared in the Early Eocene (Runnegar, 1972). *Pholadomya alpina* was reported from the Eocene deposits in southwestern Croatia (Klepač, 2003). In the Miocene sediments *Pholadomya* was detected in Bulgaria, Chile, Colombia, Croatia, Cyprus, India, Japan, Moldova, New Zealand, Panama, Poland, Russia, Slovakia, Trinidad and Tobago, United States and Venezuela.

Species *Pholadomya alpina* Matheron, 1842 was determined in Lower Miocene deposits of France, Austria and Switzerland, in the „Tortonian" (Badenian) of Bosnia and Herzegovina, Austria, Hungary, Ukraine and Bulgaria, and in the Pliocene deposits in Italy (Atanacković, 1985). Species *Pholadomya haydeni*, Moesch was described as a single specimen in the Miocene of Switzerland (Moesch, 1875).

Recent species *Pholadomya candida* Sowerby, 1823, was considered extinct in 1800s, but was rediscovered in latter part of the 19th century in the Virgin Islands (Runnegar, 1972). *P. candida* is today living in shallow settings of the Colombian Carribean Sea (Díaz & Borrero, 1995; Lazo, 2007; Díaz et al., 2009). This discovery enabled genetic studies of the species, and confirmed its living habits. It has three layered aragonitic shell, with outer prizmatic layer, and middle and inner nacreous layers, while extinct forms of *Pholadomya* had a nacreous shell (Runnegar, 1972). *Pholadomya* is a simultaneous hermaphrodite. It is one of the rarest living mollusks, today a living fossil.

Classification, shell morphology, geological history and distribution of *Panopea*
Phylum Mollusca
Class Bivalvia
Subclass Heterodonta Neumayr, 1884
Order Myoida Stoliszka, 1870
Family Hiatellidae Gray, 1824
Genus *Panopea* Menard, 1807 (formerly *Panope*)

S pecies *Panopea abrupta* (formerly *P. generosa*) was originally named by Conrad in 1849 as a species of the genus *Mya* (Bower & Blackbourn, 2003). Detailed systematic palaeontological overview and diagnosis is given in Moore (Ed. 1969), Studencka (1986) and Ruppert & Barnes (1994).

Bivalves from the Superfamily Hiatellacea Gray, 1824, and Family Hiatellidae Gray 1824, are burrowing bivalves known in geological history since the Permian. They are characterized by quadrate to trapezoidal valves, slightly to widely gaping, having hinge with one or two weak teeth, ligament on nymph and pallial sinus mostly well developed (Moore, Ed. 1969). *Panopea* Menard, 1807 is found from the Triassic till recent, usually medium size to large, elongated, gaping, with beaks subcentral, large ligamental nymph, hinge with one small cardinal tooth in either valve. They have paired siphons, which can be up to a meter long.

The findings of *Panopea* in their life position are described from Jurassic and Cretaceous deposits of Argentina, where they are found within carbonate muds deposited in very shallow waters of tide-dominated areas (inner shelf; Armella et al., 2007). As stated at the Paleobiology database, they are found in Oligocene deposits of Austria and Turkey, Miocene deposits of Austria, Algeria, Belgium, Morocco, Poland, Serbia (Rundić et al., 2013) and Slovakia, and Pliocene deposits of Belgium. In the Middle Miocene of the Vienna Basin *Panopea menardi?* represents the only bivalve found in situ, due to their deep-burrowing habits (Zuschin et al., 2007). Specimens of *Panopea abrupta* (Conrad, 1849) were collected and described from Miocene deposits of the United States of America (Oregon, California and Washington). In Croatia, findings of *Panopea menardi* were noted in the Middle Miocene from the Northern parts of the Zrinska Gora Mt. (Pikija, 1987a, b).

Recent species of genus *Panopea*, commonly called „geoduck shells", can be found in Pacific and endemic in southwestern Atlantic ocean (Goodwin & Pease, 1989; Calderon-Aguilera et al., 2010a; Vadopalas et al., 2010 and references therein). For the recent *Panopea* species it is well known that they bury themselves up to a meter deep in sand, silt, gravel and other soft substrates of the lower intertidal and subtidal zones. They grow larger in mud and sand or sand, than in mud or pea gravel and gravel. They occur in intertidal zone and are found up to 110 m deep (Goodwin & Pease, 1989; Nielsen & Nielsen, 2009 and references therein).

In their adult stages geoducks can tolerate wide range of salinity and temperature. They are usually of separated sexes, and hermaphrodites are not common. Calderon-Aguilera et al. (2010b) studied reproductive demands of species of *Panopea* with respect to temperature changes and primary productivity in the Pacific ocean and demonstrated that their reproductive activity is triggered by a decrease in temperature prior to the peak of productivity.

A developing geoduck burrows into the sediment at an approximate rate of 30 cm per year. They reach their adult size after approximately 10 years. After digging about one meter deep, the adult specimen settles in for 100 years or more (e.g., Goodwin & Pease, 1989; Nielsen et al., 2008). The recent species feeds on phytoplankton, mostly diatoms and flagellates, by filtering food particles from sea-water with their gills, through its meter long neck.

Recent *Panopea* specimens have aragonitic shell, and are often used for isotope studies on seasonality in climate and even as probable palaeoceanographic proxy (e.g., Goman et al., 2008; Nielsen et al., 2008; Nielsen & Nielsen, 2009).

METHODS

For this research nine specimens of *Panopea*, of which six specimens belong to *Panopea menardi* (Deshayes, 1828) and two specimens of *Pholadomya alpina* Matheron, 1842 were collected in the Gornje Vrapče area, while finding from the Zrin locality belongs to the species *Pholadomya haydeni* Moesch. Measurements are recorded in mm (Table 1). Length represents total shell length parallel to the hinge axis, and Height is total shell height perpendicular to Length.

Sampling of the semilithified to lithified carbonates from the Gornje Vrapče locality (Medvednica Mt.) was done at every 20 cm from the layer in which *Panopea* bivalves were found in their life position. Seven samples were sieved and studied in fractions from 63 to 500 μm to determine microfossil components. Calcareous nannoplankton and Dinoflagellata, as well as palynological determinations were done on all the samples using standard preparation methods. The samples were observed by light microscope under polarized and cross polarized light. Calcareous nannoplankton was determined on the basis of Perch-Nielsen (1985).

In order to determine if the sedimentary infill is equivalent to the surrounding sediment thin sections of the infilled and surrounding material were done.

Carbonate content was determined for seven samples from the Gornje Vrapče locality, using Scheibler aparature for gas volumetry. For the Zrin locality carbonate content was previously determined (Martinuš et al., 2013). Analysis of each sample was performed twice to ensure the analytical precision. Differences between analyses of each sediment sample were within 2% and presented results are average values of two measurements.

Study area – geographical and geological setting

Two localities with *Pholadomya* and *Panopea* bivalves have been researched, one in the SW part of the Medvednica Mt. (Gornje Vrapče), and other in the central part of the Zrinska Gora Mt.

(Zrin; Fig. 1). At both localities these infaunal bivalves are found within the Badenian coralline algal facies, which is the most common Badenian facies with predominate bioclastic component made of arenite and rudite size of grains. The main volume of these Badenian sediments is commonly made of red coralline algae, often forming rhodolites, and different amount of bryozoan remains (very abundant in the Zrin locality, and rare in the Gornje Vrapče locality). Skeletal fragments of molluscs, echinoids and foraminifera are common. High percent of the carbonate component is characteristic for coralline algal facies, with only minor influence of terrigenous material. Structural characteristics of the sediment are not clearly visible and they can mostly be described only as massive layered. For more information about the Badenian sediments in the context of facies analyses see Avanić (1997), and for "*Lithothamnium* limestone" see Basso et al. (2008).

Gornje Vrapče locality is situated in the SW part of the Medvednica Mt., in the vicinity of Zagreb. This locality belongs to the „Dolje development" of Badenian in the Medvednica Mt. (Kochansky-Devidé,1944). Deposits in this area are mostly biocalcirudites and biocalcarenites with shallow marine organisms and their skeletal fragments, marking a carbonate platform sedimentary environment (probable deep lagoon or bay close to the surrounding land represented by Dinarides; Vrsaljko et al. 2006). In the former quarry Gornje Vrapče *Pholadomya* bivalves are found in association with *Panopea* specimens. According to Vrsaljko (2003 and references within), the findings of *Panopea* bivalves and molluscs with massive shells belong to the *Pecten–Ostrea–Cardium* Zone characterized by shallow-water, euphotic, high-energy environments or „algal meadows". Findings of Foraminifera and Ostracoda in the underlying sediments belong to the *Ammonia beccarii* Zone of the upper part of the Late Badenian (K. Kos, pers. comm.), enabling us to presume that sedimentation of the studied deposits in the Gornje Vrapče took place in the latest Badenian.

Zrinska Gora Mt. represents a well defined southern area of the Sisak-Moslavina County, and is situated 80 km S-SE from the Croatian capital Zagreb. These area has not yet been studied in detail, and construction of the geological map is still in progress. The biggest part of the Zrinska Gora Mt. is built up of Neogene deposits (Ćurčić, 1898). The locality Zrin is situated in the central part of the Zrinska Gora. No *Panopea* specimens have been found in the Zrin locality, but were described from the "*Lithothamnium* limestone" in Hrastovica locality of the Zrinska Gora Mt. (Dželalija, 2007).

RESULTS

Studied infaunal bivalves are represented only by moulds, with size range for *Panopea* from 104 to 129 mm long, and from 57 to 75 mm high, and *Pholadomya* from 70 to 180 mm long and 40 to 120 mm high (Table 1; Figs. 2, 3). Only one „gigantic" mould of *Pholadomya* with well preserved outer ornamentation was found. Due to the prevailing internal moulds of *Panopea*, outer ornamentation cannot be detected, or it is generally not pronounced. Some moulds display internal surface of the valves with visible impression of the pallial sinus and muscle scars (sample V–4; Fig. 3).

Absence of aragonite valves is a result of the high porosity of the coralline algal limestone and calcarenite, and consequently common dissolving of the shells. Due to the same sediment type and fossil assemblages within the sedimentary infill and surrounding sediment, we can assume that the sediment penetrated within the shells during the early diagenesis.

Gornje Vrapče locality

Specimens of infaunal bivalves from the Gornje Vrapče locality are found in their life position. They are hardly accessible due to their „hanging" position at the top part of the studied section, which enables this finding to stay partly protected. The distance between specimens varies from 40 to 80 cm.

The carbonate content is lowest in layer in which the autochtonous *Panopea* moulds were found (P1=87.6 %), and ranging from 90–95 % in the layers above (P2=93.8 %, P3=93.9 %, P4=90.7 %, P5=93.5 %, P6=91.8 % and P7=94.7 % of $CaCO_3$). We can therefore assume restricted terrigenous input and deposition of almost pure carbonates in the Gornje Vrapče locality, which is well comparable with depositional conditions in the Zrin locality (Martinuš et al., 2013).

Out of nine collected *Panopea* specimens, six are classified as *Panopea menardi* (Deshayes, 1828; Table 1). Three specimens with pressed and partly deformed moulds are described only as *Panopea* sp., or are, due to the existing differences between them, marked as *Panopea* sp.A and *Panopea* sp.B (Table 1). Two moulds of *Pholadomya* are determined as *Pholadomya alpina*

Matheron, 1842. They have preserved well visible outer ornamentation, with 9 to 13 radial ribs on the central part of each valve, which are evenly distributed, mostly straight. Ribs meet at the ventral side in opposite position. Growth lines are also visible.

Foraminifera and Ostracoda community in the Gornje Vrapče section, based on findings of *Elphidium macellum*, *E. crispum*, *E. flexuosum*, *Cibicidoides ungerianus*, *Nonion commune*, and *Neocypideis* and *Phylctenophora farkasi* point to the inner shelf area and relatively shallow, stressed environment of the upper part of the Late Badenian (K. Kos, pers. comm.). Consequently, the upper part of the studied column, with no index fossils and with poorly preserved, mostly abraded elphidiid and miliolid foraminifera and ostracod remains, belong to the uppermost part of the Late Badenian. From calcareous nannoplankton only specimens of *Coccolithus pelagicus* (Wallich, 1877) have been determined, which are, due to its rarity and poor preservation, probably allochtonous. Liptinite has not been found, pointing that organic phytoplankton or Dinoflagellata have not been present. Few pollen specimens are found, belonging to *Pinus* sp. and *Tilia* sp., pointing to minor terrigenous influence and presence of the continental mass in the hinterland.

Infaunal bivalves are often found in their growth position, showing probably enhanced sedimentation rate influenced by storms which unabled the deep-burrowers to dig out in time. Nevertheless, the findings of the whole population of *Panopea* bivalves in their growth position document a probable mass-mortality episode in the Badenian of the Medvednica Mt.

Zrin locality

The finding of the *Pholadomya* bivalve mould in the Zrin locality 180 mm long and 120 mm high gives evidence of very large infaunal specimen (Fig. 2). It was found in its life position within fine-grained sediment. Burrowing habit of *Pholadomya*, and immanent nutrient supply, enabled the growth of this specimen.

Zrin locality is characterised by abundant crustose coralline algae and bryozoan remains, abundant regular and irregular echinoid and crinoid remains, different ostracod associations, common „larger benthic foraminifera", and planktonic foraminifera and calcareous nannoplankton in the upper part of the column. Carbonate content is higher than 89 %. Presence of index genera like *Orbulina suturalis* Broennimann with the first appearance datum set to 14.74 Ma (e.g., Kováč et al., 2007) and calcareous nannoplankton *Sphenolithus* cf. *heteromorphus*, an index fossil for NN4 and NN5 nannoplankton Zones, enabled positioning of the Zrin locality in the Middle Badenian of the Central Paratethys (Martinuš et al., 2013).

DISCUSSION

Findings of *Pholadomya* bivalve in Badenian sediments of the Northern Croatia have not been described in detail till now. Also, *Panopea* has been determined in different Miocene faunas of the Medvednica and Zrinska Gora Mts., but never described palaeoecologically, or to determine its possible facial or stratigraphic relevance. More detailed research of *Panopea* and its palaeoecological demands in Badenian of the Medvednica Mt. (Gornje Vrapče) was recently done by Šoić (2011, and this study). On the basis of sedimentological, palaeontological and palaeoenvironmental studies of the Zrin locality (Martinuš et al., 2013), deposits in which *Pholadomya* specimen was found belong to the Middle Badenian, and are therefore older than the Late Badenian deposits from the Medvednica Mt.

Lithological and palaeoenvironmental interpretation

The findings of infaunal bivalves in their growth position point to the protected sedimentation area, without major storm events which would extract the shells out of their growth position. The predominant amount of especially large bivalves and coralline algae is showing that the sedimentation took place in the shallow water environment. Corallines are important Cenozoic reef builders, and mostly prefer agitated water areas (Flügel, 2010). The presence of intense bioturbation at both localities suggest a well oxygenated sea floor with soft, muddy, but stable substrate (cf. Olivier et al., 2008). Gastropods are represented with minor number in the Gornje Vrapče locality, and have not been found in the Zrin locality.

The presence of *Pholadomya* bivalves in life orientation characterize mostly shallow, low-energy facies in close connection to the reefs (Lazo, 2007). The gigantism of the bivalves is common in agitated and nutrient rich areas of the ramp or inner shelf, probably close to the reefs and reef-like

structures. The abundance of food in these moderate to high-energy environments and protected inhabitat, with no hazard of predators, would provide a safe place for these bivalves to live in and grow. As already mentioned, other bivalves found in the studied locations are also of large dimensions but this is the first finding of the „gigantic" *Pholadomya* specimen. Since reef structures were not detected in the studied areas, nutrient rich environment can me presumed.

Higher abundance of *Panopea* in infaunal associations usually represents inner shelf levels with carbonate muds deposited in very shallow waters of tide-dominated areas (e.g., Armella et al., 2007; Lazo, 2007). In comparison with *Panopea*, *Pholadomya* is usually found in levels with fewer specimens in sandstones and coquinas of inner shelf in soft to firm well-oxygenated substrate (c.f., Lazo, 2007). *Pholadomya* specimens usually have shorter siphons (up to 30 cm) and do not burrow as deep as *Panopea*.

Due to the findings of *Pholadomya* and *Panopea*, which were in Badenian probably living in the same shallow water environment, rich in nutrients, in sediment consisting of carbonate mud and sand, we can assume that the shallow marine facies of low to moderate energy, which may have been protected by the reefal structure, was a good place for both of these infaunal burrowers to live in. Since only two *Pholadomya*, and many *Panopea* specimens were found, we can propose that *Pholadomya* specimens were less abundant than *Panopea* (cf. Lazo, 2007).

Warm-temperate carbonates

The broad distribution of *Pholadomya* in Early Cretaceous is connected to the warm tropical and temperate subtropical settings of the Tethyan Realm, especially Mediterranean area, where environmental conditions were favourable (Lazo, 2007 and references within). Climatic changes could have influenced the abundance of bivalves like *Pholadomya* and *Panopea*, especially from Miocene to recent, with the significant fall in temperatures. Miocene was characterized by Miocene Climatic Optimum, with minimal annual water temperatures in Badenian of Paratethys between 15 and 18°C (Kroh, 2007). The „gigantic" *Pholadomya* specimen from that time could be result of adjustment to the warm temperatures, especially since the only area where *Pholadomya* can be located today belong to the Carribean. *Panopea* was probably more prone to climatic changes, as it can be found today in different temperature ranges within the Pacific ocean.

Due to the composition based on dominant bioclastic component (abundant coralline algae, bryozoa, large benthic foraminifera, large bivalves and echinoid remains) and facies, and comparison with the recent temperate water carbonates, we can presume that the studied localities belong to the warm-temperate carbonates (cf. Nebelsick, 1989; Martinuš et al., 2013).

Mass-mortality scenarios

Since fossil remains of *Panopea* and *Pholadomya* have not yet been found in sediments younger than Miocene (especially in Croatia), we can presume that a specific event in Miocene have caused their disappearance from the studied area. The whole population of infaunal bivalves in their growth position document a probable mass-mortality episode in the Middle Miocene of the Medvednica Mt. One presumption for this hypothesis is that environmental changes connected to the Climatic Optimum in Middle Miocene with high temperatures in shallow marine areas, and consequently increased salinity, could be responsible for the mass mortality of these infaunal bivalves in the Gornje Vrapče locality. Also, due to the laboratory studies, it is known that the blooming of bacteria, cyanobacteria and Dinoflagellata, can influence larval growth and consequently the whole infaunal bivalve community (e.g., Goodwin & Pease, 1989).Unfortunately, since liptinite has not been found, there is no palaeoecological evidence for presence of organic phytoplankton or Dinoflagellata which could cause possible „red tyde" and mass extinction of the bivalves (K. Bakrač, pers. comm.).

Lowering of the sea-level could influence the habitat of burrowing bivalves, and bring to the enhanced mortality of the specimens. Gornje Vrapče locality might represent a high tide channel in which infaunal bivalves cohabitet, and were under strong influence of flux and reflux. Lowering of the sea level in the uppermost Badenian might have caused the mass mortality of the whole infaunal community in the channel area. Changes in sea-level were quite common in the Paratethys sea. Even though, *Panopea menardi* was determined in shallow marine and even brackisch-shallow water marine sediments in Oligocene of Turkey (İslamoğlu, 2008), and due to the consideration that *Panopea* is an

euryhaline shallow marine bivalve, these presumption is considered less probable, unless there was a considerable sea-level fall.

The closure of the seaway from the Mediterranean to Central Paratethys occured in the Late Badenian and Sarmatian. The result of these increasing continentalization and tectonic movements was isolation of Paratethys and formation of the Pannonian Lake in the area of today Northern Croatia. The drop in salinity brought to the complete disappearance of marine species in the Late Miocene (e.g., Rögl, 1998, 1999).

Findings of these infaunal bivalves are not of the same stratigraphic range, with Zrin locality belonging to the Middle Badenian and Gornje Vrapče locality from the Medvednica Mt. to the upper part of the Late Badenian. This may be a consequence of the ongoing transgression in the Middle Miocene. *Pholadomya* can more easily adapt to the deeper water, while *Panopea* bivalves prefer shallower areas of the inner shelf. Therefore, the mass presence of *Panopea* and *Pholadomya* in the Gornje Vrapče locality can be a result of the ongoing transgression going from southeast to northwest of the Central Paratethys, and consequently the regression could be responsible for the mass mortality of the infaunal bivalves in the latest Badenian. Unfortunately, in the studied deposits we have found no evidence for this presumption, since the upper part of the section is missing, due to the erosion.

CONCLUSION

In Middle Miocene (Middle and Late Badenian) deep-burrowing infaunal bivalves *Pholadomya* and *Panopea* were living in the Central Paratethys area, on shelves with almost pure carbonate sedimentation, and only minor input of terrestric material. Generally, they were found in the same facies associations of Mesozoic and Cenozoic era worlwide.

Two localities were studied, Gornje Vrapče in the southwestern part of the Medvednica Mt., where both bivalves are found at the same locality, and Zrin in central part of the Zrinska Gora Mt., where unusually large specimen of *Pholadomya*, 180 mm long and 120 mm high was found.

Most of the moulds used for this research were found in their living position. Corraline algal facies predominates at both studied localities, but Zrin locality belongs to the Middle Badenian, while Gornje Vrapče belongs to the Late Badenian. This difference was probably connected to the Middle Miocene ongoing transgression in the Central Paratethys area.

The finding of the whole population of deep-burrowing bivalves in their life position in the Gornje Vrapče locality point to the specific event which caused a probable mass mortality episode, but the cause of this mass mortality scenario is still open for discussion. Investigated infaunal bivalves have generally disappeared from the studied area in the Late Middle Miocene with the isolation of the basin caused by closure of the seaway between Paratethys and Mediterranean, and consequent decreased salinity and environment becoming brackish.

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Table 1. Mould measurements for *Pholadomya* and *Panopea* specimens from the Badenian of the Medvednica Mt. and Zrinska Gora Mt.

Sample	Species	Locality	Height (mm)	Length (mm)	Remark
Pho–1	*Pholadomya alpina*	Vrapče	40	70	mould
Pho–2	*Pholadomya alpina*	Vrapče	50	100	mould
Pho–3	*Pholadomya ?haydeni*	Zrin	120	180	mould
V–1	*Panopea menardi*	Vrapče	72	112	mould
V–2	*Panopea menardi*	Vrapče	75	122	mould
V–3	*Panopea menardi*	Vrapče	74	104	mould
V–4	*Panopea menardi*	Vrapče	60	112	mould
V–5	*Panopea menardi*	Vrapče	70	123	mould
V–6	*Panopea* sp.A	Vrapče	65	80	fragmented
V–7	*Panopea menardi*	Vrapče	74	110	mould
V–8	*Panopea* sp.B	Vrapče	57	110	pressed mould
V–9	*Panopea* sp.B	Vrapče	71	129	pressed mould

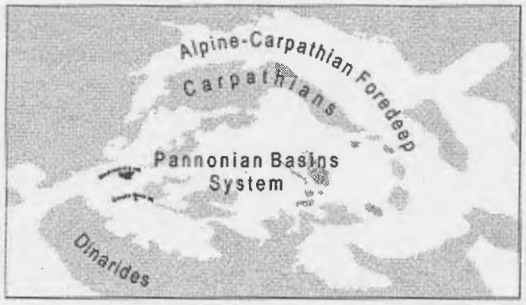

Fig. 1. Palaeogeographic map of the Central Paratethys in Middle Miocene, with marked position of the studied areas, Medvednica Mt. and Zrinska Gora Mt. (modified after Rögl 1998).

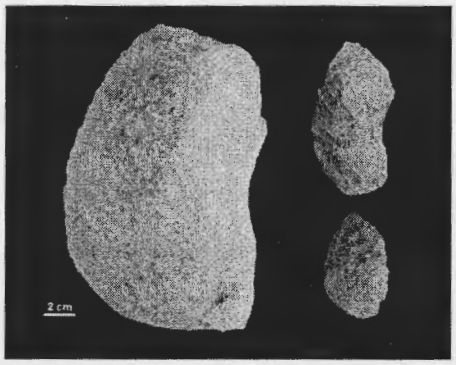

Fig. 2. *Pholadomya* external moulds from Zrin (left specimen) and Gornje Vrapče locality (two smaller specimens), placed in their life position.

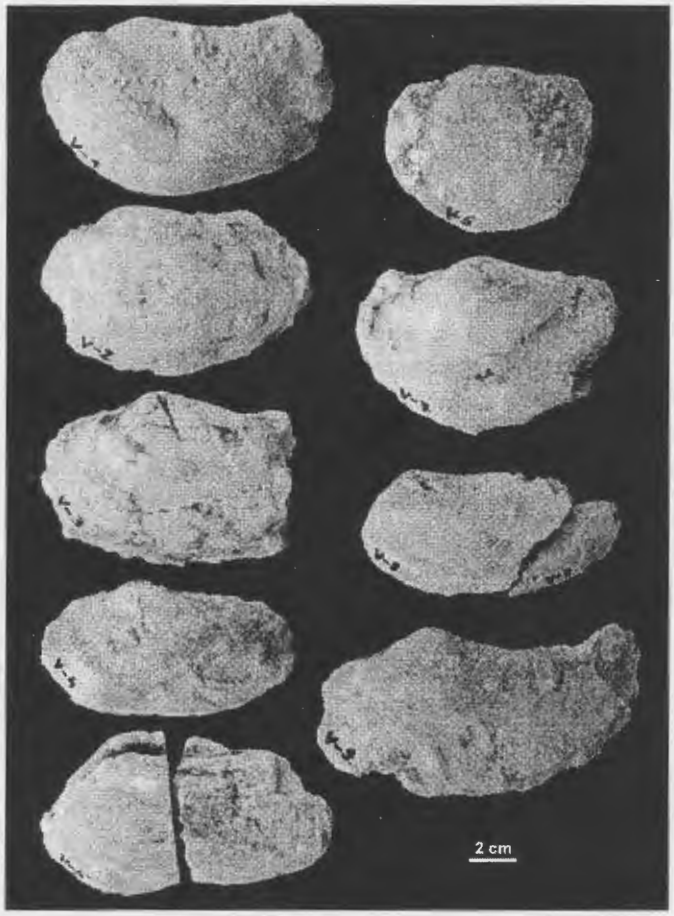

Fig. 3. Moulds of *Panopea* specimens from the Gornje Vrapče locality. Note that on sample V–4 pallial sinus and muscle scars are well visible.