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THE SAND DOLLAR *PARASCUTELLA* (ECHINOIDEA) IN THE LATE BADENIAN OF CROATIA

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Abstract. The echinoid *Parascutella gibbercula* (de Serres, 1829) (Echinoidea: Clypeasteroida) is reported from the Mali Potok area of the Medvednica Mountain in Croatia. The fossil site is situated in mixed siliciclastics and biocalcarenites of late Badenian age. These echinoids are large extremely flat echinoids, informally known as sand dollars. The discovered echinoids are preserved *in situ*. The environment of deposition is defined as a shallow, coastal, high-energy environment for which these sea-urchins have developed characteristic morphological features. The strength and hydrodynamic stability of their shells enabled the post-mortal colonisation of the skeleton by epibenthic organisms, creating a robust, relatively stable substrate within otherwise mobile, unconsolidated sediments (secondary hardground). The Mali Potok echinoid assemblage has an unusual taxonomic composition for the Late Miocene of Croatia.

Riassunto. L'echinoide *Parascutella gibbercula* (de Serres, 1829) (Echinoidea: Clypeasteroida) è stato rinvenuto nell'area del Mali Potok nelle montagne di Medvednica in Croazia. Il livello fossilifero è contenuto in una successione di biocalcareniti intercalate a silicoclasti di età badeniana. Questi echinoidi sono chiamati informalmente dollari delle sabbie per la loro forma estremamente appiattita. Essi sono conservati *in situ* nel loro ambiente di deposizione, che risulta essere di alta energia, costiero e con profondità molto basse. La loro robustezza e stabilità idrodinamica hanno permesso la loro colonizzazione *post-mortem* da parte di organismi bentonici, in quanto formano un substrato robusto, relativamente stabile, in un contesto di sedimenti altrimenti non consolidati (hardground secondario). L'associazione a echinoidi del Mali Potok mostra una composizione tassonomica inusuale per il Miocene Superiore della Croazia.

Introduction

In the Cenozoic of Croatia, echinoids are a widely distributed and important fossil invertebrate group, although they have not been subject of detailed research thus far. Their fossil findings appear in two stratigraphic horizons: Middle-Upper Eocene of External Dinarides (Mitrović-Petrović 1970; Klepač 2003; Mikša et al. 2005) and Middle Miocene of Paratethys area (Poljak 1938; Mikša et al. 2002). Eocene findings of echinoids in Croatia are represented by members of the Cassiduloida and Spatangoida. Echinoids belonging to the order Clypeasteroida represent an important part of the total fossil fauna of Middle Miocene, although restricted in published reports thus for solely by the genus *Clypeaster* (Poljak 1938; Mitrović-Petrović 1969; Mikša et al. 2002).

The new record of echinoids reported here from the region of north-east Croatia, on the slope of Medvednica Mountain in the Mali Potok area (Fig. 1), also shows the presence of the genus *Parascutella*.

The echinoid fauna from the Mali Potok locality (Fig. 2) differs considerably from other Middle Miocene localities in Croatia with the presence of *Parascutella*. Outside Croatia, *Parascutella* has been found in Late Oligocene to Late Miocene deposits of southern Europe and the wider Mediterranean region (e.g. Durham 1953; Mitrović-Petrović 1969; Mooi 1989; Nebelsick 1999; Nebelsick & Kroh 1998, 2002; Kroh & Nebelsick 2003, Néraudeau et al. 2003; Kroh 2005).

Geological setting

The sediments containing the described echinoid fauna belong to a locally developed sequence of the Middle Miocene (upper Badenian) deposits of the Central Paratethys western rim. The detailed geological column was taken in the area of outcrop 2 (Fig. 3), where the most complete profile is preserved. The in-

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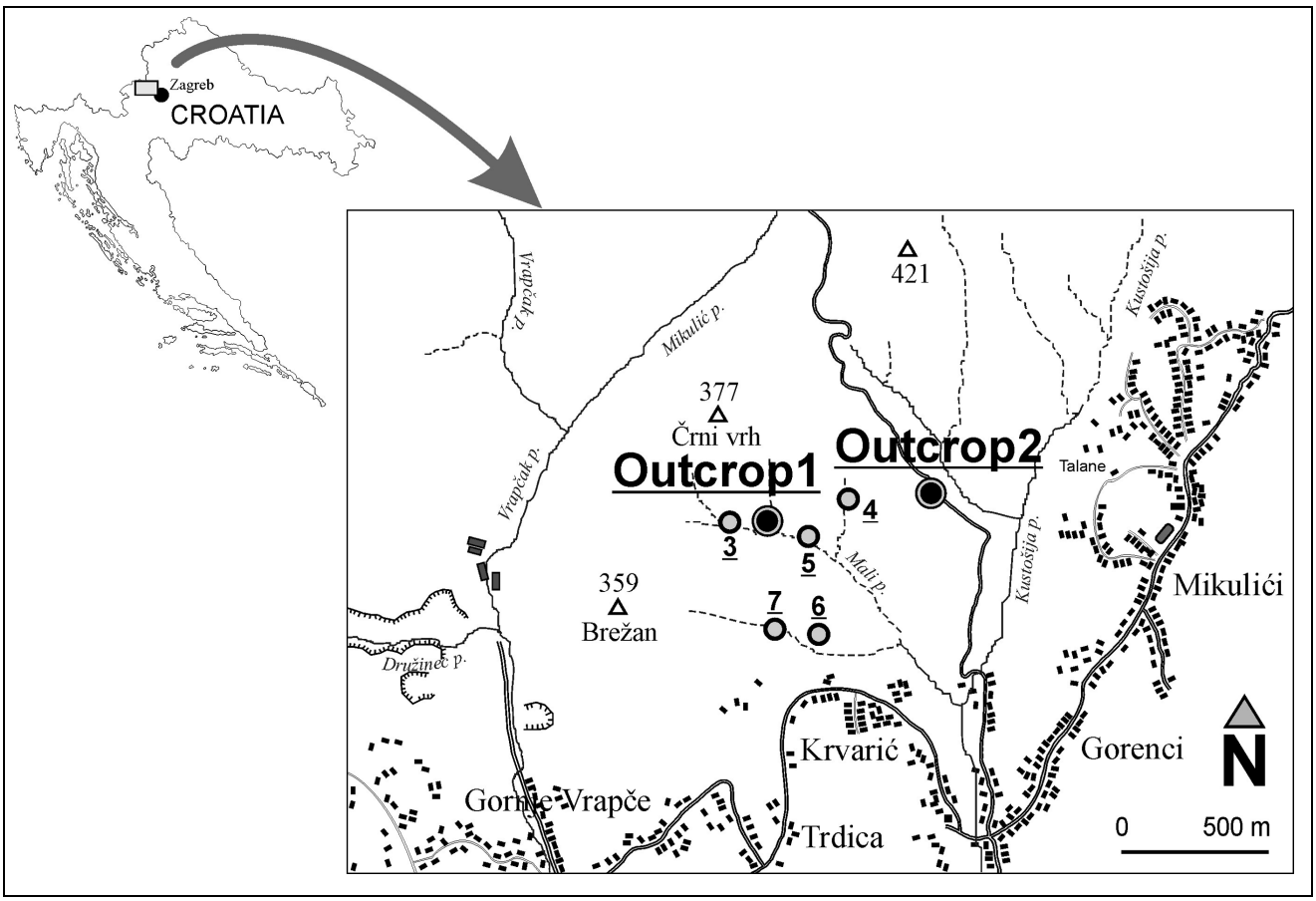

Fig. 1 - Location map with the position of main echinoid sampling localities (Outcrop 1 and 2) and five subsidiary outcrops (3 - 7).

vestigated section is in a transgressive contact with the basement, which consists of rocks from various stratigraphic units, including mostly Palaeozoic metamorphite, Triassic dolostone and Cretaceous limestone. The section is 28 metres thick and consists mostly of siliciclastic deposits with some carbonate extra-clasts and conglomerates in the lower part. The upper part of the column (after the 11th metre) is characterised by the onsetting of intra-basin sedimentation. Miliolid foraminifers appear for the first time, and among the

Fig. 2 - The upper Badenian sediments of outcrop 2. Hammer for scale.

first macrofossils are also the sand dollars described here. The influence of siliciclastic sedimentation gradually reduces upsection. After the 20th metre, there is a three metres thick clayely biocalcarenites, partly characterised by a mass occurrence of the echinoid *Schizaster parkinsoni* (Defrance), otherwise rarely present in the sedimentary sequence below. The base of this layer also designates the last *in situ* occurrence of the sand dollars. Continued sedimentation is characterised by thick bioclastic limestone (containing thoroughly reworked components) and small coquinas of bivalves (*Pycnodonta*, *Ostrea*). The investigated deposits are slightly dipping towards the south, thick bedded and covered by Sarmatian calcarenites over an erosive border, well visible to the south-east of the outcrop 2 in a road cutting.

Fossils appear integrated into a homogeneous unstratified sediment mass, with a preferred horizontal orientation of flat fossils. The age is indicated by a rich fossil assemblage characteristic for local development of late Badenian including *Elphidium crispum* (Linné), *E. macellum* (Fichtel & Moll), *E. flexuosum reussi* Marks,

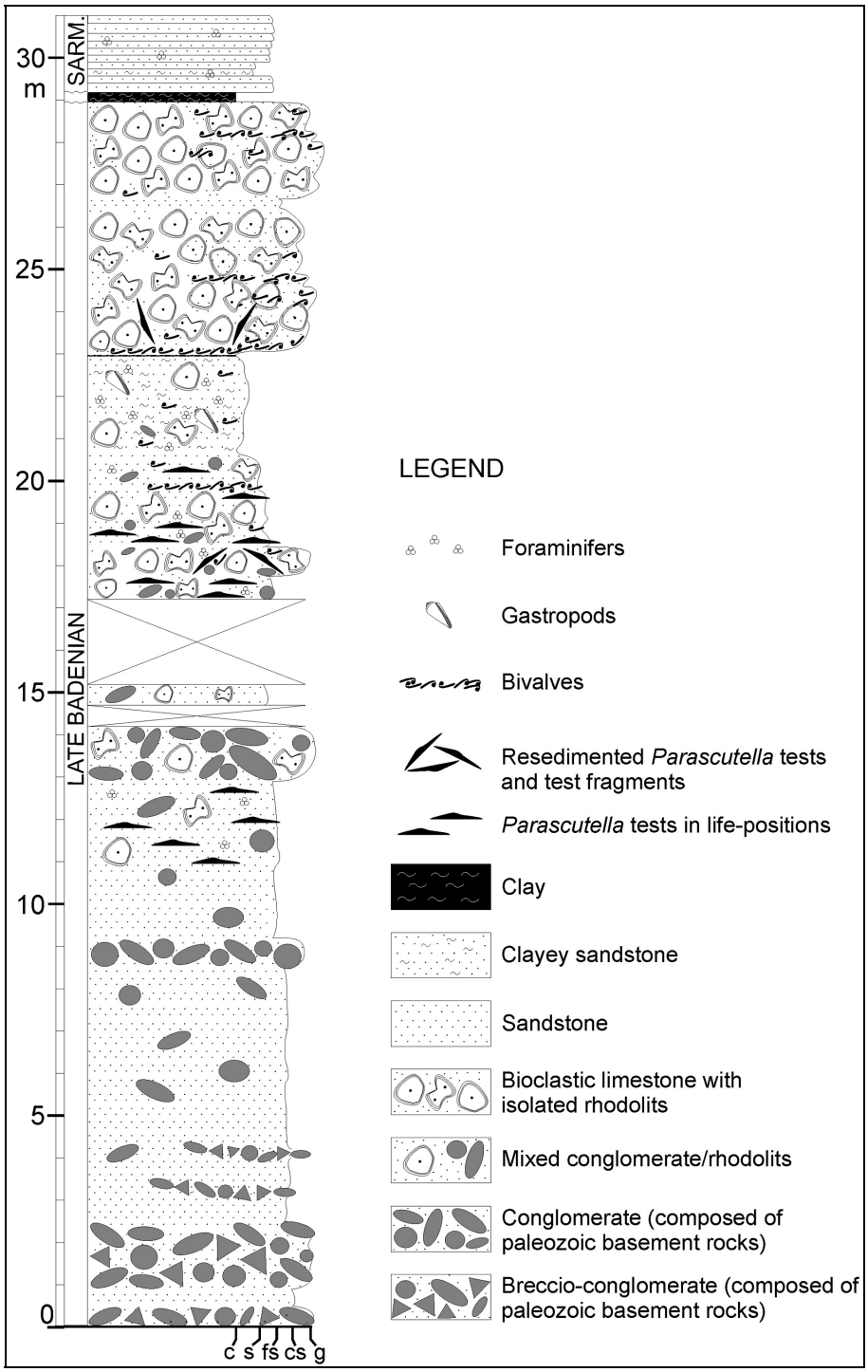

Fig. 3 - Geological column of the Mali Potok locality. Grain size: c, clay; s, silt; fs, fine sand; cs, coarse sand; g, gravel.

Ammonia beccarii (Linné), *Pecten* (*Flabellipecten*) *besseri* Andrzejowski, *Pycnodonta cochlear navicularis* (Brocchi), *Diloma* (*Oxystele*) cf. *orientalis* (Cossmann & Peyrot), etc. (Šikić 1967; Avanić et al. 1995; Vrsaljko et al. 1995; Vrsaljko et al. 2006). Besides the mentioned taxa, investigated deposits also contain a rich fauna of other molluscs, while the outcrop 1 is exclusively characterised by the occurrence of foraminifera *Borelis melo* (Fichtel & Moll), *Ammonia beccarii* (Linné) and *Quinqueloculina* sp. Based upon the microfossil assemblage and sediment types, the environment has been interpreted as a coastal, shallow-water area of higher energy. Traces of cross-stratification in the sandstones are present at the lower part of the outcrop 2. Calcite spar cement is most common in sandstones. Variations between outcrops are small, so they are assumed to belong to the same horizon, on the basis of identical palaeontological and lithological composition as well as their relation to over- and underlying deposits.

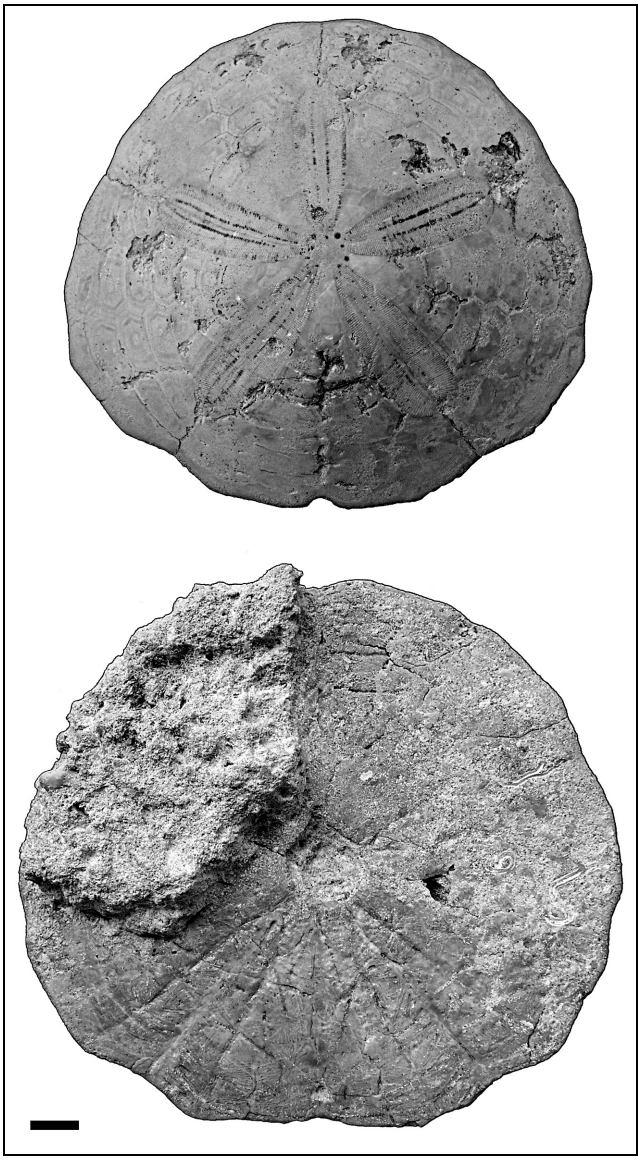

Fig. 4 - *Parascutella gibbercula* (de Serres, 1829). A) Aboral surface of sample U331 (washed-over specimen). B) Oral surface of sample U486. Scale bar = 1 cm.

Description of the material

Eleven complete sand dollar specimens were found in two outcrops in the study area - Outcrops 1 (N 45°50′46,91″, E 15°54′41,66″) and 2 (N 45°50′49,5″, E 15°55′5,14″; Figs. 1, 2). Some fragmented and more poorly preserved material has been collected from the remaining five outcrops (Outcrops 3 - 7, Figs. 1, 2). Echinoids and accompanying fauna have been deposited in the Geology and Geochemistry Department of INA-Industrija nafte Plc., Zagreb. Repository numbers are reported for single specimens in the captions of figures.

The shells are large and of very stable structure, 10-13 cm in length (Figs. 4, 5). It is flat on the oral and slightly protruding on the aboral side. The top of the shell is located in the area of interambulacrum 5, approximately at one-third distance starting from the apical disc towards the ambitus. The shells are flat (width/height ratio = 1:8), while the ambitus is sharp, particularly on the posterior side. Some specimens show a mild posterior notch on the interambulacrum 5 ambitus. The petalodium is completely inconspicuous due to preservational effects and it's visible only in eroded specimens. Petals are long and almost closed; the front petals spread up to the 68% of the corresponding test radius. The same distance in posterior petals amount to over 80%. In larger and older specimens, these values increase. Food grooves are visible in the majority of specimens. They spread along the entire length of ambulacra on the oral side, with major branching on the basicoronal circlet, widening later also on the interambulacral series of plates. Ambulacral and interambulacral zones are almost equally wide on the ambitus. Pore-pair grooves are very narrow, prolonged and densely positioned. The apical disc is situated centrally with four gonopores. The periproct is submarginally open on the oral side, between the third and fourth pairs of post-basicoronal plates. The basicoronal circlet is slightly pentastellate, and partially visible only on one specimen. The internal reinforcement structures of the shells are complex and the cross sections of shells on the outcrops are easily discernible from other morphologically similar, flattened forms of the genus *Clypeaster* (Fig. 6). Based on the described characteristics, these echinoids are determined as *Parascutella gibbercula* (de Serres, 1829) (Durham 1955, 1966; Mitrović-Petrović 1969; Kroh 2005).

Other echinoids present in Mali Potok assemblage are one cassiduloid and one spatangoid species. No clypeasteroids except *Parascutella* were found here.

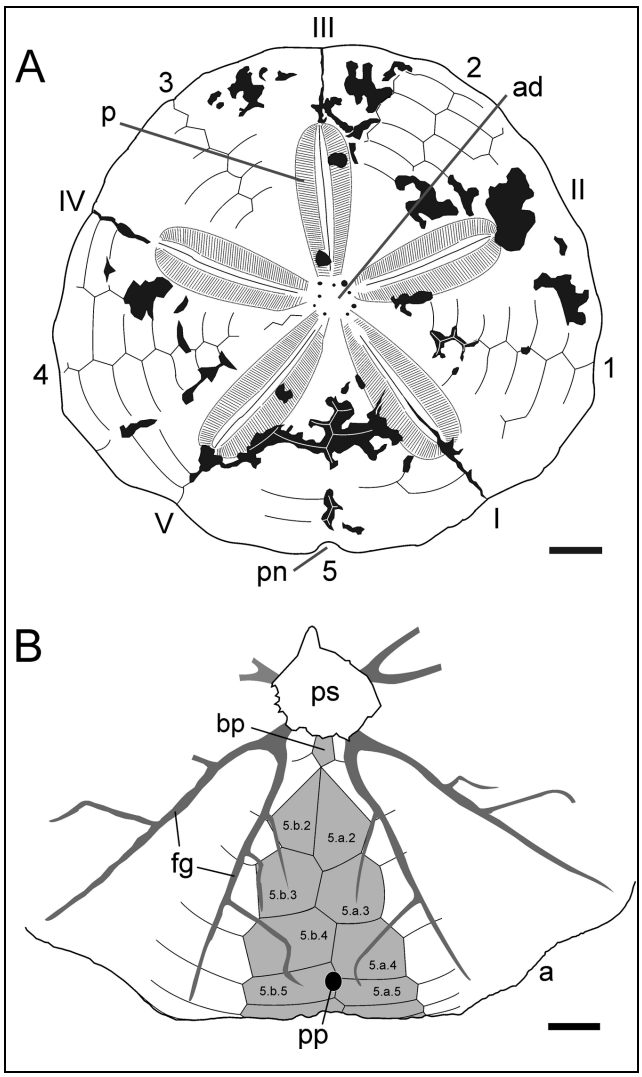

Fig. 5 - *Parascutella gibbercula* (de Serres, 1829), scale bar = 1 cm. A) Sample U331. Drawing of aboral side: p, petals; ad, apical disc; pn, posterior notch (perradial and interradial sutures numbered according to Lovén's system). Black shaded areas are damaged parts of the test. B) *Parascutella gibbercula* (de Serres, 1829), sample U486. Drawing of oral plating of interabulacrum 5 (shaded): ps, position of peristome (damaged); bp, basicoronal plates; fg, food grooves; 5.a.2-5, 5.b.2-5, post-basicoronal plates; pp, periproct; a, ambitus (margin of the test).

The cassiduloid *Echinolampas hemisphaerica* (Lamarck) (Fig. 7A-C) occurs in the same range as *P. gibbercula*. It disappears around 20th metre of the column and doesn't appear later, not even as resedimented material. The test of *Echinolampas* is oval and doomed in profile with rounded margin. The top of the shell falls into the apical disc. The poriferous zones are depressed. The petals are open and slightly narrowed near the margin of the test. The peristome is relatively large, oval and transversely elongated. The depressed phyllodes are well visible at all recovered specimens together with associated bourrelets. Tests of these echinoids are often encrusted by populations of epibenthic organisms.

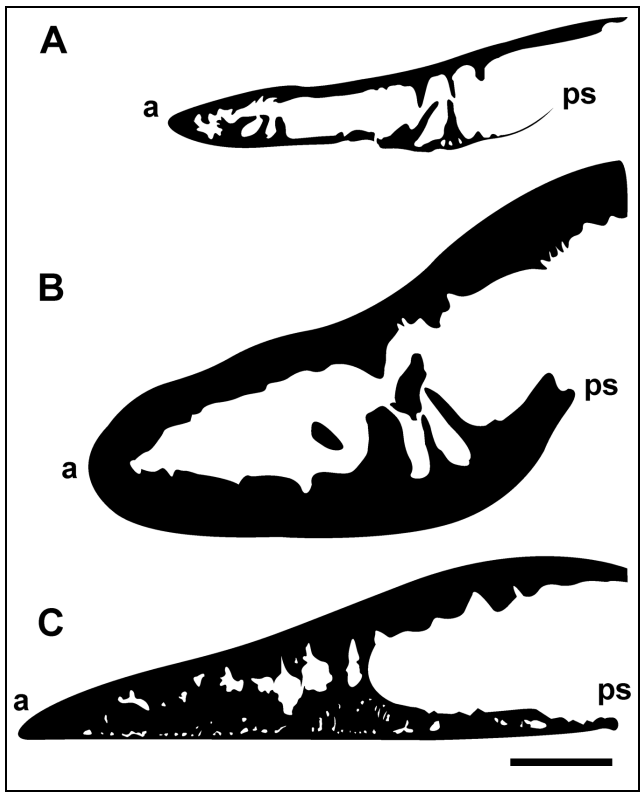

Fig. 6 - Internal support structures in clypeasteroids from the late Badenian of Medvednica Mt. (sections through the interambulacrum 2). A) *Clypeaster marginatus* Lamarck, Bizek quarry. B) *Clypeaster scillae* Desmoulins, Bizek quarry. C) *Parascutella gibbercula* (de Serres 1829), Mali Potok; a, ambitus; ps, peristome. Scale bar = 1 cm.

The spatangoid *Schizaster parkinsoni* Defrance (Fig. 7D-F) is the most common echinoid in the Mali Potok locality. It appears approximately at the same time as *Parascutella* or *Echinolampas* and after 20th meter of the section this species becomes very abundant. All specimens found here, especially those from clayey sandstones are strongly flattened or disarticulated by the rock pressure. Few specimens from the sandstones of 13th meter of the section were found less damaged. They show an ovate test with deeply sunken ambulacra forming closed petals on the aboral side. The labrum and the large symmetric sternal plates are often good preserved. The apical disc is always missing due to disarticulation of the skeletal parts.

Amongst described echinoids, Badenian sediments of Mali Potok contain a rich macrofauna of bivalves of genus *Glycymeris*, *Ostrea*, *Pholadomya* and a few members of the family Pectinidae.

Discussion

Palaeoecological significance of *Parascutella*

The *Parascutella* appears in the Medvednica Mountain in mixed, carbonate-siliciclastic sediments in-

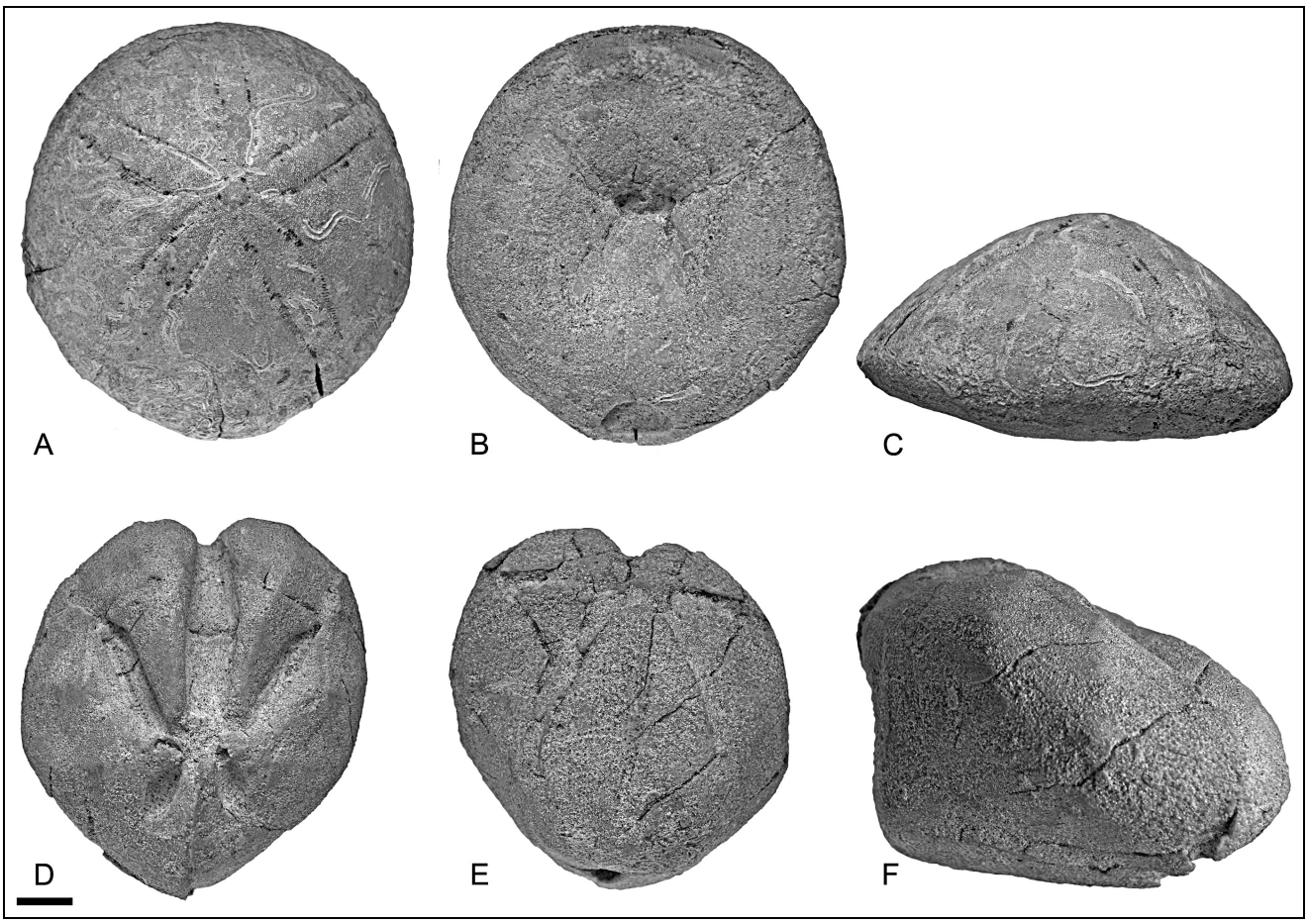

Fig. 7 - Other echinoids from the Mali Potok locality. A-C) Aboral, oral and lateral view of *Echinolampas hemisphaerica* (Lamarck), sample U155. D-F) Aboral, oral and lateral view of *Schizaster parkinsoni* Defrance, sample U152. Scale bar = 1 cm.

terpreted as a high-energy, coastal environment based on the present sedimentological features, strongly abraded shallow-water benthic foraminifera and shallow-water macrofaunal elements (foraminifera, bivalves). The *Parascutella* has no living representatives, so it is assumed, by analogy with the similar recent sand dollars, that it had lived as a shallow-water infaunal burrower (Nebelsick 1999). Nebelsick (1999), Nebelsick & Kroh (2002) and Kroh & Nebelsick (2003) analyzed the palaeoecological characteristics of *Parascutella* from the mass fossil deposits in Egypt and Turkey, classifying them into a similar mobile shallow-water coastal sandy environment. Furthermore, they show the common appearance of *Parascutella* within mixed carbonate-siliciclastic sedimentary environments. A similar situation is encountered in the Mollasse Zone of the Lower Miocene in Austria, where environmentally analogous sand dollar *Parmulechinus* occurs in micaceous sands (Nebelsick 1999; Kroh 2007). The analysis of microfauna and sediments of the Upper Badenian in the area of Mali Potok, containing *Parascutella in situ* (interval from11th to 20th metre of the column) strongly suggest a similar environment. The end of the *Parascutella* appearance in the profile (Fig. 3; 20th metre of the column) coincides with a massive appearance of echinoid *Schizaster parkinsoni* (Defrance) and corresponds to a change of conditions in the environment (deepening and/or drop of the wave/water energy), although their re-settled and fragmented remnants continue to appear as reworked clasts. Such a continued appearance of fragments can be explained by transport from coastal zone during the transgression. This leads to a different environment dominated by *Schizaster* (Néraudeau et al. 2001; Kroh & Nebelsick 2003), widely spread in the fine-grained sediments in the Middle Miocene of Medvednica Mt. The sediment succession also points to this conclusion (primarily by a weakening of the terrestrial influence on sedimentation caused by moving coast-line landward).

Due to the great hydrodynamic stability of shells, *Parascutella* post-mortally lies on the sea bottom on one of its two flat sides (flat position) (Seilacher 1979). Most of the recovered specimens were found oriented with the peristome downward position i.e. life position, well preserved, with only slight abrasion of the shells. It can be assumed that there has been no significant movement or relocation of shells from their original habitat.

In the top part of outcrop 1, the presence of possible coquinas composed of large bivalves (*Chlamys*,

Pycnodonta, *Ostrea*) were noticed, together with several records of *Parascutella*, which implies possible relocations a part of fauna during the storm events. They are deposited as numerous small bivalve and echinoid fragments densely packed together. These sediments form lense-shaped bodies with distinctly imbricated bioclasts. Other records of fossils from Mali Potok locality do not show these layering properties. They were found as isolated specimens in the massive structureless sandstone, usually good preserved with no evidence of shell transport. Top part of outcrop 1 and its sedimentological features may suggest on the possibly mass skeletal type of deposits (Nebelsick & Kroh 2002).

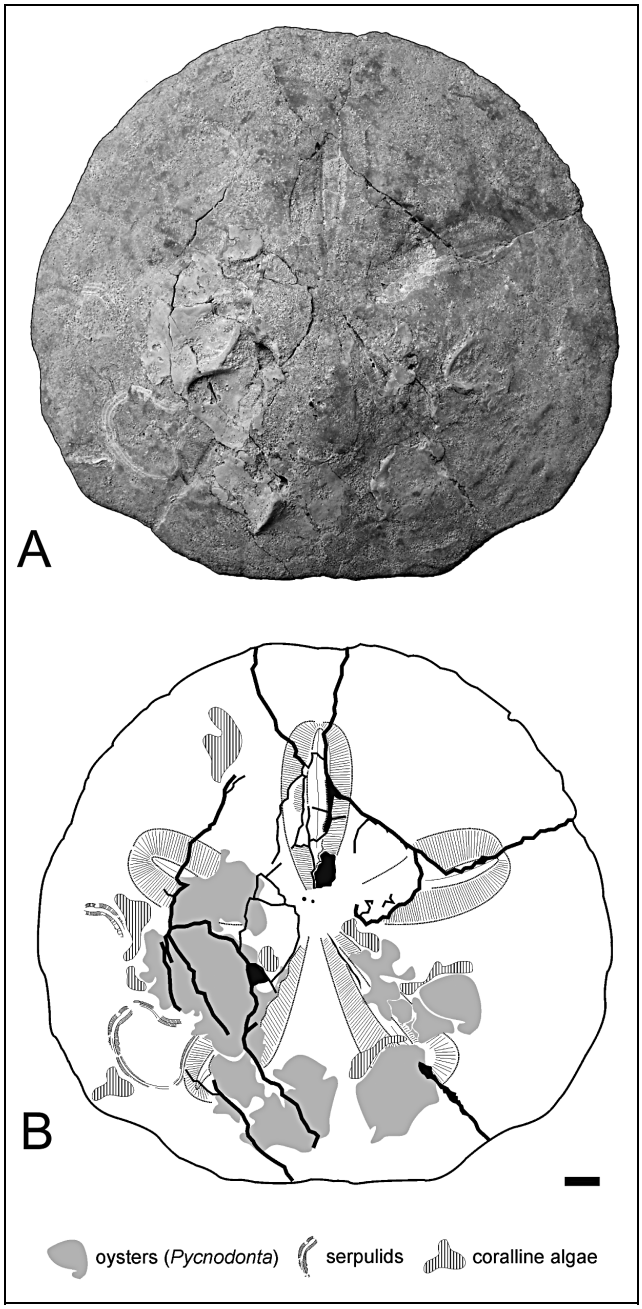

Fig. 8 - *Parascutella gibbercula* (de Serres, 1829), Outcrop 2, sample U486. A) Aboral side covered by different encrusters. B) Drawing of the same sample with different encrusters mapped out. The black shaded areas are damaged parts of the test. Scale bar = 1 cm.

Encrustations of echinoids

Skeletal encrustations of irregular echinoids are mostly possible only post-mortally (Nebelsick et al. 1997). Hard and hydrodynamically stable shells of clypeasteroids represent a secondary hardground (Nebelsick et al. 1997; Kroh & Nebelsick 2003) in an environment where colonisation would otherwise be difficult (mobile, unconsolidated sediments; Nebelsick et al. 1997). The recovered specimens of *Parascutella* contain numerous encrustations by epibionts (i.e. epibiont colonisation), mostly by coralline algae, oysters and serpulid polychaetes (Fig. 8). Encrustations have some differences in a composition from oral to the aboral side of the test. Oysters were exclusively found growing over the petalloids on the aboral side of the *Parascutella*. Encrustations cover much more the aboral side of shells, although they were found on both sides which show that even after an organism's death, shells have kept their life position for a long time and got turned on the oral side only in exceptional cases (rarely covered by any encrusters). At the other echinoids, the unilaminar bryozoans were found growing only on the oral side of *Echinolampas*; serpulid worms were found more frequently on its both sides. Shells of *Schizaster* were not colonized by any encrusting organisms.

Micropalaeontological analysis of the biogenic composition of detritus shows that there were a sporadically dominant percentage of organisms which were found growing on *Parascutella*. Therefore we can suppose that the large sand dollars shells also had a significant contribution for the sediment production (Nebelsick et al. 1997).

Characteristics of the Mali Potok echinoid fauna

The Mali Potok echinoid fauna is unique in comparison with other findings in Croatia. The investigation of 17 outcrops in the Medvednica Mt. area, 4 in the Samoborsko Gorje Mt., 2 in the Zrinska Gora Mt, one in the Ravna Gora Mt, and one in Pokuplje (the Kupa river region), reveals *Clypeaster* spp., *Conolampas elegans* (Airaghi) and *Spatangus* sp. as the dominant echinoids in the Middle Miocene assemblages. Genus *Schizaster* appears as dominant in laterally deeper and/or more protected environments, mostly in marls and marly sediments.

The Mali Potok assemblage *Parascutella gibbercula* (de Serres) (Fig. 4), *Echinolampas hemisphaerica* (Lamarck) (Fig. 7A-C) and *Schizaster parkinsoni* Defrance (Fig. 7D-F) has not been found in this area so far. The complete absence of *Clypeaster* should also be emphasized in the investigated area and represent a particularity of this locality. Although different species of

genus *Clypeaster* are the most common echinoids in the Badenian of the Medvednica Mt., absence of *Clypeaster* here is probably connected with the strong siliciclastic influence together with the shallow water coastal environment. The above-mentioned assemblage of *Clypeaster* spp., *Conolampas elegans* (Airaghi), and *Spatangus* sp. ordinarily appears in pure bioclastic limestone with minor siliciclastic input.

The well developed internal reinforcement structures also contribute to the preservation potential of clypeasteroid echinoids (Moffat & Bottjer 1999; Nebelsick 1995, 1999; Fig. 6). This peculiarity partially explains a dominance of the clypeasteroids in the largest part of Middle Miocene echinoid assemblages of Croatia and adjacent areas (Poljak 1938; Mitrović-Petrović 1969).

Weakening of terrestrial influence allowed the existence of small carbonate platforms type of sedimentation which was present during the late Badenian in this area (Vrsaljko et al. 2006). Echinoids and other fauna of the Mali Potok locality have lived in the shallow sea between algal banks mostly consisted of genus *Lithothamnion* sp. (in form of large, more than 10 cm wide algal balls) and less portion of different laminar bryozoans. Degradation of algal banks by strong waves or tidal currents provided a major source for deposition of bioclastic sediments. On the investigated section, fossil algal banks are not visible but are nicely exposed 3 km west from Mali Potok in the area of Ponikve (Pikija et al. 1995). Traces of cross-stratification and predominance of calcite spar cement in sandstones also suggest shallow water environment.

Conclusion

The sand dollar *Parascutella gibbercula* (de Serres, 1829) has been found for the first time and described in Croatia. A connection was noticed between the appearance of *Parascutella* and development of certain sediment types in the explored area. In the case of *in situ* findings, *Parascutella* fossils indicate a high-energy shallow-water environment of mobile and unconsolidated sands of mixed siliciclastic-carbonate composition, which has also been suggested by other researchers (e.g. Nebelsick 1999; Nebelsick & Kroh 2002; Kroh & Nebelsick 2003; Kroh 2007).

After death, the *Parascutella* shells act as secondary hardground that served as a suitable substrate for epibiont populations, thus contributing toward the biogenic sediment production.

By reduction of water energy and/or deepening of the environment, *Parascutella* assemblage disappears in the explored sediment succession, becoming subsequently replaced by a widely spread spatangoid fauna in a fine-grained sediments in the Badenian of Medvednica Mt. and surrounding areas.

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