SARMATIAN FORAMINIFERAL ASSEMBLAGES OF CAVERN FILLINGS IN THE BADENIAN REEFS OF MEDOBORY (POLUPANIVKA, WESTERN UKRAINE)

ZESPOŁY OTWORNIC SARMACKICH Z WYPEŁNIEŃ KAWERN W BADEŃSKICH RAFACH MIODOBORÓW (POŁUPANIWKA, ZACHODNIA UKRAINA)

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Abstract: The Middle Miocene (Upper Badenian) coralline algal reefs of Western Ukraine contain caverns (up to 1 m across) and fissures that are filled by Sarmatian deposits: marly clays, clayey carbonate sand and bioclastic, bryozoan-rich sand. These deposits often contain abundant and very well preserved calcareous benthic foraminifera; agglutinated forms have not been recorded. Foraminiferal tests quite commonly show morphological abnormalities, e.g. twin forms or tests with irregularities in size or shape in last chambers. Each of the three analysed samples is characterized by a different foraminiferal assemblage: *Elphidium aculeatum* assemblage, Hauerinidae assemblage and *Lobatula lobatula* assemblage. These assemblages are characteristic for a shallow marine environment. Low taxonomic diversity and high dominance or monospecific foraminiferal assemblages indicate generally a restricted marine environment. It seems that the increasing salinity and very high-energy environment were the most probable factors controlling the composition of the foraminiferal assemblages.

Key words: Middle Miocene, Sarmatian, foraminifers, aberrant forms, reefs, palaeoenvironments, Ukraine.

Abstrakt: Górnobadeńskie rafy koralowe zachodniej Ukrainy posiadają kawerny o przekroju do 1 m oraz szczeliny, które obecnie są wypełnione osadami sarmackimi – iłami marglistymi i zasilonym piaskiem węglanowym i bioklastycznym, często mszywiołowym. Osady te często zawierają liczne i bardzo dobrze zachowane węglanowe otwornice bentosowe; nie stwierdzono natomiast otwornic zlepieńcowatych. Dość częste są skorupki z morfologicznymi nieprawidłowościami, np. formy bliźniacze albo skorupki z nieregularnością rozmiaru lub kształtu ostatnich komór. Każda z trzech próbek zawiera inny zespół otwornicowy: w pierwszej występuje zespół z *Elphidium aculeatum*, druga zawiera zespół z Hauerinidae, a trzecia – zespół z *Lobatula lobatula*. Wszystkie te zespoły są charakterystyczne dla środowiska płytkomorskiego. Niskie zróżnicowanie taksonomiczne i wysoka dominacja lub jednogatunkowe zespoły otwornicowe wskazują na ogólnie ograniczone środowisko morskie; wydaje się, że w takich warunkach najbardziej prawdopodobnym czynnikiem warunkującym skład zespołów otwornicowych było podwyższone zasolenie i środowisko bardzo wysokoenergetyczne.

Słowa kluczowe: miocen środkowy, sarmat, otwornice, formy aberrantne, rafy, paleośrodowiska, Ukraina.

INTRODUCTION

The Middle Miocene (Upper Badenian and Lower Sarmatian) reef complex extends over more than 200 km, within a several to 40 km wide zone in western Ukraine along the NE margin of the Carpathian Foredeep Basin which is a subbasin of the Central Paratethys (Fig. 1). The most prominent component of the Medobory Hills is Upper Badenian coralline algal reefs that are associated with a variety of bioclastic, marly and rhodoid fa-

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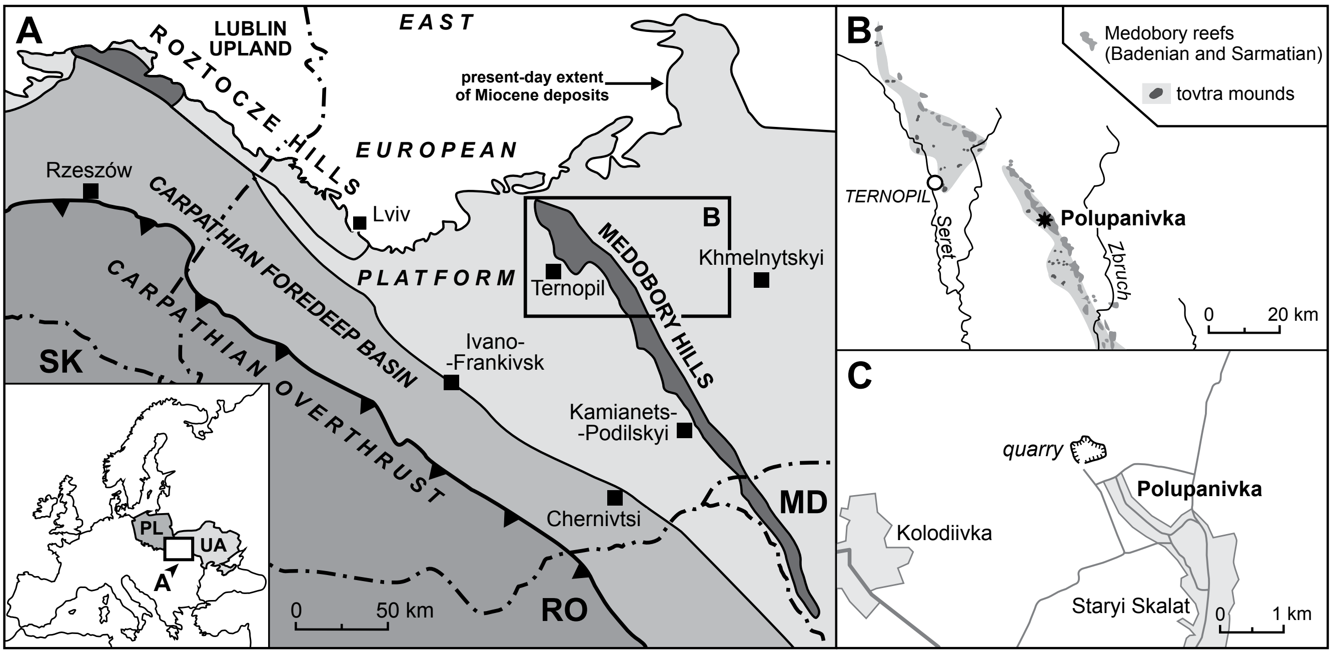

Fig. 1. A – Map of the Middle Miocene deposits in the Carpathian Foredeep Basin in Poland and Ukraine, showing the distribution of reef deposits (dotted); B – distribution of the Badenian and Sarmatian reefs of the Medobory Hills (after Korolyuk, 1952; modified); C – location of the Polupanivka quarry

cies (Korolyuk, 1952; Radwański *et al.*, 2006). The main frame-builders in the Upper Badenian reefs are crustose coralline algae with scattered hermatypic corals. The coralline algae display different growth morphologies ranging from laminar crusts to erect branching forms. Reef-associated biota comprises rich assemblages of bivalves, gastropods, echinoids, crustaceans, foraminifers, bryozoans and serpulids (Górka *et al.*, 2012). In places, boring organisms are of great importance. The coralline algal reefs are covered by the Lower Sarmatian serpulid-microbialite reefs. The origin of the serpulid-microbialite reefs is related to the restriction of the Paratethys during the Early Sarmatian and resulting palaeoenvironmental changes (Jasionowski, 2006; Jasionowski *et al.*, 2003; Studencka, Jasionowski, 2011). The Sarmatian reefs occur also within marly and clayey deposits at the SW foot of the Medobory ridge where they build several metres high rocky hills.

The Medobory reefs separated deeper environments of the Carpathian Foredeep Basin with marls and clay deposition from the nearshore facies dominated by white quartzitic sands and sandstones, discordantly overlying the pre-Neogene basement (Maslov, Utrobin, 1958). Field observations have shown the presence of breccias, vadose silt and vadose leaching in the uppermost coralline-algae boundstones, indicating considerable sea-level fluctuations and a phase of emersion of the Medobory reefs in the latest Badenian (Górka *et al.*, 2012).

The aim of this paper is to characterize the Sarmatian foraminiferal assemblages occurring in cavern and fissure fillings in the Badenian reefs, often several metres below their tops.

GEOLOGICAL SETTING

A large quarry in the village of Polupanivka, located in the northern part of the central section of the Medobory hills, just ca 40 km east of Ternopil (Fig. 1), mines Badenian and Sarmatian reef limestones. Badenian reefs exposed in the lower parts of the quarry are covered with Sarmatian deposits visible in the upper parts of the faces. The morphology of the Badenian–Sarmatian boundary is quite complex (Fig. 2), similarly as in other outcrops in this area (see Górka *et al.*, 2012). In the central part of the quarry hill (i.e. at the east face of the quarry), the Badenian–Sarmatian contact surface is horizontal (probably smoothed by abrasion) and covered by relatively thin (2–3 m) Sarmatian strata consisting mainly of small serpulid-microbialite bioherms embedded within organodetrital and coquina deposits (Fig. 2A, D). The opposite (western) face of the quarry reveals more complicated image of the Badenian–Sarmatian boundary. The contact surface is generally inclined towards the west showing however hilly or undulating relief (Fig. 2A, B, E). The overlying Sarmatian deposits reach a much higher thickness (even 10 or more metres) and comprise mainly serpulid-microbialite reef facies with a significant contribution of cockle coquinas.

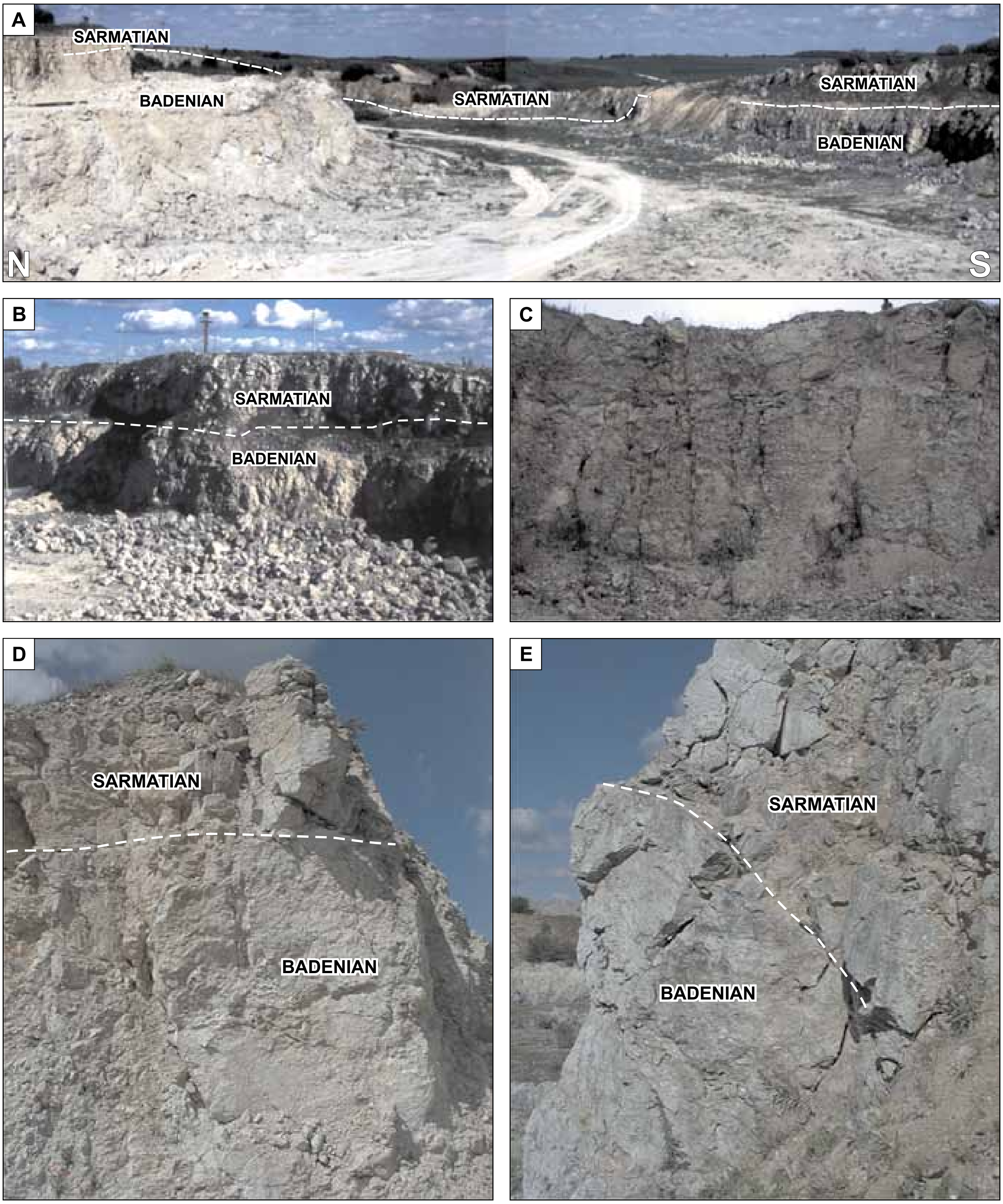

Fig. 2. Polupanivka quarry

A – a view to the southeast from the north edge of the quarry; **B** – south face of the quarry; **C** – vertical joints and/or fissures cutting the Badenian reef limestone; **D** – thin Sarmatian deposits overlying the flat (abraded) top of the Badenian reef (north face of the quarry); **E** – Sarmatian serpulid-microbialite reef limestone on the steeply inclined top of the Badenian reef (south face of the quarry)

The Badenian reef limestone underlying Sarmatian deposits is cut by a dense network of intersecting dikes or fissures that are up to several tens of cm wide and penetrate the Badenian reef several metres deep (Figs. 2C, 3D, E). The fissures are filled with Sarmatian deposits – their faces are coated with microbialite encrustations and the central space is filled up with clayey, marly or organodetrital material containing Sarmatian fossils. Additionally, in the Badenian reef limestone (several metres or more below the Badenian–Sarmatian contact) there are deep channels and/or small caverns filled with organodetrital or coquina material of Sarmatian affinity (Fig. 3C). The largest cavern is up to 1 m across.

MATERIAL AND METHODS

Four samples from Polupanivka were taken: three samples from marly clays and clayey carbonate sand that fill the karst caverns, and one sample from bioclastic, bryozoan-rich sand occurring at the Badenian–Sarmatian boundary (Fig. 2). Washed residues for the foraminiferal study were obtained from the rocks by disaggregation using Na_2SO_4. An aliquot of about 250 or more specimens from the 100–700 µm size fraction was used for foraminiferal counts.

The foraminifer-based palaeoenvironmental interpretation applies the requirements of present-day representatives of recorded taxa (Murray, 1991, 2006; Langer, 1993; Hayward *et al*., 1997; Geslin *et al*., 2000).

RESULTS

Three out of the four samples, i.e. 3/01, 4/02 and 5/02, yielded abundant and very well-preserved calcareous benthic foraminifera (Figs. 4, 5); agglutinated forms have not been recorded. In sample 12/02, only several specimens have been obtained and this sample due to the scarcity of material has not been taken into consideration for palaeoenvironmental interpretations.

Three of the samples are characterized by a different foraminiferal assemblage: the *Elphidium aculeatum* assemblage occurs in sample 3/01, sample 4/02 is characterized by the Hauerinidae assemblage, and sample 5/02 contains the *Lobatula lobatula* assemblage.

Table 1

Distribution of benthic foraminifers in the samples

Foraminifera	Sample			
	3/01	4/02	5/02	12/02
Elphidium aculeatum (d'Orbigny) (Fig. 4C, D, L, M)	298		3	
Elphidium cf. elegans Serova (Fig. 4A, E, F)	11			
Elphidium friedbergi Serova	2			
Elphidium hauerinum (d'Orbigny)	3			
Elphidium joukovi Serowa (Fig. 4I)	4			
Elphidium koberi Tollmann	8			
Elphidium macellum (Fichtell et Moll) (Fig. 4H)	4			
Elphidium macellum converia Venglinski (Fig. 4G)	1			
Elphidium macellum tumidocamerale Bogdanowicz (Fig. 4K)	1			
Elphidium poeyanum (d'Orbigny) (Fig. 5K)		2		
Elphidium reginum (d'Orbigny) (Fig. 4B, K)	6			
Elphidium sp. 1 (Fig. 5J)		4		
Articulina problema Bogdanowicz (Fig. 5L)		2		
Bolivina sp. (Fig. 5M)		1		
Cycloforina badenensis (d'Orbigny) (Fig. 5H)		4		
Cycloforina predcarpatica (Serova) (Fig. 5D)		16		3
Cycloforina suturalis (Reuss) (Fig. 5B)		7		
Cycloforina sp. (Fig. 5C)		2		
Lobatula lobatula (Walker et Jacob) (Fig. 5N-S)			296	1
Quinqueloculina buchiana (d'Orbigny) (Fig. 5F)		23		
Quinqueloculina complanata (Gerke et Issaeva) (Fig. 5A)		70		
Triloculina sp. (Fig. 5G)		11		
Varidentella reussi (Bogdanowicz) (Fig. 5E)		109		6

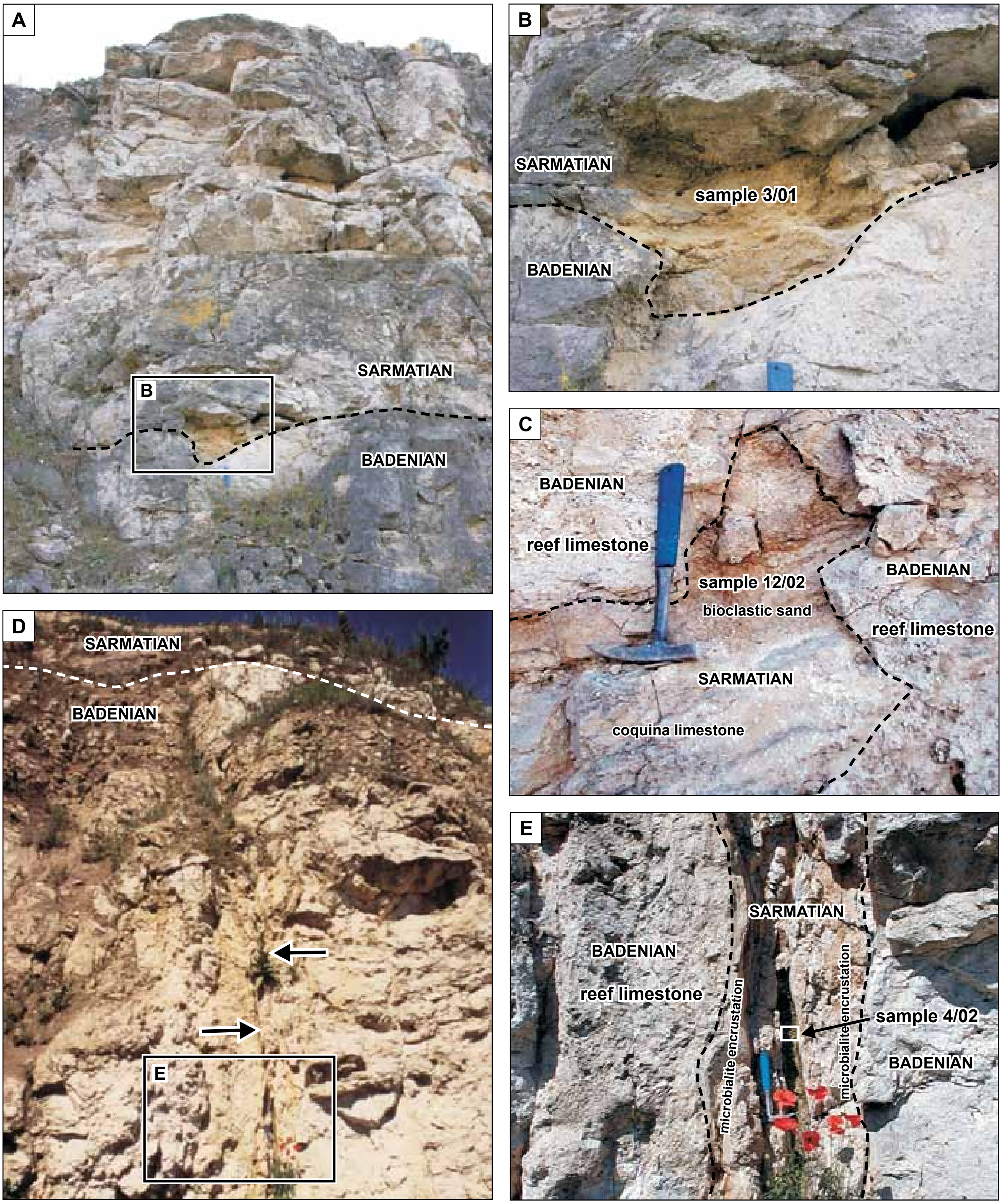

Fig. 3. Polupanivka quarry (south part)

A, **B** – a pocket in the top of the Badenian reef filled with Sarmatian calcareous sand (sample 3/01); **C** – fragment of a large cavern within the Badenian reef limestone filled up with ?Sarmatian coquina and calcareous biodetritus (sample 12/02); **D**, **E** – a vertical narrow fissure (arrows) cutting the Badenian reef limestone. Its faces are coated with microbialite encrustations and the central part is plugged with marly clay (sample 4/02)

INTERPRETATION

Elphidium reginum (d'Orbigny) and *E. koberi* Tollmann that occur in sample 3/01, are regarded to be diagnostic for the Early Sarmatian, although the former occurs also in the upper Badenian strata in Roztocze (Szczechura, 1982). Krasheninnikov (1958, p. 296 and 302; 1960, Fig. 6) noted that *Elphidium reginum* appears already in the uppermost Badenian (his horizon G), and Gedl and Peryt (2011) recorded it in the upper Badenian of Kudryntsi, located some 25 km west of the Medobory ridge (Peryt, Peryt, 2009). *Elphidium koberi*, another elphidiid species described mostly from the Sarmatian strata (Tollmann, 1955; Brestenská, 1974; Papp, Schmid, 1985; Cicha *et al*., 1998; Görür *et al*., 2000; Paruch-Kulczycka, 2007; Schütz *et al*., 2007), occurs also in the upper Badenian of Kudryntsi (Gedl, Peryt, 2011).

The foraminiferal assemblage of sample 3/01 is composed almost entirely of *Elphidium.* The most common are keeled forms with spines at the end of most sutures, e.g. *Elphidium aculeatum*, *E. reginum*, *E. koberi*. *Elphidium aculeatum* forms more than 80% of the assemblage; *E. koberi* and *E. reginum* are rare. Also very rare are keeled elphidiids, but without spines on the periphery: *Elphidium macellum, E. elegans* and *E. joukovi*. A very characteristic feature of this assemblage is the quite common occurrence of tests with morphological abnormalities, e.g. twin forms or tests with irregularities in size or shape in last the chambers.

Abnormal tests have been reported from both fossil and recent specimens. Deformation on fossil specimens is often related to environmental stress which may be due to hyposalinity or hypersalinity, variations in salinity, freshwater input affecting pH, S, nutrients and turbidity, oxygen and CO_2 mixing, trace element supply and mechanical factors associated with hydrodynamics and regeneration phenomena (e.g. Hofker, 1971; Brasier, 1975; Almogi-Labin *et al*, 1992; Stouff *et al*., 1999; Geslin *et al*., 2000; Meriç *et al*., 2004). Some authors considered that twins or triplets are primarily or entirely genetic accidents (e.g. Loeblich, Tappan, 1964; Meriç *et al*., 2001). Twinned forms, which originated in places were environmental factors played an important role, were reported from various locations of the world (Geslin *et al.* 2000). Almogi-Labin *et al*. (1992) and Stouff *et al*. (1999) demonstrated that abundant twins were formed in hypersaline conditions.

Recent keeled elphidids are mostly herbivorous, epifaunal dwellers; they prefer sandy sediment and occur in shallow marine environments (inner shelf) with warm to temperate and normal to hypersaline (35–70‰) waters (Murray, 1991, 2006). *Elphidium aculetaum,* which dominates the foraminiferal assemblage in sample 3/01, lives recently on arborescent algae and is epiphytic, suspension feeding form (Langer, 1993). *Elphidium macellum,* another keeled Sarmatian form, presumably also had the same smaller algae microhabitat with relatively short life-span (Langer, 1993). Recently it is a common member of low tidal and shallow subtidal (0–20 m depth) foraminiferal associations (Hayward *et al.*, 1997). The predominance of keeled elphidiids suggests dense arborescent algal substrate during the Early Sarmatian. However, *E. reginum* possesses few long spines on the periphery, and the reason of morphological adaptation can be explained with the transition of the algal into seagrass vegetation (cf. Tóth *et al*., 2010).

In summary, the foraminiferal assemblage of sample 3/01 which is characterized by low diversity and high dominance with common aberrant forms, indicates a shallow-water marine environment with low hydrodynamic intensity and elevated salinity.

The foraminiferal assemblage of sample 4/02 is dominated by small-sized hauerinids: *Varidentella* and *Cycloforina*; *Quinqueloculina* and *Triloculina* are minor components of the assemblage. Hauerinids (*Cycloforina*, *Varidentella*, *Quinqueloculina*, *Triloculina*) prefer shallow marine environments (0–50 m deep) of normal salinity to hypersaline, characteristic of lagoons.

Quinqueloculina is an epifaunal dweller, living free or clinging on plants or sediment, preferring shallow normal marine to hypersaline (32–65‰) environments. *Triloculina*, commonly occurring in association with *Elphidium* and *Quinqueloculina,* possesses similar ecologic requirements (Murray, 1991, 2006). The *Quinqueloculina* spp. association occurs in the recent Mediterranean Sea in shallow-marine environments (2–65 m), temperate to warm waters (10–25°C) and slightly elevated salinity (37–39‰).

The foraminiferal assemblage of sample 5/02 is a monospecific assemblage of *Lobatula lobatula*. *Lobatula lobatula* is an epifaunal dweller, usually attached and immobile, especially in high-energy waters; preferring temperate – warm, shallow, normal marine environments (Murray, 1991, 2006). According to Langer (1993), *Lobatula lobatula* is a permanently attached foraminifer that often lives on seagrass leaves or rhizomes. The *Lobatula lobatula* assemblage suggests a shallow-marine, very high-energy environment.

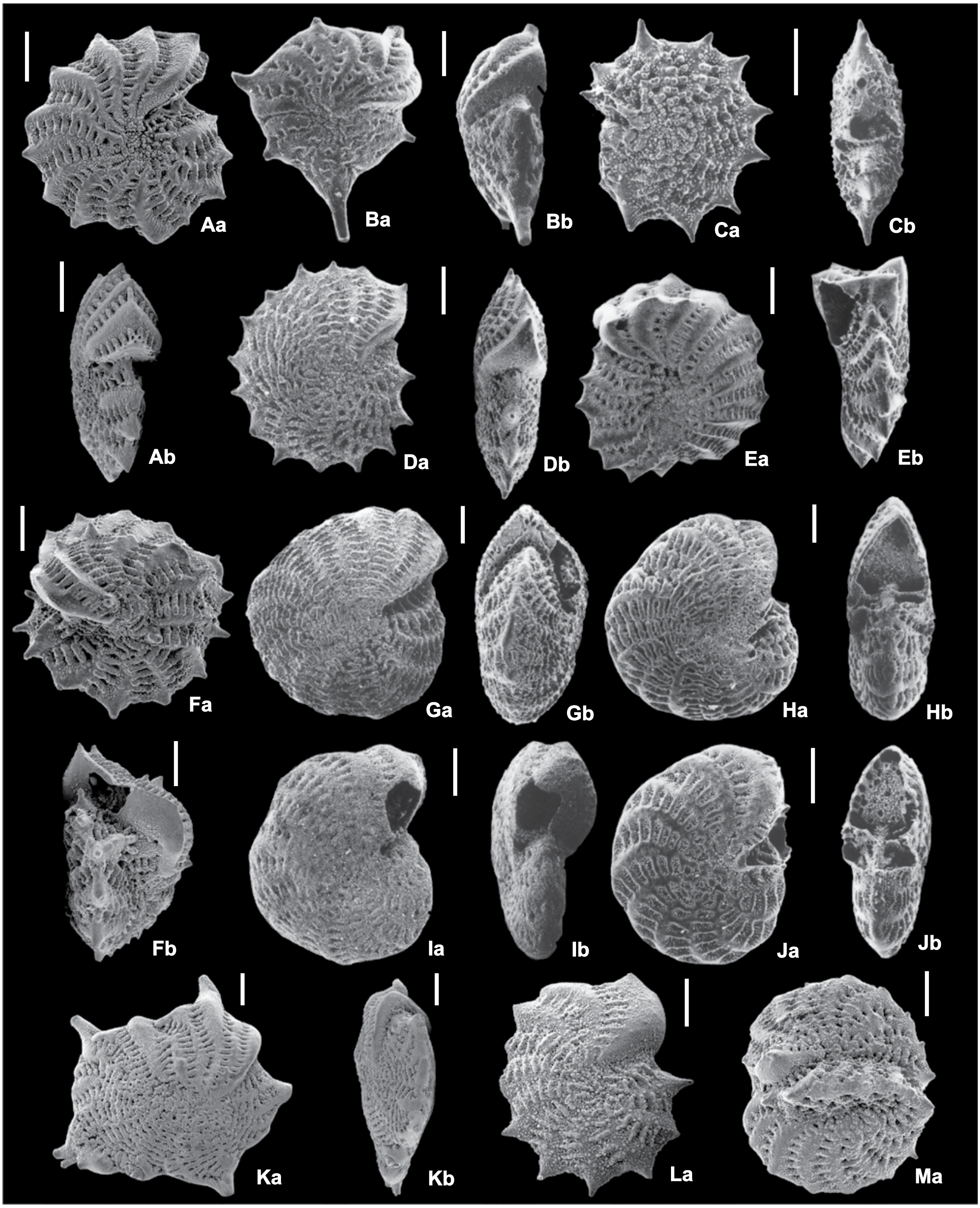

Fig. 4. Foraminifers from sample 3/01

a – lateral view, b – side view; scale bar = 200 μm

A. *Elphidium* cf. *elegans* Serova; B. *Elphidium reginum* (d'Orbigny); C, D, L. *Elphidium aculeatum* (d'Orbigny); E, F. *E.*cf. *elegans* Serova with an aberrant chamber shape; G. *Elphidium macellum converia* Venglinski; H. *Elphidium macellum* (Fichtell et Moll); I. *Elphidium joukovi* Serova; J. *Elphidium macellum tumidocamerale* Bogdanowicz; K. *Elphidium reginum* (d'Orbigny) with an aberrant test shape; M. *Elphidium aculeatum* (d'Orbigny), abnormal test

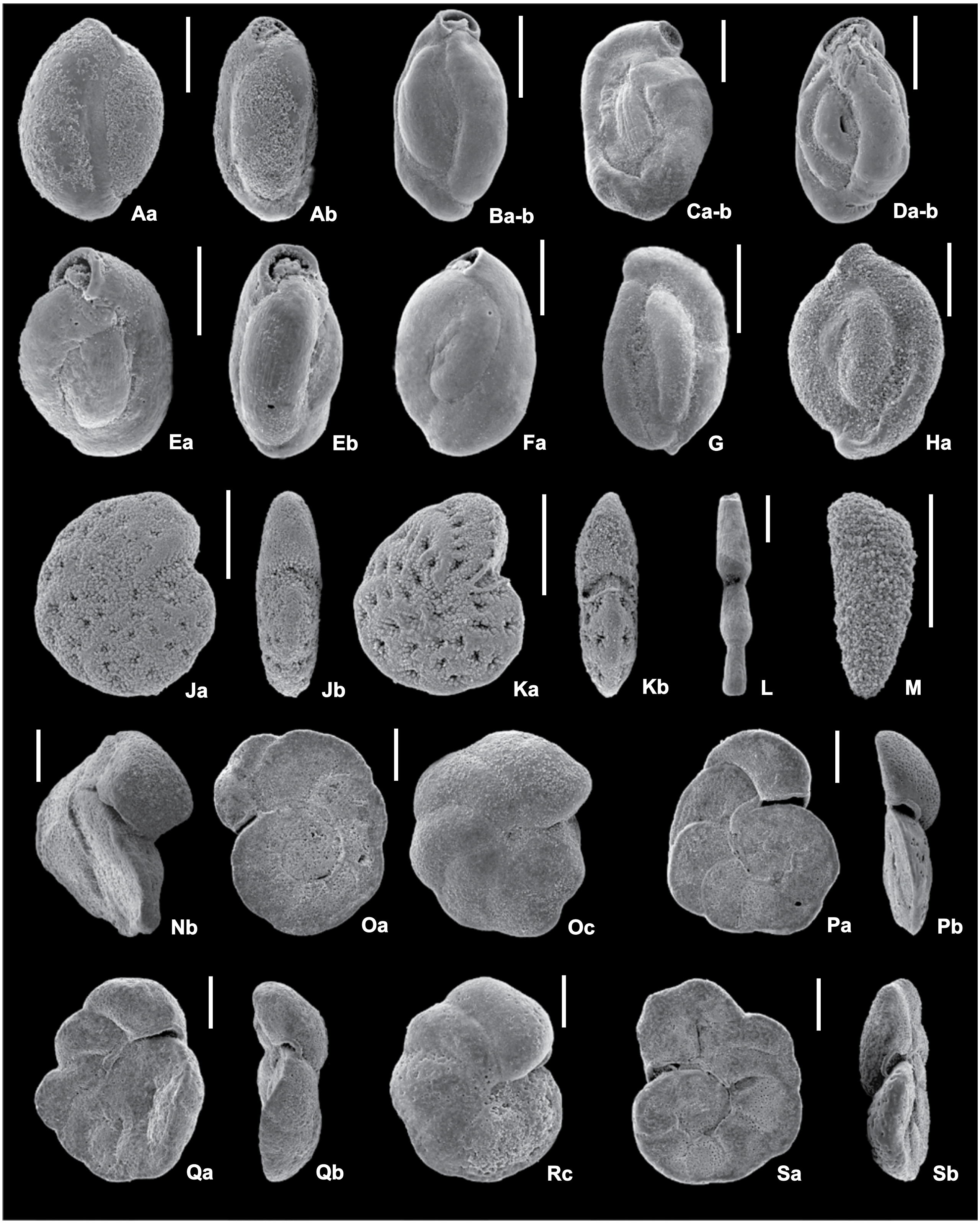

Fig. 5. Foraminifers from samples 4/02 (A–H, L, M) and 5 (J, K, N–S)

a – lateral view, b – side view, c – ventral view; scale bar = 200 µm

A. *Quinqueloculina complanata* (Gerke et Issaeva); B. *Cycloforina suturalis* (Reuss); C. *Cycloforina* sp.; D. *Cycloforina predkarpatica* (Serova); E. *Varidentella reussi* (Bogdanowicz); F. *Quinqueloculina buchiana* d'Orbigny; G. *Triloculina* sp.; H. *Cycloforina badenensis* d'Orbigny; J. *Elphidium* sp.; K. *Elphidium poeyanum* (d'Orbigny); L. *Articulina problema* Bogdanowicz; M. *Bolivina* sp.; N–S. *Lobatula lobatula* (Walker & Jacob).

CONCLUSIONS AND FINAL REMARKS

Each of the three samples (3/01, 4/02 and 5/02) is characterized by a different foraminiferal assemblage: *Elphidium aculeatum* assemblage, Hauerinidae assemblage and *Lobatula lobatula* assemblage, respectively.

Low diversity and high dominance or monospecific foraminiferal assemblages indicate in general a restricted marine environment. In such conditions, a relatively small change of any parameter (such as salinity, temperature, depth, or hydrodynamic intensity) could cause essential changes in foraminiferal assemblages although in all cases the assemblages are characteristic of a shallow marine environment. The most probable controlling factor of the taxonomic composition of foraminiferal assemblages from samples 3/01 and 4/02 was elevated salinity, and of sample 5/02 – a very high-energy environment. The paucity of foraminifer specimens in sample 12/02 seems to result from adverse environmental conditions (see e.g. Peryt *et al.*, 2004, for another Middle Miocene example).

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