

Middle Miocene coralgal facies at Maksymivka near Ternopil (Ukraine): A preliminary account

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ABSTRACT:

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A peculiar coralgal facies is recognized in the Lviv-Ternopil region, Ukraine, from the northern shores of the Middle Miocene (Badenian) Fore-Carpathian Basin. Its complex structure is dominated by algal buildups composed of interfingering red-algal (lithothamnian) colonies and blue-green-algal crusts, associated locally with numerous hermatypic corals (*Tarbellastraea reussiana*, *Porites vindobonarum prima*), either isolated, or overlapping each other. The holes amidst, and the crevices in, the buildups are filled with coarse bioclastic sediment (shell-grit), burrowed commonly by crustacean decapods (alpheid shrimps). The alpheid burrows, filled with coarser or finer shell-grit, served frequently as taphonomic traps for crustacean decapods (squat lobsters and crabs) and echinoids. Special attention is paid to the activity of rock-boring bivalves (*Jouannetia semicaudata*, *Lithophaga lithophaga*) in coralgal buildups and/or in particular coral colonies, some of which are redeposited, and riddled densely by bivalve borings. Emphasis is given to the environmental significance of alpheid shrimps, the tiered burrows of which are recorded in the Fore-Carpathian Basin for the first time. Crustacean decapods and echinoids are systematically studied. A comparison of the studied coralgal facies with others of the Lviv-Ternopil region, and those from the territory of Poland, indicates their faunistic and biogeographic identity.

Key words: Coralgal facies, Crustacean decapods, Echinoids, Alpheid burrows, Eco-taphonomy, Miocene, Ukraine.

INTRODUCTION

The Miocene of the Lviv-Ternopil region (western Ukraine) of the northern margin of the Fore-Carpathian Basin (see Text-fig. 1), has attracted many researchers since the middle of the 19th century (ALTH 1850, REUSS 1851, STUR 1859, HILBER 1881: see ŁOMNICKI 1897a, b). This has resulted from the ubiquity of fossils and the remarkable facies diversity of these deposits, with some of the facies poorly recognized and/or unknown (see WYSOCKA 1999, 2002) from other parts of the Basin. According to the present chronostratigraphic scheme these deposits should be referred to

the Badenian Stage of the Middle Miocene (see HARZHAUSER & *al.* 2003, KROH 2005).

The aim of the present paper is to present a peculiar Middle Miocene (Badenian) coralgal facies and its fauna, as exposed in the huge Maksymivka and Haluschyntsi quarries near Ternopil (see Text-fig. 2). It is assumed that some of the previous records of corals (DEMBIŃSKA-RÓŻKOWSKA 1932) and rock-boring bivalves (FRIEDBERG 1936), well known in the Polish literature, are from this facies, although exposed then at another locality, Zbarazh. This locality also yielded echinoids reported later by SZŐRÉNYI (1953). The larger coralgal buildups ('bioherms', or 'reefs' of former authors) once formed

slightly elevated monadnocks that projected over an almost flat landscape. Their range, forested largely by linden (basswood), has long been known as the *Medobory* (=Miodobory) Hills, meaning *The Melliferous Groves*. This hilly range spreads southeastward beyond Ukraine, as far as the territory of Moldova.

LOCALITY MAKSYMIVKA

The large scar in the earth's crust formed by the Maksymivka Quarry is clearly visible even on satellite images. It embraces an area of several square kilometres over a distance of about one kilometre, with a depth of

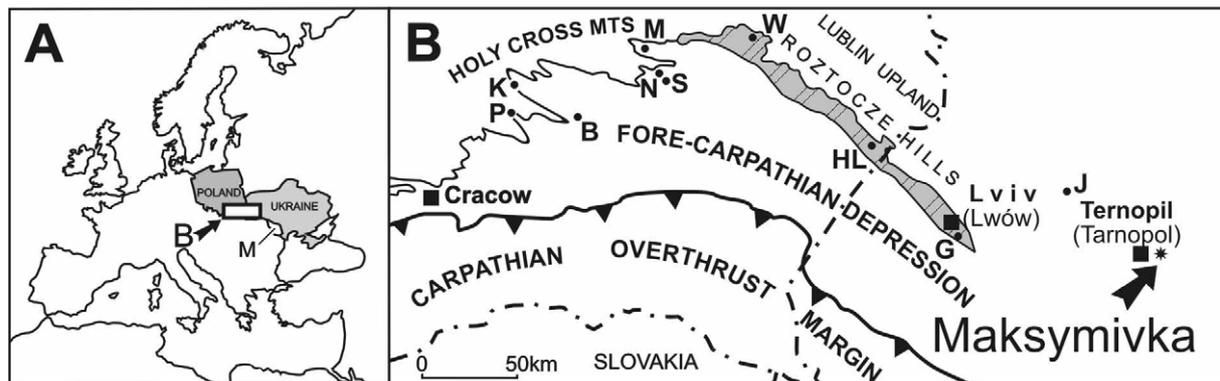


Fig. 1. General setting of the Lviv-Ternopil region in Europe (A; M indicates the Republic of Moldova), and in the Middle Miocene (Badenian) Fore-Carpathian Basin (B) stretching across the Polish/Ukrainian border, to show location of Maksymivka (arrowed) near Ternopil. Localities in Poland discussed in the text: K – Korytnica, P – Pińczów, B – Grobie near Busko-Spa, M – Męczenie, N – Nawodzice, S – Świniary, W – Węglinek, HL – Huta Lubycka. Localities in Ukraine discussed in the text: G – Gleboviti (=Chlebowice), J – Yaseniv (=Jasionów)

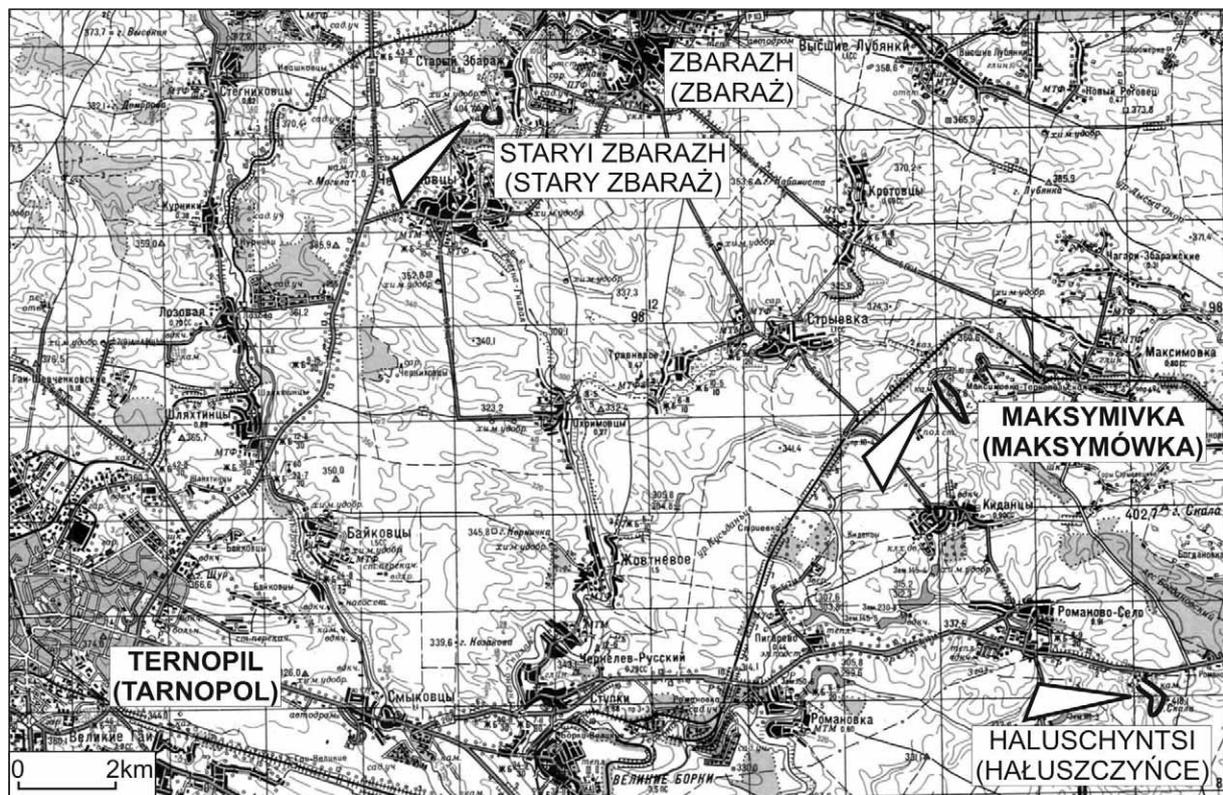


Fig. 2. Topographic map of the Ternopil area in Ukraine (see Text-fig.1), to show exposures of the Middle Miocene (Badenian) corallgal facies at Maksymivka (=Maksymówka), Staryi Zbarazh (=Stary Zbaraż) near Zbarazh (=Zbaraż), and Haluschyntsi (=Haluszczyńce), the sequence of which indicates the extent of the Medobory (=Miodobory) Hills



Fig. 3. The entrance part of the Maksymivka Quarry, to show the present-day (August 2005) exposure of the Middle Miocene (Badenian) coralgal facies, the accessibility to which is hampered by the block-sized scree (the arrow points to the part shown in close-up view in Text-fig. 4)

some tens of metres. In the quarry, where fragile calcarenites are exploited, the overlying compact coralgal limestones are often left, to form block screens and extensive dumps, along which the quarry road progresses to the present-day exposures (see Text-figs 3-4).

The coralgal facies at Maksymivka is characterised by a complex structure: particular coralgal buildups of variable size (from centimetres of rodolith forms, to several metres thick) have developed either isolated, or overlapping each other, separated by bioclastic lime-



Fig. 4. Close-up view of the block-sized scree spreading along the quarry walls at Maksymivka; the larger block in the foreground is topped by an omission surface at which the burrows of alpheid shrimps are erosionally truncated (see also Text-fig. 5A)

stones (shell-grit) of calcarenite and/or calcirudite type. The buildups are composed of red-algal (lithothamnian) colonies interfingering with, and/or encrusted by, biolithic mats/crusts of supposedly blue-green algal origin, all of which are associated locally with sparse hermatypic corals (*Porites* and *Tarbellastraea*). Some buildups are riddled by borings of the bivalve *Lithophaga*; the internal moulds of both the borings and

the shells are commonly preserved. The bioclastic limestones (shell-grit) are commonly densely burrowed by alpheid shrimps. Some of the burrows are filled by calcareous/clayey material full of bioclasts of various kinds (see Text-figs 5-6), including unique crab remains (mostly moults; see Pls 2-3) and echinoid tests (see Pl. 4). All these peculiar features/components are characterized briefly below.

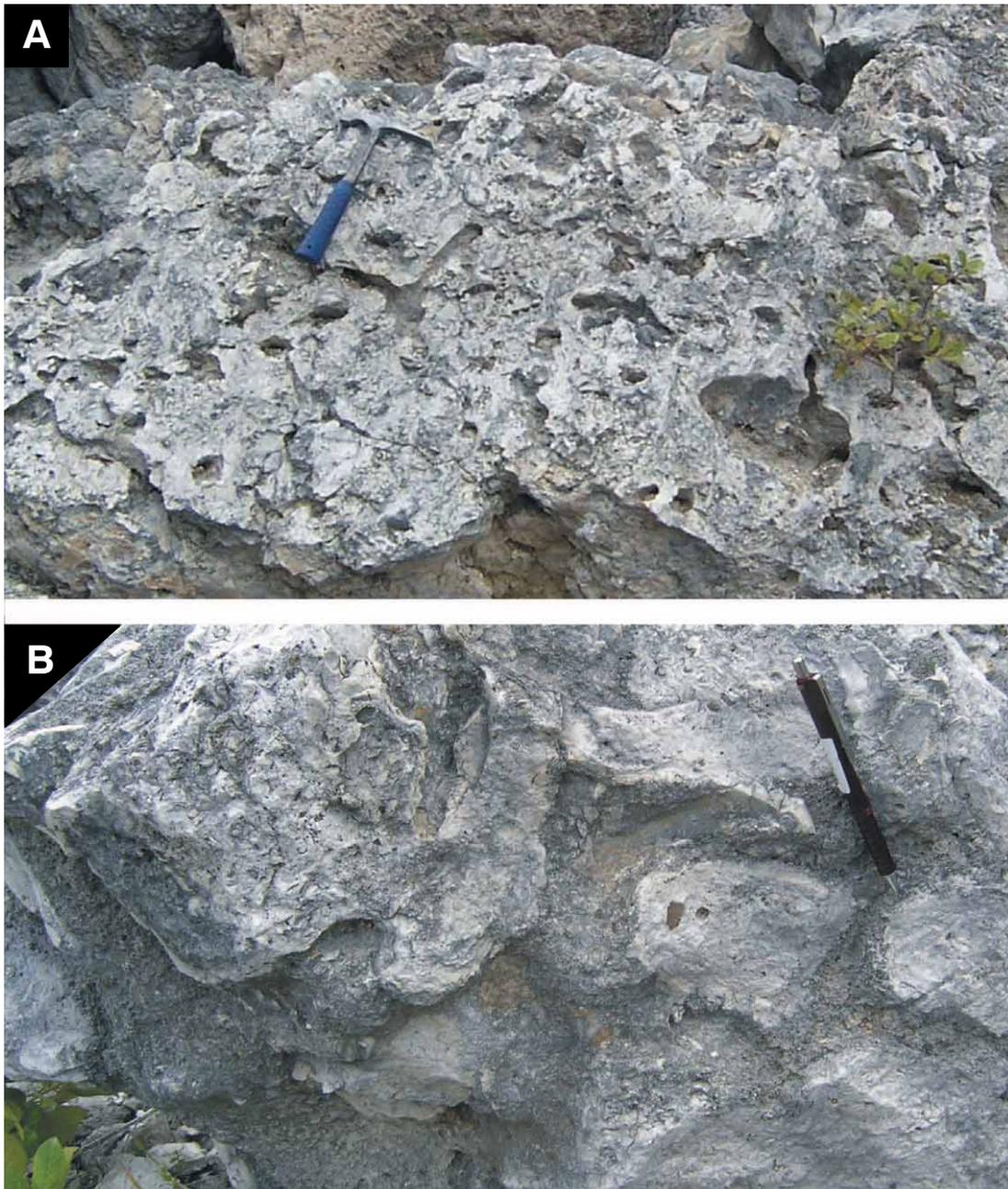


Fig. 5. Alpheid burrows amongst coralgal buildups at Maksymivka. **A** – Close-up of a scree block (see Text-fig. 4) displaying an erosional surface at which the alpheid burrows are truncated, the sectioned canals having thereby been exposed, hammer is 35 cm long; **B** – Vertical section through a network of alpheid shrimp burrows to show the irregular course of tiered canals, pen is 15 cm long

HERMATYPIC CORALS

Hermatypic corals are scattered throughout the whole complex of algal buildups, where they occur either isolated, or in small patches composed of several specimens. Most colonies are preserved as hollows left after dissolution of the aragonitic corallites (see Text-fig. 7 and

Pl. 1, Figs 1-2). The resultant external moulds preserve morphological details of the colonies to the same extent as e.g. recently recorded (RADWAŃSKI & RONIEWICZ 2005) in Early Kimmeridgian specimens from the Holy Cross Mountains (see Text-fig. 1). The preservation of the details of the surface morphology is presumably due to the presence of a micritic coating (largely of microbial

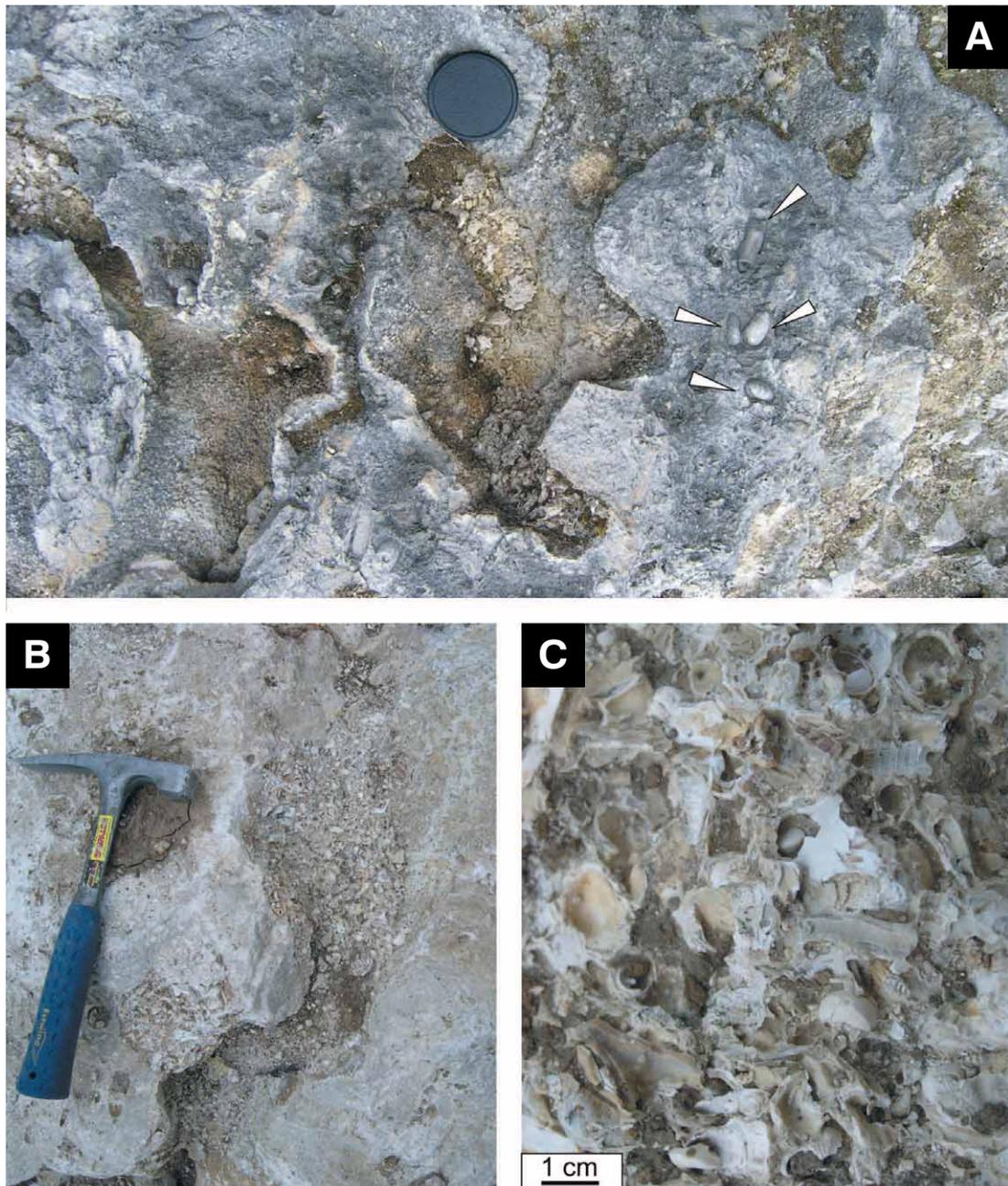


Fig. 6. Details of alpheid burrows amongst coralgall buildups at Maksymivka. **A** – Irregular, tiered burrows of alpheid shrimp, filled with variably sized, mostly bioclastic sediment (shell-grit), the coarser particles of which dominate locally in blind-ended parts of particular canals; The arrows point to a group of moulds of the borings of the bivalve *Lithophaga lithophaga* (LINNAEUS, 1758) within the buildup body, lens cap is 5 cm in diameter; **B** – Coarser shell-grit clogging a wider part of an irregular burrow of an alpheid shrimp, hammer is 35 cm long; **C** – Close-up view of the shell-grit filling an alpheid burrow

origin; cf. PURSER & *al.* 1996). Some colonies have their external parts still present, almost certainly a result of neomorphism of aragonite. In rare cases, the external parts of colonies seem to have preserved their original aragonite, which is strongly weathered and pulverized into a 'chalk-like' mass.

Although the coral colonies may locally be found in great numbers, they are always dispersed amongst red-algal thalli, and do not form the main component of the buildups. The corals are dominated by two species: *Porites vindobonarum prima* (KÜHN, 1927) and *Tarbellastraea reussiana* (MILNE-EDWARDS & HAIME, 1850), both widely known from the Fore-Carpathian Basin in Ukraine (see DEMBIŃSKA-RÓZKOWSKA 1932) and in Poland (see RONIEWICZ & STOLARSKI 1991).

The colonies of *P. vindobonarum prima* are usually dome-shaped, up to 15 cm in height/diameter (see Pl. 1, Fig. 1), and are commonly overgrown by red-algal crusts. In some cases, coral colonies interfinger with massive red-algal thalli. The less common colonies of *T. reussiana* show a wider variety of shapes (cf. BUDD & *al.* 1996), with massive and cup-shaped colonies reaching up to 20 cm in diameter. Also found was a very spectacular branched 'organ-pipe' colony, composed of numerous parallel sticks, up to 5 cm in diameter and 60 cm high each (Text-fig. 7.1, 1a). A single ?*Montastrea* sp. was also observed. Many of the colonies contain moulds of the boring bivalves *Lithophaga lithophaga* (LINNAEUS, 1758) and *Jouannetia semicaudata* DESMOULINS, 1828.

ROCK-BORING BIVALVES

Common in the coral colonies (see Pl. 1, Fig. 2a-2b), but rare in other parts of the buildups, are moulds of *Jouannetia semicaudata* DESMOULINS, 1828. Their size, up to 14 mm in diameter, corresponds to the average-size of specimens from the Polish part of the Fore-Carpathian Basin, and from other European occurrences (see RADWAŃSKI 1965a; 1969, pp. 20-22, figs 8A-C, and 11c; 1977a). The species is widely known from the Miocene of Europe (see FRIEDBERG 1934; RADWAŃSKI 1969, 1977a). Its sparse occurrences in the Polish part of the Fore Carpathian Basin are confined to areas of Upper Cretaceous bedrocks (see RADWAŃSKI 1965a, 1968). Similarly, in Ukraine, it was reported by FRIEDBERG (1934, pp. 6-7) from limestones at Zbarazh/Zaluzhia (=Zbarazh/Zaluże) and Zboriv (=Zborów), and by GORECKI (1957)

from chalky pebbles of the Cretaceous substrate in a sandy sequence at Yaseniv near Lviv (see Text-fig. 1). The new material, reported herein, comes from Haluschyntsi (see Pl. 1, Fig. 7).

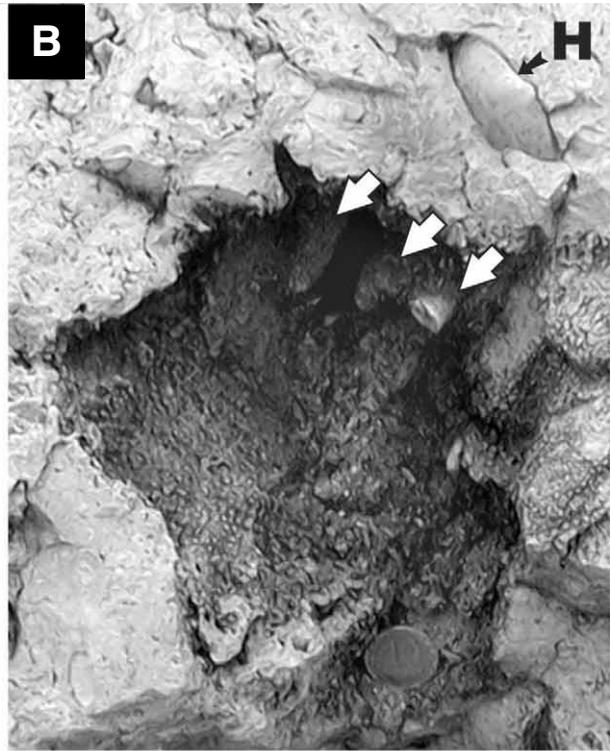
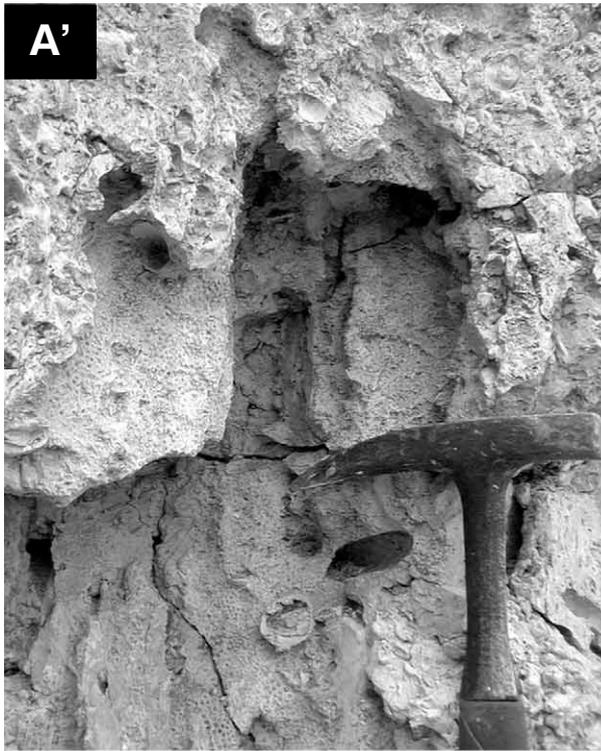
The moulds of the ubiquitous borings of the bivalve *Lithophaga* in the corallgal buildups (see Pl. 1, Figs 3-6) allow the producer to be determined as *Lithophaga lithophaga* (LINNAEUS, 1758). This extant species, common in many parts of Europe (see FRIEDBERG 1936; RADWAŃSKI 1969, 1977a), is also one of the most common rock-borers of the shore material (cliffs, boulders) in the Polish part of the Fore Carpathian Basin (see RADWAŃSKI 1964; 1965a; 1969, pp. 23-27; 1970; 1977a). In the Ukrainian part it was hitherto known only from Zbarazh (FRIEDBERG 1936, p. 200).

The size of the moulds (45-60 mm long), reflecting the actual size of the living mollusc corresponds to the smaller and average-sized forms of the Polish occurrences (see RADWAŃSKI 1969, figs 10A-C, and 11e). The two peculiar features of these moulds are: (i) a partial geopetal filling; and (ii) evidence of inhabiting of the emptied shells by the squatting bivalve *Sphenia*, preserved inside the moulds.

i. Geopetal partial filling is found in moulds of both shells and borings. It resulted evidently from incomplete filling of emptied shells or borings with mud carried by percolating water. (see Pl. 1, Figs 4-5). A slightly geopetal shell mould of *L. lithophaga* from Zbarazh was illustrated by FRIEDBERG (1936, pl. 30, fig. 17a). Geopetal fillings of *Lithophaga* borings were reported from many Miocene reefs of the Vienna Basin (BARÁTH 1992, p. 180 and pl. 6, fig.1) and from the Red Sea area (PURSER & *al.* 1996, fig. 8B and 11D).

ii. Some moulds of *Lithophaga* shells, when broken open, display the presence of a squatting bivalve, the shell morphology of which (see Pl. 1, Fig. 6) corresponds precisely to that of the species *Sphenia anatina* (BASTEROT, 1825). This species is commonly known in the littoral rubble of the Korytnica Basin in the Holy Cross Mountains, Poland (see Text-fig. 1), where it inhabits emptied borings of various bivalves (see RADWAŃSKI 1969, p. 89 and pl. 35, figs 9-10). A comprehensive study of this squatter (BAŁUK & RADWAŃSKI 1979) shows a very wide range of ecophenotypic diversity, dependent on the shape of the shell or boring of the rock-boring bivalve, which is represented mostly by

Fig. 7. Hermatypic corals *Tarbellastraea reussiana* (MILNE-EDWARDS & HAIME, 1850) from the corallgal buildups of Maksymivka. **A** – Field photo of a large, branched 'organ-pipe' colony (hammer is 35 cm long); **A'** – Close-up view, to show borings of the bivalve *Lithophaga lithophaga* (LINNAEUS, 1758); **B** – A lump of another colony, intensely bored by *Lithophaga lithophaga* (LINNAEUS, 1758); above the coral lump, **H** indicates a mould of the gastropod *Haliotis* overgrown by corallgal thalli; × 0.6



Lithophaga lithophaga (see BAŁUK & RADWAŃSKI 1979, figs 4-14). This explains the shape variability of *Sphenia* specimens coming from particular sequences/beds, or even from a single calcareous coral colony riddled by rock-boring bivalves. It is the explanation for the record (GORECKI 1957) of *S. anatina* in chalky pebbles in a sandy sequence at Yaseniv near Lviv. The two specimens, classified by GORECKI (1957, pl. 2, figs 2a-2b, 3a-3b) as "*Sphenia* sp." and "*Sphenia paulina* MAYER" respectively, clearly fall into the *lithophagicola* ecotype of *Sphenia* from the Korytnica Basin (see BAŁUK & RADWAŃSKI 1979, figs 6-10). It is noteworthy that the *lithophagicola* ecotype has recently also been reported (GÓRKA 2002, p. 527) from borings in the colonial corals *Tarbellastraea* and *Porites*, which form components of a unique Middle Miocene (Badenian) coral patch-reef at Grobie near Busko-Spa in the Holy Cross Mountains.

BURROWS OF ALPHEID SHRIMPS

The burrows of alpheid shrimps form extensive systems of tiered canals, with irregular courses, locally branched, ranging from a few up to 8 centimetres in diameter (see Text-figs 3-6). The burrows are present throughout detrital material (shell-grit) amongst the buildups and their larger holes and crevices. The burrow system is usually filled with detrital, largely bioclastic material of shell hash, mostly of molluscs (gastropods and bivalves), crabs and echinoids.

The burrow systems are comparable to those of the present-day alpheid shrimps (genus *Alpheus* WEBER, 1795, and its allies), which are typical of the intertidal zone of the U.S. Atlantic shore (see SHINN 1968, BROMLEY & FREY 1974, HOWARD & FREY 1975, BASSAN & FREY 1977) and the Indian Ocean (see FARROW 1971). In the fossil record, burrow systems attributable to alpheid shrimps have hitherto been recognized solely in

the Late Jurassic carbonate sequence of the Holy Cross Mountains, where they are known from a coral patch-reef facies of Middle Oxfordian age at Bałtów (RADWAŃSKA & RADWAŃSKI 2004; see also RONIEWICZ & RONIEWICZ 1971), and Early Kimmeridgian oolitic shoals at Małogoszcz (RADWAŃSKI 2003, RADWAŃSKA & RADWAŃSKI 2004, RADWAŃSKA 2005). In the latter location, alpheid burrows acted both as habitats for crevice faunas, as well as taphonomic/preservational traps for numerous biota, notably echinoderms (free-living and stalked crinoids, small-sized echinoids, ophiuroids and asteroids; see RADWAŃSKA 2005).

CRUSTACEAN DECAPODS

The crustacean decapods from Maksymivka (see Pl. 2) are represented by squat lobsters and crabs.

The squat lobsters (see Pl. 2, Fig. 1) are represented by an extinct species *Galathea weinfurteri* BACHMAYER, 1950, reported formerly from the Vienna and Pannonian basins (BACHMAYER 1950, MÜLLER 1984), as well as from the Fore-Carpathian Depression in Poland (MÜLLER 1996). The recent representatives of the genus *Galathea* FABRICIUS, 1793, mostly littoral, and nocturnal in life habit, live hidden under stones, in rock crevices, and/or caves during the daytime (see e.g., WIRTZ & DEBELIUS 2003, p. 140)

The crabs, the well preserved remains of which occur in shell-grit-filled holes and crevices between algal thalli, are represented by six taxa (see Pl. 2, Figs 2-7): abundant *Petrolisthes magnus* MÜLLER, 1984, *Daira speciosa* (REUSS, 1871) and *Xantho moldavicus* (JANAKEVICH, 1977), and subordinate *Petrolisthes* cf. *haydni* MÜLLER, 1984, *Chlorodiella* cf. *mediterranea tetenyensis* MÜLLER, 1984 and *Pilumnus mediterraneus* (LCERENTHEY, 1897). Two taxa are left in open nomenclature. *Ch. mediterranea* cf. *tetenyensis* is represented solely by a small carapace fragment which cannot be determined unequivocally (see also

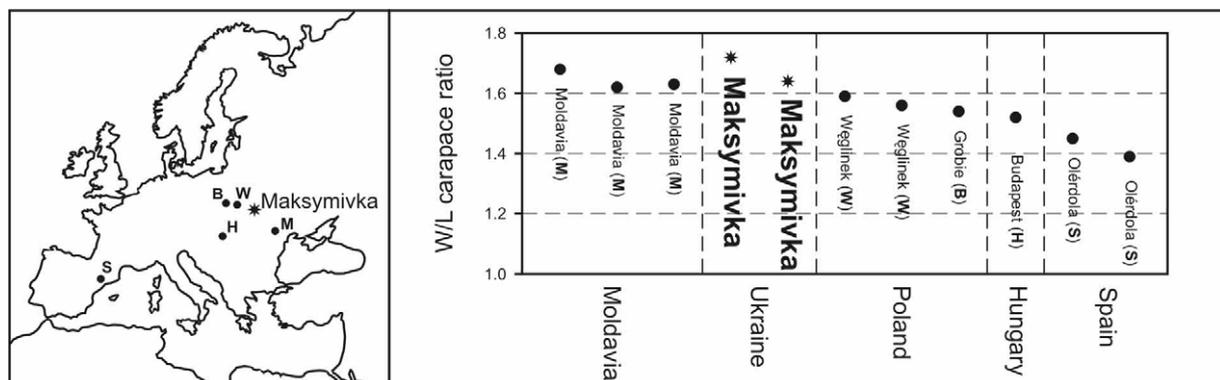


Fig. 8. Variability of carapace width/length ratio in the crab *Xantho moldavicus* (JANAKEVICH, 1977) in Europe: Note its gradual decrease westwards from Maksymivka (relevant data taken from: JANAKEVICH 1969a; MÜLLER 1984, 1993, 1996)

MÜLLER 1993, pp. 19-20). The specimens referred herein to *P. cf. haydni* differ slightly from typical representatives of *P. haydni* in the ornamentation of the chela, which lacks the diagnostic central ridge-like elevation composed of tubercles (see MÜLLER 1984, p. 61, pl. 26, fig. 4).

The specimens of *Xantho moldavicus* from Maksymivka (see Pl. 2, Figs 5-6) are characterized by extremely wide carapaces, with width/length ratio exceeding 1.7. This ratio agrees well with that of specimens from the same coralgall facies in Moldova reported by JANAKEVICH (1969a, p. 27). However, the width/length ratio of specimens from both Maksymivka and Moldova (see Text-fig. 8) is markedly higher than in specimens from the other Middle Miocene crab-bearing localities in the Central Paratethys (Węglińek and Grobie in Poland, Budapest area in Hungary; see MÜLLER 1984, 1996) and in the Western Mediterranean (Olérdola in Catalonia, Spain; see MÜLLER 1984, p. 20, fig. 10A, B). The diversity in shape and ornamentation of *X. moldavicus* from various Middle Miocene localities of Europe was emphasised by MÜLLER (1984, 1993, 1996).

It is noteworthy that the most common crab species, *Daira speciosa*, is represented almost exclusively by carapaces (see Pl. 2, Figs 3-4), which are commonly found accumulations of several specimens in shell-grit-filled crevices between algal thalli (see Pl. 3). It is uncertain whether such accumulations are just accidental (? depositional), or whether they are the 'kitchen-middens' (cf. RADWAŃSKI 1977b, p. 253 and pl. 11a-b) of unknown predators, or whether they represent carapaces discarded during moulting in a sheltered site. The latter suggestion that the crabs moulted preferentially in such sheltered sites such as buildup crevices, other cavities and emptied burrows, follows the interpretation applied recently to some Cambrian – Devonian trilobites (see SPEYER & BRETT 1985, p. 95; CHATTERTON & al. 2003).

Of the decapod assemblage studied, four genera (*Galathea* FABRICIUS, 1793, *Petrolisthes* STIMPSON, 1858, *Chlorodiella* RATHBUN, 1897, and *Daira* DE HAAN, 1833), are considered by MÜLLER (1984) to be typical dwellers of coral reefs, whereas two other genera, *Xantho* LEACH, 1804, and *Pilumnus* LEACH, 1815, are regarded as inhabitants of extremely shallow-water habitats, with an "inhomogenous, partly hard substrate" (see MÜLLER 1984). These characteristics agree well with the inferred environment of Maksymivka buildups where the stable bottom was composed of algal thalli interlaced with holes and crevices.

The crabs present in the coralgall facies of Maksymivka were reported from numerous organic buildups of Middle Miocene age, both from the Paratethys, e.g., from Hungary (see LÖRENTHEY & BEURLEN 1929, MÜLLER 1984), Romania (MARINESCU

1965), and Poland (see FÖRSTER 1979, MÜLLER 1996, GÓRKA 2002), and from the Western Mediterranean (reef complexes of Catalonia in Spain; see MÜLLER 1993). The same genera were also reported from the Eocene coral-bearing deposits of Hungary (see MÜLLER & COLLINS 1991), Late Miocene (Messinian) coral reefs of Algeria (see SAINT MARTIN & MÜLLER 1988), and from the Pleistocene and Pliocene of the Ryukyu Islands, Japan (see KARASAWA 2000). Moreover, many of the genera discussed are typical of the present-day tropical/subtropical Indo-Pacific bioprovince (see JANAKEVICH 1969a, FÖRSTER 1979, MÜLLER 1979).

ECHINOIDS

The echinoid assemblage from the Maksymivka section, well represented within the coralgall buildups, differs markedly from other echinoid assemblages known from the Middle Miocene (Badenian) of the Fore-Carpathian Basin, both in Poland (see RADWAŃSKI & WYSOCKA 2004, KROH 2005) and in Ukraine (see SZÖRÉNYI 1953, RADWAŃSKI & WYSOCKA 2001). The assemblage is composed solely of cidaroids and brissid spatangoids.

Cidaroids

The cidaroids are represented by test pieces (see Pl. 4, Figs 1-2 and 8) and fragmented primary spines (see Text-fig. 9) of a single species, *Eucidaris zeamays* (SISMONDA, 1842). Some of the specimens bear very well preserved ambulacral columns. According to the observations of U. RADWAŃSKA (personal communication), the presence of nonconjugate P1-isopores along the whole ambulacral column indicates efficient gaseous exchange by tubefeet, and a consequently higher water

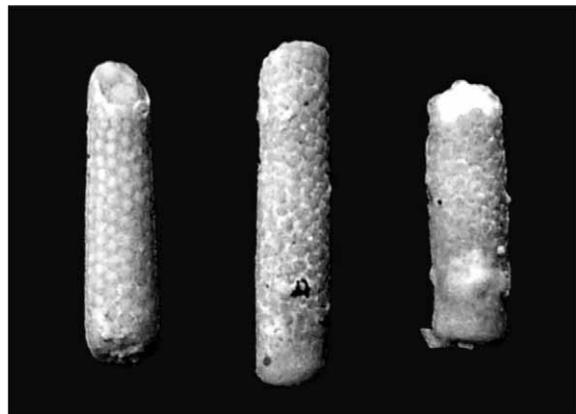


Fig. 9. *Eucidaris zeamays* (SISMONDA, 1842): broken fragments of poorly preserved primary spines; $\times 5$

temperature (cf. also SMITH 1978). The absence of the suckered discs of tubefeet associated with such pores indicates a preference for low-energy habitats because of the impossibility of adhering firmly to the substrate. Such forms could have favoured an almost cryptic mode of life, in cavern-like cavities amidst corals, sponges, algae or other objects hampering the action of strong waves. It can be inferred that the representatives of *E. zeamays* in Maksymivka were adapted to live in a very shallow zone, probably over-heated due to insolation, amidst buildups forming locally sheltered habitats protected from waves.

Any cidaroid test, even fragments, in the Fore-Carpathian Basin is a rarity, the cidaroids being represented mostly by isolated spines of uncertain taxonomic assignment (see SZÖRÉNYI 1953, KROH 2003, pp. 158-159; 2005, pp. 6-8). However, we actually have complete coronas of *E. zeamays* (Pl. 4, Figs 2 and 8) from the locality Sakhkamin near Kamianets Podilskyi, southeast of the study area.

The extant genus *Euclidaris* POMEL, 1883, is known as typically tropical/subtropical (see FELL 1966, p. U335; PHILIPPE 1998; KROH 2003, 2005; SCHULTZ 2005). Its present-day representatives live wedged tightly in rock crevices, including hermatypic corals, being thus well protected from storm action (see HENDLER & *al.* 1995, pp. 206-208; SCHULTZ 2005, pp. 36-41).

Brissid spatangoids

The brissid spatangoids represented in our material (see Pl. 4, Figs 3-7 and 9) are very close to, or identical with the present-day cosmopolitan species *Brissus unicolor* (LESKE, 1778), which is known from various warm-temperate to subtropical/tropical habitats (see MORTENSEN 1951). Although rare, it is particularly characteristic of the Caribbean (see FISHER 1966, pp. U582-U583; HENDLER 1977; HENDLER & *al.* 1995; DONOVAN & HARPER 2000), eastern Atlantic, and the Mediterranean (see STRENGER 1963, WIRTZ & DEBELIUS 2003). It lives usually buried in sand (see STRENGER 1963, WIRTZ & DEBELIUS 2003), although in the Caribbean it is also known "buried in sand-filled pockets in reef rock" (HENDLER & *al.* 1995, p. 243). The latter case is apparently the typical habitat of specimens from Maksymivka. Their habitat is also similar to that of the two recent, closely related and large-sized (140-150 mm) species, *Brissus agassizi* DÖDERLEIN, 1885, and *Brissus latecarinatus* (LESKE, 1778), living along Australian shores (see MISKELLY 2002, pp. 132-135). The specimens in Maksymivka are thought to have favoured habitats of coarser sediments (shell-grit) in which they burrowed, supposedly to a depth of about 15-20 centimetres.

The taxonomy of the material from Maksymivka

remains unclear. The recent specimens of *B. unicolor* are characterised by the two anterior petals (LOVÉN's II and IV) oriented backwards, lying at an angle of 180-190° counted anteriorly, and by the posterior petals (LOVÉN's I and V) at an angle of less than 45° (see FISCHER 1966, fig. 469/1a; HENDLER & *al.* 1995, p. 242). The Miocene specimens from the Vienna Basin were referred to *Brissus abeli* (REIDL, 1941) or *Brissus miocaenicus* SCHAFFER, 1961, based on their frontal petals being arched anteriorly at an angle of 170° or less (see REIDL 1941, SCHAFFER 1961, KROH 2005). However, the latter feature is also displayed by recent representatives of *B. unicolor* from the Azores (see WIRTZ & DEBELIUS 2003, photo on p. 261), and from the Black Sea (present authors' own collection). Consequently, it seems reasonable to refer the Maksymivka specimens simply to *B. unicolor* and, further, to regard *B. abeli* sensu REIDL (1941) and KROH (2005), and *B. miocaenicus*, as its younger synonyms.

The size (length) of the Maksymivka specimens, varying between 56 and 65 mm, slightly exceeds that typical of the Austrian specimens (see KROH 2005). The recent specimens of this species may even reach 127 mm (5 inches) or more, as noted by MORTENSEN (1951, p. 512: 135×100×65 mm) and more recently by HENDLER & *al.* (1995, p. 242).

In the Miocene of Europe, apart from the Vienna Basin, the representatives of the genus *Brissus* GRAY, 1825, have hitherto been recorded from the Rhône Basin in France (see LAMBERT 1915, PHILIPPE 1998), and from the Ukrainian part of the Fore-Carpathian Depression. A specimen from the latter area (from the Zbarazh section), referred by SZÖRÉNYI (1953, pl. 4, figs 5, 5a, 5b) to "*Brissus jacquementi* LAMBERT, 1915" was interpreted by KROH (2005, p. 169) as a juvenile or subadult specimen of *Brissus abeli* (REIDL, 1941).

The relatively high abundance of *B. unicolor* at Maksymivka is certainly due to the peculiar facies, which is rare or not represented in other European Miocene basins, but compares well with that reported by HENDLER & *al.* (1995, p. 243) from the present-day Caribbean coral reefs.

At Maksymivka, the individuals of *B. unicolor* are thought to have lived in 'pockets' and crevices in, or amidst, the coralgall buildups, burrowing and then buried in the bioclastic detritus with which these pockets are filled. The tests of some specimens are still empty (see Pl. 4, Figs 6-7), indicating the burial of live specimens (see ASLIN 1968, SMITH 1984, RADWAŃSKA 1999, RADWAŃSKI & WYSOCKA 2001), particularly because the spine canopy is detectable in the adhering compact rock. The other tests are either filled completely, or in a very peculiar way, having been largely filled geopetally with fine-grained shell-grit, above which much coarser grit accumulated (see Pl.

4, Fig. 9); this is interpreted as a result of partial damage of the geopetally-filled test, allowing the coarser material to subsequently penetrate through the resultant hole.

ENVIRONMENT AND AGE

The coralgal facies of Maksymivka is characterized by its complex structure and the ubiquity of its biota. The invertebrate content is typified by the occurrence of hermatypic corals, crustacean decapods (squat lobsters, crabs, evidence of the life activity of alpheid shrimps), and echinoids, all of which indicate open-marine conditions, with water of normal salinity. The same conditions are apparent for other facies, particularly sandy ones, of the whole Lviv-Ternopil region, from where diverse corals (see DEMBIŃSKA-RÓŹKOWSKA 1932), brachiopods (see DREGER 1889; FRIEDBERG 1921; RADWAŃSKA & RADWAŃSKI 1984, p. 260), echinoids (see SZÖRÉNYI 1953, RADWAŃSKI & WYSOCKA 2001), starfish (see KUDRIN 1957a, RADWAŃSKI & WYSOCKA 2001), sharks and dolphins (see KUDRIN 1957a,b) have long been noted. Such faunal diversity of open-marine elements in the Polish part of the Fore-Carpathian Depression is typical of all the facies classified into the single lithostratigraphic unit distinguished as the Lower Opolian (see RADWAŃSKI 1969, 1977b), which corresponds to calcareous nannoplankton zone NN5/NN6, or the Langhian/Serravallian boundary beds in the geochronologic scale (see MARTINI 1977, BAŁUK & RADWAŃSKI 1977). Within the Middle Miocene framework, this interval falls clearly into the Badenian Stage, but its exact position within the stage remains unclear. Based upon foraminiferal research, this unit should be placed in the Early Badenian according to Austrian authors (RÖGL & BRANDSTÄTTER 1993, HARZHAUSER & *al.* 2003, KROH 2005), although the boundary beds indicated (NN5/NN6, or Langhian/Serravallian) are placed much higher, in the Middle and/or Upper Badenian (see HARZHAUSER & *al.* 2003, fig. 2; KROH 2005, Table 1).

Nevertheless, in the Polish part of the Fore-Carpathian Depression the identical faunal content of an open-marine, normal salinity environment is constant throughout all regions over which the Middle Miocene (Badenian) transgression progressed. The high diversity faunal assemblages contained in facies ranging from clays (locality Korytnica, see BAŁUK & RADWAŃSKI 1977) and sands (localities Męczennice, Nawodzice, Świniary, Huta Lubycka; see RADWAŃSKI 1970, RADWAŃSKI & WYSOCKA 2004) to pure limestones (of the '*Leithakalk*' type at Pińczów; see RADWAŃSKI 1965b, CZYŻEWSKA & RADWAŃSKI 1991), always indicate open-marine conditions, with evident oceanic influx from the Indo-Pacific

bioprovince (see also RADWAŃSKI 1974; FÖRSTER 1979; MÜLLER 1979; HOFFMAN 1979; RADWAŃSKA 1992, pp. 319-321). It is thus reasonable to regard the facies and their organic communities in Ukraine as developed in the same realm established at the beginning of the Middle Miocene (Badenian) transgression. Consequently, both the coralgal facies studied and other facies with an open-marine fauna in Ukraine (see KUDRIN 1957a,b, 1966; GORECKI 1957; RADWAŃSKI & WYSOCKA 2001) are correlated with those in Poland and regarded herein as generally coeval, as traditionally treated by previous authors (ŁOMNICKI 1897a, b; DEMBIŃSKA-RÓŹKOWSKA 1932; FRIEDBERG 1934, 1936; RADWAŃSKI 1977b). However, a slight temporal shift cannot be excluded, in view of the fact that the transgression spread progressively eastward from the Vienna Basin, through Moravia, to Poland (see RADWAŃSKI 1977b, BAŁUK & RADWAŃSKI 1977). In any case, this had to take place within the framework of Badenian time, at the mid-Miocene climatic optimum, and prior to the Badenian evaporitic crisis (see HARZHAUSER & *al.* 2003) involving a drop of sea level (demise of seaways, evaporation and gypsum formation), after which the open-marine oceanic fauna of tropical/subtropical Indo-Pacific affinities never returned to the Fore-Carpathian Basin.

The environmental conditions under which the Maksymivka sequence formed are interpreted as extremely shallow-marine, often influenced by high-energy water dynamics. This is apparent from the structure of the coralgal buildups, as well as from the evidence of the activity of boring bivalves and burrowing alpheid shrimps. Also instructive is the taxonomic composition of the hermatypic coral fauna, and the state of preservation of the coral colonies.

The shapes of the coral colonies evidence a high-energy environment, resulting from low water depths and a stable bottom. In addition, the low taxonomic diversity of the coral assemblage shows great similarity with various shallow-marine Miocene coral reefs of the Tethys and Paratethys (see FRIEBE 1991, 1993; ESTEBAN & *al.* 1996; HAYWARD & *al.* 1996; BUDD & *al.* 1996; MÜLLER 1996; RIEGL & PILLER 2000; TSAPARAS & MARCOPOULOU-DIACANTONI 2005), particularly with the patch reef reported (GÓRKA 2002) from Grobie near Busko-Spa (see Text-fig. 1), on the southern slopes of the Holy Cross Mountains. Moreover, the predominance of *Porites vindobonarum prima* (KÜHN, 1927) within the coral assemblage of Maksymivka strongly suggests an input of suspended fine-grained sediment, probably of back-reef origin, into the core-reef area (see MÜLLER 1984, MCCALL & *al.* 1994, ESTEBAN 1996, TSAPARAS & MARCOPOULOU-DIACANTONI 2005). The ubiquitous presence of borings of bivalves (*Jouannetia*, *Lithophaga*),

as well as the reworking of some of the coral colonies, clearly indicate extremely shallow peritidal depths, comparable to those inferred for the similarly preserved colonial corals in Early Kimmeridgian oyster shell-beds from the Holy Cross Mountains (see RADWAŃSKI & RONIEWICZ 2005). It is also noteworthy that, in the Korytnica Basin, the hermatypic corals, mostly *Tarbellastraea reussiana* (MILNE-EDWARDS & HAIME, 1850) and *Porites* sp., appeared during gradual shallowing when the depth had dropped from several metres to almost nil (see BAŁUK & RADWAŃSKI 1977, 1984).

Also informative in the interpretation of the environmental conditions of the Maksymivka sequence is the occurrence of such coral associates as the squat lobster *Galathea* and the echinoid *Eucidaris*, the present-day representatives of which live among littoral rubble and/or coral crevices where they hide by daytime.

The high-energy dynamics of the Maksymivka environment was probably caused by storm agitation, tidal or pseudotidal waves, or bursts of land-borne winds. The dynamic events were thus dependant on weather conditions. Physical stress at low-water stands (e.g., at extreme ebbs; see HENDLER 1977) could have been another factor inducing the mortality of many biota, notably the echinoids (see discussion in RADWAŃSKI & WYSOCKA 2001). Only some of the vagile invertebrates are thought to have been buried during life (*in vivo*): echinoids with the spine canopy preserved in the adherent rock, but with empty tests. Partial carapaces of crabs are regarded as moults, most of the echinoid tests or their fragments are destitute of spines. It is assumed that during rough weather all the habitats were destroyed and that, apart from the rare live specimens, all the crab remains, echinoid corpses and abundant shell-grit were swept together into the buildup holes and/or alpheid burrows, which served then as taphonomic and/or preservational traps.

The regional extent of the coralgal facies, unique in Paratethys basins, cannot yet be determined precisely. It extends over an area of several square kilometres that includes Zbarazh, Maksymivka and Haluschyntsi, where it is exposed. (see Text-fig. 2). Its farther extension along the Medobory Hills may be detected to the southeast as far as Moldova (see KUDRIN 1966, fig. 17; JANAKEVICH 1969b, 1977; PISERA 1996; JASIONOWSKI & *al.* 2005).

Further research is required to establish the vertical succession of environmental conditions that obtained throughout the time when the peritidal lithosome of Maksymivka was formed. Were these more or less persistent during the gradual onlap of the Middle Miocene (Badenian) transgression, or did the 20-metre thickness of the lithosome result from regional subsidence, with which the accumulation of buildups and associated detrital material (shell-grit) kept pace?

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PLATE 1

Rock-boring and squatting bivalves from the coralgall buildups of Maksymivka,
and a comparative specimen from Haluschyntsi

- 1 – Field photo, to show a hollow after dissolution of *Porites* colony; $\times 0.4$
- 2 – *Jouannetia semicaudata* DESMOULINS, 1828; internal mould of the shell in the boring within *Porites* colony: side view (**2a**), to show a fragment of *Porites*, and bottom view (**2b**), to show another nearby boring, broken-off; both $\times 2$
- 3 – *Lithophaga lithophaga* (LINNAEUS, 1758); internal mould of the shell completely filled; $\times 1.5$
- 4-5 – *Lithophaga lithophaga* (LINNAEUS, 1758); internal moulds of shells, filled geopetally (oblique photos, geopetal filling outlined); both $\times 1.5$
- 6 – *Sphenia anatina* (BASTEROT, 1825) preserved in a posteriorly broken mould of a *Lithophaga lithophaga* boring: **6a** – outer view of the mould of the boring, **6b-b'** – the same mould, after breaking with a hammer, to expose an external mould of the shell of *Sphenia anatina* (BASTEROT, 1825) which lived as a squatter in the emptied *Lithophaga lithophaga* boring; taken $\times 1.5$
- 7 – *Jouannetia semicaudata* DESMOULINS, 1828; internal mould of the shell, in two oblique views (**7a**, **7b**), to show geopetal filling (outlined), $\times 2$; Haluschyntsi

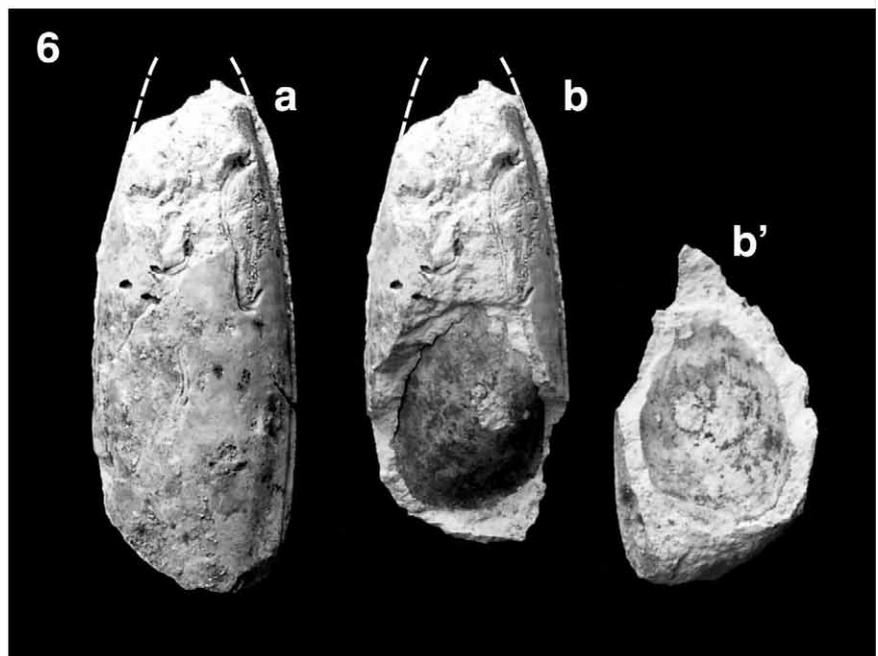
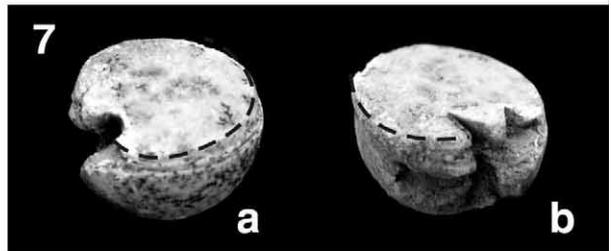
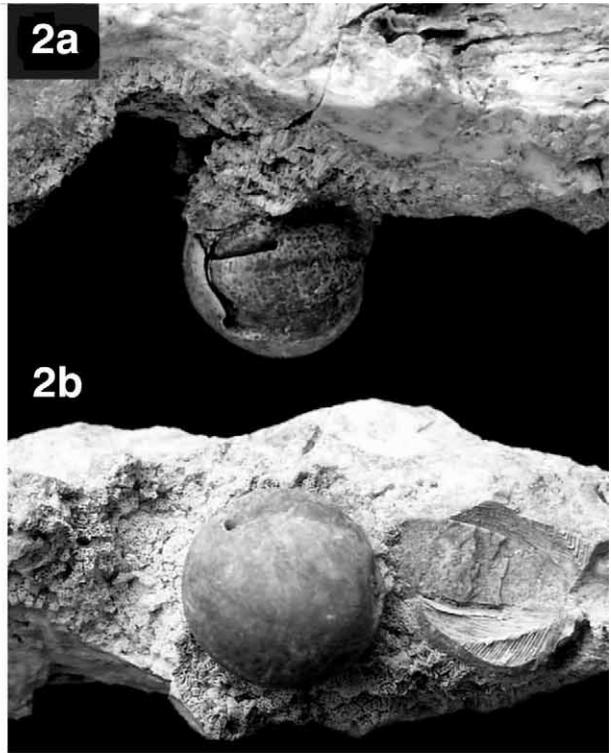
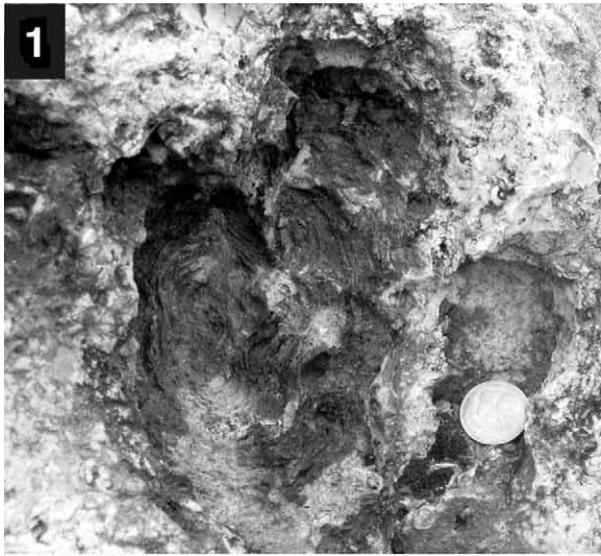


PLATE 2

Crustacean decapods (1 – squat lobster, 2-7 – crabs) from the coralgall buildups of Maksymivka

- 1 – *Galathea weinfurteri* BACHMAYER, 1950; carapace, $\times 5$
- 2 – *Petrolisthes magnus* MÜLLER, 1984, left palm with dactylus: a – inner surface, b – outer surface; both $\times 1.5$
- 3 – *Daira speciosa* (REUSS, 1871); right propodus with carpus, $\times 2.5$
- 4 – *Daira speciosa* (REUSS, 1871), carapace: a – dorsal view, b – frontal view; both $\times 2.5$
- 5 – *Xantho moldavicus* (JANAKEVICH, 1977), carapace: a – dorsal view, b – frontal view; both $\times 2.5$
- 6 – *Xantho moldavicus* (JANAKEVICH, 1977); large carapace, $\times 2.5$
- 7 – *Pilumnus mediterraneus* (LÖRENTHEY, 1897), carapace: a – dorsal view, b – frontal view; both $\times 2.5$

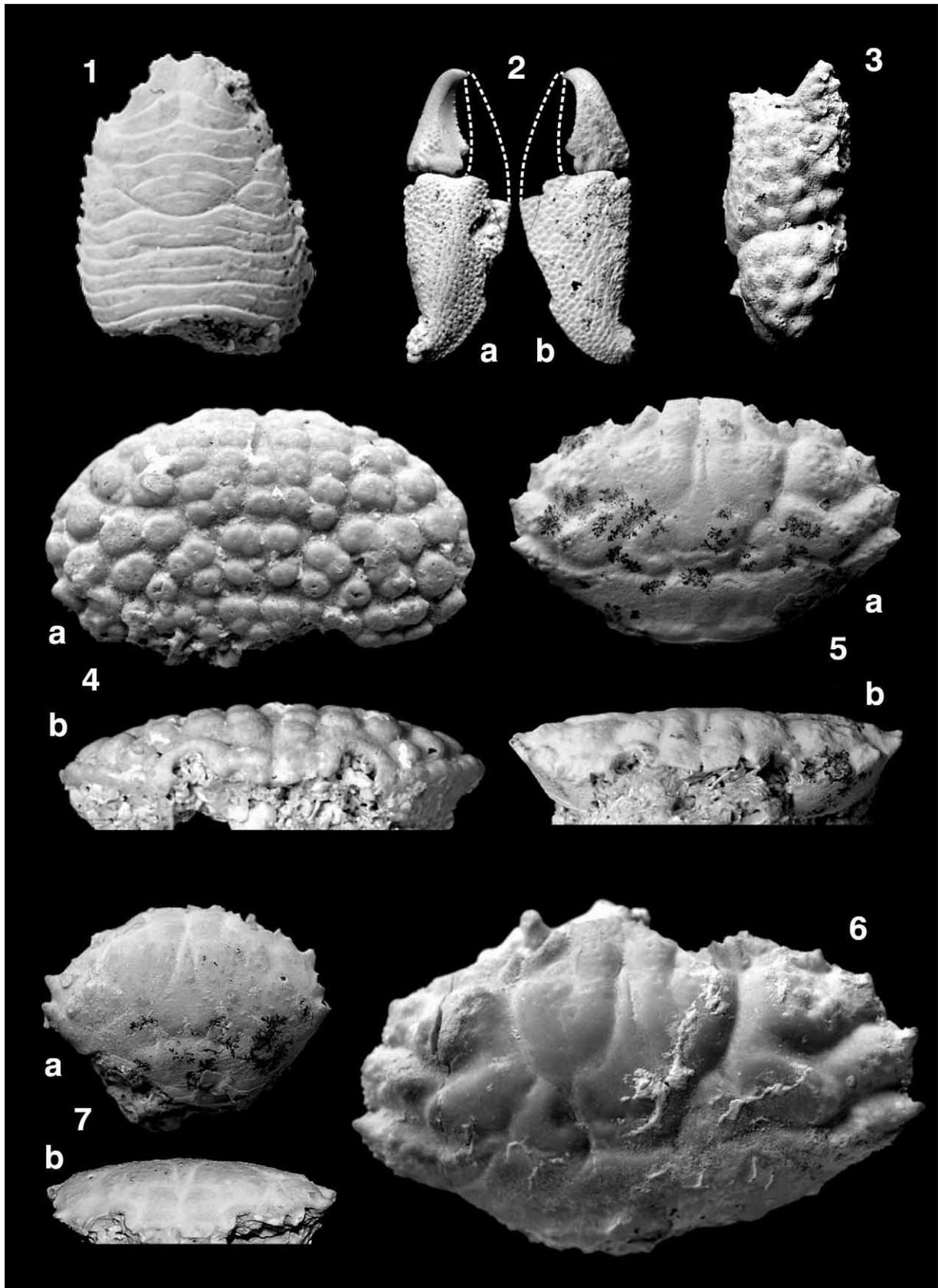


PLATE 3

Mass accumulation of moults of the crab *Daira speciosa* (REUSS, 1871) at Maksymivka in shell-grit of a buildup hole (? alpheid burrow), into which they were swept by a high-energy agent (? storm agitation); field photo, × 2



PLATE 4

Diversity and taphonomy of echinoids from the Middle Miocene (Badenian) coralgall facies of Ukraine

- 1 – *Eucidaris zeamays* (SISMONDA, 1842): interambulacral column with two adjacent ambulacra, $\times 3$; Maksymivka
- 2 – *Eucidaris zeamays* (SISMONDA, 1842): oblique view, to show the best preserved part of corona (**2a**), and top view, to show the outline of corona (**2b**); both $\times 2$; Sakhkamin
- 3-5 – *Brissus unicolor* (LESKE, 1778): aboral views, to show the extent of peripetalous fasciole, nat. size; Figs 3 and 5 from Maksymivka, Fig. 4 from Haluschintsy
- 6-7 – Field views, to show empty tests of *Brissus unicolor* (LESKE, 1778) exposed in buildup crevices at Maksymivka; about nat. size; in Fig. 7 the test lies upside-down
- 8 – Geopetally, half-filled test of *Eucidaris zeamays* (SISMONDA, 1842), $\times 1.5$; Sakhkamin
- 9 – Geopetally, partially filled test of *Brissus unicolor* (LESKE, 1778), the upper part of which, after breakage, has been filled with coarser shell-grit; nat. size, Maksymivka

