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Sedimentary record of eustatic changes on the Givetian (Devonian) carbonate platform of Małopolska Massif, southern Poland

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ABSTRACT:

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The Givetian carbonate succession of the Mzurów 49-BN borehole, SW part of the Małopolska Massif, has been divided into three lithological units: set A (*Amphipora* limestones), set B (micritic limestones; subdivided into subsets B_1 and B_2), and set C (peritidal dolomites with evaporites). The sets represent three main depositional facies identified throughout the studied section. The succession corresponds to transgressive-regressive cycles identified in the Kielce region of the Holy Cross Mts, i.e. the northern part of Małopolska Massif. The event correlation is supported by biostratigraphy, based on conodonts and benthic faunas. These data indicate that the studied interval probably belongs to the latest part of the middle and late Givetian (*Klaperina disparilis* Zone to early *Mesotaxis falsiovalis* Zone). Set A represents largely shallow subtidal sediments deposited on an extensive shallow carbonate platform; its facies development shows many similarities to the youngest part of the *Stringocephalus* Beds and Dziewki Limestones. After a transgression in the late Givetian, open-marine micritic limestones (subset B_1) were deposited. Their facies equivalent easily is readily identified as the Jaźwica Member in the southern part of the Holy Cross Mts. A regressive trend is recognized from the beginning of subset B_2. Sea-level fall finally resulted in salinity increase in an isolated shallow-water basin of the Małopolska Massif. In mostly hypersaline conditions, cyclic deposition was developed. Three upward-shallowing metre-scale cycles within set C are recognised, each of them starting with thin calcareous mudstone beds with open marine biota and capped by grey dolomudstone with beds and nodules of gypsum or anhydrite.

Key words: Givetian, Stratigraphy, Conodonts, Małopolska Massif, Eustasy, Carbonate complex.

INTRODUCTION

The occurrence of Devonian rocks in the south-western part of the Małopolska Massif has been proved only in boreholes. The closest occurrence of well known and stratigraphically subdivided Middle Devonian rocks from exposures and boreholes comes from the Holy Cross Mountains, and in the Siewierz-Zawiercie and Dębnik areas.

During the middle Givetian, a shallow-water carbonate platform extended over the investigated area, which formed part of an elongated shelf area trending from the Lublin area through the Holy Cross Mts to Moravia (NARKIEWICZ 1988). Thick stromatoporid-coral series, formed during that time in the southern part of Poland, are distinguished as the *Stringocephalus* Beds in the Holy Cross Mountains (NARKIEWICZ & *al.* 1990), the Dziewki Limestones in the Silesia Region (RACKI & *al*. 1993b) and the Siedlec Limestones in the Cracow area (NARKIEWICZ & RACKI 1984). Distinct drowning of undifferentiated platform in the late Givetian is recognized and biostratigraphically evidenced in the Holy Cross Mts as the marly open shelf Jaźwica Member (RACKI 1993). This unit is of considerable correlative value for the Małopolska succession presented in this paper.

This paper presents the results of a study of core material from the Mzurów 49-BN borehole, situated midway between Żarki and Lelów (Text-fig. 1 A, B), south of Częstochowa, and east of the Kraków-Lubliniec Fault Zone (which forms the boundary between the Małopolska and the Upper Silesian Masssif; BUŁA 1994, 2000; ŻABA 1999).

Devonian strata in the studied borehole are covered by Triassic carbonate sediments. Generally, the Devonian succesion in this part of the Małopolska Massif is covered by thick (200 m to 700 m in the Żarki area) younger sediments. No core has been stratigraphically examined hitherto in this area.

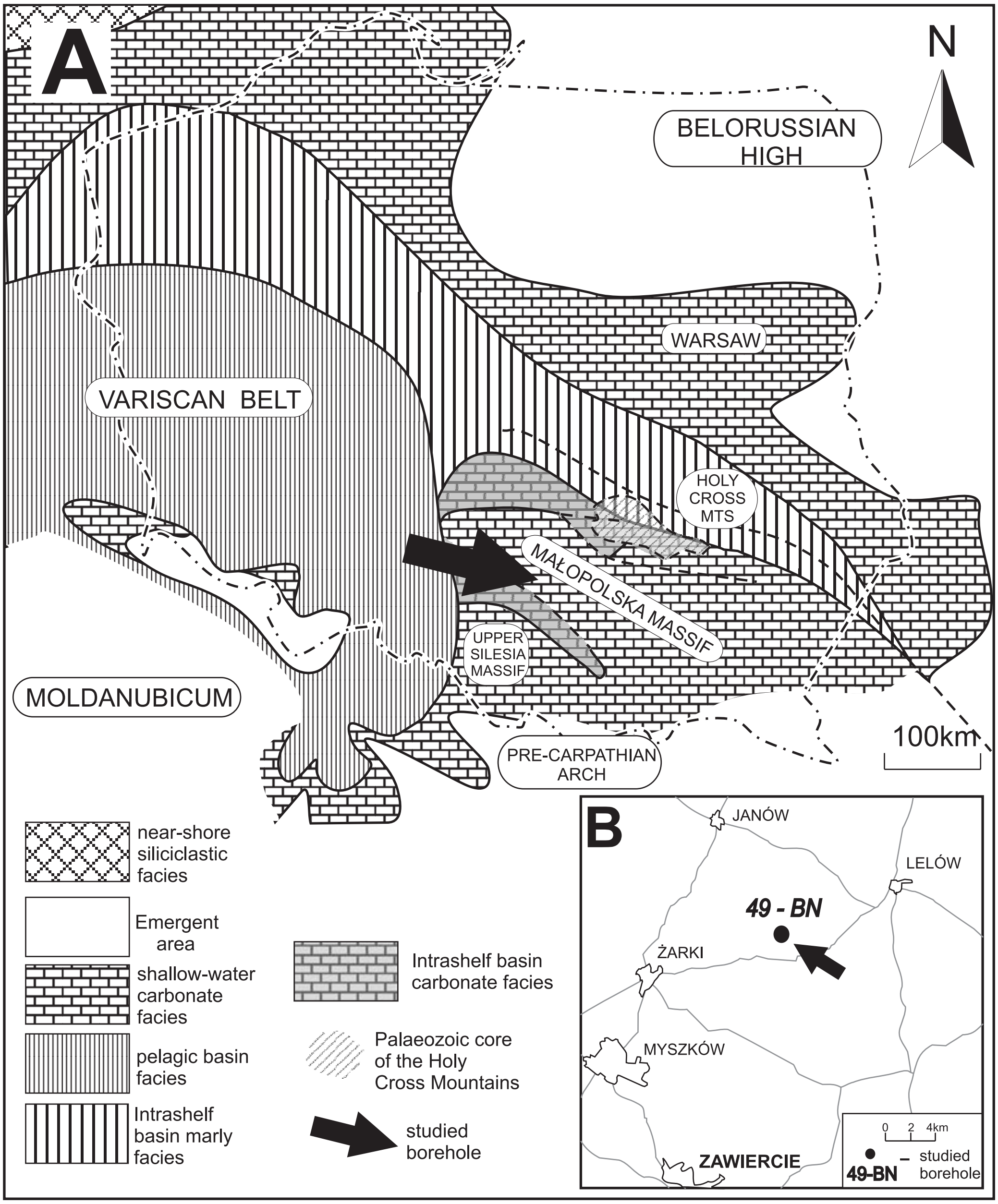

Fig. 1. A. Paleogeographic map of the Middle to Late Devonian in Poland (after RACKI 1993; fig. 1); studied area is arrowed; B. Detailed location of the studied section in Myszków area (after BUŁA 2000; fig. 2)

The present paper presents a stratigraphical examination of the middle to late Givetian carbonate succession from the Mzurów 49-BN borehole, based on conodonts and, partly, on benthic faunas. Faunal assemblages derived mostly from the distinctive late Givetian micritic limestone unit (Set B) are also documented. The stratigraphical and sedimentological record from the studied region allows the identification of eustatic changes and their correlation with the regional sedimentary cycles of Racki (1993) and with the eustatic cycles sensu JOHNSON & *al* (1985). Special attention is paid to the late Givetian transgressive level and the comparison with its reference horizon from the Holy Cross Mts (see RACKI 1993).

Over 60 samples of average weight about 0.5 kilogram from the studied core were collected, and 42 of them have been processed to obtain conodonts and other skeletal fragments. Only 9 samples from sets B and C yielded conodonts. Among 116 platform conodont elements, 17 species have been distinguished (see Table 1). Forty-six thin sections and 4 polished slabs enabled microfacies and petrographic studies.

FACIES AND FAUNAL SUCCESSION

Three sets are distinguished in the Mzurów 49-BN borehole succession (Text-fig. 2), which differ in their main lithofacies characters and fossil contents. They are described below:

Set A - *Amphipora* limestones

Amphipora-rich, wavy- and medium-bedded, mostly fine-grained, dark grey to black limestones with the clay admixture increasing upward (thickness penetrated 20.4 m). Almost the whole of set A is selectively dolomitized, which makes identification of fossils very difficult.

In the basal parts of the set (3 m thick) there are *Amphipora* and *Stachyodes* bafflestones and floatstones (Pl. 1, Fig. 1). The associated fauna is represented by poor assemblage that includes large-sized *Macrochilina* gastropods, some ostracods and abundand calcipheroids (Pl. 1, Fig. 4). Some of the larger bioclasts are coated by thin micrite envelopes in places. Some of the amphiporid colonies are rather thinly-branched in the higher part of the set. This facies is similar to facies L-2 described by RACKI (1993) in the southern Holy Cross Mts.

The thicker part of the unit (16 m) consists of various bioclastic-peloidal wackestones with partly bioturbated matrix and amphiporoid-brachiopod packstones with calcispheroids (Pl. 1, Figs 2-3). In this part of the set, among the *Amphipora* branches, the associated biota include brachiopods, calcispheroids and tubiform microproblematicas from the *Devonoscale-Jansaella* group (see RACKI & SOBOŃ-PODGÓRSKA 1993). In the *Stachyodes*-dominated assemblages, on the other hand, tabulate corals resembling *Platyaxum gracile* LECOMPTE, 1939 constitute a very common element, whereas shelly fauna is rather scarce. The facies is comparable to facies R-1b and R-2b sensu RACKI (1993)

The clay admixture, concentrated as thin irregular interbeds, plays an increasingly significant role upwards throughout the unit. In clay-rich intervals, nodular fabric is frequently marked (Pl. 1, Fig. 3). The uppermost beds contain abundant, diversified benthos of which, apart from amphiporids and *Stachyodes*, the major constituents are ambocoeliid spiriferids [*Ilmenia*(?)], demosponges (abundant spicules in places), echinoderms (mostly crinoids and rarely echinoids), ostracods, rugose corals [probably *Temnophyllum zamkowae* WRZOŁEK, 1993 (see Pl. 1, Fig. 5)], gastropods, and calcispheroids. This facies type is close to facies L-4 of RACKI (1993).

The whole succesion is interbedded with thin-bedded, wavy or nodular marly limestones (Pl. 2, Fig. 5). The nodules or layers consist of bioclastic-peloidal wackestone/packstone. The faunal content is particularly rich in ostracod assemblages including palaeocopids and podocopids (*Samarella*?); other common elements are the crinoid *Cupressocrinites*, eoumphalid gastropods, brachiopods, calcispheroids and abundant worm-like infaunal detritus-feeders. This facies is similar to facies 10D of WILSON (1975). Biostromal horizons of amphiporoid bafflestones, characteristic of lowermost strata, continue in this part of section only as thin intercalations.

Set B – Micritic limestones

Bituminous, even-bedded to nodular, marly limestones with clay-rich thin layers (cm thick) or thicker (up to 20 cm thick) intervals. It is divided into subsets B_1 and B_2 on the basis of different grain components, sedimentary structures and fossil content. The lithofacies of set B and its diverse fossil content are almost identical to those of facies M-3 sensu RACKI (1993).

Subset B_1 Bituminous, well-bedded bioclastic, bioturbated wackestones with frequent marly intercalations (thickness 6.4 m).

The most important grain type of bioturbated wackestones are skeletal fragments; whilst locally fecal pellets are also abundant (Pl. 2, Figs 1-2, 4, 6).

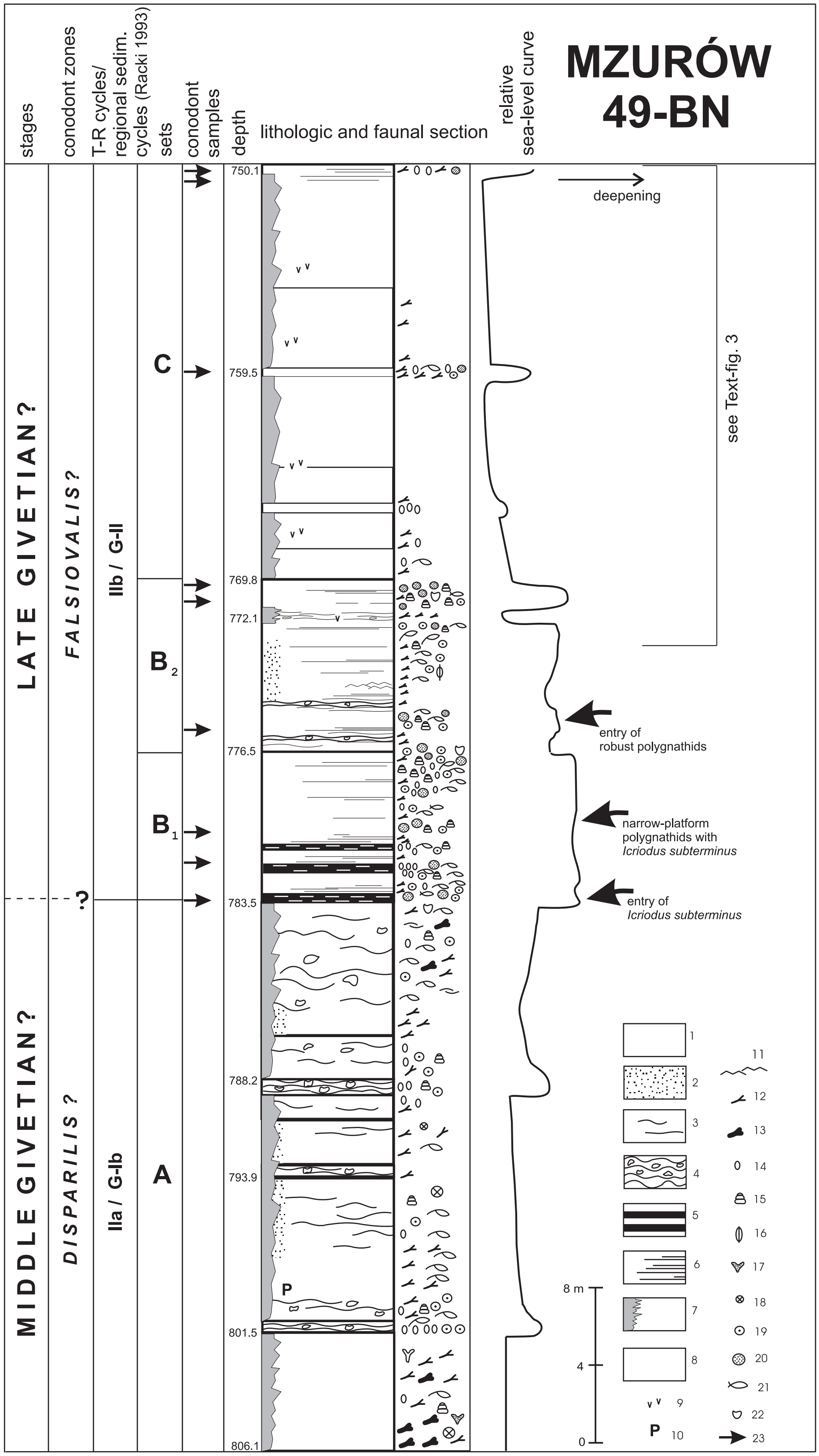

Fig. 2. Lithologic and faunal section of the Mzurów 49-BN borehole on the background of the global eustatic T-R cycles (JOHNSON & *al.* 1985), proposed relative sea-level curve in the studied area and conodont events;
1 - mudstones/wackestones,
2 - packstones/grainstones,
3 - marly wavy intercalations,
4 - wavy-bedded or nodular mudstones/wackestones,
5 - marly shales,
6 - laminated mudstones/wackestones,
7 - dolomitized limestones,
8 - laminites,
9 - evaporites,
10 - porphyries,
11 - cross-beddings,
12 - Amphipora,
13 - Stachyodes,
14 - ostracods,
15 - gastropods,
16 - bivalves,
17 - branched tabulates,
18 - branched Rugosa,
19 - crinoids,
20 - non-pelmatozoan Echinodermata,
21 - ichthyoliths,
22 - sponge spicules,
23 - conodont samples

Rhythmically-marked marly intercalations within the wackestones occur in changing proportions. They range from 20 cm thick beds of laminated marly limestone or marly shale in the basal part of the unit to mm-thick laminae in the upper part. Thin wavy or nodular layers are observed in some places. In the upper part of the unit, there occur three macrofossil-poor mudstone intervals with a few, thin (1 cm), black irregular layers or lenses of cherts. The mudstones of the whole of set B yield a very rich, mostly benthic fauna, which is very well preserved and commonly silicified. The community is represented by sessile suspension-feeding and vagile epibenthos, commonly dominated by echinoderms. The lower part of the unit is marked by relatively thick shaly intercalations (up to 20 cm) containing a particularly abundant fossil assemblage. It consists mostly of ostracods, the tiny ambocoeliid *Crurispina inflata* (SCHNUR, 1853), microcornids, echinoderms and rare euomphalid gastropods. Ostracods constitute an important group (even dominating in the lowermost marly intercalations), and they are represented by Platycopida (with common *Uchtowia refrathensis* KROMMELBEIN, 1954 and *Cavellina*), Palaeocopida (*Amphissites remesi* POKORNY, 1950, *Buregia* and *Pribylites*), and Podocopida. Echinoderms are the most important benthos, including crinoids, echinoids, asterozoans, holothurians, ophiocystoids and cyclocystoids. Crinoid columnals, occurring throughout the interval, are of very low diversity. The association is dominated by *Schyschcatocrinus delicatus* GŁUCHOWSKI, 1993, occurring together with *Cupressocrinites* adapted to muddy substrate, and rare *Ricebocrinus parvus* GŁUCHOWSKI, 1993. Vagile non-pelmatozoan echinoderms are very numerous and relatively diverse. The most important, occuring in rock-forming quantities, is the asterozoan *Furcaster cataphractus* BOCZAROWSKI, 2001. The second important group are the echinoids, with *Albertechinus devonicus* BOCZAROWSKI, 2001 present in all samples. Holothurians are dominated by *Eocaudina septaliformis* MARTIN, 1952 and *Achistrum multiperforatum* BECKMANN, 1965. Among cyclocystoids, *Concavocycloides givetiensis* BOCZAROWSKI, 2001 occurs, while the ophiocystoids comprise *Protocaudina dulcis* BOCZAROWSKI, 2001 and *Linguaserra lingula* LANGER, 1991. An additional significant element in these late Givetian deeper-water shelly-echinoderm biotas are demosponges, recorded as common monaxons (see HURCEWICZ 1993). They are the source of silica for the chert lenses in the spicule-rich micrite horizons in the middle of set B. Strata of the same age from the neighbouring Cracow-Silesia region and the Holy Cross Mountains area are barren of spicular chert layers, in contrast (see RACKI 1993; KARWOWSKI & *al* 1993). The presence of fish remains (teeth and scales), conodonts (see below), bryozoans and chitinozoans is also noteworthy.

Subset B_2 Bituminous, finely laminated mudstones to packstones, partly with nodular fabric (thickness 5.9 m).

This subset is formed of medium to thin-bedded marly mudstones to packstones with mostly preserved subtle lamination. Nodular intercalation and wavy beds of peloidal wackestone are present as well. Some of the packstone partings are occasionally characterized by small-scale cross-bedding. In the upper part of the subset, there is a distinctive laminated dolomite bed (0.5 m thick) with anhydrite nodules. The components in this interval range from bioclasts, cortoids, aggregate grains to lithoclasts. Generally, the contribution of bioclasts is lower than in subset B_1, and their composition has changed (see below). The very top of the set (almost 1.7 m) consists of bioturbated bioclastic-peletoidal wackestones with shelly fauna, similar to those of subset B_1.

Noticeable impoverishment of the open marine fauna is evident. Ostracods are scarce, brachiopods become more significant (ambocoeliids and atrypids), gastropods such as murchisonids and neritopsids are only locally common. Rarely occur rugosan *Disphyllum wirbelauense bonae* RÓŻKOWSKA & FEDOROWSKI, 1972 (Pl. 2, Fig. 3) and foraminifera *Nanicella*. *Ricebocrinus*, usually connected with reef complexes (GŁUCHOWSKI, 1993), is recorded frequently in the crinoid assemblages. Non-pelmatozoan echinoderms include sparse to abundant holothurians, associated with gastropods, bivalves, and, in places, with tubiform microproblematicas. *Amphipora* and, sporadically, *Stachyodes* are common in marly or nodular layers. Extremely numerous are varieties of irregularly tabular microproblematicas from the *Devonoscale-Jansaella* group, and the activity of infaunal detritus-feeders is recorded as burrowings and bioturbation.

Set C – Cyclic peritidal dolomites with evaporites

Thin-bedded, mostly wavy-laminated dolomudstones and lime mudstones, marked partially by nodular fabric as well as by alternating light grey and dark laminae of mm to dm in thickness. The presence of evaporites (anhydrite and gypsum) as laminae, nodules or beds (up to cm thick) is an important feature (Text-fig. 3; Pl. 3, Figs 1-7).

The following lithotypes are distinguished, partly corresponding to microfacies (MF) of BOULVAIN & PREAT (1987) and PREAT & MAMET (1989) from the Givetian of the Ardennes:

- Anhydrite-free, unfossiliferous dolomudstones.
- Dark grey to black lime mudstones to packstones, laminated or interbedded with light lenticular and wavy dolomudstones. *Amphipora* branches, ostracods and bioturbations occur, and also isolated, fine laths of anhydrite may rarely be present (Pl. 3, Figs 4, 6). This facies corresponds to microfacies MF 9.
- Interlaminated dolomudstone and anhydrite. Very fine wavy or lenticular layers of dolomitic peloidal wackestone/packstone and sporadic burrowed mudstone alternating with thin laminae of anhydrite may correspond to microfacies MF 12 (Pl. 3, Figs 1, 3). Thin lenses of anhydrite or thin beds and nodules of evaporites are very common in the upper part of the set (Pl. 3, Fig. 5). The deposits are disturbed in places by microfolds or contortions (Pl. 3, Fig. 2). The uppermost beds contain light grey planar laminite composed of weakly dolomitized mudstone or peletoidal packstone and anhydrite (Pl. 3, Fig. 3) as well as thin beds or nodules of gypsum or anhydrite. A few thin, bituminous marly intercalations with burrows and rare fossils such as *Amphipora*, ostracods, echinoderms and conodonts occur only in a single bed.
- Unfossilliferous, grey to brownish, homogeneous or slightly very finely laminated dolomudstone with thick layers (up to 5 cm) or nodules of gypsum or anhydrite. It may be interbedded with partings of fine anhydrite laminae. It corresponds to microfacies type MF 13.
- Polymict solution-collapse breccias (1m thick). These contain angular clasts of gypsum or anhydrite (up to 5 cm size) and light grey homogeneous or finely laminated dolomudstone.
- Dolomitized (or dedolomitized) and neomorphozed grainstone with *Amphipora* and other indeterminate skeletal grains.

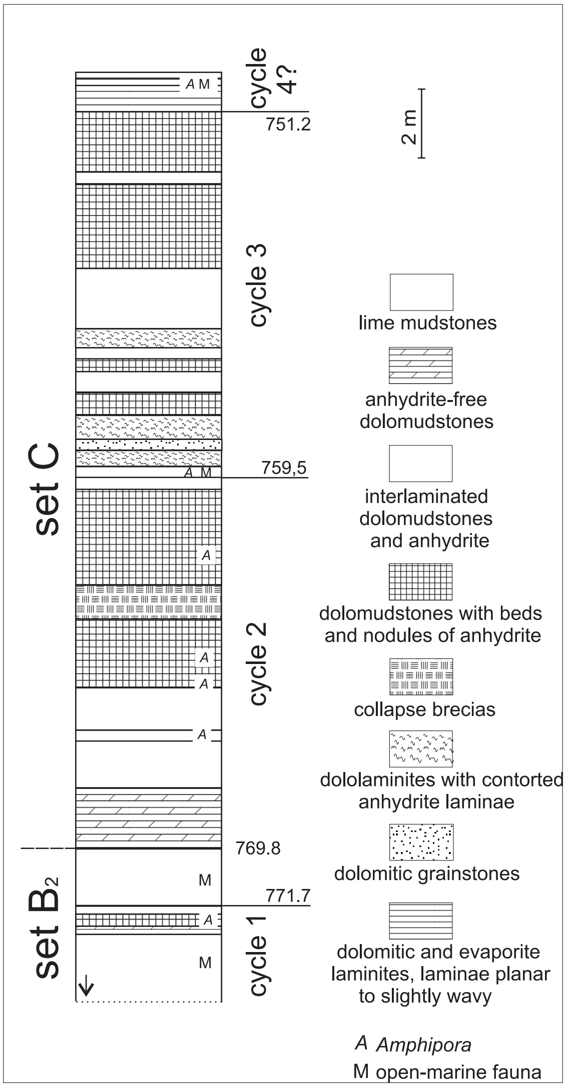

Fig. 3. Shallowing upward evaporite cyclic succession of the Mzurów 49-BN borehole (set C; see Text-fig. 2)

BIOSTRATIGRAPHY

Five samples from the whole cored interval have been processed to obtain palynological data. Unfortunately, all proved to be negative due to the high thermal maturity level. The conodonts are therefore the only important group of correlative value, albeit occurring as an impoverished polygnathid biofacies (Tab. 1), which is not very useful for dating (RACKI 1980, 1993; KLAPPER & JOHNSON 1990; UYENO & *al.* 1998). The stratigraphically oldest conodont-bearing sample came from the boundary beds of sets A and B (783.5 depth) and contains an association dominated by *Icriodus subterminus* YOUNGQUIST, 1945, with subordinate *Mehlina gradata* YOUNGQUIST, 1945 (Text-fig. 2; Pl. 4, Figs 1-5). The two higher samples from set B1 (see Text-fig. 2 and Table 1) are enriched in narrow-platform species, especially *Polygnathus pollocki* DRUCE, 1976 (Pl. 4, Figs 6-8). An analogous association, dominated by *I. subterminus* and *P. pollocki*, was described from the Holy Cross Mts from the boundary between the *Stringocephalus* Beds and the Jaźwica Member by RACKI (1993). The *I. subterminus* fauna similarly appears together with the facies changeover in the Mzurów 49-BN borehole. The base of the Jaźwica Member is dated to the *Klapperina disparilis-Mesotaxis falsiovalis* time interval, and indicates the late Givetian transgressive pulse. In fact, the first appearance of *I. subterminus* is suggested to provide evidence of the Early *falsiovalis* Zone according to the zonal scheme of BULTYNCK (1996). The *I. subterminus* Fauna of North

Conodont zone		*disparilis – falsiovalis*							
		Set B_1			Set B_2			Set C	
Depth (m)	783,5	781,1	779,4	775,0	771,0	770,2	759,9	751,2	751,4
Polygnathus aff. *xylus*			2			1			
Po. alatus		1	4	1		2			
Po. pollocki		16	6	1	1	2		1	
Po. decorosus			3			2	1		2
*Po.*aff. *pseudoxylus*		4	4			3			
Po. aff. *denisbriceae*		3	2			1			
Po. dubius				1cf		2	6		2
Po. foliatus			1?				6		3
Po. incompletus									1
Po. webbi			1?						1
Po. angustidiscus			1						
Polygnathus sp.A *sensu* Racki (1993)							6		
Polygnathus sp.									2
Icriodus subterminus	5	7	5				1		
Ic. expansus			2	1					
Ic. brevis	1			1					
Mehlina gradata	2								
Mehlina sp.	1								
Total number of specimens	9	31	31	4	1	13	21	1	11
sample weight (kg)	0,7	0,5	0,7	0,7	0,6	0,5	0,5	0,5	0,5

Tab. 1. Conodont distribution and frequency in the Mzurów 49-BN borehole

America, however, correlates with the *K. disparilis* Zone (WITZKE & *al*. 1988, see also UYENO 1998).

Subsets B_2 and Set C yield more robust polygnathids while icriodontids are very rare. Single occurrences of such forms as *P. webbi* STAUFFER, 1938 in Set C and *P. angustidiscus* YOUNGQUIST, 1945 in Subset B_1 may indicate a position close to the Givetian/Frasnian boundary (see RACKI 1993).

Well-preserved ostracods are recorded in a single sample from Subset B_2 (777.3 depth). *Uchtowia refrathensis* KROMMELBEIN, 1954, known from the late Givetian of Pomerania, Bashkiria and the late Givetian – early Frasnian of Germany (MALEC & RACKI 1993), is the predominant species.

The non-pelmatozoan echinoderm assemblage contains species typical of the open marine late Givetian environment. *Eocaudina septaliformis* MARTIN and *Albertechinus devonicus* BOCZAROWSKI, 2001 are known from the late Givetian of the Holy Cross Mts, the United States and Germany (BOCZAROWSKI 2001).

Rugose corals from Subset B_2 are represented by *Disphyllum wirbelauense bonae* RÓŻKOWSKA & FEDOROWSKI, 1972, known from the early Frasnian and ?the latest Givetian of the SW Holy Cross Mts; the uppermost strata of set A, in contrast, contain branches of *Temnophyllum zamkowae* WRZOŁEK, 1993, a species that occurs in the topmost *Stringocephalus* Beds and lower Sitkówka Beds of the Holy Cross Mts (WRZOŁEK 1993).

The *Crurispina*-microcornid assemblage, recognized above the *Stringocephalus*-bearing strata in the Holy Cross Mts and in the Siewierz area (RACKI 1993; RACKI & *al*. 1993), compares well with the benthic assemblage from set B. Thus, its appearance coincided with the late Givetian transgressive event.

In summary, although the dating is not very precise, the faunal evidence indicates that set B belongs to the *Klapperina disparilis - Mesotaxis falsiovalis* zones.

ENVIRONMENTAL INTERPRETATION

The carbonate succession of the Mzurów 49-BN borehole reveals cyclic sedimentation which resulted from relative sea-level fluctuations. The cyclicity is observed as changes in faunal composition and lithologic alteration throughout the whole section. Three main biota and depositional regimes have been recognized for the studied carbonate complex of the Malopolska Massif (see RACKI 1993).

Biostromal facies

The basal unit (set A) represents a sequence deposited on a shallow, lagoonal shelf with the gradual onset of open marine conditions. The depositional environment ranges from *Amphipora*-meadow shoals, near-turbulent *Stachyodes*-tabulata marginal shoals, to brachiopod-demosponge-echinoderm biota that colonized the quieter intershoal areas. The cyclically appearing and upward increasing clayey admixture reflects open marine condition where a homogeneous bottom community flourished.

Particular subfacies are repeated many times forming cyclic sequences typical of shallow settings due to laterally migrating shoals within the lagoon (READ 1973; RACKI 1993; RACKI & *al* 1993b; SŁUPIK 1993). The depositional environment of the lowermost strata of the Mzurów 49-BN borehole, is interpreted as a very shallow, quiet lagoonal-peritidal environment of a weakly differentiated carbonate platform, behind the high energy margin (see RACKI 1993; SKOMPSKI & SZULCZEWSKI 2000). Stratigraphically younger beds of Set A contain a more diverse brachiopod-demospongid fauna that lived in the subturbulent to quiet water habitat of the intershoal area on the initially drowned platform.

This unit, thus, is developed as lagoonal biostromes composed of various assemblages, controlled by the influence of the open-marine environment. The water depth for these lithofacies is estimated between only a few metres under fully aerobic conditions, as shown by the presence of micritic envelopes, to subtidal depth, where the nodular limestone lithofacies formed in relatively deeper water during periodic rises in sea level (e.g. BURCHETTE 1981; NARKIEWICZ 1978).

Open-shelf facies

The micritic-marly set B corresponds to an open shelf depositional environment, certainly below wave base, where quiet sedimentation took place. The most open marine conditions are interpreted for the bottom of the unit, where a number of shaly, bituminous intercalations (up to 20 cm) occur. This part of the unit (B1) reflects a quiet, deeper environment colonized by homogeneous low-diversity, high-abundance faunal assemblages. An abundant but, in anyone taxonomical group, weakly diversified level-bottom community certainly thrived in an open-shelf environment on a soft, muddy substrate. Specialized biotas comprise small-sized, thin-valved (in case of the shelly faunas) benthic organisms. Weak influences of the adjoining shallower lagoonal environment are evident throughout the set, as shown by redeposited *Amphipora* branches. Thus, the setting must be in close proximity to the marginal shoals.

Although the limestones of set B are strongly bituminous, near-bottom waters were at most dysoxic, as evidenced by extensive infaunal activity. On the other hand, the small sizes and low diversity of the main biotic components, and the occurrence of layers without or with low bioturbation and partly preserved subtle lamination may indicate periodic anoxic conditions. The above characters could be due to a very high rate of supply of organic matter to the sea floor, resulting in reducing conditions within the surface sediments (CALVERT & *al*. 1996). Moreover, deposition of the organic-rich, laminated shelly layers might have been a result of poor basin circulation following rapid sea-level rise.

The deposits of Subset B_2 document a similar facies development, but there are many distinct indications of a shallowing trend starting with this set. A significant faunal impoverishment as well as the coarse-grained and partly cross-bedded nature of the detrital sediment in some beds point to a higher energy shoals environment, intermittently under the influence of tidal currents. Such an environment appears to have been inhospitable for benthic biota; it became partially colonised by *Stachyodes* and rugosan thickets and stabilised by microbial communities.

Conodont biofacies interpretation is based on rather poor material (rarely up to 20 elements per 0.5 kg of a sample), but, on the other hand, such a low frequency is typical of the Givetian polygnathid and polygnathid-icriodontid biofacies known from shallow-water carbonate facies (RACKI 1993, UYENO 1998). The *I. subterminus* fauna, which is of value in correlation, is characteristic of basinal – outer shelf conodont biofacies (WITZKE & *al*. 1988).

Restricted lagoonal facies

Set C records carbonate sedimentation in a very restricted environment where bathymetric and salinity oscillations are clearly marked. An ecosystem change, involving the almost complete extinction or emigration of open-marine biota, is connected with the boundary between sets B and C. The deeper-water faunal association with conodonts has been noted for only a few thin layers of bituminous lime mudstones, deposited probably in a shallow subtidal environment. A shallowing trend and progressive isolation from an open sea generated a high stress hypersaline environment, which allowed the growth of very impoverished communities only. The sparse fine skeletal material included ostracodes and *Amphipora*, bioturbation was rare. In predominant shallow intertidal to supratidal conditions, sediments were frequently stabilised by growth of microbial mats, while skeletal or trace fossils are not observed. Altogether it suggests inhospitable living conditions even for lagoonal benthic communities.

Sedimentological analysis of Set C sequences reveals the cyclic character of the deposits and indicates shallow subtidal to supratidal environments. Several thin, small-scale cycles, 0.5 to 3 m thick, are recognizable in the interval They are grouped into three more distinct, thick, metres-scale sets of cycles (5-10 m thick), which display an overall shallowing upward character (Text-fig. 3). Thin calcareous mudstone beds or cm-thick laminae with open marine biota represent the earliest stages of each cycle. The succeeding anhydrite-free dolomudstones or laminated calcareous and dolomudstones were certainly formed in an already semi-closed environment, as a pre-evaporitic sequence. The remaining lithologies from set C are characterised by the presence of evaporites. The most common lithology, microbial lamination with a lenticular and wavy appearance, certainly indicates a shallow water zone within an intertidal to supratidal environment (PRATT & *al.* 1991; PREAT & RACKI 1993; SKOMPSKI & SZULCZEWSKI 2000). All the microfacies types were formed in a very restricted environment, episodically subaerially exposed. Common features are microfolds, anhydrite nodules and anhydrite laminae contortions, which were formed during displacive anhydrite growth between microbial mats (JIN & BERGMAN 1999). Each cycle is capped by a thick series of grey and brownish dolomudstones with large nodules, thicker beds of gypsum or anhydrite containing collapse breccias. Sporadic desiccation-cracks indicate episodes of superficial drying out. Lenticular gypsum crystals forming mm-sized 'gypsum mush' layers (Pl. 3, Fig. 7) within the sediment are related to subaerially exposed saline mud flats around supratidal flats or coastal sabkhas (KENDALL 1991). There is a notable absence of features indicative of tidal or wave activity.

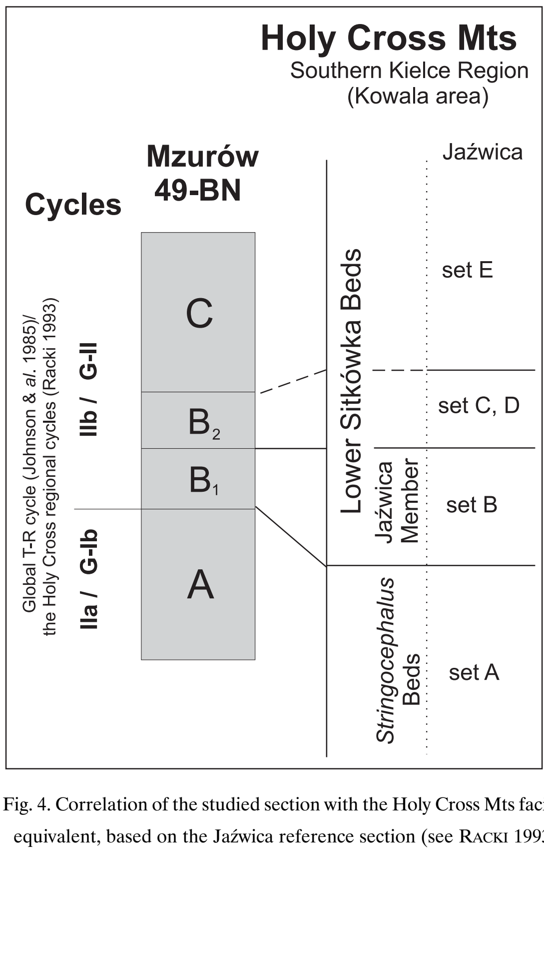

Fig. 4. Correlation of the studied section with the Holy Cross Mts facies equivalent, based on the Jaźwica reference section (see RACKI 1993)

Apart from the uppermost strata, Set C is characterised by the dark grey to black colour of the sediment, brownish anhydrite laminae, which are probably due to the presence of pyrite (as evidenced in thin-sections). That, in turn, suggests anoxic bottom conditions in salinity-controlled stratified water (see JIN & BERGMAN 1999), an environment also recognized in Eifelian peritidal dolostones in the Holy Cros Mts by NARKIEWICZ (1991) and MARYNOWSKI & *al.* (2000).

REGIONAL CORRELATION

The facies types and faunal assemblages from the SW Małopolska Massif show many similarities to those recognized in the SW part of the Holy Cross Mts by RACKI (1993). This concerns especially data obtained from set B, which provides a frame of reference for the stratigraphical interpretations (Text-fig. 4).

The most comparable units, Set B from the Mzurów 49-BN borehole and the Jaźwica Member contain an almost identical benthos inventory typical of an open shelf habitat with normal salinity where periodically changes of water depth within a generally shallowing upward trend were pronounced (see RACKI 1993).

The level-bottom community described herein is very close to the Bolechowice-type benthic biota from the Holy Cross Mts. In particular, the ostracod association resembles that from the Bolechowice facies (with dominant species *Uchtowia refrathensis*), characteristic of the Jaźwica Member correlated with regional cycle G-II in the southern part of the Holy Cross Mts. (MALEC & RACKI 1993).

Echinoderms, known from late Givetian open shelf facies from the SW-part of the Holy Cross Mts (Bolechowice and Posłowice facies); (GŁUCHOWSKI 1993, BOCZAROWSKI 2001) and the Silesia – Cracow Region (GŁUCHOWSKI 1993), are very similar to those found in the Mzurów 49-BN borehole. Particular echinoids (especially *Albertechinus*) and holothurians are common both in the studied section and in the Jaźwica Member. The same similarities are found with other echinoderms, ambocoeliid brachiopods (*Crurispina inflata*), rugosans and conodonts. The conodont fauna with *Icriodus subterminus* has been recognised in the Holy Cross Mts above the shallow-water biostromal complex of the *Stringocephalus* Beds (RACKI 1993), and indicates the late Givetian sea-level rise (cycle IIb of JOHNSON & *al*. 1985). This level corresponds to the base of the Jaźwica Member of the Kowala Formation (NARKIEWICZ & *al*. 1990). In conclusion, the interval studied reflects maximum drowning of the Givetian shallow biostromal platform during the late Givetian T-R cycle IIb (see Text-figs 2 and 4).

Comparable units from the Cracow - Silesia area are rarely precisely dated. However, some analogies in facies development are shown by micritic limestone from the Zawiercie – Olkusz area (NARKIEWICZ 1978), marly limestones from the Sosnowiec IG-1 borehole (set F) (FISHER 1995), organodetrital limestones from the RK-14 borehole (MIGASZEWSKI & TARNOWSKA 1989), and, partly, by nodular crinoid biomicrite from the Klucze 1 borehole.

Analogies concerning the older unit (Set A) are also evident. Although this part is dolomitized precluding certain dating and positive fossils identification, the facies development and faunal assemblages compare well with the youngest part of the middle Givetian biostromal *Stringocephalus* Beds in the Holy Cross Mts, and its stratigraphical equivalent (Dziewki Limestones and Siedlec Limestones) in the Cracow – Silesia Region (RACKI & *al*. 1993b; NARKIEWICZ & Racki 1984). The whole succession probably corresponds, then, to the late phases of the T-R cycle IIa of JOHNSON & *al*. (1985) and regional cycle G-Ib from the Holy Cross Mts (RACKI 1993).

The regressive set C reveals a surprisingly quite different facies development in comparison to other late Givetian sections from Poland. The only known evaporite facies come from the Radom - Lublin area (MIŁACZEWSKI 1981). In the Holy Cross Mts, set C may be partly comparable with the southern Kielce region, where a shallowing setting during cycle IIb is shown as non-fenestral laminites (Zamkowa Hill, set D; see Racki 1993) or as a rhythmic amphiporid/microbial lagoonal suite, e. g. Jaźwica set E (RACKI 1993, see also SKOMPSKI & SZULCZEWSKI 2000), preceded by *Hexagonaria* and *Stachyodes* - *Disphyllum* boundstones.

The new facies data from the SW Małopolska Massif confirm the model of the vast Givetian carbonate platform in southern Poland (see NARKIEWICZ 1988; NARKIEWICZ & *al*. 1990; RACKI 1993).

CONCLUSIONS

1) Three lithological units are recognized in the Devonian carbonate interval of the Mzurów 49-BN borehole: *Amphipora* limestones (set A), micritic limestones (set B) and cyclic peritidal dolomites with evaporites (set C) referred to the uppermost part of the middle and upper Givetian (most probably *Klapperina disparilis* to *Mesotaxix falsiovalis* zone passage). The stratigraphic distribution of lithofacies and faunas follow a cyclic pattern related to sea-level fluctuation, with the depositional environment varying from a protected, mostly hypersaline, lagoon to an open-shelf. This succession most resembles the depositional scheme described from the Holy Cross Mts (RACKI 1993).
2) A shallow carbonate platform extended in the middle Givetian over the studied SW area of the Malopolska Massif, which confirms the concept of a uniform carbonate shelf in southern Poland (NARKIEWICZ & RACKI 1985). A facies equivalent of the micritic limestones unit (set B) is found in the southern part of the Holy Cross Mts as the Jaźwica Member; some analogies in facies development are also shown by the sections from the Silesian-Cracow region (e.g. FISHER 1995), which unfortunately, are not precisely dated. There are also many similarities in facies development between set A and the correlative youngest part of the *Stringocephalus* Beds and the Dziewki Limestones.
3) Set C, appearing as a distinctive local unit, supplies new data concerning the facies characteristics of the middle to late Devonian carbonate complex of southern Poland. It reflects a protected lagoonal hypersaline environment and represents a cyclic evaporite sequence. The known uppermost Givetian strata from Holy Cross Mts, developed as lagoonal deposits, do not show any signs of an increased rate of evaporation. Furthermore, an even more humid climate is suggested for this time interval (RACKI 1993; see also FRAKES & *al*. 1992). On the other hand, late Givetian evaporite facies from eastern Poland (Radom-Lublin area; MIŁACZEWSKI 1981), that continue to Lvov area and farther eastward to the Russian Platform (SOROKIN 1978), indicate arid conditions. Also PREAT and CARLIEZ (1996) point to a semi-arid climate in the late Givetian for the Dinant Basin (France, Belgium). One may suggest a regionally more differentiated carbonate platform. In such a case, on the outer shelf of Malopolska domain (Text-fig. 1A), the existence of efficient barriers, restricting circulation, might have caused an elevation of salinity during the sea level fall in the latest Givetian.
4) Part of the regional T-R cycle coeval with eustatic cycle IIb of JOHNSON & *al*. (1985) is recognized, with a well defined record of the transgressive phase (the upper part of set A and the lower part of set B1) and the regressive phase (set B_2 and C). Thus, the late Givetian basal IIb transgression was a significant drowning event over the whole S-Poland carbonate shelf.

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PLATES 1 – 4

PLATE 1

Biostromal facies of the set A and B2; Givetian of the Mzurów 49-BN borehole

1 – *Amphipora* bafflestone with large *Macrochilina* gastropod shell, and *Amphipora* floatstone in the upper part of the photo, sample 804.2 m.

2-4 – Amphiporid-brachiopod-calcispheroid wackestones, locally with marly layers or nodular structure (**3**), and peloidal packstone partings with calcispheroids (**4**), samples 800.3 m and 786.5 m; A – *Amphipora*, B – brachiopods.

5 – *Amphipora* wackstone from subset B2, sample 776.4 m.

6 – Brachiopod-spiculitic wackestone to packstone with echinoderms and *Amphipora*; Ru – rugosa, *St* – *Stachyodes*, sample 803.7 m.

scale bar = 1cm except for fig. 4 (1mm), and fig. 5 (0.5 cm)

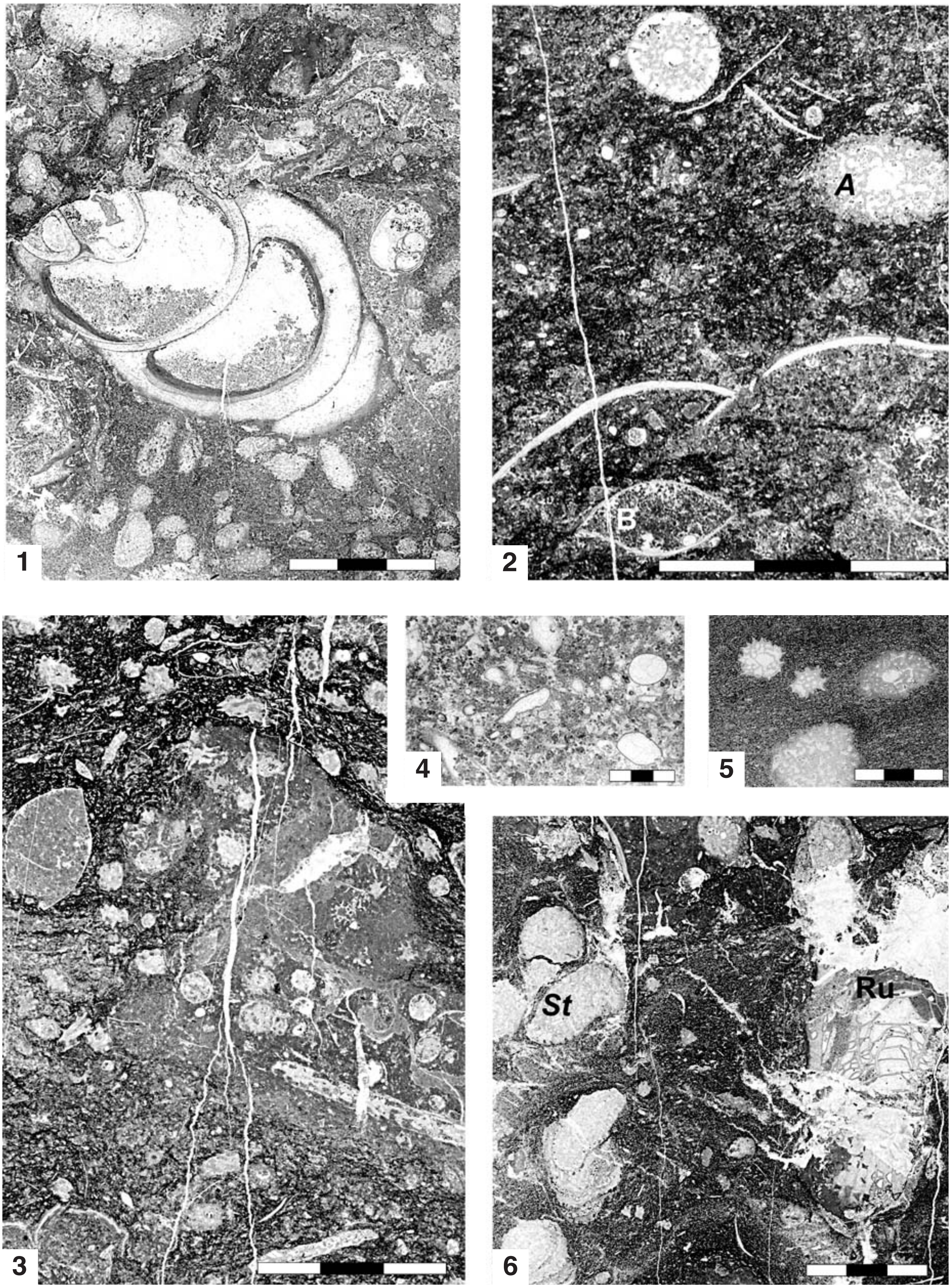
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PLATE 2

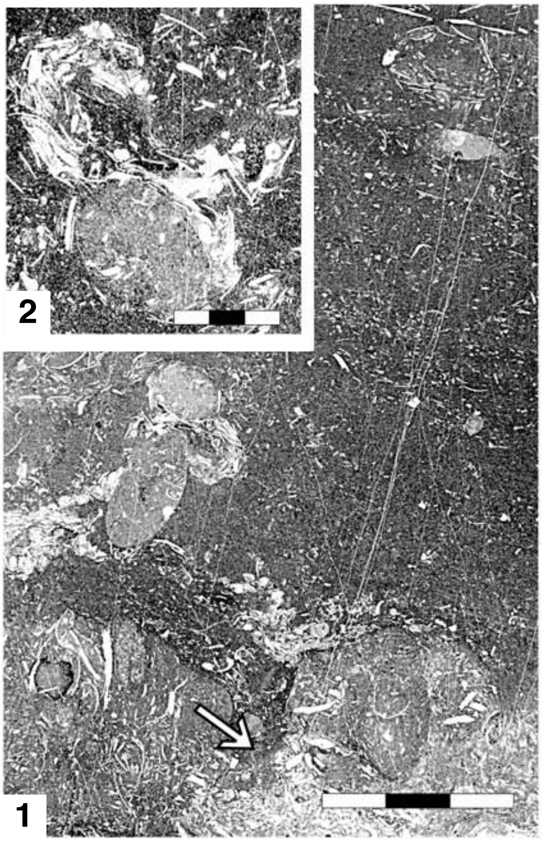
Varieties of marly open-shelf micritic limestones from sets A and B; Givetian of the Mzurów 49-BN

1-2 – Bioturbated wackestone to skeletal packstone (arrowed), sample 781.2 m; set B_1; scale bar = 1cm and 0.5 cm, respectively.

3 – Bioclastic wackestone/packstone with Rugosa and dolomudstone lenses in the upper part of the photo, sample 775.7 m; set B_2; scale bar = 0,5 mm.

4, **6** – Ostracod-brachiopod-gastropod wackestone, sample 781.2 m and 778.7 m; set B_1; scale bar = 1cm.

5 – Nodular variety (ostracod-calcispheroid wackestone/packstone with peloids) from marly layer of set A, sample 800.6 m; scale bar = 1 cm.



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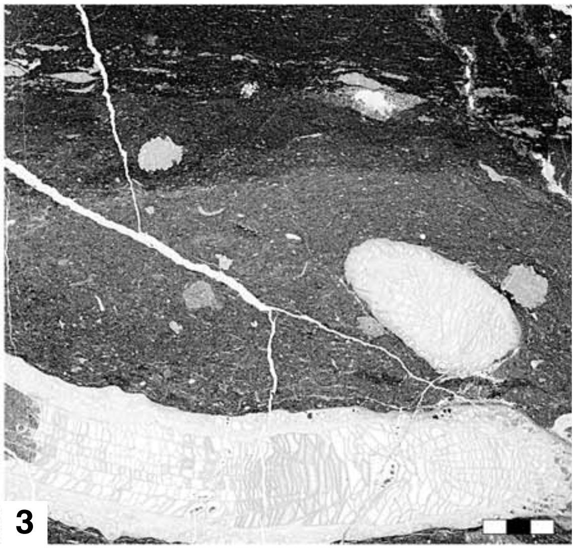

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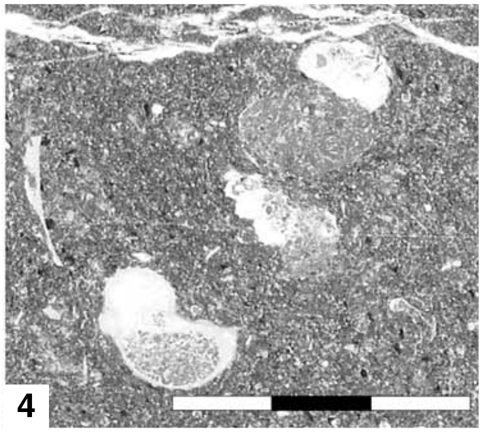

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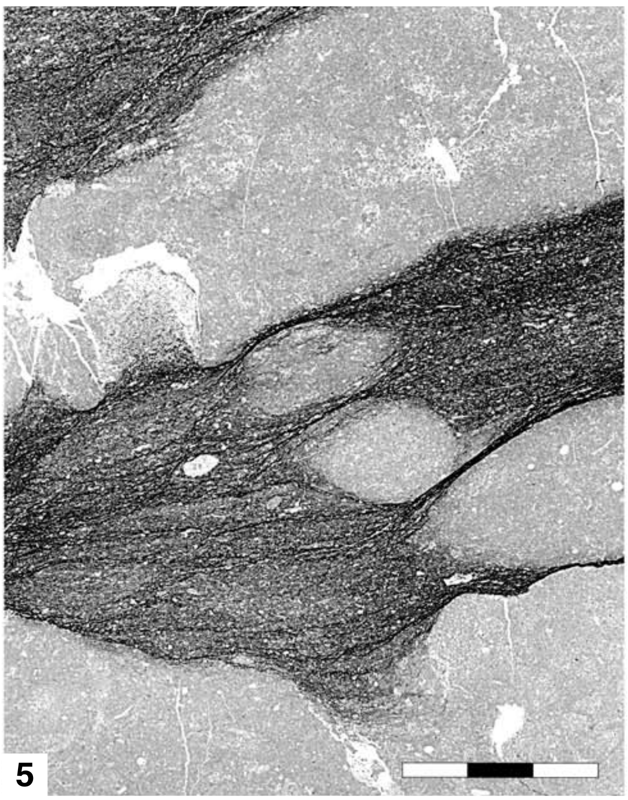

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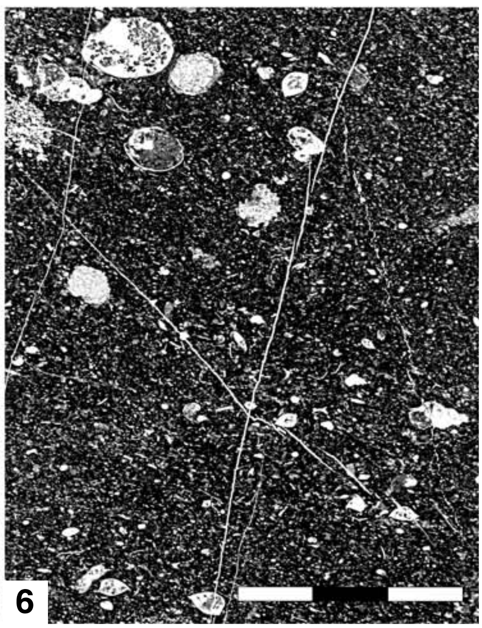

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PLATE 3

Facies types of set C; Givetian of the Mzurów 49-BN borehole

1 – Cryptalgal laminite, sample 765.5 m; thin section, scale bar = 1 cm.

2 – Microfolds and contortions of dolomite and anhydrite laminae, sample 758.0; thin section, scale bar = 1cm.

3 – Dololaminite with anhydrite laminae (darker ones) and mudstone to peloidal packstone laminae (light ones), sample 751.3 m; thin sections, scale bar = 1 cm.

4, **6** – Wavy laminated lime wackstone and dolomudstone, small ostracods and burrows are present, sample 767.8 m; thin section, scale bar = 1 cm and 0.5 cm, respectively.

5 – Dololaminite with gypsum nodule and anhydrite laminae (arrowed) in the upper part of the section, sample 765.3 m; polished section, scale bar = 1 cm.

7 – ‘Gypsum mush’ layer, sample 753.1 m; thin section, scale bar = 1 mm.

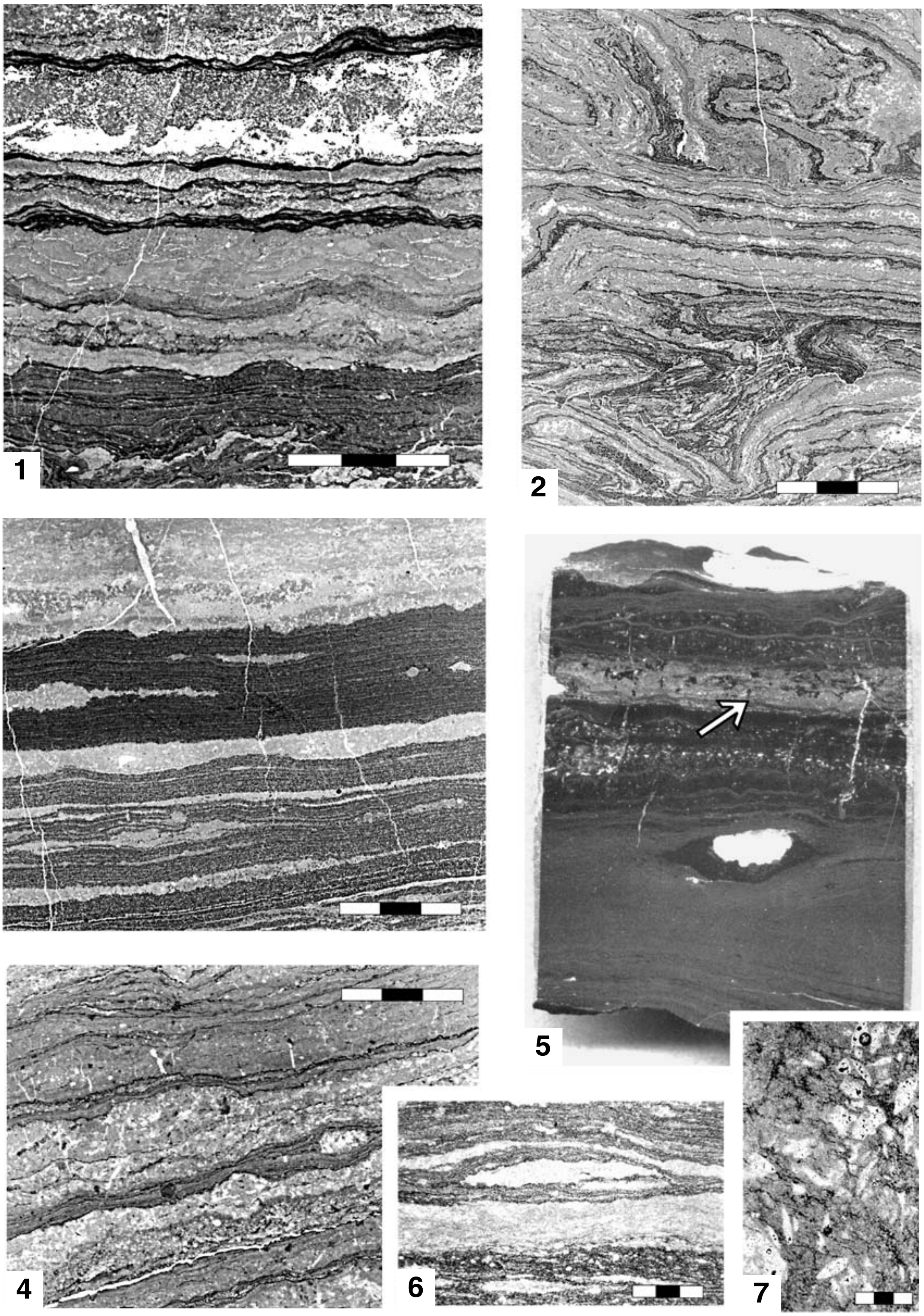
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PLATE 4

Late Givetian conodonts from Mzurów 49-BN

1-4 – *Icriodus subterminus* (YOUNGQUIST 1945), upper (1-3) and lateral (4) view, sample 781.8 m; × 52.

5 – *Mehlina gradata* (YOUNGQUIST 1945), lateral view, sample 783.1 m; × 65.

6-8 – *Polygnathus pollocki* (DRUCE 1976), specimens seem to have wider platform than nominate species, sample 781.8; × 48.

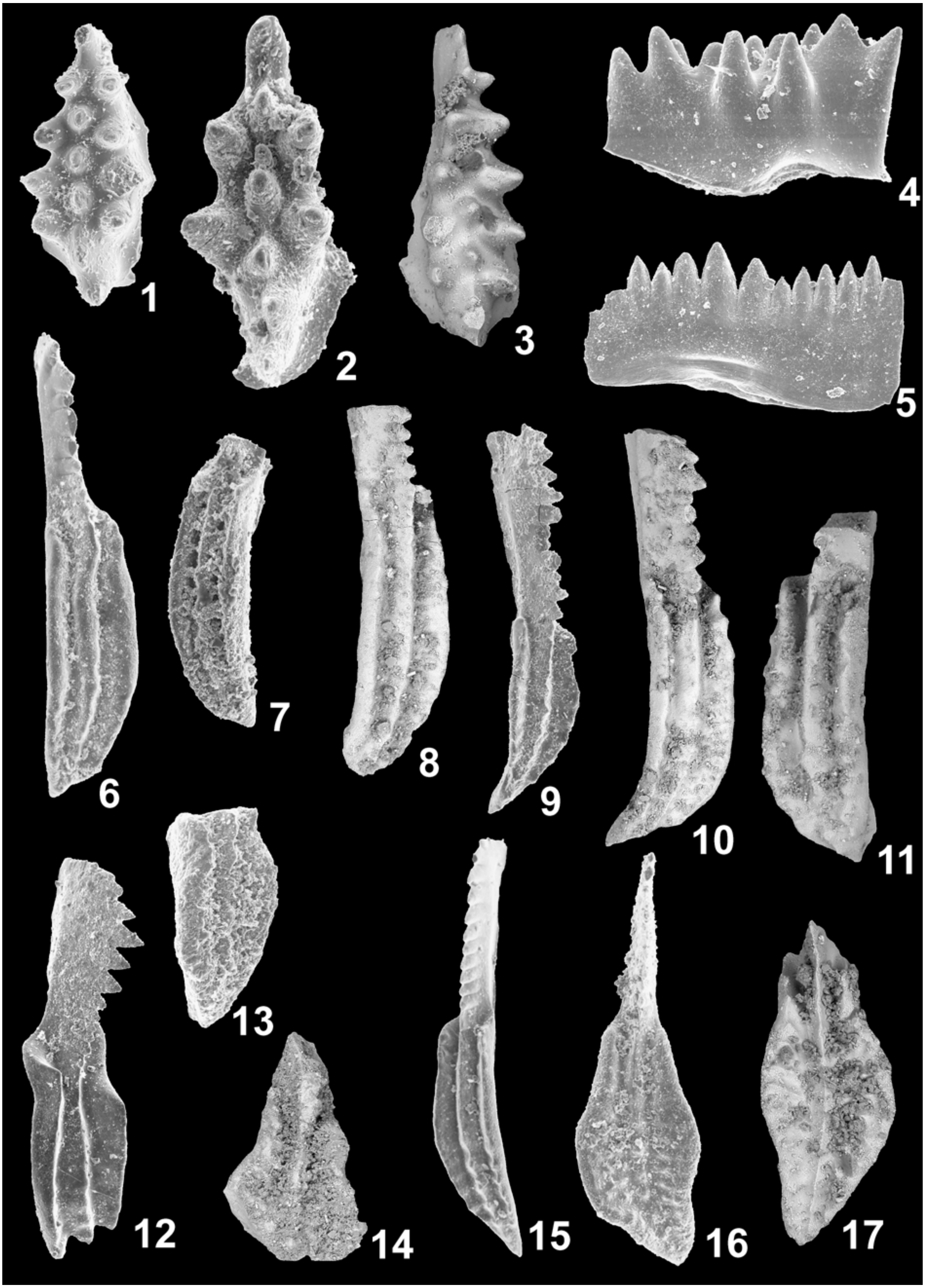
9 – *Polygnathus* aff. *xylus* (STAUFFER 1940), sample 779.4 m × 48.

10-11 – *Polygnathus* aff. *denisbriceae* (BULTYNCK 1979), sample 781.1 m; × 43.

12 – *Polygnathus* cf. *alatus* (HUDDLE 1934), sample 779.4 m; × 43.

15 – *Polygnatus* aff. *pseudoxylus* (KONOVOVA & *al*. 1996), sample 781.8 and 779.4 m; × 48.

13-14, 16-17 – *Polygnathus* sp. A *sensu* RACKI (1993), sample 759.5 m; × 43.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