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THE LATE CRETACEOUS FUCOID MARL OF THE ROPIANKA FORMATION IN THE KĄKOLÓWKA STRUCTURE (SKOLE NAPPE, OUTER CARPATHIANS, POLAND) – LITHOLOGY AND FORAMINIFERAL BIOSTRATIGRAPHY

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Abstract: A 250-m-thick sedimentary succession dominated by siliciclastic deposits occurs in the Kąkolówka Structure of the Skole Nappe. The succession was deposited in the inner part of the Skole Basin during the Late Cretaceous. In position and age, it corresponds to the Kropivnik Fucoid Marl of the Wiar Member (a subdivision of the Ropianka Formation), which was comprehensively described in the external part of the Skole Nappe. In this study, the authors provide the first complete data set on the lithological development and biostratigraphy of the Kropivnik Fucoid Marl from the inner part of the Skole Nappe. The results are compared to previous data from the outer part of the Skole Nappe.

In the Kropivnik Fucoid Marl of the Kąkolówka Structure, three main heterolithic facies associations are distinguished: shale-sandstone, marl-sandstone and sandstone-shale. The occurrences of hard, platy and soft marls within siliciclastic rocks are typical of the sections studied. The features observed indicate a turbiditic origin of the deposits studied, including the hard, platy marls. The allogenic material of the strata described includes the small, fragile tests of planktonic foraminifera, which were redeposited from the outer parts of the Skole Basin. Particularly large concentrations of planktonic foraminifera were observed in the hard, platy marls. They are less common in the soft marls and shales.

In the Zimny Dział section, a diverse assemblage of benthic and planktonic foraminifera was found. The Kropivnik Fucoid Marl was dated as uppermost Campanian to lowermost Maastrichtian on the basis of planktonic foraminifera, which represent the *Gansserina gansseri* Zone. The agglutinated foraminiferal assemblages are representative for the lower part of the *Rzehakina inclusa* Zone and the co-occurrence of the *Caudammina gigantea* (Geroch) acme with *Rzehakina inclusa* (Grzybowski) was observed.

Key words: Skole Basin, Kropivnik Fucoid Marl, Campanian–Maastrichtian, lithostratigraphy, biostratigraphy, foraminifera.

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INTRODUCTION

A significant proportion of bioturbated marls can be found within the turbiditic deposits of some Outer Carpathian lithostratigraphic units. These marls are characterized by the presence of trace fossils, mainly *Chondrites* and *Planolites*; which were known informally as 'fucoids'. Most of the bioturbated marls occur in the Cretaceous strata of the Outer Carpathians.

In the Skole Nappe, individual lithostratigraphic units have been distinguished on the basis of the presence of bioturbated marls. These units belong to the Upper Cretaceous–Paleocene Ropianka Formation (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995, and references therein). In the Cretaceous strata, these are respectively: the Holovnia Siliceous Marl (Turonian–Coniacian) and the Kropivnik Fucoid Marl (Campanian–Maastrichtian), which are separated by the siliciclastic turbidites of the Rybnik Flysch (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995, and references therein) (Fig. 1). The stratotype area and detailed sedimentological characteristics of these two marl units have been documented from outcrops, located in the marginal part of the Skole Nappe (Kotlarczyk,

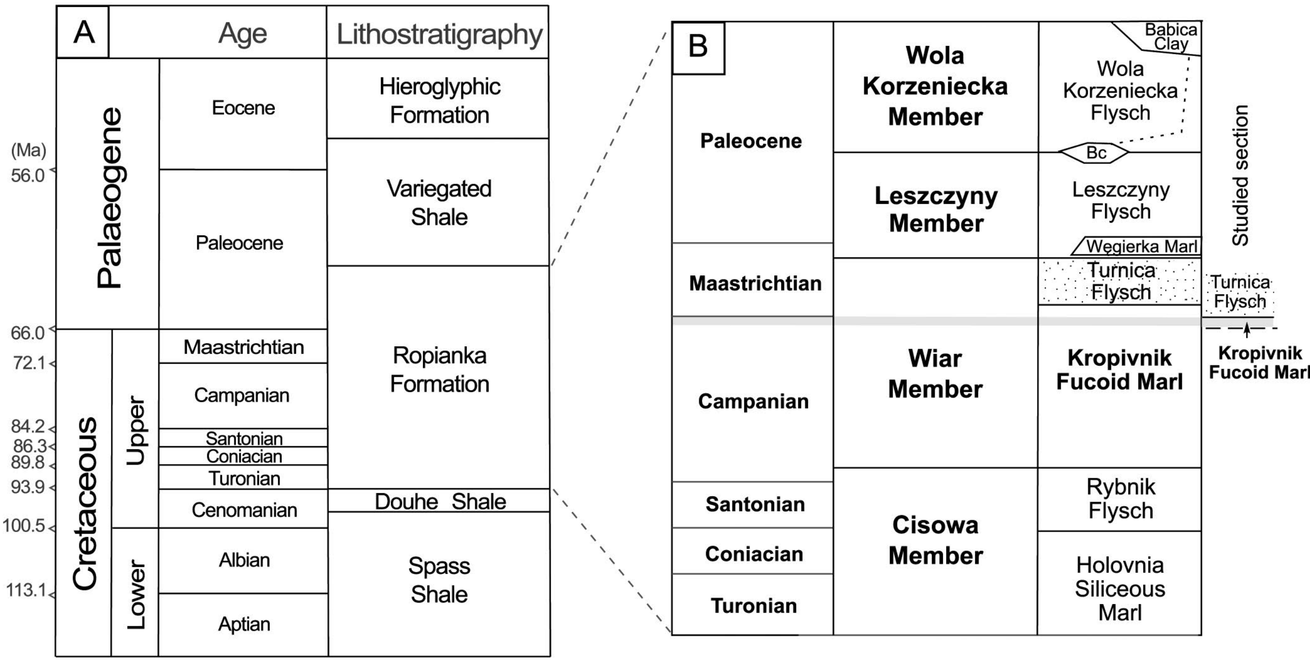

Fig. 1. Lithostratigraphic position of the studied section. **A.** Lithostratigraphical scheme of the Cretaceous–Lower Palaeogene of the Skole Nappe (based on Kotlarczyk, 1978; Gasiński and Uchman, 2009, and references therein). **B.** Lithostratigraphic division of the Ropianka Formation (after Kotlarczyk, 1978, 1985 - supplemented). Time scale after Ogg *et al.* (2016).

1978; Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995). In turn, the marly units from the inner part of the Skole Nappe are poorly known and weakly documented (Kotlarczyk, 1978). The previous research of Kotlarczyk (1978), Kotlarczyk *et al.* (1988) and Kotlarczyk and Joniec (2000) indicated significant differences in lithological development between the inner part of the Skole Nappe (representing the distal part of the Skole Basin) and the stratotype area. In the former area, the thickness of the Ropianka Fm increases several times over; its sedimentary succession is dominated here by thick-bedded sandstones with a minor amount of marly deposits. The boundaries of the lithostratigraphic members are rather sharp, but divisions of lower rank within these members are difficult to distinguish, i.e., marly units and the 'flysch' units (according to Kotlarczyk, 1978), which separate the marly units.

In the inner part of the Skole Nappe, between Lubenia and Kąkolówka (south of Rzeszów), geological field mapping was carried out (Figs 2, 3). A thick succession of shales, marls and sandstones with intercalations of the hard, platy marls was found in the Ropianka Fm.

This work documents the lithology and biostratigraphy of this succession in order to (1) supplement the geological data with new information from inner part of the Skole Nappe and (2) to compare its lithological development with that of other parts of the Skole Nappe.

GEOLOGICAL SETTING

Location of study area

The study area is in the inner part of the Skole Nappe, on the periphery of the so-called Rzeszów Bay (Fig. 2). Geographically, it is the Dynów Foothills area. The strata in question make up the frontal part of the Kąkolówka-Babica-Broniszów Thrust Sheet, which is overthrusted onto the synclinal Mogielnica Zone, the southern part of an adjoining thrust sheet (Fig. 3). The Kąkolówka Structure, located in the northeastern part of the Kąkolówka-Babica-Broniszów Thrust Sheet, is an anticline with gently dipping limbs (Kotlarczyk and Joniec, 2000) and its axis striking from NW to SE. It stretches from Łubno to the Wisłok valley. The northern and central part of the Kąkolówka Structure is composed of turbiditic deposits of the Ropianka Fm (Cretaceous–Palaeogene in age) (Fig. 3). In turn, its southern part comprises younger deposits of the Variegated Shale Formation, through the Hieroglyphic Beds and the Menilite Formation up to the Krosno Formation. The latter two form a broad strip of exposures in front of the Kąkolówka-Babica-Broniszów Thrust Sheet. Field mapping revealed the geological complexity of the Kąkolówka Structure. The beds locally are strongly folded and overturned. Their dip changes over a very short distance. Numerous small-scale tectonic reductions, mainly in the Variegated Shale Formation, were documented.

The subject of this study is the rocks forming he Kropivnik Fucoid Marl, including the calciturbidites occurring in the Kąkolówka Structure (Fig. 3). Outcrops of the Kropivnik Fucoid Marl form a strip, 350–500 m wide, stretching from NW to SE. They make up the frontal part of the anticlinal Kąkolówka Structure, which is overthrusted onto the Mogielnica Syncline, belonging to an adjoining thrust sheet. The best exposed profiles of the Kropivnik Fucoid Marl are located along stream cuts extending to the north from the slopes of the watershed, in the eastern part of the Zimny Dział area (a part of the village of Straszydle) (Fig. 3).

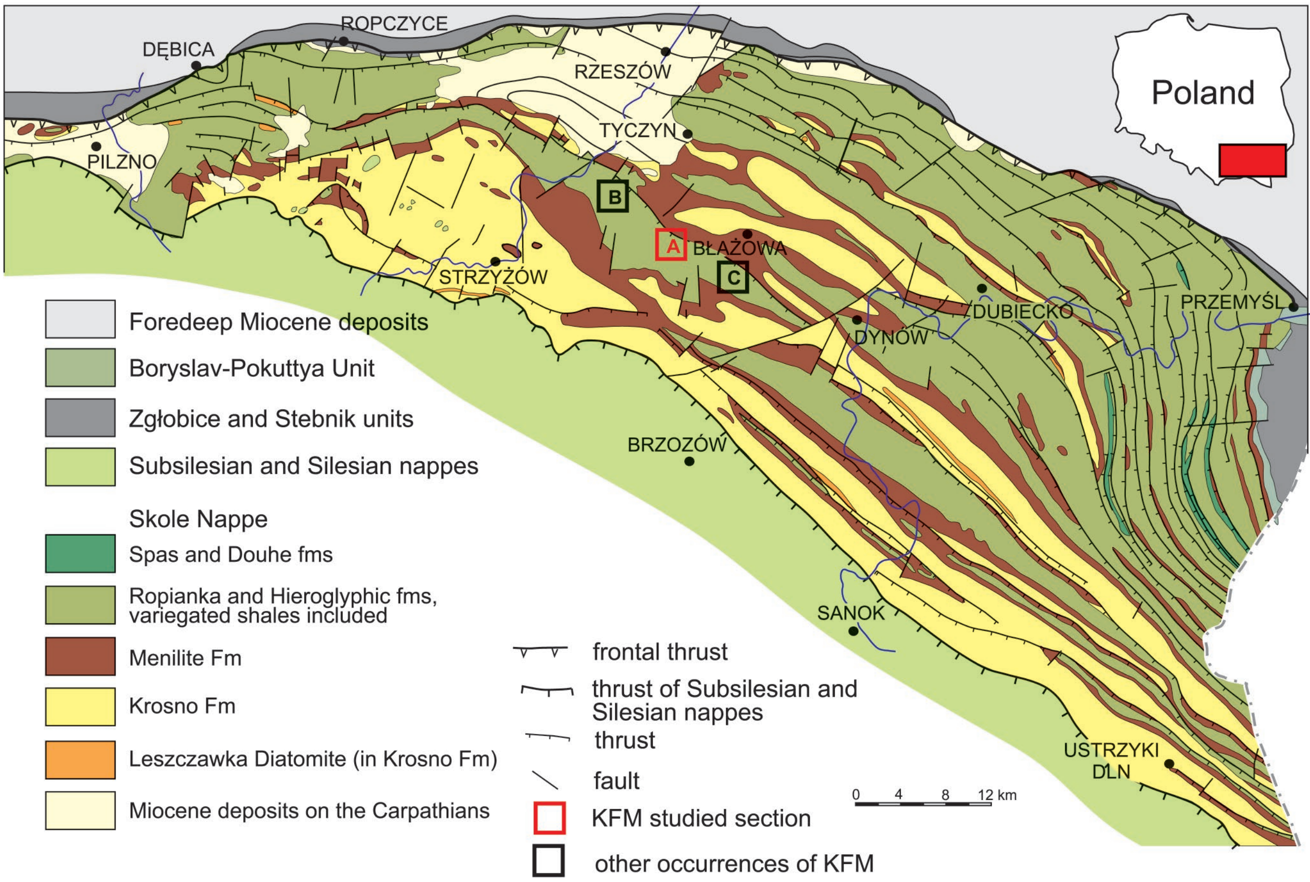

Fig. 2. Location of studied sections on the geological sketch-map of the Skole Nappe in Eastern part of the Polish Carpathians (map based on Kotlarczyk, 1985 – supplemented). A – Zimny Dział section, B – Sołonka section, C – Kąkolówka section.

Similar marls were observed in the neighbouring area: at Sołonka (northwest of the study area) and in the Kąkolówka section (southeast of the study area) (Fig. 2).

Lithostratigraphy

The Kąkolówka Structure is composed of Cretaceous–Palaeogene deposits. These are distinguished as the Ropianka Fm (*sensu* Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988), formerly known as the Inoceramian Beds (e.g., Uhlig, 1888; Wdowiarz, 1936, 1949; Koszarski and Ślączka, 1973; Bromowicz, 1974; Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Fig. 2). They are 400–500 m thick in the outer part (Bromowicz, 1974), and up to 1,500 m thick in the inner part of the Skole Nappe (Koszarski and Ślączka, 1973).

The Ropianka Fm of the Skole Nappe is a lithostratigraphic unit with diversified lithology. It is composed of thin- and medium-bedded turbidites (alternating sandstones and mudstones or marls, called heterolithic deposits), thick-bedded sandstones, marly shales and marls, variegated shales and olistostrome-type complexes of chaotic deposits (e.g., Bromowicz, 1974; Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995; Gasiński and Uchman, 2011; Łapcik *et al.*, 2016, and references therein). The sedimentary succession of the Ropianka Fm overlies the radiolarian shales of the Douhe Formation (Cenomanian) and is followed by the Variegated Shale Formation (upper Paleocene – lower Eocene; Fig. 1). The oldest lenticular bodies of the Babica Clay deposits are found in the topmost part of the Ropianka Fm (e.g., Koszarski and Ślączka, 1973; Bromowicz, 1974; Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Rajchel, 1990; Gasiński and Uchman, 2011, and references therein).

The Ropianka Fm is subdivided into four members (Fig. 1). These are (from the oldest): the Cisowa, Wiar, Leszczyny, and Wola Korzeniecka members (Kotlarczyk, 1978, 1979, 1985; Kotlarczyk *et al.,* 1988). In the opinion of the present authors, the marls discussed belong to the Wiar Member (lower Campanian – upper Maastrichtian; Kotlarczyk, 1978). In the stratotype area (the outer part of the Skole Nappe, the Wiar River catchment near Przemyśl) this unit is bipartite (Fig. 1). The lower part, represented by deposits with numerous hard, platy marls, is distinguished as the Kropivnik Fucoid Marl (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988). The hard, platy marls contain intercalations of soft marls, marly shales and thin-bedded sandstones. Higher in the section, the hard, platy marls gradually disappear. The upper boundary of the Kropivnik Fucoid Marl is marked by the Sopotnik Variegated Shale Horizon. The sandstone-shale heterolithic deposits or massive soft marls, up to 30 m thick, are recorded locally in the Kropivnik Fucoid Marl (Kotlarczyk, 1978). The Kropivnik Fucoid Marl in the stratotype area is 130–200 m thick (Kotlarczyk, 1978).

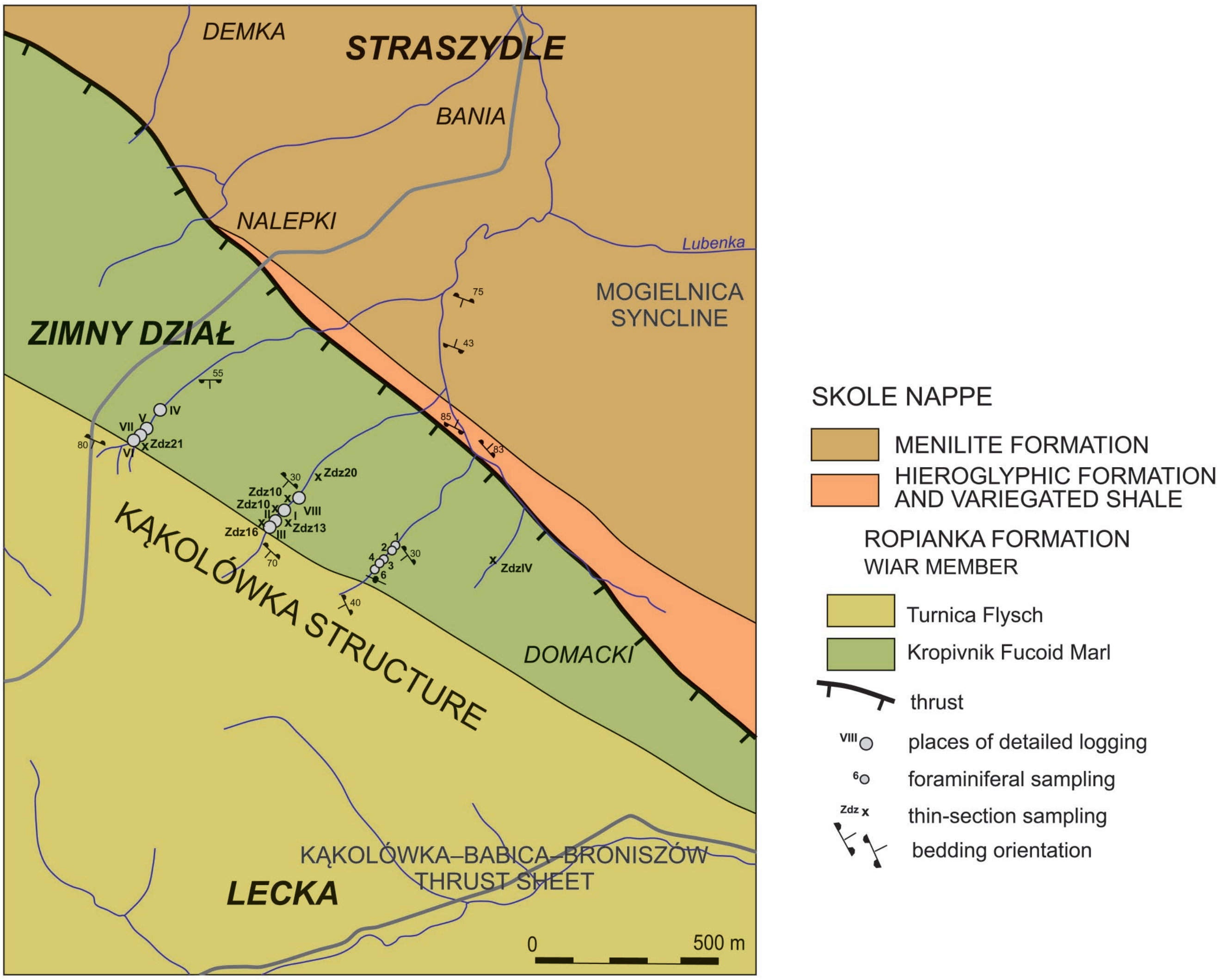

Fig. 3. Detailed geological map of the Kąkolówka Structure in the Zimny Dział area. The names of villages and hamlets are indicated with italics.

MATERIALS AND METHODS

The field work was the basis for further analyses. This included geological field mapping of the Straszydle area. Moreover, selected sedimentary profiles of Kropivnik Fucoid Marl were logged and sampled for biostratigraphic and petrographic research. The micropalaeontological studies included the investigation of washed samples and thin-section analysis under the microscope.

Nineteen samples were selected for further examination from the soft marly shales (mudstones and claystones) and soft marls to obtain washed samples. Samples weighing 300 g were prepared using standard micropalaeontological techniques. The first step was the mechanical disintegration of the rock using Glauber's salt. This involved the repeated process of salt crystallization in the pore spaces of the rocks during the cyclical freezing and heating of each sample immersed in a Glauber's salt solution. The second step was sieving through a set of sieves with a mesh diameter of 0.63 mm. The samples then were dried and the microfossils were picked by hand from the residuum obtained. These consisted of the skeletal remains of benthic and planktonic foraminifers, together with single ostracods, echinoid spines, spicules and fish teeth. The foraminifera constituted the primary and most abundant group of microfossils. These were identified to the species level and the biozones were determined using a stereo microscope and a scanning electron microscope (SEM). The preparation and micropalaeontological analyses were performed at the Department of General Geology and Geotourism of the Faculty of Geology, Geophysics and Environmental Protection, AGH University of Science and Technology in Kraków, Poland. SEM analysis was carried out and SEM-micrographs of the specimens were taken at the Laboratory of Critical Elements, Faculty of Geology, Geophysics and Environmental Protection, AGH, Kraków, Poland.

From the hard, platy marls, soft marls, mudstones and sandstones, seventeen thin-sections were prepared. Results of transmitted light microscope thin-section analysis were used for sedimentological and biostratigraphical documentation and interpretation.

All samples are housed in the Department of General Geology and Geotourism of the Faculty of Geology, Geophysics and Environmental Protection, AGH, Kraków, Poland. The collection of foraminifers is housed in the European Micropalaeontological Reference Centre of Micropress Europe Micropalaeontological Foundation (Poland, Kraków, al. Mickiewicza 30).

RESULTS

Lithology

A succession of turbidites, at least 250 m thick, with mudstones and marls predominant, form part of the deposits of the Ropianka Fm (Figs 1, 2) in the marginal (northern) part of the Kąkolówka Structure studied, along its overthrust onto the Mogielnica Thrust Sheet (Fig. 3). An occurrence of hard, platy marls is the most characteristic feature of this succession (Figs 4, 5, 6D). Such marls occur in heterolithic facies associations (informally called 'heterolithic deposits') with a predominance, in general, of calcareous mudstones or soft marls; the term 'heterolithic' is used to describe alternating coarser and finer sediments deposited under fluctuating energy conditions in many marine environments (see Catuneanu, 2006). Three types of heterolithic facies associations (HFA) were distinguished: shale-sandstone, marl-sandstone, sandstone-shale. The transitions between them are gradational (Figs 4, 5). In the present study, the authors use the term 'shales' to describe mudstones and claystones in general.

The shale-sandstone HFA predominates, with an average proportion of about 70% in the measured sections. Within this type of HFA, calcareous mudstones are the most common lithology. They are interbedded with very thin- and thin-bedded calcareous sandstones, occasionally with medium-bedded sandstones and subordinately with thin packets of soft and hard, platy marls (Fig. 6B). The proportion of the marl-sandstone HFA is estimated at 16% of the measured sections. Soft marls or a comparable proportion of soft marls and calcareous shales amount to the majority of marl-sandstone HFA. Very thin- and thin-bedded calcareous sandstones form subordinate interbedded lithologies. The hard, platy marls occur in this type of HFA (Fig. 6A). Their frequency is variable, but usually does not exceed 25% of the thickness of a single section. The sandstone-shale HFA constitutes some 14% of the measured sections, with the predominance of very thin-, thin- and medium-bedded sandstones. The sandstones alternate with calcareous shales, accompanied by a subordinate proportion of soft marls and, sporadically, with hard, platy marls.

Sandstones and siltstones: These occur in beds that are very thin, thin or of medium thickness, usually several centimetres thick (up to 15 cm), and occasionally as thick beds, reaching 30–40 cm (Figs 4, 5, 6E). The sandstones are commonly fine-grained, highly calcareous, with calcite cement, beige-greyish or greenish-grey, rarely brownish. Numerous current marks and loadcasts, as well as ichnofossils occur on the soles of beds. A massive structure and the subtle normal grading of grain sizes are common. Ripple cross-lamination (Fig. 7A), flat parallel lamination and convolute lamination are less common and occur mainly in the siltstones. The framework grains are quartz-dominated with an admixture of calcitic bioclasts. Occasionally, glauconite grains and mica flakes occur. The bioclasts consist of fragmented thin tests of planktonic foraminifera (rarely wholly preserved). Sandstones and siltstones make up the lowermost parts of composite beds. They constitute 15–45% of the measured sections. Sandstone beds are most common within the calcareous shales and are common within the soft marls. Sandstones are followed by shales or by soft marls (chiefly within marl-sandstone HFA) and hard, platy marls (Figs 4, 5).

Mudstones (shales): These are calcareous, usually grey-green, and commonly occur in thicknesses of up to 30 cm. Their amount varies significantly from 5 to 60% of the measured sections (Figs 4, 5). Generally, they are massive; parallel horizontal laminations are less common. Mudstones with subordinate proportions of claystones, together with thin intercalations of soft marls, form multi-layer packets; the transitions between each of the lithological types are gradational. The mudstones occurring above the sandstones or hard, platy marls represent a record of continuous sedimentation from sandstones to mudstones, during single depositional events.

The dominance of quartz among silt-sized grains and an insignificant amount of bioclasts were observed. Smaller particles are composed of varying content of clay minerals and carbonates. Sedimentary structures observed in mudstones include massive structure (Fig. 7B), normal grading, and faint parallel lamination. Gradational or sharp (Fig. 7C) transitions between mudstones, claystones and soft marls also were noted. The dispersed tests of agglutinated and calcareous foraminifera are bioclastic components of the soft marly shales and are found in the >63μm fraction of the washed residues. Rare tests of planktonic foraminifera belonging to *Globigerinelloides* were identified in thin sections.

Soft marls ("fucoid marls"): They occur as thin and very thin layers, a few centimetres thick (up to 10 cm) and form (1) upper parts of composite beds (sandstone-soft marl or sandstone-mudstone-soft marl) or (2) intercalations within the mudstone layers (Figs 4, 5). The soft marls are grey-green, grey or beige in colour. They are massive and characterized by a pelitic (micritic) texture (Fig. 7E). Their common feature is the presence of numerous trace fossils, occurring as large channels filled with black material. The dispersed tests of both agglutinated and calcareous benthic foraminifera are the main bioclastic components of the soft marls and occur in the >63μm fraction of the washed residues. The soft marl content varies from 5 to 13% of the studied sections.

Hard, platy marls ("fucoid marls"): Hard, platy marl occurs as thin and very thin layers, reaching 2 cm to 11 cm in thickness (Figs 4–6, 8A, B). They are creamy beige or beige-bluish on fresh surfaces, changing colour to orange during weathering (Fig. 8A, B). Ripple cross-lamination (T_c interval of the Bouma sequence; Fig. 8A), wavy and planar lamination (T_{e-1} intervals *sensu* Piper 1978, *vide* Talling *et al.*, 2012; called 'parallel streaking' after Leszczyński *et al.*, 1995; Figs 7F, 9A, C) and massive structure (T_e division of the Bouma sequence; Fig. 7D) were observed in the marls. The laminated intervals occur through entire bed

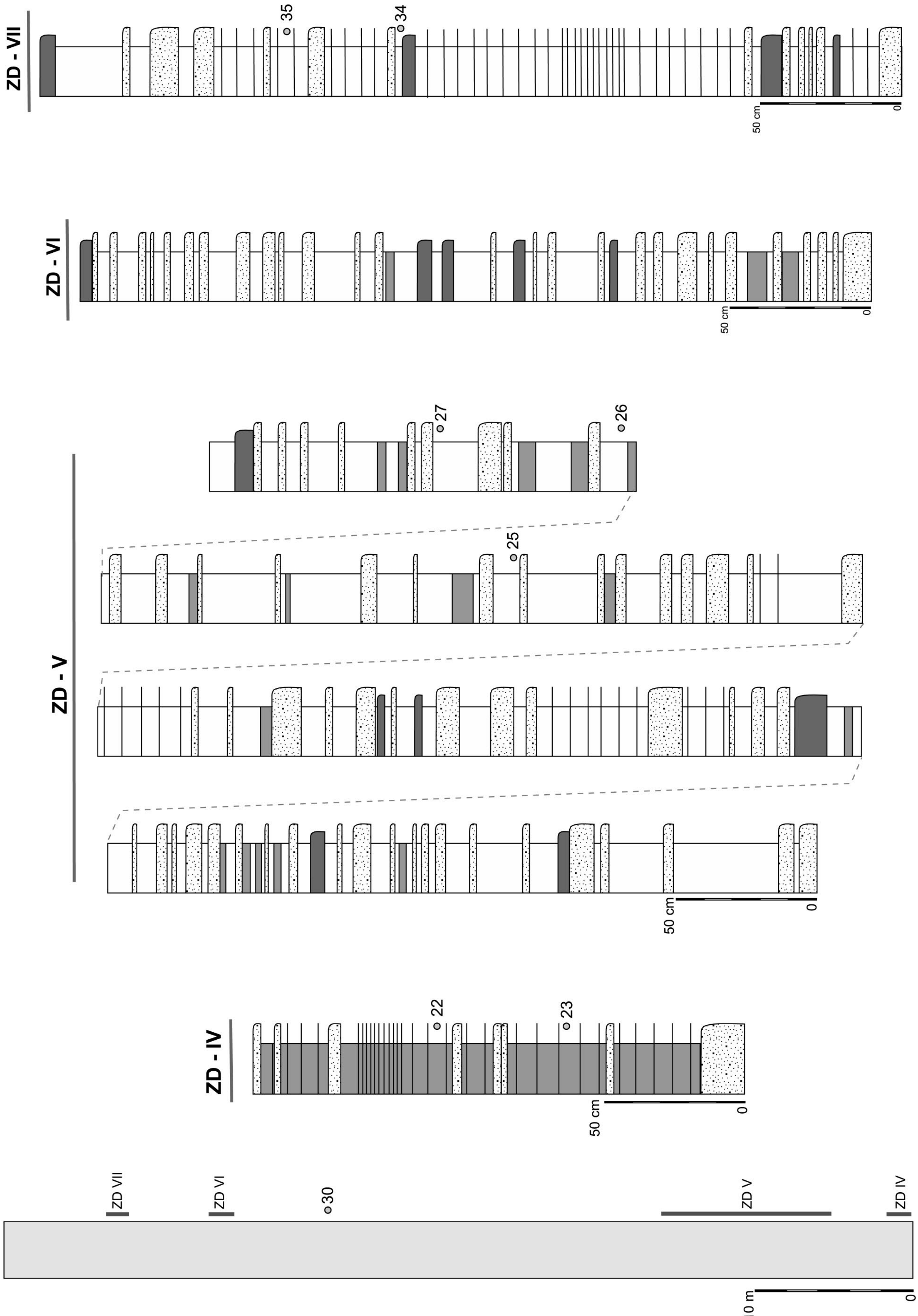

Fig. 4. Lithological logs of the Kropivnik Fucoid Marl in the Kąkolówka Structure. Explanation of lithological symbols in Figure 5, locations of logs in Figure 3.

sections, not only in their lowermost parts, and alternate with massive ones (Fig. 8A, B). This is evidence of fluctuations in the flow energy of turbidity currents. Individual laminae of T_{e-1} intervals are usually <1 mm thick, with a maximum thickness of 2 mm and their internal structure ranges from massive to normally graded (Figs 7F, 9A, C). They occur in massive marl as either single units or as parallel-laminated sets. Cross-laminated sets appear typically in beds thicker than 7 cm, just above their bases, as current ripplemarks deformed by loading (Dżułyński and Ślączka, 1965) and with signs of local liquefaction (Fig. 8A).

The hard, platy marls can be classified as marls or clayey marls ($CaCO_3$ content varying from 65 to 20%, 42% on average; see Leszczyński *et al.*, 1995) with horizons of both T_c and T_{e-1} lamination constituting carbonate-siliciclastic marly siltstones (Fig. 7F). Single, isolated silt-sized, terrigenous quartz grains occur in carbonate-clayey massive marl (Fig. 9H). The T_e intervals are devoid of gradation, both in terms of the size and the amount of the quartz grains. The siliciclastic grain concentrations occur in laminated horizons with maximum sizes in the fine sand range, but do not exceed 20% of the total rock volume. The hard, platy marls

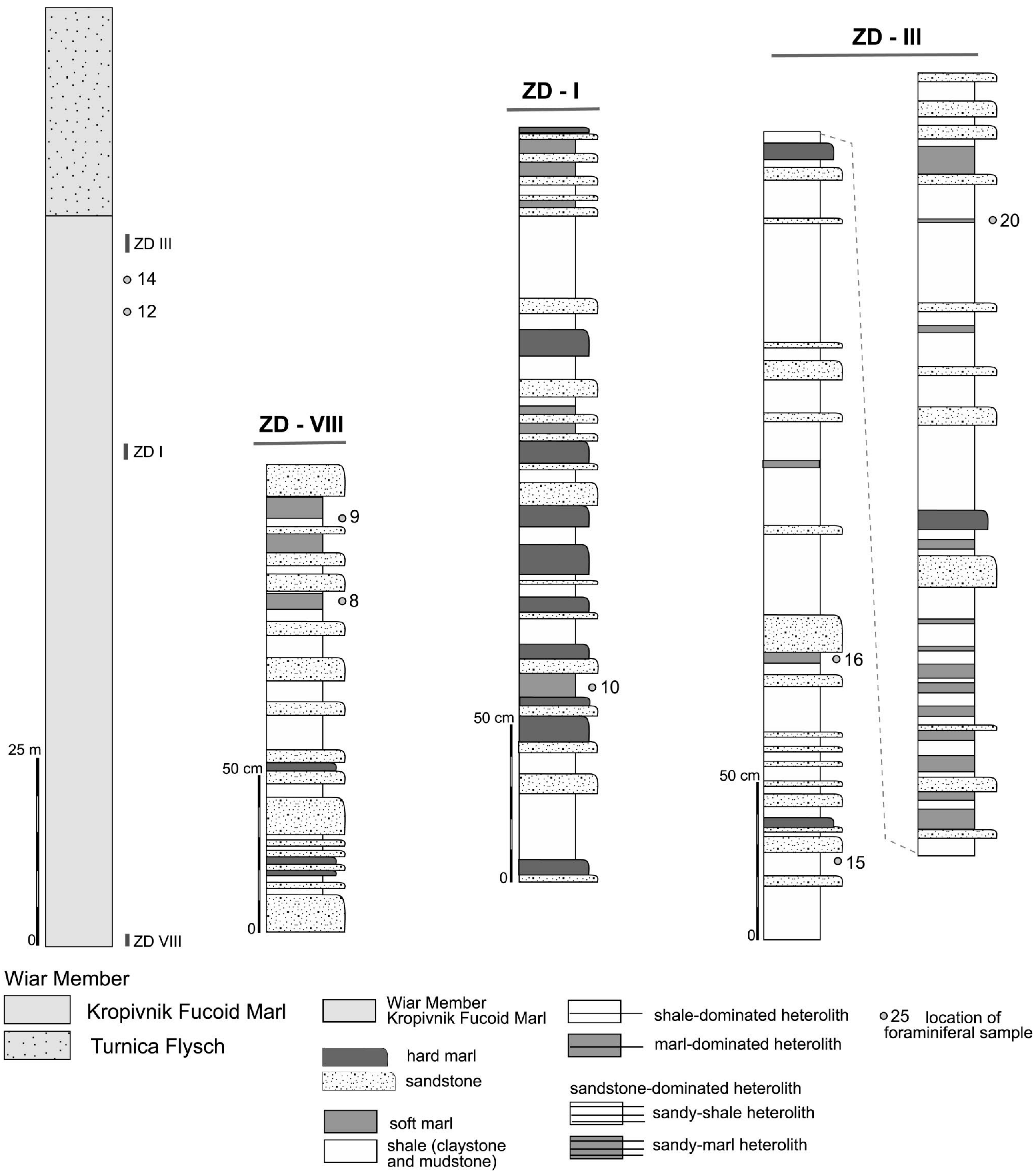

Fig. 5. Lithological logs of the Kropivnik Fucoid Marl in the Kąkolówka Structure. Locations of logs in Figure 3.

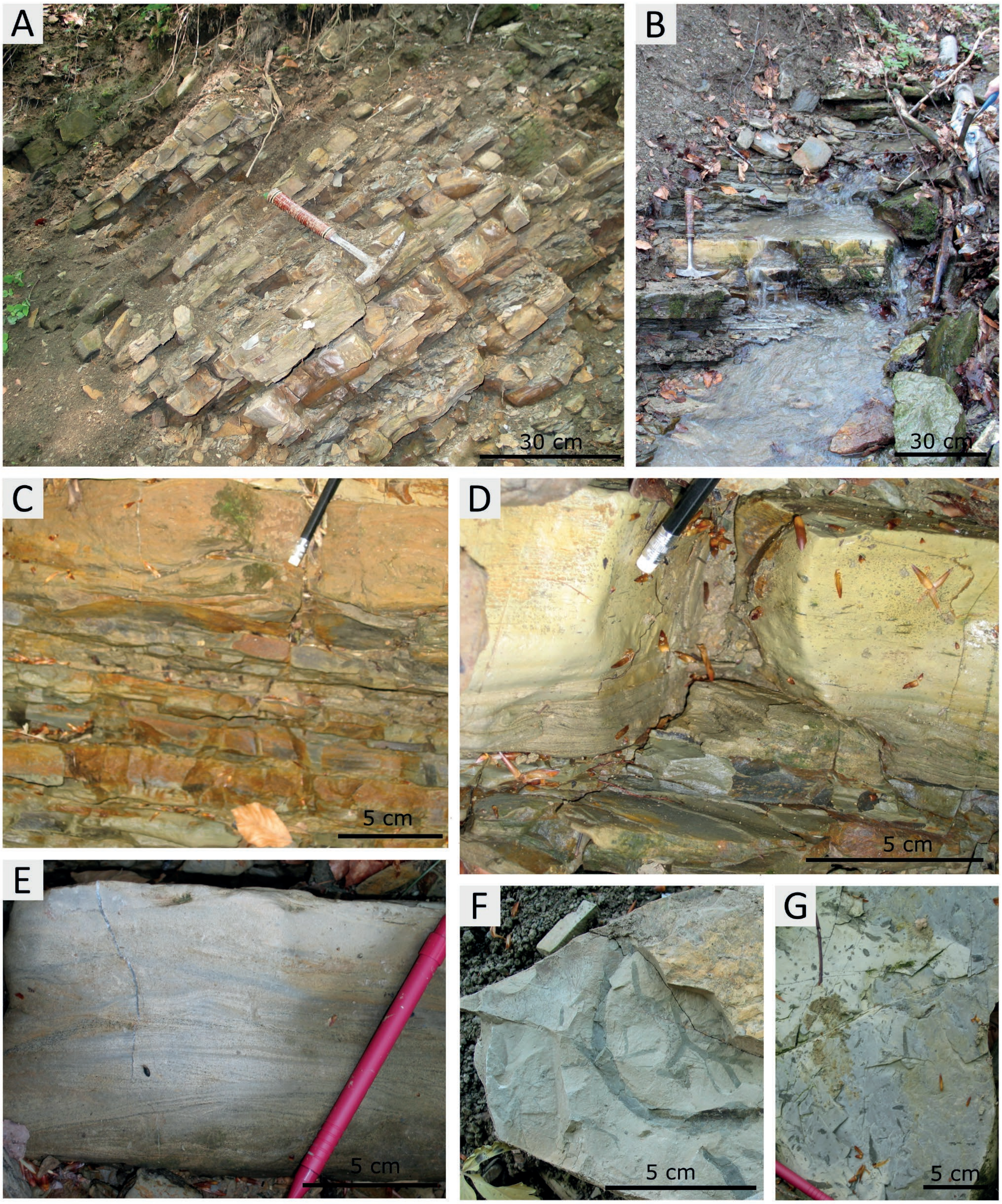

Fig. 6. Photographs of the Kropivnik Fucoid Marl. **A.** Marl-sandstone heterolithic facies association, part of section with numerous hard, platy marls. **B.** Shale-sandstone heterolithic facies association. **C, D.** Shales and marls in marl-sandstone heterolithic facies association. **E.** Laminated sandstone in sandstone-shale heterolithic facies association. **F, G.** Trace fossils in marls.

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Fig. 8. Polished slabs showing cross-sections through hard, platy marls. **A.** Sample ZDz 20. **B.** Sample ZDz 10. Explanation of symbols: bt – bioturbation structures, T_c – ripple cross-lamination (current ripplemarks deformed by loading), T_{e-1} – silt-mud lamination (*sensu* Piper, 1978); T_e – ungraded mud. Dashed circle encloses a part of cross-laminated tabular foreset with overturned upper part, resulting from horizontal shear stress caused by fluid flow above (Allen, 1982). Small rectangles and two dots labelled 8G and 8H indicate positions of microphotographs, shown in Figures 7 and 8.

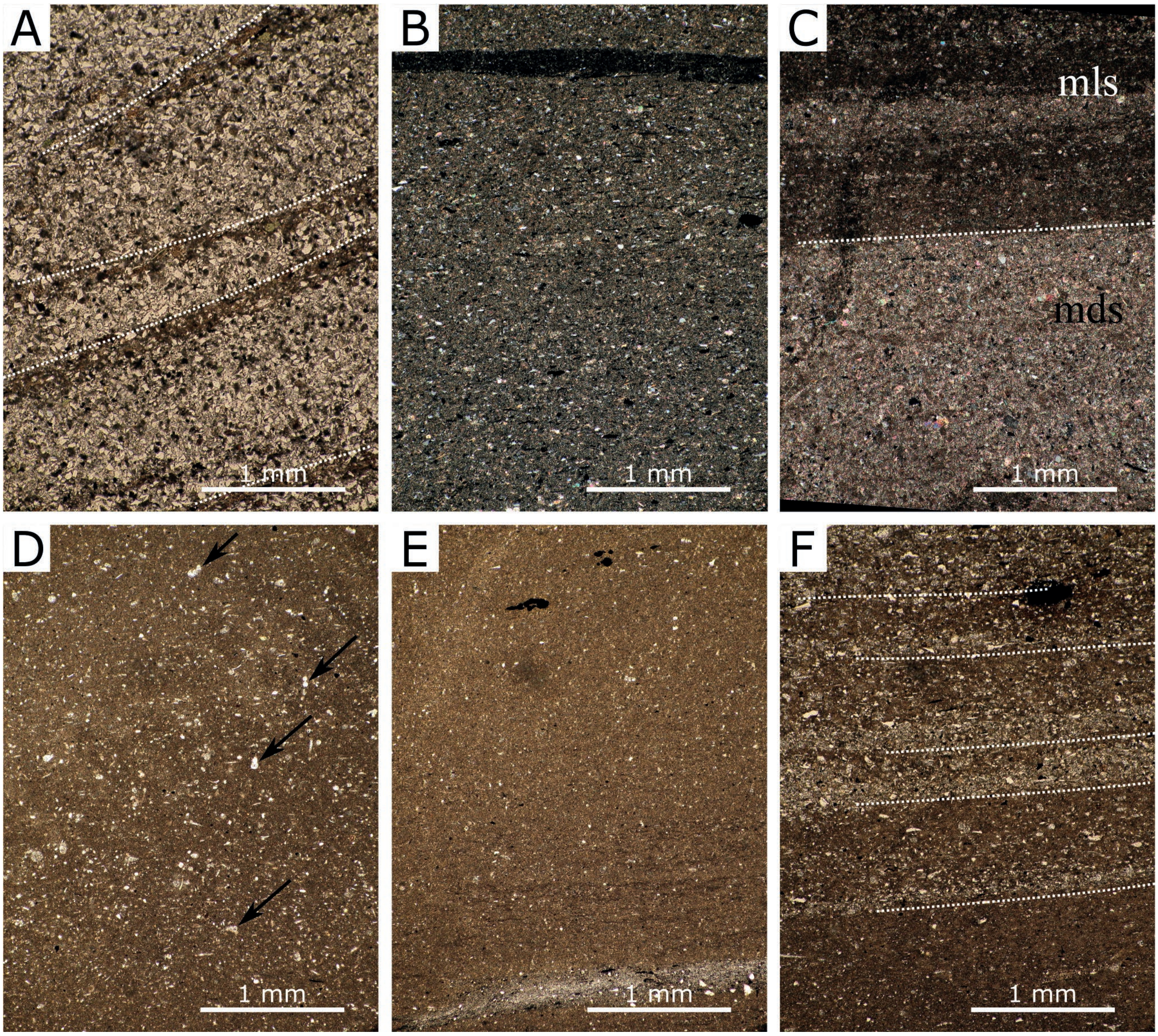
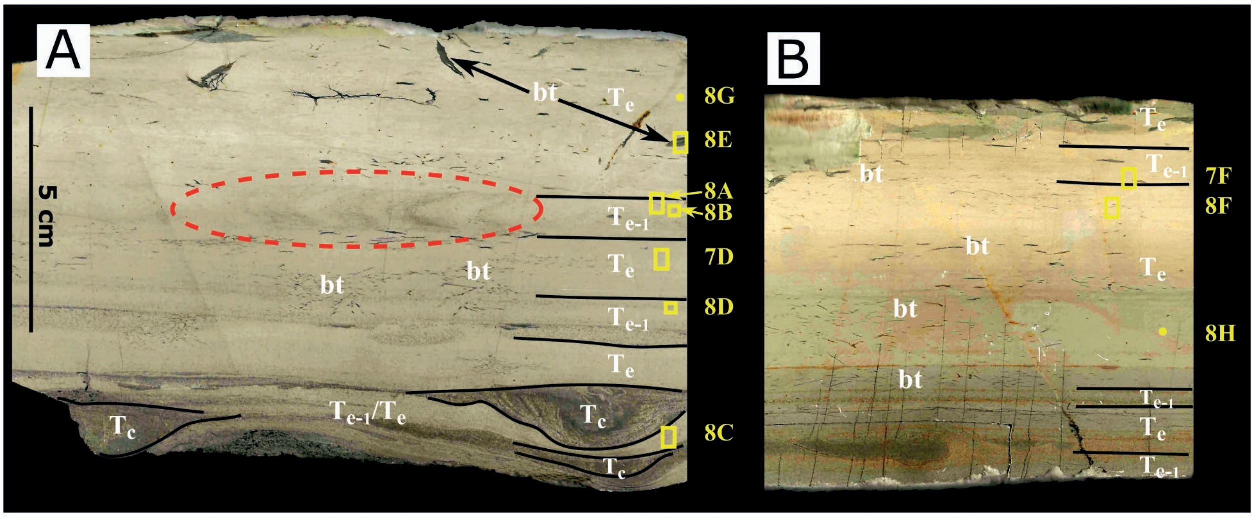


Fig. 7. Microphotographs of structures and textures. **A.** Siltstone with ripple cross-lamination (T_c). Lamination surfaces indicated with white dotted lines. Sample ZDz IV. Plane-polarised light. **B.** Ungraded mudstone. Sample ZDz 11. Cross-polarised light. **C.** Transition from ungraded mudstone (mds) into marl (mls) with single lamina of coarser material. Sample ZDz IV potok. Cross-polarised light. **D.** Marl with silt-sized calcareous fossil remnants of foraminifera (the largest tests indicated with arrows). Sample ZDz 20 (hard, platy marl). Plane-polarised light. **E.** Marl with very low number of small calcareous fossils of foraminifera. Sample ZDz 13 (soft marl). Plane-polarised light. **F.** T_{e-1} lamination (*sensu* Piper, 1978). Lamination surfaces indicated with white dotted lines. Sample ZDz 20. Plane-polarised light. Scale bar = 1 mm.



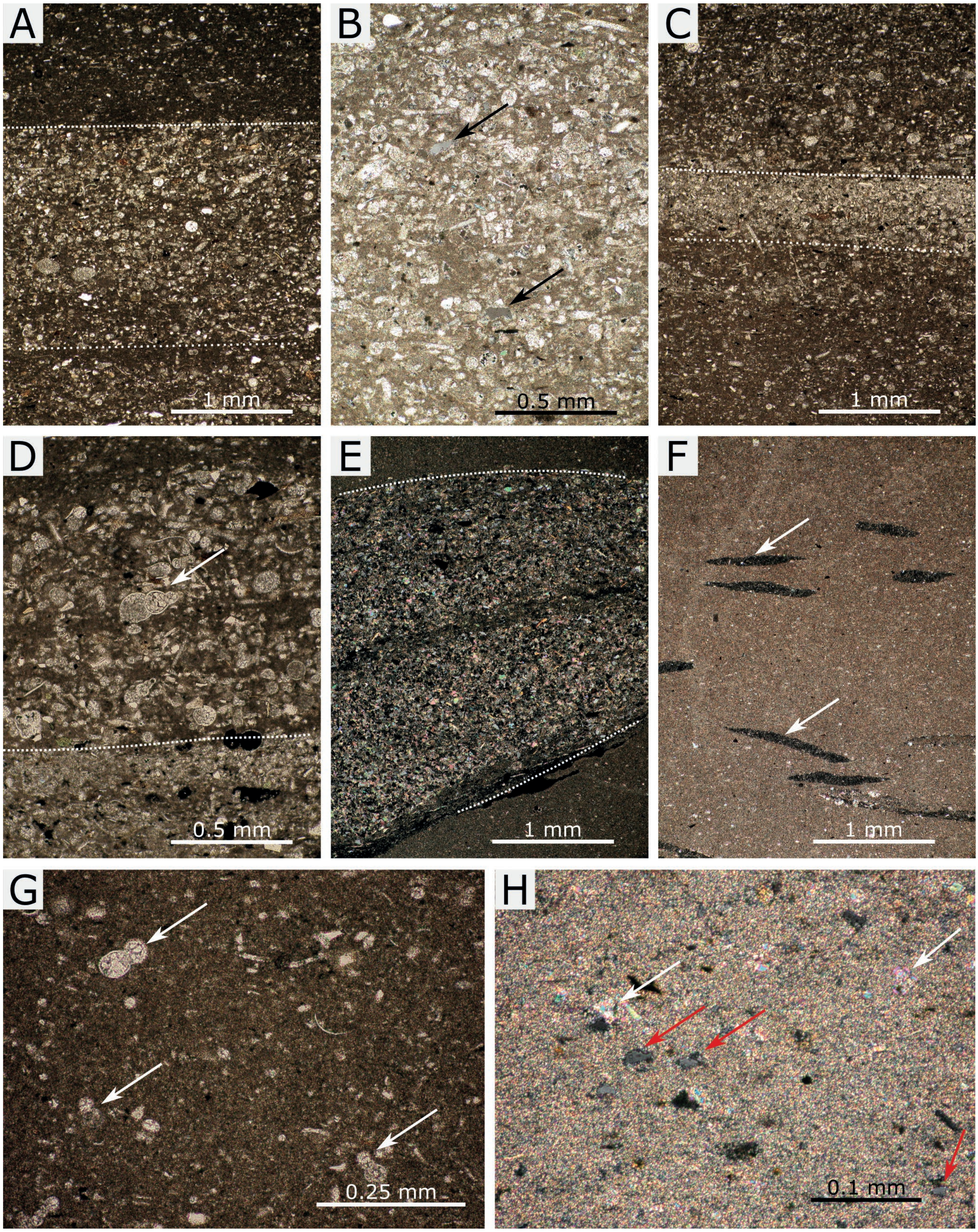


Fig. 9. Microphotographs of structures and textures observed in hard, platy marls. **A.** Thick carbonate silt lamina (T_{e-1} lamination *sensu* Piper, 1978). Silt-sized grains consist of bioclasts (mainly fragmented planktonic foraminifera tests). Upper boundary is marked with dotted line; lower one is marked with sparse-dotted line. Sample ZDz 20. Plane-polarised light. **B.** Insight into carbonate-siliciclastic silt lamina (T_{e-1} lamination). Bright grains consist of skeletal remains of planktonic foraminifera (single chambers filled with calcite and fragmented tests walls). Single, isolated angular quartz grains (grey ones) are visible. Sample ZDz 20. Cross-polarised light. **C.** Thin carbonate silt lamina (T_{e-1} lamination) consisted of packed, strongly fragmented foraminifera tests. Lower and upper boundary marked with dotted line; relatively large and well-preserved chambers are visible above upper boundary. Sample ZDz 20. Plane-polarised light. **D.** Partition of biogenic material – packed, strongly fragmented foraminifera tests (lower part) and relatively large, well-preserved chambers (upper part);

are characterized by the occurrence of bioclasts, consisting mostly of thin, fragmented calcareous tests of planktonic foraminifera. Entirely preserved foraminifera tests are much rarer and appear as plani- and trochospiral or biserial morphologies. The bioclasts are filled with crystalline calcite. The largest concentrations of bioclasts are found in and just above the carbonate-siliciclastic silt laminae (both T_c and T_{e-1} intervals; Fig. 9A, B, C, D). Most of the grains making up these laminae are bioclasts, with a minor fraction of siliciclastic grains (Fig. 9B). In some cases, these are only bioclasts (packstones *sensu* Dunham, 1962). The silt-sized material was deposited in traction and settled in a higher flow regime than the T_e intervals. The fact that deposition had taken place under flow conditions is confirmed by the arrangement of the long axes of biserial foraminifera in the transport direction and parallel to the depositional surface. In contrary to the T_c and T_{e-1} intervals, in T_e intervals bioclasts are rarer and dispersed, generally of the smaller size of the entirely preserved fossils of planktonic foraminifera (Fig. 9G), and their content ranges from 3–5% to 20–25% (Fig. 7D) of the total rock volume.

The hard, platy marls are quite hard and resonant when broken. They occur in the regolith as relatively large slabs; this is why they informally are called “platy marls”. They form rapids along the river courses. The distinctive feature of the hard, platy marls is the widespead occurrence of trace fossils, widely known as ‘fucoids’, which occur mainly in the middle and upper parts of the beds (Figs 6F, G, 8A, B, 9E, F). In very thin beds, trace fossils appear throughout all bed thickness with a tendency to be much more frequent upwards. In turn, when beds more than 5 cm thick are considered, bioturbation structures are usually absent or occur occasionally in their lowermost parts and in the intervals enriched in siliciclastic grains (Fig. 8A). Under the microscope, bioturbation structures usually are characterized by an increased content of clastic quartz grains, the occurrence of the muscovite, and the absence of bioclasts (Fig. 9E).

The hard, platy marls are usually followed by calcareous mudstones, or soft marls. When these occur within sandstone-shale HFA, they generally appear just above sandstone intervals as their continuation in vertical succession. The amount of hard, platy marls usually ranges from 3 to 7% in profiles, but locally increases up to around 25%.

The turbiditic succession with bioturbated marls passes into sandstones of the Turnica Flysch towards the top of the section (Fig. 3). Their thickness in the outcropping part of profile is estimated at 60 m. The sandstone beds are more than 1 m thick. Very thick-bedded sandstones together with thin- and medium-bedded ones form uniform bedsets with no shale intercalations. They are fine-grained, grey, grey-beige and yellowish, mostly with carbonate cements, sporadically with a higher fraction of clayey cements. They are characterized by variable hardness and a substantial admixture of mica flakes and coalified plant detritus. Many of the sandstone beds reveal normal grading (from medium- to fine-grained) in the basal parts, and they quite commonly show topmost parallel- or wavy-laminated intervals. The laminated intervals are fine-grained and with an increased content of clay minerals. Thin intercalations of grey and grey-green mudstones and claystones, up to several centimetres thick, are rare.

Foraminiferal assemblages

Foraminifera from washed samples

State of preservation: All the samples that were examined contained fossils of foraminifera. The majority of them yielded abundant and diversified assemblages that allowed biostratigraphic analysis. Generally, agglutinated foraminifera predominate, while calcareous, either benthic or planktonic taxa occur as a common but exclusive accompanying component (Table 1).

The state of preservation varies from poor to good. The agglutinated taxa are relatively well preserved, their elongated and uniserial forms are broken, but this is a typical condition for assemblages from the Outer Carpathians. In turn, benthic calcareous foraminifera represented mostly by small forms (excluding *Nodosaria*) are poorly preserved, usually as steinkerns with primary walls that are residual or even absent; the larger ones display better preservation. The planktonic foraminifera generally are poorly preserved and with barely visible features of chambers and apertures that have made difficulties in taxa identification, the larger forms are better preserved.

Taxonomic diversity: The samples investigated showed relatively high taxonomic diversity (Tables 1, 2). Tubular foraminifera predominate and belong mainly to *Nothia*, in addition to *Bathysiphon*, *Psammosiphonella, Rhabdammina* and *Rhizammina*. The second most abundant are *Caudammina*, respectively *Karrerulina* and *Recurvoides.* Common constituents of the agglutinated microfauna are *Ammodiscus* div. sp., *Ammosphaeroidina pseudopauciloculata* (Mjatliuk), *Dorothia crassa* (Marsson), *Kalamopsis grzybowskii* (Dylążanka), *Paratrochamminoides* div. sp., *Rzehakina* div. sp., *Spiroplectammina dentata* (Alth) and *Subreophax scalaris* (Grzybowski) (Table 1; Figs 10, 11, 12). Only single calcareous benthic foraminifera are present; among them *Dentalina* div. sp., *Eponides* div. sp., *Osangularia* div. sp. are the most common. Among planktonic foraminifera *Globotruncana* div. sp. predominates, *Archaeoglobigerina* div. sp. and *Planoheterohelix globulosa* (Ehrenberg) are accessory species (Table 2; Fig. 13).

few complete specimens are visible (*Planoheterohelix* sp. indicated with arrow). Complete, primarily empty chambers of foraminifera, characterized by high buoyancy, were separated during downslope flow and eventually settled from suspension in contrast to material of lower part transported in traction. Sample ZDz 20. Plane-polarised light. **E.** Cross-section of bioturbation structure; its characteristic feature is increased content of silt-sized quartz grains and lack of bioclasts. Sample ZDz 20. Cross-polarised light. **F.** Cross-sections of compacted bioturbation structures. Sample ZDz 10. Cross-polarised light. **G.** Dispersed and very small foraminifers observed in T_e intervals. Sample ZDz 20. Plane-polarised light. **H.** Single, isolated silt-sized grains of quartz (red arrows) and bioclasts (white arrows); T_e interval. Sample ZDz 10. Cross-polarised light.

Table 1

Distribution of agglutinated foraminifera in the samples studied.

Taxon \ Sample	2/1/04	25/2/04	28/3/04	1/4/04	49/6/04	50/8/04	4/9/04	51/10/04	3/12/04	52/12/04	23/14/04	19/15/04	22/20/04	21/22/04	48/23/04	16/25/04	30/27/04	24/30/04	26/34/04	29/35/04
Ammobaculites sp.								I	I											
Ammodiscus cretaceus (Reuss)	II	I	I	IV	I			I		I						I	I			
Ammodiscus perruvianus Berry	II				I			II		I	I				I	I		I		
Ammodiscus planus Loeblich			I	I						I									I	
Ammodiscus pennyi Cushman et Jarvis		I																		
Ammodiscus tenuissimus Grzybowski		I	I	I	I	I		II		I	I	I	I		I	II	I	I		I
Ammodiscus sp.	I				I			I									I			
Ammosphaeroidina pseudopauciloculata (Mjatliuk)	I		II	II		I	I	I	I		I	I				I			III	
Annectina cf. *grzybowskii* (Jurkiewicz)											I									
Annectina sp.		I	I																	
Arthrodendron grandis (Grzybowski)				I											I		I		I	
Bathysiphon div. sp.	X	X		X	X	X	X	X	X	X			X	X	X		X	X	X	X
Caudammina excelsa (Dylążanka)			I	I				II							IV	I	I		I	
Caudammina ovuloides (Grzybowski)								III	I							I		I	IV	
Caudammina ovulum (Grzybowski)	I	I	I	IV	II	I		IV	I	I	I	I	I		I	IV	II	I	IV	I
Caudammina gigantea Geroch	V		II	VI	III	IV	III	IV	IV	I	I	I	I		IV	II	IV	IV	IV	II
Conglophragmium irregularis (White)		I		I	I	I			I		I	I				I	I	I	I	
Dorothia crassa (Marsson)	II	I	I		IV	II	I	I		I	I					I		II	II	
Glomospira charoides (Jones et Parker)				I							I					I	I			
Glomospira cf. *diffundens* Cushman et Renz				I												I				
Glomospira glomerata (Grzybowski)										I										
Glomospira gordialis (Jones et Parker)			I		I				I										I	
Glomospira irregularis (Grzybowski)																			I	
Glomospira serpens (Grzybowski)																			I	
Glomospira sp.								II				I								
Glomospirella sp.						I					I									
Haplophragmoides eggeri (Cushman)		I	I																	
Haplopragmoides kirki Wickenden		I						I			I	I								
Haplophragmoides suborbicularis (Grzybowski)																	I			
Haplophragmoides walteri (Grzybowski)								I			I									
Haplophragmoides spp.						1										I				
Hormosina velascoensis (Cushman)	I		I		1			I		I	I	I			I	I	I	I		I
Hormosina spp.	II							I			I					I				
Hyperammina elongata Brady				I						I							I			
Hyperammina sp.									I						I		I	I		
Kalamopsis grzybowskii (Dylążanka)	I		1		I	I		III		II	I	I					I		IV	I
Karrerulina coniformis (Grzybowski)	II			I	IV	III		IV		I		I	I	II		I			I	
Karrerulina conversa (Grzybowski)	IV	I	III	V	I		I	I				II	I			I	I		I	
Karrerulina sp.													I							

Taxon \ Sample	2/1/04	25/2/04	28/3/04	1/4/04	49/6/04	50/8/04	4/9/04	51/10/04	3/12/04	52/12/04	23/14/04	19/15/04	22/20/04	21/22/04	48/23/04	16/25/04	30/27/04	24/30/04	26/34/04	29/35/04
Nothia div. sp. (mainly *Nothia excelsa* (Grzybowski))	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Paratrochamminoides multilobus (Dylążanka)															I					
Paratrochamminoides olszewskii (Grzybowski)					I							I							I	
Paratrochamminoides div. sp. (*Lituotuba lituiformis* (Brady) included)	I	I		I			I		I		I						I			
Placentammina placenta (Grzybowski)	I	I1		I	II	I		II	I	I	I						I	I	I	
Psammosphaera scruposa (Berthelin)		I															I			
Psammosphaera sp.															I					
Recurvoides div. sp. and *Thalmannammina* div. sp.	II	II	III	IV	I	II	I	II	III		IV	I	I	I	II	II	III		III	II
Reophax duplex (Grzybowski)	I			I	I			I	I				I				I			
Reophax sp.	I		I								I					I				I
Rhabdammina div. sp. and *Psammosiphonella* div. sp., mainly *R. discreta* Brady	V		X	V	X			X	VI					X		I	X	X		
Rhizammina sp.		X					I	VI		I			I				X	I		
Rzehakina inclusa (Grzybowski)			I	I	I			I	I	I	I				I					
Rzehakina cf. *inclusa* (Grzybowski)				I	I															
Rzehakina epigona (Rzehak)								I												I
Rzehakina lata Cushman et Jarvis	I				II	I														
Rzehakina minima Cushman et Renz			I		III	II	I	II		I			I			I	I		I	
Rzehakina sp.				I				I			I									
Saccammina scabrosa Mjatliuk	I			II	I	I				I									I	
Saccammina grzybowskii (Schubert)		I						I	I	I								I		
Spiroplectammina dentata (Alth)		I	I	II	II	II	I	II		I				I				I		
Spiroplectammina navarroana Cushman			I	I																
Spiroplectammina subhaeringensis (Grzybowski)			II									I						I	II	
Spiroplectammina spp.														I				I		
Subreophax scalaris (Grzybowski)				I	II	I	I	I		I	I				I	I		I	II	
Subreophax pseudoscalaris (Samuel)			I					I									I			
Pseudoclavulina amorpha (Cushman)						I														
Trochammina globigeriniformis (Jones et Parker)			I	I			I								I	I			I	
Trochammina quadriloba (Grzybowski)			I																	
Trochamminoides subcoronatus (Grzybowski)		I	I	I					I		I					I	I		II	

I: 1–5 specimens, II: 6–10, III: 11–20, IV: 21–50, V: 51–100, VI: 101–200, X: more than 200 specimens.

Table 2

Distribution of calcareous foraminifera in the samples studied.

Taxon \ Sample	2/1/04	25/2/04	28/3/04	1/4/04	49/6/04	50/8/04	4/9/04	51/10/04	52/12/04	19/15/04	22/20/04	48/23/04	16/25/04	30/27/04	24/30/04	26/34/04	29/35/04	Thin sections
BENTHIC FORAMINIFERA																		
Alabamina spp.		I								I								
Allomorphina sp.				I														
Anomalina tenneseensis Berry															I	II		
Anomalina spp.										x								
Anomalinoides pinguis Jennings			I				I							I	I			
Buliminella carseyae Plummer							I											
Bolivinoides spp.			I							I				I				
Cibicides spp.																I		
Cribrebella fusiformis (Gawor-Biedowa)	I					I			I						I			
Ellipsoglandulina concinna Olbertz					I													
Eponides beisseli Schijfsma							I		I							I		
Eponides concinnus Brotzen			I		II	I			I	I								
Eponides diversus Belford							I										II	
Eponides subcandidula (Grzybowski)				III					I	I	I	I		I	I			
Eponides sp.		I	I	I						I		I	I	I	I			
Gavelinella sp.										x								
Gyroidinoides globosa (Hagenov)	I		I		I		I		I	I			I					
Gyroidinoides girardana (Reuss)							I			I								
Gyroidinoides nitida (Reuss)									I							I	I	
Gyroidinoides pontoni Brotzen									I									
Gyroidinoides and *Gyroidina* spp.		I								I			I		I		I	
Lagena spp.									I	I								
Laevidentalina megalopolitana (Reuss)									II									
Lenticulina sp.									I						I			
Laevidentalina monile Hagenow			I															
Nodosaria aspera Reuss					I													
Nodosaria gracillima (Cushman)	I								I									
Nodosaria gracilis d'Orbigny									II									
Nodosaria and *Dentalina* group forms	IV	x	I		I	I	I		x	I				I				
Nonion spp.		I																
Nuttallides trümpyi (Nuttall)												I	I	I				
Osangularia cordieriana (d'Orbigny)	II			II	II	I	I		I	I				I	I	II		
Osangularia crassaformis (Cushman et Siegfus)										I					I	I		
Osangularia velascoensis (Cushman)										I								
Osangularia navarroana (Cushman)																I		
Osangularia texana (Cushman)						I	I		I	I					II			
Osangularia spp.		I	I	I			I			I					I			
Oridorsalis megastomus (Grzybowski)		I	I				I								I			

Taxon / Sample	2/1/04	25/2/04	28/3/04	1/4/04	49/6/04	50/8/04	4/9/04	51/10/04	52/12/04	19/15/04	22/20/04	48/23/04	16/25/04	30/27/04	24/30/04	26/34/04	29/35/04	Thin sections
Praebulimina spp.				I														
Quadrimorphina allomorphinoides (Reuss)									I						I			
Stensioeina exsculpta (Reuss)				I						I								
Triloculina spp.				I														
PLANKTONIC FORAMINIFERA																		
Archaeoglobigerina cretacea (d'Orbigny)				I		I				I						I		
Archaeoglobigerina blowi Pessagno						I			I	I								
Archaeoglobigerina spp.		I		I		II			I	II								
Gansserina gansseri (Bolli)				I		I												
Globigerinelloides bollii Pessagno																		x
Globigerinelloides prairiehillensis Pessagno																		x
Globigerinelloides sp.							I											x
Globotruncana linneiana (d'Orbigny)	I		III	III	I		I		I	I	II				I	I		
Globotruncana lapparenti Brotzen				I	II						I					II		
Globotruncana arca (Cushman)	IV			I	II			I	I	II	I					I		
Globotruncana cf. *mariei* Banner and Blow										I								
Globotruncana cf. *orientalis* El Naggar						I				I							I	
Globotruncana cf. *bulloides* Vogler									I		I							
Globotruncana rosetta (Carsey)	I																	
Globotruncana spp.		I	I	II	I	I			x	III	I					I		
Globortuncanella havanensis (Voorvijk)																		x
Globotruncanella sp.										I								x
Globotruncanella petaloidea (Gandolfi)		I																
Globotruncanita cf. *stuartiformis* (Dalbiez)		I																
Globotruncanita insignis (Gandolfi)				I														
Muricohedbergella holmdelensis (Olsson)																		x
Planoheterohelix globulosa (Ehrenberg)				I		I			I	I								x
Planoheterohelix sp.																		x
Radotruncana cf. *subspinosa* (Pessagno)				I														
Rugoglobigerina rugosa (Plummer)									I									
Rugoglobigerina sp.							I											

I: 1–5 specimens, II: 6–10, III: 11–20, IV: 21–50, x–presence.

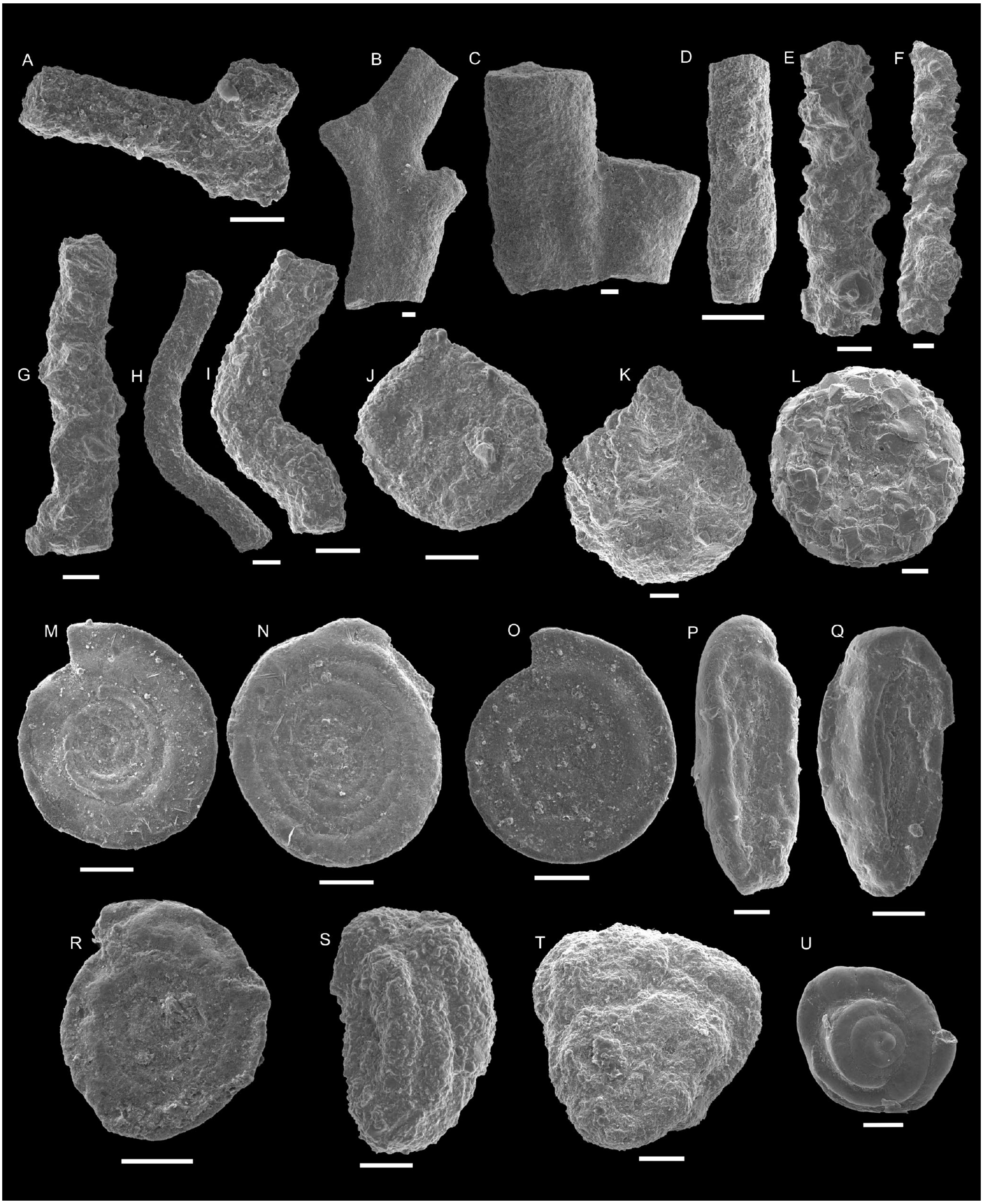


Fig. 10. SEM-images of agglutinated foraminifera from the Kropivnik Fucoid Marl in the Kąkolówka Structure. **A.** *Nothia excelsa* (Grzybowski) (sample (s.) 48/23/04). **B, C.** *Nothia robusta* (Grzybowski) (s. 48/23/04). **D.** *Rhabdammina discreta* Brady (s. 30/27/04). **E.** *Psammosiphonella cylindrica* (Glaessner) (s. 30/27/04). **F.** *Rhabdammina /Psammosiphonella* sp. with attached *Trochammina*-like form (s. 4/1/04). **G.** *Rhabdammina/Psammosiphonella* sp. (s. 22/20/04). **H.** *Rhizammina* sp. (s. 22/20/04). **I.** *Rhizammina* sp. (s. 4/9/04). **J.** *Placentammina placenta* (Grzybowski) (s. 52/12/04). **K, L.** *Placentammina placenta* (Grzybowski) (s. 49/6/04). **M.** *Ammodiscus tenuissimus* Grzybowski (s. 22/20/04). **N.** *Ammodiscus cretaceus* (Reuss) (s. 49/6/04). **O.** *Ammodiscus tenuissimus* Grzybowski (s. 49/6/04). **P.** *Ammodiscus peruvianus* Berry (s. 49/6/04). **Q.** *Ammodiscus peruvianus* Berry (s. 23/14/04). **R.** *Ammodiscus* sp. (s. 49/6/04). **S.** *Annectina* sp. (s. 25/2/04). **T.** *Glomospira irregularis* (Grzbowski) (s. 26/34/04). **U.** *Glomospira charoides* (Jones et Parker) (s. 23/14/04). Scale bar = 100 μm.

Biostratigraphical analysis of agglutinated foraminifera: The foraminifers from the washed samples are typical of the Upper Cretaceous deposits of the Outer Carpathians (e.g., Geroch *et al.*, 1967; Malinowska, 1984; Olszewska, 1997, and references therein; Table 1), including the Skole Nappe deposits (Koszarski and Ślączka, 1973; Kotlarczyk, 1978; Malinowska, 1984; Kotlarczyk *et al.*, 1988; Gasiński and Uchman, 2009, and references therein). The shortest stratigraphic range is given for *Rzehakina inclusa* (Grzybowski), occurring as single specimens in some samples (Table 1; Fig. 11). This species is commonly found in the Campanian–Maastrichtian deposits of the Outer Carpathians (e.g., Morgiel and Olszewska, 1981; Malata *et al.*, 1996; Olszewska, 1997; Cieszkowski *et al.*, 2007, and references therein). It is also an important biostratigraphic zonal marker used for age determination. Its occurrence determines the *Rzehakina inclusa* Zone of late Campanian–Maastrichtian age (Olszewska, 1997). The first occurrence of *Rzehakina inclusa* (Grzybowski) and the first occurrence of *Rzehakina fissistomata* (Grzybowski) define the lower and upper boundaries of that zone, respectively. The latter as well as other evidence of a Paleocene age were not recorded in samples of the soft marls from the Zimny Dział section. The most common Campanian–Palaeogene species among *Rzehakina* include *Rzehakina epigona* (Rzehak), *Rzehakina lata* Cushman et Jarvis and *Rzehakina minima* Cushman et Renz (Table 1; Fig. 11). Each of them occurs in quantities of up to several specimens per sample. The relatively great abundance of *Caudammina* is a characteristic feature of the agglutinated foraminifera assemblages (Table 1; Fig. 11). *Caudammina gigantea* (Geroch) is particularly numerous with an average proportion in agglutinated taxa of about 11%, in single samples exceeding 30% (estimate excludes tubular forms). The increased amounts of *Caudammina gigantea* (Geroch) are observed in samples characterized by relatively rich and diversified assemblages, which are represented by more than 100 specimens assigned to more than 20 species per sample (Tables 1, 2). Such relatively abundant assemblages are evidence of favourable conditions for the development of a benthic microfauna. In some samples, *Caudammina gigantea* (Geroch) is accompanied by increased numbers of *Caudammina ovula* (Grzybowski) or *Caudammina ovuloides* (Grzybowski). These forms are present both in Upper Cretaceous and lower Paleocene deposits, with the last occurrence of *Caudammina gigantea* (Geroch) assigned to the middle Paleocene (e.g., Geroch *et al.*, 1967; Geroch and Nowak, 1984; Malinowska, 1984; Olszewska, 1997; Kaminski and Gradstein, 2005; Waśkowska-Oliwa, 2008 and references therein). The mass occurrence of these taxa is known only from the Late Cretaceous, during the late Santonian–Campanian time interval (Morgiel and Olszewska, 1981; Olszewska, 1997). In the samples studied, the acme of *Caudammina gigantea* (Geroch) co-occurs with *Rzehakina inclusa* (Grzybowski) with a first occurrence in the late Campanian. Similarly, the coexistence of these two species is recorded in the deposits of the Silesian Nappe (Kępińska, 1986) and the Magura Nappe (Ślączka and Miziołek, 1995; Malata *et al.*, 1996). The stratigraphic zonation based on the Late Cretaceous foraminiferal assemblages of the Silesian Nappe is characterized by the *Caudammina gigantea* (Geroch) acme, then the co-occurrence of numerous *Caudammina gigantea* (Geroch) and *Rzehakina inclusa* (Grzybowski) and then the coexistence of *Rzehakina inclusa* (Grzybowski) with much less abundant *Caudammina gigantea* (Geroch) (Kępińska, 1986). In the Magura Unit, the co-occurrence of *Caudammina gigantea* (Geroch) and *Rzehakina inclusa* (Grzybowski) is restricted to the late early Campanian – earliest Maastrichtian (Malata *et al.*, 1996). However, there are poorly documented bases for the stratigraphic age mentioned above and there is no planktonic foraminiferal record that would give a positive age evaluation. Therefore, it only can be assumed that the assemblage containing many *Caudammina gigantea* (Geroch) co-occurring with *Rzehakina inclusa* (Grzybowski) represents the lower part of the *Rzehakina inclusa* Zone.

Biostratigraphical analysis of calcareous foraminifera: Among the planktonic foraminifera there are common cosmopolitan and long-lived forms, such as *Archaeoglobigerina* and Late Cretaceous (Santonian or Campanian––Maastrichtian) taxa. *Globotruncana arca* (Cushman) usually appears with *Globotruncana linneiana* (d'Orbigny). Moreover, much less abundant *Globotruncanita insignis* Gandolfi, *Globotruncana rosetta* (Carsey), *Globotruncana lapparenti* Brotzen, *Globotruncana* cf. *bulloides* Vogler, *Globotruncanita cf. stuartiformis* (Dalbiez) as well as *Rugoglobigerina rugosa* (Plummer) are present (stratigraphic ranges after Robaszynski *et al.*, 1984; Bolli *et al.*, 1985; Premoli Silva and Verga, 2004; BouDagher-Fadel, 2015 and references therein) (Table 2; Figs 13, 14). These species are not helpful for a more precise age determination. Some poorly preserved specimens of *Gansserina gansseri* (Bolli) were noted in some samples. Their occurrence has been recorded from the latest Campanian–late Maastrichtian (Premoli Silva and Verga, 2004; BouDagher-Fadel, 2015) and coincides in time with the *Gansserina gansseri* and *Abathomphallus mayaroensis* zones. Furthermore, the last *Globotruncana linneiana* (d'Orbigny), *Globotruncana lapparenti* Brotzen and *Archaeoglobigerina cretacea* (d'Orbigny) occurrences are found in the *Gansserina gansseri* Zone or in the *Contusotruncana contusa–Racemiguembelina fructicosa* Zone. On the basis of the planktonic foraminiferal assemblages, the age was determined as latest Campanian–earliest Maastrichtian, thereby making the agglutinated-taxa-based dating slightly more accurate.

Among the highly diversified calcareous benthic foraminifera assemblages, there are forms typical of a Cretaceous and Cretaceous – Early Palaeogene age. These are long-ranging taxa. Therefore, they are not used for biostratigraphic analysis (Table 2).

Foraminifera from thin-section analysis

In the hard, platy marls, the skeletal remains of foraminifera are common (Fig. 9B, D). They are found largely in intervals enriched in siliciclastic grains and are much rarer in the T_e intervals. Only the thin-walled, small planktonic foraminifera, of diameter less than 200 µm were present (Fig. 15). They largely consist of single chambers, or fragments, with major mechanical damage and advanced recrystallization. Few complete specimens were found in this

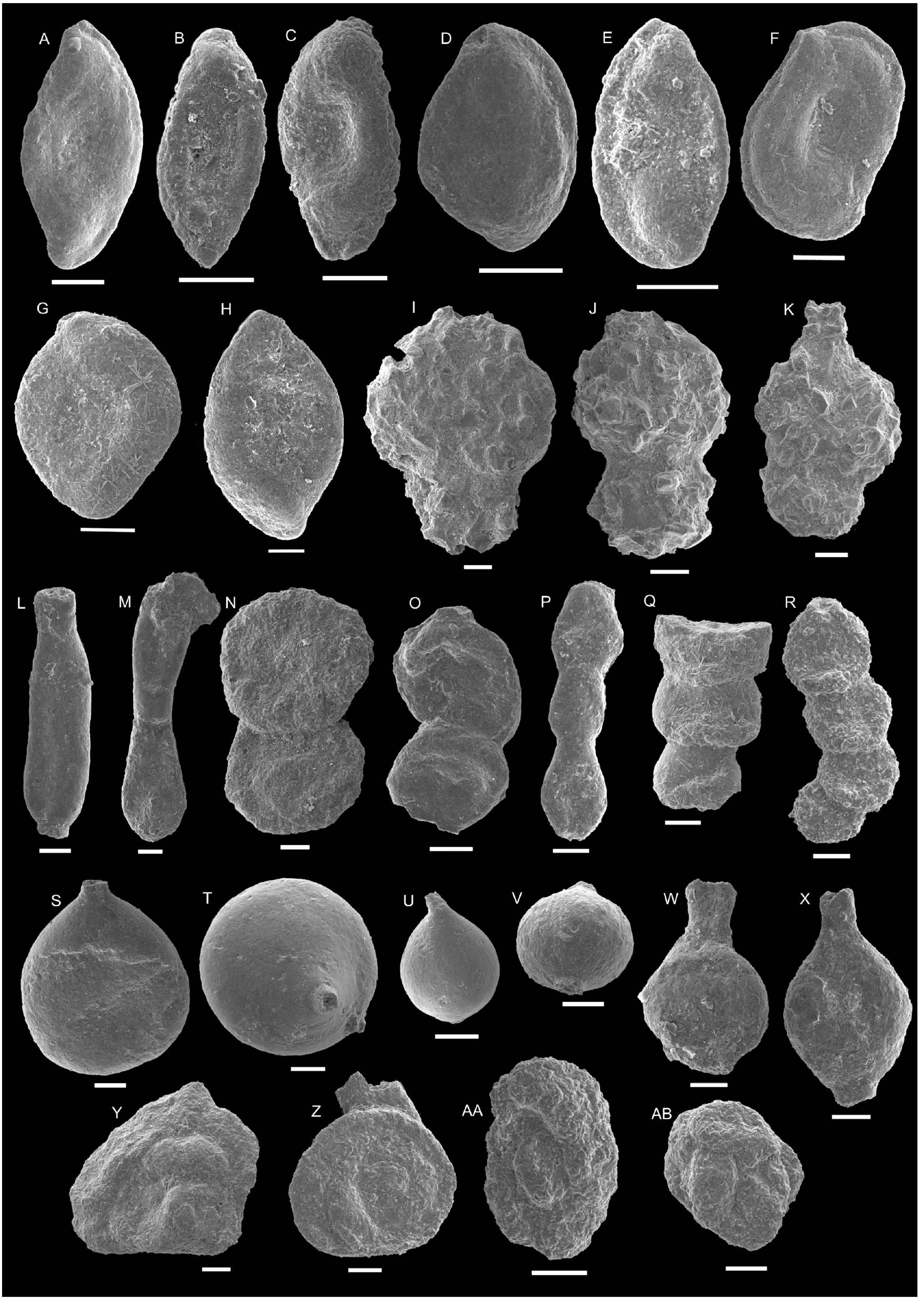


Fig. 11.

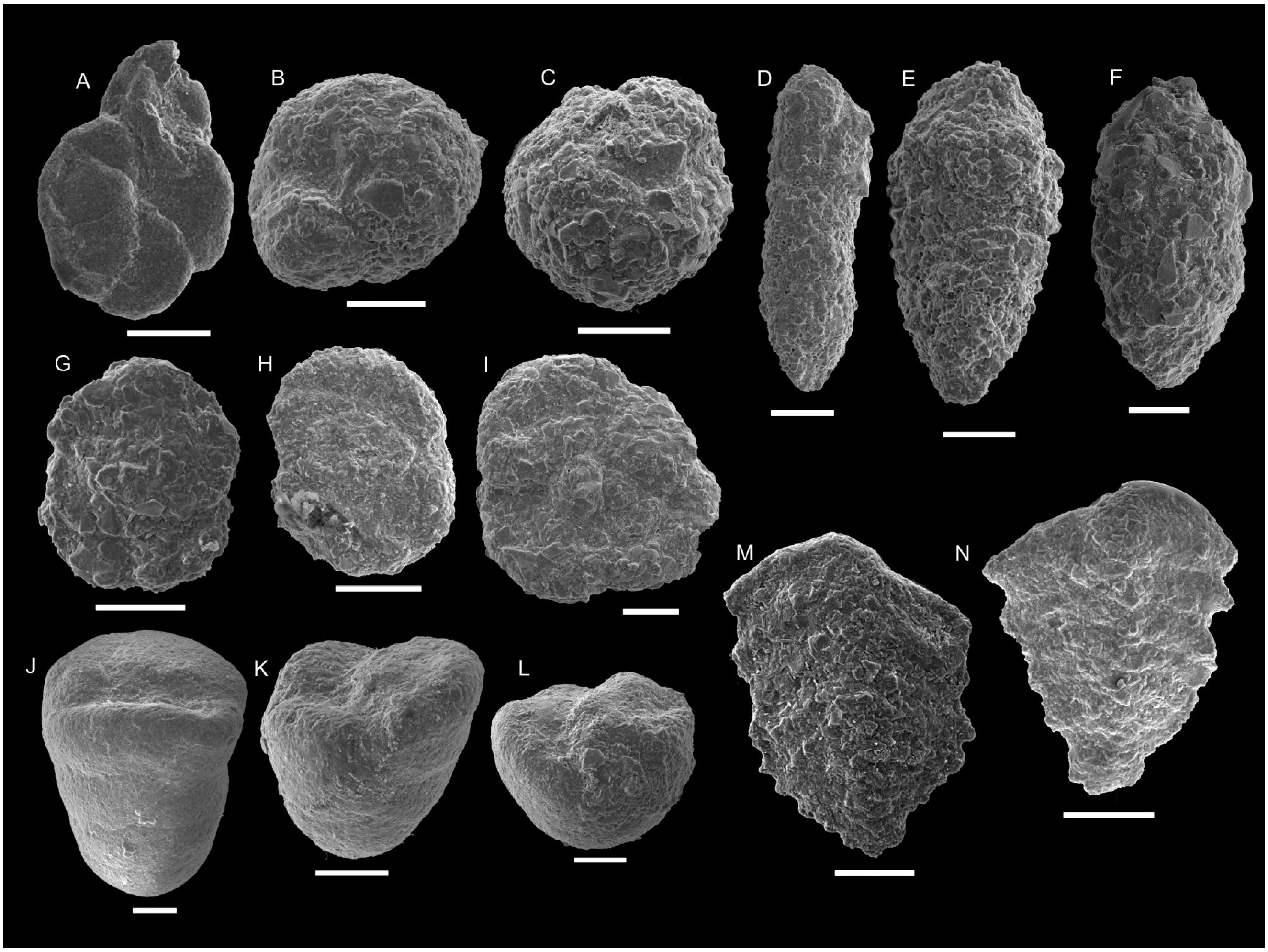


Fig. 12. SEM-images of the agglutinated foraminifera from the Kropivnik Fucoid Marl in the Kąkolówka Structure. **A.** *Haplophragmoides walteri* (Grzybowski) (sample (s.) 23/14/04). **B.** *Recurvoides nucleolus* (Grzybowski) (s. 25/2/04). **C.** *Recurvoides nucleolus* (Grzybowski) (s. 51/10/04). **D.** *Karrerulina conversa* (Grzybowski) (s. 19/15/04). **E.** *Karrerulina coniformis* (Grzybowski) (s. 16/25/04). **F.** *Karrerulina coniformis* (Grzybowski) (s. 19/15/04). **G.** *Ammosphareoidina pseudopauciloculata* (Mjatliuk) (s. 23/14/04). **H.** *Ammosphareoidina pseudopauciloculata* (Mjatliuk) (s. 30/27/04). **I.** *Trochammina globigeriniformis* (Jones et Parker) (s. 4/9/04). **J–L.** *Dorothia crassa (*Marsson) (s. 25/2/04). **M, N.** *Spiroplectammina dentata* (Alth) (s. 49/6/04). Scale bar = 100 μm.

Fig. 11. SEM-images of the agglutinated foraminifera from the Kropivnik Fucoid Marl in the Kąkolówka Structure. **A.** *Rzehakina minima* Cushman et Renz (sample (s.) 49/6/04). **B.** *Rzehakina minima* Cushman et Renz (s. 51/10/04). **C.** *Rzehakina* sp. (s. 23/14/04). **D.** *Rzehakina inclusa* (Grzybowski) (s. 23/14/04). **E.** *Rzehakina inclusa* (Grzybowski) (s. 28/3/04). **F.** *Rzehakina lata* Cushman et Jarvis (s. 49/6/04). **G, H.** *Rzehakina epigona* (Rzehak) (s. 51/10/04). **I.** *Reophax duplex* (Grzybowski) (s. 22/20/04). **J.** *Reophax duplex* (Grzybowski)(s. 49/6/04). **K.** *Reophax* sp. (s. 16/25/04). **L.** *Kalamopsis grzybowskii* (Dylążanka) (s. 23/14/04). **M.** *Kalamopsis grzybowskii* (Dylążanka) (s. 26/34/04). **N.** *Arthrodendron grandis* (Grzybowski) (s. 48/23/04). **O.** *Hormosina* sp. (s. 23/14/04). **P.** *Hormosina velascoensis* (Cushman) (s. 19/15/04). **Q.** *Hormosina velascoensis* (Cushman) (s. 52/12/04). **R.** *Subrepohax scalaris* (Grzybowski) (s. 26/34/04). **S, T.** *Caudammina gigantea* (Geroch) (s. 16/25/04). **U.** *Caudammina ovulum* (Grzybowski) (s. 23/14/04). **V.** *Caudammina ovulum* (Grzybowski) (s. 16/25/04). **W.** *Caudammina ovuloides* (Grzybowski) (s. 16/25/04). **X.** *Caudammina ovuloides* (Grzybowski) (s. 26/34/04). **Y.** *Paratrochamminoides acervulatus* (Grzybowski) (s. 25/2/04). **Z.** *Lituotuba lituiformis* (Brady) (s. 4/9/04). **AA.** *Paratrochamminoides gorayskii* (Grzybowski) (s. 23/14/04). **AB.** *Paratrochamminoides* sp. (s. 25/2/04). Scale bar = 100 μm.

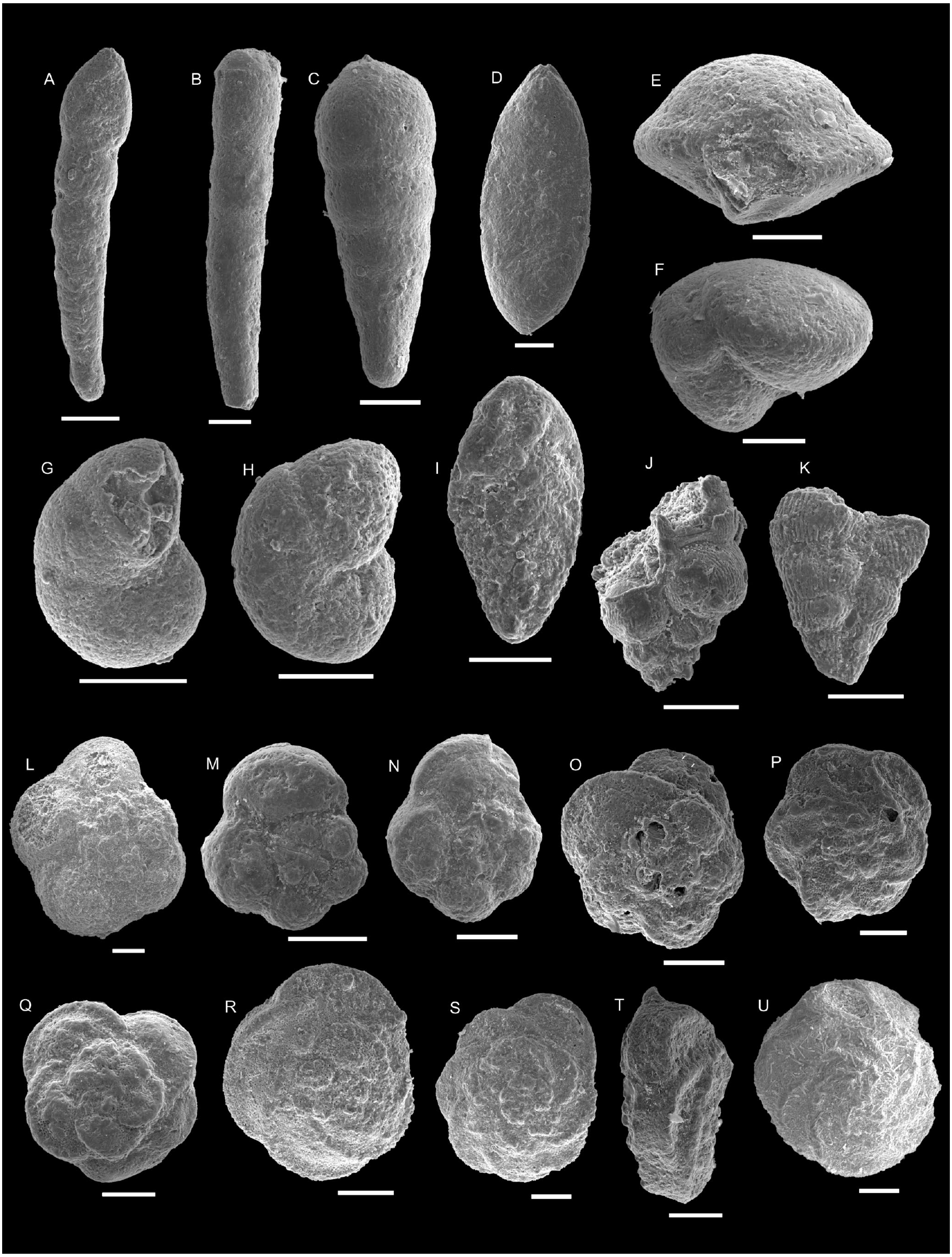


Fig. 13. SEM-images of the calcareous foraminifera from the Kropivnik Fucoid Marl in the Kąkolówka Structure. **A.** *Nodosaria gracillima* Costa (sample (s.) 52/12/04). **B.** *Ellipsoidina subnodosa* Guppy (s. 52/12/04). **C.** *Ellipsoglandulina concinna* Olbertz (s. 49/6/04). **D.** *Cribrebella fusiformis* (Gawor-Biedowa) (s. 52/12/04). **E.** *Oridorsalis megastomus* (Grzybowski) (s. 24/30/04). **F.** *Gyroidinoides globosa* (Hagenov) (s. 52/12/04). **G, H.** *Nonion* sp. (s. 25/2/04). **I.** *Bolivinoides* sp. (s. 30/27/04). **J.** *Planoheterohelix globulosa* (Ehrenberg)

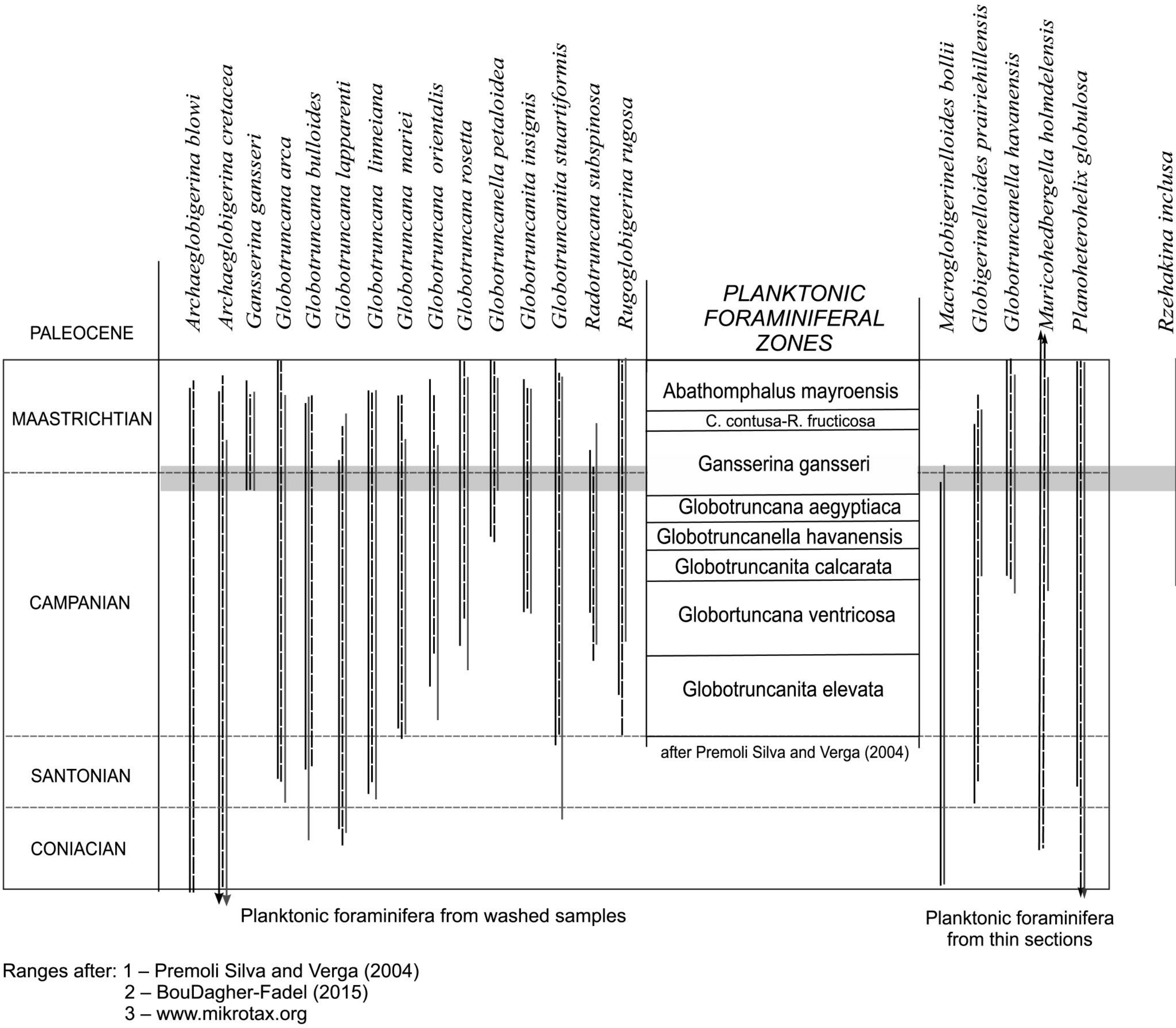


Fig. 14. The ranges of the planktonic foraminifera present in the marly succession of the Kąkolówka Structure.

material (Table 2; Fig. 15). They belong to cosmopolitan species, such as *Macroglobigerinelloides* cf. *bollii* Pessagno, *Globigerinelloides prairiehillensis* Pessagno, *Planoheterohelix globulosa* (Ehrenberg), *Muricohedbergella holmdelensis* (Olsson), and *Globotruncanella havanensis* (Voorvijk). They are all Late Cretaceous species and their stratigraphic ranges span to the Maastrichtian. The shortest range is given for *Globigerinelloides prairiehillensis* Pessagno. Its first occurrence is placed in the early Campanian or the latest Santonian, and its last occurrence is in the middle Maastrichtian, respectively (Bolli *et al.*, 1985; Premoli Silva and Verga, 2004, and references therein). The last occurrence of *Macroglobigerinelloides* cf. *bollii* Pessagno is assigned to the latest Campanian or the earliest Maastrichtian (*Gansserina gansseri* Zone) (Premoli Silva and Sliter, 2002; BouDagher-Fadel, 2015).

(s. 19/15/04). **K.** *Planoheterohelix* sp. (s. 49/6/04). **L.** A*rchaeoglobigerina cretacea* (d'Orbigny) (s. 26/34/04). **M.** *Archaeoglobigerina blowi* Pessagno (s. 52/12/04). **N.** *Archaeoglobigerina* sp. (s. 52/12/04). **O, P.** *Globotruncana arca* (Cushman) (s. 49/6/04). **Q.** *Globotruncana* cf. *bulloides* Vogler (s. 52/12/04). **R.** *Globotruncana linneiana* (d'Orbigny) (s. 22/20/04). **S.** *Globotruncana linneiana* (d'Orbigny) (s. 1/4/04). **T.** *Globotruncana linneiana* (d'Orbigny) (s. 22/20/04). **U.** *Globotruncana lapparenti* Brotzen (s. 1/4/04). Scale bar = 100 μm.

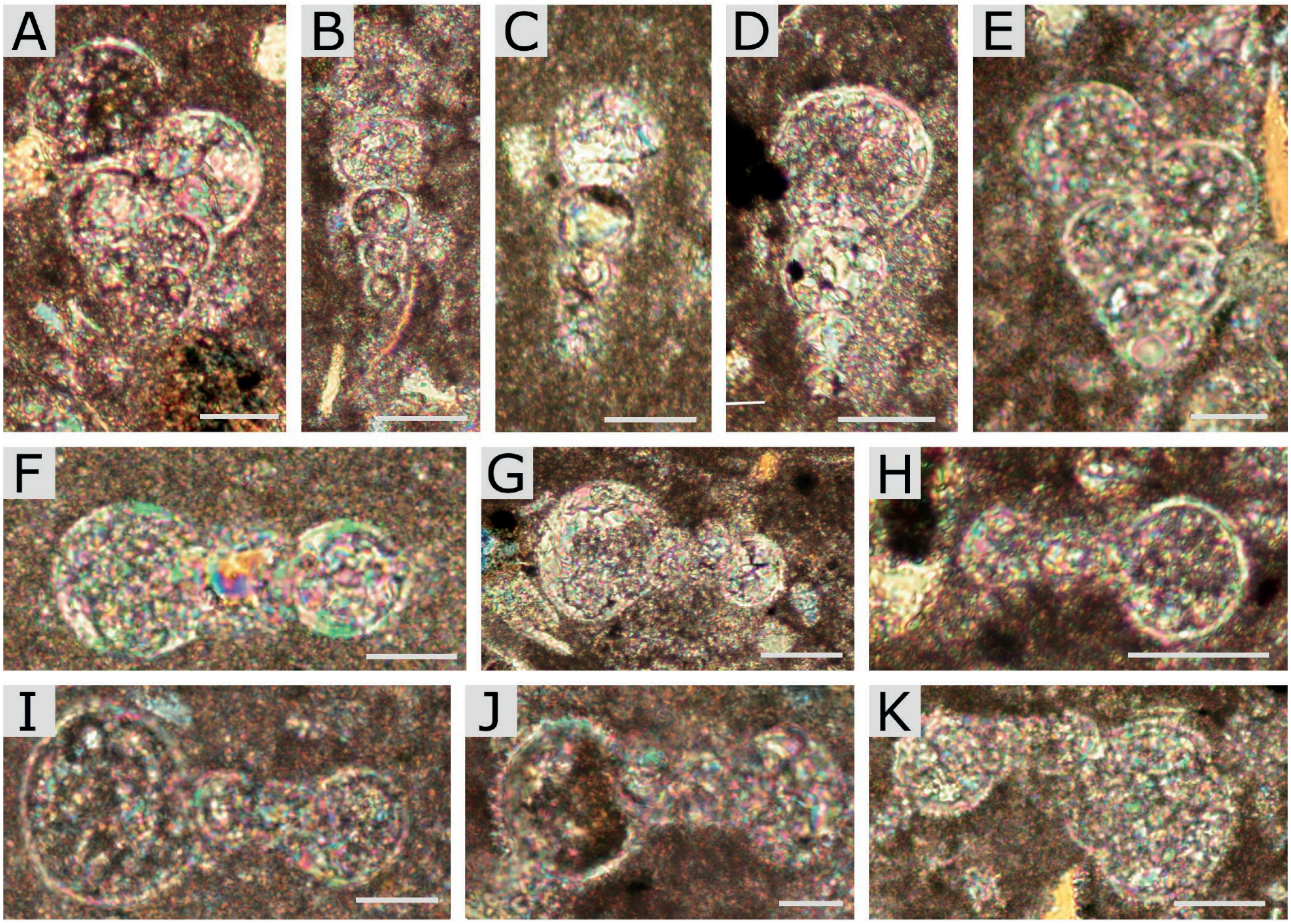


Fig. 15. The planktonic foraminifera in thin-sections from hard, platy marls. **A–E.** *Planoheterohelix globulosa* (Ehrenberg) (sample (s.) ZDz 20). **F.** *Macroglobigerinelloides bollii* Pessagno (s. ZDz 20). **G.** *Globigerinelloides prairiehillensis* Pessagno (s. ZDz 20). **H, J.** *Globigerinelloides prairiehillensis* Pessagno (s. ZDz 20). **I.** *Globigerinelloides prairiehillensis* Pessagno (s. ZDz IV). **K.** *Muricohedbergella holmdelensis* (Olsson) (s. ZDz 20). Scale bar = 50 µm.

DISCUSSION

Lithostratigraphy and lithological development

The Ropianka Formation is subdivided into four members. The subdivision is based on discriminating three depositional cycles. The two lower cycles consist of consecutive sequences of calciturbidites passing into siliciclastic turbidites (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988). The Cisowa and Wiar members respectively are distinguished on this basis. The marl units are separated in the lower part of both divisions. In the Wiar Member, the marl member is called the Kropivnik Fucoid Marl and passes into siliciclastic turbidity current deposits called the "normal" Turnica Flysch (Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995) or the Turnica "above-marls sequence" (Kotlarczyk, 1978).

Only two members of the Ropianka Fm can be clearly distinguished in the inner part of the Skole Nappe in the Kąkolówka Structure: (1) the 600-m-thick Wiar Member and (2) the 200-m-thick Leszczyny Member (Kotlarczyk and Joniec, 2000). The succession of shales, marls and sandstones, with intercalations of hard platy marls, occurs in the outcropping lower part of the Wiar Member. Their facies development and age correlate with those of the Kropivnik Fucoid Marl. It is overlain in turn by a succession of thick-bedded siliciclastic turbidites which corresponds to the Turnica Flysch. The Kropivnik Fucoid Marl is clearly delineated in the sections studied. Its boundary with the overlying the Turnica Flysch is sharp. Deposits underlying the Kropivnik Fucoid Marl were not recognized. As at Kąkolówka, a sharp lithological boundary between the Kropivnik Fucoid Marl and the Turnica Flysch is recorded in the Wola Korzeniecka section (inner part of the Skole Basin). However, in other sections located in the same part of the Skole Basin, the thick-bedded sandstones occur in different positions in the Wiar Member (Kotlarczyk, 1978; Kotlarczyk and Joniec, 2000). The transition between the Kropivnik Fucoid Marl and the Turnica Flysch is gradational in the stratotype area. Moreover, the Turnica Flysch is developed there as thin-bedded turbidites (Kotlarczyk, 1978). The boundary between the Kropivnik Fucoid Marl and the Turnica Flysch is marked by the discontinuous Sopotnik Variegated Shale Horizon found in both the inner and outer parts of the Skole Nappe (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Kotlarczyk and Joniec, 2000). This horizon was not recorded in the Zimny Dział area.

The lithological development of the Kropivnik Fucoid Marl is diversified in the inner zone of the Skole Nappe. The lower or middle parts of the Wiar Member contain couplets of thin-bedded calcareous sandstones and shales, locally with bioturbated marls and interbedded thick-bedded sandstones. This 'sandstone-shale flysch' lithofacies shows a gradual transition to 'carbonate flysch' towards the outer basinal zone (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988). The general opinion is that the lithological development of the Wiar Member changes towards the inner part of the Skole Basin. This transition is related to the successive replacement of marls by thick-bedded sandstones to the point that there is a complete decline of the marls (Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988). The predominance of siliciclastic sedimentation, significantly diluting carbonate sedimentation in the inner part of the Skole Basin, causes difficulties for the subdivision of the Wiar Member into lower-ranking units. This problem also concerns the Kropivnik Fucoid Marl, which was distinguished on the basis of the occurrence of marly facies in the outer part of the Skole Nappe (e.g., Kotlarczyk, 1978; Kotlarczyk *et al.*, 1988; Leszczyński *et al.*, 1995). The presence of the clearly delineated Kropivnik Fucoid Marl strata in the Kąkolówka Structure indicates that marl sedimentation, diluted to a lesser extent by detrital siliciclastic input, was an element of the depositional system of the inner Skole Basin. The investigation of the Zimny Dział sections makes the description of the lithofacies development of the Kropivnik Fucoid Marl more detailed. The Kropivnik Fucoid Marl is dominated here by shales and soft marls, intercalated with thin-bedded sandstones or hard, platy marls.

Three lithofacies were distinguished in the Kropivnik Fucoid Marl in the outer zone of the Skole Basin (in the stratotype area; Leszczyński *et al.*, 1995); these are: marls, marls and shales, shales (shales with sandstones). The first one, predominated by hard, platy marls, and a subordinate proportion of soft marls, shales and sandstones, is completely lacking in the Zimny Dział sections, but equivalents of the latter two were documented there. The most common is the shales-with-sandstones lithofacies, composed of shales with intercalations of thin-bedded sandstones, occurring with layers of soft marls and hard, platy marls. About 30% of the deposits constitute the equivalent of the marl-and-shale lithofacies. The occurrence of packets consisting of turbidite multi-sets is frequently observed in the Zimny Dział sections. Leszczyński *et al.* (1995) indicated that this feature is characteristic. Generally, in the inner part of the Skole Basin, the ratio of the marly and siliciclastic deposits share changes and a reduction of the marly deposits is observed in comparison to the stratotype area.

Biostratigraphy

The age of the Kropivnik Fucoid Marl in the outer part of the Skole Nappe (the stratotype area) is considered to be late Campanian – early Maastrichtian (Kotlarczyk, 1978; Kotlarczyk and Mitura, 1996) or late early Campanian – early Maastrichtian (Kotlarczyk *et al.*, 1988) on the basis of planktonic and benthic foraminifera and inoceramids. Nannoplankton indicate a Santonian/Campanian – earliest Maastrichtian age (Leszczyński *et al.*, 1995). The new biostratigraphical data of this paper relate to the middle and upper parts of the Kropivnik Fucoid Marl, though no sections are available to be sampled in the lower part. They point to a latest Campanian – early Maastrichtian age. Thus, the part of the Kropivnik Fucoid Marl studied belongs to the *Gansserina gansseri* Zone. The planktonic foraminifera collected from the hard, platy marls include, among others, *Macroglobigerinelloides* cf. *bollii* Pessagno, the last occurrence of which is reported from the latest Campanian or earliest Maastrichtian (Premoli Silva and Verga, 2004; BouDagher-Fadel, 2015) and it may be placed in the lower part of the *Gansserina gansseri* Zone. The foraminifera found in the hard, platy marls are represented by biserial, planispiral or low-trochospiral forms only and no keeled ones were registered. Plankton restricted to biserial or non-keeled forms lived in inner neritic waters (shallow, coastal waters, not deeper than a few tens of metres) during the Late Cretaceous (Premoli Silva and Sliter, 1999; BouDagher-Fadel, 2015, and references therein). Therefore, planktonic tests of such a type are considered to have been transported to the deeper parts of the Skole Basin and deposited together with clastic and calcareous material. This material, comprising planktonic foraminifera redeposited from the shallow shelf zone, according to the principles of stratigraphy, is older than or of the same age as the deposits of the Kropivnik Fucoid Marl. With some caution, it may be assumed it is isochronous: the preservation state of thin-walled, very delicate foraminifera tests indicates that they were redeposited from loose, unconsolidated shelf deposits. Moreover, significant fragmentation of the tests indicates that they were transported freely in suspension or in traction towards deeper parts of the Skole Basin. Therefore, the process of redeposition relates only to a post-depositional change in the position of primarily shelf sediments. It is a typical and common process known from many modern sedimentary basins. Taking this into consideration, the upper time limit for deposition of the Kropivnik Fucoid Marl can be estimated at the latest Campanian or earliest Maastrichtian, i.e., the lower part of the *Gansserina gansseri* Zone.

The micropalaeontological material sampled by the present authors from the stratotype area (the Wiar section) is characterized by high taxonomic diversity of foraminiferal assemblages; a high proportion of calcareous forms (both planktonic and benthic), or their predominance over agglutinated forms was observed. Kotlarczyk (1978) and Kotlarczyk *et al.* (1988) also mention numerous species of calcareous foraminifera, both planktonic and benthic, found in the stratotype sections. In turn, in material from the Kąkolówka Structure, a significant decline in the number of calcareous forms was noted; agglutinated foraminifera, including single-chambered, creeping ones of *Nothia* type, predominate. This difference in composition of foraminiferal assemblages from more proximal (stratotype area) and more distal settings (the Kąkolówka Structure) may have been connected with a basinward increase in water depth. The influence of the sedimentary regime also may have been an important factor, because of an increase in the fraction of coarse-grained clastic facies (Kotlarczyk, 1978;

Kotlarczyk *et al.*, 1988): intensified input of siliciclastics limited the growth of calcareous benthic foraminifera.

However, taking into account the taxonomic diversity and the occurrence of representative forms of all morphogroup types *sensu* Jones and Charnock (1985), it seems that general ecological conditions were quite favourable for the unconstrained development of benthic foraminifera during periods of calm sedimentation, dominated by the settling of material from suspension. One of the features of benthic taxa assemblages is rapid change in species composition. Here, depositional conditions were crucial, including the rapid sedimentation of sand which disrupted the development of a benthic fauna.

Agglutinated foraminiferal assemblages are used widely in the Outer Carpathians biostratigraphy. This is due to their widespread occurrence and the lack of other groups of fossils of stratigraphic significance. A relatively wide time span of biozones is due to the low taxonomic diversity of agglutinated taxa. The regional Carpathian zonation of the latest Cretaceous, from the Santonian to Maastrichtian, is based on the occurrence of the *Caudammina gigantea* (Geroch) acme and *Rzehakina inclusa* (Grzybowski). In the upper part of time interval of the *Caudammina gigantea* (Geroch) acme, the first occurrence of *Rzehakina inclusa* (Grzybowski) is found. Thus, there is an opportunity to improve the agglutinated taxa biozonation. The results of biostratigraphical analyses from the Kąkolówka Structure indicate that the co-occurrence of large numbers of *Caudammina gigantea* (Geroch) with *Rzehakina inclusa* (Grzybowski) lasted up until the earliest Maastrichtian. This fact can be included in the regional biostratigraphy. The confirmation of an overlap of the stratigraphic ranges of *Caudammina gigantea* (Geroch) with *Rzehakina inclusa* (Grzybowski) provides the possibility to distinguish the zone of their co-occurrence, which spans from the middle Campanian to the beginning of the Maastrichtian. It will significantly improve the biostratigraphic zonation of the Late Cretaceous.

CONCLUSIONS

1. In the inner part of the Skole Basin (northern part of the Kąkolówka Structure), in the Ropianka Formation, a 250-m-thick turbiditic succession with a significant amount of marls is present. Their lithological development, position in profiles, and age indicate that they belong to the Kropivnik Fucoid Marl in the lower part of the Wiar Member.
2. The characteristic feature of the studied succession is the occurrence of thinly bedded, hard, platy marls and soft marls. They appear within three main types of heterolithic facies associations: shale-sandstone (the most abundant), marl-sandstone and sandstone-shale.
3. The diverse assemblage of agglutinated foraminifera with minor calcareous ones (benthic and planktonic) are preserved in soft marls and shales of the Zimny Dział section. The typical feature is the co-occurrence of numerous *Caudammina gigantea* (Geroch) with *Rzehakina inclusa* (Grzybowski), which is noted up to the lowermost Maastrichtian, inclusively.
4. The deposition of the middle and upper part of the Kropivnik Fucoid Marl complex took place in the latest Campanian (or from the latest Campanian to earliest Maastrichtian), which corresponds with the age determination of the Kropivnik Fucoid Marl from the stratotype area representing the outer, shallower part of the Skole Basin. The agglutinated foraminiferal assemblages are representative of the lower part of the *Rzehakina inclusa* Zone; planktonic foraminifera are representative of the lower part of the *Gansserina gansseri* Zone.
5. Redeposited planktonic foraminiferal tests occur in the Kropivnik Fucoid Marl deposits. They were supplied from probably unconsolidated shallow-water sediments, deposited in the inner neritic zone. Their rich concentrations are found in the hard, platy marls, although they are rare in the shales and soft marls.

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