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Pliocene freshwater pollen-bearing deposits in the Mizerna-Nowa borehole, West Carpathians, Poland

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This paper describes sedimentology and palynology of freshwater plant-bearing late Cenozoic (Pliocene *sensu lato*) deposits drilled at Mizerna, the eastern part of the Nowy Targ Intramontane Depression, West Carpathians, southern Poland. Our data were obtained from a newly-analysed 39 m thick succession from the Mizerna-Nowa borehole, containing spores, pollen and freshwater organic-walled algal micro-remains. They shed light on the palaeoenvironmental conditions of the Nowy Targ Intramontane Depression, where the Mizerna palaeolake once formed.

Key words: West Carpathians, Mizerna palaeolake, Pliocene, deposits, palaeoenvironment, palynology.

INTRODUCTION

This paper discusses the geology, sedimentology, palaeobotany, palaeoenvironments and stratigraphy of the freshwater late Cenozoic strata drilled in the Mizerna-Nowa borehole in the eastern part of the Nowy Targ Intramontane Depression, West Carpathians, southern Poland. The borehole, which was ca. 39 m deep, was drilled in June 1979 for scientific purposes. Sediment and palynological samples from this borehole are housed in the Museum of the W. Szafer Institute of Botany, Polish Academy of Sciences.

The Mizerna freshwater deposits, which are rich in well-preserved plant remains, have been known for over sixty years from the eastern termination of the Nowy Targ Intramontane Depression, at the entrance to the Pieniny Mountains (Czorsztyn Range) – see Figure 1. They are listed among the most important late Cenozoic palaeobotanical sites in central Europe. According to Szafer (1949, 1952, 1954), their macrofloral remains document the development, succession and changes of vegetation cover in the West Carpathians during the Pliocene and Early Pleistocene.

Oszast (in Szafer, 1954; Szafer and Oszast, 1964; Oszast, 1973) made the first palynological studies of the Mizerna freshwater deposits. In one borehole section, site “A” (see Fig. 2), she recognized an upwards decrease in a warm-temperate element, the “Tertiary trees”, along with a simultaneous increase in herbaceous plant pollen. Seven successive floral assemblages, based on both macrofloral remains and pollen associations, were identified by Szafer and Oszast (1964), and their character became a basis for constraining the Late Pliocene/Pleistocene boundary, as well as Early Pleistocene palaeoclimatic epochs, in the Mizerna succession.

A re-evaluation of the palaeoclimatic and stratigraphical significance of the macroflora, along with a reassessment of the palaeoenvironmental and sedimentary conditions during the formation of the Mizerna freshwater deposits, has recently been initiated by Zastawniak-Birkenmajer and Birkenmajer (2012). They also reopened the question of the Pliocene/Pleistocene boundary and the presence/absence of Early Pleistocene deposits at Mizerna. These topics are discussed here based on spore-pollen analysis prepared by E. Worobiec and sedimentological analysis of the borehole log by K. Birkenmajer.

GEOLOGICAL SETTING

During the Late Neogene, weathered material from Paleogene flysch strata – the sandstones and shales of the Magura Nappe which constitute the Gorce Mountain Range and its southern foothills, was redeposited by rainfall, slope creep and slumps and streams into a shallow lake that flooded the eastern part of the Nowy Targ Intramontane Depression. Two stages of infilling of this lake are inferred: (1) Miocene (?Middle Miocene), which was disturbed by the transverse faulting of the Styrian Phase, and (2) Pliocene.

1. The older stage is represented by thin plant-bearing freshwater deposits formerly exposed at Huba (Fig. 1: Huba 1 – cf. Birkenmajer et al., 2010). In 1949 they were penetrated by a shallow borehole down to their Paleogene flysch base, found at 7.5 m below the surface. Originally, these deposits were attributed to the Pliocene (Szafer, 1949, 1954) and later to the Miocene (“Badenian” – Oszast, 1973). Presently, the site is

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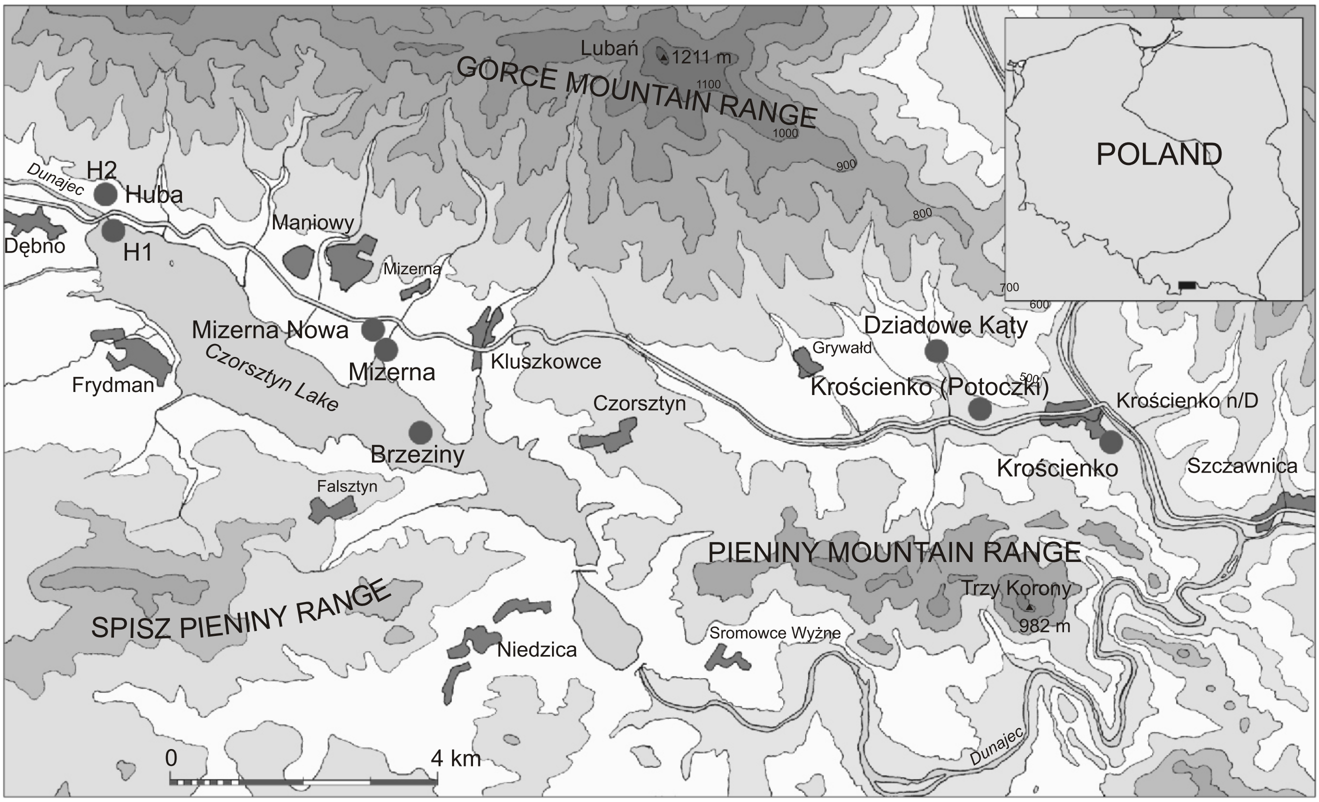

Fig. 1. Location of the Miocene, Pliocene and Pleistocene plant-bearing sites in the eastern part of the Nowy Targ Intramontane Depression and the Pieniny Mountains, West Carpathians, southern Poland (inserted map)

H 1 – Huba 1, Miocene; H 2 – Huba 2, Mindel/Riss Interglacial (= Mazovian Interglacial); Mizerna, Mizerna-Nowa – Pliocene; Brzeziny – Brørup Interstadial; Krościenko (Potoczki) – Pliocene; Dziadowe Kąty and Krościenko – Late Pleistocene

drowned by the waters of the artificial Czorsztyn Lake (see Birkenmajer, 2010).

2. The younger stage is represented by freshwater plant-bearing deposits (Pliocene and Early Pleistocene after Szafer, 1954; Szafer and Oszast, 1964; Oszast, 1973): mainly sandy clays and sands, often with unworked fragments of flysch sandstone and shale, rich in well-preserved macroscopic plant remains. They were once exposed and drilled at Mizerna near Czorsztyn (Figs. 1–4). The main exposures, now under the water of the artificial Czorsztyn Lake, lay along the Mizerka and Koprocz streams – both left tributaries of the Dunajec River. The freshwater deposits fill a narrow buried valley about 600 m long (Fig. 2) eroded in the strongly folded Paleogene flysch beds of the Magura Nappe – the southernmost tectonic unit of the Outer Carpathians (see Birkenmajer, 1954, 1958, 1961, 1963, 1979).

In a deeper part of the Mizerna succession, there occurs a 1.7 m thick intercalation of loose sandy gravels consisting of rounded to well-rounded pebbles of Lower Triassic quartzite, Carboniferous granite and pegmatite derived from the Tatra Mountains. This is the first sign that rivers, which were dissecting the Tatra Massif and its Paleogene cover, finally reached down to the core of the massif (Birkenmajer, 1954, 2009).

Mizerna-type plant-bearing freshwater deposits have also been encountered in a borehole about 100 m below the Dunajec River bed in the Frydman Graben, in the easternmost part of the Nowy Targ Intramontane Depression (Niedzielski, 1971). The capping deposits are mainly represented by the Tatra Mts.-derived glaciofluvial gravel, correlatable with the Mindel and Riss glaciations of the Tatra Mts., and divided by an interglacial-type freshwater sequence, correlatable with the Mindel/Riss (Mazovian Interglacial) lacustrine deposits at Huba, west of Mizerna (cf. Birkenmajer, 1979; Birkenmajer et al., 2010). The downfaulting which produced the Frydman Graben most probably happened during the Riss/Würm Interglacial.

The northern boundary fault which divides the Pieniny Klippen Belt from the Magura Nappe contact has intermittently been active throughout the Quaternary: during the Mindel/Riss Interglacial, at Szaflary Quarry (Birkenmajer and Stuchlik, 1975; Birkenmajer, 1976); during the Riss/Würm Interglacial, or later, at Huba 2 (Birkenmajer et al., 2010); even now, weak earthquakes affect the tectonic zone of the Pieniny Klippen Belt and its vicinity.

The Mizerna-Nowa borehole studied is located on the left slope of the Koprocz Stream (Fig. 4). Its stratigraphic description is given in Appendix 1*.

STRATIGRAPHIC SUBDIVISION AND THE SEDIMENTARY PALAEOENVIRONMENT

The Mizerna-Nowa borehole succession may be subdivided into four parts (A–D), which differ in the proportion of lacustrine bottom clay (Lc) to river sand and gravel (Fs+g) deposits, and in the presence or absence of subaqueous slump struc-

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* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1075

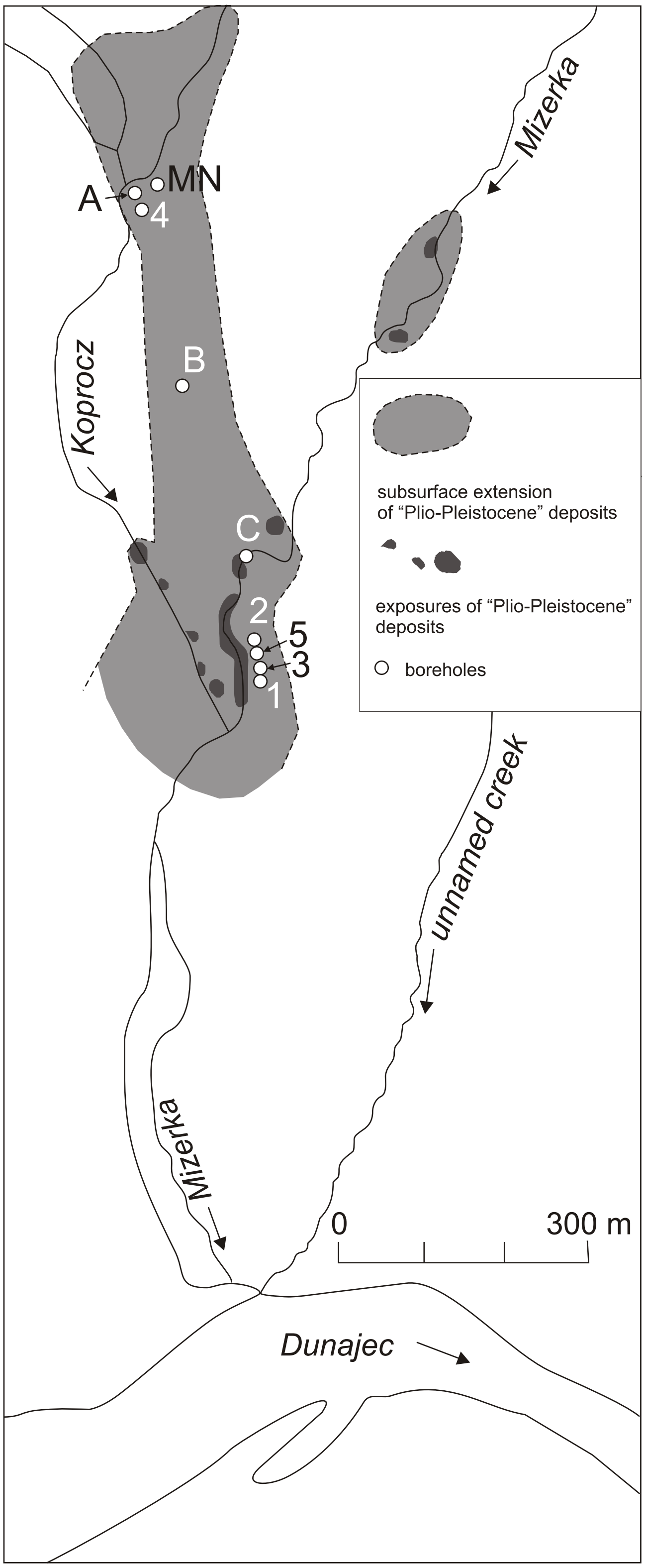


Fig. 2. Mizerna site – buried river valley filled with fluvial and lacustrine Pliocene and "Plio-Pleistocene" deposits

Boreholes (A, B) and natural exposures (1–5, C) as in Szafer (1954) and Birkenmajer (1954, 1958, 1961); MN – Mizera-Nowa borehole

tures (Fig. 5). This subdivision reflects the sedimentary/palaeoenvironmental history of the freshwater Mizerna palaeolake which, during the late Cenozoic, occupied the easternmost part of the Nowy Targ Intramontane Depression, and was dammed to the east by a rocky threshold of the Zielone Skałki–Czorsztyn Castle klippes.

The history of the Mizerna palaeolake was certainly interconnected with the stages of formation of the Dunajec River Gap through the Pieniny Mountain Range. This will be discussed separately. Here, we note only some features having a bearing on the history of the palaeolake:

- the Mizerna palaeolake probably occupied an area of about 8 × 2 km, between Dębno–Huba in the west, and the Spisz Pieniny–Gorce Ranges in the east, being comparable in location and size to the present artificial Czorsztyn Lake (see Fig. 1);
- the buried river valley of Mizerna, a tributary of the Dunajec River, represented the northern bay of the palaeolake;
- the lake was probably very shallow and intermittently filled by sand and gravel brought from the southern slopes of the Gorce Mountain Range by rivers, slope creep and landslides;
- the typical lake deposits are represented by bottom clay with fragmented plant remains;
- channelling of the lake sediment by water currents, either underwater or in subaerial conditions, was difficult to demonstrate in our borehole. As suggested by some exposures (now unavailable because of drowning by the artificial lake), the sand often filled erosional channels;
- it is likely that earthquakes played an important role in the formation of the lower part of the succession, triggering subaqueous slumps of unconsolidated deposits.

BEDROCK

The bedrock of the Mizerna deposits is represented by the oldest lithostratigraphic units of the Magura Nappe (Birkenmajer, 1963): the Szczawnica Formation (Paleocene–Lower Eocene) and the Zarzecze Formation (previously Sub-Magura Beds, Eocene – Birkenmajer, 1963; for formalization of the lithostratigraphic units see Birkenmajer and Oszczypko, 1988, 1989). During the Pliocene, the easternmost part of the Nowy Targ Intramontane Depression was already deeply incised by the Dunajec River and its tributaries: down to ca. 505 m above sea level (a.s.l.) in the major valley, and down to 512 m a.s.l. in the Mizerka–Koprocz streams (Fig. 4). The regional fluvial pattern had therefore been stabilized before inundation by the Mizerna palaeolake.

The occurrence of a 2 m thick fossil soil (regolith), at about 512 m a.s.l., below the Mizerna deposits, indicates a quiet period of weathering which preceded inundation by the palaeolake waters.

(A) FLUVIAL STAGE

The basal part of the succession, which is 7 m thick (beds 1–9 – see Fig. 5, Appendix 1), displays fluvial features: gravel beds (Fg) consisting of angular fragments of local flysch strata alternating with sand beds (sand bars – Fs). With the exception of the lowest bed (bed 1: 35.7–36.0 m), which contains flat

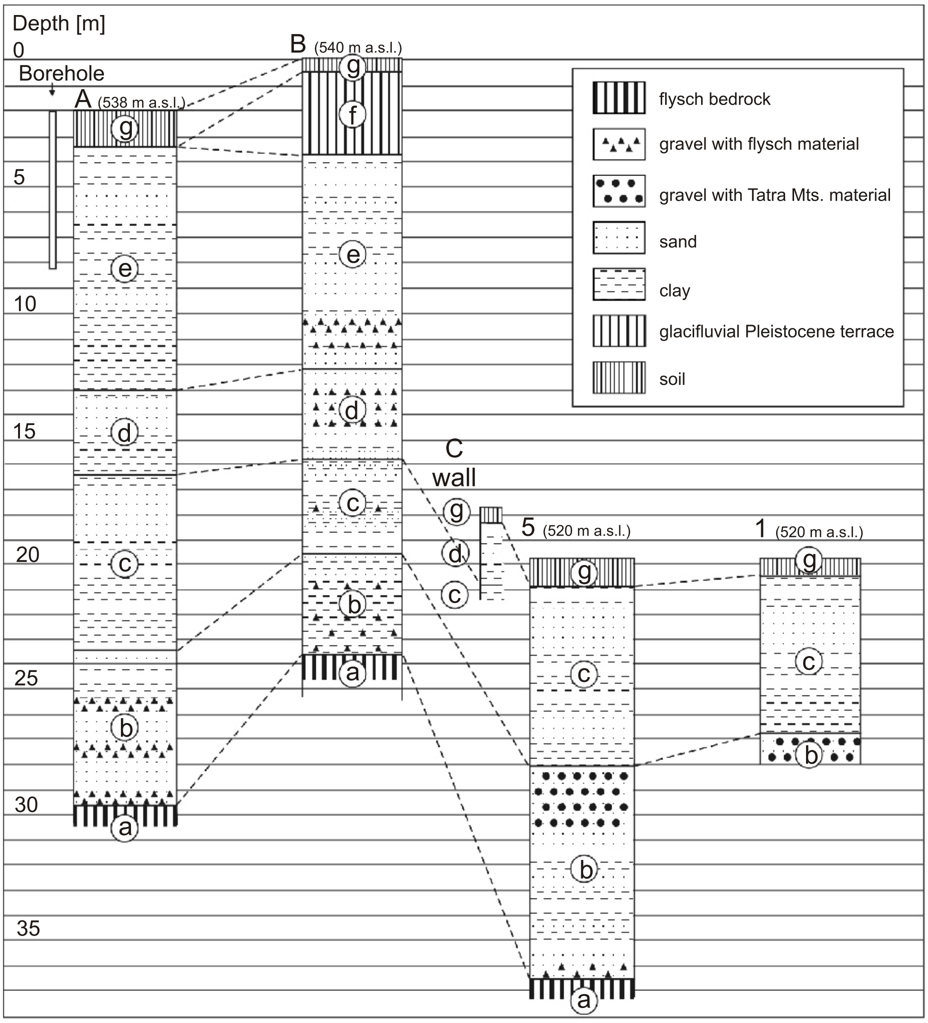


Fig. 3. Mizerna site – geological structure of the fluvial to lacustrine deposits (after Birkenmajer, in Szafer, 1954, slightly modified)

a – Eocene; b–e – after Szafer (1954): b – Middle Pliocene (pre-Günz), c – Upper Pliocene, d – Günz Glaciation, e – Günz-Mindel Interglacial (Tegelen); f, g – Pleistocene–Holocene;. for location of boreholes and natural exposures see Figure 2

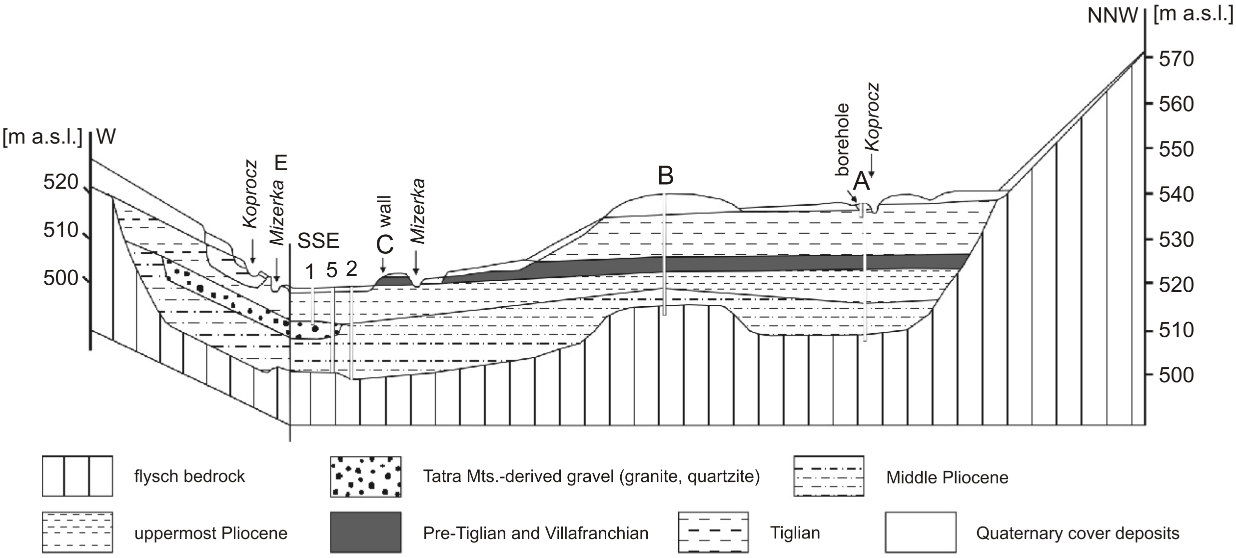


Fig. 4. Mizerna site – geological cross-section/block-diagram of fluvial-lacustrine “Plio-Pleistocene” deposits (Birkenmajer, 1961, 1979; ages of “Plio-Pleistocene” deposits after Szafer, 1954)

For location of boreholes and natural exposures see Figure 2

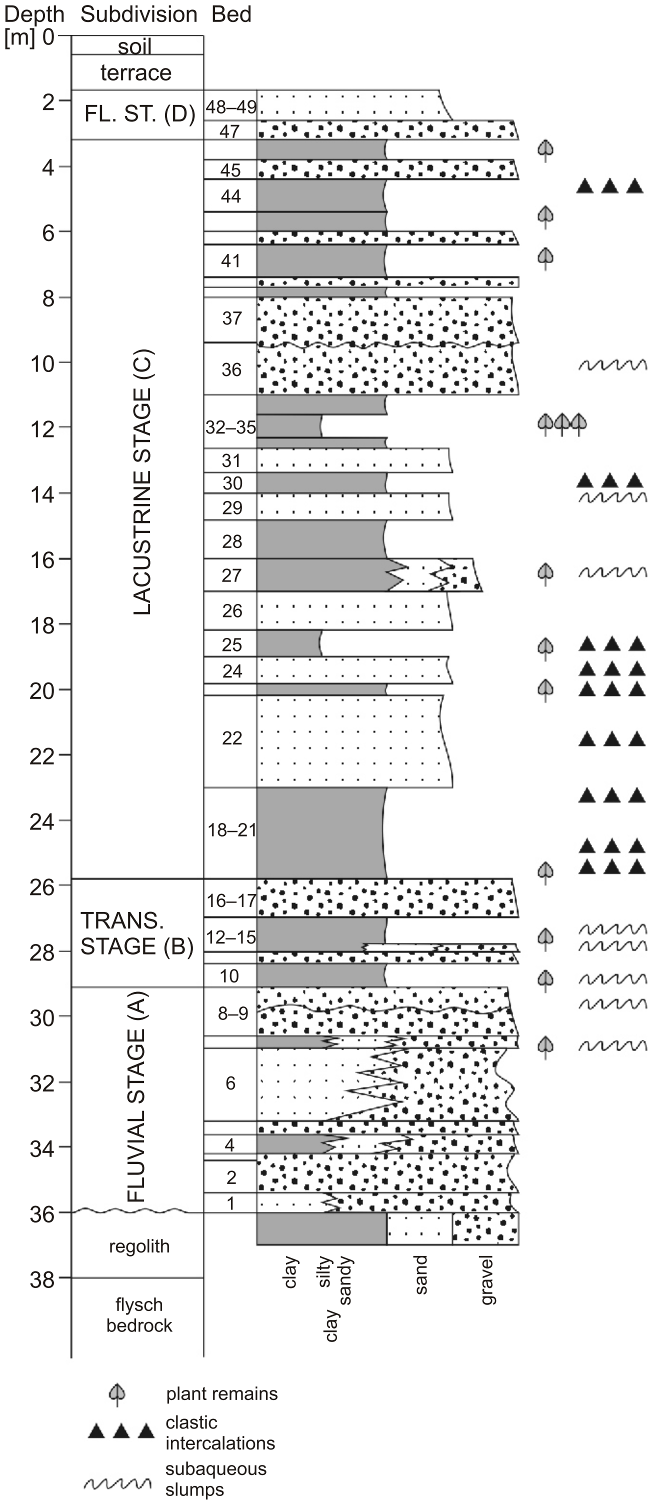


Fig. 5. Sedimentary log and lithostratigraphic subdivision (A–D) of freshwater deposits in the Mizerna-Nowa borehole

FL. ST. – fluvial stage; TRANS. STAGE – transitional stage

sandstone pebbles typical of fluvial gravel derived in the Podhale area from Paleogene flysch strata, the remaining gravel beds consist of unabraded (predominantly angular) small flysch sandstone and shale fragments. Both the gravel and sand beds are often impure – the gravel is mixed with clay (Fg+c), with sand (Fg+s), or with both (Fg+c+s). They were derived from the river-reworked cover of surrounding hills which, triggered by earthquakes, slid down the palaeovalley. The palaeoriver deposit shows numerous traces of subaqueous slumping (S), particularly in the chaotic arrangement of lignite fragments (Fg+p/S). However, neither plant stems in growth position, nor roots/rootlets (rhizoliths) have been found.

As a whole, the 7-m succession of basal fluvial deposits represents a small delta laid down in the buried river valley at its outlet to the palaeolake. Evidence for this is visible in the top part of the fluvial succession (beds 12, 13: 28.0–27.1 m), where fluvial deposits alternate with lake clay (Lc/Fg+p; Lc+s+g).

(B) TRANSITIONAL STAGE

There is a clear transition from fluvial deposits (Fg, s) to lacustrine deposits (Lc). This reflects inundation of the area of the eastern Nowy Targ Intramontane Depression by the Mizerna palaeolake. In the transition zone (beds 10–17: 28.55–25.85 m) deposits of both environments are interbedded.

(C) LACUSTRINE STAGE

This stage is characterized by bottom clay deposits (Lc) laid down in a shallow lake often disturbed by bottom currents that deposited sand bars (Lc+p) and even gravel bars (Fg). This is the thickest part of the Mizerna succession (beds 18–46: 25.85–3.9 m) – 21.95 m thick. The predominant part is formed by lake-bottom clay (Lc), usually with a considerable admixture of fragmented plant remains (Lc+p). Intercalations of gravel (Fg) and sand (Fs; Lc+s; Lc+s+g) are more frequent in lower part of the unit, some evidently filling erosional channels (Fsch). Subaqueous slumping has occasionally been recognized.

(D) FLUVIAL STAGE

This stage terminates the sedimentary history of the Mizerna freshwater basin. The lake-bottom clays (Lc) were replaced by fluvial gravel and sand bar (Fg+s; Fs), 1.6 m thick (beds 47–49: 3.2–1.6 m) and devoid of fossil plant remains. It is probable that, at that time, the Dunajec River forced a natural rocky threshold that dammed the Mizerna palaeolake from the east, causing its complete draining. Whether this had happened already during the Pliocene, or during the long Eopleistocene epoch that divided the Pliocene from the first Pleistocene glaciation (Mindel Glaciation) of the Tatra Mountains (Birkenmajer, 2009), is presently a matter of guesswork.

PALYNOLOGICAL STUDY

MATERIAL AND METHODS

The material for palynological analysis was sampled from the Mizerna-Nowa borehole core. In most cases the samples were taken every 10 to 20 cm. The sampling was at larger intervals in sand and gravel beds. The samples were processed according to a modified Erdtman's acetolysis method (Moore et al., 1991) using hydrofluoric acid to remove mineral matter. Additionally, the material was sieved at 5 μm on a nylon mesh. The microscope slides were made using glycerine jelly or glycerine as a mounting medium. A total of 160 samples have been studied and at least two microscope slides from each sample were examined.

The sporomorph taxa identified have been classified (see Appendix 2) mainly with reference to an Atlas of pollen and

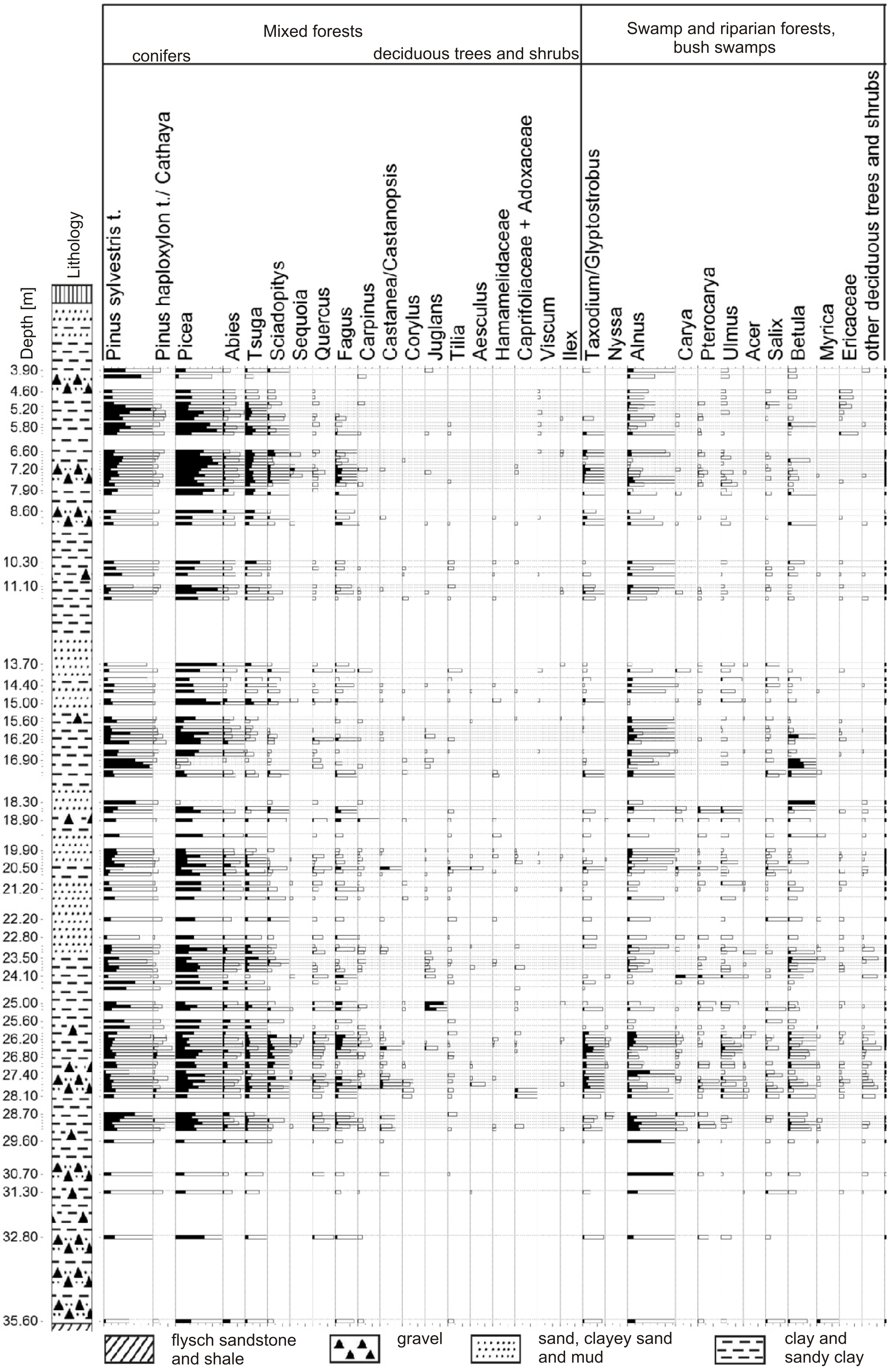
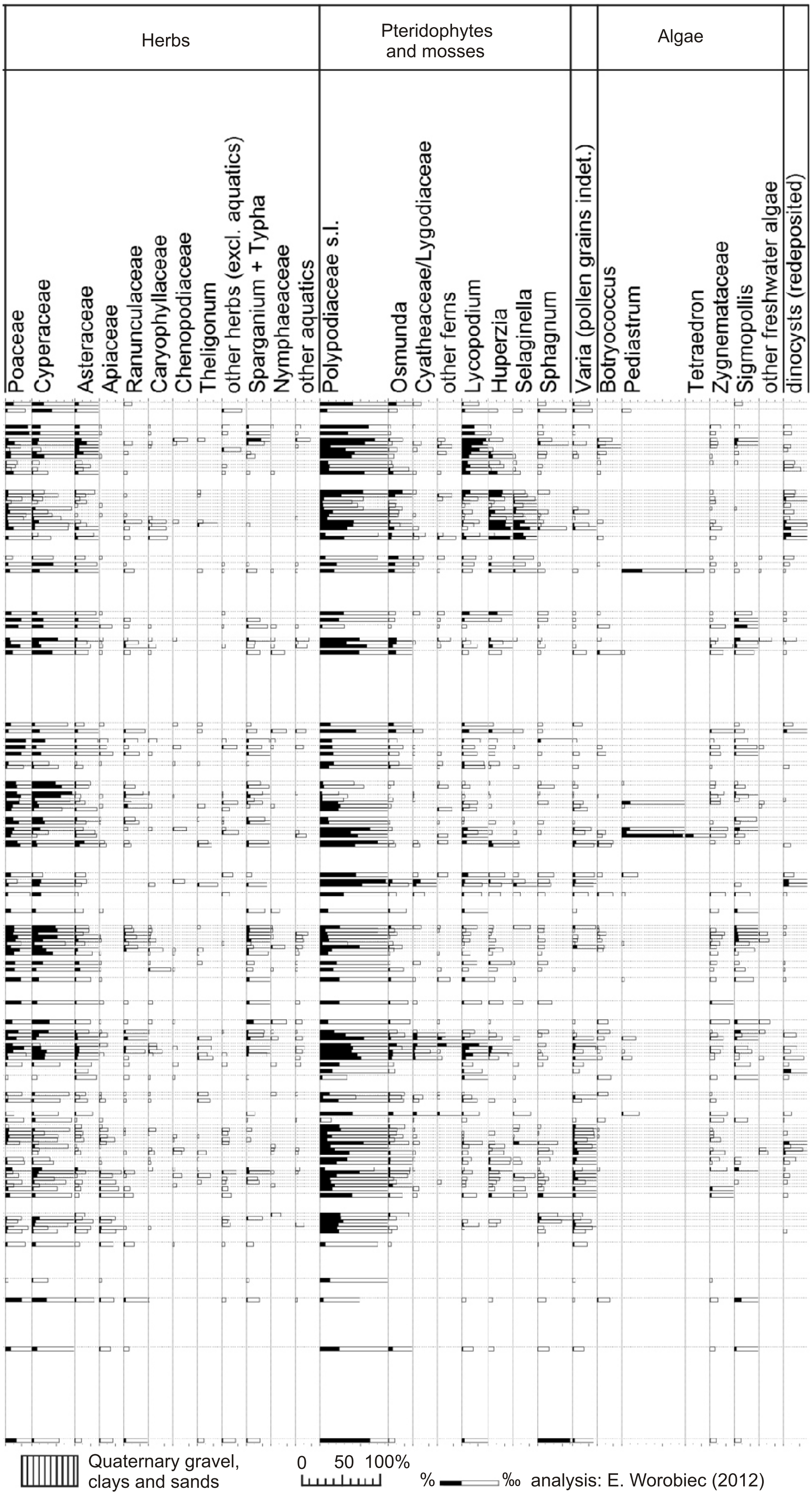


Fig. 6. Percentage diagram of selected



sporomorph and algal taxa from Mizerna-Nowa

spores of the Polish Neogene (Stuchlik et al., 2001, 2002, 2009) and the checklist of selected pollen and spore taxa from the Neogene deposits proposed by Ziembińska-Tworzydło et al. (1994).

Data from the spore-pollen spectra have been used to construct a simplified pollen diagram presenting frequencies of pollen, spores, and algae (Fig. 6). The percentage shares of the pollen taxa presented in the diagram have been calculated from the total sum of pollen grains; the proportions of spores and algal micro-remains were computed separately in relation to the total sum using the *POLPAL* computer program (Nalepka and Walanus, 2003). Most taxa have their own columns. However, some columns present the sum of a few taxa (two or more genera, one family or a few families). In addition, two diagrams, showing the frequency of pollen grains of a particular group of plants, spores and algae (Fig. 7A) and palaeofloristical elements (Fig. 7B) have been constructed, also using the *POLPAL* program. Microphotographs of selected taxa (Figs. 8–10) were taken using a *NIKON Eclipse* microscope fitted with a *Canon* digital camera.

RESULTS OF THE PALYNOLOGICAL STUDIES

Sporomorph assemblages suitable for detailed studies were found in 125 samples. In each of these samples an average of 200–300 pollen grains and all the accompanying spores and algal micro-remains were counted. For several low frequency samples, the basic sum was reduced to about 100–150 grains. The state of preservation of the palynomorphs varies from very well-preserved specimens to corroded ones with a highly damaged structure. Thirty-five samples from various intervals were barren or only yielded sparse palynomorphs. Most barren samples were taken from fluvial deposits, whereas the richest and best preserved sporomorphs were in samples taken from fine-grained sediment.

Pollen spectra from the samples that were studied in detail are more or less taxonomically diverse: in most samples, 20–40 (sporadically up to 50) taxa of pollen, spores and algae occur. A total of 145 taxa of sporomorphs, including 26 taxa of spores, 28 taxa of gymnosperm pollen and 91 taxa of angiosperm pollen have been identified (their listing, botanical affinity and palaeofloristical element are given in Appen-

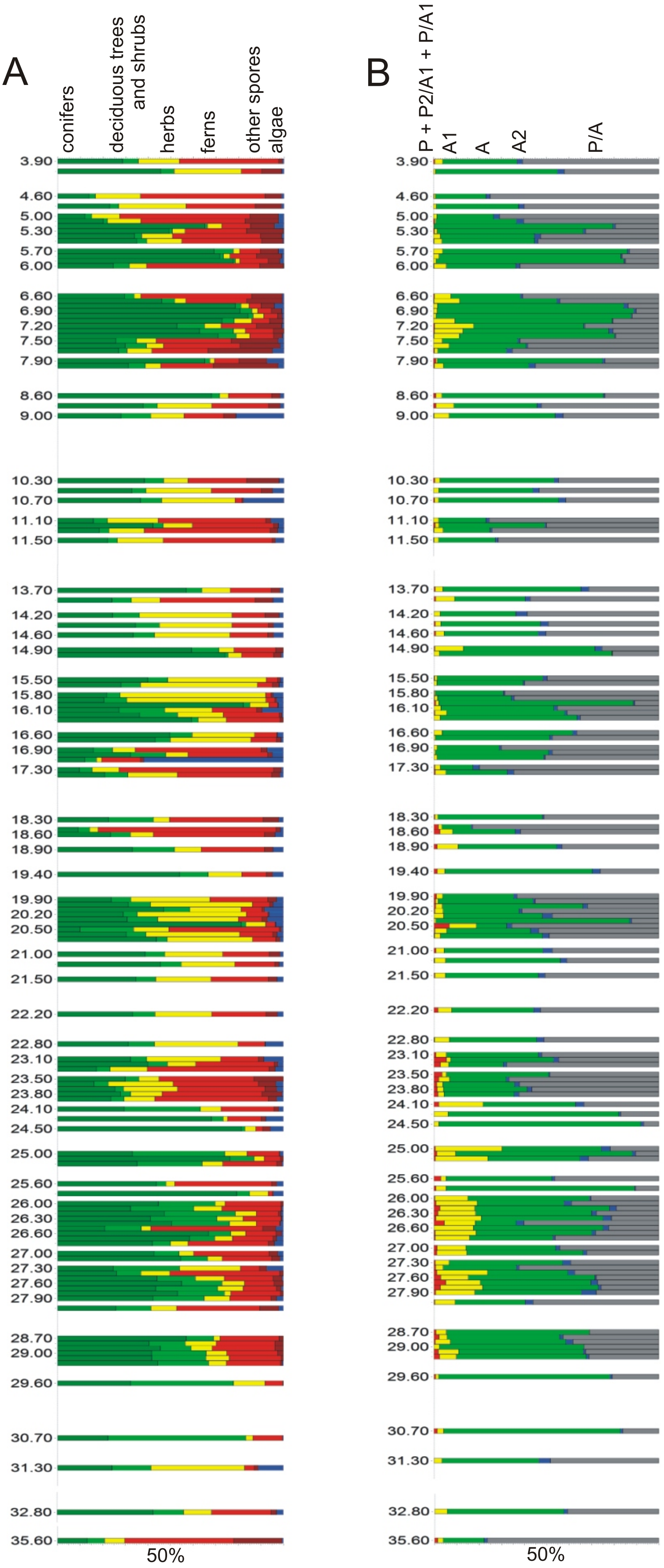


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Fig. 7A – frequency of pollen grains of particular groups of plants, spores and algae in samples studied from Mizerna-Nowa; B – ratios of palaeofloristical elements in samples studied from Mizerna-Nowa

Palaeofloristical elements: A – arctotertiary (A1 – warm-temperate, A2 – cool-temperate); P – palaeotropical (P1 – tropical, P2 – subtropical); P/A – cosmopolitan

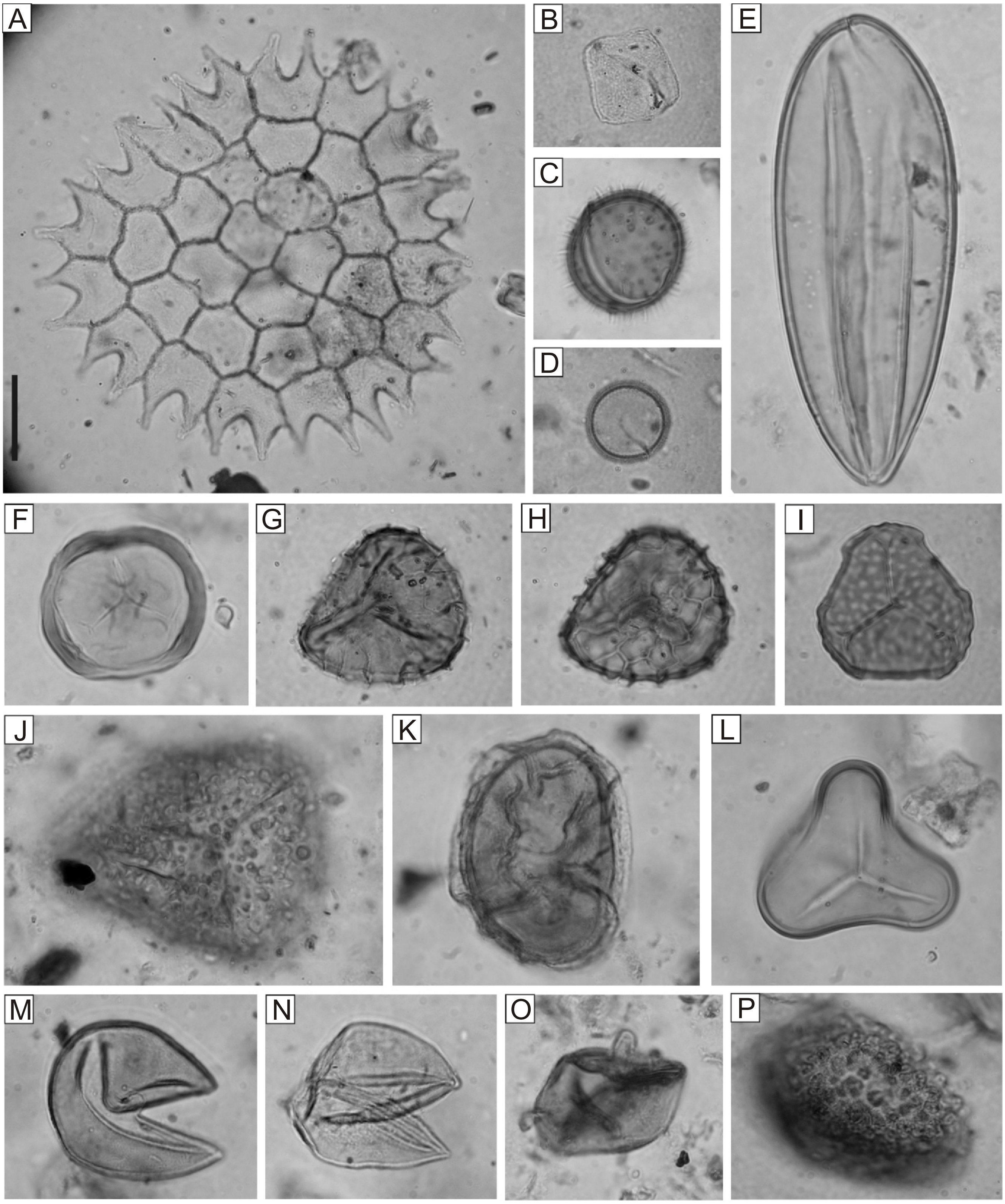

Fig. 8. Freshwater algae, spores and pollen grains from the Mizerna-Nowa borehole

A – *Pediastrum boryanum* (Turp.) Menegh., depth 17.1 m; **B** – *Tetraedron minimum* (A. Braun) Hansgirg, depth 17.1 m; **C** – *Sigmopollis pseudosetarius* (Weyland et Pflug) Krutzsch et Pacltová, depth 15.9 m; **D** – *Sigmopollis laevigatoides* Krutzsch et Pacltová, depth 15.8 m; **E** – *Ovoidites grandis* (Pocock) Zippi, depth 26.3 m; **F** – *Distancoraesporis* sp., depth 20.2 m; **G**, **H** – *Retitriletes* sp., depth 10.7 m; **I** – *Selagosporis selagoides* Krutzsch, depth 7.4 m; **J** – *Baculatisporites major* (Raatz) Krutzsch, depth 26.1 m; **K** – *Perinomonoletes* sp., depth 28.8 m; **L** – *Leiotriletes neddenioides* Krutzsch, depth 25.6 m; **M** – *Inaperturopollenites* sp., depth 29.1; **N** – *Inaperturopollenites dubius* (Potonié et Venitz) Thomson et Pflug, depth 25.8 m; **O** – *Sequoiapollenites* sp., depth 26.3 m; **P** – *Sciadopityspollenites serratus* (Potonié et Venitz) Raatz, depth 7.4 m; scale bar – 20 μm

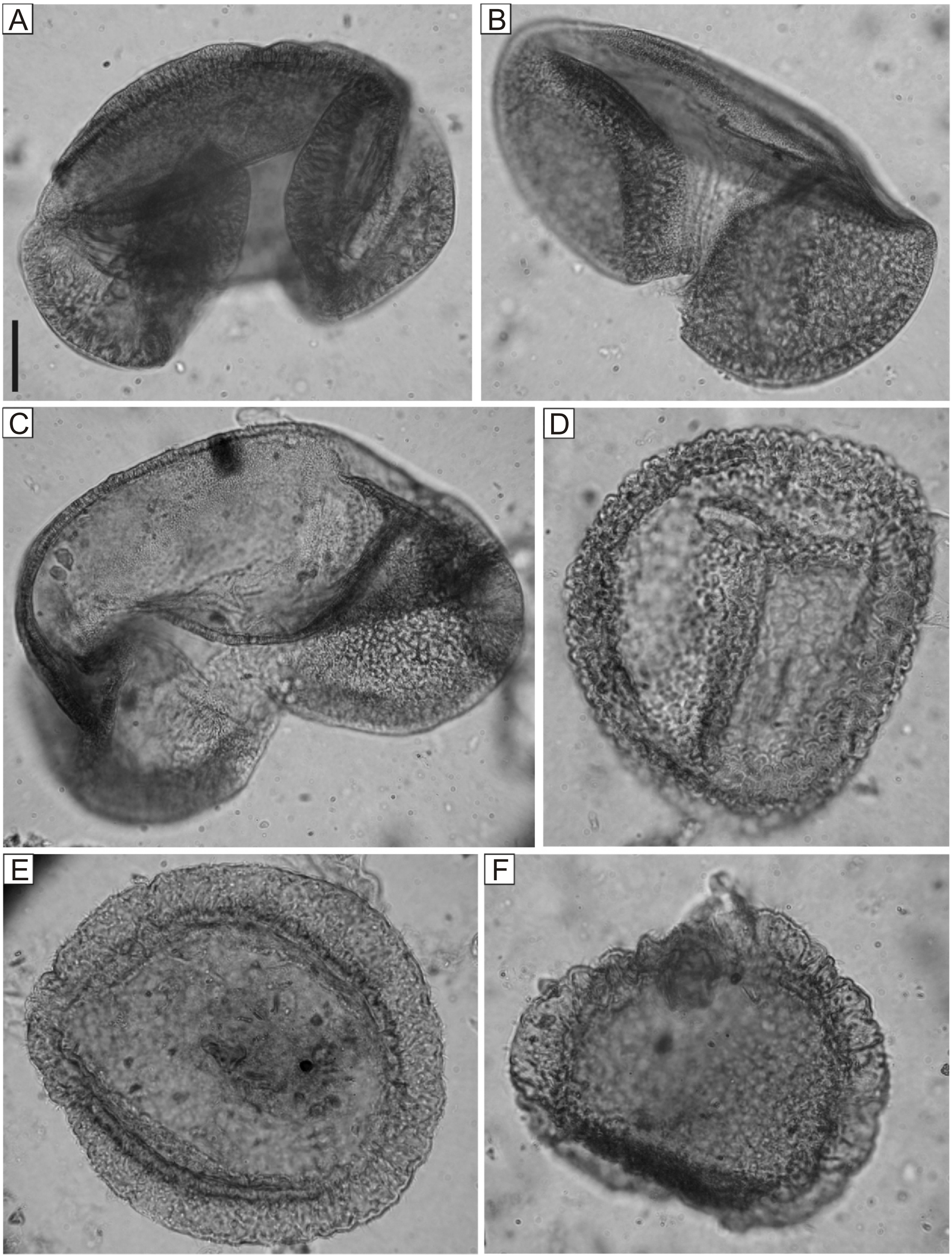

Fig. 9. Pollen grains from the Mizerna-Nowa borehole

A – *Abiespollenites absolutus* Thiergart, depth 25.8 m; **B** – *Piceapollis tobolicus* (Panova) Krutzsch, depth 25.8 m; **C** – *Piceapollis planoides* Krutzsch ex Hochuli, depth 20.2 m; **D** – *Zonalapollenites verrucatus* Krutzsch ex Ziembińska-Tworzydło, depth 20.2 m; **E** – *Zonalapollenites* sp., depth 26.3 m; **F** – *Zonalapollenites spinosus* (Doktorowicz-Hrebnicka) Ziembińska-Tworzydło, depth 15.9 m; scale bar – 20 μm

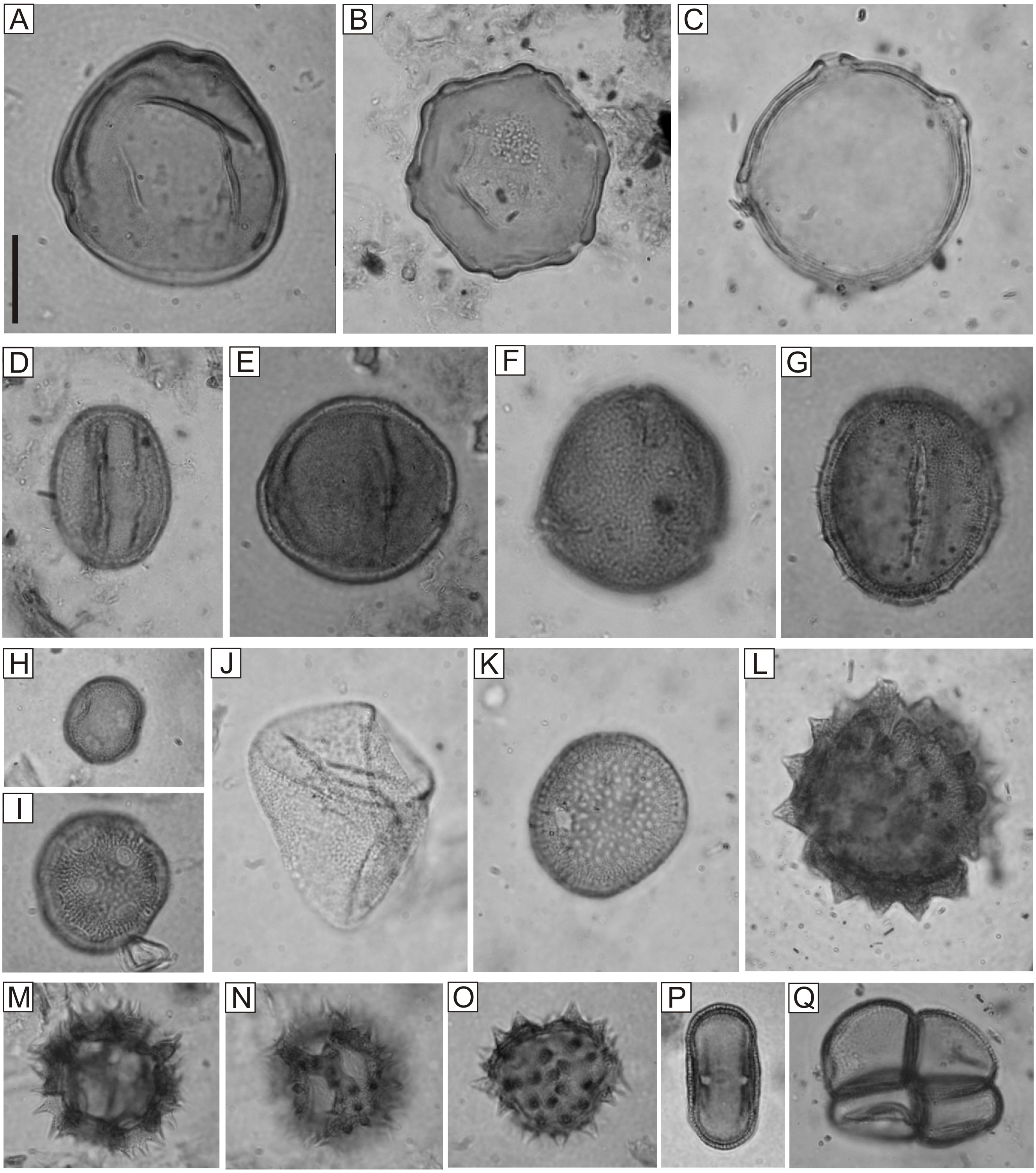

Fig. 10. Pollen grains from the Mizerna-Nowa borehole

A – *Caryapollenites simplex* (Potonié) Raatz, depth 7.4 m; **B** – *Polyatriopollenites stellatus* (Potonié) Pflug, depth 26.4 m; **C** – *Carpinipites carpinoides* (Pflug) Nagy, depth 17.1 m; **D** – *Quercopollenites poratus* Kohlman-Adamska et Ziembińska-Tworzydło, depth 26.3 m; **E** – *Faguspollenites* sp., depth 26.4 m; **F** – *Faguspollenites* sp., depth 7.0 m; **G** – *Tricolporopollenites viscoides* Stuchlik, depth 20.2 m; **H** – *Thalictrumpollis thalictroides* Stuchlik, depth 20.2 m; **I** – *Caryophyllidites hidasensis* Nagy, depth 7.4 m; **J** – *Cyperaceaepollis neogenicus* Krutzsch, depth 20.4 m; **K** – *Sparganiaceaepollenites neogenicus* Krutzsch, depth 15.9 m; **L** – *Tubulifloridites macroechinatus* Nagy, depth 10.7 m; **M**, **N** – *Cichoreacidites gracilis* (Nagy) Nagy, depth 7.4 m; **O** – *Tubulifloridites granulosus* (Trevisan) Nagy, depth 20.2 m; **P** – *Umbelliferoipollenites tenuis* Nagy, depth 29.1 m; **Q** – *Tetradomonoporites typhoides* Krutzsch, depth 15.9 m; scale bar – 20 μm dix 2). In addition, 24 taxa of freshwater algae have been identified (Appendix 3).

Bisaccate pollen related to conifers (Pinaceae) strongly prevails among the pollen grains. In most samples *Picea* (mainly *Piceapollis tobolicus*) and *Pinus* (mainly *Pinuspollenites labdacus*) strongly dominate. Additionally, frequent *Tsuga*, *Sciadopitys* (mainly *Sciadopityspollenites serratus*), *Abies*, and *Cathaya* pollen grains occur. *Taxodium/Glyptostrobus* pollen is encountered regularly, but in low frequencies. *Sequoia* pollen grains are found sporadically.

Deciduous trees are represented mainly by: *Alnus*, *Betula*, *Fagus*, *Quercus* (*Quercopollenites*), *Ulmus*, *Salix*, *Pterocarya*, *Carya*, and *Juglans* (*Juglanspollenites*). Pollen from *Carpinus*, *Tilia*, *Acer*, *Aesculus*, *Corylus*, Hamamelidaceae (*Corylopsis* and *Tricolporopollenites indeterminatus*), *Myrica*, and others, is encountered regularly. *Castanea/Castanopsis* (mainly *Cupuliferoipollenites oviformis*) and *Nyssa* (*Nyssapollenites* sp.) pollen mainly occurs in the lower section of the profile. Ericaceae are found regularly but in very low frequencies. Caprifoliaceae, Adoxaceae, *Ilex* (mainly *Ilexpollenites margaritatus*), Rosaceae, *Viscum*, and others, are encountered sporadically.

In the samples studied, herbs are represented by sedges, grasses, Asteraceae, Apiaceae, Ranunculaceae, Caryophyllaceae, Chenopodiaceae, *Theligonum*, and others. Aquatic and wetland plants are mainly represented by pollen from Sparganiaceae, *Typha*, *Potamogeton*, Alismataceae, Nymphaeaceae, *Utricularia*, and others.

Fern spores, mainly Polypodiaceae s.l., *Osmunda* (mainly *Baculatisporites*) and, in some samples, also spores from the morpho-genus *Leiotriletes* (?Lygodiaceae, ?Cyatheaceae), are very important components of the sporomorph assemblages. In addition, numerous *Lycopodium* (variable in form), *Huperzia*, and *Selaginella* (*Echinatisporis longechinus*) spores have been found. *Sphagnum* spores are only numerous in the lowermost sample, but in other samples they occur subordinately.

Freshwater algal taxa also occur relatively frequently, mainly *Sigmopollis*, *Botryococcus* and Zygnemataceae zygospores (*Cycloovoidites*, *Diagonalites*, *Ovoidites*, *Stigmozygodites* and *Zygodites*), as well as freshwater dinoflagellate cysts, and others. In some samples *Pediastrum* (mainly *P. boryanum* and *P. integrum*) as well as *Tetraedron minimum* occur.

In addition, single specimens of micro-fungi (sporocarps of Microthyriales and *Tetraploa* type) and fungal spores, as well as fragments of plant tissue (sclereids of Nymphaeaceae, dispersed stomata and cuticles) have been found. Several recycled dinocyst specimens were recorded in the samples investigated. They are probably recycled from Paleogene flysch rocks.

In the material studied the following palaeofloristical elements have been identified: palaeotropical (P), including: tropical (P1) and subtropical (P2); and arctotertiary (A), including: warm-temperate (A1) and cool-temperate (A2), as well as cosmopolitan (P/A) elements. The composition of the pollen spectra shows an apparent dominance of arctotertiary (including warm-temperate and cool-temperate) and cosmopolitan palaeofloristical elements (Fig. 7B). Palaeotropical elements are represented by a few taxa only (mainly subtropical), all occurring as rare specimens (*Leiotriletes neddenioides* spores, and *Corsinipollenites ludwigioides*, *Symplocoipollenites vestibulum*, and *Tricolporopollenites indeterminatus* pollen grains). Some taxa (e.g., *Rugulatisporites quintus* spores, and *Inaperturopollenites concedipites*, *I. verrupapilatus*, *Araliaceoipollenites* sp., *Cupuliferoipollenites oviformis*, *C. pusillus*, *Ilexpollenites iliacus*, *I. margaritatus*, *Magnoliaepollenites* sp., *Myricipites* sp., *Nyssapollenites* sp., *Spinulaepollis arceuthobioides*, *Tricolporopollenites exactus*, *T. fallax* and *T. liblarensis* pollen grains) represent a palaeotropical/warm-temperate element.

In the samples studied, marked changes in the frequency and preservation of sporomorphs were undoubtedly related to the process of deposition. Nevertheless, changes in the composition of sporomorph assemblages (Figs. 6 and 7A), probably caused by both average temperatures and humidity, are also present. For example, apart from the permanent domination of conifers, in the lower section of the profile, pollen grains from deciduous trees and shrubs are more frequent and richer in taxa. This part is the richest in palaeotropical and warm-temperate elements (Fig. 7B), representing both deciduous trees and ferns. Later these were replaced by herbs, including *Artemisia* and *Ambrosia*. In the uppermost section, conifers (especially *Picea* and *Tsuga*) strongly dominate among the pollen taxa, whereas Lycopodiaceae (*Huperzia* and *Lycopodium*, in turn) as well as *Selaginella* increase their share among the spores. These changes taken together with the deposit type made it possible to distinguish the main trends in the palynofloral assemblages.

PLANT COMMUNITIES – SEDIMENTARY SETTING AND PALAEOCLIMATE

Pollen analysis indicates that the sediment studied was deposited in a water body surrounded by herbaceous vegetation as well as by mixed and coniferous forests. More elevated habitats in the area studied were forested with conifers, of which *Picea* as well as *Pinus*, *Abies*, *Tsuga*, and *Sciadopitys* were particularly important. Ericaceae and Lycopodiaceae were probably components of the groundcover of these coniferous forests, or they formed their own communities. Along riversides and streams favourable conditions existed for riparian forests dominated by *Alnus*, *Ulmus*, *Salix*, *Betula*, and accompanied by *Pterocarya*, *Carya*, *Juglans*, *Acer*, and others. In places with high ground-water level, *Taxodium* and lone *Nyssa* trees probably also grew. Drier higher terrains were presumably covered by mixed forests with *Fagus*, *Quercus*, *Carpinus*, *Castanea* and *Betula*, accompanied by *Tilia*, *Aesculus*, *Corylus* and conifers. The hemi-parasitic shrub *Viscum* lived on tree stems.

The occurrence of aquatic pollen (e.g., Nymphaeaceae) and abundant freshwater algae (mainly *Pediastrum*, *Botryococcus*, *Sigmopollis* and morphologically differentiated Zygnemataceae zygospores) points to sedimentation in a freshwater body. Most of the algae identified prefer mesotrophic to eutrophic conditions, and are characteristic of stagnant or slow-flowing, shallow water (Appendix 3). For example, modern *Botryococcus* mainly lives in freshwater bogs, temporary pools, ponds and lakes. The genus *Sigmopollis* is associated with eutrophic to mesotrophic open waters (Pals et al., 1980). Also, most of the filamentous algae of the Zygnemataceae family occur in shallow, stagnant, clean, oxygen-rich waters. They may, however, also occur near lake margins, in slow-flowing water and in moist soils or bogs (Kadłubowska, 1972; van Geel and Grenfell, 1996; Johnson, 2005; Naselli-Flores and Barone, 2009). In temperate climatic zones Zygnemataceae conjugate in shallow (often less than 0.5 m), relatively warm water, forming dormant hypnozygotes that may be exposed to desiccation (e.g., in summer) without damage to the living contents (van Geel, 2001). On the other hand, the presence of sediment layers with abundant *Pediastrum* algae accompanied by *Tetraedron* suggests that, at least during some periods, the water was stagnant or only slow-flowing. *Pediastrum* algae are often found in the phytoplankton of lakes and ponds. *Pediastrum boryanum* generally occurs in eutrophic waters, whereas *Pediastrum integrum* is an alga found mainly in oligotrophic and dystrophic water biotopes (Komárek and Jankovská, 2001). The temporary presence of both of these taxa suggests changes in the water biotope.

Among the floating and rooted macrophytes were *Nuphar*, *Nymphaea*, *Potamogeton*, *Utricularia*, and probably also *Ludwigia* and *Lemna*. The water body was surrounded by swamp-aquatic vegetation, composed of herbs, including *Typha* (e.g., *T. latifolia*), *Sparganium*, Alismataceae (*Alisma* and *Sagittaria*), sedges, grasses, Apiaceae, Caryophyllaceae, Ranunculaceae (e.g., *Thalictrum*), Polygonaceae (e.g., *Polygonum*), Lythraceae, Lamiaceae, Chenopodiaceae, Onagraceae and Asteraceae. On damp and shady soils, rocks and crags *Selaginella* and *Theligonum* probably grew (Rutishauser et al., 1998; Jiarui and Funston, 2011). The occurrence of pollen grains of such taxa as *Artemisia* and *Ambrosia* also points to the presence of light-demanding and open-country plant communities, though growing in drier places.

Pollen analysis of the Mizerna-Nowa profile revealed changes in the frequency of particular taxa (Figs. 6 and 7A). Changes in the palynoflora reveal, in turn, a decrease in mixed forests relatively rich in warm-temperate taxa, the development of more light-demanding and open-landscape plant communities and, finally, an increase in coniferous forests containing *Picea*, *Pinus*, *Tsuga* and *Abies*, which fare badly among warm-temperate taxa. The main change in the composition of the spore-pollen spectra is a decrease in both palaeotropical and warm-temperate taxa (Fig. 7B). Although the composition of the spore-pollen spectra is also connected with facies conditions, they point to gradual changes in vegetation and the palaeoclimate during sedimentation. Unfortunately, because of the deposit type, there is no possibility of relating the observed changes to the vegetational succession within climatic cycles (such as the millenial-scale or Milankovich cycles) described at other Pliocene localities (Kloosterboer-van Hoeve et al., 2006).

Over the profile as a whole, the predominance of plants belonging to genera that now grow under temperate climatic conditions, the low proportion of warm temperate plants and scarce presence of tropical taxa is evident (Fig. 7B). However, some of the plant taxa and *Tetraploa* fungi encountered have recently occurred in areas with a mild climate (Worobiec et al., 2009; Karpińska-Kołaczek et al., 2010). All these observations indicate that the climate during deposition of the studied deposits was temperate (distinctly cooler than during the Miocene, but still warmer than the present-day climate of Poland). This state is consistent with those inferred from other Pliocene localities (Salzmann et al., 2011).

The presence of the *Microthyriales epiphyllous* micro-fungi, especially in the lower part of the profile studied, suggests generally high total annual rainfall – probably over 1000 mm (Elsik, 1978) or high air humidity (G. Worobiec, pers. comm.). In the sub-mountainous area the annual rainfall was probably higher than in the lowlands.

AGE OF THE PALYNOFLORA

Comparison of the Mizerna-Nowa profile with results from previous palynological investigations of the Mizerna A profile studied by Oszast (Szafer, 1954; Szafer and Oszast, 1964; Oszast, 1973; unpublished data from the lower part of the profile) introduces a new interpretation of the age of the Mizerna fossil flora. In the previously examined material a high frequency of indeterminate pollen and spores was reported. Moreover, the algal micro-remains, which can yield significant data, e.g. concerning sedimentation, were not studied in the previous investigations. These circumstances indicate that only the main palynofloral trends reported from both Mizerna profiles are similar.

Comparison of the Mizerna-Nowa palynoflora with the Neogene palynofloras of southern Poland revealed the former's similarity to some Pliocene assemblages. For example, there are many similarities to the assemblage from Krościenko on the Dunajec (Oszast, 1973), considered on the basis of fruit-and-seed flora to be Early Pliocene in age (Szafer, 1946–1947). In particular, the lowermost part of the Mizerna-Nowa profile is most similar to the Krościenko spore-pollen assemblage. At both localities the most widespread (by far) coniferous tree was *Picea*, which, together with an admixture of *Abies*, *Pinus*, *Tsuga*, and *Sciadopitys*, composed the coniferous-forest communities. The deciduous and mixed forests growing both in the immediate and more distant environment at Krościenko were composed mainly of *Alnus*, *Pterocarya*, *Carya*, *Salix*, *Fagus*, *Quercus*, *Carpinus*, *Tilia*, *Betula*, *Corylus*, *Ulmus* and *Acer*. The frequency of particular taxa in both profiles is similar. The main difference is the abundance of *Pterocarya* pollen in the Krościenko profile. In both these assemblages, pollen of the *Pinus haploxylon* type/*Cathaya* and Taxodioideae tend not to exceed 10%, whereas only single grains of *Nyssa* pollen were recorded.

The palynoflora studied is also very similar to the assemblage from Domański Wierch near Czarny Dunajec, Nowy Targ–Orawa Basin (West Carpathians), considered to be Late Pliocene in age (Oszast, 1973; Oszast and Stuchlik, 1977). In the Domański Wierch profile, a marked dominance of such conifers as *Pinus* and *Picea*, accompanied by *Abies* and *Tsuga*, occurs. Pollen of the *Pinus haploxylon* type/*Cathaya* and of theTaxodioideae is regularly encountered, tending not to exceed 10% in frequency. Of the deciduous trees and shrubs, *Alnus* is the most frequent, while *Betula*, *Quercus*, *Fagus*, *Pterocarya*, *Carya*, *Ulmus*, *Tilia*, *Fraxinus* and *Carpinus* occur commonly. Pollen analysis of this site revealed the presence of several plant communities adapted to different types of topography and habitat. The communities in the wet habitat were composed of *Alnus*, with an admixture of other riparian taxa. Drier habitats were occupied by deciduous forests of a different type, while higher up there were coniferous forests with a predominance of *Picea*.

The Mizerna-Nowa spore-pollen assemblage is also similar to the Pliocene palynoflora from Kłodzko, Kłodzko Basin, central Sudetes (Jahn et al., 1984). The main difference is the abundance of *Aesculus* pollen in the Kłodzko II profile. In both Kłodzko profiles the conifers that were particularly abundant were *Pinus sylvestris* and *Picea*, as well as *Tsuga*, *Sciadopitys* and *Abies*; whereas among deciduous trees it was the following that predominated: *Alnus*, *Fagus*, *Quercus*, *Ulmus*, *Carya* and *Carpinus*. *Aesculus*, *Betula*, *Tilia*, and *Pterocarya* pollen also occurred regularly. Pollen of the *Pinus haploxylon* type/*Cathaya* and Taxodioideae do not exceed 6%, whereas only single grains of *Nyssa* and *Sequoia* pollen were recorded. Of the herbs, Poaceae, Cyperaceae, Apiaceae, Asteraceae, and Nymphaeaceae were most frequent. Pollen analysis of the Kłodzko profiles indicated a standing water body environment, probably (an) ox-bow lake(s), with abundant aquatic plants. This water body was surrounded by alder-rich marshy meadows, with an admixture of trees, shrubs, and herbs typical of wet habitats. Somewhat further away the area was covered by mixed forests with shrubs and climbers. Some of the conifer pollen, particularly the *Picea* pollen, is likely to have been derived from the coniferous forests which occurred at higher altitudes around the Kłodzko Basin.

The palynoflora studied also shows some similarities to Pliocene assemblages from Tułowice, southeastern Silesian

Lowland, SW Poland (Badura et al., 2006). Although the frequency of *Picea*, *Tsuga*, *Sciadopitys*, *Fagus* and herb pollen as well as spores is noticeably higher in the Mizerna-Nowa material, there are distinct similarities as regards vegetational changes. The lower part of the Tułowice I pollen profile is dominated by coniferous trees (*Pinus*, *Picea*, *Abies*), and the middle part shows a marked contribution from herbaceous (Poaceae, *Artemisia*, Chenopodiaceae) and light-demanding plants. The upper part of the profile suggests the disappearance of light-demanding and open-country plant communities, which were replaced again by (mainly coniferous) forests containing *Pinus*, *Picea* and *Abies*. Another characteristic feature of the Tułowice and Mizerna-Nowa palynofloras is the presence of relatively numerous *Theligonum* pollen grains. The various plant assemblages probably reflected distinct differences between the sub-mountainous plant communities, which mainly consisted of conifer forest, and lowland plant communities consisting of deciduous forest with a small admixture of warm-temperate taxa, existing during the Pliocene (Piwocki and Ziembińska-Tworzydło, 1997).

On the other hand, the pollen diagram from Mizerna-Nowa distinctly differs from the pollen diagram from Różce, central Poland (Stuchlik, 1987, 1994), in which the Pliocene/Pleistocene boundary was recognized. There, at this boundary, pollen from warm-temperate taxa disappears and *Pinus* and *Picea* pollen decreases, whereas *Betula* (including *B. nana*) and herb pollen increases. In the Mizerna-Nowa profile such changes have not been observed (Fig. 6). In the material studied, changes are gradual, for example *Fagus* pollen is present throughout the profile with only a small drop in frequency in its middle part. Similarly, the palynoflora studied more closely resembles the pollen assemblage from the lower (Pliocene) part of the Ponurzyca profile, central Poland (Stuchlik, 1975), in which the Pliocene/Pleistocene boundary is probably also present. Moreover, the palynoflora studied revealed only negligible similarities to other Pleistocene assemblages, e.g. the lowermost part of the Szaflary profile, West Carpathians (Birkenmajer and Stuchlik, 1975), in which Quaternary taxa distinctly prevail.

The palynostratigraphy of the inland Pliocene deposits in Poland has not been worked out in detail yet because it is based on scarce spore-pollen profiles (Grabowska, 1998). According to Ziembińska-Tworzydło (1998; Piwocki and Ziembińska-Tworzydło, 1997), two climatic phases, XIII and XIV, can be identified in the Pliocene. These phases are connected with the *Sequoiapollenites* and *Faguspollenites* spore-pollen zones. The Mizerna-Nowa profile reveals many similarities to both these zones, mainly in the composition of spore-pollen spectra and in the main vegetational succession. Therefore, a Pliocene (*sensu lato*) age of the whole Mizerna-Nowa palynoflora can be suggested. Compared with palynofloras from other localities, the assemblage studied is probably somewhat younger than the Early Pliocene palynoflora from Krościenko on the Dunajec and older than the Pliocene/Pleistocene Różce palynoflora. The Mizerna-Nowa profile reveals a pre-Pleistocene change in vegetation due to increasing aridity and climate cooling.

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