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Palynology of the Palaeogene and Neogene from the Warmia and Mazury areas (NE Poland)

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Abstract

Pollen, phytoplankton and microfauna from the Palaeogene and Neogene of two boreholes in NE Poland have been studied. Borehole Klucznik 1 is located in the Warmia area, and borehole Sąpłaty 3 borehole in the Mazury area. The oldest palynomorph assemblage comes from the Klucznik sediments; it consists of phytoplankton from the Early Palaeocene (Danian) D1 and D2 dinocyst zone, and from the Selandian D3 zone. The Eocene is present in the both the Klucznik and the Sąpłaty successions. The Middle Eocene assemblage has been dated as late Bartonian and belongs to the D11 dinocyst zone. The Late Eocene (Priabonian) D12 dinocyst zone is also present in both boreholes. Sporomorphs of a Late Eocene palynomorph assemblage point on the proximity of land and on terrestrial vegetation. The dinocyst zone D13, characteristic for the earliest Oligocene ('Latdorfian') has been found in both profiles as well. A Neogene sporomorph assemblage dating from the Middle Miocene (Early Serravallian) occurs only in the Sąpłaty profile. This sporomorph assemblage is correlated with pollen zone VIII. Pollen zone IX is present in the uppermost part of the Middle Miocene (Middle Serravallian). Late Miocene deposits (Late Tortonian) with pollen zone XI are present, too. The Miocene deposits accumulated in densely vegetated swamps, resulting now in the occurrence of lignite. The sedimentary conditions in the Warmia and Mazury regions were identical during the Neogene and Palaeogene, implying that both provinces belonged at the time to one sedimentary basin.

Keywords: pollen and spres, dinocysts, palynostratigraphy, Palaeogene, Neogene, NE Poland

Introduction

Geological studies of NE Poland point out that –the Warmia and Mazury areas in NE Poland (Fig. 1) developed as quite different palaeogeographic provinces during Pleistocene (Morawski, 2009a). The different developments resulted from various types of tectonic activity (Morawski, 2009b). These two areas are located above different large-scale structural elements. Warmia belongs to the Peribaltic Syneclise in the West and Mazury to the Mazury-Suwałki Anteclise in the East. During the Pleistocene, the Warmia area was still mobile, whereas Mazury remained stable. The differences in Pleistocene lithostratigraphy of Warmia and Mazury are a consequence.

A fundamental question is whether these palaeogeographic differences existed also earlier, in the Palaeogene and Neogene. Palaeo-

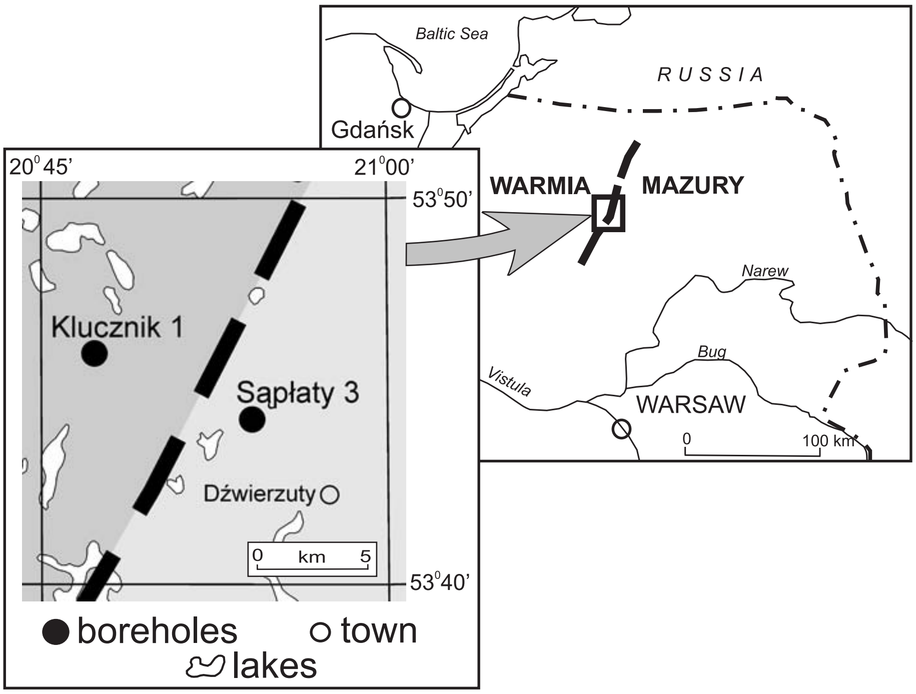

Fig. 1. Location map of the study area.

botanical analysis seems to be the best tool to solve this problem, and this is the main objective of the present contribution. The palynological analyses of pre-Quaternary deposits were carried out for samples from two borehole: the Klucznik 1 borehole in Warmia and the Sąpłaty 3 borehole in Mazury (Fig. 1).

Geological structure and lithology

The Palaeogene and Neogene of NE Poland show a clear difference in thickness. The greatest thickness of the Palaeogene and Neogene – exceeding 400 m, with the average of 250–300 m – occurs in Warmia. The Palaeocene there are up to 100 m (on average 55 m) thick. The average thickness of the Eocene in the Warmia area is 45 m, with a highest value of 100 m. The Oligocene in both the Warmia and Mazury areas is on average around 45 m thick, with local thicknesses up to 80–100 m. The Miocene is 30–40 m thick; it rarely exceeds 120 m.

Palaeogene

Palaeocene

The Palaeocene shows no significant differences between the Warmia and Mazury provinces. The Cretaceous/Palaeocene boundary is lithologically fairly well pronounced, but it has not been reached in the Klucznik and Sąpłaty boreholes. The Palaeocene consists of greyish-green sandy marls, calcareous sandstones, grey mudstones and occasional marls with limestones. The rocks commonly contain glauconite, phosphatic concretions and dark-grey cherts. Infrequent and poorly preserved molluscs and echinoids are present. The deposits (Puławy Formation: Fig. 2) contain assemblages that are typical of benthic and planktonic foraminifers distinctive of both cold-water and warm-water Danian and Montian faunal provinces (Pożaryska & Szczechura, 1968; Giel, 1981), and a Danian phytoplankton association (Słodkowska, 2007). The deposits are overlain by the brackish Odra Formation, which consists of greyish-brown sandy mudstones containing xylite fragments.

Similar deposits occur at other localities in the Warmia and Mazury regions. Palynological investigations suggest a Thanetian age for these deposits (Słodkowska, 2006).

Eocene

The Palaeocene is unconformably overlain by Eocenesediments. A green unsorted quartz sand, containing fine gravel-sized quartz clasts, occurs at the base, as found in the Klucznik borehole. The lower part of the succession (Olsztyn Member) is commonly composed of greyish-green fine-grained glauconitic quartz sands, locally with intercalations of unsorted sand and fine gravel (Piwocki, 2004).

The upper part of the Eocene (Pomorze Formation) consists of slightly calcareous greyish-green mudstones and olive-green and greyish-green claystones, clays and clayey shales with glauconite-rich quartz-sand flasers. The sediments, which contain poorly preserved fragments of molluscs and fishes, sponge spicules and rare foraminifers, have a Bartonian to Priabonian age (Fig. 2), as evidenced by phytoplankton (Słodkowska, 2006, 2007).

Oligocene

The lowermost layer of the Oligocene is a green and greyish-green fine-grained glauconitic quartz sand with occasional fine gravel, siderite clasts and sandy phosphatic concretions. The transgressive nature of the layer is accentuated by thin gravelly intercalations, which are present in many boreholes (Piwocki & Kasiński, 1995). These sediments contain numerous foraminiferal siliceous moulds and phytoplankton represented by dinocysts that are characteristic of the Lower Mosina Formation (Fig. 2), dated as earliest Early Oligocene: 'Latdorfian' (Słodkowska, 2006, 2007).

In both the Warmia and Mazury regions, these deposits are commonly overlain by grey, brown and brownish-grey muddy sands, sandy muds and mudstones, frequently laminated and containing abundant ichnocoenoses (Piwocki & Kasiński, 1995). Flasers and intercalations of greyish-green quartz sand with glauconite are common. The greyish-brown mudstones contain plant detritus and thin (up to 1 m) intercalations of muddy lignite. They are correlated with the Czempin Formation and contain lignite lenses (Piwocki, 2004).

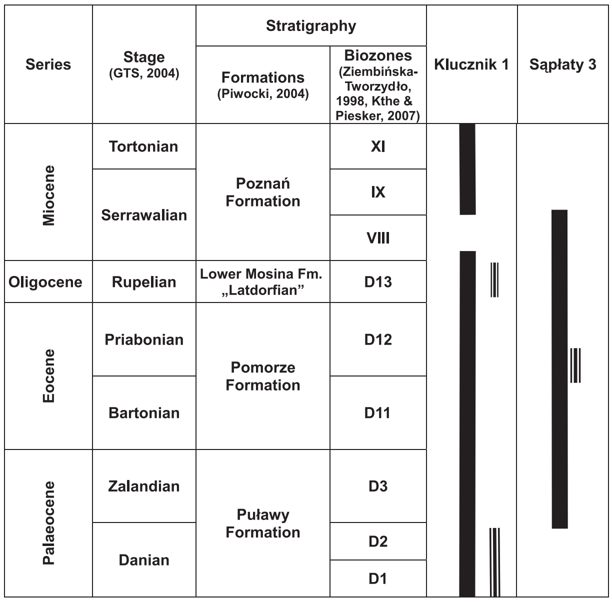

Fig. 2. Klucznik 1 and Sąpłaty 3 profiles on the background of Palaeogene and Neogene stratigraphic units. Thick line – palynologic study, striped line – microfaunistic study.

The upper part of the Oligocene consists of greyish-green fine-grained and glauconitic silty quartz sands with abundant muscovite flakes. Close to the boundary with the Czempin Formation, they frequently contain fine gravel and an increased amount of glauconite. The occurrence of the Lower Oligocene (Rupelian) is also proven by phytoplankton (Słodkowska, 2006). These deposits represent the Upper Mosina Formation, which records the Rupelian marine transgression.

Neogene (Miocene)

A hiatus exists between the Oligocene and the Miocene. The Oligocene is disconformably overlain by a Miocene succession represented by grey sands, greyish-brown muds with xylite fragments, and grey, greyish-green, locally different clays. These belong to the Middle and Late Miocene, and they contain relatively thin clayey lignite lenses with thicknesses of >11 m. This part of the Miocene belongs to the Poznań Formation (Fig. 2), and contains lignite. It records fluvial and thelmatic (marshy) sedimentary environments (Piwocki, 2004).

Methods used for palynological analysis

Palynological analyses were performed by studying material from the cores of the Palaeogene and Neogene from the Klucznik 1 and Sąpłaty 3 boreholes. A total of 30 samples, taken from sands, muds, clays and lignites, were used for the purpose. They were collected from the 115–303 m depth interval in the Klucznik borehole, and from the 141–298 m interval in the Sąpłaty borehole. The samples were processed at the laboratory by the standard palynological preparation procedure, which is based on the segregation of the organic and mineral fractions using the methods of density separation and modified Erdtman's acetolysis. Microscopic preparations from the macerates were analysed using a Leica ARISTOPLAN microscope. The full spectrum of palynological material was examined in the microscopic preparations: palynomorphs (sporomorphs, phytoplankton and zoomorphs) and palynoclasts (phytoclasts and inorganic remains).

The concentration of sporomorphs (spores and pollen grains) was high in most of samples from the Neogene, but low in the Palaeogene. The state of preservation was satisfactory. Spores and pollen grains were identified using the mixed morphological-natural taxonomy, with the botanical identity of taxa given if possible. The Palaeogene samples contained abundant phytoplankton (dinocysts, acritarchs, prasinophytes, etc.), which form the basis for palynostratigraphic subdivisions. Phytoplankton was determined using the morphological taxonomy. Phytoclasts, represented by brown and black wood fragments, cuticules and amorphous organic matter, are also present, as well as foraminiferal organic linings, spicules and diatoms.

Results

Palynology of the Klucznik 1 borehole

The 31 samples enabled identification of six phytoplankton assemblages in the Palaeogene and two spore-pollen assemblages in the Neogene (Fig. 3, Table 1).

Palaeogene

The role of palynostratigraphic marker in the Palaeogene is played mainly by marine phytoplankton. Sporomorphs are rare. The oldest Palaeogene assemblage was identified at a depth of 300–303 m in sandy muds containing carbonaceous material and glauconite. Sporomorphs are rare in this interval. *Oculopollis* cf. *obligatus* and *Trudopollis,* representing the extinct group of Normapolles, occur rarely. The deposits contain an abundant and taxonomically diverse marine phytoplankton assemblage represented by a number of characteristic taxa, including *Carpatella cornuta, Senoniosphaera inornata, Hystrichocolpoma bulbosum, Cerodinium diebelii, Palaeotetradinium silicorum, P. minusculum, Apectodinium homomorphum, Spinidinium clavum, S. echinoideum, Isabelidinium ? viborgense, Fibradinium annetorpense,* and *Palaeocytodinium lidiae*. Foraminiferal organic linings are also present among the palynological matter. The above phytoplankton spectrum, especially the abundance of *Carpatella cornuta* which has a very short stratigraphic range, indicates an Early Palaeocene age.

The next assemblage was identified at a depth of 277–287 m in sandy muds with glauconite. Marine phytoplankton plays an important stratigraphic role also in this assemblage. Sporomorphs are rare, but single *Extratriporopollenites* and *Trudopollis* pollen grains of the Normapolles group are present. The abundant marine phytoplankton is represented by, among others, the species: *Cerodinium striatum, Spinidinium clavum, Apectodinium summisum, Palaeoteradinium silicorum, P. minusculum, Fibradinium annetorpense, Isabelidinium ? vibor-*

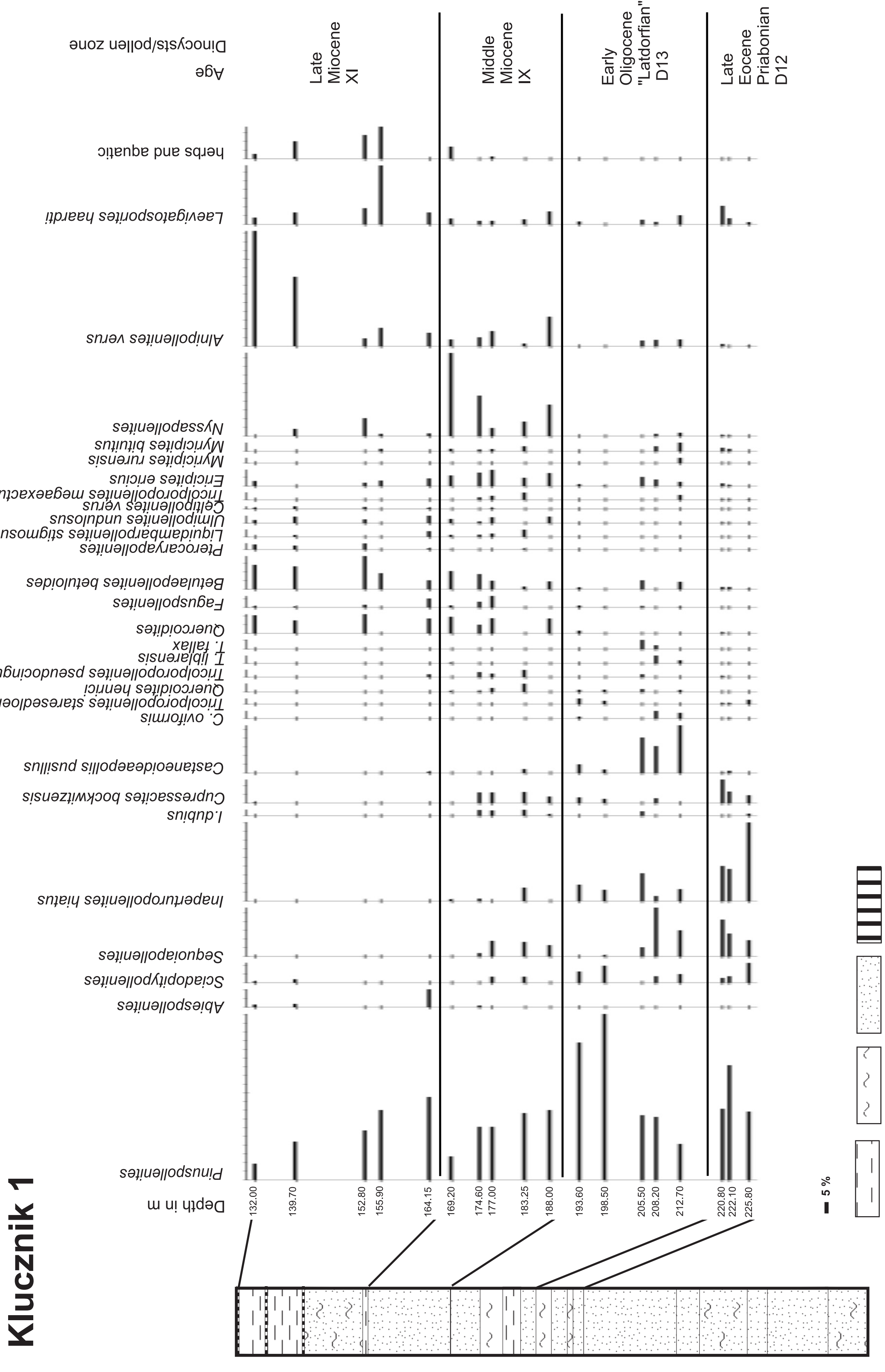

Fig. 3. Pollen diagram of Klucznik 1 borehole.

age / dynocyst zone	Late Miocene XI					Middle Miocene IX					Early Oligocene ('Latdorfian') D13					Late Eocene (Priabonian D12			Middle Eocene (Bartonian) D11		Middle Palaeocene (Selandian) D3					Early Palaeocene (Danian) D2			Early Palaeocene (Danian) D1	
Structizygodites			x	x																										
Spintetrapidites			x	x																										
Sigmopollis pseudosetarius	x	x	x	x	x	x		x																						
Diagonalites diagonalis			x	x																										
Deflandridium stellatum			x	x																										
Closteritetrapidites				x																										
Ovoidites ligneolus	x			x		x			x	x																				
Tetrapidites crassus	x					x				x																				
Pediastrum		x								x																				
Stigmozygoidites				x						x																				
Botryococcus	x	x		x		x				x	x	x		x	x		x		x											
Hystrichocolpoma rigaudiae											x	x																		
Chiropteridium lobospinosum												x																		
Wetzeliella samlandica												x																		
Cordosphaeridium fibrospinosum												x																		
Rhombodinium freienwaldensis											x	x	x																	
Pentadinium laticinctum											x		x																	
Wetzeliella symmetrica											x	x	x	x	x															
Wetzeliella articulata											x		x		x															
Homotryblium teniuspinosum												x			x															
Cordosphaeridium cf. *funiculatum*																x														
Enneadocysta cf. *pectiniformis*																x														
Membranophoridium aspinatum											x							x												
Glaphyrocysta pastielsii																		x												
Glaphytocysta cf. *vicina*																		x												
Deflandrea phosphoritica											x	x	x		x	x	x	x	x											
Spiniferites pseudofurcatus											x	x							x											
Corrudinium cf. *incompositum*																			x											
Areosphaeridium diktyoplokum																			x											
Paucilobimorpha incurvata											x	x	x				x		x	x										
Areosphaeridium michoudii																			x	x										
Paucilobimorpha triradiata																			x	x										
Charlesdownie clathrata																	x	x	x	x										
Apectodinium cf. *quinquetatum*																					x									
Deflandrea cf. *oebisfeldensis*																							x							
Cerodinium speciosum																										x				
Cymatiosphaera radiata											x	x							x								x			
Pterospermella barbare																											x			
Phanerodinium crenulatum																											x			
cf. *Isabelidinium cretaceum*																											x			
Paralecaniella																						x	x	x		x	x			
Paleoperidinium pyrophorum																							x	x	x	x	x			
Hystrichocolpoma cinctum																							x	x	x	x		x		
Cerodinium striatum																							x	x	x	x	x	x		
Apectodinium sumissum																										x	x	x		
Achomosphaera alcicornu											x	x									x					x	x		x	
Thalassiphora pelagica												x			x					x							x	x	x	
Operculodinium													x		x			x	x	x	x		x		x	x	x	x	x	
Isabelidinium viborgense																R						x	x		x		x	x	x	
Impagidinium																			x			x	x		x		x	x	x	
Microdinium cf. *ornatum*																			x									x	x	
Spiniferites cornutus																			x										x	
Paleocystodinium golzowense																						x	x	x	x	x	x		x	
Spinidinium clavum																						x	x	x	x	x	x		x	
Paucilobimorpha denticulata																								x	x				x	
Paleotetradinium silicorum																												x	x	
Hystrichocolpoma bulbosum																													x	
Areoligera																													x	
Caligodinium aceras																													x	
Spinidinium echinoideum																													x	
Apectodinium homomorphum																													x	
Senoniasphaera inornata																													x	
Carpatella cornuta																										R		R	x	
Apteodinium												x							x		x	x					x	x	x	x
Cordosphaeridium inodes																x				x	x		x	x	x	x	x	x	x	x
Spiniferites ramosus																			x				x	x	x	x	x	x		x
Membranosphaera																					x	x	x	x	x	x	x	x	x	x
Hystrichosphaeridium tubiferum																						x	x	x	x	x	x	x	x	x
Fibradinium annetorpense																						x	x	x	x	x	x	x	x	x
Paleotetradinium minusculum																							x	x	x	x			x	x
Spinidinium densispinatum																							x	x	x	x				x
Palambages morulosa																							x	x	x		x	x	x	x
Fromea																									x				x	x
Paleocystodinium lidiae																										x				x
Cerodinium diebellii																													x	x
Eatoniacysta ursulae																														x
Alterbidinium																														x
depth (m) taxon	132.0	139.7	152.80	155.90	165.15	169.20	174.60	177.00	183.25	188.00	193.60	198.50	205.50	208.20	212.70	220.80	222.10	225.80	231.15	235.90	250.80	254.60	259.10	266.00	273.00	277.40	281.50	287.40	299.50	302.50

Tab. 1. Distribution of Palaeogene and Neogene phytoplankton in Kluczník 1 borehole. R – reworked taxa.

gense, I. cf. *cretaceum, Paralacaniella, Paleoperidinium pyrophorum, Phanerodinium crenulatum, Pterospermella, Spinidinium densispinatum* and *Paleocystodinium lidiae*. The remaining components of the palynological material include organic linings of foraminifers, small concentrations of amorphous organic matter, and black wood fragments. This assemblage can be assigned to the late Danian.

Another assemblage was identified at a depth of 254–273 m in muddy, glauconitic sands. Sporomorphs are rare, with a trace contribution of pollen grains belonging to the Normapolles group: *Interpollis velum, Nudopollis* cf. *endargulatus* and *Trudopollis*. The abundant phytoplankton is represented by, among others: *Spinidinium densispinatum, S. clavum. Paleotetradinium minusculum, Isabelidinium ? viborgense, Fibradinium annetorpense, Palambages morulosa, Cerodinium striatum, Palaeoperidinium pyrophorum, Fromea* and *Paralacaniella.* The remaining components are, again, represented by organic linings of foraminifers, small concentrations of amorphous organic matter, and black wood fragments. This phytoplankton spectrum, in particular the frequent presence of *Palaeoperidinium pyrophorum* and *Spinidinium densispinatum,* limits the age of the assemblage to the early part of the Middle Palaeocene (Selandian).

The next assemblage was identified at a depth of 231–236 m in sandy/muddy deposits that contain glauconite. This assemblage is also dominated by marine phytoplankton, which prevails over other palynomorphs. The following index species were identified: *Areosphaeridium michoudii, A. diktyoplokum, Corrudinium incompositum, Charlesdowniea clathrata* and others of longer stratigraphic ranges: *Paucilobimorpha triradiata, P. incurvata, Microdinium* cf. *ornatum, Cymatiosphaera radiata.* This assemblage can be assigned to the Middle Eocene (late Bartonian). Some other, not typical, species were found, too. Among the other components in the palynological preparations, the most common are foraminiferal linings**.**

Higher up, at a depth of 221–226 m, another pollen-phytoplankton assemblage was identified in brown clays with xylite, and in glauconitic sands. For the first time, sporomorphs are a significant palynostratigraphic element in this assemblage. Gymnosperm pollen accounting for not less than79–89% of the total assemblage spectrum. The most frequent pollen grains are: *Pinuspollenites*, *Inaperturopollenites hiatus*, *Sequoiapollenites* and *Cupressacites bockwitzensis*. Due to the large amount of gymnosperm pollen, angiosperm pollen grains are relatively scarce, but they are taxonomically very diverse. They are represented by, among others: *Tricolporopollenites staresedloensis, Platanipollis ipelensis, Engelhardtioipollenites quietus, Platycaryapollenites, Castaneoideaepollis pusillus, C. oviformis, Fususpollenites fusus* and *Tricolporopollenites liblarensis.* Marine phytoplankton occurs also in significant amounts; identified species include C*ordosphaeridium* cf. *funiculatum, Enneadocysta pectiniformis, Charlesdowniea clathrata, Pentadinium laticinctum, Paucilobimorpha incurvata,* and *Glaphyrocyta pastielsii*. The remaining components of the palynological preparations include brown to black wood fragments. The entire assemblage spectrum strongly suggests a late Eocene (Priabonian) age**.**

The youngest Palaeogene assemblage was identified at a depth of 194–213 m in muddy and sandy deposits. It contains abundant pollen grains and phytoplankton. In the upper, sandy part of the interval (depth 194–98 m), the assemblage is dominated by gymnosperm pollen grains with abundant *Pinuspollenites*, *Sciadopityspollenites* and *Inaperturopollenites hiatus*. Gymnosperms, represented by *Pinuspollenites*, *Sequoiapollenites*, *Inaperturopollenites hiatus* and others, are also significant components of the lower part of the interval (depth 206–213 m), but they occur here in smaller amounts. Angiosperms are represented mainly by *Castaneoideaepollis pusillus* and less frequent *C. oviformis, Tricolporopollenites staresedloensis, T. megaexactus, T. bruhlensis, T. liblarensis, T. fallax, Platanipollis ipelensis* and *Engelhardtioipollenites quietus.* The stratigraphically important species of *Boehlensipollis hohli* and *Cupanieidites eucalyptoides* are also present. The marine phytoplankton contains the taxa: *Wetzeliella symmetrica, W. articulata, Rhombodinium freienwaldenis, Paucilobimorpha incurvata, Homotryblium teniuspinosum, Pentadinium laticinctum, Deflandrea phosphoritica, Chiropteridium lobospinosum, Cordosphaeridium fibrospinosum* and *Hystrichoc-*

olpoma rigadiae. The remaining components of the palynological preparation include brown to black wood fragments, foraminiferal organic linings and sponge spicules. This palynomorph assemblage, finishing the Palaeogene in this borehole, is most similar to that of the lowermost Oligocene 'Latdorfian' facies.

Neogene (Miocene)

The biostratigraphy of the Neogene is based in this borehole on sporomorphs. Phytoplankton is represented in the assemblages by freshwater specimens. Local admixtures of marine phytoplankton originated from reworking of older deposits.

The older of the two Neogene palynomorph assemblages was identified in carbonaceous muds and sands at a depth of 169–188 m. Gymnosperm and angiosperm pollen grains usually occur in comparable percentages. Among the gymnosperms, the most frequent are *Pinuspollenites*, *Sequoiapollenites*, *Inaperturopollenites hiatus* and *Cupresacites bockwitzensis*. The angiosperms are taxonomically diverse; the most frequent are pollen grains of taxa with moderate thermal requirements, such as *Nyssapollenites*, *Alnipollenites verus*, *Betulaepollenites betuloides*, *Quercoidites*, *Ericipites ericius* and *Faguspollenites*, but pollen of plants that require a warmer climate occur as well, such as *Quercoidites henrici*, *Tricolporopollenites pseudocingulum,* and *T. megaexactus*. The samples contains trace amounts of reworked Palaeogene marine phytoplankton. The remaining palynological material consists of relatively abundant brown and black wood fragments and cuticules. This palynological spectrum points to a Middle Miocene age.

The younger sporomorph assemblage was identified in carbonaceous muds from a depth of 132–165 m. It contains a large amount of spores and pollen grains. A high frequency (up to 27%) of *Laevigatosporites haardtii* spores is characteristic. The gymnosperm pollen spectrum is poor, both in diversity and frequency. *Pinuspollenites* and *Abiespollenites* (in a single sample) were identified. The remaining taxa occur in even smaller amounts. The most frequent angiosperm specimens are *Alnipollenites verus*, *Betulaepollenites, Quercoidites* and *Nyssapollenites.* Herbaceous and aquatic plants contribute significantly to the assemblage: *Cichoraecidites gracilis, Corsinipollenites parvus, C. oculisnoctis, Lythraceaepollenites bavaricus, Malvaceaepollenites, Nupharipollenites, Presicarioipollenites, P. pliocenicus, Psudotyphoipollis, Sparganiaceaepollenites, Tubulifloridites* and *Umbelliferoipollis.* Fresh-water phytoplankton is also present; its taxonomic diversity is particularly large in a sample from a depth of 156 m, where, among others, the following taxa were identified: *Botryococcus, Closteritetrapidites, Crassosphaera, Deflandridium stellarium, Diagonalites diagonalis, Ovoidites ligneolus, Sigmopollis, S. pseudosetarius, Spinitetrapidites, Stigmozygodites* and *Structizygodites.* Other components are brown to black wood fragments and cuticules. This palynomorph assemblage can be dated as Late Miocene.

Palynology of the Sąpłaty 3 borehole

Three Palaeogene phytoplankton assemblages and three Neogene pollen assemblages have been identified in the 30 samples from this borehole (Fig. 4, Table 2).

Palaeogene

The palynostratigraphic zonation of the Palaeogene of this borehole is based mainly on the phytoplankton spectrum, supported by supplementary evidence from spore and pollen grain analyses. The oldest assemblage was identified in muds and sands at a depth of 280–294 m. The main component of the assemblage is marine phytoplankton represented by the index species: *Dracodinium pachydermum, Cerebrocysta bartonensis, Pterospermella australiensis, Areosphaeridium michoudii, Cordosphaeridium fibrospinosum*; other species have a larger stratigraphic range, such as *Paucilobimorpha incurvata, P. triradiata, Pentadinium laticinctum* and *Wetzeliella eocaenica*. Sporomorphs are relatively rare. The remaining palynological material is represented by foraminiferal organic linings. This palynomorph assemblage can be dated as Middle Eocene (Bartonian).

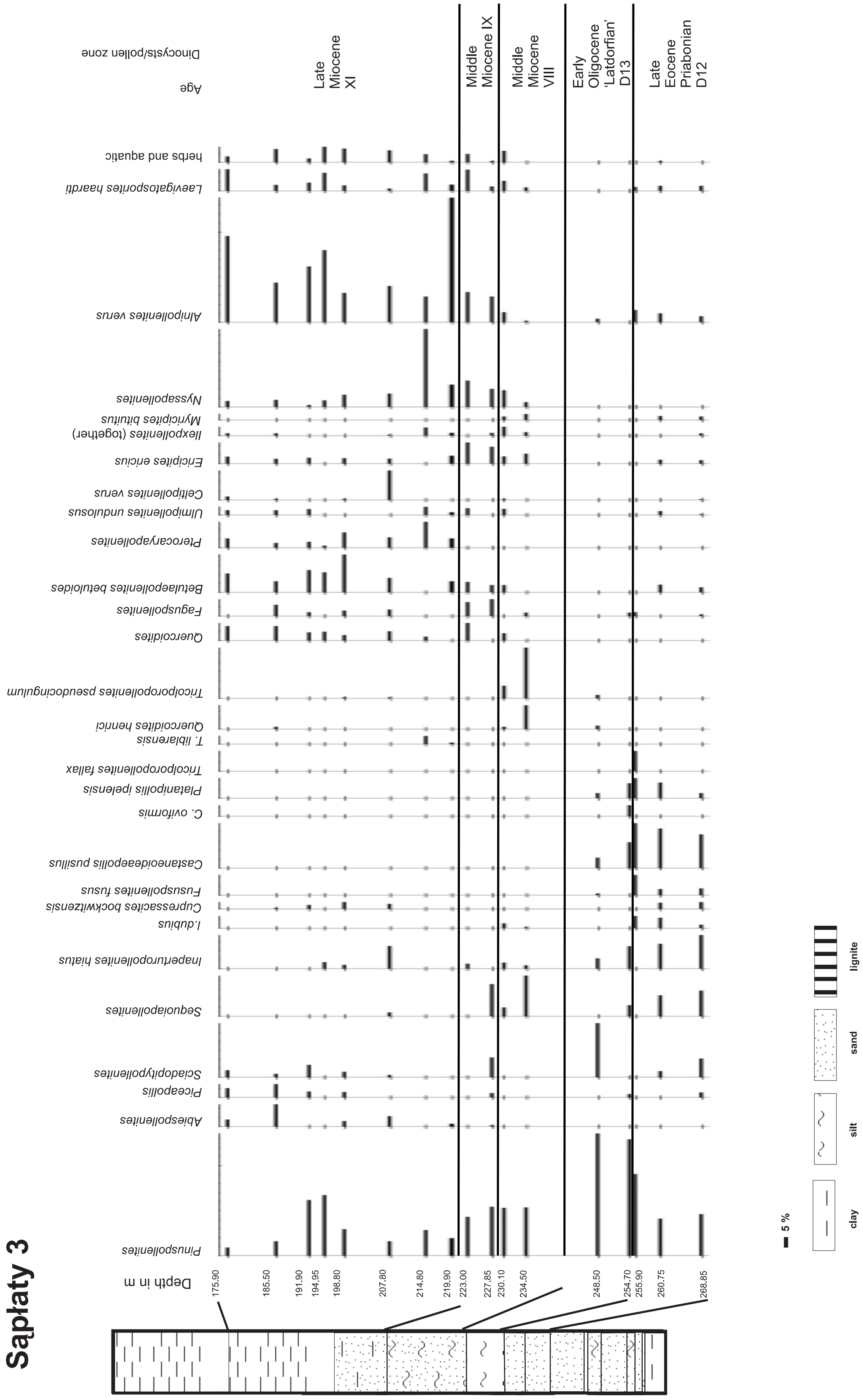

Fig. 4. Pollen diagram of Sąpłaty 3 borehole.

depth (m) / taxon	*Cerebrocysta bartonensis*	*Dracodinium pachydermum*	*Wetzeliella eocaenica*	*Deflandrea phosphoritica*	*Wetzeliella gochtii*	*Areosphaeridium michoudii*	*Paucilobimorpha triradiata*	*Paucilobimorpha incurvata*	*Operculodinium*	*Wetzeliella articulata*	*Cymatiosphaeropsis*	*Cordosphaeridium fibrospinosum*	*Homotryblium teniuspinosum*	*Charlesdowniea clathrata*	*Cordosphaeridium funiculatum*	*Spiniferites pseudofurcatus*	*Thalassiphora pelagica*	*Glaphyrocysta pastielsii*	*Enneadocysta pectinifomis*	*Cymatiosphaera ancorae*	*Rhombodinium freienwaldense*	*Cymatiosphaera radiata*	*Rhombodinium longimanum*	*Deflandrea heterophlycta*	*Membranophoridium aspinatum*	*Crassosphaera*	*Botryococcus*	*Pediastrum*	*Deflandridium stellarium*	*Sigmopollis*	*Stigmozygodites*	*Ovoidites ligneolus*	*Tetrapidites crassus*	*Tetrapidites*	age / dyocyst zone
175.90																														■		■		■	Late Miocene XI
185.50																																			
191.90																																			
194.95																														■					
198.90																										■							■		
207.50																														■					
214.80																																			
219.90																															■				
223.00																											■					■			Middle Miocene IX
227.85																											■					■			
230.10																											■			■	■				Middle Miocene VIII
234.50																																			
241.60																																			
248.50									■		■		■				■						■	■	■	■									Early Oligocene ('Latdorfian') D13
252.50								■									■					■		■	■	■				■					
254.70								■		■	■					■	■			■	■	■	■	■	■	■									
255.90																			■																Late Eocene (Priabonian) D12
260.75																		■									■		■						
268.85				■					■	■				■	■	■	■										■	■							
280.25			■	■		■					■	■	■													■									Middle Eocene (Bartonian) D11
283.10																																			
290.50				■		■	■	■	■	■																■									
294.50	■	■	■	■	■																														

Tab. 2. Distribution of Palaeogene and Neogene phytoplankton in Sąpłaty 3 borehole.

Another assemblage was identified in laminated clayey muds from a depth of 256–269 m. The palynomorph spectrum is characterized by comparable amounts of phytoplankton and sporomorphs. The latter are represented mainly by gymnosperm pollen grains: *Pinuspollenites*, *Sequoiapollenites, Inaperturopollenites hiatus* and *Sciadopityspollenites*. Angiosperm pollen grains belong mostly to *Castaneoideaepollis pusillus*, *Fususpollenites fusus, Platanipollis ipelensis, Tricolporopollenites liblarensis, Quercoidites microhenrici* and some less frequent species. The relatively scarce assemblage of marine phytoplankton includes the characteristic taxa of *Cordosphaeridium funiculatum, Charlesdowniea clathrata, Enneadocysta pectiniformis, Wetzeliella articulata, Deflandrea phosphoritica, Glaphyrocyta pastielsii, Thallasiphora pelagia, Achomosphaera crassipellis* and *Spiniferites pseudofurcatus.* The remaining material is represented by brown wood fragments and concentrations of amorphous organic matter. The pollen/phytoplankton spectrum suggests a Late Eocene (Priabonian) age.

The third assemblage was found at a depth of 248.50–255 m in sandy muds and clays. Among the sporomorphs, the most frequent are gymnosperm pollen grains: *Pinuspollenites, Inaperturopollenites hiatus* and *Sciadopityspollenites*. Angiosperms are rare and represented mainly by *Castaneoideaepollis pusillus, Platanipollis ipelensis, Fususpollenites fusus* and *Tricolporopollenites staresedloensis.* The phytoplankton is more frequent and diverse than the sporomorphs. There is an abundant assemblage containing *Deflandrea heterophlycta*, cf. *Eatoniecysta ursulae, Rhombodinium longimanum, Homotryblium abbreviatum, Paucilobimorpha incurvata, Pterospermella austaliensis, Cymatiosphaera radiata, Wetzeliella articulata* and *Membranophoridium aspinatum*. In addition, the samples contain fragments of diatoms, crushed sponge spicules, foraminiferal organic linings and single brown phytoclasts. This assemblage can be attributed to the earliest Early Oligocene 'Latdorfian' facies. It is the youngest Palaeogene assemblage in this borehole.

Neogene (Miocene)

Three sporomorph assemblages with a small addition of fresh-water plankton are present in the Neogene.

The oldest spore/pollen assemblage was identified in laminated carbonaceous sandy muds from a depth of 230–234 m. Gymnosperm pollen grains are represented by *Pinuspollenites, Sequoiapollenites* and other genera. Angiosperms are most commonly represented by *Tricolporopollenites pseudocingulum, Quercoidites henrici* and *Nyssapollenites*. Pollen grains of plants that require a high temperature include, among other species,: *Araliaceoipollenites edmundii, Engelhardtioipollenites punctatus, lporopollenites bruhlensis, T. exactus, T. megaexactus,* and *T. fallax*. Fresh-water plankton occurs sporadically. The abundant phytoclasts are represented by brown to black wood fragments and cuticules. The spectrum can be dated as Middle Miocene.

Higher up, another sporomorph assemblage was identified, in laminated carbonaceous muds at a depth of 223–228 m. The assemblage contains rare and taxonomically poor specimens. Gymnosperms are represented by *Pinuspollenites*, *Sequoiapollenites, Sciadopityspollenites* and others. Angiosperms are dominated by *Alnipollenites verus, Nyssapollenites, Quercoidites, Faguspollenites* and *Ericipites ericius*. There are also thermophilous taxa: *Quercoidites henrici, Araliaceoipollenites edmundii, Engelhardtioipollenites punctatus, Tricolporopollenites megaexactus, T. exactus* and others. The remaining microcomponents include brown to black wood fragments and cuticules. This pollen spectrum can be attributed to the Middle Miocene.

The youngest assemblage in this borehole was found at a depth of 176–220 m, in sandy muds with sporadic lignite and clay intercalations. The gymnosperm pollen grains are represented by *Pinuspollenites, Inapertutopollenites hiatus, Abiespollenites* and *Piceapollis*. Angiosperms predominate, the assemblage contains a considerable amount of *Alnipollenites verus*, but *Betulaepollenites betuloides, Quercoidites* and *Nyssapollenites* also occur in high percentages. The amounts of herbaceous and aquatic plants are significant. They are represented by *Butomuspollenites, Cichoraecidites gracilis, Corsinipollenites, Lythraceaepollenites bavaricus, Persicarioipollis, Pseudotyphoidites, Sparganiaceaepollenites, Tricolporopollenites* cf. *vicia, T.* cf. *centaurea, Tubulifloridites, Umbelliferoipollenites* and *Vitipites.* Fresh-water phytoplankton occurs sporadically. The remaining organic matter includes mainly phytoclasts: brown to black wood fragments and cuticules. This spore/pollen spectrum dates from the Late Miocene.

Microfauna

The microfauna of the Palaeogene was investigated for 16 samples from the Klucznik borehole and for 11 samples from the Sąpłaty borehole (Giel, 2005 – unpublished data). Determinable foraminifer specimens were found

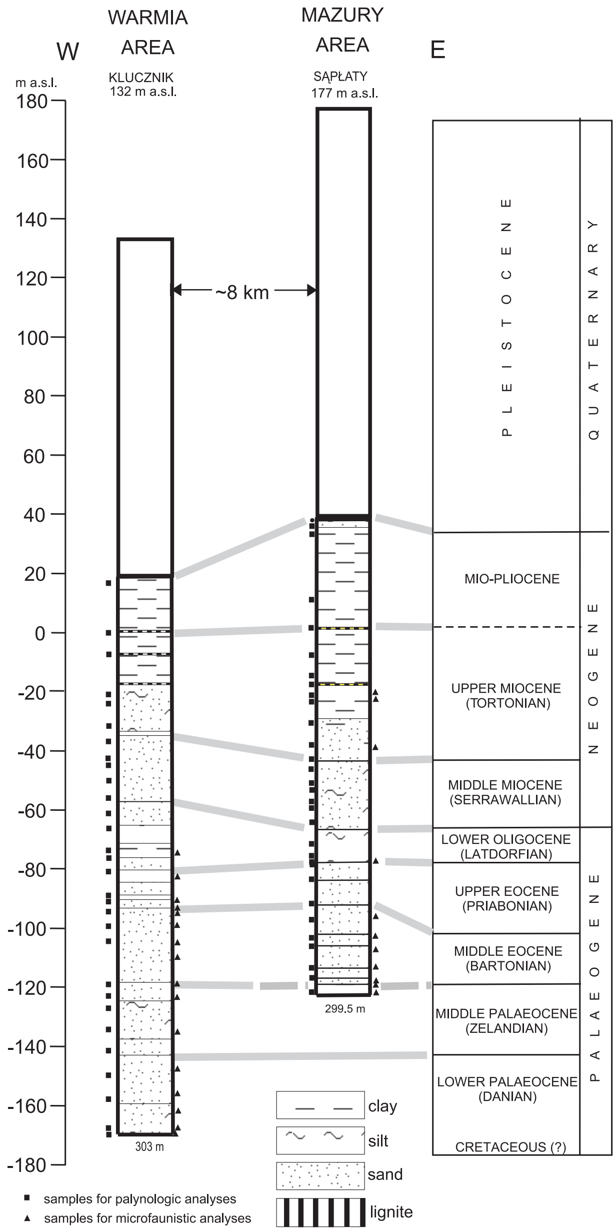

Fig. 5. Stratigraphic correlation of Palaeogene and Neogene deposits of Klucznik 1 and Sąpłaty 3 boreholes.

only in two samples from the Klucznik borehole. Sandy muds from a depth of 302–303 m contain rare small foraminifer individuals of: *Guttulina problema* d'Orbignyi, *Loxostomoides applinae* (Plummer), *Kolesnikovella europaea* (Suchman et. Edwards), *Cibicides ekblomi* Brotzen, *C. proprius* (Brotzen), *C. lectus* Vassilenko, *C. sahlstroemi* (Brotzen), *C. succedens* Botzen, *Gavelinella danica* Brotzen, *G. minor* (Pożaryska et Szczechura), *Protelphidium graniferum* (Terquem), *P. sublaeve* (Ten Dam) *Pulsiphonina prima* (Plummer) and *Bulimina paleocenica* Brotzen.

Radiolarians are rare. Occasional quartz moulds of indeterminate foraminifers and large quartz grains representing foraminifer moulds are present, too. Sponge spicules are sporadically present.

In the Sąpłaty borehole, these components are accompanied by plant detritus and sponge spicules. No foraminifers have been found in this borehole. Quartz locally occurs as foraminifer moulds.

Discussion

Interpretation of the palynostratigraphic data

The oldest assemblage identified in the Klucznik borehole is the phytoplankton assemblage characteristic of the Early Palaeocene (early Danian) defined by dinocyst zone D1 (Powell, 1992; Köthe & Piesker, 2007). The sediments belong to the Puławy Formation (Figs. 2, 5, 6; Table 1) and could be dated because the marine phytoplankton is typical. The sediments in the borehole form a continuous succession into the overlying assemblage of dinocyst zone D2 (Powell, 1992; Köthe & Piesker, 2007), which belongs lithostratigraphically to the upper part of the Puławy Formation, and which is characteristic of the late Danian (Early Palaeocene) (Figs. 2, 5, 6; Table 1). The next Palaeocene phytoplankton assemblage was identified in samples from the marine Selandian (Middle Palaeocene), which age could be assigned on the basis of index species. This assemblage is ascribed biostratigraphically to dinocyst zone D3 (Powell, 1992; Köthe & Piesker, 2007) and lithostratigraphically to the Puławy Formation (Figs. 2, 5; Table 1). Dinocyst zone D3 has been recorded in the Mazury region (Słodkowska, 2006) and in the Yantarnyy section on the Sambian Peninsula (Słodkowska, 2008). No Late Palaeocene, Early Eocene or early Middle Eocene deposits have been found in the Klucznik borehole.

The next sedimentary succession, consisting of Eocene deposits, was identified in both the Klucznik and Sąpłaty boreholes. The oldest, Middle Eocene (late Bartonian), assemblage is defined here by dinocyst zone D11 (Powell, 1992; Köthe & Piesker, 2007), which forms part of the Pomorze Formation (Figs. 3, 5; Tables 1, 2). This is a widespread phytoplankton marker horizon found over large areas of NE Poland (Słodkowska, 2006); it is also reported from the Yantarnyy section on the Sambian Peninsula (Słodkowska, 2008). Both sections also contain the Late Eocene (Priabonian) dinocyst zone D12 (Powell, 1992; Köthe & Piesker, 2007), which also belongs lithostratigraphically to the Pomorze Formation (Figs. 2, 5; Tables 1, 2). A similar assemblage was found in the Podlasie region (Słodkowska, 2006) and in the Yantarnyy section on the Sambian Peninsula (Słodkowska, 2008).

A continuous transition follows in both regions into the younger phytoplankton assemblage identified as dinocyst zone D13 (Powell, 1992; Köthe & Piesker, 2007), which is characteristic of the lowermost Oligocene, and which forms part of the marine 'Latdorfian facies' of the Lower Mosina Formation; it comprises important dinocyst taxa (Figs. 2, 5, 7; Tables 1, 2). The percentage of sporomorphs is considerable in this assemblage; they indicate that terrestrial plants, dominated by coniferous and mixed forests including thermophilous species, became significant (Figs. 2, 3). Small differences in the assemblage of the upper part of the borehole indicate a deepening of the marine environment, resulting in the deposition of (relatively) larger amounts of gymnosperm pollen grains (which are better adapted to survive transport over long distances) and in a more diverse phytoplankton assemblage. The differences

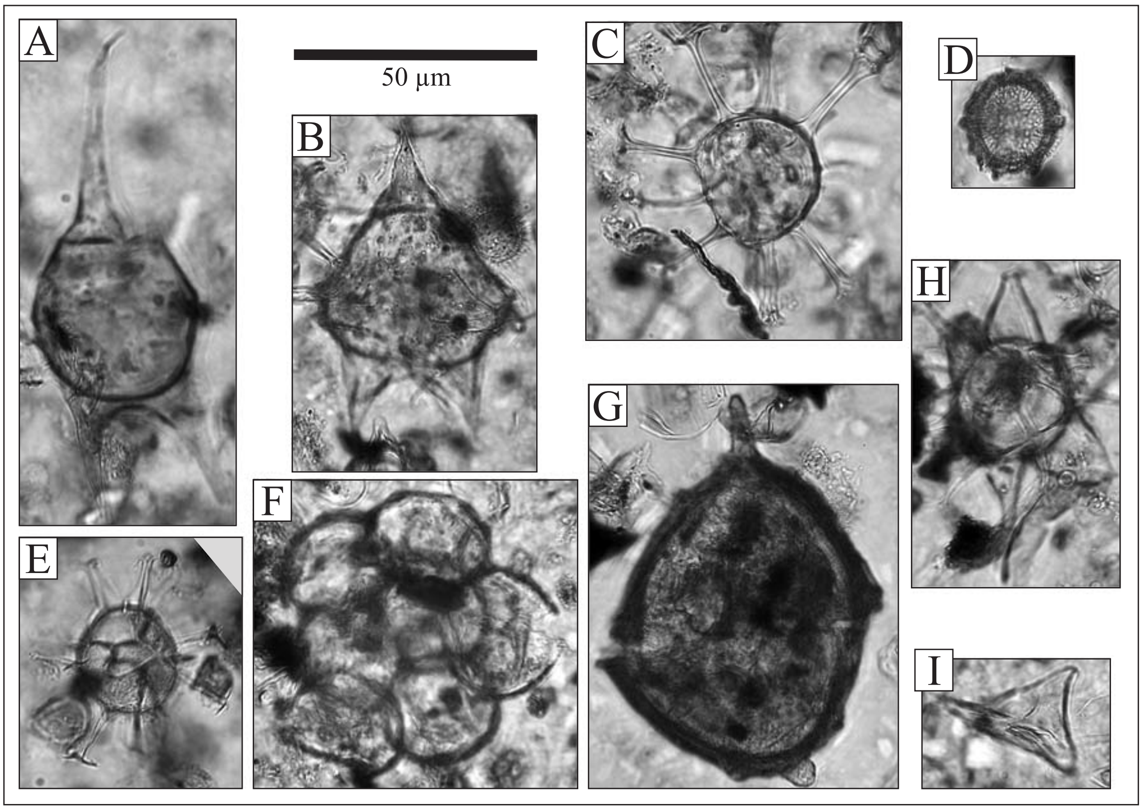

Fig. 6. Selected phytoplankton from Lower Palaeocene (Danian) deposits: A – *Cerodinium diebelii* (Alberti 1959) Lentin & Williams 1987; B – *Cerodinium speciosum* Lentin & Williams 1987; C – *Hystrichosphaeridium tubiferum* (Ehrenberg 1838) Deflandre 1937 emend. Davey & Williams 1966; D – *Fibradinium annetorpense* Morgenroth 1968; E – *Spiniferites ramosus* (Ehrenberg 1838) Mantell 1854; F – *Palambages morulosa* Wetzel 1961; G – *Carpatella cornuta* Grigorovich 1969; H – *Hystrichocolpoma bulbosa* (Ehrenberg 1838) Morgenroth 1968; I – *Palaeotetradinium silicorum* (Deflandre 1936) Deflandre & Sarjeant 1970.

are consequently attributed to habitat controls rather than to stratigraphical factors. Similar assemblages have been reported from many other sections in northern Poland (Grabowska & Ważyńska, 1997) and NE Poland (Słodkowska, 2006). The three dinocyst zones D11, D12 and D13, identified in both the Klucznik and Sąpłaty successions, are highly important horizons for correlation (Figs. 2, 5; Tables 1, 2).

No assemblages that could be dated as Late Oligocene or Early Miocene have been found in these boreholes.

The Neogene (Miocene) deposits show the development of vegetation-rich swamps (Figs. 2, 3, 4, 5), which would eventually result in the presence of lignite. The oldest Neogene sporomorph assemblage was dated as Middle Miocene (Early Serravallian); it occurs in the Sąpłaty borehole (Figs. 2, 4, 5, 8). Pollen grains of thermophilous plants dominate. This assemblage points to the VIII Celtipollenites verus pollen zone, which is characteristic of the Mid-Polish Lignite Seam I of the Poznań Formation (Ziembińska-Tworzydło, 1998). Similar spore/pollen assemblages have been described from northern Poland (Słodkowska, 2004). Younger assemblages of the Miocene were found in both the Klucznik and the Sąpłaty boreholes. Pollen zone IX Tricolporopollenites pseudocingulum (Figs 2, 4, 5, 8), which is correlated with the Oczkowice Lignite Seam IA of the Poznań Formation, represents the latest Middle Miocene (middle Serravallian) (Ziembińska-Tworzydło, 1998). Pollen of plants that require a temperate thermal regime dominate and are accompanied by a small percentage of thermophilous plants. Similar assemblages have been reported from many sections of NE Poland (Słodkowska, 2006) and northern Poland (Słodkowska, 2004). Pollen zone X has not been encountered.

Palynological evidence indicates the presence of Late Miocene (late Tortonian) deposits;

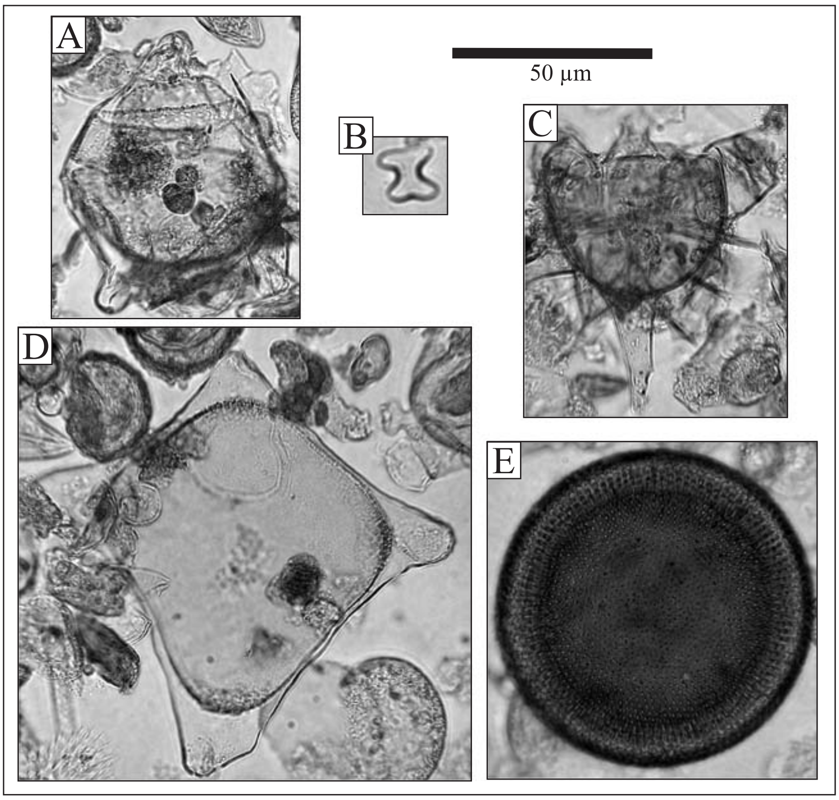

Fig. 7. Selected phytoplankton from the lowermost Oligocene ('Latdorfian') deposits: A – *Deflandrea phosphoritica* Eisenack 1938; B – *Paucilobimorpha incurvata* (Cookson & Eisenack 1962) Prosl 1994; C – Hystrichocolpoma rigaudiae Deflandre & Cookson 1955; D – *Rhombodinium freienwaldense* (Gocht 1955) Grabowska 1996; E – *Crassosphaera* sp.

they constitute the upper (but not the uppermost) part of the Poznań Formation. The pollen spectrum points to pollen zone XI Betulaepollenites – Cyperaceaepollis (Figs. 2, 3, 4, 5, 7). A sudden event of mass occurrence (>50%) of *Alnipollenites* took place during this zone. Similar assemblages have been reported from several sections in the Mazury region (Słodkowska, 2006) and in central and northern Poland (Słodkowska, 2004).

The overlying deposits contain sporadically sporomorphs, but these are useless for palynostratigraphic subdivisions. Such sporomorphs in sediments that are younger than pollen zone XI have been preserved sporadically over large parts of NE Poland, particularly in the uppermost 'flamy clays' of the Poznań Formation. The bad preservation is probably due to unfavourable physio-chemical during, and diagenetic conditions after deposition. The presence of barren and poor assemblages in both boreholes supports this hypothesis.

Interpretation of the microfaunal data

The microfauna in the sample from the Klucznik borehole (depth 302-–303 m) is not abundant. The foraminifer assemblage contains no agglutinated or planktonic specimens. The benthic foraminifer assemblage is typical of Early Palaeocene (Danian) boreal species (Fig. 2). The major characteristic species are *Loxostomum applinae* (Plummer), *Cibicides succdens* Brotzen, *C. lectus* Vassilenko, *Gavelinella minor* (Pożaryska et Szczechura), *Protelphidium graniferum* (Terquem) and *P. sublaeve* (Ten Dam).

The other samples do not contain calcareous foraminifer specimens, but large, frosted quartz grains are present that have a shape and structure typical of foraminifer tests. Large glauconite grains also sometimes appear to be diagenetically changed foraminifer moulds. The foraminifer quartz moulds are presented in

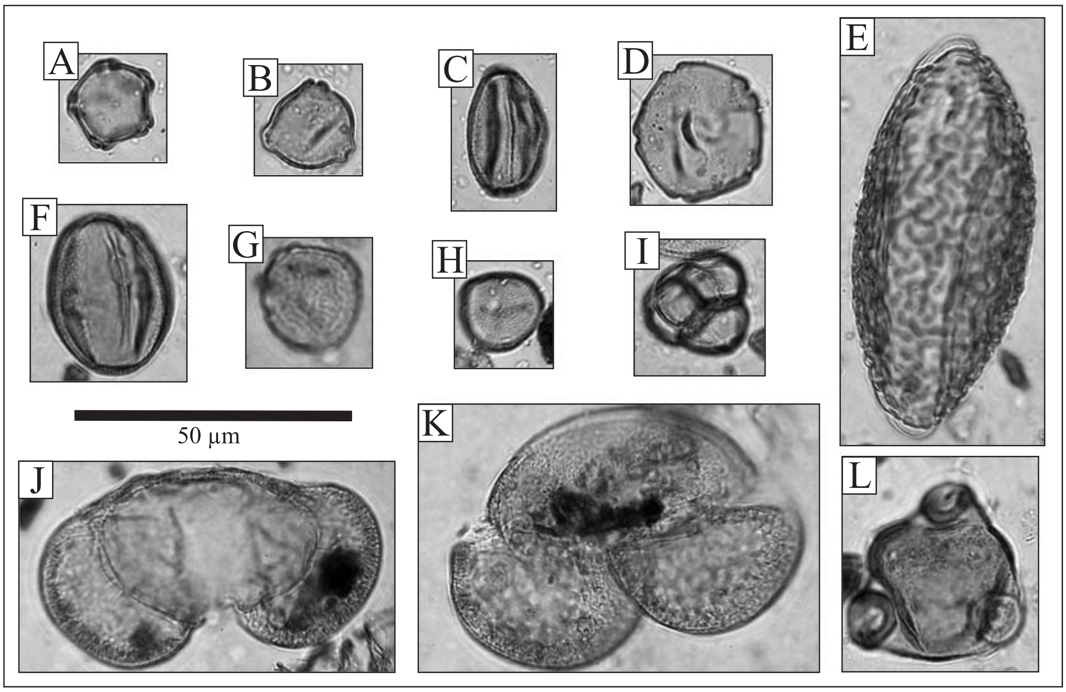

Fig. 8. Selected sporomorphs and phytoplankton from the Middle Miocene deposits: A – *Alnipollenites verus* Potonié 1931; B – *Myricipites bituitus* (Potonié 1931) Nagy 1969; C – *Quercoidites* sp.; D – *Multiporopollenites maculosus* (Potonié 1931) Thomson & Pflug 1953; E – *Ovoidites ligneolus* (Potonié 1951) Krutzsch 1959; F – *Nyssapollenites rodderensis* (Thiergart 1947) Kedves 1978; G – *Ulmipollenites undulosus* Wolff 1934; H – *Sparganiaceaepollenites* sp.; I – *Ericipites ericius* (Potonié 1931) Potonié 1960; J – *Pinuspollenites labdacus* (Potonié 1931) Potonié 1958; K – *Abiespollenites latisaccatus* (Trevisan 1967) Krutzsch 1971; L – *Corsinipollenites parvus* (Doktorowicz–Hrebnicka 1956) Słodkowska 2009.

variable quantities in most of the sandy deposits from the Klucznik and Sąpłaty boreholes. The moulds show a relatively well-preserved inner structure, shape and aperture. These features suggest that the moulds represent the genera *Cibicides, Bulimina, Lenticulina, Gavelinella* and *Miliolidae*. Silica fillings of foraminifer tests are also present in the western Warmia area. A lithology-based correlation with other boreholes suggests that the deposits are equivalent to the Early Oligocene (Rupelian) Lower Mosina Formation (Fig. 2).

Conclusions

The Klucznik and Sąpłaty boreholes are located on both sides of the intermediate zone between two different large-scale structural units: the Peribaltic Syneclise and the Mazury-Suwałki Anteclise. The Palaeogene succession from the Klucznik borehole is more complete, spanning the Palaeocene, Eocene and the Middle to Late Miocene, whereas the Sąpłaty succession contains Eocene and Middle-Late Miocene deposits (it did not reach the Palaeocene).

The Middle Eocene (Bartonian) is about 20 m thick in both boreholes. The Upper Eocene (Priabonian) is about 22 m thick in the Sąpłaty, and approx. 10 m in the Klucznik borehole. The difference in thickness is probably due to erosion. The Lower Oligocene shows also a difference in thickness, due to erosion that removed part of a sand unit in the Sąpłaty borehole. A huge hiatus exists between the Palaeogene and Neogene in both successions, representing the Late Oligocene, Early Miocene and much of the Middle Miocene (about 17 million years). This hiatus is due to an erosional event that affected a large part of NE Poland (Słodkowska, 2006).

The Neogene is more complete in the Sąpłaty section, where the Middle Miocene (Serravallian) is represented by pollen zones VIII and IX. In the Klucznik succession, only pollen zone IX is present. The lack of VIII zone in this succession is probably a local feature as the Neogene deposits in both boreholes are about 22 m thick. The Upper Miocene (Tortonian) is thicker in the Sąpłaty borehole (44 m) than in the Klucznik borehole (30 m). This difference is probably due to erosion. The overlying uppermost Miocene to lowermost Pliocene 'flamy clays' are palynologically barren. They are thinner in the Klucznik 1 borehole as a result of glacial erosion during the Pleistocene.

The individual stratigraphic units have similar thicknesses and lie at similar altitudes in both boreholes (Figs. 2, 5), which implies that the sedimentary conditions during the Palaeogene and Neogene were quite similar in the Warmia and Mazury areas. The Palaeogene and Neogene differ only little in their palynostratigraphic records. It can therefore be concluded that the palaeogeographic differentiation into two distinct provinces must have taken place during the Quaternary.

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