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New palyno- and lithostratigraphic interpretation of the Cenozoic lake sediments in the section Goleń, Mazury Lakeland

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Three lacustrine series were examined in the section Goleń. History of vegetation and respective climatic changes were presented on the basis of a palynological study. The Upper Miocene and Lower Pliocene sequence was defined at depth 119.10–138.75 m. Fragment of pollen succession at depth 35.10–36.92 m has been correlated with pollen periods II, III and IV of the Mazovian Interglacial. A new warm unit of the Pleistocene in Poland is represented by pollen succession recorded at depth 50.31–53.21 m. Petrographic analysis determined lithotypes of tills within the Quaternary complex. The tills were ascribed to Sanian, Wilgian, Liviecian, Odranian, Wartanian and Vistulian Glaciations. Interglacial lacustrine sediments defined by a palynological study are to be located at two stratigraphic positions alternatively. According to the first one, they can be correlated with the Mazovian Interglacial with the lower series *in situ*, and the upper being a glacial raft. The second version assumes that the upper series is also a formation *in situ* of the Mazovian Interglacial, while the lower series represents a new warm unit in the stratigraphy of the Quaternary of Poland.

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INTRODUCTION

Geological works carried out in 1981 at the sheet Piecki of the *Detailed Geological Map of Poland* at scale 1:50 000 included drilling of a test-cartographic borehole at Goleń. The borehole was located in the central Mazury Lakeland, about 15 km to the north of Mrągowo (Fig. 1). In total, 60 test-cartographic boreholes have been drilled in this area. Palynological study resulted in a conclusion that six boreholes encountered lacustrine sediments of the Mazovian Interglacial (M. Sobolewska, 1975; H. Winter, 1986; Z. Borówko-Dłużakowa, W. Słowański, 1991; K. M. Krupiński, 1997*a–c*).

The test-cartographic borehole at Goleń was drilled at a morainic plateau, within extent of the younger stadial of the Vistulian Glaciation, in a zone between Poznań and Pomeranian end moraines. 90 samples of Quaternary sediments and 91samples of Tertiary sediments were collected from a core, a total length of which was equal to 139 m. These figures include 48 samples of the Quaternary sediments (Z. Borówko-Dłużakowa, 1983; H. Winter, 1986) and 91 samples of the Tertiary sediments, collected for palynological examination (out of the latter, only 81 were analysed).

Three series of lacustrine sediments from the section at Goleń have been studied by pollen analysis. The lowest series (pre-Quaternary one) is represented by silts and clays at depth 119.10–138.75 m. Two younger lacustrine series occur within the Pleistocene complex, underlain and overlain by tills. The lower silty-clayey-peaty series at depth 50.31–53.21 m and upper at 35.10–36.92 m were examined. Both series are separated from each other by till and glaciofluvial sands, thickness of which is equal to 15 m (S. Lisicki, 1986).

The remaining 42 samples of Cenozoic sediments were subjected to lithologic and petrographic analyses. Petrography of gravels 5–10 mm was done for 31 samples of tills (E. Woźniak *et al.*, 1985).

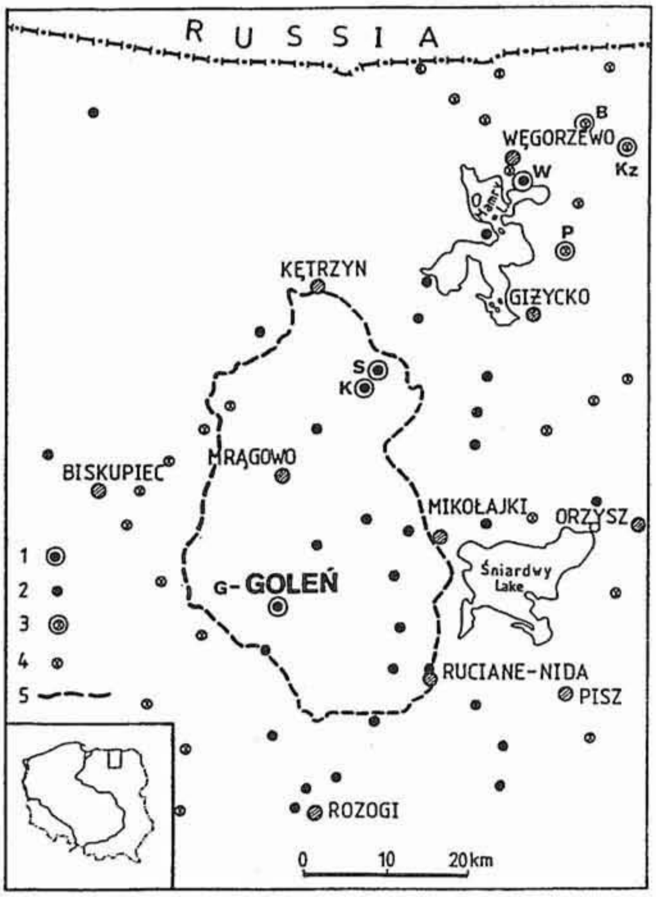


Fig. 1. Location of test-cartographic boreholes at Goleń in the central part of the Mazury Lakeland

1 — boreholes with palynologically examined sediments of the Mazovian Interglacial (W — Węgorzewo III, S — Sykstyny, K — Koczarki, G — Goleń), 2 — other test-cartographic boreholes, 3 — boreholes with palynologically studied sediments of the Mazovian Interglacial (profiles subject to analysed after 1995: B — Budry, Kz — Koźlak, P — Pozezdrze), 4 — other test-cartographic boreholes, with profiles analysed after 1995, 5 — limit of detailed research (Mrągowo Lakeland)

Lokalizacja otworu kartograficzno-badawczego Goleń w centralnej części Pojezierza Mazurskiego

1 — otwory z palinologicznie udokumentowanymi osadami interglacjału mazowieckiego (W — Węgorzewo III, S — Sykstyny, K — Koczarki, G — Goleń), 2 — pozostałe otwory kartograficzno-badawcze, 3 — otwory z palinologicznie zbadanymi osadami interglacjału mazowieckiego — profile analizowane po 1995 r. (B — Budry, Kz — Koźlak, P — Pozezdrze), 4 — pozostałe otwory kartograficzno-badawcze z profilami analizowanymi po 1995 r., 5 — granica obszaru szczegółowych badań geologicznych (Pojezierze Mrągowskie)

POLLEN ANALYSIS

METHOD

Preparation of samples for pollen analysis was dependent on type of sediment. Samples containing calcium carbonate were treated with 10% HCl first. All samples were boiled with 7% KOH. Then, mineral fraction was separated from organic one in water solution of cadmium and potassium iodides, density ca. 2.1 and then subjected to the Erdtman's acetolysis.

Results of pollen analysis of the Pleistocene series are presented in a percentage pollen diagram. Calculations were based on the basic pollen sum of trees, shrubs and dwarf shrubs (AP), and terrestrial herbaceous plants (NAP). Content of spores and pollen of aquatic plants, unknown and indeterminable because of deterioration, and of plankton were calculated with respect to the basic sum AP + NAP = 100%.

The local pollen assemblage zones L PAZ 1–17 were distinguished in the pollen diagram at depth 119.10–138.75 m and 9 at depths 50.31–53.21 and 35.10–36.92 m (Fig. 2). They are designed with a character symbol coming from the name of the site. Numbers are given in ascending order from the section bottom towards its top.

PRE-QUATERNARY SEQUENCE

Sediments at depth 119.10–138.75 m in the section Goleń are decalcified, beige or olive-green-blue clays and silts with brown-yellow spots and streaks of humus. Initially, age of selected samples subjected to pollen analysis was defined as the Upper Pliocene or the Early Quaternary (I. Grabowska, 1985).

Detailed pollen analysis of studied sediments provided very interesting data dealing with changes of vegetation and climate and made their dating possible. Different forest communities and open habitats were distinguished. The former were represented by mixed as well as swampy forests. Coniferous trees such as *Pinus*, *Picea*, *Sciadopitys*, *Abies*, *Tsuga* and *Sequoia,* and deciduous trees such as *Betula*, *Quercus*, *Carpinus*, *Tilia*, *Juglans*, *Castanea* and *Aesculus* were the main components of mixed forests growing at dry places. Riparian forests overgrowing moist habitats were composed of *Ulmus*, *Pterocarya, Fraxinus*, *Liquidambar*, *Salix* and *Celtis*. Swampy forests were distinctly predominated *Alnus* and varying participation of *Nyssa* and trees of the group *Taxodiaceae-Cupressaceae.*

Cyclic appearance of open area vegetation, alternating with forest communities, is a very important symptom for variability of vegetation communities in the neighbourhood of Goleń. Communities of open habitats are represented by high values of pollen of herbaceous plants and by great taxonomic variety. Predominant were *Gramineae*, contents of which increased to 30%. Increasing of *Gramineae* was followed by a marked increase of pollen of plants such as *Cruciferae*, *Anthemis* type, *Chenopodiaceae* and *Artemisia,* representative for dry habitats. Abundant frequency of pollen of *Polygonum persicara* type, *Rumex acetosa* type and *Urtica* indicates presence of wet habitat communities.

Vegetation communities in the neighbourhood of Goleń were subjected to various transformations. Among others, the latter were expressed by changes within mixed forest, with numerous coniferous trees and gradually increasing role of *Quercus.* A role of forest communities has occasionally decreased. They were replaced by dry communities of open steppe habitats.

Transformations of vegetation communities and formations resulted from climatic changes. Very poor participation of palaeotropical elements represented by pollen of *Itea*, *Engelhardtia* and *Reevesia* as well as emphatic predominance of Arcto-Tertiary elements provide evidence for a temperate warm climate with variable humidity and cyclic continentality. Increasing of continentality is revealed by abundant occurrence of herbaceous plants of open areas.

The examined sediments belong to the variegated clays that terminate deposition of the Poznań Formation. The latter was dated to the Upper Miocene and the Early Pliocene, including the Pontian and Dacian (M. Piwocki, M. Ziembińska-Tworzydło, 1997).

Cyclic appearance of steppe-like vegetation is typical for pollen spectra from a depth 119.10–38.75 m. Changes of such type indicates that climate with variable humidity prevailed. In addition, considerably greater temperature fluctuation occurred if compared with warm and humid climate of the Miocene.

Some notes appeared in relevant palaeobotanic literature (W. Szafer, 1954; L. Stuchlik, 1980, 1987) on possibility of such climate in Poland that could result in development of steppe and forest-steppe communities. However, such drastic vegetation changes as those at Goleń have never been recorded.

QUATERNARY SEQUENCE

Zone G 18 ***Picea-Alnus-Abies*** (samples 43–33; depth 53.21–52.29 m). Pollen of trees (AP 77.4–95.6%) predominates. Pollen of *Pinus* is relatively abundant (up to 62%) in the lower part of the zone while pollen of *Picea* predominates in the upper part (with its highest occurrence at 47.2%). Values of *Alnus* fluctuate from 0.7 to 24%, and *Betula* from 2.5 to 20.5%. Content of *Abies* gradually increases and exceeds 13%. *Quercus, Fraxinus* and *Carpinus* distinctly mark their presence among thermophilous deciduous trees, though with low values: *Quercus* up to 5%, *Fraxinus* in excess of 4%, and *Carpinus* less than 4%. Pollen of other termophilous trees as *Tilia, Acer* and *Ulmus* does not exceed 1.5%. Pollen of *Corylus* reaches its highest values in the whole section (1–8%). Pollen of *Taxus* is rare (maximum to 1.18%).

Values of herb pollen are variable (4.4–22.6%), *Cyperaceae* and *Gramineae* are the main representatives. Pollen aquatic plants is present by *Potamogeton*.

Upper boundary of the zone is marked by decreasing content of *Picea* and *Alnus* and rise of *Betula* pollen and NAP pollen.

Zone G 19 ***Betula-Picea*-NAP** (samples 32–28; depth 52.22–51.51 m). High values of *Betula* (14–41.2%, maximum occurrence in the whole section) and high values of herb pollen (19.2–29.9%) are the characteristic feature of this zone. Values of *Pinus* increase slightly and reach 32%. Drop of *Alnus* values is distinct. Values of pollen of *Quercus, Ulmus, Tilia, Fraxinus, Carpinus* and *Taxus* fall too. *Abies* pollen does not exceed 14% and *Corylus* 4.6%.

Among NAP, pollen of *Gramineae* and *Cyperaceae* reaches the highest values (*Gramineae* 9.5–13.6% and *Cyperaceae* 3.1–9.4%). More abundant is *Artemisia* pollen.

The upper boundary is defined by insignificantly increasing in values of *Betula* and *Pinus*, and fall in NAP values.

Zone G 20 ***Betula-Pinus*** (samples 27–25; depth 51.43–51.11 m). This zone is characterized by gradual increase of *Pinus* values to about 45% and high values of pollen of *Betula* (25.5–31.2%). Values of *Picea* decrease and pollen of *Abies* is continuously present with values of 2.3–7.2%. *Corylus* disappears. Thermophilous taxa (except for *Quercus*) occur occasionally. Values of herbaceous plants decrease.

The upper boundary is marked by a rise of *Pinus* and *Picea* pollen values, and decline of values of *Betula*.

Zone G 21 ***Pinus-Picea*** (samples 24–22; depth 50.79–50.31 m). This is the zone with the highest values of *Pinus* (52–60%), accompanied by rise of *Picea* pollen to 38%. Pollen of *Abies* is still above 1%. *Betula* falls rapidly below 3.2%. NAP does not exceed 6%.

Zone G 22 ***Pinus-Picea-Alnus*** (samples 21–19; depth 36.92–36.70 m). *Pinus* and *Picea* are the predominant pollen types. Values of *Alnus* range between 7.2 and 16.9%. Pollen of other trees does not exceed 5% and NAP is low (4.5–5.8%).

The upper boundary is marked by rise of *Abies* and *Carpinus*, associated with decline of *Pinus* and *Picea*.

Zone G 23 ***Abies-Carpinus*** (sample 18; depth 36.70–36.63 m). Predominant is pollen of *Abies* (42.7%). Values of *Carpinus* increase to more than 13%. Values of *Pinus* and *Picea* fall. Thermophilous taxa are represented by pollen of *Quercus, Corylus, Fraxinus* and *Ulmus*.

The upper boundary is at the rise of *Alnus* and *Picea*, and the drastic fall of *Abies* and *Carpinus*.

Zone G 24 ***Alnus-Picea*** (samples 17–16; depth 36.63–36.53 m). In this zone *Alnus* reaches 32.9% i.e. the highest value in the whole section; it is associated with high values of *Picea* (37.6%). Frequency of *Abies* and *Carpinus* is low: *Abies* below 3% and *Carpinus* below 1%. *Quercus, Ulmus, Tilia, Fraxinus* and *Corylus* are not abundant; however, their presence is marked by continuous curves.

The upper boundary is located at rise of *Abies* values and *Carpinus* pollen values.

Zone G 25 ***Abies-Carpinus-Quercus*** (samples 15–5; depth 36.53–35.50 m). A lower part of this zone is characterized by the highest values of *Abies* in the whole section (max. 54.21%); however, it falls down to 10% in the upper part of the zone. The curve of *Carpinus* displays insignificant fluctuation from 8.4 to 14.2%. More abundant is pollen *Quercus*, reaching its maximum equal to 14%. Pollen of other thermophilous taxa as *Corylus, Ulmus, Tilia* and *Fraxinus* does not exceed 2.5%. Pollen of *Picea* decreases. The curve of *Alnus* shows appreciable oscillations (4–27%). NAP values are the lowest in the whole section.

The upper boundary is marked by fall of values *Carpinus* and *Quercus*, and rise of *Pinus* and *Picea* pollen values.

Zone G 26 ***Pinus-Picea-Abies*** (samples 4–1; depth 35.50–35.10 m). Pollen of *Pinus* (35–40%) predominates in this zone. Values of *Picea* are equal to 16.4–33.7% values, of

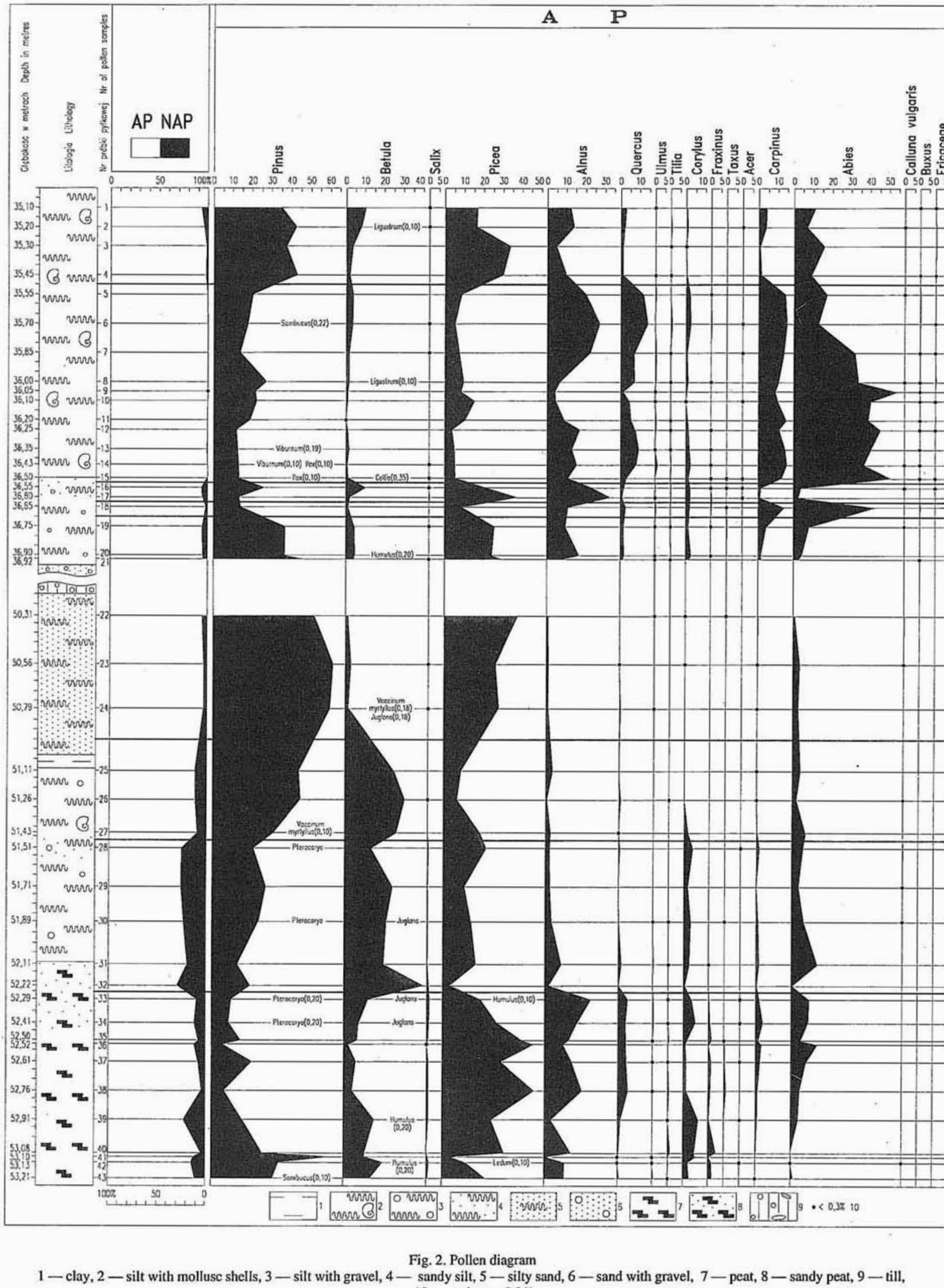


Fig. 2. Pollen diagram
1 — clay, 2 — silt with mollusc shells, 3 — silt with gravel, 4 — sandy silt, 5 — silty sand, 6 — sand with gravel, 7 — peat, 8 — sandy peat, 9 — till, 10 — values < 0.3%

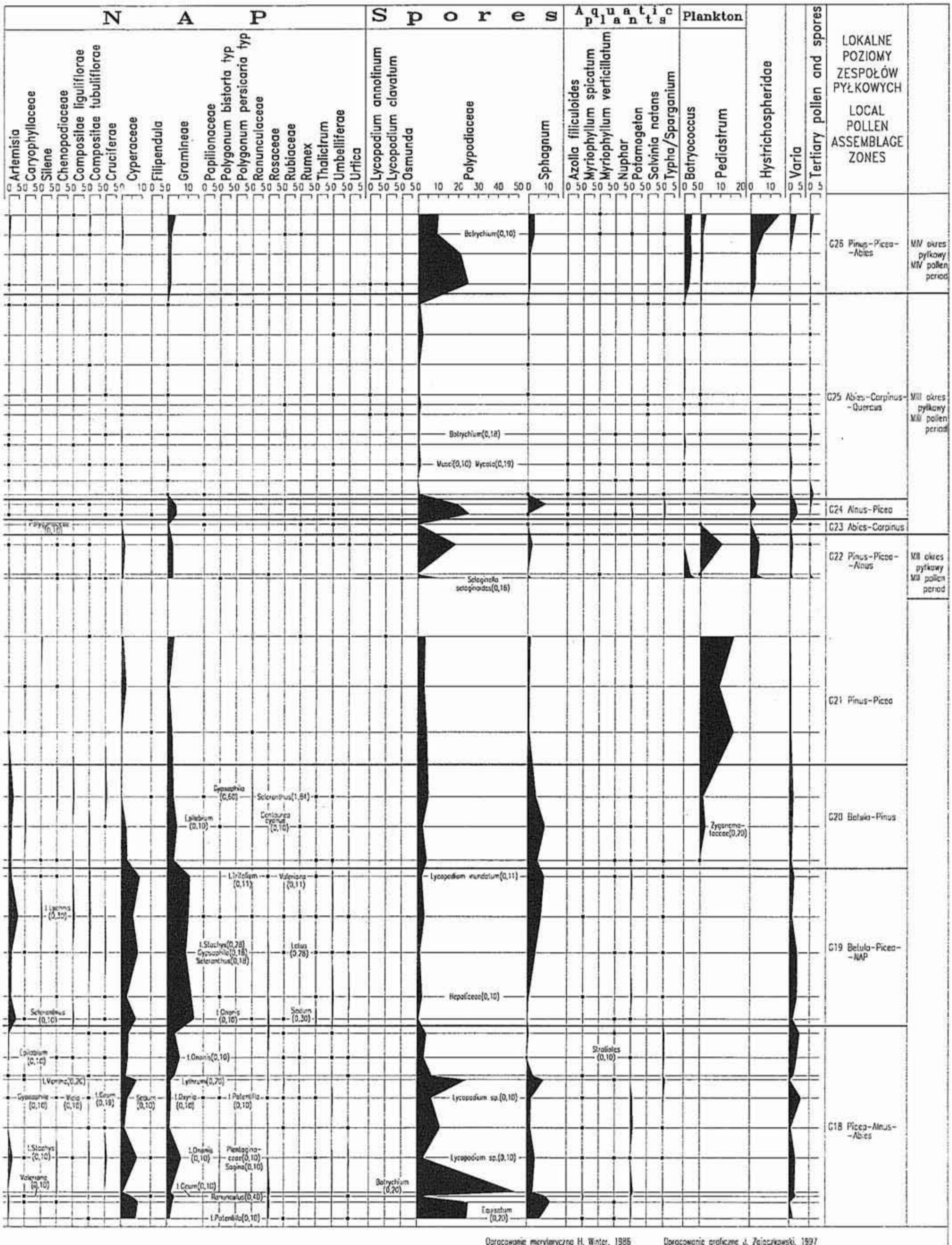


Diagram pyłkowy

1 — ił, 2 — mułek z fauną, 3 — mułek ze żwirem, 4 — mułek piaszczysty, 5 — piasek mułkowaty, 6 — piasek ze żwirem, 7 — torf, 8 — torf piaszczysty, 9 — glina zwałowa, 10 — wartości < 0,3%

Abies are from 6.7 to 15.8% and *Alnus* reach 14%. Content of *Betula* increases to 10%. Frequency of *Carpinus* is low, less than 4.1%. Values of *Quercus* fall below 3%. Contents of other thermophilous taxa do not exceed 1%.

HISTORY OF VEGETATION AND CLIMATIC CHANGES

Local pollen assemblage zones L PAZ, distinguished in the pollen diagram (Fig. 1), are the base for history of vegetation in the area around the Goleń reservoir. Climatic classification and relationship between climate and vegetation zones (developed by H. Walter, 1976) provide the basis to correlate vegetation communities with types of climate.

Zone G 18 *Picea-Alnus-Abies*. Predomination of AP indicates that forest communities prevailed. Forests were mixed: with spruce, pine and birch. High values of *Picea* indicate considerable participation of this tree at moist habitats. Drier places were occupied by pine (*Pinus*), birch (*Betula*), oak (*Quercus*), hornbeam (*Carpinus*) and linden (*Tilia*). Fertile and fresh soils were favourable for *Juglans*. Share of fir (*Abies*) gradually increased. Hazel (*Corylus*) and presumably yew (*Taxus*) were the main elements in the undergrowth.

Wet areas were occupied by riparian forests with ash (*Fraxinus*), elm (*Ulmus*) and alder (*Alnus*). These forests seem to have been the source of pollen of hop (*Humulus*) and *Pterocarya*. Very wet habitats were occupied by marshy forests with alder, in which *Polypodiaceae* was the main component in the undergrowth. Pollen of herbaceous plants, in excess of 22%, may indicate open habitats.

Relatively abundant occurrence of *Sphagnum* and presence of peat in the section proves existence of peatbogs. Aquatic plants are represented by *Potamogeton*, *Typha* and *Sparganium*.

The climate was subhumid one as that time. It is indicated by occurrence of yew (*Taxus*) and *Pterocarya*.

Zone G 19 *Betula-Picea*-NAP. Successive decrease in pollen of spruce (*Picea*), alder (*Alnus*) and oak (*Quercus*) and increasing contents of birch (*Betula*) and pine (*Pinus*) were due to changing forest communities. Expansion of birch (*Betula*) could take place in habitats occupied by spruce (*Picea*) as well as it could supersede alder (*Alnus*) in marshy forests to form birch ones. Riparian forests lost their significance as indicated by disappearance of ash (*Fraxinus*), elm (*Ulmus*) and maple-tree (*Acer*). Increasing NAP values, in particular of *Gramineae, Cyperaceae* and *Artemisia*, indicates that communities representative for open habitats expanded.

Changes of vegetation in the zone G 19 were caused by increasing continentality and cooling.

Zone G 20 *Betula-Pinus*. Changes of vegetation communities continued. Communities of open habitats were replaced by forests with predominant pine (*Pinus*) and birch (*Betula*). Pine-birch forests with admixture of spruce (*Picea*) and fir (*Abies*) were predominant. Changeable character of forests provides evidence for further cooling, until boreal climate was attained.

Zone G 21 *Pinus-Picea*. Expansion of pine (*Pinus*) and spruce (*Picea*) is indicated by very low values of *Betula* in areas occupied by birch (*Betula*). Although the forest communities were transformed, climatic conditions have not changed much probably.

The pollen zones G 18–G 21 create palaeobotanic evidence for the series at depth 50.31–53.21 m which should be referred to a warm unit during the Pleistocene. The series is overlain by a till, representative for a glacial episode.

Zone G 22 *Pinus-Picea-Alnus*. Predominant vegetation communities were the pine-spruce forests with insignificant admixture of fir (*Abies*), oak (*Quercus*) and hornbeam (*Carpinus*). Hazel (*Corylus*) and *Buxus* grew in the undergrowth. Very wet habitats were overgrown by alder forests with *Polypodiaceae* and hop (*Humulus*).

Zone G 23 *Abies-Carpinus*. Forest communities were very distinctly transformed. Increasing contents of *Abies* and *Carpinus*, associated with fall *Pinus* and *Picea*, indicates expansion of the fir-hornbeam forests. *Corylus* and *Buxus* still were the main representatives of the undergrowth in the mixed forests. Moist areas have been continuously overgrown by alder forests with ash (*Fraxinus*) and elm (*Ulmus*).

In both zones G 22 and G 23 a temperate climate predominated; however, appearance of yew (*Taxus*) and microsporangia of *Azolla filiculoides* indicate gradual warming.

Zone G 24 *Alnus-Picea*. Retreat of fir (*Abies*) and hornbeam (*Carpinus*) indicates changes in forests, which were invaded by spruce (*Picea*), alder (*Alnus*) and to smaller degree, by pine (*Pinus*) and birch (*Betula*).

Changes in pollen spectra as well as supply with silt with sand and gravel reflect transformation into a more humid climate.

Zone G 25 *Abies-Carpinus-Quercus*. Maximum expansion of fir (*Abies*) is a characteristic feature in the lower part of this zone. This tree invaded areas which had been occupied by spruce (*Picea*) and pine (*Pinus*). This fact is reflected by decreasing values of pollen of these trees. Hornbeam (*Carpinus*) and oak (*Quercus*) became more important in forest communities. Pollen of *Ilex* and *Celtis* appeared. Hazel (*Corylus*) and box (*Buxus*) played the most important role among shrubs, and occurrence of hazel was rather stable. There is sporadic presence of *Ligustrum*.

Gradual fall of fir (*Abies*) follows in the upper part of this zone. This phenomenon indicates decreasing role of fir in forest communities. On the other hand, rise of oak (*Quercus*) indicates its great importance. Wet habitats were overgrown by forests with alder (*Alnus*), ash (*Fraxinus*) and elm (*Ulmus*).

A climate got warmer. Occurrence of *Ligustrum* indicates warm summers while presence of *Ilex* — very mild winters.

Zone G 26 *Pinus-Picea-Abies*. Forest communities were transformed in this zone. Contents of thermophilous deciduous trees as hornbeam (*Carpinus*), oak (*Quercus*), ash (*Fraxinus*), linden (*Tilia*), hazel (*Corylus*) and box (*Buxus*) were markedly decreasing. Fir-hornbeam-oak forests gradually changed into pine-spruce ones due to climatic cooling.

AGE OF SEDIMENTS AND CHRONOSTRATIGRAPHIC CORRELATIONS

Z. Borówko-Dłużakowa (1983) examined four samples of sediments from Goleń (three of them from the lower series and one — from the upper one). According to her opinion, the samples represented a single interglacial with two climatic optima or the lower samples could be correlated with the Mazovian Interglacial and the upper sample — with "the younger interglacial (Eemian?)".

Pollen succession in sediments at depth 35.10–36.92 m is the same as the one of pollen periods II, III and IV of the Mazovian Interglacial. The typical features are: predomination of pollen of spruce and alder in spectra of the period II, then of fir and hornbeam, the greatest participation of oak among thermophilous deciduous trees and occurrence of *Ilex*, *Buxus* and *Ligustrum*, and microsporangia of *Azolla filiculoides* in the period III. High contents of *Picea* and *Abies* are accompanied by abundant *Alnus*, with low participation of thermophilous taxa in the period IV. Pollen spectra of this fragment are very close to the ones of the pollen periods II, III and partly IV at the type locality at Krzyżewo — the representative for eastern Poland (Z. Janczyk-Kopikowa, 1996) as well as in other sections in this region (Z. Borówko-Dłużakowa, W. Słowański, 1991; M. Sobolewska, 1975).

Comparison of the fragment of succession at depth 50.31–53.21 m with other pollen successions in Poland proves its difference from other successions such as Augustovian, Ferdynandovian or Eemian. High values of *Picea* and *Alnus*, and their coexistence as well as presence of *Taxus*, *Quercus*, *Ulmus*, *Corylus* and *Fraxinus* suggest correlation of this fragment of succession with the period II of the Mazovian Interglacial.

The Mazovian pollen succession is well documented in northeastern Poland. In particular, sites in the Biała Podlaska area are numerous (K. Bińka, J. Nitychoruk, 1995, 1996; K. M. Krupiński, 1995) and to a smaller degree — in the Mazury and Suwałki regions (Z. Borówko-Dłużakowa, W. Słowański, 1991; Z. Janczyk-Kopikowa, 1996; K. M. Krupiński, 1995; M. Sobolewska, 1975). Presently, high values of *Taxus* are characteristic for the period II of the Mazovian Interglacial. A section at Kępiec was the first one in which high values of yew pollen (up to 35%) were recorded (Z. Janczyk-Kopikowa, 1981). Very high values of yew are also noted in sections from Biała Podlaska (K. M. Krupiński, 1995) and its vicinity including localities at Ossówka, Komarno (K. M. Krupiński, 1995), Woskrzenice (K. Bińka, J. Nitychoruk, 1995) and Kaliłów (K. Bińka, J. Nitychoruk, 1996). Markedly lower values of yew (10%) are noted in the section Krzyżewo (Augustów Lowland). In the section Koczarki, yew is very rare while at Węgorzewo it is completely absent (M. Sobolewska, 1975). At Goleń maximum value of *Taxus* is 1.2% only.

The presented fragment of the pollen diagram from Goleń cannot be easily correlated with the pollen period II of the Mazovian Interglacial, recorded in other diagrams. Although spruce (*Picea*) and alder (*Alnus*) are also the characteristic taxa for this period, but presence of fir (*Abies*) with values to 14% is very distinct. Pollen of fir appears relatively early in the diagram of Węgorzewo only (M. Sobolewska, 1975; W. Szafer, 1953), but its values do not exceed 10%.

There are more distinct differences connected with very high share of pollen of birch (*Betula*) in the zones G 19 and G 20, and relatively high values of NAP (over 29%). These changes are associated with distinct fall in values of alder (*Alnus*) and less distinct fall in values of spruce (*Picea*).

Occasional increase in contents of pine and birch is noted in several pollen diagrams of the Mazovian Interglacial. However, these changes are not followed by distinct increase of NAP. Such changes in vegetation were considered by Z. Janczyk-Kopikowa (1996) as index of some climatic dessication. On the other hand, K. M. Krupiński (1995) and K. Bińka, J. Nitychoruk (1996) recognized them as cooling that had taken place during climatic optimum of the Mazovian Interglacial. Changes in pollen succession at Goleń markedly reflect a cooling, during which forest communities represented a cool interstadial rather, being loose birch-pine-spruce forests.

Comparison of a fragment of the pollen succession recorded at depth 50.25–53.25 m in the section at Goleń with the pollen period II of the Mazovian Interglacial proves their general similarity. However, distinct differences as mentioned above exist between particular pollen successions. These differences suggest that, despite a former opinion (H. Winter, 1986), fragment of the discussed pollen succession should have not been univocally correlated with the pollen period II of the Mazovian Interglacial. It likely represents a fragment of a separate pollen succession of indeterminate palynostratigraphic rank. Due to rare values of pollen of deciduous trees, this pollen succession has interstadial character. However, occurrence of *Pterocarya* and *Juglans* — representatives of important, thermophilous deciduous trees — may suggest its interglacial character.

Stratigraphic position of sediments characterized by pollen succession provides other argument which indicates its individual nature. They are overlain by tills and sediments, unquestionably representing the pollen period III of the Mazovian Interglacial.

The Mazovian Interglacial sediments separated by a till have been also encountered in the section at Śniadowo (H. Winter, 1993). Two series of sediments were examined in this section. Both series have been recognized as sediments representing the Mazovian Interglacial.

In the lower part of the Śniadowo pollen diagram, *Pinus* has the highest content. It is associated by abundant pollen of spruce (*Picea*) to 16%, with alder (*Alnus*) and fir (*Abies*) to 11%. Pollen of deciduous trees such as oak (*Quercus*), elm (*Ulmus*), linden (*Tilia*) and hornbeam (*Carpinus*) do not exceed 2%. Pollen of herbaceous plants are abundant (up to 31%). They are mostly represented by *Cyperaceae*, grasses (*Gramineae*) and motherworts (*Artemisia*).

The upper part of the diagram from Śniadowo represents a fragment of a pollen succession with abundant fir (*Abies*) up to 27%, spruce (*Picea*) to 40% and alder (*Alnus*) exceeding 14%. Such pollen spectra may refer to decline of the period III of the Mazovian Interglacial (fir-hornbeam), with considerably high values of spruce, alder and fir, and low values of hornbeam.

A till between two series of lacustrine sediments assigned to the Mazovian Interglacial is also noted in the section at Gawrychruda (Z. Janczyk-Kopikowa, 1986). A lower silty series at depth 134.9–145.0 m, examined by pollen analysis, is predominated by *Pinus*, with abundant spruce (*Picea*), birch (*Betula*), alder (*Alnus*) and fir (*Abies*). Thermophilous trees are rare (< 1%).

Similar pollen spectra occur in samples from depth 99.90–104.95 m. Thermophilous deciduous trees are represented by *Pterocarya*, accompanied by increased values of herbs. Similar increase of *Pterocarya*, in correlation with increase of NAP, is recorded within a local pollen assemblage zone Krz 6 *Pinus-Betula-Picea*, distinguished in the pollen diagram Krzyżewo, which represents the pollen period III of the Mazovian Interglacial. Fragment of the pollen succession at depth 99.90–104.95 m was correlated by Z. Janczyk-Kopikowa (1986) with the pollen period II of the Mazovian Interglacial. Due to similarity of the discussed pollen succession at the termination of the Mazovian Interglacial recorded in the section Krzyżewo, this fragment of succession should be correlated with decline of the pollen period III or beginning of the pollen period IV.

The purpose of this paper is to suggest a possibility of the occurrence of a silty-clayey series which can represent a warm unit of still unknown stratigraphic rank. This series seems to occur below sediments that, based on the palynological study, have been referred to the Mazovian Interglacial.

LITHOLOGY, GENESIS AND AGE OF CENOZOIC SEDIMENTS

A top of the Tertiary formation in the section Goleń occurs at the 43.1 m a.s.l. (Fig. 3). The borehole penetrates 33 m of lime-free olive-grey clays and silts, with brown-yellow spots and tan-coloured streaks of organic matter. They represent the so-called variegated clays under the Quaternary complex in the western part of the Piecki Plateau (S. Lisicki, 1996, 1997). Palynological study indicated that they are mainly of the Pliocene age. Clays below the depth 138 m were defined as the Upper Miocene ones.

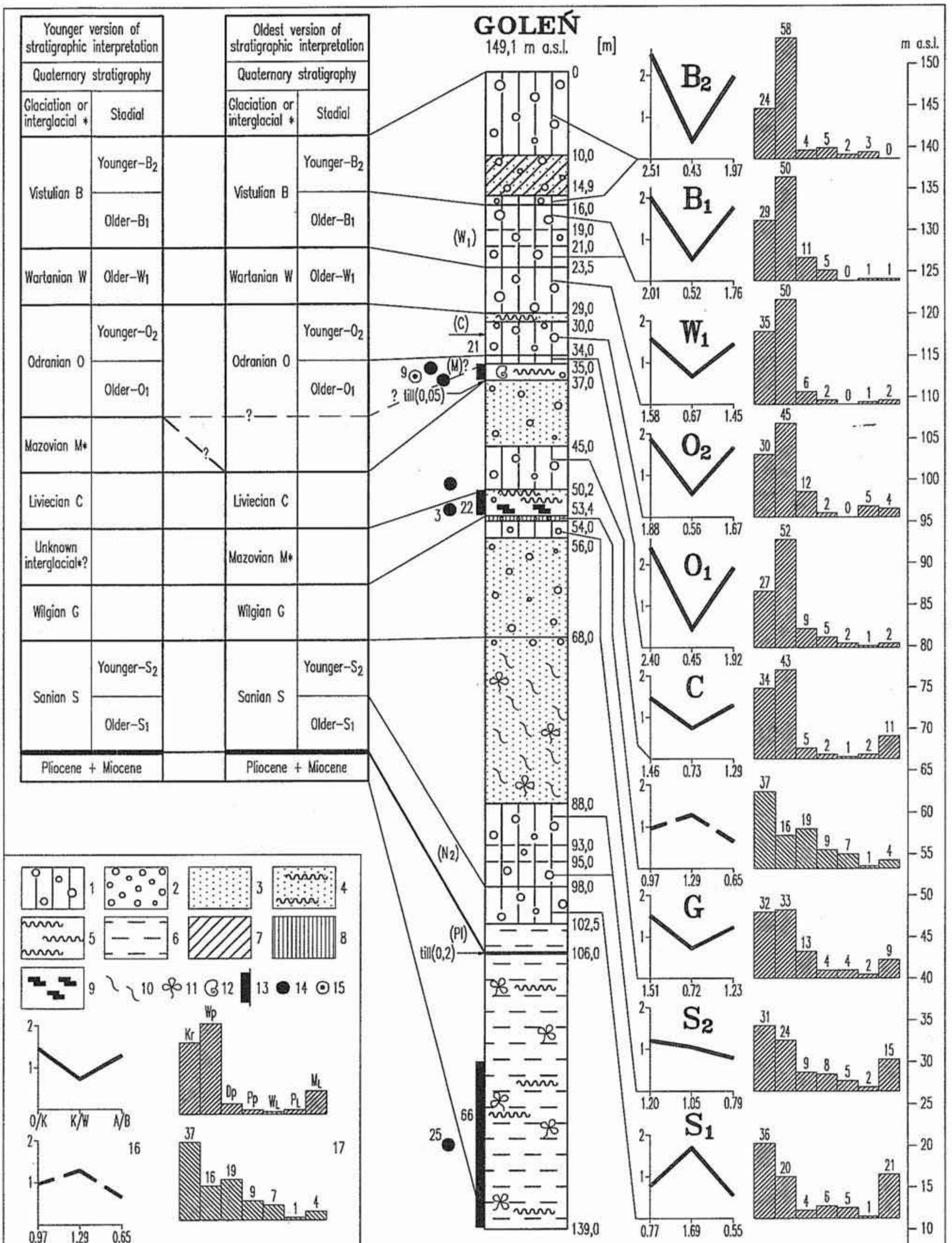
Detailed examination of 32 profiles of test-cartographic boreholes, along with analysis of 28 mutually intersecting cross-sections compiled for the area of the Mrągowo Lakeland, provided basis for stratigraphic subdivision of the Pleistocene in the central Mrągowo Lakeland (S. Lisicki, 1996, 1997). Lithological and petrographical study was done, mainly petrographic analysis of gravels (5–10 mm in size) of more than 1200 samples of tills with calculation after J. Rzechowski's method (1971, 1974, 1977) of contents of Scandinavian rocks (Kr — crystalline, Wp — northern limestones, Dp — northern dolomites, Pp — northern sandstones and quartzites) and groups of local rocks (W_L — local limestones and marls, P_L — local sandstones, M_L — local siltstones and claystones). Petrographical coefficients O/K–K/W–A/B expressed relations between different groups of Scandinavian rocks (O — total of sedimentary rocks, K — total of crystalline rocks and quartz, W — total of carbonate rocks, A — total of rocks no-resistant to destruction, B — total of resistant rocks). Palynological study of interglacial sediments (Z. Borówko-Dłużakowa, W. Słowański, 1991; M. Sobolewska, 1975; H. Winter, 1986 and others), was helpful to distinguish 14 tills of 8 glaciations (Narevian, Nidanian, Sanian, Wilgian, Liviecian, Odranian, Wartanian and Vistulian; Fig. 3).

The Pleistocene formation in the Goleń profile starts with sediments of the Sanian Glaciation **S** (Fig. 3). Tills of this glaciation are 18 m thick. They are grey, sandy and very stiff. A lower part of the complex is represented by a till of the older stadial $\mathbf{S_1}$ with petrographical coefficients O/K–K/W–A/B equal to 0.77–1.69–0.55. A glacial raft of Pliocene variegated clays (3.1 m thick) occurred in a bottom part of the older till. The upper part of the complex is composed of a till of the younger stadial $\mathbf{S_2}$. Its petrographical coefficients are represented by 1.20–1.05–0.79. A glacial raft of the older till of the Nidanian Glaciation was encountered in this till. Predominant position of crystalline rocks (Kr) over northern Palaeozoic limestones (Wp) is a characteristic feature of both tills of the Sanian Glaciation. Overlying sands are green, fine- and medium-grained, mainly quartzic-glauconitic ones (glauconite 28.0 to 68.6%). They contain much $CaCO_3$ and abundant tourmaline, rutile, disthene and sillimanite. Quartz grains are poorly rounded and sorting is variable. These sediments are 20 m thick. Geological investigations in a large area found these sediments to form a vast outwash fan of the younger stadial of the Sanian Glaciation (S. Lisicki, 1996, 1997).

Sediments of the Wilgian Glaciation **G** starts with glaciofluvial sands and gravels, 12 m thick. They are covered with grey sandy till, 2 m thick, petrographical coefficients of which are 1.51–0.72–1.23. The overlying till, 0.6 m thick, despite of its grey colour, was included in the so-called "red clay complex". Similarly to solifluction clays of this complex in other sections (S. Lisicki, 1996), it contains more — if compared with tills of the Wilgian Glaciation — northern dolomites (Dp), up to 19%.

A bottom of lacustrine and boggy sediments of the Mazovian Interglacial in the section Goleń occurs at 97.5 m a.s.l. (depth 53.4 m). These sediments are likely of limited extent. At the bottom there is 1.3 m layer thick of dark brown peat; its top part contains sandy interbeddings. The peat layer is covered with grey and dark brown siltstones with single gravel, which are rich in organic matter. Silty sand in the upper part is 0.9 m thick. Total thickness of lacustrine and boggy sediments is about 3.2 m. Palynological study and respective pollen diagram (H. Winter, 1986) revealed that significant similarity exists between this succession and the W. Szafer's (1953) pollen period II (spruce and alder type) of the Mazovian Interglacial.

A complex of the Liviecian Glaciation **C** starts with a till, 5.2 m thick. It is grey, sandy and very stiff. Its average petrographical coefficients are 1.46–0.73–1.29, close to average indices of the till of the Wilgian Glaciation G. Sands in the upper sequence are vari-grained, with predominant coarse-grained fraction and individual gravels, and total thickness to 8 m.



Analysed by S. Lisicki. Drawn by J. Zajączkowski, 1997

Fig. 3. Two versions of stratigraphic correlation of sediments in the section Goleń

1 — till, 2 — gravel, 3 — sand, 4 — silty sand or sand and silt, 5 — silt, 6 — clay, 7 — glaciofluvial — flowtill deposits, 8 — red clay complex, 9 — peat, 10 — glauconite (large concentrations), 11 — fossil flora, 12 — fossil fauna, 13 — pollen diagram, 14 — pollen expertise, 15 — palaeozoological expertise, 16 — petrographical coefficients of tills and flowtills, 17 — average content (%) of gravels in tills and flowtills; detailed explanation in the text; stratigraphic symbols in brackets mean glacial rafts

Dwie wersje korelacji stratygraficznej osadów z profilu Goleń

1 — glina zwałowa, 2 — żwir, 3 — piasek, 4 — piasek pylasty lub piasek i mułek, 5 — mułek, 6 — ił, 7 — osad wodnomorenowy, 8 — osad czerwonego kompleksu ilastego, 9 — torf, 10 — glaukonit (duże nagromadzenia), 11 — flora kopalna, 12 — fauna kopalna, 13 — diagram pyłkowy, 14 — ekspertyza palinologiczna, 15 — ekspertyza paleozoologiczna, 16 — współczynniki petrograficzne glin zwałowych i glin spływowych, 17 — średnie zawartości (%) żwirów z glin zwałowych i spływowych; szczegółowe objaśnienia w tekście; symbole stratygraficzne w nawiasach — osady w formie porwaków

Complex of sediments of the Odranian Glaciation **O** is 8 m thick. Till of the older stadial $\mathbf{O_1}$ is grey and sandy, and its petrographical coefficients are equal to 2.40–0.45–1.92. The overlying grey-brown till of the younger stadial $\mathbf{O_2}$ of the Odranian Glaciation is characterized by the following average coefficients equal to 1.88–0.57–1.65. Distinct predominance of northern limestones (Wp) over crystalline rocks (Kr) is clear in both tills. The younger till is overlain by grey, mostly fine-grained sands, 1 m thick, laminated with grey silt.

Interpreted as a glacial raft, lacustrine formation of the Mazovian Interglacial is the most interesting sediment in this complex. It appears at depth 35.0–36.5 m as the olive-grey, dominantly clayey, stiff silt with white mollusc shells, covered with the older till of the Odranian Glaciation $\mathbf{O_1}$, to 1 m thick. Shells are destroyed below depth 36.0 m. This silt is underlain by grey sandy silt with single gravels, similar in appearance to a till, of reservoir origin, to almost 2 m thick. These reservoir sediments are possibly underlain by 5 cm thick layer of the older till of the Odranian Glaciation $\mathbf{O_1}$. Palynological study and respective pollen diagram (H. Winter, 1986) indicate considerable relationship of this succession and the W. Szafer's (1953) pollen period III (hornbeam and fir type) of the Mazovian Interglacial. It was S. Skompski's (1989) achievement to prove that the sediment with 11 mollusc species, 3 snail species and 8 ostracod species was formed in a reservoir with stagnant water during the Mazovian Interglacial.

A till of the older stadial $\mathbf{W_1}$ is the only one of the Wartanian Glaciation **W**. This till is grey and sandy and it is 5.5 m thick. Average values of petrographical coefficients are 1.58–0.67–1.45.

Directly in top there is a till of the Vistulian Glaciation **B**. Till of the older stadial $\mathbf{B_1}$ is 7.5 m thick and grey; however, it is different from a till of the Wartanian Glaciation due to different petrographical coefficients equal to 2.01–0.52–1.76. The older till of the Vistulian Glaciation contains a glacial raft of a till of the Wartanian Glaciation. The present land surface is composed of light brown, predominantly sandy till of the younger stadial $\mathbf{B_2}$. It is 16 m thick, contains abundant gravels and is decalcified to a depth of 6 m. There are glaciofluvial sediments in a lower part of the younger till composed of silty vari-grained sands with considerable admixture of small gravels and lumps of till. Average petrographical coefficients of the younger till are equal to 2.51–0.43–1.97. Noteworthy is that gravels (5–10 mm in size) of northern limestones (Wp) predominate over gravels of crystalline rocks (Kr) in both tills.

DISCUSSION AND CONCLUSIONS

Both pollen successions of the Mazovian Interglacial in the section Goleń form a mutually logic temporal continuation of deposition in a single lacustrine reservoir. However, in connection with occurrence of glaciofluvial sands and gravels (8 m thick) and a till of the Liviecian Glaciation (5.2 m thick) between both lacustrine series (Fig. 3), such interpretation cannot be accepted. Tills of this glaciation have been well defined with respect to geology and their lithostratigraphy was described in 21 sections in the central Mazury Lakeland (S. Lisicki, 1996, 1997). Thus, unquestionable is a stratigraphic position, also in the section at Goleń, of the till of the Liviecian Glaciation, being younger than a till of the Wilgian Glaciation. Neither solifluction nor landslide is attributed to a till under consideration. Basing on such litho- and chronostratigraphic interpretation, the lower lacustrine sediments of the Mazovian Interglacial (H. Winter, 1986) are *in situ*, so the upper lacustrine sediments can be a glacial raft only, underlain possibly by a thin layer of till (Fig. 3).

In light of a new palynological analysis, also other version of stratigraphic interpretation of sediments in the section Goleń seems probable (Fig. 3). The upper lacustrine sediments occur *in situ* under a till of the older stadial of the Odranian Glaciation $\mathbf{O_1}$, provided that they appear at depth 37 m, directly on glaciofluvial sands and gravels, and in their lower part they are entirely composed of till-like reservoir deposits. Undoubtedly, the upper series of lacustrine sediments belongs to the Mazovian Interglacial. The lower lacustrine sediments at depth 50.2–53.4 m unquestionably occur *in situ*. This would be the basis to conclude that according to the second version, the lower sediments could be older than the Mazovian Interglacial. Most probably, in the section at Goleń there are sediments of a warm unit of unknown stratigraphic rank yet. If we accept this version, then till C should be older than the Mazovian Interglacial. A question remains open whether such different position of this till is rare or common in sections in the Mazury Lakeland. As a till G in the section Goleń is considered, it should be, as before, identified with the Wilgian Glaciation.

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INTERPRETACJA PALINOLOGICZNO-LITOSTRATYGRAFICZNA UTWORÓW JEZIORNYCH W PROFILU GOLEŃ (POJEZIERZE MAZURSKIE)

Streszczenie

W 1981 r. w centralnej części Pojezierza Mazurskiego wykonano kartograficzno-badawczy otwór wiertniczy Goleń (fig. 1). Do 1997 r. odwiercono w tym rejonie łącznie 60 otworów kartograficzno-badawczych. W profilach sześciu z nich stwierdzono, na podstawie badań palinologicznych, jeziorne osady interglacjału mazowieckiego (Z. Borówko-Dłużakowa, W. Słowański, 1991; K. M. Krupiński, 1997*a–c*; M. Sobolewska, 1975; H. Winter, 1986). W profilu Goleń metodą analizy pyłkowej przebadano trzy serie osadów jeziornych. Na podstawie wyników analizy pyłkowej scharakteryzowano zbiorowiska roślinne, rozwój roślinności i zmiany klimatu.

Spektra pyłkowe najstarszej serii jeziornej z głębokości 119,10–138,75 m charakteryzują różnego typu zbiorowiska leśne i zbiorowiska terenów otwartych. Zbiorowiska leśne reprezentowane są przez lasy mieszane z *Pinus, Picea, Sciadopitys, Abies, Tsuga, Sequoia, Betula, Quercus, Carpinus, Castanea, Tilia* i *Aesculus*, lasy łęgowe z *Ulmus, Pterocarya, Fraxinus, Liquidambar* i *Salix* oraz lasy bagienne z przewagą *Alnus, Nyssa* i przedstawicielami *Taxodiaceae-Cupressaceae*. Roślinność zbiorowisk otwartych o charakterze stepu jest reprezentowana głównie przez *Gramineae, Cruceferae, Chenopodiaceae* oraz *Artemisia*. Pojawia się ona cyklicznie na przemian ze zbiorowiskami leśnymi. Tego typu zmiany uwarunkowane były zmianami klimatu w kierunku klimatu umiarkowanie ciepłego o zróżnicowanej wilgotności.

Wiek osadów omawianej serii określono jako najwyższy górny miocen i najniższy dolny pliocen.

W serii najmłodszej z głębokości 35,31–36,92 m udokumentowano fragment mazowieckiej sukcesji pyłkowej obejmujący okres pyłkowy II, III i IV. Okres pyłkowy II charakteryzuje panowanie lasów świerkowo-olchowych, stopniowo przeobrażających się w lasy jodłowo-grabowe cechujące okres pyłkowy III. W okresie IV zanika grab, a powraca świerk, który stanowi najważniejszy składnik lasów świerkowo-jodłowo-olchowych.

Fragment sukcesji pyłkowej z osadów z głębokości 50,31–53,21 m prezentuje początkowo mieszane lasy świerkowo-olchowe z liczną domieszką sosny, brzozy i wzrastającym udziałem jodły, dębu, graba, leszczyny i cisa oraz ze sporadycznym udziałem *Pterocarya* i *Juglans*. Stopniowo następujące zmiany w składzie lasów cechujące się ekspansją brzozy i wzrostem udziału roślin zielnych wskazują na pogorszenie warunków klimatycznych. Dalsze zmiany w zbiorowiskach leśnych scharakteryzowane są przez wycofywanie się brzozy i formowanie się lasów sosnowo-świerkowych. Fragment sukcesji pyłkowej pochodzącej z głębokości 50,31–53,21 m odbiega od innych sukcesji pyłkowych. Jest to prawdopodobnie fragment nowej sukcesji

pyłkowej o niepewnej randze klimatycznej i palinostratygraficznej, której pozycja stratygraficzna jest określona poprzez nadległe położenie gliny zwałowej i osadów reprezentujących okres pyłkowy II, III i IV interglacjału mazowieckiego.

Na Pojezierzu Mrągowskim wyróżniono gliny zwałowe 8 zlodowaceń: narwi, nidy, sanu, wilgi, liwca, odry, warty i wisły, głównie na podstawie analizy składu petrograficznego żwirów (średnica 5–10 mm) z glin zwałowych oraz obliczenia procentowej zawartości różnych skał skandynawskich (Kr, W_P, D_P, P_P), skał lokalnych (W_L, P_L, M_L) i współczynników petrograficznych O/K–K/W–A/B, a także badań palinologicznych osadów interglacjalnych, pobranych z 32 profilów otworów kartograficzno-badawczych.

Z rdzenia wiertniczego z profilu Goleń 42 próbki poddano badaniom litologiczno-petrograficznym. Utwory plejstoceńskie tworzą tu kompleksy osadów zlodowaceń: sanu **S_1** i S_2, wilgi **G**, liwca **C**, odry **O_1** i **O_2**, warty **W_1** i wisły **B_1** i **B_2** (fig. 3). Między glinami zwałowymi zlodowacenia wilgi i liwca przewiercono osady jeziorne o grubości 3,2 m. Badania palinologiczne (H. Winter, 1986) wykazały duże podobieństwo tej sukcesji do Szaferowskiego piętra pyłkowego II interglacjału mazowieckiego. W części spągowej starszej gliny zlodowacenia odry **O_1** stwierdzono mułki jeziorne z muszelkami mięczaków (S. Skompski, 1986), o grubości prawie 2 m. Badania palinologiczne (H. Winter, 1989) pozwoliły skorelować tę sukcesję z Szaferowskim piętrem pyłkowym III interglacjału mazowieckiego.

Jeśli przyjąć, że obie serie osadów jeziornych należą do interglacjału mazowieckiego, należy górne osady traktować jako leżące w pozycji porwaka, gdyż dolne i górne utwory jeziorne przedziela m.in. glina zwałowa litotypu C grubości 5,2 m. W świetle nowych dociekań palinologicznych możliwa jest również inna interpretacja stratygraficzna osadów z profilu Goleń. Młodsze osady interglacjału mazowieckiego leżą *in situ*, a starsze osady jeziorne należą do ciepłej jednostki o nieznanej do tej pory randze stratygraficznej. W tej wersji należałoby w profilu Goleń określić pozycję gliny zwałowej litotypu C jako starszą od interglacjału mazowieckiego.