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Pleistocene of the Mrągowo Lakeland

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Eight glaciations were distinguished in the study area, including: the Narevian, the Nidanian, the Sanian, the Vilgian, the Liviecian, the Odranian, the Wartanian, and the Vistulian, separated by sediments of seven interglacials: the Podlasian, the Malopolanian, the Ferdynandovian, the Mazovian, the Zbojnian, the Lublinian, and the Eemian. Only the Mazovian Interglacial is univocally documented in respect of its position by results of palynologic study. Deposits of red clay complex belonging to the Vilgian Glaciation form an important stratigraphic horizon. Lacustrine and fluvial sediments of the Mazovian Interglacial occurring within the Mrągowo Lakeland were penetrated to their base in 12 boreholes that have been drilled with the view of collecting data for mapping and further study. 14 glacial till horizons of different age were distinguished; all were analyzed to define petrographic features of their lithotypes.

INTRODUCTION

The area covered by this study lies in a central part of the Mazury Lake District in north-east Poland (Fig. 1). It is encompassed by such natural geographic borders as rivers and lake troughs. Its surface area is approx. 1200 km^2. Geological material was collected and analyzed not only from the area under this study but also from the central part of the Mazury Lake District from Biskupiec in the west to Orzysz in the east, Rozogi in the south, and the state boundary in the north (approx. 5800 km^2). Geological material acquired for the study area and its immediate surroundings includes 32 boreholes aimed at collecting data for testing and mapping (the test-cartographic boreholes) — whose total length was 6659.2 m, logs of 367 water wells, geophysical data of three vertical electric sounding (VES) cross-sections, and all relevant materials collected for 7 sheets of the *Detailed Geological Map of Poland*, 1: 50 000, and 2 sheets of the *Geological Map of Poland*, 1:200 000 (*fide* S. Lisicki, 1996).

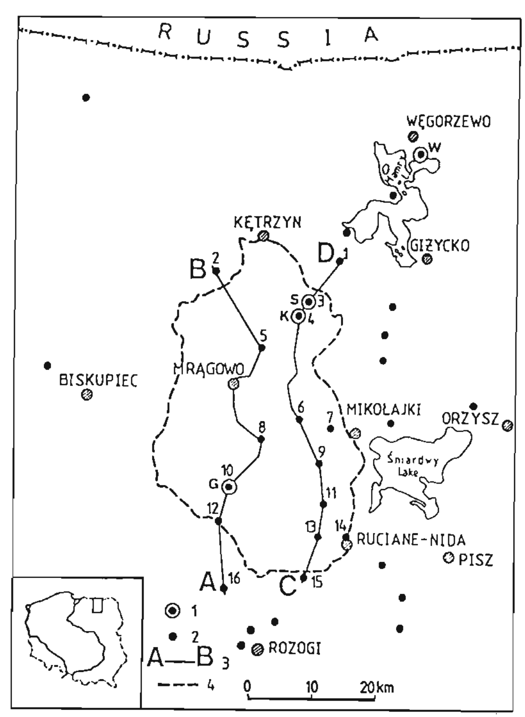


Fig. 1. Location of the study area

1 — boreholes with sediments of the Mazovian Interglacial, documented palynologically (W — Węgorzewo III, S — Sykstyny, K — Koczarki, G — Goleń), 2 — remaining test-cartographic boreholes (borehole identification numbers — see Figs. 2–4), 3 — lines of geological cross-sections, 4 — boundary of the study area

Położenie obszaru badań

1 — otwory z palinologicznie udokumentowanymi osadami interglacjału mazowieckiego (W — Węgorzewo III, S — Sykstyny, K — Koczarki, G — Goleń), 2 — pozostałe otwory kartograficzno-badawcze (identyfikacja numerów otworów patrz fig. 2–4), 3 — linie przekrojów geologicznych, 4 — granica obszaru badań

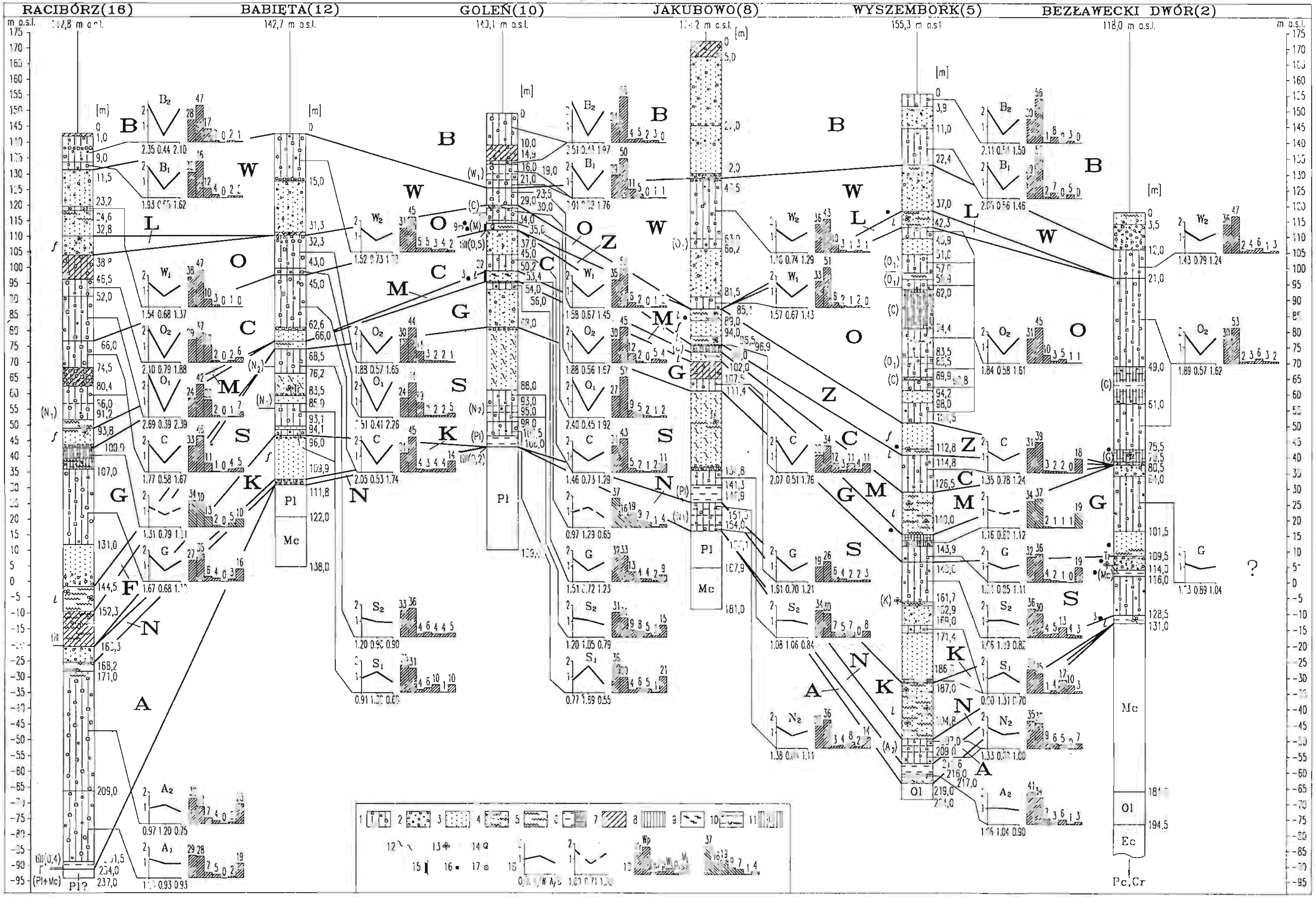

RACIBÓRZ(16)
BABIĘTA(12)
GOLEŃ(10)
JAKUBOWO(8)
WYSZEMBORK(5)
BEZŁAWECKI DWÓR(2)
m o.s.l.

Fig. 2. Pleistocene profiles in boreholes: Racibórz (16), Babięta (12), Goleń (10), Jakubowo (8), Wyszembork (5) and Bezławecki Dwór (2)

1 — glacial till, 2 — gravel, 3 — sand, 4 — silty sand or sand and silt, 5 — silt, 6 — clay and varved clay, 7 — watermoraine sediment, 8 — ice-dammed lake-watermoraine sediment, 9 — peat, 10 — gyttja, 11 — sediment of red clay complex in a form of glacial raft, 12 — glauconite (in big concentrations), 13 — floral Quaternary fossils, 14 — faunal Quaternary fossils, 15 — pollen diagram, 16 — pollen expert evidence, 17 — palaeozoological expert evidence, 18 — petrographical coefficients of glacial tills and watermoraine loams (flow-till), 19 — average (%) content of gravels in glacial tills and watermoraine loams (flow-till); stratigraphic symbols: A — Narevian Glaciation, P — Podlasian Interglacial, N — Nidanian Glaciation, K — Malopolanian Interglacial, S — Sanian Glaciation, F — Ferdynandovian Interglacial, G — Vilgian Glaciation, M — Mazovian Interglacial, C — Liviecian Glaciation, Z — Zbojnian Interglacial, O — Odranian Glaciation, L — Lublinian Interglacial, W — Wartanian Glaciation, E — Eemian Interglacial, B — Vistulian Glaciation; applicable are stratigraphic symbols of formations of Pleistocene substratum and other stratigraphic and genetic designations — given in Figs. 6 and 7; stratigraphic symbols in brackets indicate sediments occurring in the form of glacial rafts

Profile plejstocenu w otworach: Racibórz (16), Babięta (12), Goleń (10), Jakubowo (8), Wyszembork (5) i Bezławecki Dwór (2)

1 — glina zwałowa, 2 — żwir, 3 — piasek, 4 — piasek pylasty lub piasek i mułek, 5 — mułek, 6 — ił i ił warwowy, 7 — osad wodnomorenowy, 8 — osad zastoiskowo-wodnomorenowy, 9 — torf, 10 — gytia, 11 — osad czewonego kompleksu ilastego w formie porwaka, 12 — glaukonit (duże nagromadzenia), 13 — czwartorzędowa flora kopalna, 14 — czwartorzędowa fauna kopalna, 15 — diagram palinologiczny, 16 — ekspertyza palinologiczna, 17 — ekspertyza paleozoologiczna, 18 — współczynniki petrograficzne glin zwałowych i glin spływowych, 19 — średnia zawartość żwirów (%) w glinach zwałowych i glinach spływowych; oznaczenia stratygraficzne: A — zlodowacenie narwi, P — interglacjał podlaski, N — zlodowacenie nidy, K — interglacjał małopolski, S — zlodowacenie sanu, F — interglacjał ferdynandowski, G — zlodowacenie wilgi, M — interglacjał mazowiecki, C — zlodowacenie liwca, Z — interglacjał zbójna, O — zlodowacenie odry, L — interglacjał lubelski, W — zlodowacenie warty, E — interglacjał eemski, B — zlodowacenie wisły; symbole stratygraficzne utworów podłoża plejstocenu oraz pozostałe oznaczenia stratygraficzne i genetyczne osadów plejstoceńskich — jak na fig. 6 i 7; symbole stratygraficzne w nawiasach — osady w formie porwaków

A study of deposit samples, that has been carried out for the purpose of establishing the detailed profiles of test-cartographic boreholes, included palynologic examination of 275 samples of Quaternary sediments and the construction of 3 pollen diagrams for the Mazovian Interglacial. The diagrams were based on three profiles at Goleń, Koczarki, and Węgorzewo III. Lithologic-petrographic determinations of 2745 samples of sediments were also made; they included: grain-size distribution, composition of heavy mineral assemblies, content of carbonates, petrographic composition of pebbles contained in the glacial till, and roundness of quartz grains forming the sandy sediments.

Apart from palynologic study, the results of determination of petrographic composition of pebbles from glacial till, of 5–10 mm in diameter, occurred to be most valuable for the construction of stratigraphic scheme of the Pleistocene; a J. Rzechowski's method (1971, 1974)[1] was used to compute the results.

Three compilations are presented to show profiles of 16 boreholes of test-cartographic character along with the results of petrographic study (Figs. 2–4). Computed petrographical coefficients O/K, K/W and A/B are presented graphically to illustrate relations between shares of different groups of Scandinavian (northern) rocks. Content (by percentage) of different local and Scandinavian rocks, calculated earlier, was also presented graphically.

Geological structure and stratigraphy of Pleistocene sediments of the Mrągowo Lakeland were defined on the basis of analysis of 28 cross-sections (intersecting with each other) of total length of 640 km, and 7 maps of intra-Pleistocene structural planes characterizing interglacial periods. Two main cross-sections as well as a map of most important structural plane have been presented in this work; the map mentioned here shows both the position of sediments older than the Mazovian Interglacial and the extent of sediments of this interglacials age.

Works made so far on the Tertiary and Quaternary issues dealing with central part of Mazury Lake District focused on three main questions: a structure of Pleistocene substratum, the stratigraphy of the Quaternary, and geomorphologic development of the region at the close of the Pleistocene and during the Holocene.

Among the most important researchers involved in studies of these three questions, attention should be directed to:

— German geomorphologists and geologists who before the World War II were the authors of the *Geologische Karte von Preussen und benachbarten Bundesstaaten* on the scale of 1:25 000, namely H. Hess von Wichdorf — the founder of the Mazurian Interstadial, and P. G. Krauze and H. Gross — the discoverers of the Holstein Interglacial in the region of Węgorzewo and Kętrzyn (*fide* S. Lisicki, 1996);

— W. Słowański, the indefatigable explorer of the region, the author of the Pisz and Kętrzyn sheets of the *Geological Map of Poland* on the scale of 1:200 000 and many studies on the stratigraphy of Quaternary in the Mazury area (W. Słowański, 1971, 1981), the discoverer of the Mazovian Interglacial site at Koczarki (Z. Borówko-Dłużakowa, W. Słowański, 1991), and the author of stratigraphic interpretation of the Węgorzewo III profile (W. Słowański, 1975);

— J. Kondracki (1952, 1957, 1972) and K. Świerczyński (1967, 1972) — who were mainly involved in geomorphologic issues;

— the authors of numerous studies on palynology (M. Sobolewska, Z. Borówko-Dłużakowa, H. Winter), and on lithology and petrography (B. Gronkowska-Krystek, K.

[1] Petrographical coefficients O/K, K/W and A/B is calculated to characterize relations between shares of different groups of Scandinavian (northern) rocks represented by pebbles contained in glacial tills: O — total of sedimentary rocks, K — total of crystalline rocks and quartz, W — total of carbonate rocks, A — total of rocks non-resistant to destruction, B — total of resistant rocks. Content by percentage of different groups of Scandinavian (northern rocks of Palaeozoic or earlier age) was calculated earlier for Kr, W_P, D_P, and P_P and local rocks (Tertiary and Mesozoic) for W_L, P_L, and M_L, where: Kr — crystalline rocks, W_P — limestones of northern origin, D_P — dolomites of northern origin, P_P — sandstones and quartzites of northern origin, W_L — local limestones and marls, P_L — local sandstones, M_L — local siltstones and claystones (values given with accuracy of 1%).

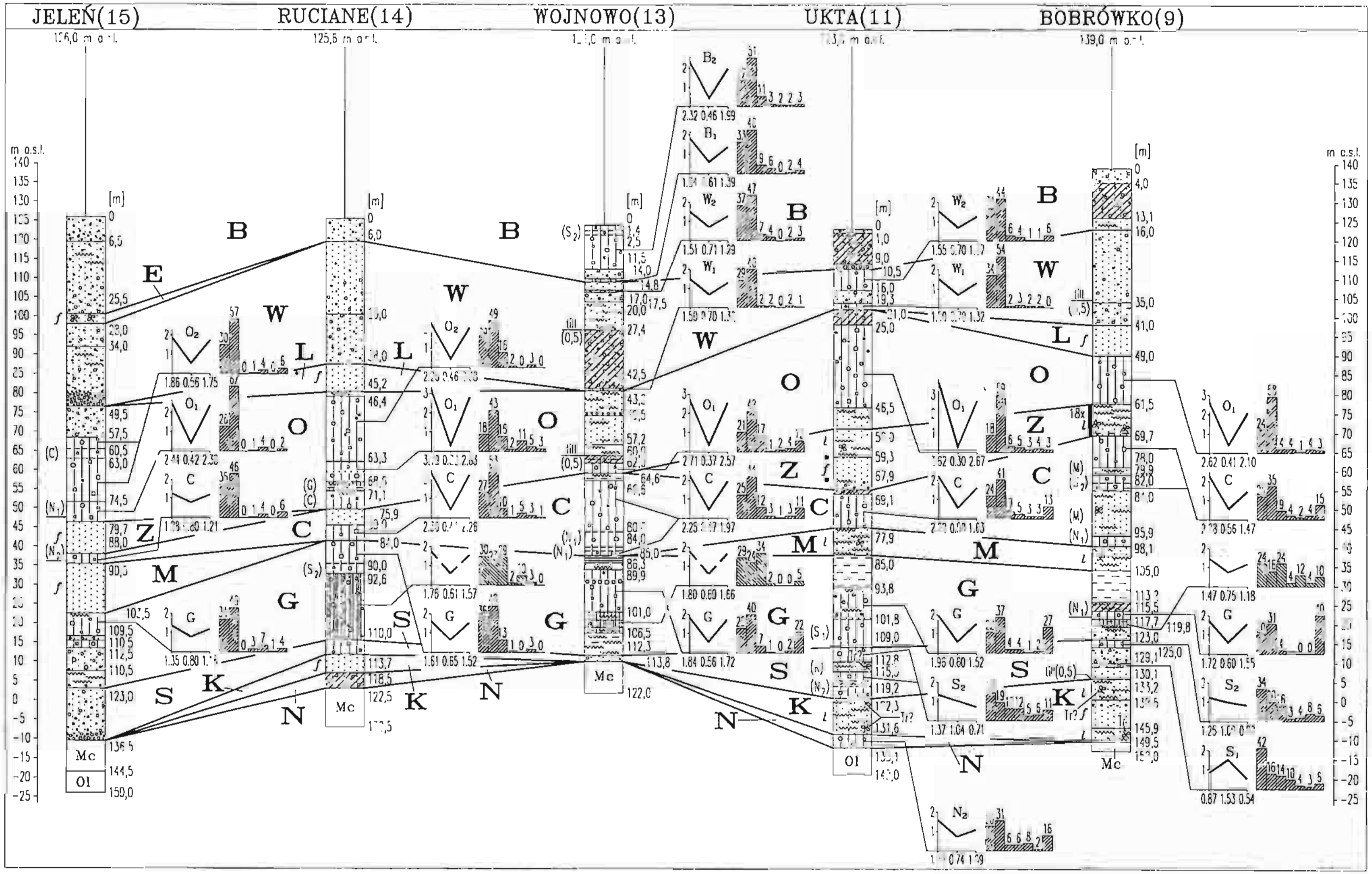


Fig. 3. Pleistocene profiles in boreholes: Jeleń (15), Ruciane (14), Wojnowo (13), Ukta (11) and Bobrówko (9)
Explanations as in Fig. 2

Profile plejstocenu w otworach: Jeleń (15), Ruciane (14), Wojnowo (13), Ukta (11) i Bobrówko (9)
Objaśnienia jak na fig. 2

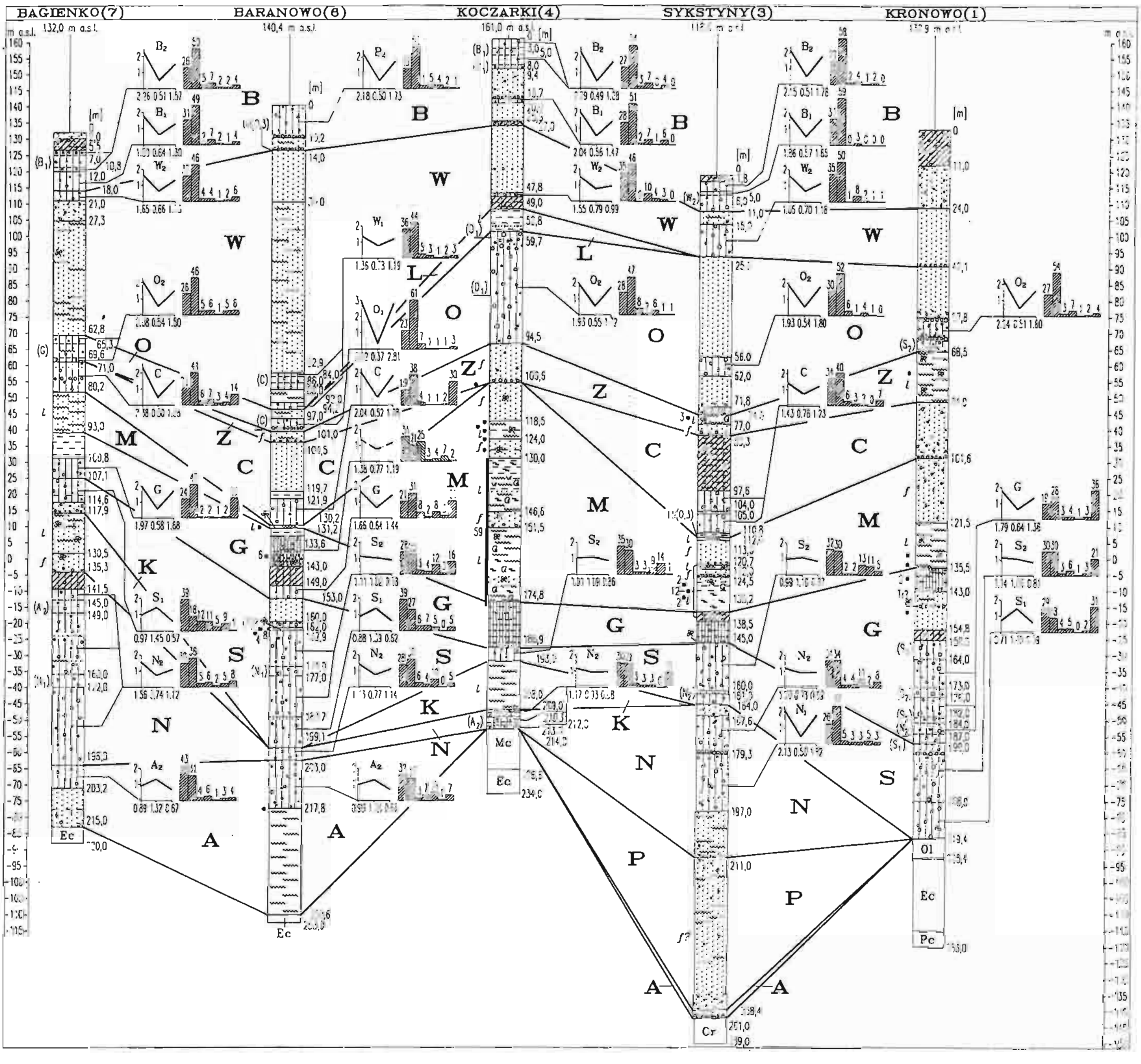


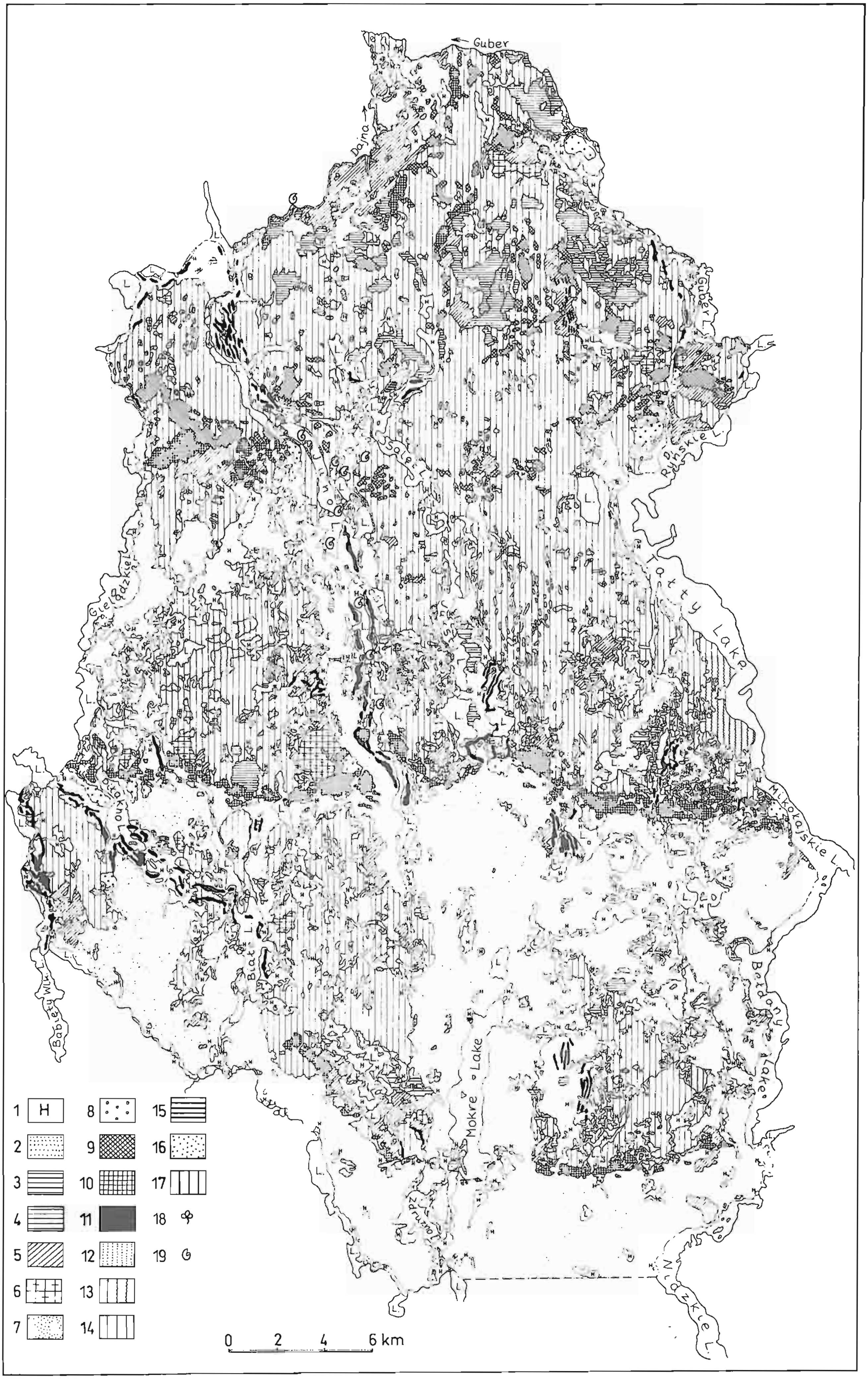
Fig. 4. Pleistocene profiles in boreholes: Bagienko (7), Baranowo (6), Koczarki (4), Sykstyny (3) and Kronowo (1)
Explanations as in Fig. 2

Profile plejstocenu w otworach: Bagienko (7), Baranowo (6), Koczarki (4), Sykstyny (3) i Kronowo (1)
Objaśnienia jak na fig. 2

Kenig, J. Rzechowski, J. Czerwonka, Z. Fert, B. Makarewicz, B. Zaczkiewicz *fide* S. Lisicki, 1996).

Such numerous and differentiated geological works as well as the authors investigation of his own (S. Lisicki, 1986, 1993) have created a basis for this work on geological structure and stratigraphy of Pleistocene in the Mrągowo Lakeland.

Configuration of the land surface is considerably differentiated in the study area. Culmination of the terrain at the altitude of 219.5 m a.s.l. is situated on a hill of push frontal moraine, occurring in the northern part of the area under this study; the lowest region at the altitude of 62.3 m a.s.l. lies in the vicinity of Kętrzyn — where the Dajna River falls into the Guber River.



Guber
Dajna
Guber L.
Ryńskie L.
Sałęt L.
Tałty Lake
Mikołajskie L.
Bełdany Lake
Mokre Lake
Nidzkie L.
Bobięcy Wilk L.
Białe L.
Gielądzkie L.
Juno L.
Zyzdrój
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Three main geomorphologic units can be distinguished in the landscape of the area covered by this study; they are: a morainic post-glacial plateau with humps in its northern part, vast outwash areas — that developed mostly in the south, and subglacial channels (Fig. 5).

The Mrągowo Lakeland is being cut by six zones of frontal moraines, with the southernmost one belonging to the Poznań Phase (according to J. Kondracki, 1972) and the second — to the Pomeranian Phase of the youngest glaciation. A detailed division dealing with the surficial geological structure is shown on the geological-geomorphologic map (Fig. 5).

CONFIGURATION AND GEOLOGICAL STRUCTURE OF PLEISTOCENE SUBSTRATUM

The area covered by this study lies in the region of the Mazury–Suwałki Elevation. Four structural units have been distinguished in the morphology of the Pleistocene substratum. They include (from the north southwardly): the Kętrzyn Trough, the Mrągowo Elevation, the Mikołajki Depression, and the Piecki Plateau (Fig. 6).

The Kętrzyn Trough is dissected by numerous faults into horsts with their surface built up of Miocene deposits and tectonic grabens with their bottom built up even of Cretaceous formation. A throw of sediments along the fault planes is ranging from 10 to 40 m.

It is likely that the Mrągowo Elevation is made of overlapping glaciotectonic scales formed by Tertiary sediments, in places with likely admixture of Quaternary gravels. This unit lies in the northern background of main fault of WNW–ESE trend.

As compared with this fault, similar position is taken by the Mikołajki Depression the bottom of which is covered with Eocene sediments.

The Piecki Plateau is elevated approx. 40 to 80 m above the level of the Kętrzyn Trough. The surface of the plateau is built up of Pliocene and Miocene formations, and Oligocene sediments are exposed in the bottom of an interglacial form of erosive origin.

The Upper Cretaceous includes marine sandy marls, and occasionally siltstones of the Maastrichtian. Palaeocene marly sands, marls, or silts represent the sediments being the continuation of marine sedimentation, Upper Cretaceous in age. The Middle Eocene is formed by quartz-glauconitic sands of the Olsztyn Beds sedimented in a transgressive epicontinental sea, while the Upper Eocene — by clays and silts of the Pomeranian Beds (E. Ciuk, 1972). The Oligocene quartz-glauconitic sands, in places interbedded with silts, and belonging to the Lower and Upper Mosina Beds, are also sediments of the eipcontinental sea. The Middle Miocene is represented by quartzic sands with admixture of brown coal dust; I. Grabowska is of the opinion that they form beds of the Adamów Formation while B. Słodkowska's idea deals with their belonging to the Ścinawa Formation with a coal II Group of Seams (Lusatia Seam) (*fide* S. Lisicki, 1996). Beds of the Poznań Formation developed as greenish-brown clays with a brown coal I Group of Seams (Middle Polish Seam), or 0 Group of Seams (Orłowo Seam). The upper part of the Poznań Formation was already formed during the Upper Miocene, the close of which was marked with the beginning of sedimentation of vari-coloured clays. The best development of Pliocene vari-coloured clays was found in profiles at Goleń (10) and Jakubowo (8) (Fig. 2), both localized within the Piecki Plateau. In the Upper Pliocene this area was subject to relative uplifting which ceased the sedimentation in Tertiary reservoir. This was the period of the Malopolanian tectonic phase.

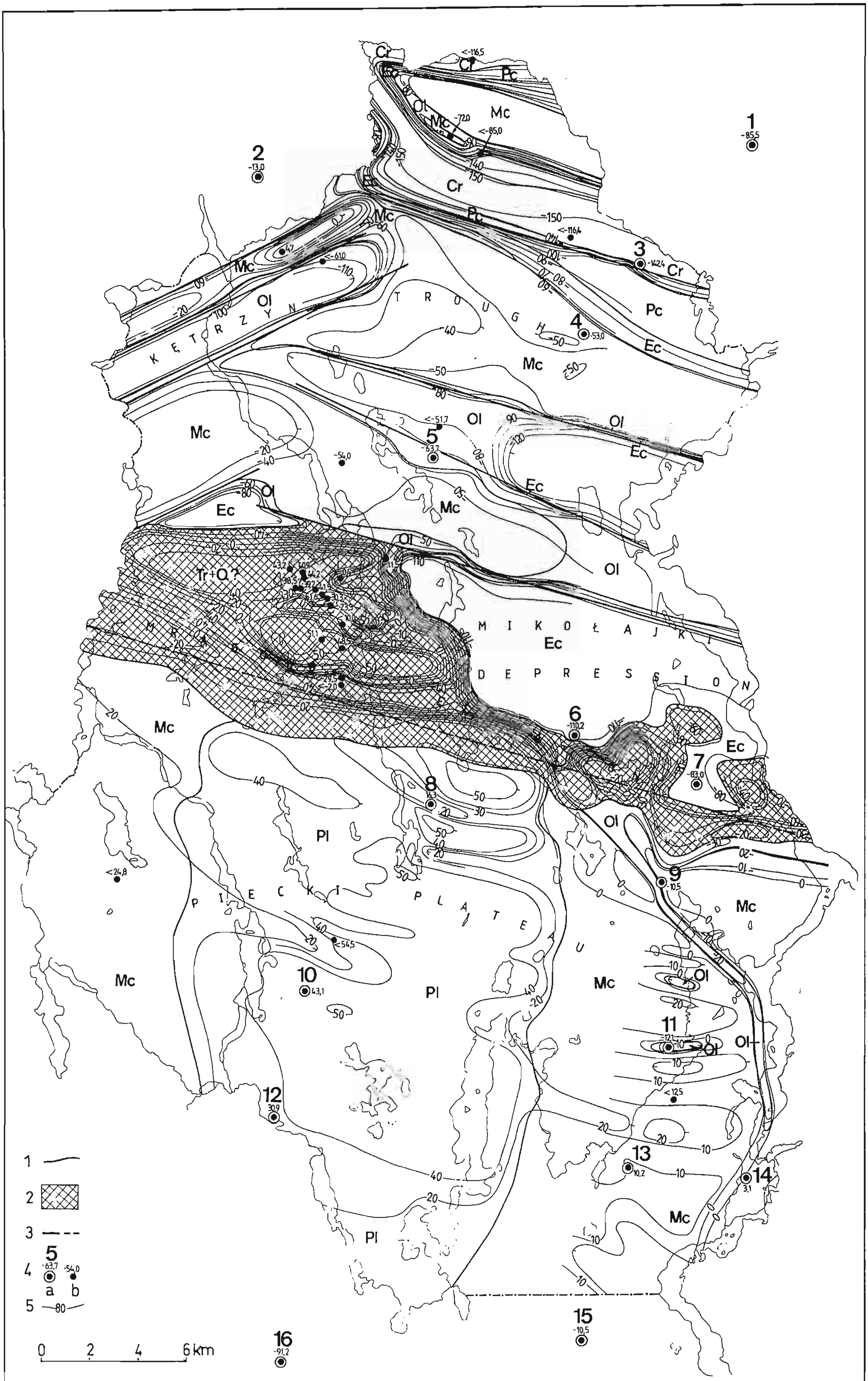
The undifferentiated Tertiary, maybe, with admixture of the Quaternary, builds up the Mrągowo Elevation (Fig. 6) and is documented in profiles of 11 water wells. Sediments under discussion are visibly disturbed in many profiles. Palynologic study of sediments from one of the wells, conducted by I. Grabowska, revealed that spore-pollen spectra are mixed, Neogene–Quaternary in age (*fide* S. Lisicki, 1996). The elevation under discussion, built up of glaciotectonic scales, was subject to forming and modelling by consecutive glaciations: the Narevian, the Nidanian, and the Sanian — when respective ice-sheets crossed over a high morphologic escarpment which developed on the main tectonic fault dissecting the area (Fig. 6).

Fig. 5. Geological-geomorphologic map

Holocene: 1 — undifferentiated Holocene sediments; **Pleistocene**: **Vistulian Glaciation**: P o m e r a n i a n – L e s z n o S t a d i a l : 2 — clays, silts, sands and gravels as well as peats of older lake bottoms, 3 — clays, silts, and sands of ice-dammed lake areas, 4 — kames and kame terraces, 5 — watermoraine covers, 6 — dead-ice moraines, 7 — sands and gravels of outwash areas and courses, 8 — sands and gravels of short outwash fans, 9 — accumulative frontal moraines, 10 — push frontal moraines, 11 — eskers and crevasse forms, 12 — drumlines, 13 — extrusion moraines, 14 — glacial tills; Ś w i e c i e S t a d i a l : 15 — clays and silts of ice-dammed lake origin, 16 — fluvioglacial (outwash) sands and gravels; **Wartanian Glaciation**: Y o u n g e r S t a d i a l : 17 — glacial tills; findings of late-Pleistocene organic remains: 18 — floral detritus, 19 — valves of molluscs

Mapa geologiczno-geomorfologiczna

Holocen: 1 — nierozdzielone osady holoceńskie; **plejstocen**: **zlodowacenie wisły**: s t a d i a ł p o m o r s k o – l e s z c z y ń s k i : 2 — iły, mułki, piaski i żwiry oraz torfy starszych den jeziornych, 3 — iły, mułki i piaski obszarów zastoiskowych, 4 — kemy i tarasy kemowe, 5 — pokrywy wodnomorenowe, 6 — moreny martwego lodu, 7 — piaski i żwiry obszarów i szlaków sandrowych, 8 — piaski i żwiry krótkich stożków sandrowych, 9 — moreny czołowe akumulacyjne, 10 — moreny czołowe spiętrzone, 11 — ozy i formy szczelinowe, 12 — drumliny, 13 — moreny z wyciśnięcia, 14 — gliny zwałowe; s t a d i a ł ś w i e c i a : 15 — iły i mułki zastoiskowe, 16 — piaski i żwiry wodnolodowcowe (sandrowe); **zlodowacenie warty**: s t a d i a ł m ł o d s z y : 17 — gliny zwałowe; znaleziska późnoplejstoceńskich szczątków organicznych: 18 — detrytus roślinny, 19 — skorupki mięczaków



KĘTRZYN TROUGH
MIKOŁAJKI DEPRESSION
PIECKI PLATEAU
Tr+Q?
Cr
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STRATIGRAPHY, LITHOLOGY, AND ORIGIN OF PLEISTOCENE SEDIMENTS

Detailed examination of 32 profiles of test-cartographic boreholes (Fig. 1.) provided a basis for working out of stratigraphic division of the Pleistocene. Apart from detailed observation or analysis of descriptive core logs, lithological -petrographic and palynologic investigation was also carried out (*fide* S. Lisicki, 1996). Averaged results of petrographic analysis for 32 boreholes have been compiled in Table 1. Characteristic features of lithotypes of glacial tills are clearly shown in respect of their attachment to particular stadials and glaciations.

Sediments of eight glaciations have been distinguished in the study area; they represent: the Narevian, the Nidanian, the Sanian, the Vilgian, the Liviecian, the Odranian, the Wartanian, and the Vistulian. Sediments separating them belong to seven interglacials: the Podlasian, the Malopolanian, the Ferdynandovian, the Mazovian, the Zbojnian, the Lublinian, and the Eemian. The total number of glaciations was the reason for adopting such a stratigraphic scheme of Pleistocene division as proposed by M. D. Baraniecka (1990). Only the position of the Mazovian Interglacial sediments has univocally been documented by results of palynologic study. Sediments of remaining interglacials have mostly been identified on the basis of mineralogical studies and the reconstruction of drainage system for each warm period; helpful was also the reconstruction of places of these sediments deposition in relation to lithostratigraphically well defined position of glacial tills.

OLDER PLEISTOCENE

Except for sediments of the Vilgian Glaciation, sediments of every glaciation older than the Mazovian Interglacial were reckoned among two stadials (Tab. 1). The glacial tills of the Sanian and Vilgian Glaciations are clayey in places, and typically are brownish and red-brownish. The red colour of these clays comes from red clastic rocks of the Lower Triassic — the exposures of which on the Baltic sea-bottom and in the Lithuanian area are subject to destruction. As to remaining tills, they are dominantly sandy and grey, green-greyish, and brown-greyish in colour. Glacial tills of both the Narevian Glaciation and the older stadials of the Nidanian Glaciation have been preserved only in tectonic grabens within the Kętrzyn Trough (Figs. 7 and 8).

Younger glacial tills are common over the entire Mrągowo Lakeland. A total mean value of petrographical coefficients (compiled in Tab. 1) for the younger till of the Narevian Glaciation is representative for J. Rzechowski's (1986) lithotype (N) of the oldest glaciation. The younger till of the Nidanian Glaciation represents the first lithotype (P_1) of glacial till of the South-Polish Glaciation, the older glacial till of the Sanian Glaciation corresponds to second and third lithotypes (P_{2a} and P_{2b}) of glacial till belonging to South-Polish Glaciation, and the younger till of the Sanian Glaciation — corresponds to the youngest lithotype (P_3) of till of the South-Polish Glaciation (J. Rzechowski, 1974, 1977, 1986).

A high content (over 20%, in places) of local rocks is a characteristic feature of all of the glacial tills mentioned here. As to the glacial till of the Vilgian Glaciation, share of siltstones of local origin is predominantly very high (up to 40%); this provides a very important characteristics of this morainic sediment.

The older glacial tills contain glacial rafts and inclusions of Tertiary rocks, glacial rafts of older glacial tills, as well as glacial rafts of interglacial sediments.

The Baranowo (6) profile (Fig. 4) reveals the existence of clay series along with peat, of total thickness of 0.9 m, embedded in the glacial till of the younger stadial of the Sanian Glaciation.

As defined by Z. Janczyk-Kopikowa, they contain pollens of *Pterocarya* in total amount reaching 15% (*fide* S. Lisicki, 1996). It is likely that these sediments form a glacial raft of the oldest Podlasian Interglacial.

The glacial tills are accompanied by ice-dammed lake and fluvioglacial sediments. Characteristically developed are upper fluvioglacial sediments of the younger stadial of the Sanian Glaciation within the Piecki Plateau (Fig. 7). They are composed of distinctly limy sands, green, with glauconite in total amount reaching 68%, and with laminae of brown coal. They reached maximum thickness of 25.4 m at Jakubowo (8) (Fig. 2), and make up a vast buried outwash fan. Its origin dates back to a period of deglaciation at the close of the Sanian Glaciation, when Tertiary sediments forming the Mrągowo Elevation were subject to washing out.

Clastic sediments, likely of the Podlasian Interglacial age, were penetrated in the test-cartographic borehole at Sykstyny (3) (Fig. 4). Sands with fine gravels, interbedded with silts in some portions, 47.4 m thick — developed during four sedimentary cycles. Poor roundness of quartz grains suggests fluvial-periglacial character of sediments accumulating during the Kuiavian tectonic phase. In a borehole at Góra (near Orzysz, Fig. 1), sands and gravels were encountered in similar geological situation; W. Słowański (1971) identified them as

Fig. 6. Geological map of substratum of Pleistocene sediments

1 — geological boundaries; 2 — disturbed Tertiary (undifferentiated) and Quaternary(?) formations; 3 — tectonic faults; 4 — test-cartographic boreholes: a — with their identification number as in Figs. 2–4, b — other boreholes; absolute altitude of Pleistocene base is indicated (in m); 5 — isohypses of sub-Pleistocene plane; Cr — Cretaceous; Pc — Palaeocene; Ec — Eocene; Ol — Oligocene; Mc — Miocene; Pl — Pliocene

Mapa geologiczna podłoża osadów plejstoceńskich

1 — granice geologiczne; 2 — zaburzone utwory trzeciorzędowe (nierozdzielone) i czwartorzędowe(?); 3 — uskoki tektoniczne; 4 — otwory kartograficzno-badawcze z wysokością bezwzględną (w metrach) spągu plejstocenu: a — otwory z numeracją jak na fig. 2–4, b — pozostałe otwory; 5 — izohipsy powierzchni podplejstoceńskiej; Cr — kreda; Pc — paleocen; Ec — eocen; Ol — oligocen; Mc — miocen; Pl — pliocen

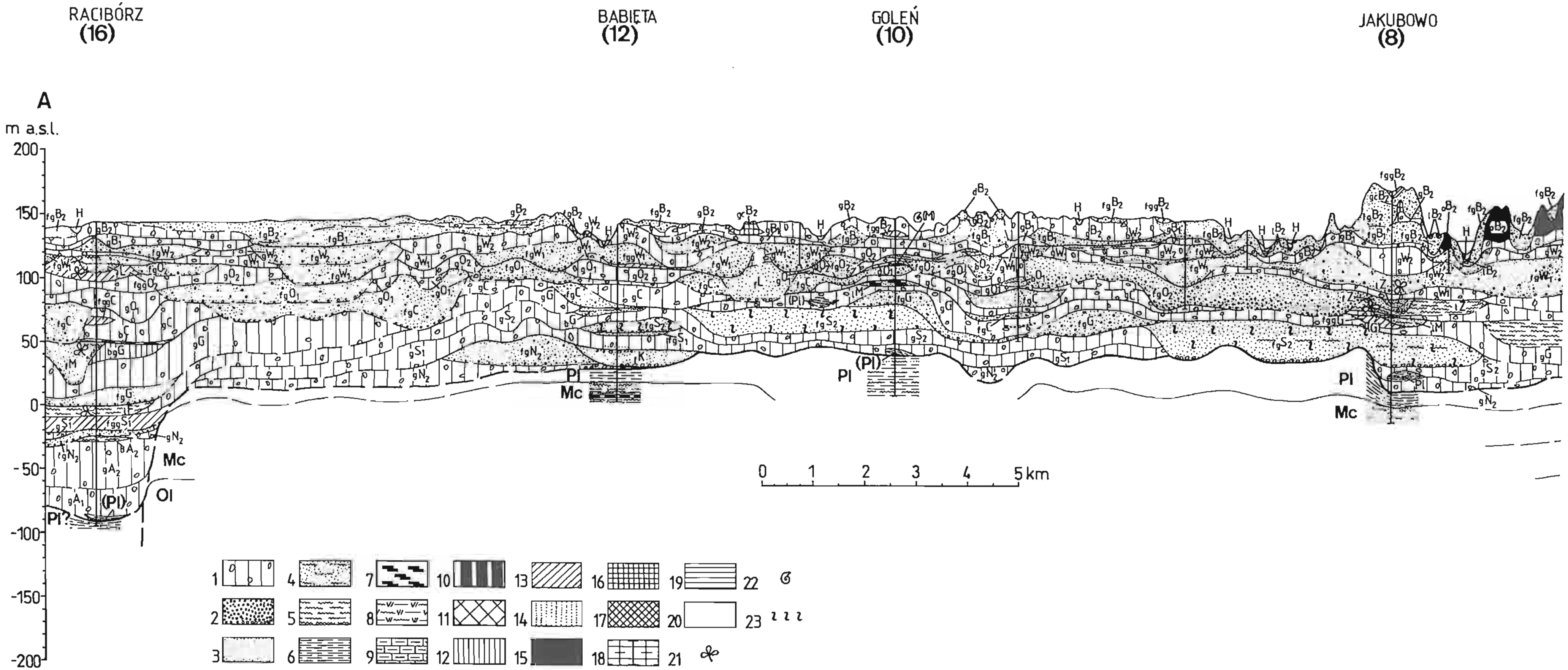
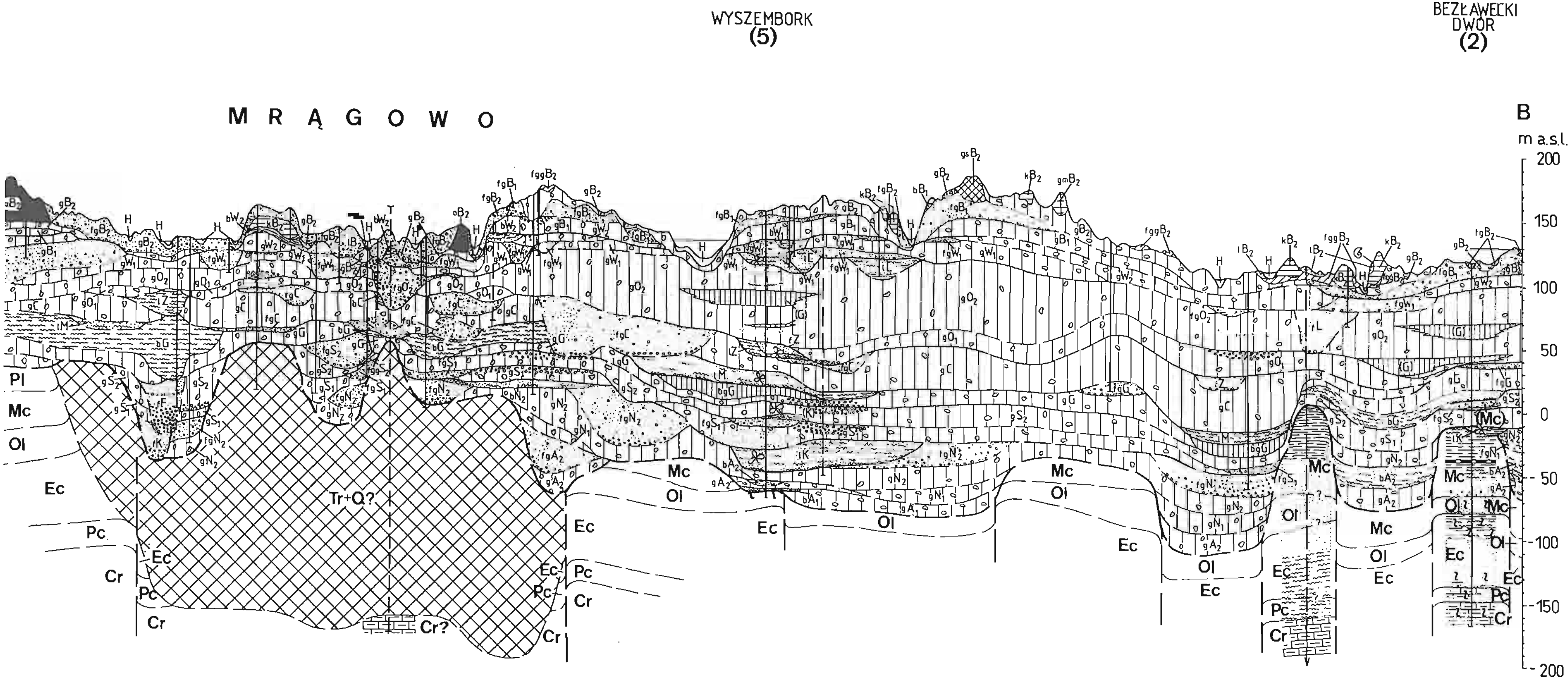


Fig. 7. Geological cross-section A–B

1 — glacial tills; 2 — gravels; 3 — sands; 4 — silty sands or sands and silts; 5 — silts; 6 — clays and varved clays; 7 — peat; 8 — gyttja; 9 — marls; 10 — lignite; 11 — disturbed Tertiary (undifferentiated) and Quaternary(?) formations; 12 — ice-dammed lake-watermoraine sediments (red clay complex); 13 — watermoraine sediments; sediments: 14 — of drumlin, 15 — of eskers and crevasse forms, 16 — of accumulative frontal moraines, 17 — of push frontal moraines, 18 — of dead-ice moraines, 19 — of kames and kame terraces; 20 — Holocene sediments; 21 — remains of Quaternary plants and humus; 22 — remains of Quaternary molluscs; 23 — glauconite (in big concentrations); stratigraphic symbols: Narevian Glaciation: A_1 — older stadial, A_2 — younger stadial; P — Podlasian Interglacial; Nidanian Glaciation: N_1 — older stadial, N_2 — younger stadial; K — Malopolanian Interglacial; Sanian Glaciation: S_1 — older stadial, S_2 — younger stadial; F — Ferdynandovian Interglacial; G — Vilgian Glaciation; M — Mazovian Interglacial; C — Liviecian Glaciation; Z — Zbójnian Interglacial; Odranian Glaciation: O_1 — older stadial, O_2 — younger stadial; L — Lublinian Interglacial; Wartanian Glaciation: W_1 — older stadial, W_2 — younger stadial; E — Eemian Interglacial; Vistulian Glaciation: B_1 — older (Świecie) stadial, B_2 — younger (Pomeranian–Leszno) stadial; H — Holocene; genetic-facial symbols: f — fluvial, l — lacustrine and boggy, b — ice-dammed lake, bg — ice-dammed lake-watermoraine, fgg — watermoraine, fg — fluvioglacial, g — glacial, gw — of extrusion moraines, d — of drumlin, o — of eskers and crevasse forms, gc — of accumulative frontal moraines, gs — of push frontal moraines, gm — of dead-ice moraines, k — of kames and kame terraces; stratigraphic symbols of Pleistocene substratum — as in Fig. 6; stratigraphic symbols in brackets indicate sediments occurring in the form of glacial rafts



Przekrój geologiczny A–B

1 — gliny zwałowe; 2 — żwiry; 3 — piaski; 4 — piaski pylaste lub piaski i mułki; 5 — mułki; 6 — iły i iły warwowe; 7 — torf; 8 — gytia; 9 — margle; 10 — węgiel brunatny; 11 — zaburzone utwory trzeciorzędowe (nierozdzielone) i czwartorzędowe(?); 12 — osady zastoiskowo-wodnomorenowe (czerwony kompleks ilasty); 13 — osady wodnomorenowe; osady: 14 — drumlinów, 15 — ozów i form szczelinowych, 16 — moren czołowych akumulacyjnych, 17 — moren czołowych spiętrzonych, 18 — martwego lodu, 19 — kemów i tarasów kemowych; 20 — osady holoceńskie; 21 — szczątki roślin czwartorzędowych i humus; 22 — szczątki mięczaków czwartorzędowych; 23 — glaukonit (duże nagromadzenia); oznaczenia stratygraficzne: zlodowacenie narwi: A_1 — starszy stadiał, A_2 — młodszy stadiał; P — interglacjał podlaski; zlodowacenie nidy: N_1 — starszy stadiał, N_2 — młodszy stadiał; K — interglacjał małopolski; zlodowacenie sanu: S_1 — starszy stadiał, S_2 — młodszy stadiał; F — interglacjał ferdynandowski; G — zlodowacenie wilgi; M — interglacjał mazowiecki; C — zlodowacenie liwca; Z — interglacjał zbójna; zlodowacenie odry: O_1 — starszy stadiał, O_2 — młodszy stadiał; L — interglacjał lubelski; zlodowacenie warty: W_1 — starszy stadiał, W_2 — młodszy stadiał; E — interstadiał eemski; zlodowacenie wisły: B_1 — starszy stadiał (świecia), B_2 — młodszy stadiał (pomorsko-leszczyński); H — holocen; oznaczenia genetyczno-facjalne osadów: f — rzeczne, l — jeziorne i bagienne, b — zastoiskowe, bg — zastoiskowo-wodnomorenowe, fgg — wodnomorenowe, fg — wodnolodowcowe, g — lodowcowe, gw — moren wyciśnięcia, d — drumlinów, o — ozów i form szczelinowych, gc — moren czołowych akumulacyjnych, gs — moren czołowych spiętrzonych, gm — moren martwego lodu, k — kemów i tarasów kemowych; symbole stratygraficzne podłoża plejstocenu patrz fig. 6; symbole stratygraficzne w nawiasach — osady w formie porwaków

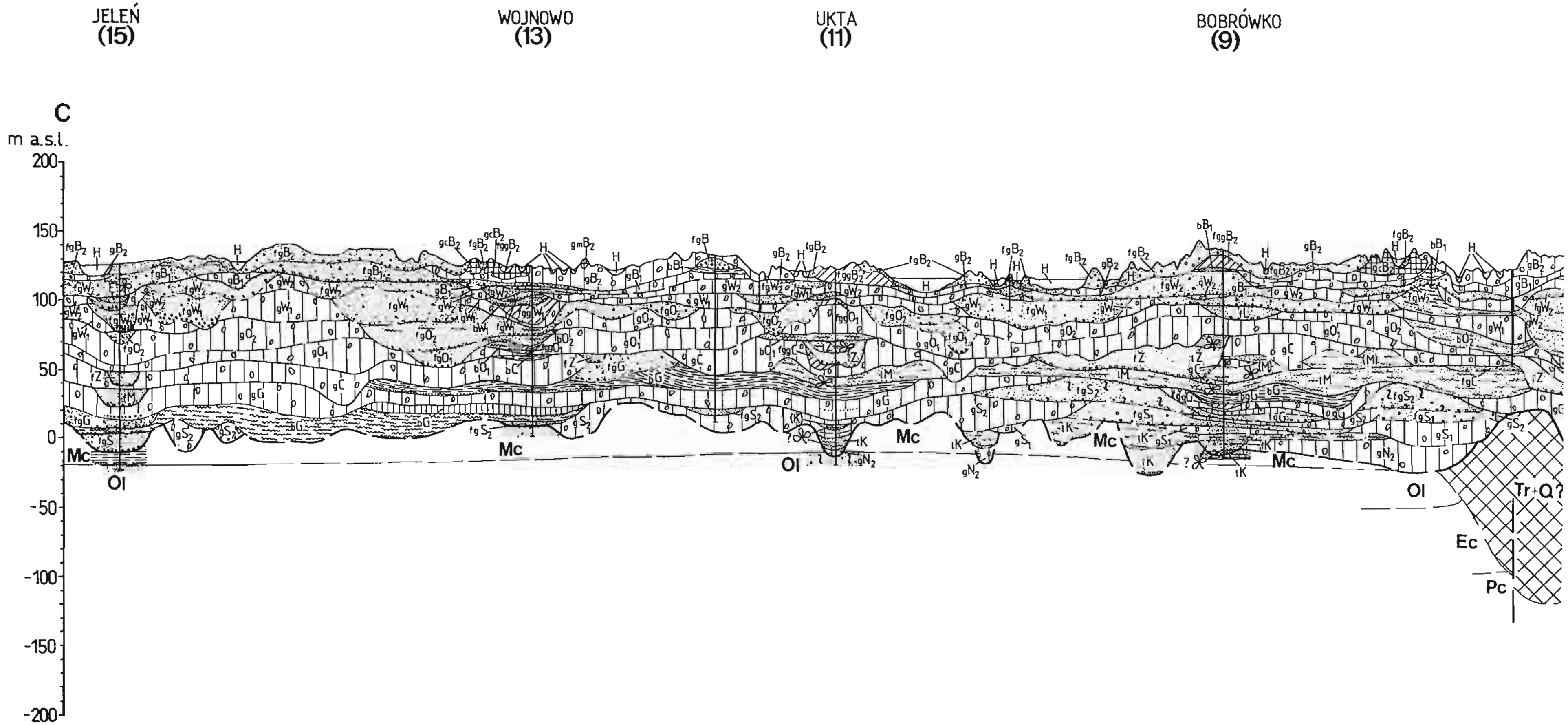
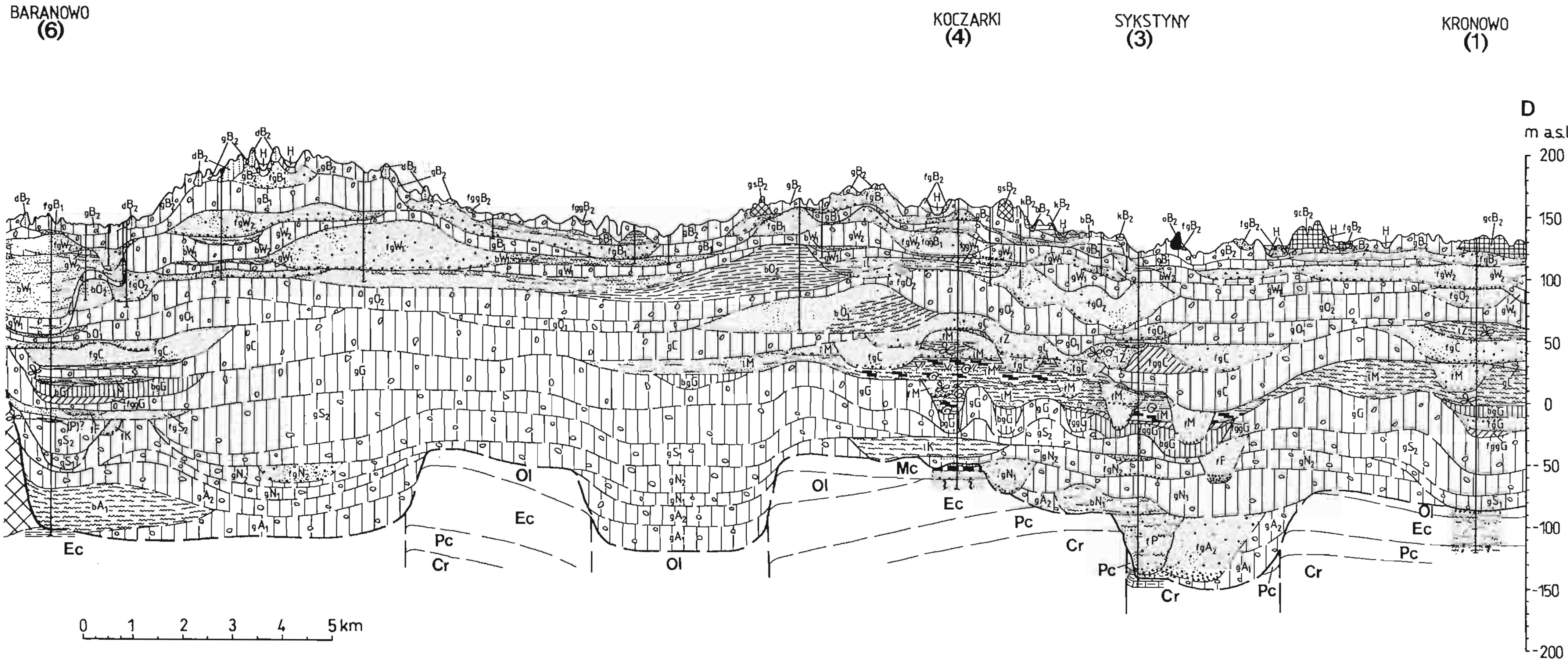


Fig. 8. Geological cross-section C–D
Explanations as in Fig. 7



Przekrój geologiczny C–D
Objaśnienia jak na fig.7

the fluvial sediment of the Cromerian Interglacial. It is likely that during the Podlasian Interglacial the main river valley had flowed through Góra and Sykstyny — longways the outwash course that developed during deglaciation.

Sediments of the Malopolanian Interglacial developed in the fluvial and lacustrine facies. Fluvial sediments were penetrated in boreholes at Babięta (12) (Fig. 2) and Bobrówko (9), Ruciane (14) and Bagienko (7) (Figs. 3 and 4). They predominantly developed as well rounded sands with admixture of gravels, their assembly of heavy minerals is marked with domination of garnets over amphiboles. As to lacustrine sediments, they developed as silty sands with interbeddings of silts and humus substance. In the Bobrówko (9) and Bagienko (7) boreholes these sediments cover the fluvial formation of the Malopolanian Interglacial (Figs. 3 and 4). As revealed in boreholes at Ukta (11) (Fig. 3), Wyszembork (5) (Fig. 2) and Koczarki (4) (Fig. 4), the ice-dammed lake sediments are immediately overlying a glacial till of the younger stadial of the Nidanian Glaciation.

Two river valleys existed in the southern part of the Mrągowo Lakeland throughout the Malopolanian Interglacial. One of them, of general trend towards the north-west, can be traced on the map of the substratum of Pleistocene sediments (Fig. 6) in the eastern part of the Piecki Plateau.

Formation of the Ferdynandovian Interglacial is not too spread over the area of the Mrągowo Lakeland and predominantly occurs as the fluvial sediments. Its occurrence has been interpreted in profiles of archival water wells. In the borehole at Racibórz (16) (Fig. 2), lacustrine silts and silty sands with humus reach a thickness of 7.8 m. A deep valley of this interglacial formed in the very place where an older river valley had already existed during the previous interglacial (Fig. 7).

Ice-dammed lake-watermoraine sediments of the red clay complex make an important stratigraphic horizon. They are widespread, and their development was going on in two facies. A facies of watermoraine sediments developed as red-brownish and chocolate brown loams (flow- till), mostly clayey, green-spotted, with considerable admixture of fine gravels, and visible solifluctional structures. A facies of ice-dammed lake sediments is represented by brown and red clays with individual grains of gravel 2–3 mm in size, laminated with grey or green-greyish clayey silts, locally containing plant debris. In particular profiles of the test-cartographic boreholes both facies appear separately or interfinger with each other. A likely extent of reservoirs of red clay complex is shown on the map of structural plane (Fig. 9).

The red colour of sediments discussed here is given by red matrix of iron oxides contained in the complex; the iron oxide matrix was, together with the clayey substance, transported by ice-sheets from outcrops of the Lower Triassic formation. This material entered the ice-dammed lake-watermoraine sediments due to repeatable redeposition. The main stratigraphic horizon of red clay complex lies on glacial till of the Vilgian Glaciation or less frequently — on glacial till of the younger stadial of the Sanian Glaciation (Figs. 7 and 8). Locally, it also underlies glacial till of the Vilgian Glaciation (Fig. 8); however, this horizon always belongs to the Vilgian Glaciation.

A period of deglaciation which followed at the close of this glaciation was at that time, when vast water reservoirs formed in many places of the area under discussion and throughout northeastern Poland. Most likely, the reservoirs developed among blocks and patches of dead-ice. Red flow-till melted out of ice was common. It formed mud tongues that were flowing down to water reservoirs where — in a form of density currents — the mud was transported towards deeper reservoir parts. These deeper parts acted in favour of sedimentation of clean red clays of calm lamination. Ice floats were floating on surfaces of glacial lakes and the melting out was the source of fine gravelly material entering the clayey sediment environment. At that time the ice-dammed reservoirs were subject to filling up with sediments. Under the climatic warming up, the "cool" glacial lakes were slowly transforming into interglacial lakes.

MAZOVIAN INTERGLACIAL

Lacustrine and fluvial sediments of the Mazovian Interglacial occur in many places of the Mrągowo Lakeland and the entire area of the Mazury Lake District. They occur mainly in the eastern part of the study area, which is shown on the map of structural plane on the top of formations older than the Mazovian Interglacial (Fig. 9). The map was produced in such the way that using contour lines it shows the configuration of buried surface of sediments deposited prior to interglacial period; this surface is combined with a plot of borders delineating the occurrence of lacustrine and fluvial sediments of the Mazovian Interglacial.

The lacustrine sediments occurring within the Mrągowo Lakeland have been penetrated to their base in nine test-cartographic holes; in other three — only fluvial deposits of this interglacial have been encountered. In the profile at Goleń (10), the lacustrine and boggy deposits are 3.2 m thick (Fig. 2).

A palynologic study and the H. Winter's diagram (*fide* S. Lisicki, 1996) revealed that this succession is to large extent similar to the Szafer's II pollen stage of the Mazovian Interglacial. Interglacial sediments can also been found in the following boreholes located in the southern part of the area: Jakubowo (8) (Fig. 2), Ukta (11), Bobrówko (9) (Fig. 3), Bagienko (7), and Baranowo (6) (Fig. 4). The most complete development of sediments of the Mazovian Interglacial is that encountered in the Koczarki (4) profile (Fig. 9). These sediments occur at the altitude between 13.8 m b.s.l. and 54.4 m a.s.l., and their thickness is 68.2 m.

Both the palynologic study and the Z. Borówko-Dłużakowa's diagram (Z. Borówko-Dłużakowa, W. Słowański, 1991) made it possible to trace the development of vegetation from taiga through mixed forests with considerable share of thermophilous trees during the climatic optimum, then repeated return of taiga followed by the development of mixed forests with a lesser share of thermophilous trees, and at the close of the interglacial — the development of forests of taiga type. Relevant study is a basis for conclusion that forests surrounding the lake reservoirs were the wet leafy forests growing on waterlogged soils. The interglacial sediments at Koczarki (4) were deposited during four sedimentary cycles whose sequence was related to climatic changes. The first and third cycles were decisive for the deposition of lacustrine clays, silts, and sands with malacofauna, inserts of peat and fragments of wood, a limy gyttja was also developing in places. The sediments of the first cycle are those in which the interglacial climatic optimum had been inscribed. The second and fourth cycles favoured the deposition of fluvial sands, with gravels 2 cm in diameter appearing at the base of the second cycle.

Development of older drainage network was connected with the transgression of Holstein Sea that affected the northern area (O. Kondratiene, W. Gudelis, 1982). A coast of a sea bay is expected to have been lying approx. 30 km northwards of the area under consideration. In the northern part of the Mrągowo Lakeland, sediments of the Mazovian Interglacial were penetrated to their base also in the Wyszembork (5) (Fig. 2), Sykstyny (3), and Kronowo (1) (Fig. 4) boreholes.

The distribution of the biggest lake reservoirs in the eastern part of the area under this study can be connected with the influence of subsidence taking place in the Mazury Lake District (adhering from the east) during the Mazovian tectonic phase.

YOUNGER PLEISTOCENE

Except for the Liviecian Glaciation, sediments of any other glaciation that is younger than the Mazovian Interglacial have been classified among two stadials (Tab. 1). As shown in the Table 1, there is close relationship between petrographic features of glacial tills of the Liviecian Glaciation and petrographic composition of till of the Vilgian Glaciation. A poor share of local rocks (4–9%, on the average) is characteristic for remaining glacial tills of younger age. As to sediments of the Liviecian Glaciation and the Odranian one, numerous glacial rafts have been found in glacial tills of both. A raft of clayey silts with valves of gastropod fauna, detached from deposits of the Mazovian Interglacial, has been encountered in the profile of the Goleń (10) borehole (Fig. 2).

A palynologic study conducted by H. Winter (*fide* S. Lisicki, 1996) revealed a considerable similarity of the succession to the Szafer's III pollen stage of the Mazovian Interglacial.

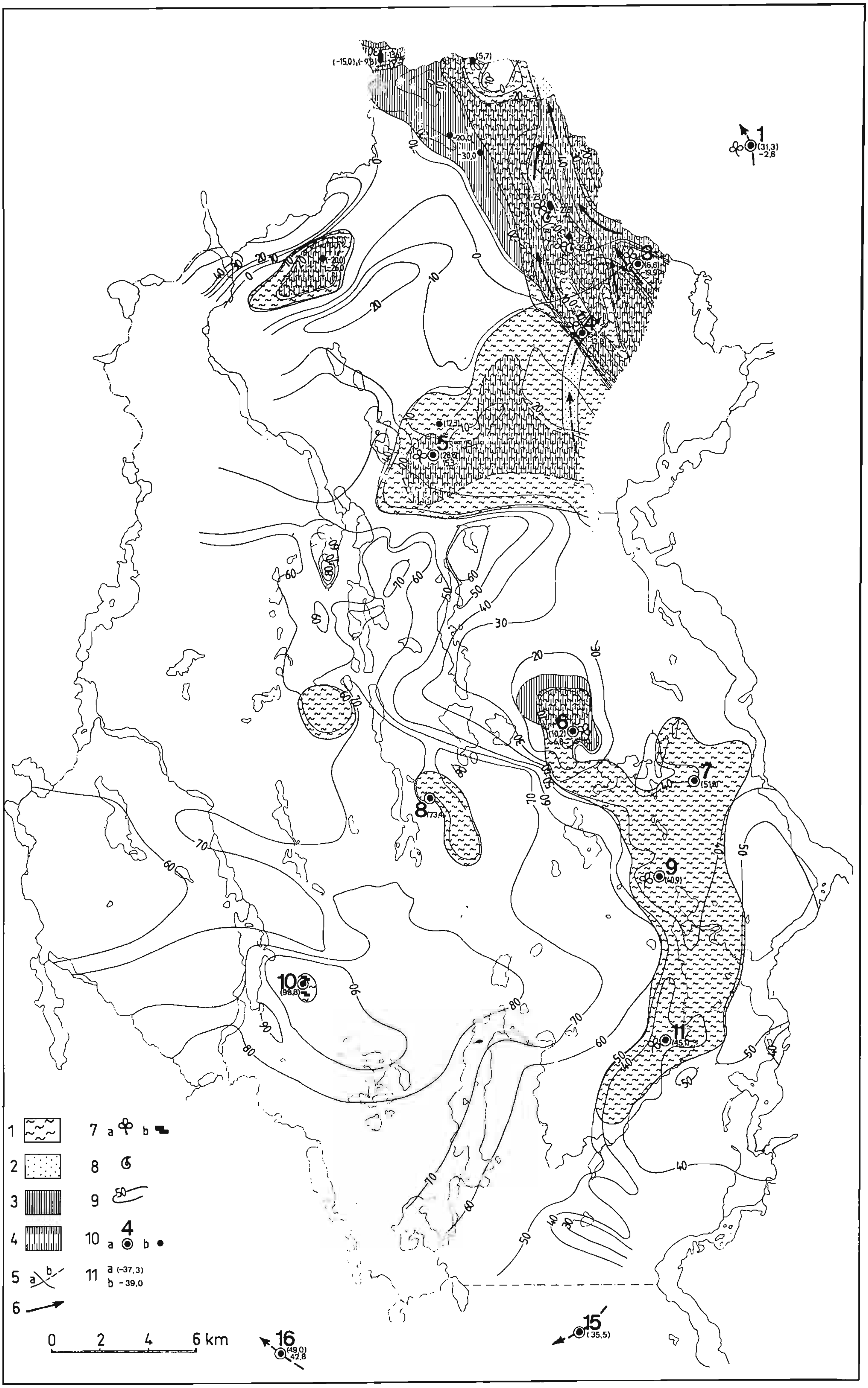
The Wyszembork (5) profile (Fig. 2) shows that glacial rafts of red clays and flow-tills were encountered in the younger till of the Odranian Glaciation; brown clays encountered at similar depth in the profile at Bezławecki Dwór (2) are also the glacial rafts of the Vilgian Glaciation sediments (Fig. 7). Glacial tills of glaciations mentioned here are common in the study area. Glacial till of younger stadial of the Odranian Glaciation in the area of the Kętrzyn Trough is of very impressive thickness, in places in excess of 60 m (Fig. 7). On the other hand, the thickness of glacial tills of the Vistulian Glaciation stadials does not exceed 12 m. The thickness of fluvioglacial and ice-dammed lake deposits is considerably high. It is likely that ice-dammed lake deposits of the Wartanian Glaciation, also of impressive thickness of 52.9 m at Baranowo (6) and 35.5 m at Bagienko (7) fill the glaciotectonic troughs (Fig. 4).

Sediments of the Zbojnian Interglacial in the Mrągowo Lakeland developed in two facies: lacustrine and fluvial ones. Older lacustrine sediments have been penetrated in the boreholes at Jakubowo (8) and Wyszembork (5) (Fig. 2) as well as Kronowo (1) (Fig. 4). Fluvial sands are slightly limy, predominantly well rounded, with traces of plant matter. As to assembly of heavy minerals, garnets take dominant position over amphiboles. These sediments fill two valleys of meridional orientation and can be found in the profiles of the Jakubowo (8) and Wyszembork (5) (Fig. 2), as well as Jeleń (15) and Ukta (11) (Fig. 3), Baranowo (6), Koczarki (4), and Sykstyny (3) (Fig. 4). Lacustrine sediments of oxbows occur in the upper tracts of valleys. The Bobrówko (9) (profile (Fig. 3) is that one in which silty sands, silts and clays of total thickness of 7.6 m overlie fluvial sands 0.6 m thick.

H. Winter (*fide* S. Lisicki, 1996) has palynologically studied these sediments and concluded the interstadial character of the succession. However, results of palynologic analysis has induced the author of this work to include this fragmentary succession to the close of the Zbojnian Interglacial, in particular to the close of the II and to the III pollen period of the Zbójno profile (L. Lindner, E. Brykczyńska, 1980).

Sediments of the Lublinian Interglacial in the study area also developed in lacustrine and fluvial facies. Lacustrine sands and silts with plant matter have been penetrated to their base at Wyszembork (5) and Koczarki (4) (Figs. 2 and 4). Based on palynologic examination of her own, Z. Borówko-Dłużakowa (*fide* S. Lisicki, 1996) has found that a sample from the Wyszembork (5) profile may characterize the Mazovian Interglacial or post-optimum period of the Eemian Interglacial. It is likely that fluvial sands have been penetrated at Racibórz (16), Ruciane (14), and Bobrówko (9) (Figs. 2 and 3) as well as in many water wells. These sediments fill two valleys of meridional courses. Their assemblage of heavy minerals is characterized by domination of garnets over amphiboles.

As to formation of the Eemian Interglacial, its occurrence is only occasionally in the central part of the Mazury Lake District area. In the area of the Mrągowo Lakeland, lacustrine and boggy sediments, most likely of that age, 2.5 m thick — have been encountered in the archival borehole at Szpigiel, and fluvial sands with fragments of wood — in the test-cartographic borehole at Jeleń (15) (Fig. 3). It should be assumed that drainage pattern of the Eemian Interglacial had been destroyed by advancing ice-sheets of the Vistulian Glaciation, namely by the Świecie and Pomeranian–Leszno Stadials.


1
2
3
4
5 a b
6
7 a b
8
9 50
10 a 4 b
11 a (-37,3) b -39,0
0 2 4 6 km
1 (31,3) -2,8
3 (6,6) -19,9
5 (28,8) 15,3
6 (10,2)
7 (51,8)
8 (73,4)
9 (40,9)
10 (98,8)
11 (45,1)
15 (35,5)
16 (49,0) 42,8

PLEISTOCENE TECTONIC PROCESSES

The area of the Mrągowo Lakeland, manifestations of tectonic processes can be found in the following phases: the Malopolanian, the Kuiavian, and the Mazovian; all the three were distinguished in the Quaternary of Middle Poland by M. D. Baraniecka (1981).

A zone of main fault was activated during the Malopolanian tectonic phase that was taking place on the turn of the Tertiary and Quaternary. The area of the Kętrzyn Trough situated northwards of this fault was depressed in comparison with the Piecki Plateau on the southern side of the fault. This resulted in the opening of a route for and facilitating the invasion of ice-masses of older glaciations. A high morphologic escarpment formed in the region of main fault; this, in turn, obstructed the movement of glacial lobes. Pressing forward and stepping over the escarpment the glacial masses of older glaciations caused that a glacio-elevation developed at Mrągowo (Figs. 6 and 7).

Tectonic grabens in the area of the Kętrzyn Trough were rejuvenated in the Kuiavian tectonic phase which most likely took place at the time of the Podlasian Interglacial. At the close of the Narevian Glaciation a wide outwash-type valley developed in the deeper trough situated south of Kętrzyn; during the interglacial it was occupied by a river valley about 50 m deep (Figs. 6 and 8).

In the Mazovian tectonic phase, being connected — in respect of age — with the Mazovian Interglacial in a broad sense, the entire area of the Mazury Lake District was subject to depressing movements. This was the reason why extended water reservoirs developed in the eastern part of the Mrągowo Lakeland at the close of the Vilgian Glaciation; during the Mazovian Interglacial they transformed into lakes and bogs (Fig. 9).

BASE OF LITHOSTRATIGRAPHIC CORRELATION OF PLEISTOCENE

The analysis of results of lithological-petrographic determinations of sediments sampled in 60 test-cartographic boreholes drilled in the central part of the Mazury Lake District and surrounding areas provided a base of lithostratigraphic correlation of the Pleistocene in the Mrągowo Lakeland. Due to acquired comparative material a conclusion can be drawn that the determination of petrographic composition of components of gravelly fraction (5–10 mm in diameter) in glacial tills is the most important contribution to the characterization of lithotypes of these tills. A total number of petrographic analysis amounted to 1189; samples of glacial tills or watermoraine loams (flow-till) for analysis were collected from 32 test-cartographic boreholes drilled in the central part of the Mazury Lake District. It is further concluded that lithotypes of glacial tills reflect, first of all, the lithology of rocks in central areas of ice-sheet alimentation, and to lesser extent — the lithology of local bedrock.

Well documented sites, in respect of palynology, of the Mazovian Interglacial were the basis of lithostratigraphic correlation of glacial tills and the stratigraphy of the entire Pliocene as well.

The formation of red clay complex of ice-dammed lake-watermoraine origin, in many places underlying the interglacial sediments, is widespread and of identical stratigraphic situation in its lowermost position. It belongs to the Vilgian Glaciation. This formation is also frequent in the entire area of northeastern Poland and southern Lithuania as well.

Fourteen horizons of glacial tills of different age were distinguished in the Mrągowo Lakeland area. Petrographic features of their lithotypes were defined and presented in Table 1. Compilation of these results shows that distinct deviations exists in some determinations in comparison with the petrographic background. The author has interpreted them as characterizing the glacial rafts of tills deposited in younger

Fig. 9. Map of intra-Pleistocene structural plane on the top of sediments older than the Mazovian Interglacial

1 — interglacial lacustrine sediments lying on structural plane; 2 — interglacial fluvial sediments lying on both lacustrine sediments and structural plane; 3 — ice-dammed lake-watermoraine sediments (red clay complex) cropping out on the structural plane; 4 — ice-dammed lake-watermoraine sediments covered with interglacial sediments; 5 — boundaries of extent of sediments: a — lying on structural plane, b — occurring under the cover of interglacial sediments; 6 — direction of river water outflow; 7 — findings of remains of Quaternary: a — humus, b — peat; 8 — findings of remains of Quaternary molluscs; 9 — isohypses of structural plane (at each 10 m intervals); 10 — test-cartographic boreholes: a — with identification numbers as in Figs. 2–4, b — other boreholes; 11 — absolute altitude (in m) of the top of sediments: a — lying on the structural plane, b — exposed on the structural plane

Mapa śródplejstoceńskiej powierzchni strukturalnej — stropu osadów starszych od interglacjału mazowieckiego

1 — interglacjalne osady jeziorne leżące na powierzchni strukturalnej; 2 — interglacjalne osady rzeczne leżące na osadach jeziornych i na powierzchni strukturalnej; 3 — osady zastoiskowo-wodnomorenowe (czerwonego kompleksu ilastego) odsłaniające się w powierzchni strukturalnej; 4 — osady zastoiskowo-wodnomorenowe leżące pod osadami interglacjalnymi; 5 — granice zasięgu osadów: a — leżących na powierzchni strukturalnej, b — występujących pod przykryciem osadów interglacjalnych; 6 — kierunek odpływu wód rzecznych; 7 — znaleziska szczątków roślin czwartorzędowych: a — humus, b — torf; 8 — znaleziska szczątków mięczaków czwartorzędowych; 9 — izohipsy powierzchni strukturalnej (co 10 m); 10 — otwory kartograficzno-badawcze: a — z numeracją jak na fig. 2–4, b — pozostałe; 11 — wysokość bezwzględna (w metrach) stropu osadów: a — leżących na powierzchni strukturalnej, b — odsłaniających się w powierzchni strukturalnej

Table 1

Average results of petrographic study of gravels (5–10 mm in size) occurring in glacial tills encountered in 32 test-cartographic boreholes

Stratigraphy		Petrographical coefficients	Mean contents of gravels (%)	Number of boreholes with tills	
Glaciation	Stadial	O/K – K/W – A/B	Kr-Wp-Dp-Pp-W_L-P_L-M_L	with petrographical studies	with petrographical studies or weathered tills *
Vistulian-B	younger-B_2	2,29-0,48-1,85	26-52-6-4-1-5-1	13	5*
	older-B_1	1,92-0,57-1,57	30-50-6-4-1-3-1	17	-
Wartanian-W	younger-W_2	1,51-0,74-1,20	35-45-5-5-3-2-3	15	1
	older-W_1	1,49-0,70-1,35	35-48-5-2-1-2-1	8	-
Odranian-O	younger-O_2	1,96-0,55-1,69	30-48-9-3-3-2-3	17	-
	older-O_1	2,70-0,40-2,34	24-52-11-3-2-2-3	15	1
Liviecian-C		1,87-0,60-1,60	28-42-8-3-3-3-10	21	-
Vilgian-G		1,59-0,71-1,33	28-37-6-3-2-3-14	19	-
Sanian-S	younger-S_2	1,14-1,06-0,82	32-27-7-6-7-6-9	14	1
	older-S_1	0,86-1,41-0,64	38-25-6-6-11-3-10	10	1
Nidanian-N	younger-N_2	1,35-0,82-1,10	32-34-7-4-7-3-6	16	1
	older-N_1	2,03-0,54-1,71	27-42-10-3-8-4-2	7	-
Narevian-A	younger-A_2	0,99-1,18-0,76	37-28-6-5-3-2-12	6	-
	older-A_1	1,38-0,78-1,25	34-35-12-2-3-3-6	5	-

* two horizons only

glacial tills. Deviations were neglected when determining features of individual lithotypes. Dissipation of averages in such sets of indices for given tills appeared to be relatively small. Considerably greater scatter of results is characteristic only for tills of the Vilgian and Liviecian Glaciations.

It was assumed that stadial glacial tills of one glaciation should be similar in respect of their petrography — and this is shown in Table 1. The author followed the idea of many geologists that in the interstadial periods the Scandinavian ice-sheet did not melt completely (after L. Lindner, S. Z. Różycki, 1992). He also assumed that during any individual glaciation its centre, from which ice-masses were shifting in different directions including that one towards Poland, remained — more or less — in the same place of Scandinavia.

To the south of crystalline basement of Fennoscandia, there is a belt of exposures of Palaeozoic calcareous rocks, extending considerably to the east. In particular stadials of the same glaciation, the ice-sheet collected its rock load from exposures of similar width. Ice-sheets of different glaciations were spreading from centres lying in different places in Scandinavia, so they were flowing southwards on rock exposures of variable width. This is reflected by considerable differences in petrographic composition of glacial tills that originated during different glaciations.

One can assume that the centre of ice-cap during the Narevian and Sanian Glaciations was situated in the Scandinavian Mts., during the Nidanian, Vilgian, Liviecian, and Wartanian Glaciations — in the northern sector of the Gulf of Bothnia, and during the Odranian and Vistulian Glaciations — in the north of Finland.

The presented approach to a subject of lithological-petrographic studies, in particular to petrography of glacial tills — in combination with obtained results allows to draw a conclusion on univocal applicability of these studies to determining of lithostratigraphy of glacial tills over a larger area. In turn, these lithostratigraphic studies satisfactorily define the stratigraphy of the Pleistocene as the whole.

RECAPITULATION

1. The Mrągowo Lakeland enters into the composition of central part of the Mazury Lake District, where the Pleistocene reaches the maximum thickness all over Poland. This region was repeatedly covered with ice-sheets advancing from Scandinavia, that left horizons of glacial tills.

In this paper, the glacial tills within the study area have been well defined petrographically. Distinguished have also been interglacial sediments separating glacial tills from each other. Accordingly, the study area is that one which is stratotypical for the lithostratigraphy and stratigraphy of the Pleistocene in Poland.

2. Thickness and extent of sediments of different Pleistocene stages within the Mrągowo Lakeland depend on the tectonic structure of the substratum. In regions of tectonic depressions the thickness of sediments is the greatest and stratigraphic gaps are the smallest.

3. One can state that tectonic processes in the Mrągowo Lakeland manifest themselves in three phases: the Malopolanian, the Kuiavian, and the Mazovian.

4. Glaciotectonic processes in the Mrągowo Lakeland were going on during the entire Pleistocene. They were closely connected with tectonics of the substratum. The best development of the frontal morainic zone of the youngest ice-sheet took place in the region over main tectonic fault whereas the younger zones of push moraines — within the Kętrzyn Trough densely dissected by faults.

5. Glacial rafts of Tertiary formation, sediments of red clay complex, interglacial sediments, and older glacial tills are common in younger glacial tills in the study area.

6. Fluvial processes were active during every interglacial, and in many places the fluvial tracts of drainage were rejuvenated in consecutive warm periods. A distinct dependence of river valley tracts on tectonics of Pleistocene substratum could be observed until Mazovian Interglacial. This dependence ceased to exist after this interglacial.

7. The Pleistocene formation within the Mrągowo Lakeland is composed of eight glacial complexes separated by seven complexes of sediments deposited during interglacial periods. These sediments developed as fluvial and lacustrine facies. The majority of glacial complexes occurs to be easily divided into stadial series. Sediments of the oldest glaciation have been preserved only in deep tectonic depressions of the substratum. Sediments of consecutive glaciations are of the greatest thickness in the northern part of the area. The red clay complex belonging to the Vilgian Glaciation is a very important stratigraphic horizon for the Mrągowo Lakeland and entire northeastern Poland. The Mazovian Interglacial is that one when lacustrine and fluvial sediments developed in full. Their thickness at Koczarki reaches 70 m. Four alternating sedimentary cycles were identified, including two lacustrine cycles and two fluvial ones. The climatic optimum of the Mazovian Interglacial was recorded in sediments of the first (older) lacustrine cycle. The glacial tills of the younger stadial of the Odranian Glaciation is the thickest among all other glacial tills. Sediments of the youngest Vistulian Glaciation have been divided into two stadials: the older one — the Świecie Stadial, and the younger — the Pomeranian–Leszno one. Glacial tills of the younger stadial form one morainic horizon, thus no evidence is available on the existence of the Mazurian Interphase separating the Poznań–Leszno (or Poznań) Phase from the Pomeranian one.

The study presented herewith is a summary of the authors doctor thesis that had been developed at the Division of Geology of Quaternary at the Polish Geological Institute in 1993–1996, under the direction of Asst. Prof. Dr. hab. A. Makowska. The thesis was reviewed by: Prof. Dr. hab. L. Lindner and Prof. Dr. hab. J. E. Mojski.

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PLEJSTOCEN POJEZIERZA MRĄGOWSKIEGO

Streszczenie

Prezentowany artykuł jest skrótem pracy doktorskiej powstałej w latach 1993–1996 w Zakładzie Geologii Czwartorzędu Państwowego Instytutu Geologicznego w Warszawie pod kierunkiem doc. dr hab. A. Makowskiej.

Celem pracy było rozpoznanie budowy geologicznej i stratygrafii osadów plejstoceńskich Pojezierza Mrągowskiego (fig. 1). Przeanalizowano wyniki badań palinologicznych (275 próbek) i litologiczno-petrograficznych (około 3 tys. próbek) osadów czwartorzędowych z 32 otworów kartograficzno-badawczych. Z 28 przekrojów geologicznych i 7 map śródplejstoceńskich powierzchni strukturalnych charakteryzujących okresy międzylodowcowe przedstawiono 2 przekroje geologiczne (fig. 7 i 8) oraz mapę powierzchni strukturalnej interglacjału mazowieckiego (fig. 9). Profile 16 otworów kartograficzno-badawczych z wynikami badań petrograficznych przedstawiono na figurach 2–4.

Na Pojezierzu Mrągowskim wyróżniono trzy jednostki geomorfologiczne: wysoczyznę polodowcową, obszary sandrowe i subglacjalne rynny lodowcowe. Szczegółowe wydzielenia utworów powierzchniowych przedstawia mapa geologiczno-geomorfologiczna (fig. 5).

W rzeźbie podłoża podplejstoceńskiego wyodrębniono cztery jednostki strukturalne: nieckę Kętrzyna, elewację Mrągowa, depresję Mikołajek i płaskowyż Piecków (fig. 6).

Na badanym terenie wyróżniono osady 8 zlodowaceń: narwi, nidy, sanu, wilgi, liwca, odry, warty i wisły oraz 7 interglacjałów: podlaskiego, małopolskiego, ferdynandowskiego, mazowieckiego, zbójna, lubelskiego i eemskiego. Tylko pozycja osadów interglacjału mazowieckiego jest jednoznacznie udokumentowana wynikami badań palinologicznych. Osady pozostałych interglacjałów rozpoznano głównie na podstawie odtworzenia sieci dolin rzecznych dla każdego okresu ciepłego, a także badań mineralogicznych i miejsca zalegania tych osadów w stosunku do dobrze litostratygraficznie określonej pozycji glin morenowych i petrograficznych cech ich litotypów (tab. 1).

Osady każdego zlodowacenia, z wyjątkiem utworów zlodowacenia wilgi i liwca, zaliczono do dwóch stadiałów. Wyróżniono więc 14 różnowiekowych poziomów glin zwałowych (tab. 1). Ważnym poziomem stratygraficznym są osady czerwonego kompleksu ilastego, należące do zlodowacenia wilgi. Osady rzeczne i jeziorne interglacjału mazowieckiego na Pojezierzu Mrągowskim przewiercono w 12 otworach kartograficzno-badawczych. Najważniejsze profile z osadami tego interglacjału to Goleń, Koczarki, Sykstyny i Węgorzewo III (fig. 1). Do interglacjału mazowieckiego zaznaczyła się wyraźna zależność kierunku przebiegu dolin rzecznych od tektoniki podłoża plejstocenu; dla okresów młodszych zależności tej nie zaobserwowano. Na omawianym obszarze stwierdzono przejawy procesów tektonicznych trzech faz: małopolskiej, kujawskiej i mazowieckiej.

W glinach zwałowych odnotowano powszechne występowanie porwaków trzeciorzędowych, osadów czerwonego kompleksu ilastego, osadów interglacjalnych i starszych glin zwałowych. Odtworzono prawdopodobne kierunki nasuwania się lądolodów zlodowaceń: narwi i sanu — z Gór Skandynawskich, nidy, wilgi, liwca i warty — z północnej części Zatoki Botnickiej oraz odry i wisły — z północnej części Finlandii.

Wyniki badań petrograficznych pozwalają wysunąć wniosek o jednoznacznej przydatności tych badań w określaniu litostratygrafii glin zwałowych na dużym obszarze.