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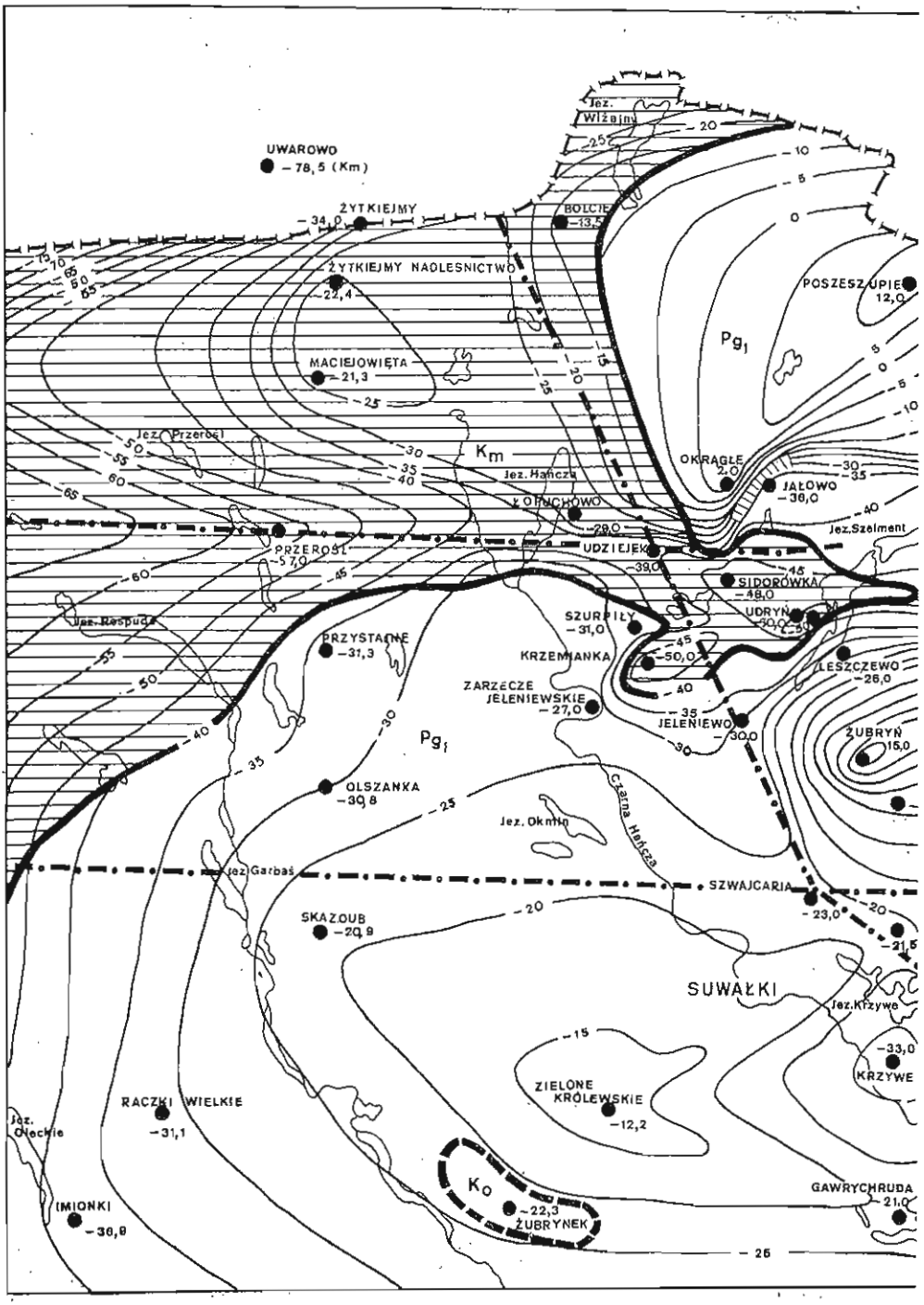
Stratigraphy of the Quaternary of the Suwałki Lakeland and its substrate based no recent data*

Basing o analyses and investigations of sections of 40 boreholes done during the last ten years in the Suwałki Lakeland, new data are presented on geologic structure and morphology of sub-Quaternary substrate and on stratigraphy of Pleistocene deposits. The borehole Żubrynek proved that in the Quaternary substrate there are, but sediments of the Upper Cretaceous (Maestrichtian) and Lower Palaeocene, the Upper Eocene deposits of the zone *Turborotalia cerroazulensis*, 7.7 m thick. A morphology of the sub-Quaternary substrate results in its subdivision into two morphostructural regions: a platcau and an accompanyig depression, separated by quite a steep edge about 35 m high, of tectonic-erosive origin. In the Suwałki Lakeland area there are 7—8 glacial horizons that represent sediments of South-Polish (Wilga), Middle-Polish (Odra) and North-Polish (Wisła) glaciations. Still there are no stratigraphic bases for finding the sediments of the earlier glaciations than the South-Polish (Wilga) Glaciation in the described area. On the other hand, organogenic sediments of Mazovian (Holstein) and Eemian interglacials were noted. An advance of the ice-sheet of the North-Polish (Wisła) Glaciation and the following deglaciation are also generally presented.

INTRODUCTION

During the last ten years detailed geologic-cartographic and hydrogeologic works were carried through in the Suwałki Lakeland by the Geological Institute. Within these works 40 full-cored boreholes were done in the Quaternary sequence that reached the older substrate, either of the Tertiary (Lower Palaeocene, Eocene) or of the Cretaceous (Maestrichtian) age. Some cores have been already analyzed, among others micropalaeontologic investigations of Tertiary and Cretaceous sediments


UWAROWO
– 78,5 (Km)
ŻYTKIEJMY
– 34,0
ŻYTKIEJMY NADLEŚNICTWO
– 22,4
MACIEJOWIĘTA
– 21,3
Jez. Przerośl
PRZEROŚL
– 57,0
Jez. Raspuda
PRZYSTAJNE
– 31,3
OLSZANKA
– 30,8
Jez. Garbaś
SKAZOUB
– 20,9
RACZKI WIELKIE
– 31,1
Jez. Olecko
(MIONKI
– 36,8
Km
Pg1
Ko
Jez. Hańcza
CZUCHÓWO
– 29,0
UDZIEJEK
– 39,0
Jez. Okmin
Czarna Hańcza
Jez. Wiżajny
BOLCIE
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POSZESZUPIE
12,0
OKRĄGŁE
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JAŁOWO
– 36,0
Jez. Szelment
SIDORÓWKA
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UDRYŃ
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SZURPIŁY
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KRZEMIANKA
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JELENIEWO
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LESZCZEWO
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ŻUBRYŃ
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SZWAJCARIA
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Jez. Krzywe
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ŻUBRYNEK
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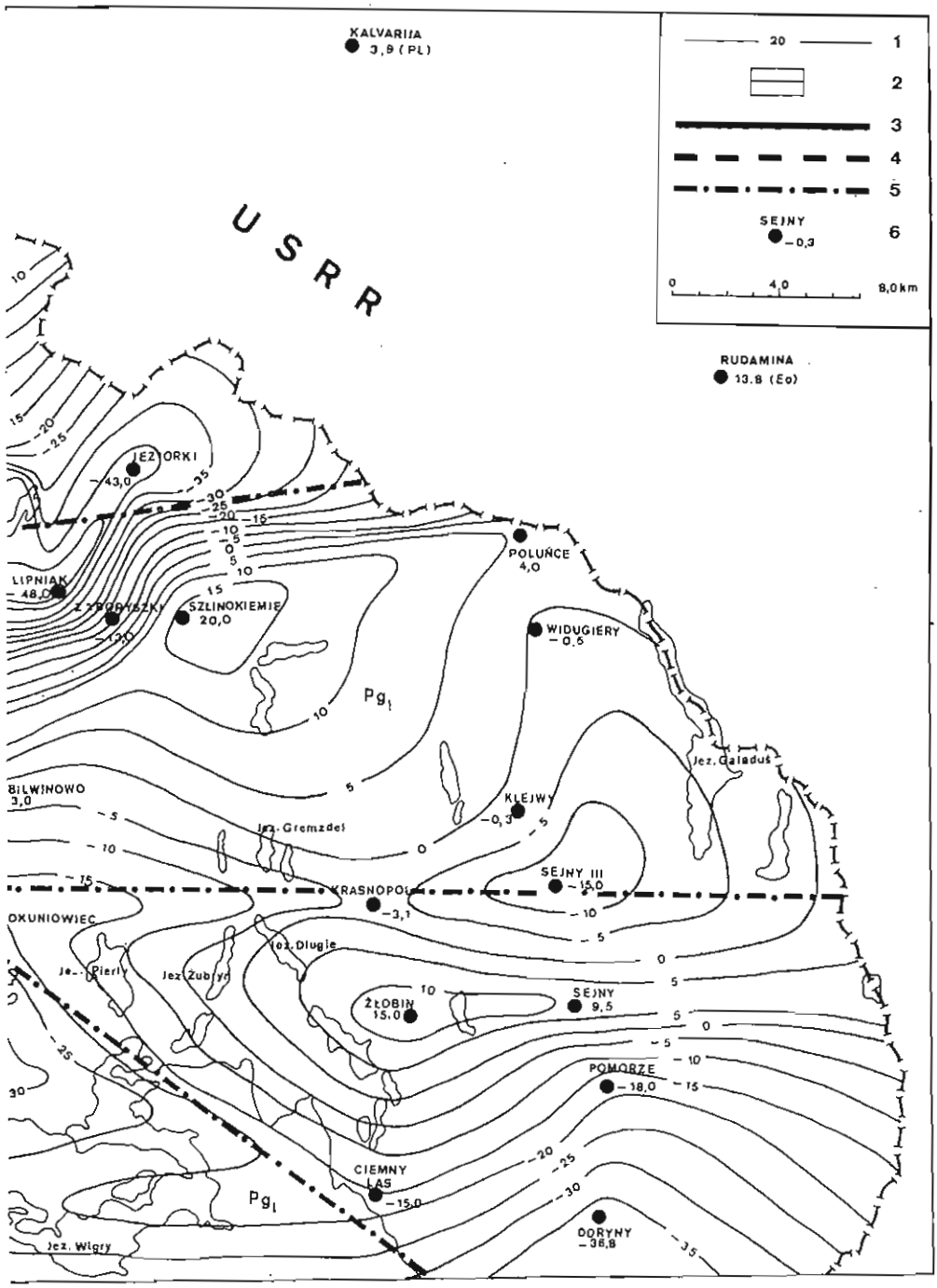
KALVARIJA
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SEJNY
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8,0 km
JEZIORKI
43,0
LIPNIAK
-48,0
SZLINOKIEMIE
20,0
POLUNCE
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Pg1
Jez. Galaduś
BILWINOWO
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Jez. Gremzdel
KLEJWY
-0,3
SEJNY III
-15,0
KRASNOPOL
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OKUNIOWIEC
Jez. Dlugie
Jez. Pierty
Jez. Zubry
ŻŁOBIN
15,0
SEJNY
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POMORZE
-18,0
CIEMNY LAS
-15,0
Pg1
DORYNY
-36,8
Jez. Wigry

(E. Gawor-Biedowa, E. Odrzywolska-Bieniek), preliminary palaeobotanic analyses of the Pleistocene organic deposits (Z. Borówko-Dłużakowa, Z. Kopikowa) and lithologic-petrographic investigations (B. Gronkowska, K. Kenig, 1974; J. Rzechowski, 1980; Z. Fert, K. Pruszek, 1984; K. Kenig, 1985) have been already finished but thermoluminescence datings of collected samples (F. M. Pazdur) are still unknown. Besides, a stratigraphic correlation of the cores was done with the palaeobotanicly dated Quaternary sections from the Mazury Lakeland (W. Słowański, 1975), Kaliningrad District and Lithuania (O. Kondratiene, W. Gudelis, 1983).

The received data, in connection with detailed geologic mapping (A. Ber, T. Krzywicki, S. Lisicki, P. Woźniak), hydrogeologic (J. Mitręga), geologic-engineering (B. Jakubicz) and geophysic (geoelectric and gravimetric) investigations allowed for a new approach to the stratigraphy of the Quaternary of the Suwałki Lakeland. It is considerably different from the first synthesis of the Quaternary of this area (A. Ber, 1972, 1973, 1974, 1980, 1982).

MORPHOLOGY AND GEOLOGIC STRUCTURE OF SUB-QUATERNARY SUBSTRATE

A geologic sketch of the sub-Quaternary surface of the Suwałki Lakeland (Fig. 1) was prepared on the basis of 44 boreholes that reached the older substrate, composed of Cretaceous or Tertiary deposits. Amongst these boreholes, 32 fully-cored ones were drilled just for investigations of the substrate structure as well as lithology and stratigraphy of the Quaternary of the Suwałki Lakeland. These works were undertaken within the preparation of the Detailed Geologic Map of Poland in a scale of 1 : 50,000 as well as in connection with hydrogeologic investigations carried through in sites of ilmenite-magnetite ore deposits, that is in the Krzemianka and Udryń region. The published borehole sections that pass through the Quaternary of southern Lithuania (Uwarowo, Kalvarija and Rudamina) were also used.

In the Quaternary substrate of the Suwałki Lakeland, the rocks of the Upper Cretaceous (Maestrichtian) age are exposed. They include gaizes, marls and marly limestones. Besides, there are also rocks of the Lower Palaeocene, comprising limy gaizes (S. Cieśliński, M. Jaskowiak, 1973). Only at Żubrynek (Fig. 1) the Quaternary substrate encloses the 7.7 m thick series of the Upper Eocene (zone *Turborotalia cerroazulensis*: E. Odrzywolska-Bieniek, 1984), composed of glauconite sands and sandstones. A distribution of Maestrichtian and Lower Palaeocene deposits corresponds in general with the structure of the crystalline bedrock i.e. with the Peribaltic Syneclise (in the north-western part of the area)

Fig. 1. Morphology and geologic structure of the sub-Quaternary bedrock of the Suwałki Lakeland

Rzeźba i budowa geologiczna powierzchni podczwartorzędowej Pojezierza Suwalskiego

1 — contour lines of the sub-Quaternary surface in metres a.s.l.; 2 — Maestrichtian (Km); 3 — Lower Palaeocene (Pg1); 4 — Upper Eocene (Eo); 5 — probable tectonic discontinuities; 6 — boreholes with altitudes of sub-Quaternary surface in metres a.s.l.

1 — poziomice powierzchni podczwartorzędowej w m n.p.m.; 2 — mastrycht (Km); 3 — paleocen dolny (Pg1); 4 — eocen górny (Eo); 5 — linie prawdopodobnych nieciągłości tektonicznych; 6 — otwory wiertnicze z rzędnymi powierzchni podczwartorzędowej w m n.p.m.

in which the Quaternary complex is underlain by the Maestrichtian series, and with the Mazury-Suwałki Anteclise in which the Maestrichtian rocks are only outcropping inside the erosive cuts but are overlain by the Lower Palaeocene and locally, isolated patches of the Upper Eocene rocks (Fig. 1).

The morphology of the sub-Quaternary bedrock of the Suwałki Lakeland can be divided into two morphostructural regions: eastern region that forms a plateau at 12—20 m a.s.l., western region that forms a depression with a diversified bottom at 12—57 m b.s.l. and below. Both regions are separated by a distinct and quite steep edge that runs almost meridionally and is up to 35 m high, with erosive cuts. Approximately in the central part of the Suwałki Lakeland this edge as well as the plateau are cut by quite a broad river valley, running from northeast southwestwards and locally almost meridionally, from Jeziorki in the northeast through Lipniak, Udryń and Udziejek to Przerośl in the southwest. This valley probably corresponds with its course to a tectonic loosening (fault) within the crystalline bedrock. Other directions of these cuts (resembling in shape the African wadis) correspond to the west-east pattern of a fault system in the crystalline bedrock of this area (S. Kubicki, W. Ryka, 1982) whereas the edge itself runs closely with the system of meridional discontinuities in the crystalline bedrock. Thus, it seems to be of tectonic--erosive origin. In turn, the main morphologic features of the sub-Quaternary surface are repeated in many elements of the present landscape (Wigry depression, Jeleniewo channel, Szelment channel, etc.). It is particularly visible in photolineaments, noted by B. Danielska as well as J. Bażyński et al. (1984).

The analysis of the sub-Quaternary surface, subdivided into both mentioned regions, proves its origin to result from tectonics, Neogene erosion and from karst, but in a smaller degree from a glacial erosion.

OUTLINE OF STRATIGRAFHY OF QUATERNARY DEPOSITS (WITHOUT DEPOSITS OF THE WISŁA GLACIATION)

In the Suwałki Lakeland there are 7 or 8 glacial horizons of the South-Polish Glaciation (Wilga Glaciation: 1—2 horizons) Middle-Polish Glaciation (Odra Glaciation: 4—5 horizons) and North-Polish Glaciation (Wisła Glaciation: 1 horizon). A stratigraphic rank of the glacial horizons of the Middle-Polish Glaciation can be higher so, they can represent separate glaciations as their deposits are divided by still not analyzed lake sediments with plant remains and mollusc shells (Figs 2 and 3). In spite of numerous boreholes that pass through the Quaternary complex, no sediments of the Oldest Glaciation and the Cromer Interglacial were found, although they have been noted in the Mazury Lakeland (W. Słowański, 1975). According to the recent lithologic-petrographic works (Z. Fert, K. Pruszek, 1984) the tills, considered for the ones of the South-Polish Glaciation age, may belong to the Oldest Glaciation. But this fact is opposed by results of the pollen analyses (Z. Borówko-Dłużakowa,, 1983; Z. Kopikowa, 1986). Tills that are expected, due to lithologic-petrographic analyses, to represent the Oldest Glaciation, are divided by lake silts with flora and fauna (mollusc shells), with a plant succession and composition

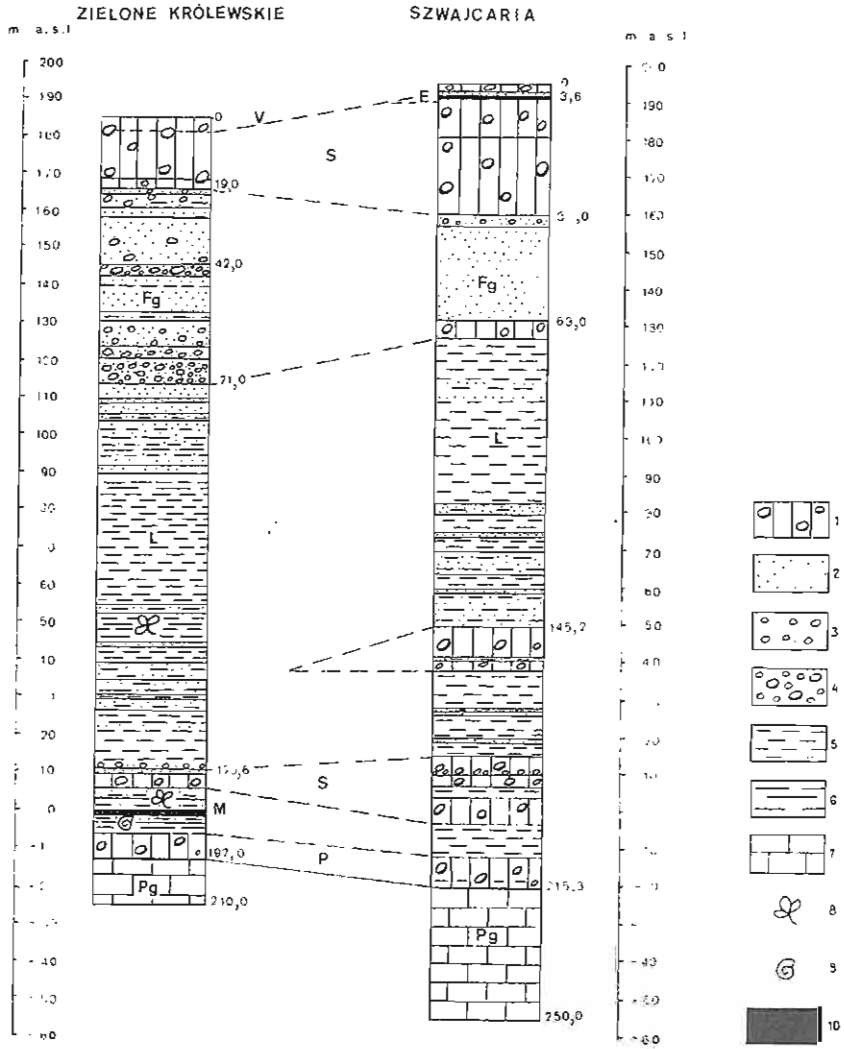

Fig. 2. Geologic sections of the boreholes with thick series of ancient lake sediments

Profile geologiczne wierceń z miąższymi kompleksami kopalnych osadów jeziornych

1 — tills; 2 — sands; 3 — sands with gravels; 4 — gravels and boulders; 5 — silts; 6 — clays; 7 — marls and marly limestones; 8 — plant remains; 9 — mollusc shells; 10 — peats; E — Eemian Interglacial; M — Mazovian Interglacial; P — South-Polish Glaciation (Wilga); S — Middle-Polish Glaciation (Odra); V — North-Polish Glaciation (Wisła); L — lake sediments; Fg — glacifluvial sediments; Pg — Lower Palaeocene

1 — gliny zwałowe; 2 — piaski; 3 — piaski ze żwirem; 4 — żwiry i głazy; 5 — mułki; 6 — iły; 7 — margle i wapienie margliste; 8 — szczątki roślinne; 9 — skorupki ślimaków; 10 — torfy; E — interglacjał eemski; M — interglacjał mazowiecki; P — zlodowacenie południowopolskie (Wilgi); S — zlodowacenie środkowopolskie (Odry); V — zlodowacenie północnopolskie (Vistulian); L — osady jeziorne; Fg — osady fluwioglacjalne; Pg — paleocen dolny

typical for the Mazovian Interglacial (Fig. 2).

The mentioned glacial horizons are not separated, as presented in previous papers (A. Ber, 1973, 1974, 1980), by two intervals of interglacial

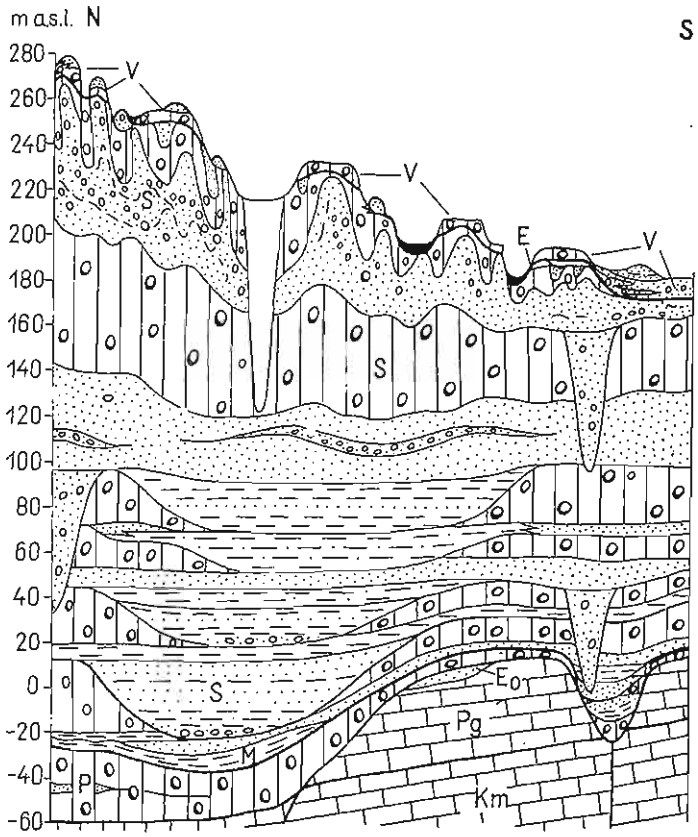

Fig. 3. Summarizing stratigraphical column
Syntetyczny profil geologiczny
Explanations as in Fig. 2
Objaśnienia jak na fig. 2

erosion (Mazovian and Eemian interglacials) and 5 intervals of interstadial or interphasal erosion but by 5 or 6 periods with glacial water or glacial erosion.

Due to glacial water erosion in different times, the whole system of glacial channels was formed, being repeated in a vertical sequence (Fig. 3). During the Early Pleistocene they ran from northwest southeastwards whereas during the Late Pleistocene from northwest southeastwards and from northeast southwestwards. In this second case the crossing channels formed systems, defined as "casket" ones by hydrogeologists.

Interglacial sediments composed of lake silts with flora and fauna as well as of peats of the Mazovian and Eemian interglacials, are noted only in glacial eroded or thaw depressions in earlier surfaces (of the South-Polish or Middle-Polish glaciations age). During the interglacials no fluvial valleys with alluvia and systems of accumulative terraces were formed in the Suwałki Lakeland but only a system of drained glacial channels was created.

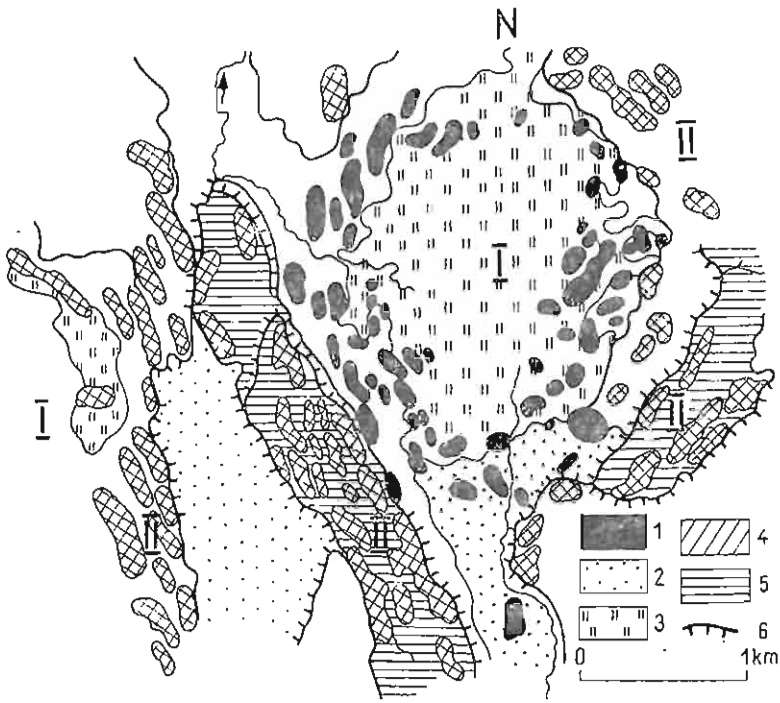

Fig. 4. Glaciotectonic depression and upthrusting from the Bilwinowo area
Depresja i wyciśnięcie glacitektoniczne z okolic Bilwinowa
I — glaciotectonic depression: 1 — dead-ice features, 2 — glacifluvial sands and gravels, 3 — peats; II — glaciotectonic upthrusting: 1 — upthrust and moraines, 2 — zone of glaciotectonic deformations, 3 — abrasive and erosive edges
I — depresja glacitektoniczna: 1 — formy martwego lodu, 2 — piaski i żwiry wodnolodowcowe, 3 — torfy; II — wyciśnięcie glacitektoniczne: 1 — moreny czołowe wyciśnięcia, 2 — strefa zaburzeń glacitektonicznych, 3 — krawędzie abrazyjne i erozyjne

In the whole Pleistocene sequence of the Suwałki Lakeland a trend is noted for repeating i.e. renewing during successive glacial and interglacial episodes, of large lake basins similar in their shape, area and depth to the present ones of Wigry, Śniardwy and Mamry lakes, filled with sediments over 100 m thick (Fig. 3). Cyclothems of lake sediments of different age are separated from one another by thin beds of washed (by lake waters) stratified clays, coming from primary tills. The origin of these depressions should be connected with glacial depressions (A. B. Basalykas, 1969; H. Ruszczyńska-Szenajch, 1979, 1983; W. Jaroszewski i in., 1985).

WISŁA GLACIATION

An ice sheet of the Wisła Glaciation advanced only once into the Suwałki Lakeland and reached the Biebrza ice marginal streamway. This advance is proved by a single discontinuous and thin till bed, locally erod-

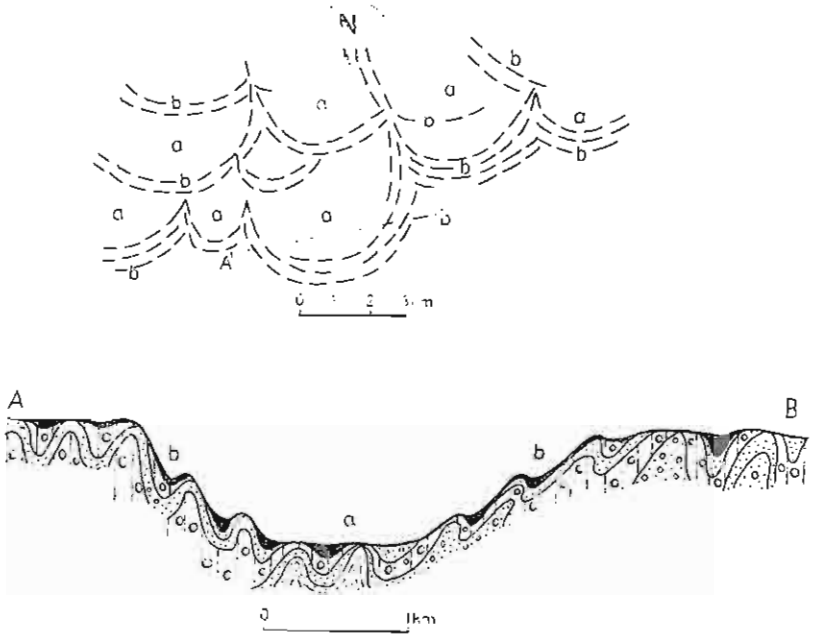

Fig. 5. Festoon-like pattern of glaciotectonic depressions (a) and upthrustings (b) in the Suwałki Lakeland

Festonowy układ depresji (a) i wyciśnięć glacitektonicznych (b) na Pojezierzu Suwalskim

ed, and by three retreat morainal zones. Taking into account a thickness of tills (basal and flow ones) of this glacial stage, to several metres only, and in the same time a range and a size of glaciotectonic deformations created during this advance into the Suwałki Lakeland, the ice sheet of the Wisła Glaciation seems to have been thin but considerably active in deformations of the close forefield.

The advance of the ice sheet of the Wisła Glaciation in the Suwałki Lakeland was presented in a previous paper (A. Ber, 1982). The ice sheet formed two glacial streams: the Mazury and the Lithuanian ones. They were divided in turn into the Rospuda, Hańcza and Sejny lobes. But it should be added that a subdivision of the ice sheet front and the prosesses occurring during its advance are primarily influenced by a geologic structure as well as morphology of the Suwałki Lakeland and the Augustów Plain. It results from the case that main features of these areas survived almost unchanged since the Middle-Polish (Wilga) Glaciation. The Suwałki Lakeland has been in general a plateau area, composed of tills and glacifluvial gravels and sands. It has a highly differentiated relief whereas the Augustów Plain, being a remnant of a vast water reservoir, shows a monotonous and almost flat surface, with only local and slightly elevating hills of glacial origin.

The advance of the ice sheet of the Wisła Glaciation is marked in the Suwałki Lakeland by intensive glacial deformations of deposits in the forefield and so, terminal depressions of various sizes have been formed.

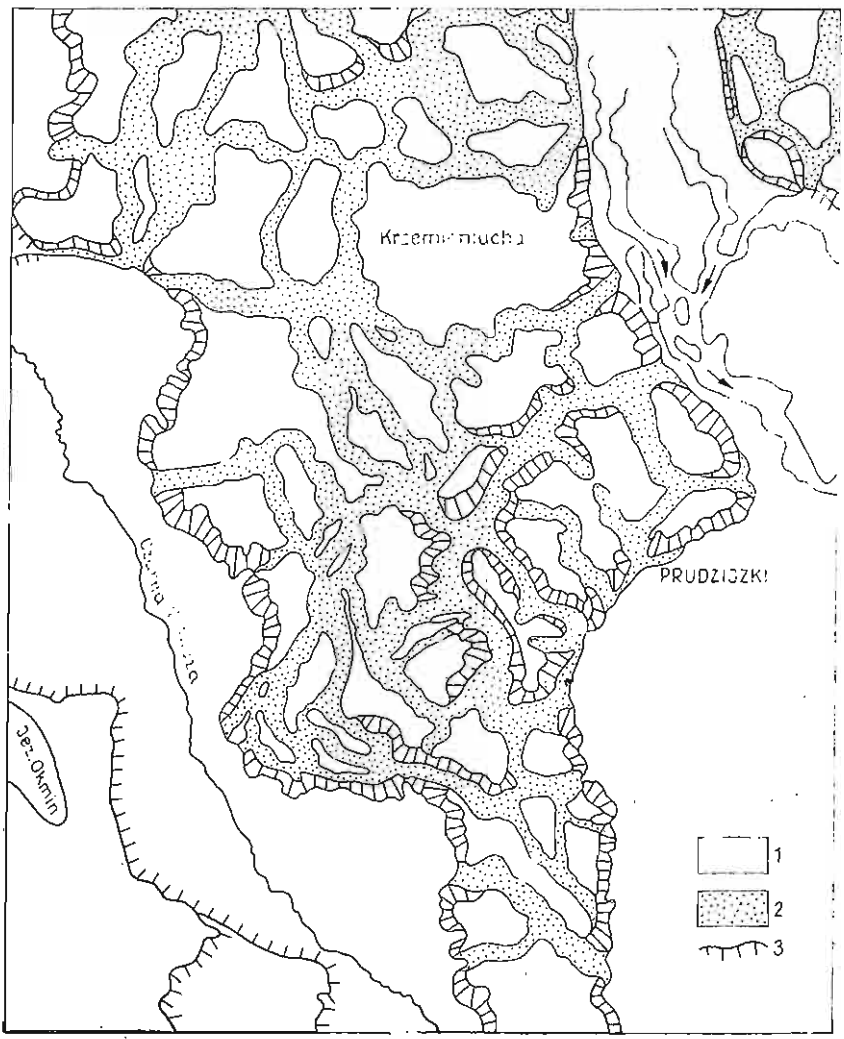

Fig. 6. "Polygon-like" pattern of erosive valleys in the Szurpiły and Krzemianka plateau

„Poligonowy" układ dolinek erozyjnych na obszarach wysoczyzny Szurpił i Krzemianki

1 — glacial plateau; glaciotectonicly deformed; 2 — erosive valleys; 3 — edges

1 — zaburzona glacitektonicznie wysoczyzna lodowcowa; 2 — dolinki erozyjne; 3 — krawędzie

They were named the glaciodepressions (A. Ber, 1974) after A. B. Basalykas (1969) but now are defined as glaciotectonic depressions after H. Ruszczyńska-Szenajch (1983) and W. Jaroszewski i in. (1985).

The largest glaciotectonic depressions in the Suwałki Lakeland include: the Szeszupa depression, Wigry basin, Bilwinów area (Fig. 4) and Krasnopol area. Glaciotectonic depressions are encircled by end-moraine features, commonly with a disturbed structure (glaciotectonic struc-

tures of M. Pasierbski, 1984) of scales or inclined and vertical folds that form the so-called glacioelevations (A. B. Basalykas, 1969) or glaciotectonic upthrustings (H. Ruszczyńska-Szenajch, 1983). They make the surface of this area have a typical rhythmic pattern (in west-east and south-north directions) of alternate depressions and elevations of various sizes (the latter have a deformed structure). At contacts of glacial lobes or tongues there are also triangular, wedge-shaped end-morainic massifs with common glaciotectonic deformations at their margins. As the ice sheet advanced, the glacioelevations have been deformed again i.e. folded or cut off and so, smoothed in their top parts.

Some plateau fragments as the morainic plateau of Szurpiły and Krzemianka, surroundings of the Szelment Lake, Osinki and Szwajcaria villages etc. have been ice sheet deformed into upthrustings caused by a vertical pressure of the ice mass as well as by lateral stress of glacial lobes and tongues. At the end of the Pleistocene and now, the erosion have been acting between folds, scales and diapires of glaciotectonic origin. It formed a typical "polygon-like" pattern of erosive incisions and valleys (Fig. 6).

In the Augustów Plain the ice sheet of the Wisła Glaciation advanced into a frozen surface of a vest water reservoir and so, has not created such intensive and any deformations as in the Suwałki Lakeland. The Augustów Plain has not been investigated in detail yet and demands separate studies in future.

During deglaciation the ice sheet, highly disintegrated into numerous lobes, tongues and microtongues, and intensively fissured, was subdivided into numerous dead ice blocks that usually filled the glaciodepressions (source depressions). Meltwaters formed vast ice-dam lakes, connected with one another, that left limnoglacial series of varied thickness (usually several dozen centimetres) but also formed levels or abrasive levels at various altitudes (e.g. Szurpiły Lake: 210—215 m a.s.l., Wigry Lake: 170—175 m a.s.l.). Ice-dam lakes of the Suwałki Lakeland were connected through depressions of varying origin with the Augustów reservoir and with the Lithuanian lowland. A final melting of dead ice blocks is represented by concentric dead ice moraines around the glaciodepressions as well as various kames and kame terraces that make their bottoms and margins irregular. In the same time, the glaciotectonicly deformed end moraines around the glaciodepressions (that had not been entirely smoothed during the ice sheet advance) were covered by discordant i.e. horizontal series of watermorainic sediments (terms after W. Morawski, 1984).

The ice sheet of the Wisła Glaciations within the Augustów reservoir disintegrated also into numerous dead ice blocks and their melting occurred partly under water. Subglacial channels, kame areas and traces of abrasive levels at tops of glacial accumulative features are the relics and the evidence for an areal and partly subaqueous deglaciation of this area.

FINAL REMARKS

1. The Suwałki Lakeland relief was finally formed by the ice sheet of the Wisła Glaciation but not during a deglaciation, rather during glaciation (that is the advance). Glacial sediments and features deposited

due to areal deglaciation, have not obliterated the glaciotectonic morphologic elements as glaciotectonic depressions and upthrustings (glacioelevations) from the time of the ice sheet advance. Detailed studies proved that the ice sheet of the Wisła Glaciation was thin but very active.

2. The presented scheme of processes that occurred during the last glaciation and deglaciation of the Suwałki Lakeland and the Augustów Plain can be possibly referred also to other parts of northern and central Poland of a similar structure. They can be referred not only to the youngest i.e. Wisła Glaciation but also to the earlier glaciations, especially as a presence of a buried glaciotectonic depression was already noted by Z. Lamparski in 1981 from the Mochowo area in Kujawy.

3. Studies carried through in the Suwałki Lakeland prove that the last deglaciation occurred in this area in the areal way. Landforms of a frontal deglaciation, described by me previously, have been mainly created during the ice sheet advance and only rarely are included into retreat morainal zones. Therefore, it seems that M. Pasierbski (1984) while discussing with T. Bartkowski (1969) and other authors, considered at least some of the features of the ice sheet advance time for being developed during a frontal deglaciation.

4. Meltwaters from dead ice blocks flew from the Suwałki Lakeland partly into the Augustów reservoir and partly into the Lithuanian lowland through the Szeszupa depression. Lowerings of the water table in the Augustów reservoir and smaller local ice-dam lakes was marked by several (usually 2—3) abrasive levels, erosive terraces of Czarna Hańcza and erosive levels in water trains. As the value of the highest meltwater level is known (210—215 m — Szurpiły Lake and 170—175 m a.s.l. — Wigry Lake), a reconstruction was possible of the Suwałki Lakeland landscape at the end of the Pleistocene. It is already possible to say now that only some and the highest areas and glacial features have been emerged form waters, covering the Suwałki Lakeland and the Augustów Plain in that time.

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CZWARTORZĘD POJEZIERZA SUWALSKIEGO I JEGO PODŁOŻE W ŚWIETLE NOWYCH DANYCH

Streszczenie

Na podstawie analizy i badań profili 40 otworów wiertniczych, wykonanych w ostatnim dziesięcioleciu na Pojezierzu Suwalskim, przedstawiono nowe dane dotyczące budowy geologicznej i ukształtowania powierzchni podczwartorzędowej oraz stratygrafii utworów plejstoceńskich. W podłożu czwartorzędu oprócz osadów kredy górnej — mastrychtu i paleocenu dolnego — w otworze Żubrynek stwierdzono utwory eocenu górnego, poziom *Turborotalia cerroazulensis*, o miąższości 7,7 m. Powierzchnia podłoża podczwartorzędowego Pojezierza Suwalskiego różnicuje się na dwa regiony morfostrukturalne: płaskowyż oraz towarzyszące mu obniżenie, rozdzielone dość stromą krawędzią o wysokości około 35 m pochodzenia tektoniczno-erozyjnego.

Na Pojezierzu Suwalskim występuje 7—8 poziomów glacjalnych reprezentujących zlodowacenie południowopolskie (Wilgi), środkowopolskie (Odry) i północnopolskie (Wisły). Nadal nie ma podstaw stratygraficznych, aby wyróżnić tu utwory zlodowaceń starszych od zlodowacenia południowopolskiego (Wilgi), stwierdzono natomiast osady organiczne interglacjału mazowieckiego (holsztyńskiego) i eemskiego.

W artykule przedstawiono także w ogólnych zarysach okres nasunięcia się lądolodu zlodowacenia północnopolskiego (Wisły) i jego deglacjację.

Анджей БЕР

ЧЕТВЕРТИЧНЫЙ ПЕРИОД СУВАЛЬСКОГО ОЗЕРНОГО КРАЯ И ЕГО ОСНОВАНИЕ В СВЕТЕ НОВЫХ ДАННЫХ

Резюме

На основании анализа и исследований разрезов 40 буровых скважин пробуренных за последнее десятилетие в Сувальском озерном крае, в статье представленны новые данные касающиеся геологического строения и конфигурации подчетвертичной поверхности, а также стратиграфии плейстоценовых отложений. В основании четвертичных отложений, кроме осадков верхнего мела — мастрихта и нижнего палеоцена — в скважине Жубринок были обнаружены осадки верхнего эоцена, зона *Turborotalia cerroazulensis*, мощностью 7,7 м. Поверхность отложений подчетвертичного основания Сувальского озерного края расчленена на два морфоструктурных района — плато и сопутствующее ему понижение — разделенные довольно крутой гранью высотой около 35 м, тектонически-эрозионного происхождения.

На территории Сувальского озерного края находится 7—8 гляциальных горизонтов представляющих осадки оледенений: южнопольского

(Вильги), центральнопольского (Одера) и севернопольского (Вислы). В дальнейшем нет стратиграфического основания для выделения на исследованной территории отложений старше южнопольского оледенения (Вильги). Обнаружено зато нахождение органических осадков мазовецкого межледниковья (хольштынского) и эемского. Представлен также период надвига континентального ледника севернопольского оледенения (Вислы) и период отступания ледника.