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# Stratigraphy of the Younger Pleistocene in the Dolne Powiśle and the Elbląg Elevation based on mapping and boreholes*

Mapping carried through in the Dolne Powiśle and its vicinity during the last 20 years resulted in preparation of sheets of the *Geological map of Poland*, scale 1:200 000 and of 26 sheets of the *Detailed geological map of Poland* scale 1:50 000. These maps were completed with 60 boreholes that reached the Quaternary substrate. The whole work enabled to present stratigraphy of the Younger Pleistocene sediments. Well developed and widespred sediments of the Eemian Interglacial were distinguished, overlain with post-Eemian complex of terrestrial and marine sediments of the Toruń and Vistula glaciations, separated with deposits of the Krastudy Interglacial.

## INTRODUCTION

During the last twenty years the Dolne Powiśle was mapped by the staff of the State Geological Institute. These works have been done at first in the Institute itself, but then in cooperation or through coordination of works of the Geological Enterprise from Warsaw and its representative from Gdańsk. The first phase of these works, including mapping of the Vistula Valley with larger or smaller fragments of embracing plateaux, has been finished lately what enables preliminary recapitulation of results.

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* This report was presented on September 2, 1991, in Sopot at the conference „Last Glaciation in the Dolne Powiśle and eastern seaside of Poland", organized by the Committee for Quaternary Research and the Committee for Sea Research, Polish Academy of Sciences. But a lecture, field exposures at Kadyny, Próchnik, Gniewskie Młyny, Gniew and borehole core Pagórki (with W. Rabek) were presented.

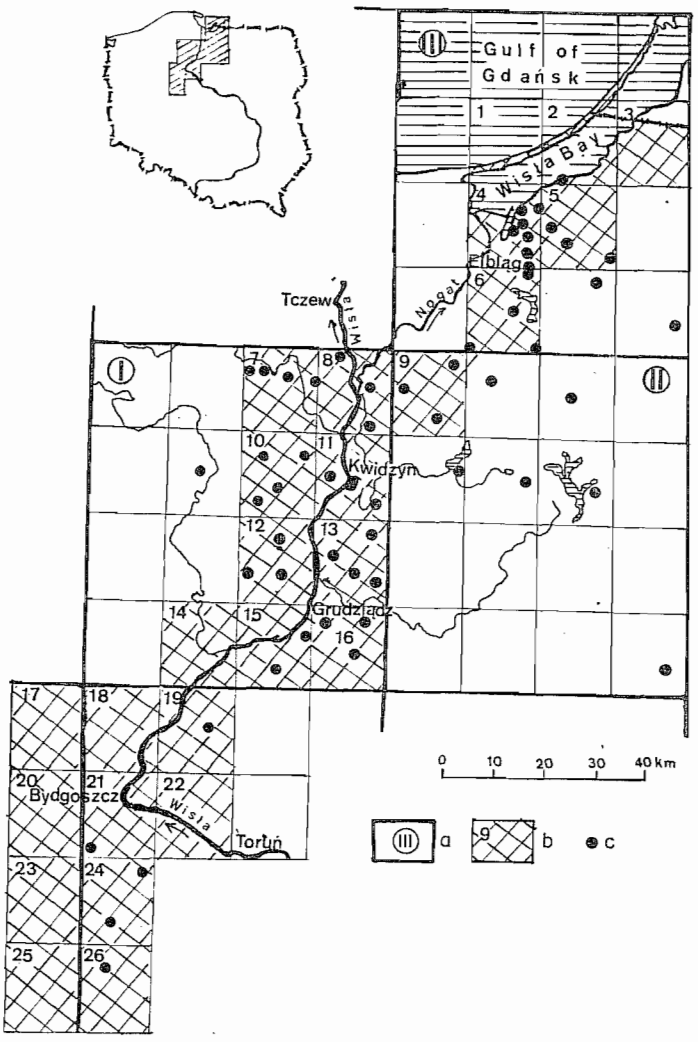


Fig. 1. Location of mapping works in Dolne Powiśle and neighbouring areas (realized by the present authoress and the authors from Geological Enterprise from Warsaw and Gdańsk)

a. *Geological map of Poland* in scale 1:200 000, sheets: I — Grudziądz (A. Makowska, 1972, 1973*a*), II — Iława (A. Makowska, 1976, 1980*a*), III — Elbląg (A. Makowska, 1977*a*, 1979*a*)

b. *Detailed geological map of Poland* in scale 1:50 000 (coordination by A. Makowska, 1977–1991), sheets: 1 — Krynica Morska (A. Makowska, *1987b*, 1991*b*), 2 — Frombork (W. Rabek, in press *b*), 3 — Braniewo (W. Rabek, in press *c*), 4 — Elbląg Północ (A. Makowska, 1987*a*, 1991*a*), 5 — Młynary (W. Rabek, in preparation), 6 — Elbląg Południe (A. Makowska, in preparation), 7 — Starogard Gdański (W. Rabek, 1984, 1987), 8 — Gniew (K. Wrotek, 1983, 1986*a*), 9 — Sztum (W. Rabek, 1986, in press *a*), 10 — Skórcz (H. Listkowska, 1982, 1985), 11 — Kwidzyn (M. Kozłowska, I. Kozłowski, 1981, 1985*a*), 12 — Nowe (H. Listkowska, 1980, 1981), 13 — Gardeja (I. Kozłowski, K. Wrotek, 1980, 1981), 14 — Chełmno (N. Butrymowicz, 1980, 1981), 15 — Grudziądz-Rudnik (S. Maksiak, 1981, 1983), 16 — Grudziądz (M. Uniejewska, 1980; M. Uniejewska, M. Nosek, 1982), 17 — Koronowo (H. Listkowska, 1985, 1988), 18 —

## MAPPING

The mapping comprised at first preparation of the *Geological map of Poland*, scale 1:200 000 and then, after it had been already finished, of the *Detailed geological map of Poland*, scale 1:50 000. Further in this paper, these maps are named shortly the general and the detailed maps respectively.

Geological maps in scale of 1:200 000 cover the sheets Grudziądz, Iława and Elbląg. Their total area is equal about 12 000 km$^2$. The works were done in 1969–1977 by A. Makowska, in the final phase with partial cooperation with the Geological Enterprise from Warsaw (A. Makowska, 1972, 1973*a*, 1976, 1977*a*, 1979*a*, 1980*a*). After the maps in scale of 1:200 000 had been finished, preparation of the *Detailed geological map of Poland* in scale of 1:50 000 was undertaken. It comprised firstly the Lower Vistula Valley, fragments of surrounding morainic elevations Eastern Vistula Delta and Western Elbląg Elevation. Then other areas were mapped: Kujawy in the south, Eastern Elbląg Elevation and Warmia Lowland in the north. In these works staff of the Geological Enterprise from Warsaw and Gdańsk also participated. The whole work was coordinated by A. Makowska (Fig. 1).

Twenty six sheets of the *Detailed geological map of Poland* in scale of 1:50 000 have been prepared until 1990 for the Dolne Powiśle, Kujawy, Elbląg Elevation and

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Żołędowo (M. Kozłowska, I. Kozłowski, 1985*b*, 1990), 19 — Unisław (M. Kozłowska, I. Kozłowski, 1986, in press *a*), 20 — Bydgoszcz Zachód (N. Butrymowicz, in preparation), 21 — Bydgoszcz Wschód (M. Kozłowska, I. Kozłowski, in press *b*), 22 — Rzęczkowo (K. Wrotek, 1986*b*, 1990), 23 — Łabiszyn (M. Uniejewska, M. Nosek, 1988, in press *a*), 24 — Złotniki Kujawskie (K. Wrotek, in press), 25 — Gąsawa (M. Uniejewska, M. Nosek, 1989, in press *b*), 26 — Pakość (H. Listkowska, in press)

c. Documentary boreholes to the *Geological map of Poland* in scale 1:200 000 and to *Detailed geological map of Poland* in scale 1:50 000

Skorowidz prac kartograficznych na Dolnym Powiślu i w obszarach sąsiednich (wykonywanych przez autorkę artykułu i autorów z Przedsiębiorstwa Geologicznego z Warszawy i Gdańska)

a. *Mapa geologiczna Polski* w skali 1:200 000, arkusze: I — Grudziądz (A. Makowska, 1972, 1973*a*), II — Iława (A. Makowska, 1976, 1980*a*), III — Elbląg (A. Makowska, 1977*a*, 1979*a*)

b. *Szczegółowa mapa geologiczna Polski* w skali 1:50 000 (koordynacja prac A. Makowska, 1977–1991), arkusze: 1 — Krynica Morska (A. Makowska, 1987*b*, 1991*b*), 2 — Frombork (W. Rabek, w druku *b*); 3 — Braniewo (W. Rabek, w druku *c*), 4 — Elbląg Północ (A. Makowska, 1987*a*, 1991*a*), 5 — Młynary (W. Rabek, w opracowaniu), 6 — Elbląg Południe (A. Makowska, w opracowaniu), 7 — Starogard Gdański (W. Rabek, 1984, 1987), 8 — Gniew (K. Wrotek, 1983, 1986*a*), 9 — Sztum (W. Rabek, 1986, w druku *a* ), 10 — Skórcz (H. Listkowska, 1982, 1985), 11 — Kwidzyn (M. Kozłowska, I. Kozłowski, 1981, 1985*a*), 12 — Nowe (H. Listkowska, 1980, 1981), 13 — Gardeja (I. Kozłowski, K. Wrotek, 1980, 1981), 14 — Chełmno (N. Butrymowicz, 1980, 1981), 15 — Grudziądz-Rudnik (S. Maksiak, 1981, 1983), 16 — Grudziądz (M. Uniejewska, 1980; M. Uniejewska, M. Nosek, 1982), 17 — Koronowo (H. Listkowska, 1985, 1988), 18 — Żołędowo (M. Kozłowska, I. Kozłowski, 1985*b*, 1990), 19 — Unisław (M. Kozłowska, I. Kozłowski, 1986, w druku *a*), 20 — Bydgoszcz Zachód (N. Butrymowicz, w przygotowaniu), 21 — Bydgoszcz Wschód (M. Kozłowska, I. Kozłowski, w druku *b*), 22 — Rzęczkowo (K. Wrotek, 1986*b*, 1990), 23 — Łabiszyn (M. Uniejewska, M. Nosek, 1988, w druku *a*), 24 — Złotniki Kujawskie (K. Wrotek, w druku), 25 — Gąsawa (M. Uniejewska, M. Nosek, 1989, w druku *b*), 26 — Pakość (H. Listkowska, w druku).

c. Dokumentacyjne otwory wiertnicze dla *Mapy geologicznej Polski* w skali 1:200 000 i *Szczegółowej mapy geologicznej Polski* w skali 1:50 000

Warmia Lowland. Among them, 18 sheets were already published, the others are in print or are prepared to print.

During mapping for needs of general and detailed maps in the study area, documentary full-cored boreholes were done. Almost all of them went through the whole Quaternary complex and reached its substrate. These boreholes were of principal significance for Quaternary and for Tertiary or Cretaceous sediments that directly underlie the Quaternary sequence. In most cases they record a new geological and stratigraphical setting. Among others the boreholes Bągart, Mniszek, Nowiny, Krastudy and lately Pęklewo and Pagórki are to be mentioned (A. Makowska, 1970, 1977*b*, 1986*a, b*, 1991*c*; A. Makowska, W. Rabek, 1990).

In the studied area 60 boreholes were done (Fig. 1), among which 24 were elaborated by the authoress during documentation works foı general and detailed maps. The other ones were described by the Geological Enterprise during realization of detailed maps. Chosen fragments of boreholes were subjected to laboratory analyses, namely petrographical, lithological, palaeobotanical and micropalaeobotanical ones, in agreement with the *Instrukcja...* (1977). These works were done in varying scope, dependent on technical, organization and financial possibilities. They were carried through by a staff team from the State Geological Institute and the Geological Enterprise from Warsaw and Gdańsk. In single sites radiocarbon and thermoluminescence datings were also done.

Numerous geological sections formed an important element in preperation of maps. These sections put together and analyzed archival borehole data. Already during preparation of the general maps, the studied area was dissected with about 200 geological sections that comprised about 6000 archival boreholes. Analysis of these boreholes on the basis of the authoress's own documentary boreholes, enabled to present the first stratigraphical schemes of the Quaternary in the studied area. These schemes were to considerable degree correct until the end of mapping works, although they were gradually verifield and could be more detailed when hundreds of new boreholes and tens of sections prepared during realization of detailed maps were reconsidered.

## PUBLICATIONS PUBLISHED IN PARALLEL WITH FIELD MAPPING

The mapping was accompanied by separate works that dealt with different Quaternary subjects. Some of them played a principal cognitive role and considerably influenced picture of geological structure and stratigraphy of Quaternary sediments presented on geological maps. They were published during preparation of maps (A. Makowska, 1970, 1973*b*, 1977*b*, 1979*b*, 1980*b*, 1982, 1986*a, b*, 1990, 1991*c*; A. Makowska, W. Rabek, 1990; B.J. Nowak, W. Rabek, 1987). The most important is the paper on the Eemian Interglacial in the Dolne Powiśle (A. Makowska, 1979*b*), initiated already before preparation of the general maps. It has been continued together with preparation of the sheet Grudziądz of the *Geological map of Poland*, and its results were for the first time presented on this map (A. Makowska, 1972, 1973*a*). Eemian sediments documented in this paper formed a key stratigraphical horizon in the Dolne

Powiśle. It separated sediments of the older Pleistocene from the younger – post-Eemian series. This principal subdivision of the Pleistocene is now visible on general and detailed geological maps.

All geological works carried through in the studied area by other research teams have been taken into account during preparation of maps (a.o. E. Drozdowski, 1974, 1979, 1980, 1986; E. Drozdowski, K. Tobolski, 1972; A. Olszewski, 1974).

## STRATIGRAPHICAL TERMINOLOGY ON MAPS AND IN PUBLICATIONS OF THE LAST YEARS

Stratigraphical terminology on general and detailed maps has been in every case adapted to the applied instruction, obligatory in the territory of the whole country. Stratigraphical names took into account opinions on subdivision of the Quaternary, accepted in Polish bibliography at the time when the instruction were published. The instruction to the *Geological map of Poland* scale 1:200 000, was published in 1973. Stratigraphical subdivision of the Quaternary, proposed in this instruction, was obligatory for all the maps in this scale until the last map of this series was prepared. The instruction to the *Detailed geological map of Poland* was published in 1977. Subdivision of the Young Pleistocene and the whole Quaternary was more detailed in this instruction, although similar to the one used on maps in scale of 1:200 000. It was obligatory until 1991 when the instruction was amended: a.o. with new stratigraphical subdivision of the Quaternary (M.D. Baraniecka, 1990) that is to be used in the next years *(Instrukcja...,* 1991*)*.

The whole Polish, stabile stratigraphical subdivision of the Quaternary in both instructions has not corresponded obviously many a time with local subdivisions, occasionally considerably reworked as the studies progressed. Such situation was common in case of the Dolne Powiśle. For this reason after proper setting of Eemian sediments was fixed, only a general lithostratigraphical subdivision on maps was possible. On the other hand, stratigraphical terminology based on the instructions is already out-of-date. Correlation of this terminology with the one in last publications of the authoress is therefore presented (Table 1).

## PRINCIPLES OF STRATIGRAPHIC SUBDIVISION OF THE YOUNGER PLEISTOCENE SEDIMENTS

It is to be underlined that stratigraphical subdivision of the Pleistocene in the Dolne Powiśle and the Elbląg Elevation is concordant and uniform on all the maps. Simplified stratigraphical scheme of the Younger Pleistocene, supplemented with results of last investigations is presented (Fig. 2; A. Makowska, 1986*a*).

Subdivision of the Pleistocene is based on a key horizon, represented by sediments of the Eemian Interglacial. They spread in vast area from the Toruń Basin to the Vistula Bay (Fig. 3) and separate sediments of the Older Pleistocene from younger i.e.

**Correlation of stratygraphic terminology Powiśle and the Elbląg Elevation based**

| *Geological map of Poland*, scale 1:200 000 [1] | | | | | *Detailed geological map of Poland*, scale 1:50 000 [2] | | |
|---|---|---|---|---|---|---|---|
| Sheet Grudziądz (A. Makowska1972, 1973*a*) | | | Sheets: Iława, Elbląg (A. Makowska 1976, 1977, 1979*a*, 1980*a*) | | Sheets located in key figure (Fig. 1) | | |
| North-Polish Glaciation | Main Stadial | Younger Dryas | Main Stadial | | North-Polish Glaciation | Main Stadial | Younger Dryas – Bölling |
| | | Older Dryas | | | | | |
| | | Pomeranian Phase | | Pomeranian Phase | | | Pomeranian Phase |
| | | Poznań Phase | | Poznań Phase | | | Poznań Phase |
| | | | | | | | Pre–Poznań Interphase |
| | | Leszno Phase | 2 glacial series | | | | Leszno (Świecie) Phase |
| | Hrubieszów Interstadial | | | | | Hrubieszów (Gniew) Interstadial | |
| | Sandomierz (Szczecin) Stadial | | | | | Sandomierz Stadial | |
| Eemian Interglacial | | | | | Eemian Interglacial | | |

[1] *Instrukcja...* ( 1973 )

[2] *Instrukcja...* (1977 )

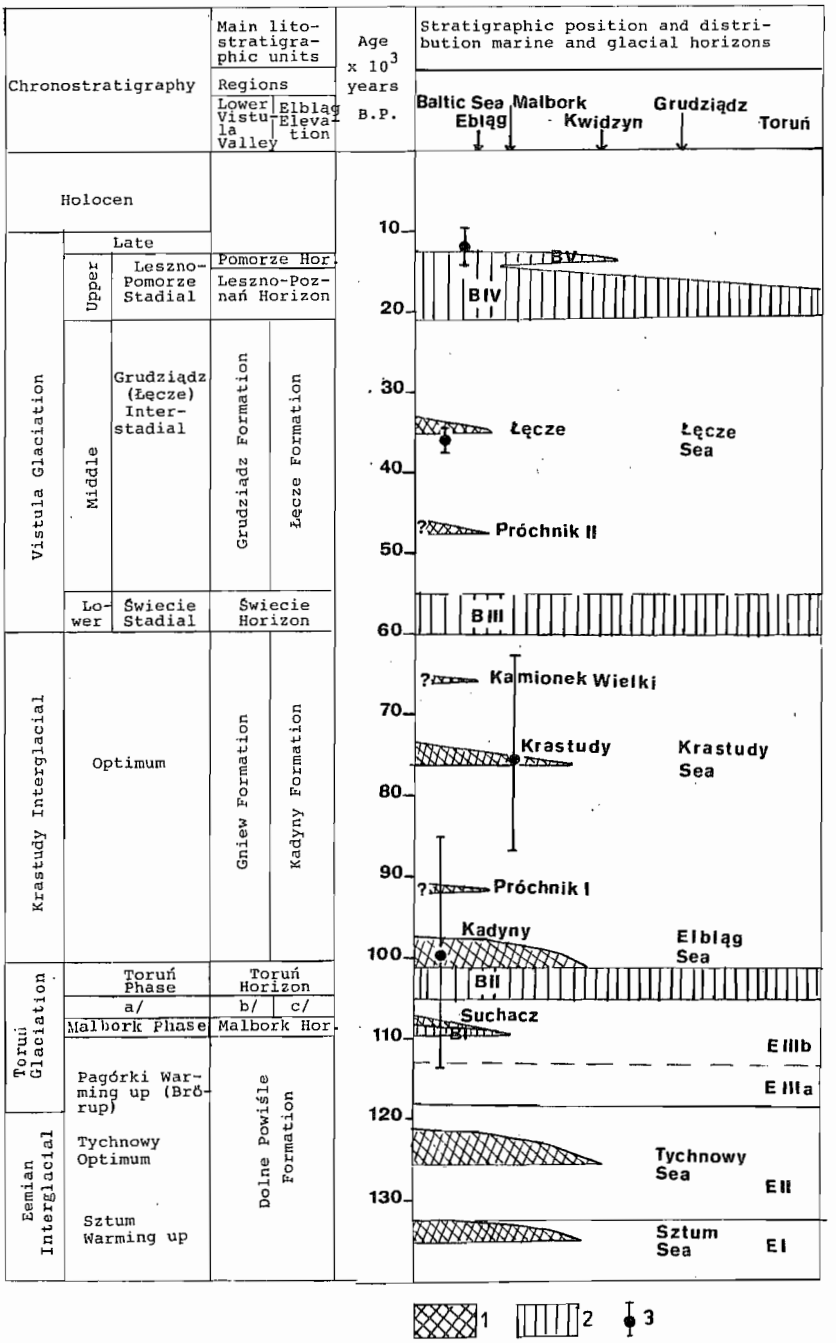
post-Eemian deposits. The latter have been previously correlated with the Vistula Glaciation but at present — with two glaciations, separated with an interglacial (Table 1). Location and occurrence of Eemian deposits was examined at the turn of

Table 1

**of the Younger Pleistocene deposits in the Dolne on mapping and authoress publications**

| A. Makowska | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1973*b* (tills) | | 1980*b* | | | 1986*b*, 1990, 1991*c* | | | | |
| North-Polish Glaciation | | Vistula Glaciation (Vistulian) | Younger Stadial | | Vistula Glaciation (Vistulian) | Late? | Younger Dryas<br>Alleröd<br>Older Dryas<br>Bölling<br>Oldest Dryas | | |
| | BV | | | Poznań-Leszno Substadial | | Upper | Leszno-Pomeranian Stadial | | Pomeranian Phase |
| | BIV | | | | | | | | Poznań Phase<br>Leszno Phase |
| | | | | Grudziądz Subinterstadial | | Middle | Grudziądz (Łęcze) Interstadial | Łęcze Interstadial<br>Stadial?<br>Próchnik?<br>Interstadial | |
| | BIII | | | Świecie Substadial | | Lower | Świecie Stadial | | |
| | | | Gniew Interstadial | | Krastudy Interglacial | | | | |
| | BII<br>BI | | Older Stadial | Toruń Phase<br>Knibawa Interphase<br>Malbork Phase | Toruń Glaciation (Torunian) | | Toruń Phase<br>Kibawa Interphase<br>Malbork Phase | | Pagórki Warming (Brörup)<br>Cooling |
| Eemian Interglacial | | | | | Eemian Interglacial | | | | Tychnowy Optimum<br>Cooling<br>Sztum Warming |

the sixties and the seventies (A. Makowska, 1979*b*). The studies were carried through parallel with preparation of the sheet Grudziądz of the *Geological map of Poland* in scale of 1:200 000. Their results could be presented therefore for the first time on


Chronostratigraphy
Main litostratigraphic units
Regions
Lower Vistula Valley
Elbląg Elevation
Age x 10³ years B.P.
Stratigraphic position and distribution marine and glacial horizons
Baltic Sea
Elbląg
Malbork
Kwidzyn
Grudziądz
Toruń
Holocen
Late
Vistula Glaciation
Upper
Leszno-Pomorze Stadial
Pomorze Hor.
Leszno-Poznań Horizon
BV
BIV
Middle
Grudziądz (Łęcze) Interstadial
Grudziądz Formation
Łęcze Formation
Łęcze
Łęcze Sea
Próchnik II
Lower
Świecie Stadial
Świecie Horizon
BIII
Krastudy Interglacial
Optimum
Gniew Formation
Kadyny Formation
Kamionek Wielki
Krastudy
Krastudy Sea
Próchnik I
Kadyny
Elbląg Sea
Toruń Glaciation
Toruń Phase
Toruń Horizon
a/
b/
c/
Malbork Phase
Malbork Hor.
BII
Suchacz
BI
EIIIb
EIIIa
Eemian Interglacial
Pagórki Warming up (Brörup)
Tychnowy Optimum
Sztum Warming up
Dolne Powiśle Formation
Tychnowy Sea
EII
Sztum Sea
EI
10
20
30
40
50
60
70
80
90
100
110
120
130
1
2
3

this map (A. Makowska, 1972, 1973*a*, Fig. 3). The Eemian sediments studied recently are in lower hypsometrical and stratigraphical, or at least stratigraphical setting if related to their position presented in earlier publications (R. Galon, 1934; B. Halicki, 1951; Z. Kotański, 1956). In this way the lowermost till bed (locally underlain with an extra till) was added to the post-Eemian complex. This till has been considered previously to be of the Middle Polish Glaciation age (A. Makowska, 1977*b*).

Subdivision of the post-Eemian complex is based firstly on lithostratigraphy. This complex is very thick in the Dolne Powiśle (locally over 100 m), much more than in other parts of Poland. It comprises five tills, separated with four intermorainic series (Fig. 2). Tills were determined by the authoress with symbols BI-V (A. Makowska, 1973*b*, Table 1). They occupy varying areas in the Dolne Powiśle. Two middle tills (BIII and BIV) are known from the whole area. The third till (BII) fills mainly the post-Eemian depressions and spreads in northeastern and central part of the area, reaching the Toruń Basin in the south (Fig. 3). The other tills: the lowest BI and the uppermost BV, form individual beds only in the northern part of the region. Tills are separated with intermorainic series of varying thickness and lithology. They are not the same in the Dolne Powiśle and in the Elbląg Elevation. In the latter area they are glaciotectonicly deformed. Intermorainic series developed during different ice-free phases, comprise periglacial and extraglacial, but also interstadial or even interglacial sediments. They are composed exclusively of terrestrial sediments in the south and they contain marine sediments in the north. Two series that separate the three middle tills i.e. the lower between the tills BII and BIII, and the upper between the tills BIII and BIV, are of primary significance. They were named the formations: the lower one — the Gniew Formation in the Dolne Powiśle and the Kadyny Formation in the Elbląg Elevation, the upper — the Grudziądz Formation and the Łęcze Formation respectively (Fig. 2). The lowest and the uppermost intermorainic series that separate the tills BI and BII, BIV and BV, are of secondary significance and occur only locally in the north. The lowest intermorainic series is known as the from Knibawa Beds and as the Suchacz Formation. The uppermost series, being discontinuous, has not been well recognized yet.

The described general lithostratigraphical subdivision was for needs of detailed maps in many places documented with lithological-sedimentological analyses, and in single cases — with radiocarbon and thermoluminescence datings. Number of the latter is however insufficient and should be in future considerably extented in mapping works.

Fig. 2. Chronostratigraphy of marine and glacial horizons of the Younger Pleistocene in Dolne Powiśle
1 — marine horizons; 2 — tills; 3 — TL datings of marine and lake sediments; EI, EII, EIIIa,b — valley series; horizon of tills: BI, BII — Toruń Glaciation, BIII, BIV, BV — Vistula Glaciation; a — Knibawa Interphase, b — Knibawa Beds, c — Suchacz Formation

Chronostratygrafia poziomów morskich i glacjalnych młodszego plejstocenu na Dolnym Powiślu
1 — poziomy morskie; 2 — poziomy glin zwałowych; 3 — datowania osadów morskich i jeziornych metodą TL; EI, EII, EIIIa,b — serie dolinne; poziomy glin zwałowych: BI, BII — zlodowacenia toruńskiego, BIII, BIV, BV — zlodowacenia Wisły; a — interfaza Knibawy, b — warstwy z Knibawy, c — formacja z Suchacza

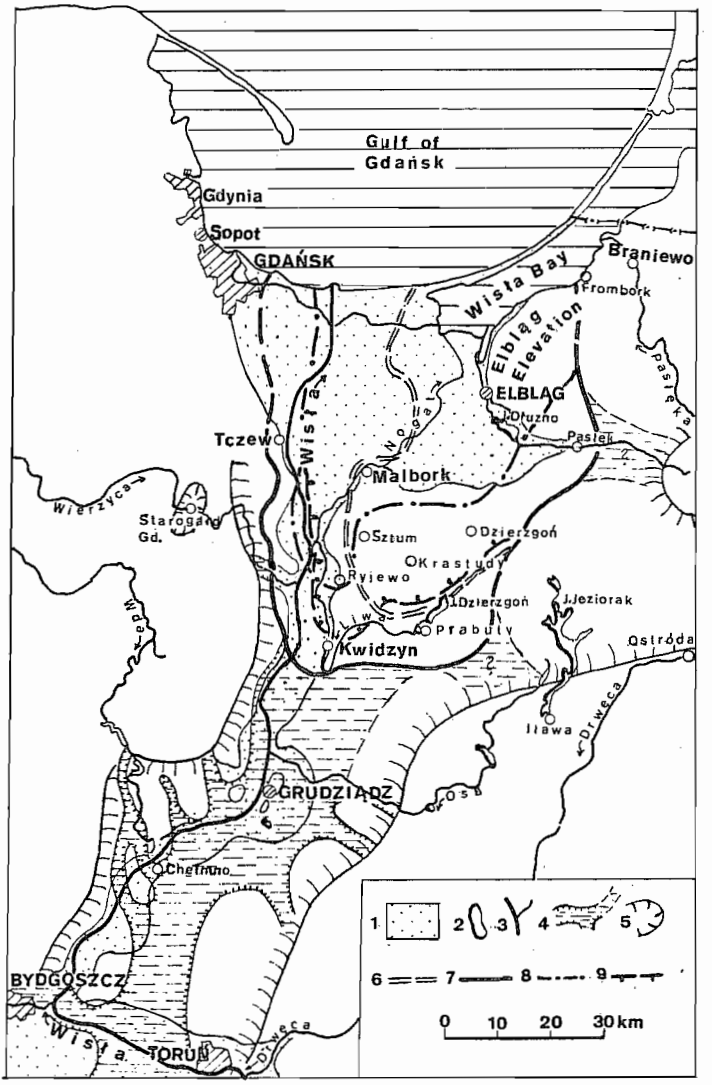



Fig. 3. Extents of Pleistocene seas, till of the Toruń Glaciation and river valleys of the Eemian Interglacial in Dolne Powiśle

1 — Vistula valley and delta; 2 — lakes; 3 — rivers; 4 — fluvial valleys of the Eemian Interglacial; 5 — extent of till of the Toruń Glaciation (BII); extents of Pleistocene seas: 6 — Sztum, 7 — Tychnowy; presumable extets of the seas: 8 — Elbląg, 9 — Krastudy

Zasięgi mórz plejstoceńskich, gliny zwałowej zlodowacenia toruńskiego oraz dolin rzecznych interglacjału eemskiego na Dolnym Powiślu

1 — dolina i delta Wisły; 2 — jeziora; 3 — rzeki; 4 — doliny rzeczne interglacjału eemskiego; 5 — zasięg gliny zwałowej zlodowacenia toruńskiego (BII); zasięgi mórz plejstoceńskich: 6 — sztumskiego, 7 — tychnowskiego; przypuszczalne zasięgi mórz: 8 — elbląskiego, 9 — krastudzkiego

The post-Eemian sediments have been primarily entirely included into the Vistula Glaciation (Vistulian, North-Polish Glaciation; Table 1; A. Makowska, 1980*b*). Basing on studies of marine sediments in the northern part of the area, their age has been ascribed to two glaciations (Table 1; A. Makowska, 1986*b*). These two glaciations were separated with an interglacial, during which the Dolne Powiśle was subjected to several sea transgressions. In the Younger Pleistocene four main intervals were therefore distinguished: the Eemian Interglacial, the Toruń Glaciation, the Krastudy Interglacial and the Vistula Glaciation (Fig. 2).

A boundary between the Eemian Interglacial and the Toruń Glaciation is defined by palynological analyses (Z. Janczyk-Kopikowa, 1991; A. Makowska, 1991*c*) but boundaries between other units are based on lithology.

## STRATIGRAPHY OF THE YOUNGER PLEISTOCENE SEDIMENTS ON GEOLOGICAL MAPS AND SECTIONS OF DOCUMENTARY BOREHOLES

### EEMIAN INTERGLACIAL

A series with the Eemian Interglacial sediments was named the Lower Vistula Formation (A. Makowska, 1986*b*). It spreads from south northwards, from the Toruń Basin to the Vistula Bay (Fig. 3), what is proved on the all geological maps, either in scale of 1:200 000 or 1:50 000. Sediments of this formation occur beneath a bottom of the Vistula Valley and almost do not outcrop in any place. For this reason they are indicated mainly in geological (see Figs 4–7) or synthetical sections enclosed to the maps. The Lower Vistula Formation is from about 30 m thick in the south (terrestrial sediments) to about 157 m in the north (terrestrial and marine sediments). Terrestrial sediments mainly fill a valley pattern from Solec Kujawski to Kwidzyn. To the north of the latter they separate and cover marine beds. Three main series were distinguished in river valleys (A. Makowska, 1977*b*, 1979*b*): lower (EI), middle (EII) and upper (EIII), composed of fluvial channel and overflood deposits, lake and ice-dam deposits that cap valley deposition. In the north there are two horizons of marine sediments, Sztum and Tychnowy ones, separated and covered with fluvial and fluvial-deltaic sediments. Expertises and pollen analyses (Z. Janczyk-Kopikowa, 1970, 1976, 1991) indicate that the middle valley series and the Tychnowy marine horizon form an interglacial series *sensu stricto*. Three pollen diagrams i.e. Mniszek (E. Drozdowski, K. Tobolski, 1972), Nowiny and Pagórki, were elaborated for the Lower Vistula region and the Elbląg Elevation. The most significant role is played by the diagram from Pagórki that recorded a.o. the upper palynological boundary of the Eemian Interglacial and the first distinct post-optimal warming (named the Pagórki warming), correlated by Z. Janczyk-Kopikowa (1991) with the Amersfoort-Brörup Interstadial.

The upper part of the interglacial is defined in top of lake sediments, deposited after retreat of the Tychnowy sea. This boundary forms in the same time the lower limit of the Toruń Glaciation and the Amersfoort-Brörup Interstadial belongs already to this glaciation. This interstadial has been already earlier suggested as the so-called

Mniszek Warming, in a single sample from Mniszek (E. Drozdowski, K. Tobolski, 1972) and in many other sections due to bipartity of organic sediments (A. Makowska, 1979*b*). Now, for the first time its full palynological documentation is known, what gives to the diagram from Pagórki and to the whole section the significant documentary role, not only for the Dolne Powiśle (A. Makowska, 1991*c*).

## TORUŃ GLACIATION

Beginning of this glaciation is indicated by deposition of fluvial sediments in top of the 2nd valley series in the terrestrial zone, and by filling a depression left by the Tychnowy Sea and remaining lakes in the marine zone. During the Pagórki Warming, a short renewal of lake reservoirs is noted in the whole area; afterwards they are gradually overgrown with vegetation.

Greater cooling is indicated by deposition of the 3rd valley series in fluvial valleys and of deltaic fans in area of ancient interglacial seas. As a glacier comes closer, runoff is dammed and deposition of ice-dam sediments in valleys occurs. Such phenomena indicated the first glaciation episode, named the Malbork Phase (A. Makowska, 1979*b*). The largest depression left by the Eemian seas in the present Vistula Delta and not filled with deltaic deposits, was flooded with water, into which the first ice sheet advanced. After ice sheet retreated, the depression was shortly occupied by a cool sea, sediments of which were examined at Suchacz (sheet Elbląg Północ, Fig. 2).

During the next phase, the ice sheet occupied almost the whole Dolne Powiśle and advanced as far as the Toruń Basin. This episode is indicated by the Toruń till (BII), present in northern and central part of the area, spreading along the ancient Eemian valleys to Toruń. The till is marked on all general and detailed geological maps, as well as on enclosed geological sections (Figs 4–7). On land surface this till is exposed only in single sites along the Vistula Valley and near Elbląg, but it occurs generally beneath a bottom of the Vistula. On the other hand, is was noted in most documentary boreholes along the Vistula Valley and its vicinity. The western till limit was quite precisely defined on geological maps. It runs along and not far from the Vistula Valley (Fig. 3). Also the eastern limit is not far from the Vistula Valley. Extent of the till proves that ice sheet advance during the Toruń Glaciation in the Dolne Powiśle was strictly dependent on the post-Eemian depressions.

It should be explained and underlain on this occasion that the Toruń Glaciation cannot be correlated with the so-called Kaszuby Stadial, set according to opinion J.E. Mojski (1985, 1991) between the Eemian Interglacial and the Konin Interstadial — correlated to the Brörup. Studies of pollen in the section Pagórki (Z. Janczyk-Kopikowa, 1991) indicated absence of reasonable evidence to distinguish this stadial (as a glacial stadial with till) in Poland (A. Makowska, 1991*c*).

Till of the Toruń Glaciation (till BII) cannot be either correlated to the so-called third glacial horizon, distinguished by E. Drozdowski. His last publications proved (E. Drozdowski, 1986, 1988) that the third horizon is to be connected with the his second glacial horizon, and with till of the horizon BIII in a stratigraphical scheme of the authoress (Fig. 2).

## KRASTUDY INTERGLACIAL

Sediments of the Krastudy Interglacial occur within the lower intramorainic formation (located between tills BII and BIII), named the Gniew Formation in the Dolne Powiśle and the Kadyny Formation in the Elbląg Elevation (Table 1, Fig. 2; A. Makowska, 1986*b*).

This formation contains terrestrial and marine sediments, similarly as the Eemian (Lower Vistulian) Formation. Marine sediments occur in the northern part of the area. The Gniew-Kadyny Formation seems to be equally well, although differently developed as the Lower Vistulian Formation. It has the same or locally greather thickness of about 60 m in the south to 139 m in the north, where it is however glaciodislocated.

The Gniew-Kadyny Formation contains, but interglacial series, also sediments of decline of the Toruń Glaciation and beginning of the Vistula Glaciation. Sediments from a final part of Toruń Glaciation are composed of silty-clayey ice-dam series in the terrestrial zone and of silts and clays in the marine zone. The latter were deposited in the Baltic Basin and are mainly the red clays, interbedded in varying proportions with grey clays or silts. These clays are typical for the Elbląg Elevation and have been known to many authors from exposures. They are indicated in more important localities on the sheet Elbląg Północ of the detailed map. Red clays are overlain with the marine Elbląg Clays, known also as the Yoldia Clays. They form the most significant marine horizon in the northern part of the area, studied for more than a hundred years in cliff exposures of the Vistula Bay. Many new outcrops of these sediments are presented on the sheet Elbląg Północ. The Elbląg Clays pass upwards into lake clays and silts, deposited in freshwater lakes formed due to regression of the Elbląg Sea. This episode was presumably connected with climatic warming. In the Gniew Formation on the Lower Vistula, ice-dam sediments are overlain with marine series that contains thermophilous marine fauna, known from the borehole Krastudy (A. Makowska, 1986*b*; B. Nowak, W. Rabek, 1987; W. Rabek, 1986). These sediments are presumably younger than the Elbląg series and were deposited during the climatic optimum (Fig. 2). The locality at Krastudy gave the name to the Krastudy Interglacial. In the Kadyny Formation there are, but the Elbląg Clays, also other younger marine beds defined as marine members from Próchnik I and Kamionek Wielki. Their outcrops are indicated on the sheet Elbląg Północ of the detailed map. Beside the marine series in this area, there are also numerous beds and sites with lake sediments that are younger than the Elbląg Clays. They prove the Kadyny Formation to be to a considerable degree formed within or at border of the Baltic Basin, bottom of which occasionally emerged and was subjected to terrestrial processes.

Studies of the Kadyny Formation has not been finished yet and can result in future in numerous information on evolution of a pre-Baltic sea during the Krastudy Interglacial. The Gniew Formation on the Lower Vistula is overlain by a thick sandy series, capped locally with ice-dam sediments. The sandy series contains sediments of varying origin, partly ice-dam — connected with lower part of the series composed of varved clays and silts, and partly glaciofluvial and fluvial — deposited during climatic optimum. Sediments of this formation are exposed at plateau edges to the east and west of the Vistula Valley. They are indicated on all general and detailed maps, from the

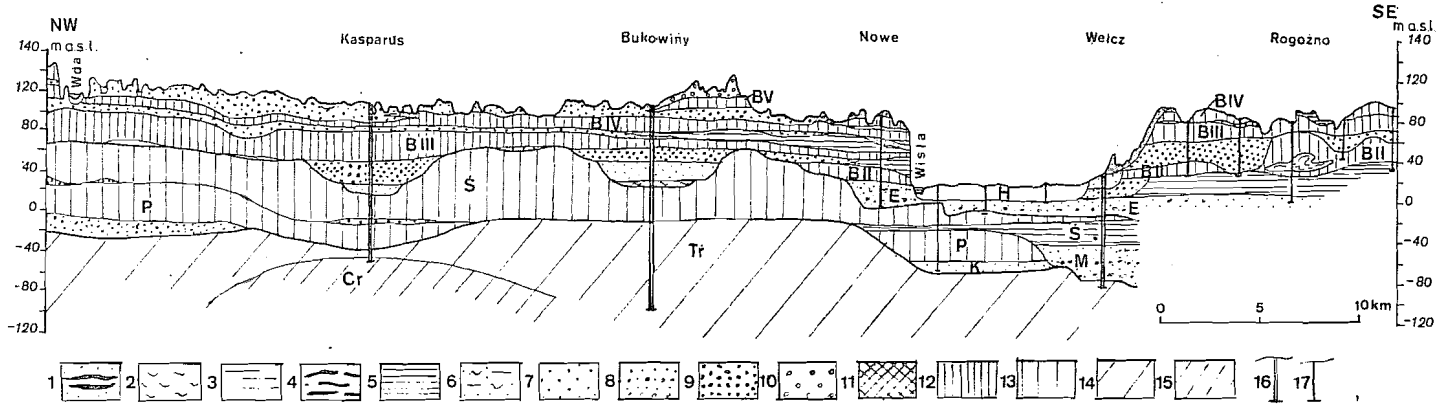



Fig. 4. Fragment of geological section to the sheet Grudziądz of the *Geological map of Poland* in scale 1:200 000 (A. Makowska, 1972)

1 — peats; 2 — silts; 3 — clays; 4 — red clays; 5 — varved clays and silts; 6 — clays, silts and sands; 7 — sands; 8 — sands with gravel interbeds; 9 — sands and gravels; 10 — sands, gravels and boulders; 11 — marine sediments; 12 — tills of the post-Eemian Pleistocene, 13 — tills of the pre-Eemian Pleistocene; 14 — Tertiary sediments; 15 — Cretaceous rocks; boreholes: 16 — documentary to geological maps, 17 — archival; Cr — Cretaceous; Tr — Tertiary; K — Cromer Interglacial; P — South Polish Glaciation; M — Mazovian Interglacial; S — Middle Polish Glaciation; E — Eemian Interglacial; BI–V tills of the post-Eemian Pleistocene; H — Holocene

Fragment przekroju geologicznego do arkusza Grudziądz *Mapy geologicznej Polski* w skali 1:200 000 (A. Makowska, 1972)

1 — torfy; 2 — mułki; 3 — iły; 4 — iły czerwone; 5 — iły i mułki warwowe; 6 — iły, mułki i piaski; 7 — piaski; 8 — piaski z przewarstwieniami żwirów; 9 — piaski i żwiry; 10 — piaski, żwiry i głazy; 11 — osady morskie; 12 — gliny zwałowe plejstocenu poeemskiego; 13 — gliny zwałowe plejstocenu starszego od eemu; 14 — osady trzeciorzędowe; 15 — osady kredy; otwory wiertnicze: 16 — dokumentacyjne dla map geologicznych, 17 — archiwalne; Cr — kreda; Tr — trzeciorzęd; K — interglacjał kromerski; P — zlodowacenie południowopolskie; M — interglacjał mazowiecki; S — zlodowacenie środkowopolskie; E — interglacjał eemski; BI – BV — poziomy glin zwałowych młodszego plejstocenu (poeemskie); H — holocen

Toruń Basin to the Nogat River. They form outcrops along the Vistula as well as its right and left tributaries, and are marked in geological sections enclosed to the maps (Figs 4–7). Sandy series that overlies the lower varved clays and silts on a map in scale of 1:200 000, has not been geneticly defined, but generally considered as glaciofluvial sediments, age of which was connected with age of the overlying till. On detailed maps a complex origin of this series was usually presented and it was referred to an interstadial.

## VISTULA GLACIATION

Ice sheet of the Vistula Glaciation occupied twice the described area, advancing considerably further to the south and then retreating every time completely to the north beyond the area. Advance and retreat intervals of each ice sheet were defined as Świecie and Leszno-Pomeranian stadials (Fig. 2, Table 1). Between the first and the second stadials the area was ice-free but no favourable conditions for landscape processes and deposition of sediments existed, as during the directly preceding Krastudy and Eemian interglacials. This fact is expressed by relatively thin and poor intramorainic sediments of the Grudziądz Formation on the Lower Vistula. Sediments of this formation are absent in many places, whereas tills overlie directly one another what is well visible in many geological sections enclosed to general and detailed maps, particulary in southern part of the area (Fig. 5). Similarly insignificant separation of these tills is also visible in the Elbląg Elevation (Fig. 7), although the intramorainic formation (Łęcze Formation) is slightly fuller and differently developed

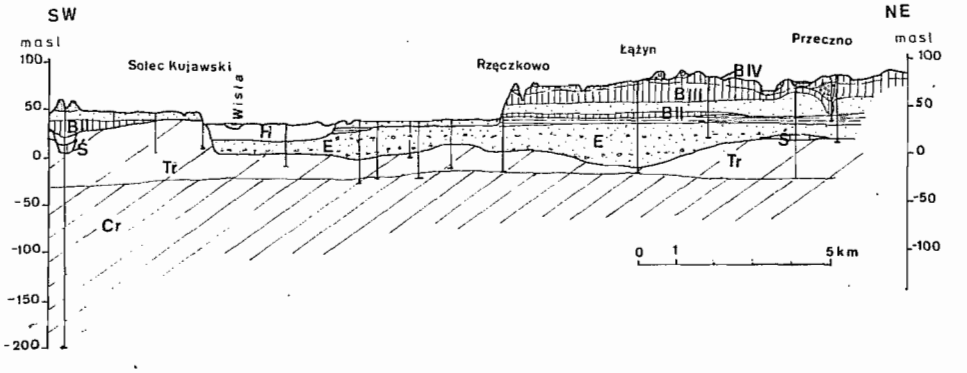



Fig. 5. Geological section to the sheet Rzęczkowo of the *Detailed geological map of Poland*, scale 1:50 000 (after K. Wrotek, 1986*b*)
Explanations — see Fig. 4

Przekrój geologiczny do arkusza Rzęczkowo *Szczegółowej mapy geologicznej Polski* 1:50 000 (według K. Wrotka, 1986*b*)
Objaśnienia jak na na fig. 4

than the Grudziądz Formation. In contains a.o. organic and marine sediments. Such sediments were found for the first time in the Elbląg Elevation, therefore the name Łęcze Interstadial was applied primarily for this interval (A. Makowska, 1986*b*). There are also premisses that suggest subdivision of this interval into more interstadials. For this reason, it seems reasonable to come back to the earlier name of the Grudziądz Interstadial (E. Drozdowski, 1980), being the superior name — eventually with the name of the Łęcze Interstadial in brackets (Table 1). In such case, there is still a possibility to introduce other names for new interstadials during this interval.

### ŚWIECIE STADIAL

This interval is most distinctly indicated by the till BIII (Fig. 2, Table 1). It occurs in the whole studied area, except deeper river valleys, and outsteps southwards — at least as far as Inowrocław and Mogilno (M. Uniejewska, M. Nosek, 1989; H. Listkowska, in press). To the south of Mogilno this till is usually absent.

A till is composed of various facies, studied by A. Olszewski (1974) along the Vistula Valley a.o. near Świecie where it was distinguished for the first time on the sheet Grudziądz, *Geological map of Poland* (A. Makowska, 1972). For this reason also the interval of till deposition was named the Świecie Stadial. The till is visible on all general and detailed geological maps, as well as in geological sections enclosed to these maps (Figs 4–7). It is also exposed in plateau edges on the Lower Vistula and in the Elbląg Elevation — in discontinuos outcrops at shore of the Vistula Bay and in deeply incised erosive cuts. It was also found in most documentary boreholes in this area.

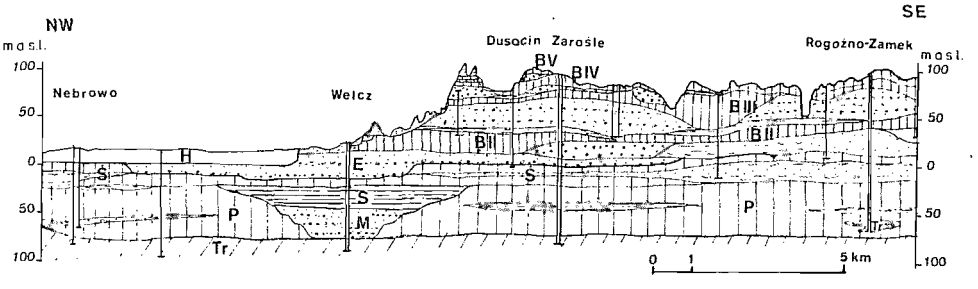



Fig. 6. Geological section to the sheet Gardeja of the *Detailed geological map of Poland* in scale 1:50 000 (after I. Kozłowski, K. Wrotek, 1980)
Explanations — see Fig. 4

Przekrój geologiczny do arkusza Gardeja *Szczegółowej mapy geologicznej Polski* 1:50 000 (według I. Kozłowskiego i K. Wrotka, 1980)
Objaśnienia jak na fig. 4

GRUDZIĄDZ (ŁĘCZE) INTERSTADIAL

Sediments of this age are thin and separate the tills BIII and BIV (Figs 2, 4, 6 and 7). They are located in the Lower Vistula valley and in the Elbląg Elevation and spread westwards and eastwards from these areas. Thickness of these sediments is varying, locally they are very thin or absent, especially in the south (Fig. 5), but generally thicken from south nortwards. They have varying composition. On the Lower Vistula these sediments were mainly deposited during deglaciation of the area, when ice sheet of the Świecie Stadial retreated. In the Grudziądz Elevation and in several exposures to the north from the Grudziądz Basin, the sediments were studied in detail by E. Drozdowski (1974, 1979, 1986). Results of these studies, accompanied with datings of sediments, enabled to distinguish this interval as the Grudziądz Interstadial. Beside deglaciation sediments, there are also vastly spreading extraglacial, ice-dam and glaciofluvial series of the Grudziądz Formation on the Lower Vistula. In the Elbląg Elevation (Fig. 7) sediments of the Grudziądz Interstadial (named here the Łęcze Interstadial — Table 1), are developed differently than on the Lower Vistula. These sediments come from warmer interval. They are of lake, fluvial and in single sites — of marine origin, and represent a proper interstadial or several interstadials. They were best recognized at Łęcze where amidst sandy fluvial or fluvio-deltaic series, marine beds were also noted. The latter overlie organic lake sediments, age of which was radiocarbon defined at 35.2Ë1.5 ka BP (M.F. Pazdur, 1984) what enables to correlate them with sediments dated on the Lower Vistula (E. Drozdowski, 1986), and with the Denekamp Interstadial. From the locality at Łęcze, the whole formation of intramorainic sediments was named the Łęcze Formation.

Sediments of the Grudziądz Formation are indicated on all general and detailed geological maps, where they occur on the land surface but also are noted in geological sections. On the sheet Elbląg Północ of detailed map, marine sediments of this age were also marked at Łęcze, Próchnik II and Miedniki.

LESZNO-POMERANIAN STADIAL

Ice sheet of this stadial, similarly as the earlier one, occupied the whole Dolne Powiśle and the Elbląg Elevation. In the latter area it pushed in main glaciotectonic phase deposits that had been partly displacemented from Baltic basin. It passed afterwards across the whole area, probably as far as the maximum extend of the Vistula Glaciation. A till of this age, defined as BIV, is marked on all general and detailed maps. It forms commonly surface of morainic plateaux. The areas within the limit of the Pomeranian Phase are the only exception. On general and detailed maps usually a separate till is indicated, defined in publications of the authoress as BV (Fig. 2). Individual character of this till is not everywhere documented. Locally it is really separated with intramorainic sediments (mostly of glaciofluvial origin) from the till BIV. In most areas separation of these tills is however only a conventional one. In the Elbląg Elevation a till of the Pomeranian Phase was not indicated as there is no evidence to consider it as a separate horizon. The Pomeranian Phase was probably a retreat phase only. Generally speaking, distinction of till of this phase still constitutes an open question.

Beside tills, the described stage contains also sediments of various landforms of frontal and areal deglaciation. At the end of the stadial, from the Bölling to the youngest Dryas,

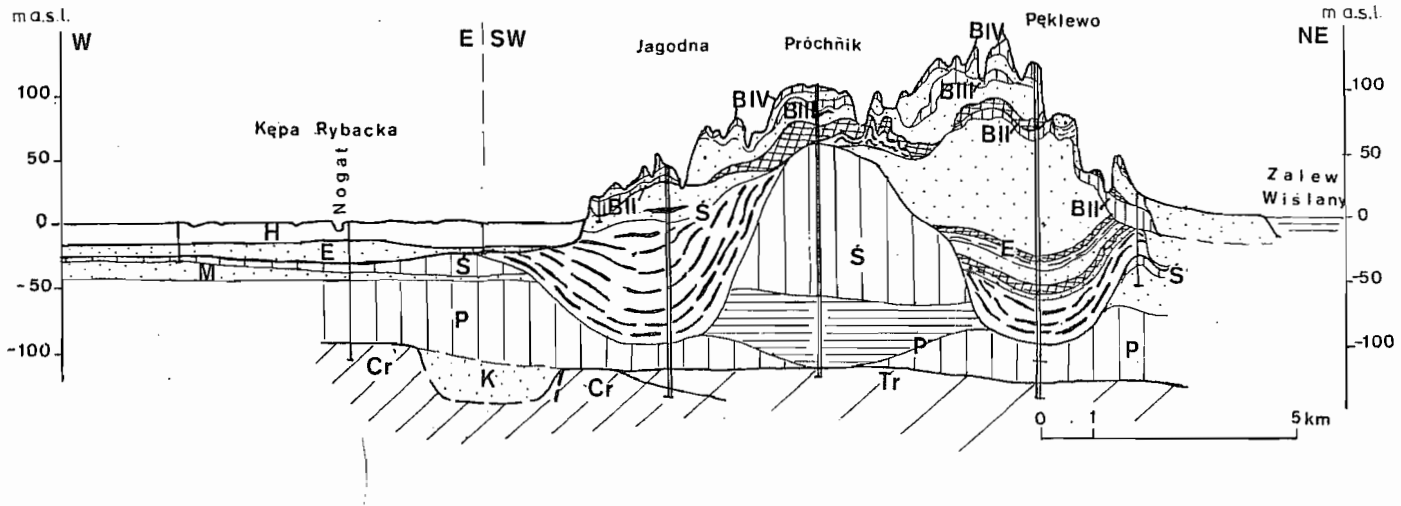



Fig. 7. Geological section to the sheet Elbląg Północ of the *Detailed geological map of Poland* scale 1:50 000 (after A. Makowska, 1987*a*)
Explanations — see Fig. 4

Przekrój geologiczny do arkusza Elbląg Północ *Szczegółowej mapy geologicznej Polski* 1:50 000 (według A. Makowskiej, 1987*a*).
Objaśnienia jak na fig. 4

the so-called Late Glacial is distinguished. In this time suprainundation terraces of the Vistula were formed. Their sediments are marked on many maps, basing on morphological analyses or bibliography. On the sheet Elbląg Północ, there are single sites with organic sediments that fill thaw depressions, formed at the end of the Pomeranian Phase. The Late Vistulian age of these sediments was determined with use of radiocarbon datings.

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Aurelia MAKOWSKA

## STRATYGRAFIA MŁODSZEGO PLEJSTOCENU DOLNEGO POWIŚLA I WZNIESIENIA ELBLĄSKIEGO W ŚWIETLE DOTYCHCZASOWYCH PRAC KARTOGRAFICZNYCH I WIERTNICZYCH

Streszczenie

W ostatnich latach zakończono duży etap prac kartograficznych obejmujących Dolinę Dolnej Wisły i jej najbliższe sąsiedztwo od Kotliny Toruńskiej po Zalew Wiślany. Kartowanie prowdzono w ramch obowiązków statutowych przez Państwowy Instytut Geologiczny, początkowo samodzielnie, a następnie przy współpracy lub w koordynacji z Przedsiębiorstwem Geologicznym z Warszawy i Gdańska.Prace szczegółowe poprzedziło wykonanie w latach 1969–1977 *Mapy geologicznej Polski* w skali 1:200 000 (3 arkusze), po ukończeniu której przystąpiono do sporządzenia *Szczegółowej mapy geologicznej Polski* w skali 1:50 000 (26 arkuszy). Kartowaniem objęto zarówno Dolne Powiśle, jak i Wzniesienie Elbląskie i Nizinę Warmińską na północy oraz fragment Kujaw na południu. Mapy są obecnie w większości wydrukowane bądź znajdują się w druku (fig. 1). Oprócz autorki artykułu, która również koordynowała całość prac, w realizacji map brał udział duży zespół autorów z Przedsiębiorstwa Geologicznego.

W toku prac kartograficznych na omawianym obszarze wykonano 60 otworów badawczych przebijających z reguły całą pokrywę czwartorzędową i docierających do jej podłoża (fig. 1). Wiercenia dostarczyły obfitego materiału do badań szczegółowych i pozwoliły na rozpoziomowanie osadów czwartorzędowych. Najważniejsze profile otworów (Mniszek, Bągart, Nowiny, Pęklewo, Krastudy, Pagórki) oraz inne wyniki badań prowadzonych w toku prac kartograficznych były równolegle publikowane w odrębnych pracach i artykułach (A. Makowska, 1970, 1973*b*, 1977*b*, 1979*b*, 1980*b*, 1982, 1986*a*, *b*, 1990, 1991*c*; A. Makowska, W. Rabek, 1990; B.J. Nowak, W. Rabek, 1987). Duże znaczenie dla podziałów stratygraficznych tego obszaru miało rozpoznanie oraz ustalenie położenia i zasięgu osadów lądowych, a także morskich interglacjału eemskiego (A. Makowska, 1979*b*), rozdzielających plejstocen starszy od plejstocenu poeemskiego. Ten zasadniczy podział plejstocenu Dolnego Powiśla jest widoczny na wszystkich mapach geologicznych, zarówno ogólnych, jak i szczegółowych. Młodszy plejstocen obejmuje osady eemskie i poeemskie. Podział stratygraficzny tego okresu i całego plejstocenu jest na wszystkich mapach zgodny i ujednolicony. Uproszczony schemat stratygrafii młodszego plejstocenu ilustruje fig. 2. Nomenklatura stratygraficzna zastosowana na mapach jest oparta o odpowiednie instrukcje obowiązujące dla całej Polski. Na Dolnym Powiślu jest ona już nieaktualna w stosunku do publikacji z tego obszaru. Odpowiednie korelacje nazw stratygraficznych na mapach i w publikacjach autorki oraz w niniejszym artykule przedstawiono w tab. 1.

Podstawą podziału stratygraficznego młodszego plejstocenu Dolnego Powiśla i innych obszarów objętych mapami jest podział litostratygraficzny poparty wynikami różnokierunkowych badań laboratoryjnych (litologicznych, petrograficzno-mineralogicznych, paleontologicznych oraz w pojedynczych miejscach również datowaniem osadów metodami $^{14}C$ i TL). Poziom przewodni, jaki stanowi seria osadów eemskich (formacja dolnopowiślańska), ciągnie się przez całe Dolne Powiśle z południa na północ od Kotliny Toruńskiej po Zalew Wiślany (fig. 3). Znajduje się on poniżej dna doliny Wisły i na ogół nie odsłania się na powierzchni terenu, dlatego też zaznaczony jest głównie na przekrojach geologicznych załączonych do map (fig. 4–7). Na południu są to osady lądowe, wypełniające sieć kopalnych dolin rzecznych i wykształcone w trzech głównych seriach dolinnych. Na północy występują natomiast dwa poziomy osadów morskich (sztumski i tychnowski) rozdzielone i przykryte osadami rzecznymi i rzeczno-deltowymi. Serię interglacjalną *sensu stricto* stanowi środkowa seria dolinna oraz tychnowski poziom morski. W stropie tych osadów zaznacza się górna granica interglacjału, określona analizą pyłkową w profilu Pagórki na ark. Braniewo *Szczegółowej mapy geologicznej Polski* 1:50 000. W profilu tym ujawniło się też pierwsze ocieplenie pooptymalne korelowane z Brörupem (Z. Janczyk-Kopikowa, 1991). Ponad formacją dolnopowiślańską spoczywa kompleks osadów dochodzących lokalnie do 100 m miąższości (tab. 1), które odsłaniają się w różnym stopniu na powierzchni terenu i są przedstawiane na wszystkich mapach geologicznych. Wyróżniono w nim pięć poziomów glin zwałowych, rozdzielonych czterema seriami międzymorenowymi (fig. 2). Poziomy glin zwałowych oznaczane w publikacjach autorki symbolami BI–BV (A. Makowska, 1973*b*; tab. 1) mają na Dolnym Powiślu różny zasięg. Dwie gliny środkowe (BIII, BIV) obejmują zasięgiem cały obszar przedstawiony na mapach geologicznych. Glina BII wypełnia głównie poeemskie obniżenia podłoża i zajmuje północno-wschodnią i środkową

część obszaru dochodząc do Kotliny Toruńskiej (fig. 3). Glina zwałowa najniższa i najwyższa (BI, BV) jako poziomy odrębne występują jedynie lokalnie w północnej części obszaru.

Gliny rozdzielone są seriami międzymorenowymi o różnej miąższości i wykształceniu litologicznym. Są one zróżnicowane regionalnie nad dolną Wisłą i na Wzniesieniu Elbląskim, gdzie wraz z glinami zwałowymi są zaburzone glacitektonicznie. W południowej i środkowej części obszaru są zbudowane wyłącznie z osadów lądowych, natomiast na północy zawierają też osady morskie. Najważniejsze znaczenie mają dwie serie międzymorenowe rozdzielające trzy środkowe poziomy glin zwałowych, które zostały nazwane formacjami Gniewu i Grudziądza nad dolną Wisłą oraz Kadyn i Łęcza na Wzniesieniu Elbląskim (fig. 2). Osady poeemskie były początkowo w całości zaliczane do zlodowacenia Wisły (A. Makowska, 1980*b*; tab. 1). W 1986 r., na podstawie badań nad osadami morskimi w północnej części obszaru ich wiek rozdzielono na dwa zlodowacenia przedzielone interglacjałem, w czasie którego Dolne Powiśle i Wzniesienie Elbląskie podlegało kilkakrotnym transgresjom morskim (A. Makowska, 1986*b*; fig. 2, tab. 1).

W młodszym plejstocenie na całym obszarze wyróżniono w ten sposób cztery główne okresy: interglacjał eemski, zlodowacenie toruńskie, interglacjał krastudzki i zlodowacenie Wisły.