POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

GEOGRAPHICAL STUDIES
SPECIAL ISSUE No. 4

EVOLUTION OF THE VISTULA RIVER VALLEY DURING THE LAST 15000 YEARS

PART II

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СПЕЦИАЛЬНОЕ ИЗДАНИЕ № 4

ЭВОЛЮЦИЯ ДОЛИНЫ РЕКИ ВИСЛЫ НА ПРОТЯЖЕНИИ ПОСЛЕДНИХ 15000 ЛЕТ

II

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Editor:
LESZEK STARKEL

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CONTENTS

Geographical Studies
Evolution of the Vistula River Valley
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LESZEK STARKEL

INTRODUCTION TO THE SECOND VOLUME PRESENTING THE RESULTS OF THE PROJECT ON THE EVOLUTION OF THE VISTULA RIVER VALLEY DURING THE LAST 15 000 YEARS (REALIZED IN THE IGCP — PROJECT NO. 158-A)

In the year 1978 the interdisciplinary research group affiliated to the National Committee of the Quaternary Research begun the study of the evolution of the Vistula river valley based on the principle of the programme IGCP-158 "Paleohydrology of the temperate zone during the last 15 000 years". In the years 1981—1985 the major part of these studies have been financially supported by the national programme "Changes of the geographical environment of Poland" coordinated by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences.

The first volume of the results of these studies was published in 1982 (Starkel ed. 1982). It contained 8 papers dealing with the evolution of the sections of the valleys of the middle and lower Vistula river, the Vistula delta and the Carpathian tributaries (the Wisłoka, Ropa and San rivers). The study of the upper Vistula valley section in the immediate foreland of the Flysch Carpathians in the Oświęcim subsidence basin was published in 1985 (Niedziałkowska *et al.* 1985).

Several other sections have been studied in the 2nd stage; these results are presented in this volume (Fig. 1). These studies introduce the abundant material documenting the simultaneous action of various factors: climatic, eustatic, tectonic and the anthropogenic ones. The picture of changes in the longitudinal profile of the Vistula river appears to be much more complex than it was originally assumed. There are also controversies between particular authors which will require further discussion as well as supplementary datings of the absolute age.

K. Klimek is presenting the section of the course of the Vistula with its large tributaries in the eastern part of the Oświęcim basin of the propensity to subsidence. The author stresses the role of deforestation in the accretion of the alluvial plain.

J. Rutkowski is indicating the presence of a sequence of alluvial

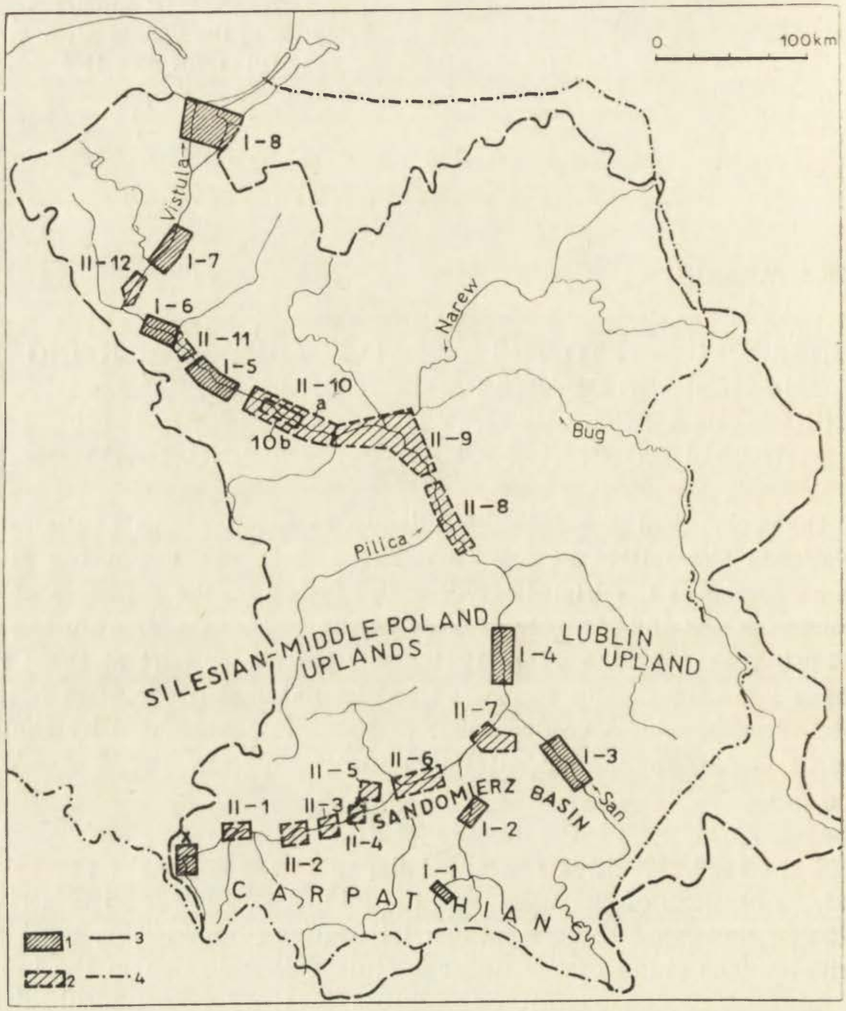

Fig. 1. River reaches elaborated in the Vistula valley project

1 — reaches elaborated in the first phase (published in 1982); *2* — reaches published in the present volume; *3* — watershed; *4* — state frontier; *x* — section published in 1985 by Niedziałkowska *et al.*

fills and generations of paleomeanders in the gorge section of the Cracow Gate due to the use (among the others) of the original mineralogical and petrographical methods.

T. Kalicki and L. Starkel are stating the lack of the channel deepening in the Holocene and a tendency to aggradation initiated from the Roman period in the section downstream of Cracow.

P. Gębica and L. Starkel are proving, for the western part of the Sandomierz Basin, the presence of several alluvial fills and the channel avulsions characteristic of the subsiding areas.

Z. Śnieszko presents an abbreviated review of a study of the evolution of the left-bank Nidzica valley within the loess upland, proving the continuous tendency to aggradation from the Late Glacial, amplified from the Neolithic period (see Śnieszko 1985).

T. Sokołowski is discussing the evolution of two series of troughs down the junction of the Vistula and Dunajec rivers in the central part of the Sandomierz Basin.

The similar sequence of changes in the channel system from the pleniglacial to the Holocene is presented by E. Mycielska-Dowgiałło for the section downstream of the Wisłoka outlet in the northern part of the Sandomierz Basin.

There is no study presented on the foreland of the gorge through the Uplands. It is only the reach between the Radomka outlet and the Warsaw Basin for which Z. Sarnacka analyses the sequence of terraces from the Pomeranian phase until the Younger Holocene.

The most extensive study involving the stratigraphic background of the Eemian and all of the Vistulian is the paper of M. D. Baraniecka and K. Konecka-Betley. The authors present former structures of the Vistula valley and discuss the problem of the ice-marginal lake in the Warsaw Basin. The varved clays, underlain by the Eemian deposits, are of the Vistulian, however, the up-to-date TL datings shift their age (about 50 000) to the lower pleniglacial. The authors relate the Otwock terrace series, inserted into an incision, to the period of the climax of the glaciation (ca. 20 000 BP); the subsequent lower terraces are of the Late Glacial.

E. Wiśniewski does not support the above viewpoint. The author analyses the history of the Vistula valley between the Warsaw and Płock Basins and states the very high location of the sandur levels when related to the Otwock terrace. The low alluvial substratum of the dune, found by B. Manikowska (1985), allows for an assumption that about 14 000 BP the river had cut down already to the level close to the present-day flood-plain.

E. Florek *et al.* present the detailed results of their studies of the section located between Kępa Polska and Płock, drawing the attention to the changes in both the channel parameters and the alluvia in the Late Glacial and the Holocene.

A. Tomczak gives an account of the studies in the Toruń Basin based on the research in the area of Ciechocinek. The author explains the deepest incision at the turn of the Late Glacial by the lowest level of the Baltic Sea.

W. Niewiarowski refers to these topics and especially to the shift of the Vistula from the Noteć ice-marginal valley (pradolina) to the Baltic Sea when presenting the results of his studies in the Unisław Basin.

The third volume of a summary-monographic character, presenting the general account of the studies in the Vistula valley, and to a certain degree in the Vistula catchment, will be submitted for publication during the coming year. It should also provide a broad background of the present-day environment as well as of the paleogeographical one what will allow for a better understanding of the complexity of the Vistula valley evolution. The valley, being 1068 km long, originates in the Carpathians, the latter belonging to the Alpine system; and dissects along its course the subsidence basin, old uplands and the Central-European Lowland descending to the Baltic Sea. The valley was within the extent of several Scandinavian glaciations. The key problem, in such a valley, is the interrelation of sandur plains and deposits, the glacilacustrine and the river ones in the immediate foreland of the last ice-sheet, the latter being the very section from which the lowering of the base level and deepening of the Vistula valley was initiated in both the up- and downstream directions.

The Polish term *mada* is used throughout the text. *Mada* denotes poorly sorted loamy sediments, lacking a definite lamination, deposited on a flood-plain by inundating flood water; of a variable content of sand, clay and silt particles and of the grain size decreasing with a distance from the river channel. The mada can be understood as an equivalent of backswamp sediments or overbank facies. The closest terms are "alluvial loam" or "haugh loam" in English and "Auelehm" in German.

As the coordinator of this programme I wish to express my gratitude for the fruitful cooperation to all the contributing authors, especially to Ms., Ms. M. D. Baraniecka, K. Konecka-Betley and Z. Sarnacka for their gratuitous contributions to the work of the group and filling the gap in the studies of the middle Vistula. Mrs. Teresa Mrozek is kindly acknowledged for preparing the English translation of the texts.

Polish Academy of Sciences
Institute of Geography and Spatial Organization
Department of Geomorphology and Hydrology
31-018 Krakow, ul. św. Jana 22

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KAZIMIERZ KLIMEK

VISTULA VALLEY IN THE EASTERN PART OF THE OŚWIĘCIM BASIN DURING THE UPPER VISTULIAN AND HOLOCENE

The Oświęcim Basin is of a shape of an elongated triangle, limited of the north by the tectonic edge of the Silesian-Cracow Upland, of the SE by the Carpathian Foothills, and of the west by the Pleistocene elevation of the Rybnik Plateau (Fig. 1). Three rivers of similar drainage

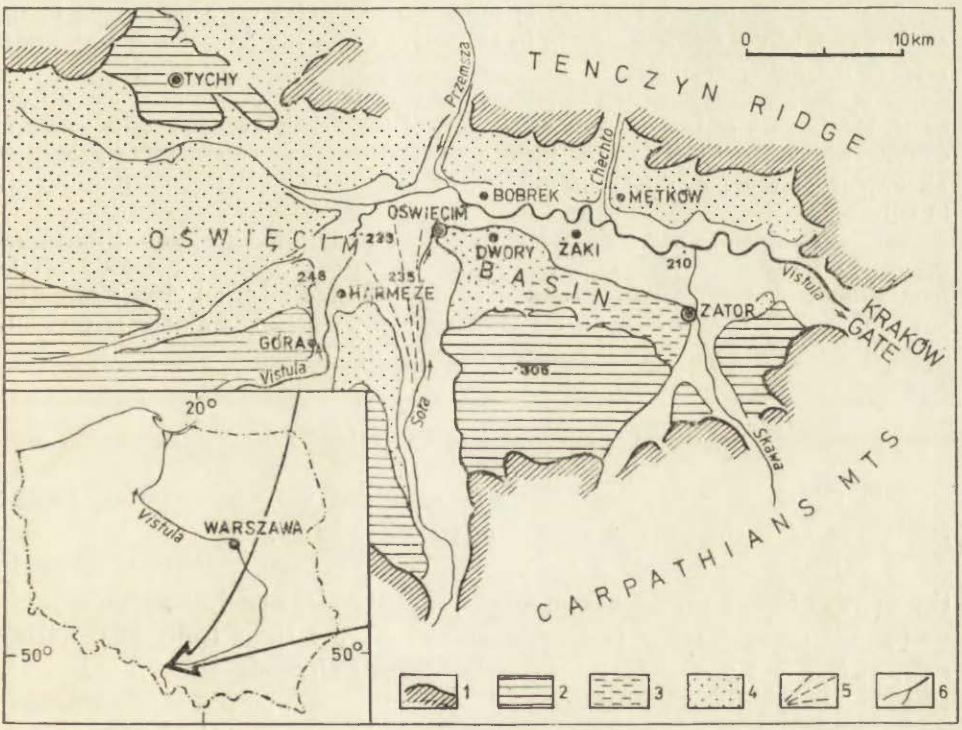

Fig. 1. Vistula valley in the Oświęcim Basin

1 — limit of mountains and uplands; *2* — fore-Carpathian plateaus; *3* — loamy plains (Pleistocene); *4* — sandy plains (Pleistocene); *5* — alluvial fans (Holocene); *6* — valley floors (Holocene) basin areas and of similar mean discharges join in the northern part of the Oświęcim Basin. These are: Silesian Vistula [1] ($A = 1748$ km^2, $Qm = 21.7$ m^3/s), Przemsza [2] ($A = 1996$ km^2, $Qm = 19.0$ m^3/s) and Soła [3] ($A = 1386$ km^2, $Qm = 23.1$ m^3/s). The joined tributaries form the river of the catchment area of 5000 km^2 and of the mean discharge of 61 m^3/s [4].

The Quaternary of the Oświęcim Basin in the zone of the Vistula valley and its neighbourhood has been studied more precisely only in a few sites (Konior 1936; Koperowa, Środoń 1965; Gilot *et al.* 1982; Klimek and Zawilińska 1985) or in the lower course of Vistula tributaries (Środoń, Starkel 1961). The study of Klimek (1972) dealing with the whole region becomes slowly outdated due to a large amount of new information. The collected information during last decades based on the profiles of numerous drillings enables one to learn better the formation and thickness of the Quaternary deposits and their substratum relief (Kotlicka 1964, 1969). There is a good opportunity for direct observations of the alluvial sediments filling the Vistula valley due to an initiation of the navigable channel construction in the recent years.

The paper presents the results of investigations which were performed in the eastern part of the Oświęcim Basin in 1981—1984 under the project MR I-25, under prof. L. Starkel leadership.

A primary paleobotanical analysis of the organic deposits has been carried out by K. Mamakowa of the Institute of Botany, of the Polish Academy of Sciences in Cracow while the ^{14}C datings of these deposits have been determined by dr hab. M. Pazdur of the Laboratory of Physics, of the Silesian Polytechnical University in Gliwice.

Mgr J. Grocholska and mgr L. Zawilińska of the Nature and Natural Resources Protection Research Centre Polish Academy of Sciences assisted helpfully in the field work and during the elaboration of the collected material. The figures for publication have been drawn by my wife mgr M. Klimek. The author is cordially grateful to the above mentioned persons.

PRESENT-DAY ENVIRONMENT

The following orographic units (Fig. 1) are very pronounced in the landscape of the discussed section of the Vistula valley:

a) valley floor dissected by the meandering Vistula channel down to the depth of 3—5 m. Its banks are artificially stabilized at present;

b) extensive "loamy plain" developed on the right (southern) valley side, at the foot of the fore-Carpathian Osieck Upland;

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[1] Nowy Bieruń gauge, mean values of 1951—1975.

[2] Jeleń gauge, mean values of 1956—1975.

[3] Oświęcim gauge, mean values of 1956—1975.

[4] Dwory gauge, mean values of 1951—1975.

c) "sandy" level surrounding the Vistula valley floor of the north, at the foot of tectonic block hills of the Silesian-Cracow Upland.

The Holocene floor of the Vistula valley is of a differentiated width. The Holocene Soła fan has shifted it to the north, towards the edge of the Pleistocene level (Fig. 2) upstream of the Przemsza river outlet. The above resulted in the floor narrowing to the width of 0.8—1.0 km. Prior to channelization the Vistula channel in this section possessed a classically developed system of meanders of the radius of 70—120 m, 96 m at average. At present, after the embankments have been constructed and some meanders cut off, the meandering nature of the river is still preserved what causes that the water table gradient between the settlements of Góra and Nowy Bieruń is 0.46 m/km provided the gradient valley of the order of 0.68 m/km.

Downstream the junction of the Vistula, Soła and Przemsza rivers, the Vistula valley floor becomes wider to 3—4 km. The Vistula channel still forms regular meanders of the radii of 200—300 m what results in the water table gradient of 0.39 m/km provided that of the valley of 0.52 m/km. The channel is limited by the natural levees up to 1—2 m high and 500—800 m wide. Well preserved paleomeanders with the radii of 130—300 m, 178 m at average, occur in the area of the above levee. The levees separate flat backswamps, located 1—2 m below, especially well developed between Bobrek Górny and Gromiec on the left valley side, and between Dwory and Podbrzezie on its right side.

The hydrological regime of the Vistula in the Oświęcim Basin is influenced by the Carpathian tributaries of the pluvio-nival type of freshets (Upper Vistula, Biała and Soła rivers) and by the tributaries from the Oświęcim Basin (Korzenica, Pszczynka rivers) or from the Silesian-Małopolska Upland (Przemsza, Chechło rivers) with a dominating ground water alimantation. Therefore, despite of large amplitudes of the floods of the Carpathian tributaries during which maximum discharges increase 56 times in the case of the Soła and over 100 times in the case of the Upper Vistula and Biała rivers when compared to the mean discharges, the maximum discharge of the Silesian Vistula recorded in Nowy Bieruń was only 30 times larger than the average, and downstream of the Przemsza and Soła outlets in Dwory only 24 times larger than the mean discharge. However, the amplitudes of the water stages in that period reached 4.5 m in Nowy Bieruń and 6.6 m in Dwory due to the embankments.

The Vistula channelization consisting in the meander cutting off and construction of embankments was initiated at the turn of the 19th and 20th centuries. The channel management was intensified in the period of 1900—1920 (Punzet 1981) and included the entire Vistula section in the Oświęcim Basin. The above resulted in substantial changes of the channel gradient. For example, the Vistula channel between the outlets of the Biała and Przemsza rivers has been shortened from 51 km to 32 km, hence, the channel gradient has increased from 0.25 to 0.41 m//km. Smaller changes of the channel took place downstream of the Przemsza mouth (Galarowski 1984).

SUB-QUATERNARY RELIEF AND QUATERNARY DEPOSITS

The Oświęcim Basin is located in the area of the Carpathian Foredeep — the young geological structure separating the Carpathians from the foreland. This foredeep, intensively deepened during the Miocene, was filled with the sediments of that period (Alexandrowicz 1964) which thickness reaches 500 m here (Kaziuk 1980). The upper face of the Miocene is differentiated. Extensive "plateaus" of the height of 240—250 m a.s.l. separated by depressions (Kotlicka 1964, 1969), are fairly well pronounced. The depressions in the western and eastern fringes of the Basin definitely possess properties of valleys. However, in the case of the northern part of the Basin between Żory and the Skawa outlet these are broad, basin-like widenings at the height of 200—220 m a.s.l. of an indefinite gradient. Young Quaternary tectonic movements of a blocky nature, accepted by Kowalczyk (1964) and recently by Kotlicka (1964), might be a reason of such a formation of the Quaternary substratum. The analysed section of the Vistula valley between Góra and the Skawa mouth extends parallely to one of such a board depression, the axis of which at the height of ca. 210—200 m a.s.l. is slightly more to the south when compared to the present Vistula valley floor.

The Oświęcim Basin was covered with the Scandinavian ice-sheet during the South-Polish (Cracow) Glaciation (Klimaszewski 1936). The remnants of the ground moraine or erratics occurring south of the discussed area are preserved of that period. During the next glaciation, the Middle Polish one, the Vistula valley was a proglacial streamway from the Odra lobe (Klimek 1972). The glacifluvial sands were deposited at that time. They form in the north-western part of the Basin a plain, slightly inclined to the east, in the drainage basin of the Korzenica and Gostyńka. In the eastern part of the Basin, they have been dissected later and removed. Their fragments are preserved in a few zones under the younger deposits. During the Last Glaciation, the Vistulian one, i.e. during the period of the maximum development of the Scandinavian ice-sheet ca. 20 000 years ago, the Oświęcim Basin was located about 250 km south of the ice-sheet front. Severe climatic conditions, characteristic of a tundra formation (Środoń 1952), prevailed here.

VISTULIAN MORPHOLOGY AND COVERS

Accumulation levels surrounding the Holocene floor of the Vistula valley were created in a general form in the Vistulian.

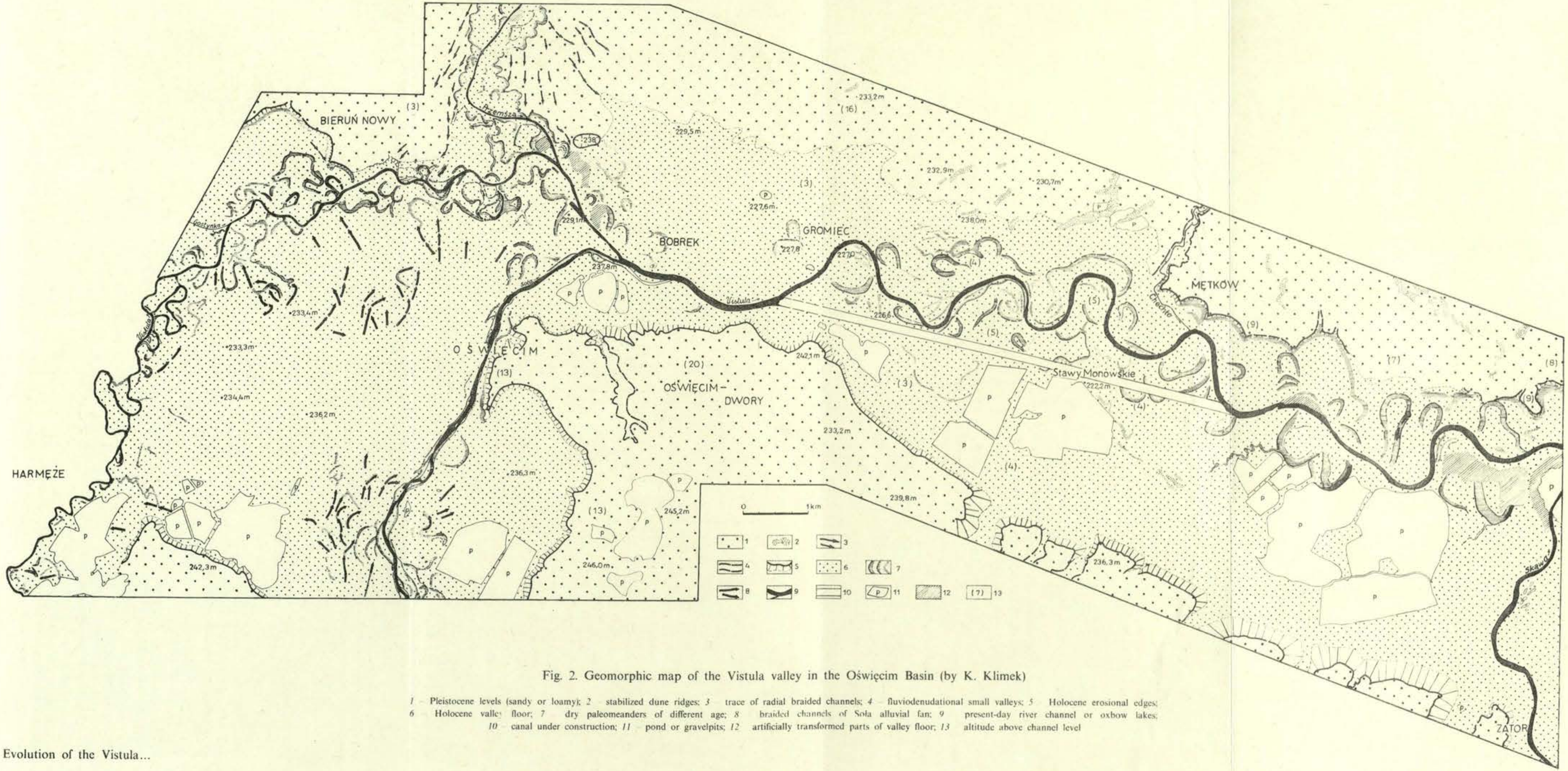


Fig. 2. Geomorphic map of the Vistula valley in the Oświęcim Basin (by K. Klimek)

1 – Pleistocene levels (sandy or loamy); *2* – stabilized dune ridges; *3* – trace of radial braided channels; *4* – fluviodenudational small valleys; *5* – Holocene erosional edges; *6* – Holocene valley floor; *7* – dry paleomeanders of different age; *8* – braided channels of Sola alluvial fan; *9* – present-day river channel or oxbow lakes; *10* – canal under construction; *11* – pond or gravelpits; *12* – artificially transformed parts of valley floor; *13* – altitude above channel level

The "loamy" terrace is the very definite element of the relief. It borders of the south the Vistula valley floor between the Soła and Skawa mouths and reaches upstream these rivers. A gently undulated terrace surface, built of the loess-like loams at the upper face, rises 18—20 m (240—244 m a.s.l.) above the mean Vistula level. The loamy terrace of the maximum width to 3 km is limited of the south by the steep slope of the fore-Carpathian plateaus while it descends to the north with the very pronounced 16 m edge down to the Vistula valley floor. The loess loam cover disappears only to the south of the line Oświęcim—Dwory while the (Middle Polish) glacifluvial sands (Kaziuk, Lewandowski 1980 a, b) appear in a meridional terrain depression of the width of 3—4 km.

Despite of the early initiated studies (Zaręczny 1981) and later cartographic approaches (Biernat, Krysowska 1955; Zero 1956) the sediments building up this terrace are still weakly recognized. Klimaszewski (1948) and Książkiewicz (1951) after him, have distinguished this terrace in the Skawa valley as so called "medium level" related to the Riss (Middle Polish) Glaciation. However, loess loams covering this level were related to the Last Glaciation according to the above authors. Next Środoń and Starkel (1961), have also noticed the younger alluvia of the beginning of the Baltic Glaciation, building the base of this terrace, besides the gravels of the Riss Glaciation underlaying the loesses. The well documented work of Koperowa and Środoń (1965) presents a new opinion about sedimentation conditions and an age of the loess-like loams. In the clay-pit of the Zator brick-yard, dissecting the plain of the terrace in question, the latter authors have stated the occurrence of 5.5 m thick loess-like sandy silts underlain by 3 m thick layer of peaty silts which overlay the fluvial gravels of the Skawa. The paleobotanical analysis of this peat layer occurring in these silts indicated the dominance of the forestless tundra during their sedimentation. The ^{14}C dating of the peat indicated the age elder than 40 000 years (K-739). Based on the above, the mentioned authors have related the peaty silts deposition to the chilly and moist phase of the Pleniglacial A while that of the overtopping them loess-like loams without humus remnants to the cold and dry period of the Pleniglacial B. The loamy terrace in the pit of the Łowiczki Pańskie brick-yard near Przeciszów, distant by 3 km to the west, is of analogical structure.

Ten km farther to NW, in the vicinity of Oświęcim, the structure of this terrace has been recognized based on the archival profiles of drillings. Here, gravels (flysh ones probably) rest on the undulated upper face of the Miocene clays of the height of 220—225 m a.s.l. The evened out upper face of these gravels reaches to 230 m a.s.l., i.e. to the level of the present-day Vistula valley floor. Clays, changing into "silts" and "loamy silts" overlay the gravels in the western part. The

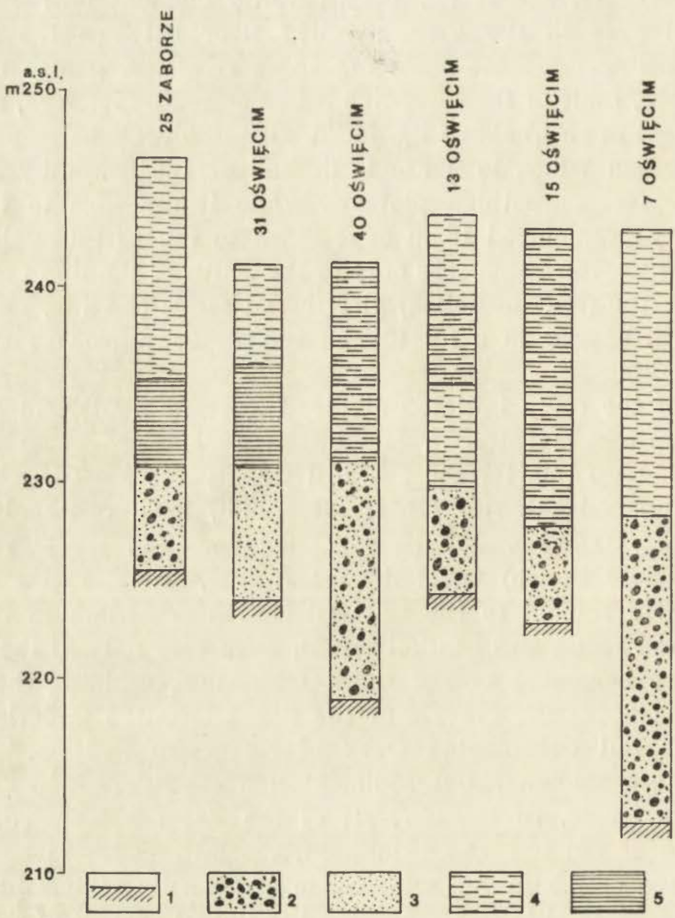


Fig. 3. Structure of the loamy terrace in the region of Oświęcim—Dwory

1 — top of Miocene deposits; *2* — gravels; *3* — sands; *4* — "loams"; *5* — clays

upper face of the deposits consists of the loess-like loams (Fig. 3). The sequence of deposits is analogical here to that in the sites Zator and Łowiczki Pańskie. The loess-like loams resting on the peaty silts could have been deposited both during a direct silt sedimentation on higher hills of the Carpathian Foothills (280—300 m a.s.l.) and during the washing of these sediments out into lower locations, i.e. into the river terraces.

The loess-like loams cover the northern edge of the 20 m high terrace as well. The lack of alluvial fans at the mouth of small valleys cutting this edge (Macocha, Bachórz, Łowiczanka and others) indicates that the Vistula flew at the terrace edge during the loess sedimentation and carried away the alluvia supplied by the tributaries. The straight course of the edge in question, however, indicate that this was a braided river of a discharge larger than the present one. The extensive areas of the inter-channel bars, being not stabilized with vegetation, were direct contribution areas of the material for eolian transportation as assumed by Jersak (1976).

An intensified transportation and sedimentation of the eolian silts one can relate to the upper pleni-Vistulian (Starkel 1980) during which the younger loess, "lower" or "upper" one has been deposited (Maruszczak 1976).

The "sandy" level at the foot of the Tenczyn Ridge occupies the zone of the width of 2.5—3 km. Its morphological surface is inclined to the south towards the Vistula valley and its gradient is 5—6 m/km, following the general inclination of the Miocene substratum. This level cuts away the glacifluvial deposits of the Middle Polish Glaciation in the higher part of 260—250 m a.s.l. It was formed in the lower part of 230—226 m a.s.l. due to redeposition of the sandy material left as alluvia or small alluvial fans at the mouths of periodical streams. The Pleistocene alluvial fans of the Przemsza and Chechlo rivers, inactive at present, correspond to the lower part of the sandy level. The stabilized ridge dunes, high up to some meters and with the SW—NE axis (Fig. 2) occur in some locations on the sandy level.

Up-to-date, the sandy level was not of a research interest. There is no basis for its dating as well. The conditions suitable for the formation of the sandy level were fulfilled during the entire Vistulian, after dissection of the sediments of the Middle Polish Glaciation. However, it seems that conditions were more favourable in the moister phases of the Vistulian when the peaty muds were deposited on the southern side of the Vistula. The sandy deposits of the level in question were the sources of the material for a dune formation in the upper and drier phase of the pleni-Vistulian and in the Late Vistulian as it has been assumed by Starkel (1980).

In the zone between the Przemsza and Chechło mouths the sandy level when descends farther to the south is overlain by the loamy overbank deposits of the Vistula flood-plain. The above is also confirmed by some cross-sections of the Vistula valley (Fig. 5). Therefore, one can assume that the Vistula valley floor in this part of the Oświęcim Basin during the period of the sandy level formation was at the level of the present floor, or may be even lower. The alluvial fans of the Przemsza and Chechło rivers, developing at that time, pushed the Vistula current to the south, at the mentioned edge of the loamy terrace causing its undercutting.

The system of radial paleochannels, draining the Przemsza fan surface, is well preserved in the vicinity of Gorzów. The majority of the above channels are filled with peats up to 2 m thick. Up-to-date the attempts to determine its age have failed. It seems, however, that the

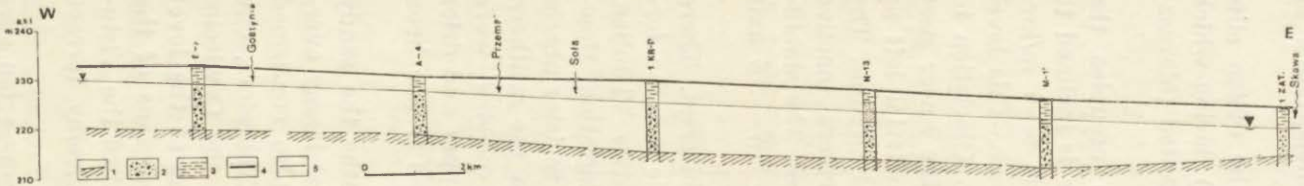
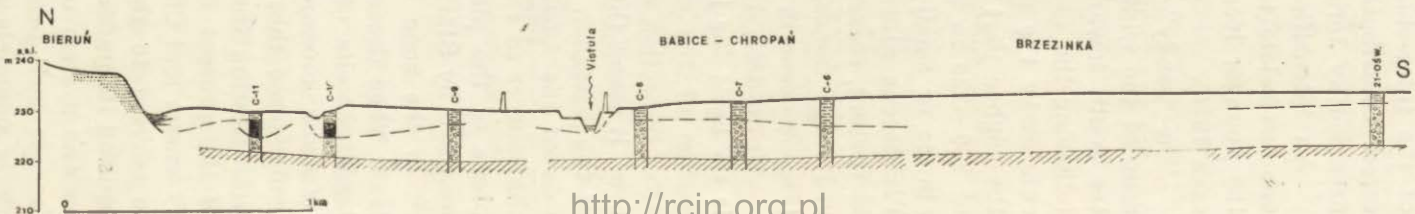


Fig. 4. Examples of formation of the main series of alluvia filling the Vistula valley floor in the Oświęcim Basin

1 — erosional top of the Miocene deposits; *2* — gravel and sands of channel deposits; *3* — loams and silts of the overbank series; *4* — valley floor surface; *5* — mean water level of the Vistula



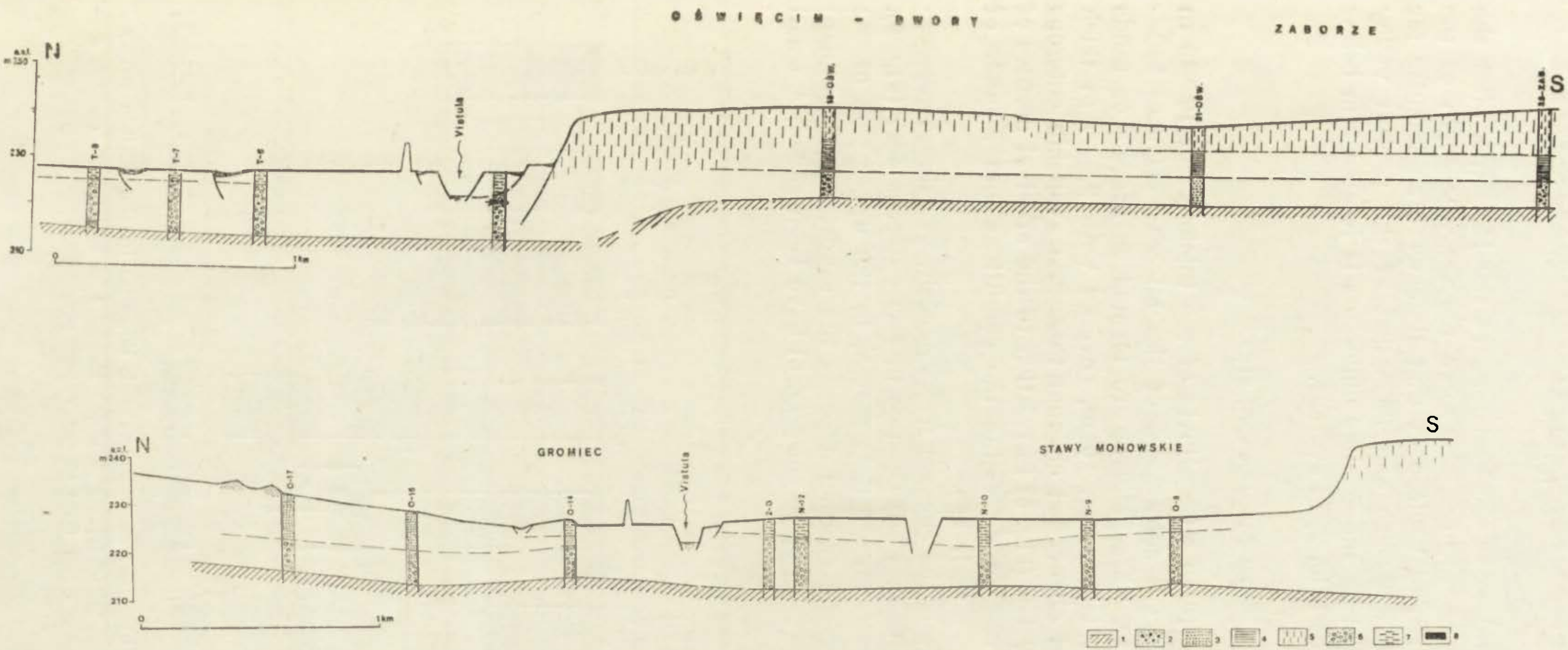


Fig. 5. Chosen examples of the typical series of the Quaternary deposits in the Vistula valley between the Gostyń and Skawa outlets

1 — erosional surface of the Miocene deposits; *2* — gravels and sands of the Pleistocene; *3* — sands (Pleistocene); *4* — clays (Pleistocene); *5* — loess-like loams (Pleistocene); *6* — gravel-sandy channel deposits; *7* — loamy-silty overbank deposits; *8* — peat

peat started to accumulate at the beginning of the Holocene, after the radial channels were abandoned. The more regular discharges of the Przemsza river and limited bedload at that time were an impulse for a dissection of the fan surface and formation of the present valley floor. The latter limited by the arc-like undercuts is located 2 m below the inactive fan surface (Fig. 2) at average.

THE HOLOCENE FILL

The valley floor is filled with alluvia of the thickness of 10—15 m resting on the evened out substratum of the Miocene clays of 220—210 m a.s.l. (Fig. 4, 5). These alluvia are formed as gravels or sands with gravels of the thickness ca. 10 m, covered with 2.5—5 m thick overbank deposits and abandoned channel fills. The available outcrops of the deposits in question (Fig. 5) in relation to the archival profiles of the drillings enable one to determine the conditions and manner of sedimentation as well as their age.

The gravel member is the channel facies deposit. The direct observations of the above sediments are possible in few outcrops only (Fig. 6). In Harmęże 9 km upstream the Sola mouth, in the upper part of the 7 m thick complex of the channel deposits the sandstone (Carpathian) gravels of the diameters up to 30 cm (Fig. 6) have been stated. A small

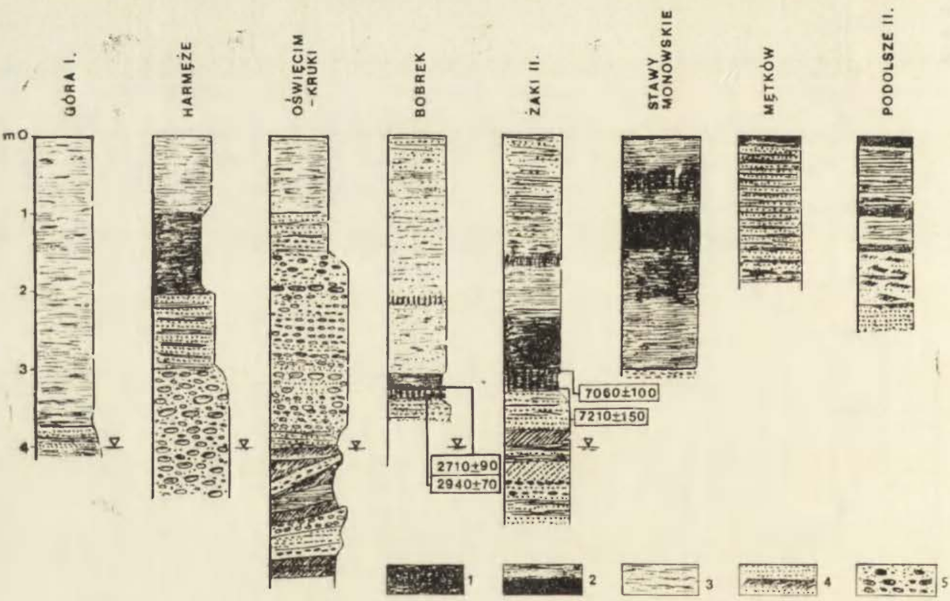


Fig. 6. Structure and thickness of the overbank deposits in the Vistula valley
1 — organic silts; *2* — clayey silts/clays; *3* — sandy loams; *4* — sands; *5* — gravels; *6* — mean water level in the Vistula channel

Vistula gradient and related to it the limited bedload allow to assume that coarse gravels could have been supplied by the Soła river during the intensified fan progradation.

In the large gravel-pit Oświęcim-Kruki at present filled with water, below the 1.5 m thick cover of the overbank deposits, the sandstone flysch gravels, of the thickness of 5.5 m and with the diameter of 5—8 cm, and to 20 cm sporadically, overlaying the coarse sands were outcroping. The well visible intercalations underlain by the levels of the imbricated pavements occurred in the upper part of the gravels. The sandy intercalations with a cross-lamination appeared in the lower part of the gravel complex. The large horizonal extent of these intercalations suggests that these are deposits of a braided river of a large transportation competency. The outcrop location just downstream of the Soła outlet allows to assume that this is the Carpathian material supplied by the river, may be on the secondary lodge. The presence of tree trunks in the upper part of the gravels indicates the Holocene age of this complex.

The amount of the gravel intercalations in the structure of the channel deposits diminishes down the valley in favour of the sandy ones. The gravel diameters decrease as well, although, they reach 10 cm sporadically in the settlement Żaki (Fig. 6).

The gravel series in the top part are undoubtedly the Holocene ones. They have been deposited simultaneously with the overbank series sedimentation. However, the depth of the reworking of the old gravels of the Vistulian is difficult to be determined. Based on the depth of the tree trunk occurrence one can assume that the upper part of the gravel layer, at least to the depth of 2—3 m, was subject to the Holocene reworking of these deposits in the process of the lateral migration of the Vistula channel.

The overbank deposits are more diversified depending on the location within the valley floor. The overbank facies in the section upstream of the Soła and Przemsza outlets (outcrop Góra I) are developed in a form of the structureless sandy loams with the organic content to 1.6%. Downstream of the Soła outlet in the zone of the natural levee, these are usually sandy silts with sandy intercalations in some spots (outcrop in Żaki I). They rest on clayey-silty fills of the abandoned channels in numerous locations.

In the case of the backswamp zone the overbank deposits are developed as strongly clayey silts or clays with organic intercalations (outcrop Stawy Monowskie). Here, the cover of these sediments likely conceals the elder abandoned channel fills what can be concluded on the basis of the archival drillings.

The overbank deposits are of various ages. The arc-like undercutting of the edge of the higher sandy level occurs in the vicinity of Bieruń Nowy, downstream of the Gostyńka mouth. It was formed due to lateral migration of the meander with a radius of 640 m; the latter being 6 times larger than the mean radius of other meanders preserved in this valley section. The above suggest that this undercutting was due to the river of a different hydrological regime than the present one. It is very likely, because the discussed undercutting forms a small fragment of the formerly existing here complex of large meanders well preserved in the another valleys in the Carpathian Foreland like Wisłoka (Klimek, Starkel 1974; Starkel (ed.) 1981; Starkel *et al.* 1982) and San (Szumański 1977). There, they are filled with the Pre-Boreal deposits. Thus, one can assume that conditions suitable for a formation of large meanders existed in the discussed section of the Vistula valley before the beginning of the Holocene as well.

In the area of the bend the valley floor is located slightly lower than in the direct vicinity of the present-day channel. Moreover, the preserved micro-relief allows to distinguish the levees being indistinct here. The lateral migration of the younger Vistula meander entered into this bend only insignificantly. Based on the analysis of the archival drillings it has been stated that the 3.5 m complex of peat lies directly on the channel gravels below the 1 m thick silt cover. Further to the undercutting in a slightly lower location, the peat appears at the surface (Fig. 5). Such a sequence of deposits can be interpreted as an effect of the lateral meander migration on the same level allowing for a continuous peat accumulation in the abandoned channel. The very thin cover of the overlaying overbank deposits or its lack indicate a large vertical stabilization of the Vistula channel in this valley section.

In the outcrop Żaki II, in the excavation of the constructing canal, the clay abandoned channel fill with the 0.6 m layer of organic muds at the lower face, has been stated below the 2.5 m thick cover of the sandy-silty deposits building the levee.

The primary paleobotanical analysis of the organic series performed by Mamakowa has indicated a large amount of the linden pollen what suggests the Atlantic age of these sediments. The later datings by the ^{14}C methods were 7060 ± 100 BP (Gd-1773) for the upper part of the organic layer and 7210 ± 150 BP (Gd-2254) for the lower part of this layer.

The organic layer filling the fossil abandoned channel has been stated below the 3 m over of the silty-sandy deposits of the levee in the settlement Bobrek, downstream of the Przemsza outlet, in the excavation for the plumbing system. The primary paleobotanical expertise performed by Mamakowa indicated the abundance of pollen and macrofossils of the fir what indicates, according to her, the age younger than 3000 BP. The later ^{14}C datings indicated the age 2710 ± 90 BP (Gd-1774) for the sample from the upper part of this layer, and respectively

2940 ± 70 BP (Gd-1772) in the case of the sample from the lower part.

The presence of the vari-aged abandoned channel fills at the similar level above the Vistula channel and below the levee deposits of the similar thickness indicates that the Vistula channel was of a large vertical stability at least 3000 years ago, i.e. in the period SB_2 (Starkel 1977). The paleomeanders of the Sub-Boreal, Atlantic and probably of the Pre-Boreal (near Bieruń) periods occurred in the valley floor one near the other. The natural levee, especially well developed downstream of the Soła outlet, started to accrete intensively just after that period. This intensified transport and sedimentation, mainly of the fine material, could have been caused, first, by the regional climatic changes, second, by an increased deforestation, especially in the Carpathian part of the Soła drainage basin, the latter being well documented in other catchments of the Carpathian tributaries of the Vistula (Ralska-Jasiewiczowa 1977). The Medieval agricultural colonization of the Carpathian Foreland and Foothills and that of the Żywiec Basin in the upper part of the Soła catchment (Niedziałkowska *et al.* 1985) influenced strongly this intensified sedimentation of the overbank deposits.

PRESENT-DAY FLUVIAL ACTIVITY AND SEDIMENTATION

The increased gradient and the narrowing of the flood water flow to the width of 200—500 m of the interembankment zone resulted in a larger water velocity. The overbank sedimentation has been also limited to this narrow zone. This sedimentation rate is fairly high.. On the stony channel structures of the first decades of this century the covers of the overbank sediments, 2—3 m thick, have been deposited. Due to this process, the accretion of the interembankment zone takes place.

Sediments deposited in the interembankment zone are characterized by the rhythmical stratification, well visible in outcrops of Góra II, Mętków and Podolsze II, pronounced by layers of coal-dust (Fig. 6). The youngest deposits of the interembankment zone are more sandy than the overbank ones deposited on the extensive valley floor. The fraction above 0.1 mm constitutes 50—80% while the clay fraction, below 0.02 mm, constitutes 5—25%. The alluvia pH varies between 6.5—7. The content of the organic matter increases substantially reaching 4—6%, and exclusively up to 24% in the outcrop Podolsze II. The location of the centres of mining industry (mainly of coal and zinc), of metallurgy of the machine construction and of the fabric and textile industry in the catchment of the upper Vistula results in a large pollution by the industrial and municipal wastes of the Vistula river and its tributaries: Przemsza and Biała. These rivers carry very large amounts of the trace elements. These elements adsorbed by fine mineral or organic matter, carried in the suspension or by the bedload, are concentrated in muds deposited in the interembankment zone after each larger flood.

The concentration of these microelements in the elder overbank deposits of the Vistula is much smaller than in the fundamental types of the sedimentary rocks (Green 1959; Vinogradov 1962) while in the youngest deposits it exceeds significantly the clark values (Klimek and Zawilińska 1985).

Geochemical studies of the Vistula alluvia in the profile Góra located downstream of the Biala mouth (i.e. downstream the Bielsko industrial centre) have indicated that the concentration of some trace elements such as: Cu, Zn, Cd, Co, in the youngest Vistula alluvia deposited already in the 20th century is 10—30 times larger than in the elder overbank deposits of this valley section. In the case of the profile Podolsze, located downstream of the Przemsza outlet — the latter draining the Upper Silesian Industrial Region — it has been stated almost a double increase of Ni concentration, 10—40 times increase of Zn concentration and 50 times increase of Cd concentration.

Hence, the geochemical studies of the younger alluvia in the drainage basins with industrial centres can be very helpful for the age determination of the youngest alluvia.

RESULTS AND CONCLUSIONS

In contrary to the well recognized river valleys, located more to the east (eg. that of Wisłoka — Klimek, Starkel 1974; Starkel ed. 1981) the Vistula channel in the Oświęcim Basin between the upper Vistulian until the period of the middle Sub-Boreal was probably characterized by a large vertical stability. That is indicated by the wedging of the "sandy" level being inclined towards the valley axis under the younger alluvia. Much later, the migration of meanders with a small curvature radius has caused this level undercutting and the formation of the erosional edge, e.g. near Mętków.

The simultaneous occurrence of the fills of different age: PB(?) (Nowy Bieruń), AT (Żaki) and SB (Bobrek), in the same level indicates that the process of lateral channel migration, linked with the reworking of the alluvia in the same level, dominated during substantial part of the Holocene. In the section of the Vistula valley upstream of Oświęcim the additional factor limiting the vertical erosion was a fast development of the Soła alluvial fan which shifted the valley axis northwards. The present-day valley relief, characterized by the occurrence of the extensive levee with the meander network and flat backswamps at their hinterland, is the element younger than 3000 years.

Besides the global climate changes such a situation was mainly caused by the local lithological-orographic conditions.

The concentric junction of a few larger (Soła, Vistula, and Przemsza) and a few smaller (Biała, Korzenica with Pszczynka, Gostyńka with Mleczna) rivers and the related to it the concentric supply of the alluvia under the conditions of the Oświęcim Basin closing by a narrow gorge of the Cracow Gate, are largely responsible for such a situation. The Holocene processes of erosion and sedimentation in this area are in this respect similar to those occurring in the Vistula valley downstream of Cracow (Starkel 1984). The role of the tectonic factor, possible to be accepted in very strong limitations, is difficult, however, to be proven.

Polish Academy of Sciences
Nature and Natural Resources Protection Research Centre
31-512 Kraków, ul. Lubicz 46

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JACEK RUTKOWSKI

VISTULA RIVER VALLEY IN THE CRACOW GATE DURING THE HOLOCENE

INTRODUCTION

The subject of the study is the Holocene Vistula valley in the Cracow Gate, between Cracow and Czernichów. The Carpathian Foredeep is a considerable narrowing in this zone and the tectonic blocks (horsts) built mostly of the Jurassic limestones are approaching the Carpathian fringe to the distance of 3—4 km. The valley of the Vistula river flowing between these horsts was formed due to erosion of the nonresistant Miocene deposits filling the foredeep (Alexandrowicz 1960). During the South-Polish Glaciation this area was filled up with deposits and then was subject to removal. The Holocene of the Cracow Gate has been studied by Książkiewicz (1951), Alexandrowicz (1960), Kmietowicz-Drathowa (1964a, b), Tyczyńska (1968), Rutkowski (1984a, b). The petrography of sands has been studied by Kociszewska-Musiał (1969) and that of gravels by Rutkowski and Sokołowski (1983) and Rutkowski (1984b, 1986). The site of Piastowska St. has been subject to paleobotanical studies (Mamakowa 1970). Results of the studies on the site in Ściejowice were given by Sawicki (1957) and interpreted by Mamakowa and Srodoń (1977). The stratigraphic position of the site in Ludwinów was reinterpreted by Sokołowski and Wasylikowa (1984).

Grain size composition of sands and gravels was determined by mgr inż. M. Czuj and mgr inż. U. Józefko and that of madas by dr Z. Śnieszko. Identification of the tree trunks was performed by inż. Z. Tomczyńska from the Institute of Botany of the Polish Academy of Sciences (PAN) in Cracow. Most of the absolute age datings by the ^{14}C method were performed by doc. dr M. F. Pazdur from the Polytechnical University in Gliwice. The age of tree trunks from Ściejowice was determined by dr M. A. Geyh from the Niedersächsisches Landesamt für Bodenforschung in Hannower.

The studies for the section down Ściejowice were financially supported by the Geological Institute in Warsaw as a part of the project on the Detailed Geological Map of Poland 1 : 50 000 — the sheet Cracow. The study of the western part was supported by a grant from the Institute of Geography and Spatial Organization of the Polish Academy of Sciences in Warsaw under the project MRI/25.1 "Changes of the geographical environment of Poland".

HYDROLOGICAL CHARACTERISTICS

Vistula is a lowland river of the gradient of 0.4‰ at the analysed reach (between Czernichów and the mouth of Skawinka). Its largest tributaries are: Skawinka — draining the Carpathians and Sanka and Rudawa draining the terrains built mostly of the carbonate rocks covered with loesses. The river regime of the analysed reach of Vistula is under the influence of floods in Carpathians, especially in the drainage basins of Soła and Skawa. There are 3 river gauges: in Czernichów (records in 1900—1959), in Tyniec (from 1900) and in Cracow (1813—1964). The area of the drainage basin to Tyniec is 7524 km^2. Mean annual flow is here ca. 90 m^3/s, the minimum one of the year 1921 was 13.7 m^3/s (Punzet 1981), and the maximum one (in 1960) — 2310 m^3/s.

Differences between the maximum and minimum water stages at the Tyniec gauge are large (Fig. 1), and are of 0—880 cm. In Cracow they are of similar order of magnitude. One should notice the permanent decrease of the low water stages what reflects the deepening of the channel caused by channelization and exploitation of gravel and sand from the river bed. In the years 1900—1950 this deepening in Tyniec and Cracow was of about 1.5 m while in Czernichów it was substantially lesser (0.7 m). According to Trafas (1975) this process is pronounced from the beginning of the 19th century. Another feature is a more or less constant value for the maximum water stages. This indicates the increase of specific runoff during the culmination, as the bottom of the channel was subject to significant lowering and thus the channel capacity increased. It is related both to the decrease of a basin storage capacity caused by the agricultural activity of man and channelization practices resulting in an increased runoff. According to Punzet (1981) the water gauge records do not allow for drawing conclusions about the present-day tendencies in changes of climate.

In 1813, when the channel capacity was lower than nowadays, during the great flood almost the whole Holocene valley floor was inundated up to the edge of the medium terrace (Chitreyko *et al.* 1851). Only in the area of Wielkie Drogi the southern limit of the flooded area was moved about 1 km to the north from the border of the valley floor. It was connected to the presence in this area of very flat alluvial cones built of madas deposited by streams flowing from the south. During the flood of 1934 the width of the flooded zone was definitely lesser, however, Lewakowski's map (1 : 500 000) based, in part, on questionnaires does not allow for more detailed comparisons.

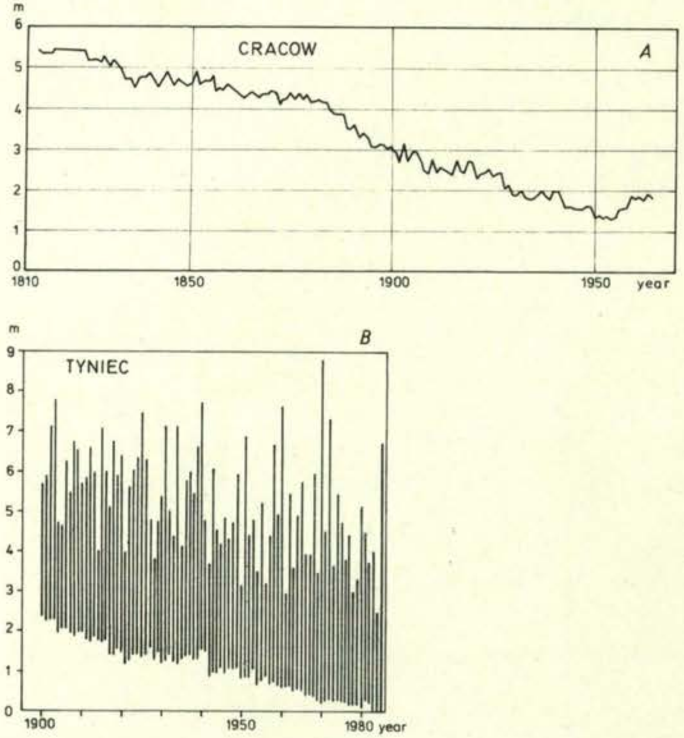


Fig. 1. Water stages at the water gauge in Cracow and in Tyniec

A – minimum water stages in Cracow according to Punzet (1981) and Trafas (1975); *B* – maximum and minimum water stages in Tyniec (water stages reduced to zero of the water level gauge of 1960)

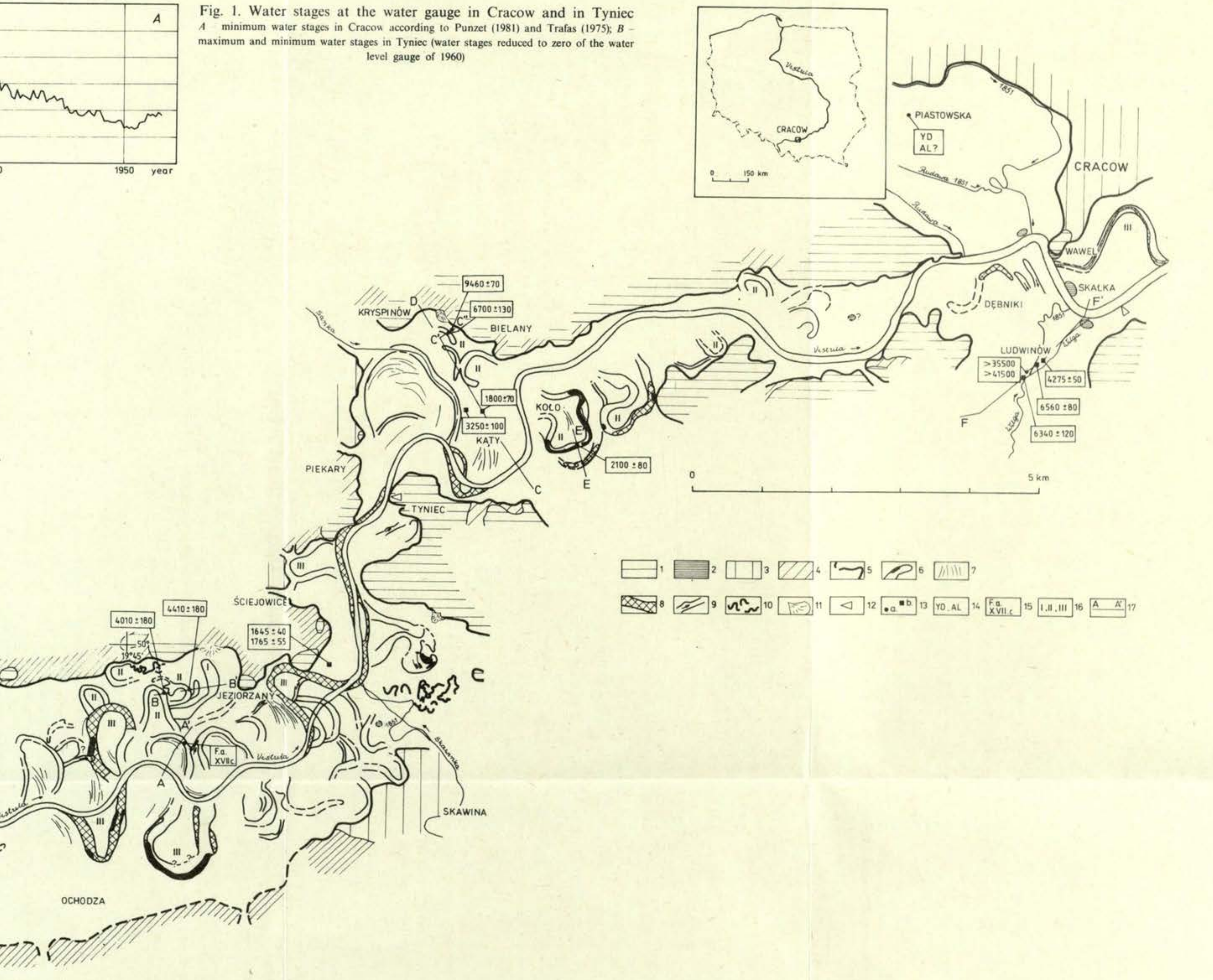


Fig. 2. Holocene Vistula valley floor between Czernichów and Cracow (region of Cracow mainly presented after Kmietowicz-Drathowa 1964)

1 – horst hills built of the Jurassic limestones visible at the terrain surface; *2* – fossil horsts built of the Jurassic limestones visible at the Sub-Quaternary surface within the range of the Holocene valley floor; *3* – middle terrace and Skawinka fan (Vistulian); *4* – hills built of the Miocene clays and Quaternary sands; *5* – extent of the Holocene valley floor; *6* – meander and oxbow lakes; *7* – meander bars; *8* – extent of oxbow lakes and of the Vistula channel according to Chitreyko (1851) in locations where it differs substantially from the present one; *9* – flood troughs; *10* – meanders of minor tributaries of the Vistula; *11* – alluvial fans; *12* – water level gauges; *13* – ^{14}C datings in years BP of: *a* – peats and silts, *b* – tree trunks; *14* – paleobotanical datings: YD – Yoldia, AL – Alleröd; *15* – abandoned channel filled after the 17th century; *16* – meander generations; *17* – cross-sections. Anthropogenic forms produced after 1950 are neglected on the map

In the years 1946—1953, when the river channel up the analysed section was close to the natural one the amount of material transported in Tyniec was about 98—236, average 165 thousands of tons/year (Jarocki 1957). The mean concentration of the suspended load was 63 g/m^3 while the maximum value during the flood of 1960 was 2456 g/m^3.

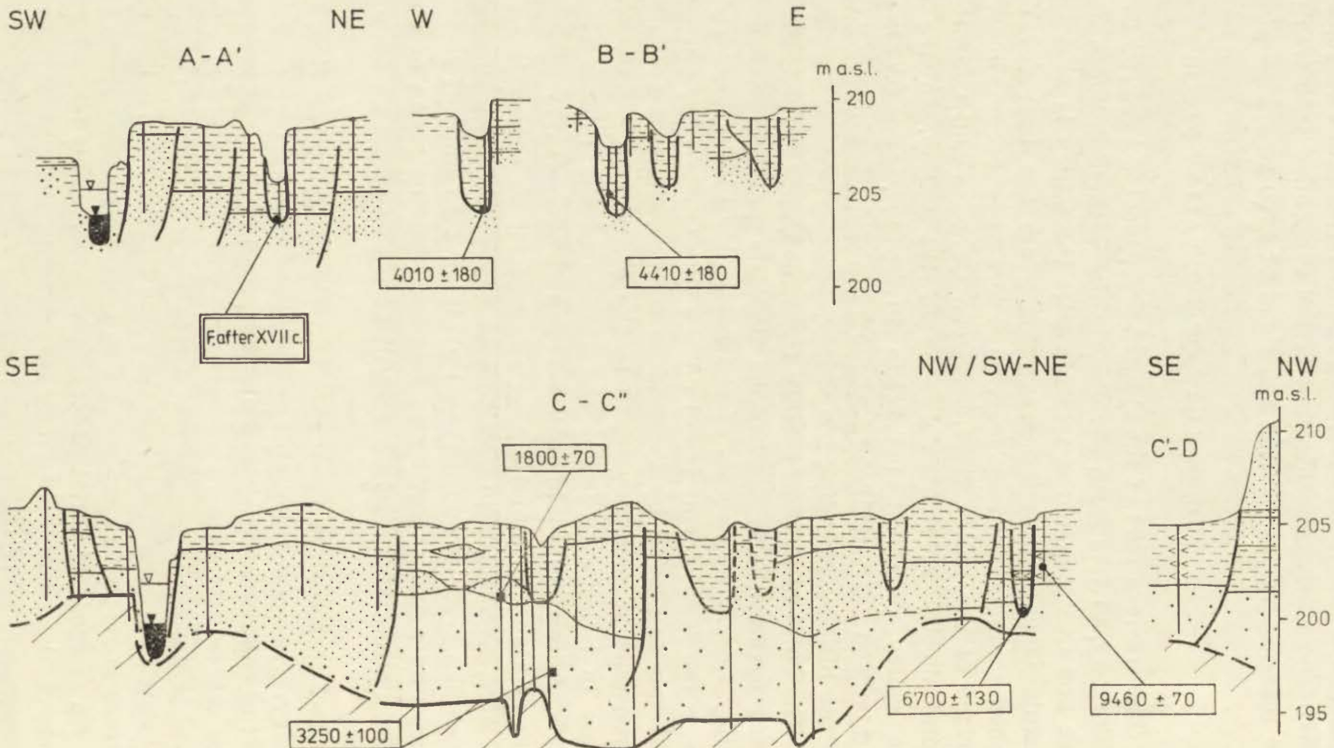
MORPHOLOGY OF THE VALLEY FLOOR

The western part of the studied area, located between Czernichów and Jeziorzany, differs from the eastern one located between Jeziorzany, Tyniec and Cracow. In the western part the valley is 3—4.5 km wide and Vistula is a meandering river. Meanders are best developed between Ochodza and Jeziorzany (Fig. 2) where they occur almost over all the surface of the valley floor. Between Ochodza and Czernichów they are found mostly in the axial zone of the valley. In the eastern part, the valley narrows to 0.4 km in Tyniec, and 0.7 km in Cracow, and only in the vicinity of Kąty is 2 km wide. Meandering is here limited by the hills surrounding the valley.

The horst hills, built mainly from the Upper Jurassic limestones, sometimes covered with Cretaceous deposits protrude above the Holocene valley floor. The heights of the particular blocks vary rof 362 m. a.s.l. up to the fossil forms found on the Sub-Quaternary surface. An important role is played by the middle terrace, built of sands sometimes covered with loesses, developed in the centre of Cracow. Silts with flora occur in Ściejowice under the loesses of the middle terrace (Sawicki 1957). According to Mamakowa and Środoń (1977) they represent the turn of Denekamp and Upper Pleniglacial. A sand cover may be found on some horst hills in Tyniec and Kryspinów. The gravel-sand cone of Skawinka river (Vistulian) and a higher step built of fluvioglacial sands constitute a valley border in Skawina. To the south of Czernichów the hills limiting the valley are built of the Miocene deposits covered with loess.

Two terraces are pronounced within the Holocene floor of the Vistula valley. The most important is the "rendzina" terrace covering the major part of the river valley and elevated 4—6 m above the mean water level. The meadow terrace of an elevation 2.5—3.0 m above the mean water level is limited to the narrow strips along the river channels. Most of it is located between the levees. In some locations the origin of the meadow terrace is related to sedimentation caused by construction of groynes.

An analysis of aerial photographs, topographic maps from various periods of time and field studies allowed to distinguish three generations of meanders differing in geometry and stage of preservation (Fig. 2) on the surface of the rendzina terrace. The channels related to the water flow during floods are also observed.


SW
A - A'
NE
W
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E
m a.s.l.
210
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F.after XVII c.
4010 ± 180
4410 ± 180
SE
C - C"
NW / SW-NE
1800 ± 70
3250 ± 100
6700 ± 130
9460 ± 70
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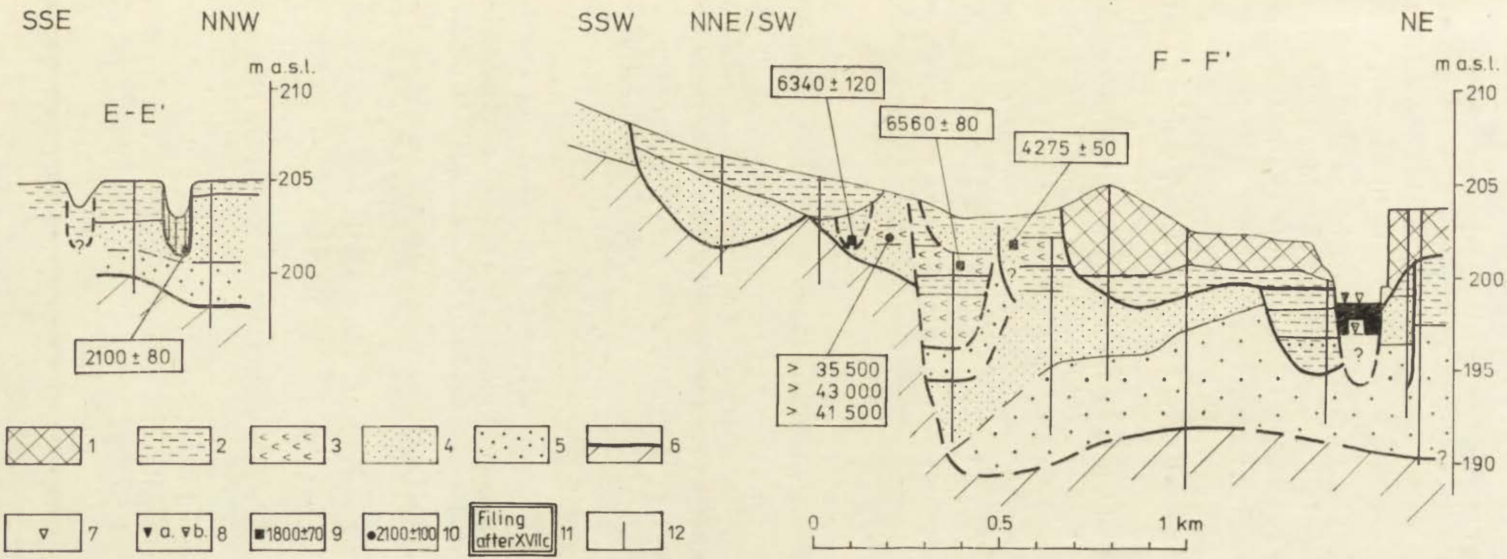

Fig. 3. Geological cross-sections of the Vistula valley between Czernichów and Cracow — location in Fig. 2 (FF′ — section according to Sokołowski and Wasylikowa (1984) slightly modified and revised in the northern part)

1 — levee; *2* — madas and silts filling abandoned channels; *3* — peats; *4* — sands; *5* — gravels and gravels with sands; *6* — upper face of the Miocene clays; *7* — mean water level of 1983; *8* — approximated water level: *a* — ca. 1900, *b* — ca. 1950; *9* — tree trunks ^{14}C dated; *10* — silts and peats ^{14}C dated; *11* — abandoned channels filled after the 17th century; *12* — drilling. Dating results in radiocarbon years

One meander at Jeziorzany, of large radius (490 m) and of a substantial width 170 m visible in the field system is included to the I generation. It is distinguished from the environment as a small depression to 0.5 m and a larger moisture content. The meander is filled with gray, rich in sand muds of a thicknes up to 4 m which do not contain organic materials and differ from muds filling the younger abandoned channels. Meanders of such a geometry are known in Nowa Huta (Kalicki, Starkel in press), where they are filled with silts covered by peat dated for Pre-Boreal (9660 ± 100 BP) and in Niepołomice Forest where they are filled with peaty silts of the Boreal period (8760 ± 90 BP, Gębica, Starkel in press). Meanders of the I generation were formed then at the turn of Vistulian and the Holocene which is in agreement with the succession of paleomeanders as described by Falkowski (1975), Szumański (1982) and Alexandrowicz *et al.* (1981).

In the studied area the peats of Bielany (dated 9460 ± 70 BP, Gd 1886) underlained by peaty silts are of the Pre-Boreal. They occur in the vicinity of an edge of the middle terrace built of sands and dissected bend-like. There is no substance, however, for connecting them to the meanders of the I generation.

Meanders of the II generation are characterized by small radius of curvature (100—300 m) and small widths of their channels (50—100 m). Relative to the surrounding terrain they are recessed about 1—3 m and thickness of the deposits filling them is 2.5—4.5 m. The gray muds of abandoned channels and, higher, the madas occur in that area. Meanders of this generation are preserved to the various extent. Their area is covered usually with meadows, to less extent with arable fields and marshes. Only in the area of Kolo Tynieckie they are very fresh, to great an extent filled up with marshes and water.

Meanders of the II generation are related to decreased and evened out discharges in the middle Holocene. Filling of the oldest dated meander at Bielany started in Atlantic (^{14}C date 6700 ± 130 BP, Gd 2361). Meanders from the Jeziorzany region (Fig. 2, 3) are filled up with muds of the Sub-Boreal (^{14}C date 4410 ± 180 BP, Gd 2362 and 4010 ± 180 BP, Gd 2375). Troughs and abandoned river channels of the Atlantic and Sub-Boreal are known from Ludwinów (Fig. 3), from the terrain which was very strongly transformed anthropogenically (Sokołowski, Wasylikowa 1984). For the trunks of the ash-trees stuck in the abandoned river channels the following ^{14}C dates have been found: 6560 ± 80 BP, Gd 1370, 6340 ± ± 120 BP, Gd 900 and 4275 ± 50 BP, Gd 1374.

The abandoned channels belonging to the II generation were active at least in the Sub-Atlantic what is indicated by the age of silts filling the meander in Koło Tynieckie (^{14}C date 2100 ± 80 BP, Gd 2173). It is in agreement with findings of Strzelecka (1958) of the Wisłok valley where the meanders of small radii were still active at the beginning of the 17th century.

The abandoned channels, of similar widths as the former ones but of the bend radii of 240—310 m, thus closer to those of the upper limit of meander radii for the II generation, occur to the west of Jeziorzany. One may not exclude the possibility that they are connected with the initial deforestation of the upper Vistula drainage basin due to human impact. For the silts filling the bottom of the abandoned river channel (sampled in a pond overgrown with vegetation) the date $^{14}C < 160$ BP, Gd 2172 was stated. According to the curve given by Stuiver (1978) the age below 160 BP in the radiocarbon scale may correspond to less than 260 years in a calendar scale, i.e. after the year 1690. Moreover, the dating in question is an average age of the deposits of the thickness of 20 cm of an unknown sedimentation rate. Then the process of filling up of the meander started earlier. Under these circumstances one may assume that the results found are not in contradiction with the map of Mieg and Waldau (1775—1783) where the channel of the Vistula is located in this zone close to its present position.

Meanders of the III generation exhibit large radii of curvature (300—470 m) and substantial channel widths 120—200 m, max. 230 m. They are recessed to 3.5 m, max. 4 m. Meadows, marshes and lakes, sparsely arable fields occur in their area. They are best developed to the west of Jeziorzany, and they also occur in the area of Kąty. The totally filled up abandoned channel located to the east of Wawel belongs to the same generation. In the case of development under constrained conditions radii of curvature are abnormally small (Jeziorzany 250 m, Ściejowice 180 m). Two abandoned channels belonging to this generation are of an unusual shape (Fig. 2). It is probably related to the shallow Miocene deposits occurring in the area of Kąty. One may not, however, eliminate the presence of the Jurassic horsts occurring not deeply under the Quaternary sediments. The well preserved traces of meander bars occur in the meanders of this generation.

The oak-tree trunks found in the vicinity of the Vistula channel and within the migration range of the meanders of III generation are of the Sub-Atlantic (^{14}C dates: in Ściejowice — 1645 ± 40 BP, Hv 9706, 1765 ± 55 BP, Hv 9707; in Kąty — 1800 ± 70 BP, Gd 2074). The elm-tree trunk from Kąty, described in the previous paper (Rutkowski 1984) as *Juglans*?, is of the Sub-Boreal (3250 ± 100 BP, Gd 2073). Thus, the relicts of earlier deposits (the Sub-Boreal ones in this case) are preserved in the zone where meanders of the III generation occur.

The meanders of the III generation had been fully formed at the end of the 18th century what may be stated from maps of Mieg and Waldau (1775—1783) and Mayer von Heldensfeld (1801—1804). Such a situation lasted until 1851 (Chitreyko) when the first channelization works were initiated. The meandering coefficient was 1.91 for the section Czernichów—Jeziorzany where the channel developed unconstrained. There were meander bars in every bend and two channel bars. Moreover, there were five islands mostly occuppied by meadows and to less extent by bushes in the discussed section. Two of those connected to the bank are preserved at present. The traces of a transfer to the braided channel system, being that characteristic of the lower San valley and middle Vistula (Szumański 1982; Falkowski 1975) are marked here only to a minimum degree.

DEPOSITS

The Miocene clays are the substratum of the Quaternary deposits in the Vistula valley (Fig. 3). Their upper surface is rather evened out (with denivelations of an order of several meters). The top of the Miocene strata is gently sloping down to the east from 199—202 m in the area of Ochodza, 197—201 m in Sambork, 193—201 m in Kąty to 189—190 m a.s.l. in Cracow.

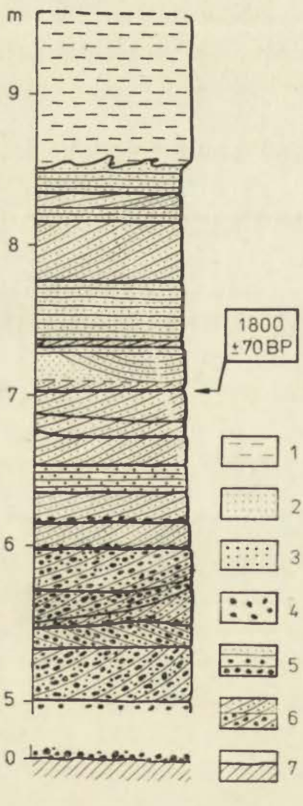

Fig. 4. Profile of the upper part of the Holocene deposits in Kąty

1 — madas; *2* — fine and medium sands; *3* — coarse sands; *4* — gravels; *5* — horizontally stratified deposits; *6* — cross-stratified deposits; *7* — Miocene clays

The valley is filled usually with sandy gravels or gravels, in the lower part, which are covered with sands and in the top of the stratum with madas (Fig. 4). The thickness of coarse-grain deposits is usually of 2—10 m (max. 11 m) within the area of rendzina terrace. This thickness may be split as follows: gravel-sandy deposits to the east of Czernichów take 2.3—8.7 m and sands covering them 1.0—6.5 m. Madas are of the thickness of 2—5 m.

The internal structure of deposits forming the valley floor is complex (Fig. 3) and difficult to be interpreted. The fragments of elder deposits may occur at the level of the Holocene valley floor. They are elder than 35 500 and 43 000 years BP (Gd 1365 and 1366) in Ludwinów. Similar is the situation to the east of Cracow (Kalicki, Starkel in press). The pre--Holocene deposits may occur particularly in troughs dissecting the top of the Miocene and which, in Cracow, are reaching obliquely the edge of the middle terrace (Kmietowicz-Drathowa 1964a), the deposits filling them are thus not younger than the Vistulian.

DEPOSITS OF THE RENDZINA TERRACE

Sandy madas (Fig. 4) are overlaying the sandy gravels covered with sands in the area of Kąty. Gravels and sands are usually cross-stratified and a thickness of particular sedimentation units ranges from several to more than 30 cm. The complexes horizontally stratified are observed less frequently, especially in sands. The gradient of the cross-stratification is of 8—33°, and most often 20°. Particular measurements are diverse what results in a low value for a compaction coefficient equal to 0.48 what is typical of the meandering rivers.

The sandy gravels occurring in the lower part of the outcrop only partly do contain gravels coarser than 64 mm, and grains finer than 0.12 mm occur in them in a minimum amount only (Fig. 5A). The grain size distributions are bimodal with prevailing grains of 0.25—1.0 mm and 8—64 mm. The mean grain size M_z, calculated according to Folk and Ward (1957) is usually from −0.45 to 2.69 ϕ (1.36—6.35 mm). Sorting is very poor (σ_I = 1.99—2.78). The sands occurring in the upper part of the outcrop are mostly medium- and fine ones (M_z = 1.48—2.46 ϕ, i.e. 0.35—0.18 mm). Usually their sorting is medium, less frequently poor (σ_I = 0.36—0.99).

Petrographic analyses of gravels have been performed for the samples from the rendzina terrace in Ochodza and from the floor of the Quaternary deposits in Kąty (Rutkowski, Sokołowski 1983). Results for both the samples indicate a very similar petrographic composition, the only difference is the presence of the 64—128 mm fraction in Kąty. The major component of gravels, among the coarse fractions, are sandstones transported from the Carpathians (Fig. 6), treated as one entity with

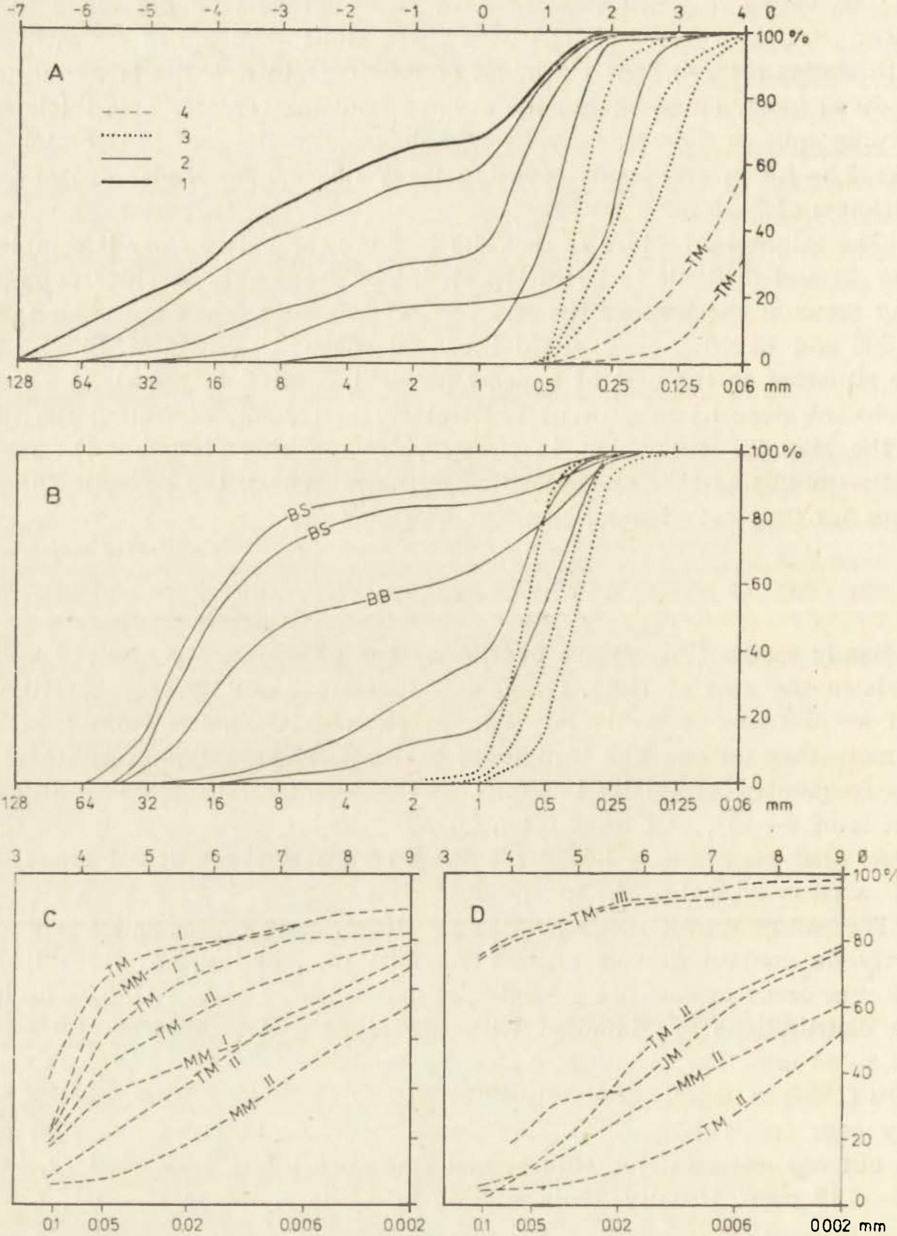

Fig. 5. Grain size composition of sands and madas filling abandoned channels

1 — gravels of the lower part of the Quaternary deposits; *2* — gravels and sandy gravels; *3* — sands; *4* — madas and silts filling abandoned channels; *A* — deposits of the outcrop in Kąty; *B* — gravels and sands of meander bars close to the Vistula channel. *BS* — samples from the bar surface, *BB* — samples from the bar surface substratum; *C* — madas of the Jeziorzany region: I — in a range of the I meander generation, II — in a range of the II meander generation; *D* — madas of the region of Kąty—Bielany: II — in a range of the II meander generation, III — in a range of the III meander generation; *TM* — terrace madas; *MM* — madas and silts filling abandoned channels; *JM* — industrial madas

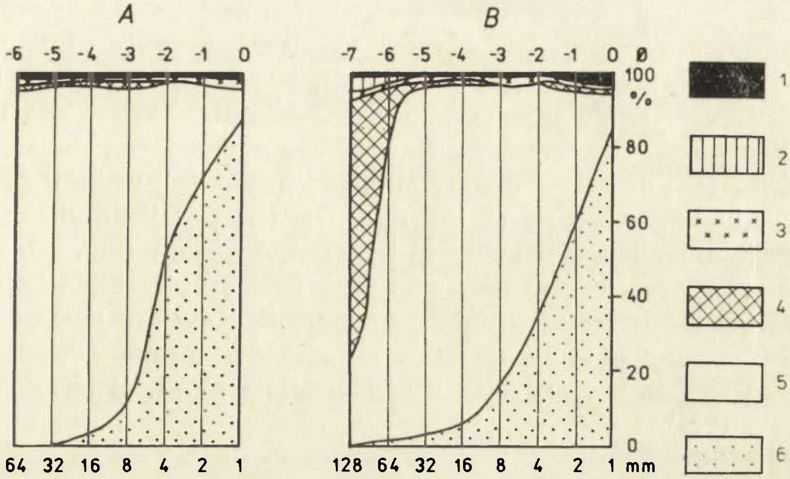

Fig. 6. Variation of the petrographic composition of the Holocene gravels of Ochodza (*A*) and of Kąty (*B*) depending on the grain size in per cent of the number of grains (after Rutkowski and Sokołowski 1983)

1 — other components; *2* — quarzites; *3* — igneous and metamorphic rocks; *4* — flintstones; *5* — sandstones and Carpathian hornstones; *6* — quartz

hornstones of Lgota beds, occurring here in an insignificant amount. The content of quartz particles increases with the decrease of the grain size. Quartz comes mostly from the Quaternary deposits of the Upper Silesia. It may be also transported from the Carpathians and from the sandstones of the Upper Carboniferous. That is supported by the presence of gravels of silificated trunks of *Dadoxylon schrolianum* Goeppert washed away from the deposits of Stephanian. The sand may, in part, originate also from the Jurassic deposits. Quartzites and igneous and metamorphic rocks occur in nonsignificant amounts. They are related to the glacial deposits (Middle Polish and South Polish glaciations). One may not eliminate the possibility that these rocks represent, in part, exotics transported either from the Carpathians or from the Upper Carboniferous deposits.

The gravels of Jurassic limestones are not present in the Holocene sandy-gravels. This is related to their fast abrasion and leaching as well as to a small supply from the lateral valleys compared to the mass of material of the Carpathian region. The important components, however, are flintstones coming from the weathered Jurassic limestones where they form concrections. They may originate, in part, from the Tertiary waste mantle occurring in the area of Tyniec (Alexandrowicz 1960) and Czernichów. Majority of flintstones belong to the coarsest fraction (64—128 mm), what is typical of gravels originating from destruction of the Jurassic limestones under the periglacial conditions. The influence of the Cracow upland on the petrographic composition of gravels of the discussed area is negligible.

Madas covering the rendzina terrace, and filling also the upper parts of meanders are gray-yellowish coloured rocks. They are usually silts, sometimes fine- and very fine silty sands, less often silty clays. Small intercalations of sands are sometimes found in the madas. The madas filling the eldest meander of the I generation and those at the meander edge in the area of Jeziorzany are silty sands (Fig. 5C) while the madas occurring in the meanders of the II generation and their vicinity are clay silts. Similar is the situation in the area of Bielany (Fig. 5D) where some samples are close to caly silts. The madas occurring within the range of the meanders of the III generation in Kąty are much coarser and are between fine sands and silts. They contain a small admixture of organic carbon (0.2—0.3%) and heavy metals (Tab. 1, Helios-Rybicka, Rutkowski 1984).

Table 1. Content of heavy metals (from to, mean) in the natural and „industrial" mada of the Vistula River near Tyniec in ppm (Fe in per cent) after Helios-Rybicka and Rutkowski (1984) and in the contemporary Vistula River sediment (in fraction smaller than 0.06 mm (after Helios--Rybicka 1983)

	Natural mada	Industrial mada	Bottom sediment
Cd	0.2–0.8	61–200	
	0.5	111	90
Zn	22–90	1960–4200	
	59	3126	4600
Pb	0.2–20.0	220–660	
	5.7	399	440
Cu	2–8	150–440	
	5.3	301	350
Ni	4–6	80–130	
	4	116	80
Cr	1–22	120–330	
	13	246	20
Mn	60–670	310–670	
	377	543	950
Fe	0.9–1.3	2.7–4.7	
	1.1	4.0	3.7

Silts filling the floor part of the abandoned river channels have a characteristic dark, almost black colour, related to the presence of hydrotroillite. The interbedded very dark and light coloured laminae are frequently observed. The thickness of these laminae may vary from one to several cm. Hydrotroillite in a contact with air is subject to fast oxidation and the rock turns gray. Due to the further oxidation of Fe^{++} to Fe^{+++} silts change their colour to yellowish-gray or chocolate-brown. An admixture of calcium carbonate is sporadically observed. Plant remains which sometimes form larger concentrations, so the silt becomes peaty or even changes into peat (Fig. 3), are frequently observed. In the area of Bielany small concentrations of vivianite were observed in them.

PRESENT-DAY DEPOSITS

Present-day gravels, sands and madas have been studied in the area of Tyniec and Koło Tynieckie. Meander bars visible at low water stages are built of gravels and sandy gravels at proximal sides and of sands at distal sides. The grain size distribution of the gravel sandy deposits is bimodal with a dominance of grains of 8—32 mm and 0.25—1.0 mm. Coarse gravels (80—95% fraction coarser than 2.0 mm) occur in the upper face of the channel-lag deposits, below there are sandy gravels (61—73% fraction above 2.0 mm, Fig. 5B). Gravels exceed 64 mm only sporadically. Mean grain size M_z is for the channel-lag deposits of -3.78 to -4.8 Φ (13.2—16.8 mm). Below, sediments are finer ($M_z = -2.50$ to -2.92 Φ, i.e. 5.60—7.65 mm). Sorting of gravels of the channel-lag deposits is poor ($\sigma_I = 1.31$—1.87), below is very poor ($\sigma_I = 2.18$—2.63). Sands building the distal parts of the bar are of medium and less frequently of coarse grains ($M_z = 0.57$ to 1.22 Φ, i.e. 0.67—0.43 mm). Mostly, they are very well sorted ($\sigma_I = 0.42$—0.49).

The petrographic composition of the present-day gravels is very similar to that of the Holocene one. The only difference is the presence of anthropogenic components: coal which is of major importance (Tab. 2,

Table 2. Content of coal in contemporary gravel-sandy sediments of the Vistula River near Tyniec in per cent of number of grains after Rutkowski (1984b)

	Fraction [mm]						
	64	32	16	8	4	2	1
Tyniec S	—	—	—	—	—	—	
Tyniec B, MF	—	—	0.3	—	2.1	3.2	
Tyniec CI			100.0	93.0	92.8	98.3	
Kąty S	—	—	—	1.4	8.0	15.6	
Kąty B	—	0.3	0.2	3.2	26.9	39.7	
Kąty MF	—	—	—	0.6	1.2	2.7	
Koło Tynieckie	3.3	1.7	11.7	31.5	31.9	12.7	
Koło Tynieckie		—	0.6	1.5	5.3	2.3	

S — gravel from bar surface, B — gravel beneath the bar surface, CI — coal intercalation, MF — the most frequent. No sign — lack of fraction, — lack of coal.

Rutkowski 1986), clusters of Jurassic limestones originating from channel management structures (0—2.7%), pieces of bricks, ceramics etc. Coal occurs as grains and gravels of the diameter up to 8, sometimes 64 mm.

It can be either dispersed in sediments or it can form intercalations of the almost pure coal between the stratified sands and gravels. It can also form covers on the so-called sand shadows and lee sides of the relief forms at the bar surfaces. The amount of coal is small or even lacking in the upper face of the channel-lag deposits. That refers to some sand samples as well.

Not only dispersion but concentration of coal is associated with density differences between it and gravels of quartz and sandstones. In the case of samples saturated with water and immersed in water the concentration is 0.36, 1.66 and 1.47 $kg/m^3 \cdot 10^3$, respectively. Thus, the coal is 4 times lighter than other components of the sediments (Rutkowski 1986). That is possible due to the fact that fairly large amount of coal between Tyniec and Koło Tynieckie is associated with washing away between the studied area and the water dam in Łączany and with an intensified sedimentation in the investigated area.

The coal occurring in the present-day Vistula deposits originate from the Upper Silesia (Kociszewska-Musiał 1969). That is an important stratigraphic indicator, dating the sediments containing it as not elder than the first half of the 19th century. It also shows the depth to which alluvia were reworked during the floods in the 19th and 20th centuries.

Some coal intercalations in the area of Tyniec are accompanied by abundantly occurring shells of mollusca, mainly *Physsa acuta* Draparnaud (Alexandrowicz in press). Its abundance is related to the electric power plant in Skawina which warms water in the river since ca. 1958. In the Vistula river, 3.5 km up the outlet of the Skawinka river which carries away the warmed water, the discussed form occurs in small amounts while *Lymnaea peregra* (Müller) and *Ancylus fluviatilis* Müller predominate among the molusca.

The present-day industrial madas associated with industrial development are characteristic deposits. They are deposited between the groynes during the higher water stages. When unweathered, they are dark-gray or black-gray and dark-gray-yellowish near the surface. When compared to the natural madas (Helios-Rybicka, Rutkowski 1984) they are usually finer (5—39% grains coarser than 0.06 mm, and 17—26% fractions below 0.002 mm). Organic carbon content is 7.1—11.8%. Bituminiferous compounds determined by extraction with chloroform constitute 0.3—1.9%. They are paraffins, to a lesser extent resins and aromatic hydrocarbons, less frequently asphaltenes. These are pollutants occasionally flowing in a river channel.

The content of heavy metals in the industrial madas is especially large (Tab. 1), several times larger than that in the natural madas and close to that observed in the present-day Vistula bottom sediments (Helios-Rybicka 1983). For example, 99.6% Cd and more than 98% Zn, Pb are associated with industrial activity of man. Such high content of heavy metals in the present-day madas is also recorded at the upper Vistula (Klimek, Zawilińska 1985). That is characteristic of rivers draining out the large industrial centres and the presence of sediments of this type is a stratigraphic indicator.

EVOLUTION OF THE VISTULA VALLEY

At the turn of the Vistulian, after the permafrost had disapeared, the studied area was subject to a rapid erosion. The latter caused that the sandy terrace, being of the Vistulian origin and fragmentarily covered with loess, in the valley of the Vistula and that of its tributary Rudawa had been dissected. Peat sedimentation had been initiated in some locations in the valley formed this way. The bottom part of the peat located at Piastowska St. is dated as the Younger Dryas while the underlaying clays represent supposedly Alleröd (Mamakowa 1970).

Meanders of large radii of curvature and of large widths were initially formed in the Vistula valley under conditions of large channel forming discharges. The only form is preserved in the studied area in the vicinity of Jeziorzany.

Next, due to decrease and smaller variations of discharges the radii and widths of meanders became smaller (II generation). The obtained datings indicate that these meanders were present in the area in question at least since the Atlantic (^{14}C date 6700 ± 130 BP, Gd 2361) until the Sub-Atlantic (^{14}C date 2100 ± 80 BP, Gd 2173). However, they could have existed much later as meanders of small radii of curvature were active in the Wisłok valley (Strzelecka 1958) still in the 17th century. Moreover, the abandoned channels of small radii of curvature in the Niepołomice Forest are filled with sediments of similar age: ^{14}C 5300—4400 BP (Gębica, Starkel in press).

An increase in channel forming discharges was associated with forest clearing in a catchment due to intensification of farming practices during over a thousand years. That caused a formation of the III generation of meanders of large radii of curvature and large channel widths known from the maps of the 18th and 19th centuries. It should be emphasized that on the map of Porębski (1563) the valley floor between Tyniec and Czernichów was covered by forests which had been mainly cut down before the end of the 18th century.

The presented succession of the meanders is characteristic of the upper Vistula valley both up and down the studied section (Klimek in press; Kalicki, Starkel in press) as well as of other rivers of the southern Poland. A shift towards a braided pattern so typical of the lower San valley or of the middle Vistula, are only slightly pronounced here.

A gravel sandy filling of the valley can be observed in Kąty and is expressed by an ascending lower face of the madas towards the valley axis (Fig. 3). That process acted since the Atlantic at least. The above is also visible in the area of Jeziorzany and in Cracow (Radwański 1972). East of Cracow the phenomenon is described by Kalicki and Starkel (in press). Traces of a river incision caused by human impact are noticeable just among the youngest sediments in the levee zone.

Consequent changes are also observed in the grain size composition of madas. They are strongly sandy in a range of the meander of the I generation. That is associated with washing away of fairly coarse material from nonforested slopes at the turn of the Vistulian and Holocene. The finer madas are found in a range of the II generation of meanders. That results from the presence of a compact vegetation cover protecting against erosion on slopes. Sedimentation of finer particles in a zone farther from the main channel was likely to take place. Madas occurring in a range of the III generation of meanders (younger than 1645—1800 BP) are coarser and contain a large amount of sands. That is probably related to washing off coarser and coarser fractions from slopes into rivers when forest clearing and farming intensification progressed as it has been stated in Besko (Ralska-Jasiewiczowa, Starkel 1975).

According to archeological studies (Radwański 1972) settling directly north of the Wawel hill occuppied the Holocene terrace and the lower parts of the middle terrace slopes until the beginning of the 11th century due to adavantageous and fairly dry climate. Since the middle of the 11th century sedimentation of flood deposits was initiated due to increased precipitation and floods, and thus settling recessed towards the higher areas (from ca. 200.5 m to 203—203.5 m a.s.l.). That process lasted until the modern ages. According to Radwański (1972) that process is climatically controlled. However, following the studies of Tobiasz (1977) that was likely to be caused by an intentional turning of the Vistula valley into a marsh for defensive purposes. Channels leading Rudawa water to the town fortifications built in the first half of the 14th century as well as a construction of a dam near Skałka leading the Vistula water into the northern channel contributed to the above. The dam existed in the 16th and 17th centuries although its construction timing is not clear.

Aggradation within the area of Cracow facilitated a channel shift to the south, to the area of Dębniki, which traces are troughs visible on the map of Chitreyko (1851). In order to prevent the above tendency a dam in the vicinity of the present Rudawa outlet (in the region of Norbertanki cloister) was constructed, and then destroyed and rebuilt several times in the 16th and 17th centuries (Tobiasz 1977).

Channelization of the Vistula river west of Cracow was started in the second half of the 19th century. In the initial phase the groynes were built what is marked on the maps of Chitreyko (1851), and then digging of meanders located NE and N of Ochodza (in the years 1842—1849 and

1896—1906) and in Jeziorzany (1895—1918) and finally filling up of the meander east of Wawel (1877) took place as well as flood control embankments (after 1934) were constructed. These processes have resulted in a narrowing and deepening of the channel.

Lining of the channel banks with blocks of the Jurassic limestones, and recently with the Carpathian sandstones causes the channel to be stable and its position does not change even during large floods. At present that is an artificial channel of a shape following a pattern of the meandering river of the middle of the 19th century.

An effect of the meander digging during channelization (mainly down of Cracow) as well as of an exploitation of sands and gravels from the river bottom is a river incision into substratum. It reached the depth of ca. 4 m in Cracow in 1813—1960 while in Tyniec in 1900—1982 ca. 2 m. The above results in a decrease of the thickness of the Quaternary gravels and sands which are 0—1.5 m in the region of Kąty and are exposed at the bottom of Miocene substratum. The layer of such a thickness is probably reworked during each flood. The lowering of the ground water table in the terrace and vanishing of oxbow lakes are successive results of erosion.

Vistula is the regulated river, and in the region of Cracow it is channelized and located within a range of backwater due to the water dam located down the town. The next water dam is under construction in Kąty. The channel character between Czernichów and Skawinka outlet is closest to the natural one. Under such circumstances a decline of natural processes and intensified sedimentation of industrial madas in the dammed up channel sections and in the inter-embankment areas are likely to be expected. More intensive erosion as well as sedimentation may only occur at bends during the floods. Results of that are gravel and sand bars forming even in the channelized sections as it was the case near the Wawel castle in August 1985.

Technical University of Mining and Metallurgy
Institute of Geology and Mineral Deposits
30-059 Kraków, al. Mickiewicza 30

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TOMASZ KALICKI, LESZEK STARKEL

THE EVOLUTION OF THE VISTULA RIVER VALLEY DOWNSTREAM OF CRACOW DURING THE LAST 15 000 YEARS

HISTORY AND ORGANIZATION OF THE STUDIES

The area extends over the quarters of the town of Cracow, i.e. Nowa Huta and Podgórze, and comprises the 10 km long section of the Vistula valley. The wide Holocene bottom (5—6 km) is bordered from the north by the middle Vistula terrace (10—20 m) which is covered with loess of the Vistulian. They valley bottom is limited from the south by ridges of the Carpathian foreland. The fundamental divisions of the Quaternary deposits are found already on the map of Zaręczny (1894): alluvia (alluvial layers), loess (deluvial loam), sands and gravels. Kleczkowski (1964) presents a structure of the loess terrace and uneven erosional socle on the valley floor. Tyczyńska (1968) describes 2 terrace steps covered with loess. According to her, the lower face of gravels of these terraces as well as gravels below the fine Holocene alluvia are associated with the Odra Glaciation. Organic sediments of the Younger Dryas and of the Eoholocene, which had been covered with madas in the Atlantic, were stated by Mamakowa (1970) in the abandoned channel in the vicinity of Rondo Mogilskie. Trafas (1975) has analysed the changes of the Vistula channel since the 18th century. The loess terrace in Nowa Huta is built of the late Vistulian loesses while the mid-Vistulian paleolithic cultures indicate they Early Glacial age of the calcareous gravels at the lower face (Kozłowski *et al.* 1970). According to Mamakowa and Środoń (1977) under-loess silts are of the interpleniglacial age (date: 27 745 ± 300 BP).

A more recent stage of investigations is related to a discovery of deluvia down of the neolithic settlement in Pleszów (Godłowska 1976). These deluvia enter the peaty fill of the abandoned channel (Wasylikowa *et al.* 1985). Geomorphological (Starkel, Niedzialkowska), pedological (Skiba), paleobotanical (Wasylikowa) and malacological (Stworzewicz) studies have been performed here. The presented studies, excluding those in Pleszów, were initiated in 1982.

The Young Holocene alluvia in a gravel-pit Branice-Stryjów were investigated by L. Starkel in a collaboration of T. Kalicki and J. Gradowski. The study of the site of Nowa Huta as well as a geomorphological mapping were performed by T. Kalicki (1984). Sedimentological analyses were carried out by J. Gradowski and A. Podgórska-Tkacz of the Department of Geomorphology and Hydrology of the Institute of Geography, Polish Academy of Sciences (PAN), paleobotanical expertises were provided by K. Wasylikowa, D. Nalepka and Z. Tomczyńska of the Institute of Botany (PAN) while radiocarbon dates were determined by M. Pazdur of the Radiocarbon Laboratory of the Polytechnical University in Gliwice (9 samples from the site in Pleszów were investigated by W. G. Mook of Gröningen).

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

LOCATION OF THE STUDIED SECTION

The analysed section is located between the 187 km and 205 km of the river course, in the western corner of the Sandomierz Basin, directly down of the gorge of the Vistula through the Cracow Gate limestones. The Holocene valley floor, wide up to 6 km and of the height of 195—200 m a.s.l., is limited from the north by loess terraces and fans of the tributaries: Prądnik and Dłubnia. The right tributaries of the Vistula from the Carpathian Foreland are smaller. Due to a small gradient (0.3—0.4‰) and a large distance from the mountains this section is well suited for deposition of the carried material, mainly of the suspended load. The region of the Niepołomice Forest located downstream exhibits distinct properties of subsidence in the Younger Quaternary (see — Gębica, Starkel in this volume). The valley floor is completely deforested and significantly changed by numerous industrial plants and water dams on the Vistula.

CHANNEL AND THE PRESENT-DAY FLOOD PLAIN

The Vistula channel upstream of the flood-gate in Przewóz is 90—130 m wide and to 6 m deep while downstream of that it is 40—80 m wide and ca. 2 m deep. Undisturbed gradient of the reach Kraków—Przewóz was 0.27‰, while that downstream was of 0.25‰ (at present the gradient upstream of the dam in Przewóz is 0.03‰). Numerous groynes are found within the channel.

The suspended load at the Raba outlet is of an order of 340 000 t/yr (Brański 1972) and varies in a very wide range.

Actually the flood plain is limited only to the inter-embankment area and its width is 450 m. Only at the outlets of the Dłubnia and Podłężanka rivers this zone widens to 600 m while together with the cut off channels it is 1 km wide in Przewóz. The embankments, up to 6 m high above the water level, protect the valley bottom against flooding. The floods result in aggradation of the flood plain. The latter is covered with

1—2.5 m thick madas which change into silty sands in a vicinity of the channel. Below the madas, there are most frequently sands, of the thickness of 1.5 m, laying on the gravel-sandy channel facies. The flood plain relief is diversified and is subject to changes after each larger flood. Numerous erosional troughs and pot-holes occur there.

CHARACTERISTICS OF THE HYDROLOGICAL REGIME AND HYDROLOGICAL AND GEOMORPHOLOGICAL CHANGES DURING THE LAST 200 YEARS

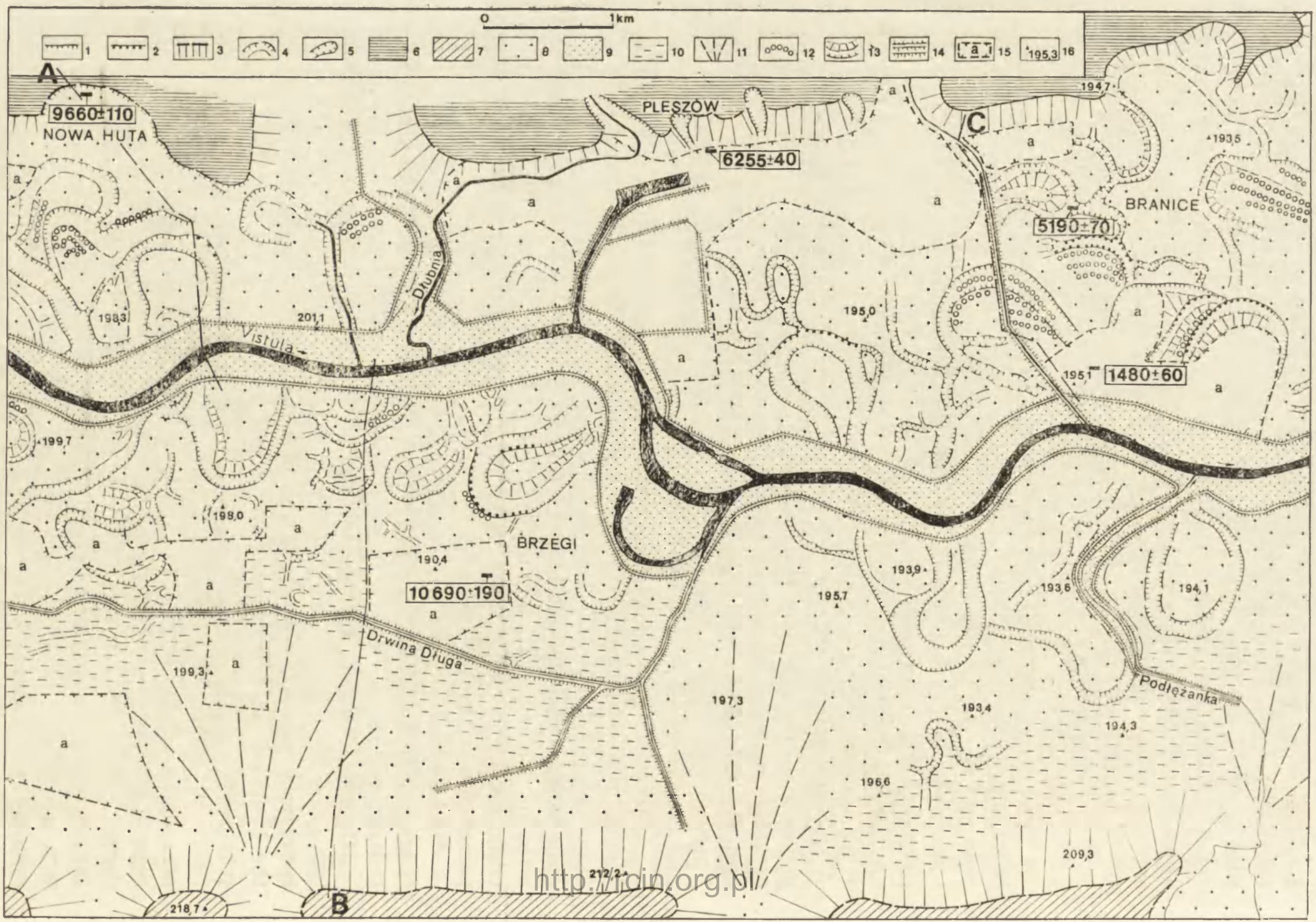
The hydrological regime of the Vistula river in the vicinity of Cracow is mainly under the influence of the Carpathian tributaries, namely the Soła and Skawa. Construction of the water reservoirs on the Sola and upper Vistula rivers (in 1938—1967) has caused high discharges to be decreased and less variable (Punzet 1979).

The maximum water stages in Cracow were observed in 1813 (995 cm) while the minimum ones in 1954 (130 cm). Thus, the amplitude is 8.65 cm. After 1900, a twice increase of the amplitude of the annual maximum stages is noticed. The amplitude was 3.34 m until 1900 while it increased actually up to 6 m (Punzet 1981). The frequency of the floods of the high and catastrophic water stages increased as well, especially since 1930. These floods occurred every 4.2 years and every 2.8 years in the 19th and 20th centuries, respectively (Punzet 1972a,b, 1973).

A large irregularity of discharges is a characteristic feature of the Vistula regime (Dynowska 1974). Maximum discharges are recorded in June—August (melt-generated and summer floods), most frequently in July while minimum discharges occur in September—February, most often in September. Minimum discharge in Tyniec is 14.4 m^3/s (in 1921) while maximum one — 2310 m^3/s (in 1960). Mean discharge of the 50-year period (1921—1970) is 91.4 m^3/s.

Hydrological changes are mainly caused by man. These are channelization and exploitation of gravels. The Vistula is a very strongly polluted river and since 1959 it does not freeze in the vicinity of Cracow.

Geomorphological changes of the Vistula channel during the last 200 years have been studied by Trafas (1975). Actual sinuosity is 1.2, however, it was much larger in the past. Already in the last 25-years of the 18th century, the channel was straightened and shortened in a natural way, e.g. the meander at Holendry had been cut off during large floods in 1785—1788. Free meandering and meander development took place in the period from 1813 to 1848. At that time the number of meanders of the radii of curvature below 300 m and that of straight sections decrease from 26—27% to 12% and from 9% to 6%, respectively, in favour of the meanders of the radii of 300—1000 m. The channelization was undertaken in 1848—1850. Several meanders were cut off what resulted in a decrease of the length of the Vistula river between Cracow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and Niepołomice by 33.8%. After channelization the meanders of the radii larger than 300 m have disappeared and straight sections increased to 20%. The channel management works were carried out in 1891—1900. Thus, the Vistula channel became narrowed and the resistant channel, able to hold the mean high water stages, was formed. Large floods did not cause substantial changes in the horizontal course of the channel since 1850. The distribution of the minimum and mean water stages of the Cracow water gauges indicates that bottom erosion took place in the channel. That erosion was almost 4 m in Cracow (since 1813), 2.25 m in Płaszów (since 1920), 2.5 m in Przewóz (since 1897), 2 m in Niepołomice (since 1883). The process of natural erosion observed since the beginning of the 19th century was accelerated due to channelization carried out in the first half of the 19th century and due to the gravel exploitation being especially intensive since 1926 unitil 1950s. The channel deepening was stopped because of a construction of flood-gates and dams in Przewóz (1954/1955) and in Dąbie (1960). Upstream of these gates accumulation takes place while erosion dominates downstream.

CHARACTERISTICS OF THE FORMS AND SEDIMENTS AT THE VALLEY FLOOR

GEOMORPHIC DIVERSITY OF THE VALLEY FLOOR

The width of the Holocene floor of the Vistula valley increases from 3 km at the outlet of the Cracow Gate to 6 km in the east, in the area of Branice. Seven zones differing with respect to the relief and geological structure and only slightly with respect to the height can be distinguished in the N-S profile (Fig. 1, 2). Definite borders between zones in forms of edges or inflections are lacking. Starting of the north, the zones are as follows:

I. Zone at the loess terrace edge. That is a flat plain with abandoned channels which are slightly pronounced in the morphology or even not pronounced. Often, their presence is evidenced only by bend-like undercuttings of the loess terrace edge or by sediments filling the old channels. This zone is broken by the younger fans of the Vistula tributaries: Prądnik, Dłubnia and Suchy Jar. The width of this zone varies and reaches

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Fig. 1. Geomorphological map of the Vistula valley in the action Nowa Huta—Branice (elaborated by T. Kalicki)

Erosional edges: *1* — to 3 m; *2* — 3—5 m; *3* — above 5 m; *4* — abandoned channels; *5* — erosional valleys; *6* — upper terrace level; *7* — Wieliczka Upland; *8* — Holocene valley floor; *9* — present-day flood-plain (interembankment area); *10* — depressions within the valley floor; *11* — alluvial fans; *12* — point bars; *13* — slope of the convex bank of the bend; *14* — flood-control embankments; *15* — areas modified anthropogenically; *16* — height posts. Lines A, B, C are lines of the profiles (see Fig. 2). Framed are ^{14}C datings up to 1 km while the height is of 200—194 m a.s.l., i.e. 4.5—5 m above the Vistula level. This zone as well as the terrace edge is strongly modified by mounds and excavations. Three subregions can be distinguished within this zone:

I.A. The region between Rondo Mogilskie and Plac Centralny with preserved arcs of paleomeanders which undercut the loess terrace edge. The paleomeanders are of very large radii of curvature of the order of 600—700 m, widths more than 100 m and depths 5—6 m. The meanders are filled at the bottom with silts which are covered with thick peat layers (2—5 m). In this area the top of the Miocene is uneven, therefore, the thickness of alluvia varies from 4 to 10 m. The gravel and gravel-sandy members of the thickness of 5—7 m are deposited on the top of the Miocene. Sands of the thickness up to 6 m occur in the point bar zones. The upper member is formed by silty madas which are 1.5—2 m thick.

I.B. The region of Pleszów between the outlets of Dlubnia and Suchy Jar with the relief entirely modified by man. Here, the loess terrace edge is of a linear course and below it deposits of abandoned channel, filled with silts and peats covered with deluvia, are preserved. The thickness of alluvia in this zone does not exceed 12 m. The gravel-sandy series of the thickness of 7—8 m lies on the Miocene. Intercalations of abandoned channels clays, underlain by sands of the thickness of 2.5 m, occur within this series at the height of 189.5 m, i.e. 6.5 m below the terrace plain.

The sandy series of the thickness of 1—1.5 m rests on the above series. The sandy one is covered with clay-silty madas up to 3 m thick.

I.C. The region between Branice and Wyciąż where the loess terrace is undercut by meander of definitely lesser radii (200—300 m) and widths (50 m). The meanders are filled with clays of the thickness of 2.5—3 m. The thickness of alluvia in this zone reaches 12—13 m. The gravel series, 7—10 m thick, lies on the Miocene. Sands covered with madas of the thickness of 2—5 m rest on the above series.

II. Zone located far away from the edge, between Pleszów and Branice, of the length of 3 km and the width of 1 km and the height of 196—194 m a.s.l. (5 m above the river level). The outlines of single meanders and entire systems of the depth of 1.5 m and with a clay fill of the thickness up to 2 m are well visible. The radii of paleomeanders are small (200—300 m) and their widths reach up to 50 m. The thickness of alluvia in this zone varies from 10 to 13 m. The gravel-sandy series of the thickness of 6—10 m lies on the Miocene. Clay intercalations, being probably the remnants of the older abandoned channel fills, occur within the above series at the height of 187—188 m a.s.l., i.e. 7 m below the terrace surface.

III. Zone located close to the present-day channel with numerous

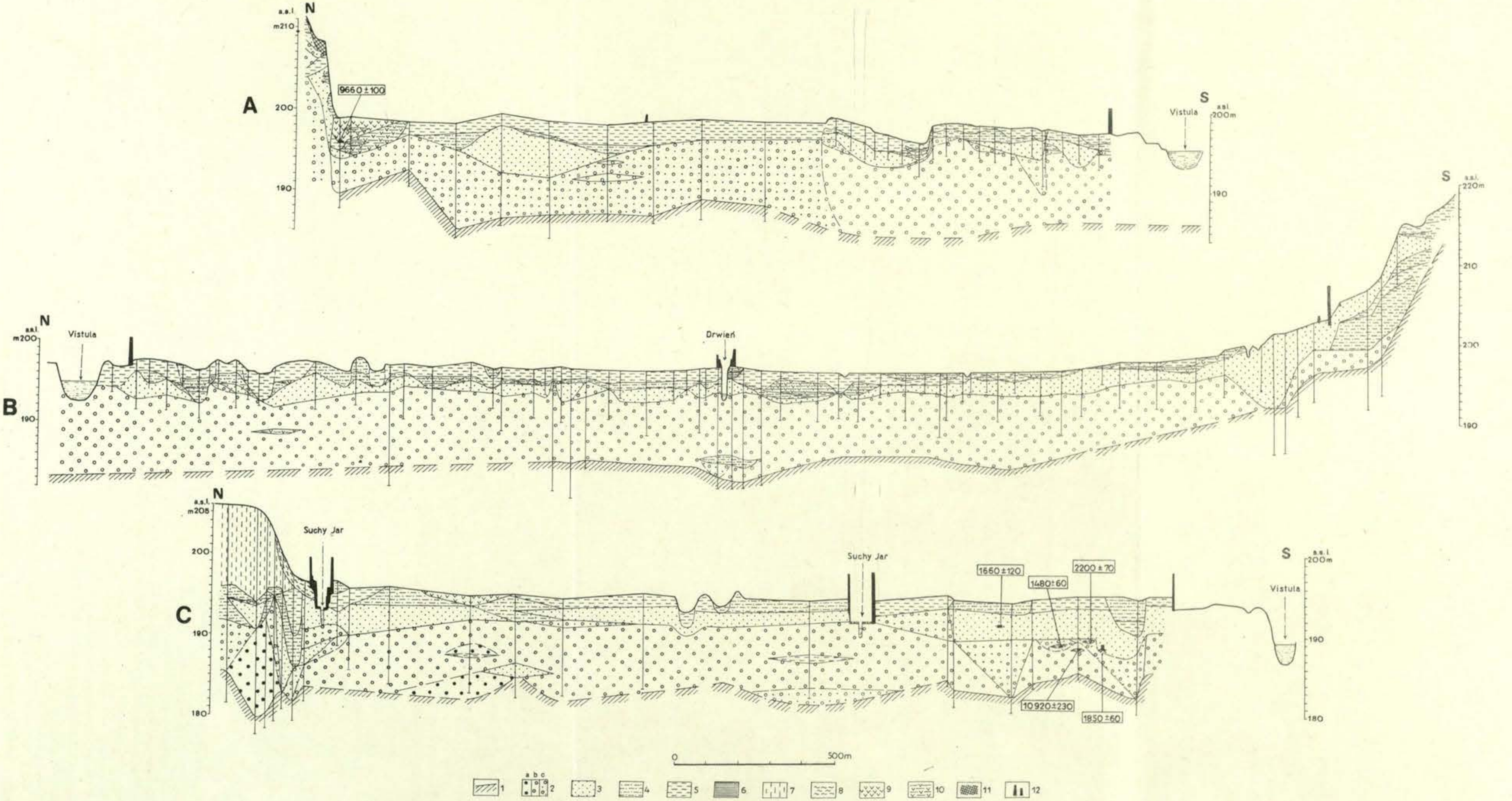

Fig. 2. Geological cross-sections of the Vistula valley (elaborated by T. Kalicki)

1 – Tertiary clays (Miocene); *2a* – gravels and pebbles; *2b* – gravels; *2c* – gravels with sands; *3* – sands; *4* – sandy silts; *5* – silts (madas); *6* – clays; *7* – loesses; *8* – deluvia; *9* – peats; *10* – organic silts; *11* – anthropogenic levees; *12* – flood-control embankments meanders of the radii of 400—500 m and channel widths of 70—120 m which were cut off in the Middle Ages (historical evidences) and during the last 200 years (cartographic data — Trafas 1975). The meander outlines are clearly visible, the height of the edge exceeds 3 m while water--logged areas and ponds occur within the majority of the recent abandoned channels. Point bars and levees are well preserved in this zone. The widths of this zone extending along the whole channel is 0.5—2 km while the height varies from 200 to 193 m a.s.l., i.e. 4—4.5 m above the river channel. The thickness of alluvia is 9—14 m. The gravel series of the thickness of 7—12 m lies on the top of the Miocene. Clay intercalations are related to the abandoned channel fill. Sands, 1—3 m thick, covered with sandy madas are found on the gravel-sandy series.

IV. Inter-embankment zone, height of 2—5 m above water level, being an actual flood plain with the regulated Vistula channel (cf. section *Channel and present-day flood plain*).

V. The right-bank zone with large meanders, equivalent of the III zone of the left-bank of the Vistula. Its width is ca. 1 km, height 201—194 m a.s.l., i.e. 5—5.5 m above the channel. The thickness of alluvia varies from 10 to 13 m. The gravel series, 9—11 m thick, lies on the top of the Miocene. Clay intercalations of the abandoned channel fill occur within this series at the heights of 189, 191, 184.5 m a.s.l., i.e. 9—10 m and 6 m below the terrain level. Sands (up to 3 m) covered with sandy madas (up to 2 m) occur on the gravels in the areas of point bars.

VI. Zone with small meanders of radii of 200 m and widths of ca. 60 m. Meanders are of a various stage of preservation and of a distinct course, they possess edges up to 1 m or are covered with younger and weakly developed madas. This zone extends from Plaszów to Brzegi. Its width varies from 0.3 to 1 km while the height from 199.5 to 196.5 m a.s.l., i.e. ca. 5 m above the Vistula water level. The thickness of alluvia is 11—13 m. Gravel series of the thickness of 8—10 m lies on the top of the Miocene. Sands 2—3 m thick, and covered with 1—2 m thick silty madas are found above this series.

VII. Zone of the flat, 1.5 km wide depression drained by the Drwień stream. The height of this zone varies from 199 to 193 m, a.s.l., i.e. ca. 4 m above the Vistula level. Two regions can be distinguished within this zone:

VII.A. West of Płaszów up to Brzegi there is a flat plain in which the 0.5 m deep and narrow troughs are incised 10 m below the abandoned Drwień channel. At the south, this zone is accreted by the fan of the tributary — Serafa. The gravel member with a flat top and of the thickness of 9—10 m lies on the evened out erosional surface of the Miocene clays of the depth of 12 m. Thin, 1 m layer of sand which thickness increases up to 3 m within the area of the fan, rests on the above. Excluding the fan, the peat layer of the thickness of 0.5 m, extending over a large area and covered with very clayey madas of the thickness up to 2 m, occurs on sands. The fan is covered with thin, 0.5—1 m sandy madas.

VII.B. Insubstantial traces of meanders with very diversified radii (from 100—400 m) are noticeable in the eastern part. The gravel series of the thickness of 8—10 m lies on the Miocene which top is at the depth of 8—11 m. That series is covered with madas of the tickness of 1.5—3 m.

CHARACTERISTICS OF ALLUVIA OF THE CHOSEN SITES

Late Glacial meander in Nowa Huta — Plac Centralny. This site represents fills of the Late Glacial channels located in the western part (zone I.A.) at the edge of the loess terrace of the radius of 650 m and the width over 100 m. Here (Fig. 3), the Vistula river has incised down to the top of the Miocene and incised into an erosional bench at the height of 192—193 m a.s.l. (Kalicki 1984). The filling of the 4.7 m deep channel starts with the mud series of the maximum thickness of 2.2 m. Silts with sandy fraction admixed, the latter constitutes 10—40%, are predominant in a composition of these muds while clay fraction constitutes 10—20%. The mud series is intercalated with 4 inserts of loamy sands (up to 10 cm thick) which provide the evidence of a periodical flow of water during floods. The mud member is covered with the peat layer of the thickness of 2.3 m in the studied profile (it reaches up to 4 m in other profiles). The bottom of that peat is dated for 9660 ± 100 BP (Tab. 1). The peat layer is divided into 4 parts: a) the lower part of peat, 1.1 m thick, containing 70—80% of the organic matter; b) clayish peat, 60 cm thick, containing 35—40% of the organic matter — this clayish peat is related to an intensification of fluvial processes; c) the part of peat originating of the period of maximum fluvial intensity, may be of the Atlantic period — this part, 20 cm thick, comprises peaty mud and very strongly clayed peat (the content of organic matter is 15%); d) the part of peat which contains 50—60% of the organic matter providing the evidence of the limited flood influences at the top.

Similar sequence of the abandoned channel sediments originating from the paleochannel located 6 km to the west, near Rondo Mogilskie, was described by Mamakowa (1970). The clayish peat was dated as of 9390 ± 180 years BP. The age of the muds underlaying the peat was determined as of the Younger Dryas on the basis of the pollen analysis. Organic sedimentation was discontinued at the beginning of the Atlantic by accumulation of sandy madas.

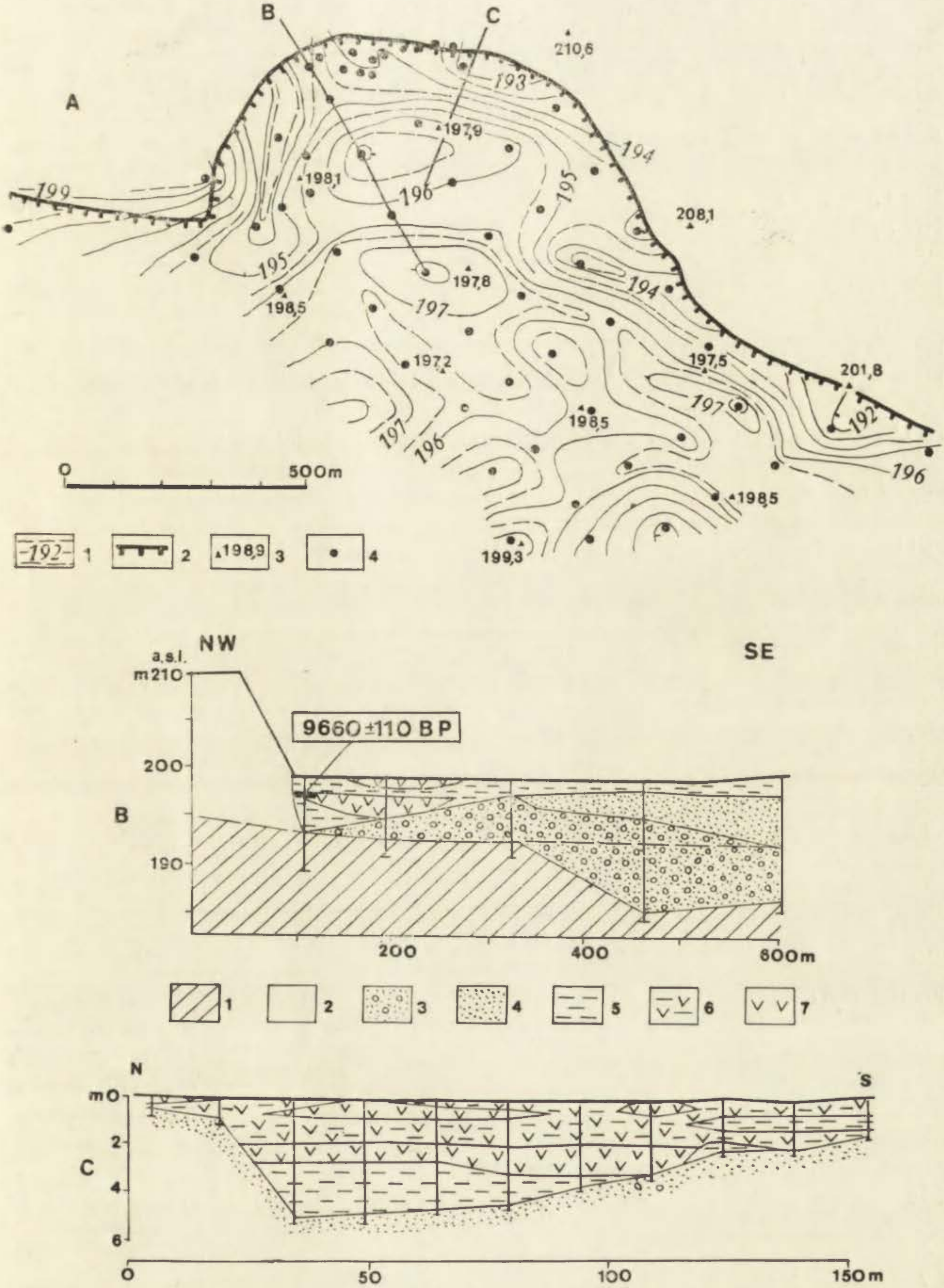

Fig. 3. Late Glacial paleomeander in Nowa Huta — Plac Centralny (elaborated by T. Kalicki)

A — map of the lower face of the flood facies (of madas): *1* — isohypses of the lower face of the facies; *2* — edge of the upper terrace level; *3* — spot heights of the terrain surface; *4* — drillings. *B*, *C* — geological cross-sections of paleomeanders: *1* — Miocene clays; *2* — deposits of the upper terrace; *3* — gravels with sands; *4* — sands; *5* — silts *6* — clayey peats and peaty silts; *7* — peat

Table 1. Collection of the radiocarbon dating

Site	Elevation m a.s.l.	Zone	Depth m	Type of material	Laboratory No.	Date BP	Comments
Rondo Mogilskie RM	200.0	IA	4.0	peat	H-1458-1031	9390±180	peats filling abandoned channel
Nowa Huta NH 11/84	198.9	IA	2.36	peaty mud at the bottom of peat	Gd-1791	9660±110	bottom of peats filling abandoned channel
Brzegi Bg 2	196.6	VIIB	2.0	trunk	Gd-2351	10690±190	possible redeposition
Pleszów	198.4	IB					peats filling abandoned channel
PIbis 9			5.06	peat with wood	GvN-9271	6255±40	
PI 12			4.88	peat with wood	GvN-9272	6075±40	
PIbis 10			5.15	peat with wood	GvN-9183	6050±40	
PI 11			4.34	peat with wood	GvN-9184	5985±50	
PIbis 7			4.77	peat with wood and some muds	GvN-9269	5910±40	
PIbis 8			4.85	peat with wood and some muds	GvN-9270	5905±40	
PIbis 6			4.61	peat with charcoal	GvN-9268	5830±45	
PID 5			2.76	decayed peat with mollusc shells	GvN-9182	5380±60	
PID 4			2.66	decayed peat	GvN-9267	4750±35	
Branice BrA1	194.0	II	1.97	trunk *Tilia* sp.	Gd-1848	5190±70	possible redeposition; at the bottom of the abandoned channel mud fill at the sand interface
Branice-Stryjów		III					
B 15	195.1		6.5	peaty mud	Gd-2087	10920±230	in clay deposits of the abandoned channel
B 7	195.2		3.2	organic detritus	Gd-2082	2700±70	redeposited material
B 12	195.5		4.0	tree trunk in sands	Gd-2088	2220±120	redeposited
B 3	194.9		5.2	pole of palisade	Gd-2080	2200±70	possible redeposition, in clay depo-

						sits of the abandoned channel
BR7	193.5	5.0	stump standing in sands cut by man	Gd-1700	1950±60	possible redeposition
B 2	195.2	6.7	stump standing in sands cut by man	Gd-2081	1850±60	in situ?, growing at the sand-gravel interface
B 26	194.6	4.1	organic detritus	Gd-2184	1660±120	possible redeposition; organic detritus at the sands and sands with gravels interface
B 16	195.0	6.0	organic detritus	Gd-1603	1480±60	possible redeposition; organic detritus of the abandoned channel clays

Late Atlantic paleochannel in Pleszów. Slope covers varnishing the fossil edge of the gradient of 55° (Wasylikowa *et al.* 1985; Starkel *et al.* 1984) are found on the slope of the loess terrace edge (slope inclination of 25—30°) settled since the early Neolithic. These covers consist of colluvium of the earth-slide which is cementated by calcium carbonate and covered with a mantle of deluvia of the thickness over 3 m. They overtop the abandoned channel deposits.

At the foot of the bend-like edge there is the plain of the Holocene terrace of the height of 196—198 m a.s.l. with a socle of the Miocene clays occurring at the depth of 12—14 m (182—186 m a.s.l.). The member of gravels which upper face reaches 192—195 m a.s.l. overlies the socle. The gravels are overtopped with the 2—4 m layer of madas. A trough, up to 2.5 m deep and wide much more than 50 m, filled with sands (1.5—4.5 m) and peats (2—4.5 m) is incised in the above gravels. Closer to the edge, the thickness of peats decreases and they are substituted by the organic mud and deluvia being 2—4.5 m thick (Fig. 4). Pollen and macro-remnants analyses indicate the Atlantic age of the lower organic layer with the bottom date as of 6255 ± 40 BP. Just below, the first phase of agricultural management is noticeable in a mineral filling. Two subsequent agricultural phases are terminated by the date 5830 ± 45 BP after which activating of the deluvial processes took place. Organic muds with aquatic mollusca being the evidence of a rise of the groundwater level and probably of an increased frequency of floods of the Vistula appear again on the 1 m layer of muddy deposits. That phase is dated between 5380 ± 60 and 4750 ± 35 BP. Above, there are only barren deluvia of the grain size composition being iden-

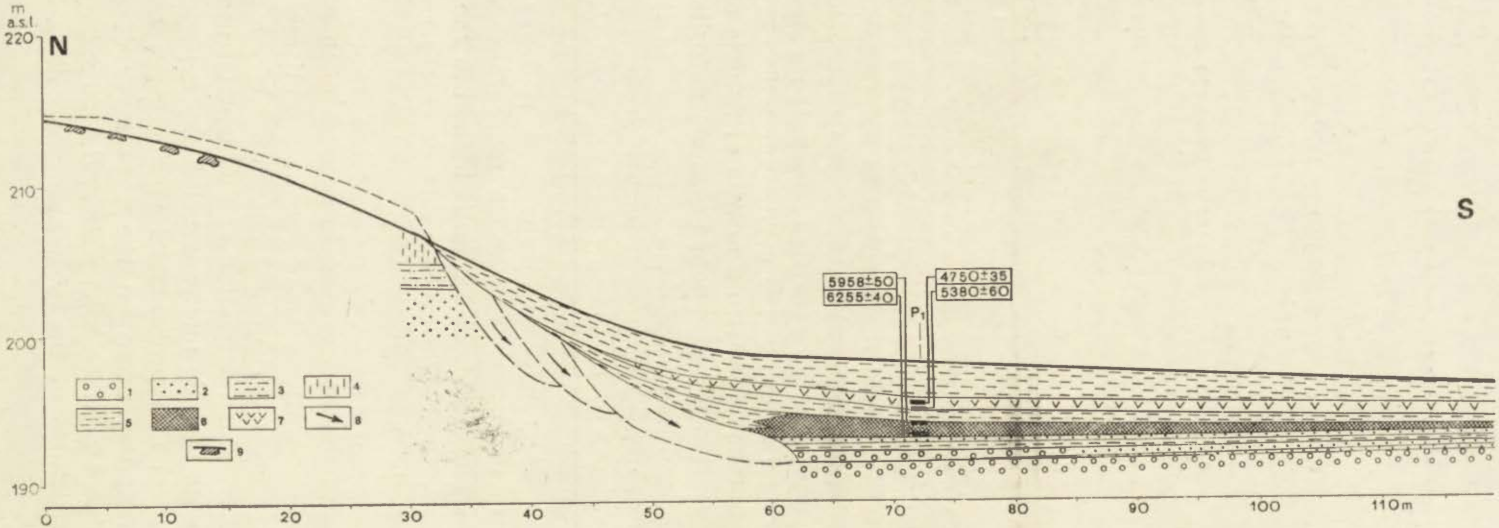

Fig. 4. Geological profile of the abandoned channel in Pleszow (elaborated by L. Starkel)

1 — gravels; *2* — sands; *3* — sandy silts; *4* — loess; *5* — deluvia; *6* — peat; *7* — organic silts; *8* — landslide; *9* — storage pits tical to that of loesses forming the edge (60—75% of 0.002—0.05 mm fraction).

The site in Pleszów is very important in the recognition of the history of the Vistula valley in the Atlantic period. The river channel had been likely abandoned slightly earlier than 6300 BP. The avulsion of the system of channels was associated with a significant flood activity known, among others, from the Wisłoka valley (Starkel 1981). Rise of the groundwater table at the turn of the Atlantic is undoubtedly the reflection of an increased humidity and of the floods registered by the Vistula channel shifts over ca. 20 km long section downstream (cf. Gębica and Starkel in the same volume).

Atlantic paleomeander in Branice. This site is characterized by sediments filling the system of channels with small parameters ($r = 200$—300 m) located in the zone II and reaching the loess terrace edge in the eastern part. The abandoned channel of the radius of 230 m and width ca. 50 m is marked in the morphology by a distinct edge up to 1 m high. Wood dated as of 5190 ± 70 BP was found below the muds of the thickness of 2 m at the interface of the underlaying sands. The muds at the bottom are more sandy (20—40% sand and up to 30% clays). Their thickness is 0.6 m. The middle member of the fill of the thickness of 0.6 m is clayey (up to 20% sand, 50—60% clay). The abandoned channel clayey fill of a character of an old mada confirms the Atlantic age what is associated with large forestation of the area and still a relatively weak human impact. The top stratum of 20 cm thick is again more sandy-silty (clay fraction is only 20—25%) what may be related to the Medieval Vistula flooding (young mada).

Gravel-pit in Branice-Stryjów. The gravel-pit providing the opportunity to learn the structure of the terrace of the height of 195 m a.s.l. is located in the zone of large abandoned channels (zone III) with the parameters similar to those of the cut ones during the last 200 years (Trafas 1975), i.e. of the width over 100 m and radius of curvature over 350 m.

The top of the Miocene clays is uneven (181—184 m a.s.l.). There are 10—12 m of alluvia on it which consist of 3 members: 6—7 m of gravel, 3—5 m of sands and 1—2 m of flood madas.

The remnants of the fills of the fossil channels of various ages occurring one besides the other (Fig. 2) have been stated at the top of the gravel member, i.e. at the height 188.5—190 m a.s.l. The oldest ones are clays and peaty muds with a distinct erosional surface at the top. The pollen spectrum of the bottom part is of the Late Glacial, the ^{14}C date is 10 920 ± 230 BP. To the west, a pole hewn by man and dated as of 2200 ± 270 BP has been found in the fill of the trough with the

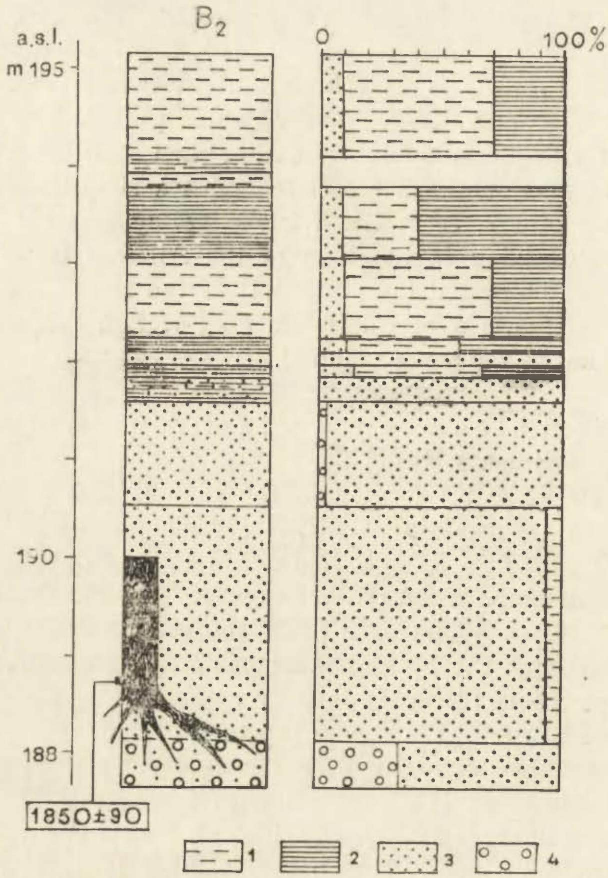

Fig. 5. Grain size composition of the profile B_2 of the gravel-pit in Branice-Stryjów
1 — silt; *2* — clay; *3* — sand; *4* — gravel

lower face 1 m above, in the striped clays. The latters are also pinched out by a pavement of gravels of the diameter up to 10 cm. To the NE, the following fills of the abandoned channels are built of a sandy bar with clays in the trough axis with wood dated as of 1480 ± 60 BP.

The vertically standing oak stump, which root part is buried under the 6.5 m layer of sands and madas, has been found in the southern part at the similar level (Fig. 5). The trunk is dated as of 1850 ± 60 BP. That is the only stump which appears to be rooted *in situ* identical to several others displaced by dredging. All of them were definitely cut by man 0.5—1.5 m above the root zone. Among their roots there is preserved a sandy mada on which they had grown. In order to verify their similar age the second stump was dated and the obtained result is 1950 ± 60 BP. That proves the tree downcutting in the 1st and 2nd centuries A.D. When at the terrace edge the settlements of potters were located and people were preoccupied with iron smelting that process required hard, high caloricity wood. After the trees had been cut down they were probably displaced because the roots of the only standing stump are in gravels. When resting on the similar level as the abandoned channel with the date 1480 ± 60 BP that stump is the evidence of erosion which occurred about the 4th and 5th centuries.

The member of well sorted sands, being definitely bipartite, is found above. The lower sands of the W—E direction of transportation are separated from the upper ones by the layer with pavement and lenticles of plant detritus occurring at the height of 191—192 m a.s.l. That was either a braided river or meandering one, however, in any case transporting a substantial amount of the material and rapidly shifting its channel. The directions of transportation follow those of levees (fossil ones), the latter are in relation to a large abandoned channel, definitely elder than the system located closer to the east and terminated by the 18th century abandoned channel. The sub-mada surface of the system of the 18th century is lower by ca. 1 m.

The presence of a pavement at the height of 191—192 m a.s.l. indicates that the channel had reached so high level which was lowered in the next period when the following meander swept to the location of the 18th century. In the zone of drillings, the reworking of sands in the channel reached up to 187—189 m a.s.l. Thus, the elder material was reworked and in a result it was placed on the secondary layer. Such a reworking of the elder sediments also explains the presence of tree trunks and of the accumulation of the plant detritus in the described series, especially at the pavement level (190—192 m). One of the trunks was dated as of 2220 ± 120 BP while two dates obtained from the plant detritus were overestimated: 2700 ± 70 BP and 1660 ± 70 BP (the date 1480 ± 60 BP has already occurred below in the abandoned channel). Wasylikowa has identified the followings among the macro-fragments: fruits of *Fagus, Quercus, Carpinus, Corylus, Potamogeton,* and among the pollen — *Abies.*

The relations between the upper sands (above the pavement level and detritus) and the abandoned channel suggest that accumulation and channel shifts occurred already in the Middle Ages. Upstream, in Cracow, Radwański (1972) has discovered two cultural levels of the 10th—14th centuries with a layer of madas indicating the floods in the second half of the 11th century. The water level was also low in the 7th—9th centuries what is confirmed not only by the settling in the area of Cracow but also by the low located clay filling of the abandoned channel at the level of 189 m a.s.l. (1480 ± 60 BP), next covered with gravels.

At the top of sands there is the mada layer of the thickness of 1—2 m. The thickest are the madas in the southern part of the gravel-pit laying within the top of the standing stump, which gradually change below into sands without any sedimentation break. The lack of gravels at the height of 191—192 m a.s.l. in the profile indicates that the entire profile of alluvia constitutes the deposit either elder than that of the Medieval channels in the northern part or if the stump was redeposited it would be the younger insert. The clayish bottom part (75% clay fraction) is characteristic and increase of coarser fractions at the top (13% sands and 60% silts) what has a character of the levee in a close neighbourhood of the Vistula channel during the last 200 years.

Gravel-pit in Brzegi. The site Brzegi, located in the western part of the Drwień depression, is now under studies (zone VII.A). Here, gravels are actually exploited. On the old maps there is visible an outline of the paleomeander of the radius $r = 360$ m and width ca. 50 m what is confirmed in outcrops by a texture of bars associated with a lateral channel shift. In particular depressions among the bars, in current shadows, there was the plant detritus in which only fragments of *Salix* sp. (3 pieces) and *Pinus* sp. (1 piece) were found (according to Tomczyńska identification). That can prove the Late Glacial age of the system. The channel which profile is exposed over the distance of 19 m is filled with clays of the thickness of 1.7 m excluding exploited mada. Some hundred meters to the east (outside the meander) there is the area with gravels of the channel facies occurring very high. The top of the gravels is directly below the madas at the depth of ca. 1.5 m what is an unusual phenomenon on the entire valley floor. Two tree trunks, one out of which was dated as of 10 690 ± 190 BP, have been found in that facies at the depth ca. 2 m below the terrain surface.

The wide zone of the Late Glacial paleochannels found on the right bank with a simultaneous presence of a slightly elder paleomeander on the opposite side, at the foot of the loess terrace edge, indicate frequent shifts of the Vistula over the flood plain and probably its generally braided nature at the turn of that period, i.e. in the Younger Dryas.

SEQUENCE OF EVENTS

Changes of the Vistula functioning in the Late Glacial and the Holocene are results of an interaction of tectonic and anthropogenic factors influencing changes of the hydrological regime and sediment load transportation which are associated with the climatic changes. They can be analysed both in a spatial approach and with respect to the extent of sediments of a particular age, that of facies and paleochannels as well as with respect to vertical changes of the Vistula longitudinal profile (cf. Fig. 6, 7).

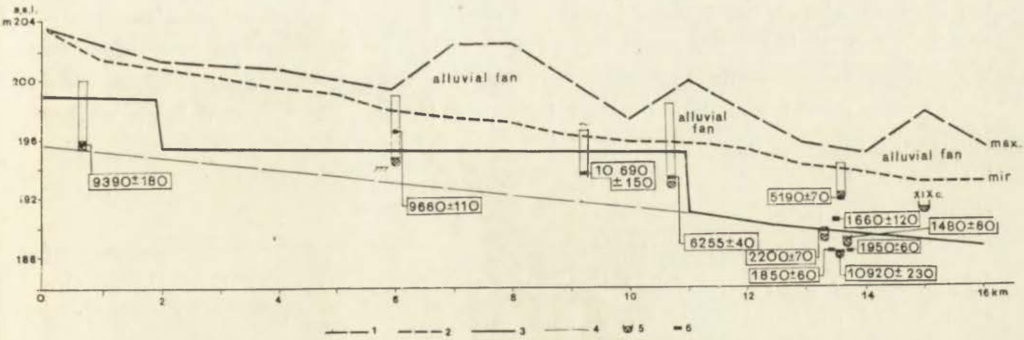

Fig. 6. Longitudinal profile of the Vistula in the section Rondo Mogilskie—Branice (elaborated by T. Kalicki)

Height of the valley bottom: *1* — maximum, *2* — minimum; *3* — profile of the present-day water level in the Vistula; *4* — reconstructed height of the water level; *5* — bottom side of the abandoned channel fills; *6* — sampling site and ^{14}C date

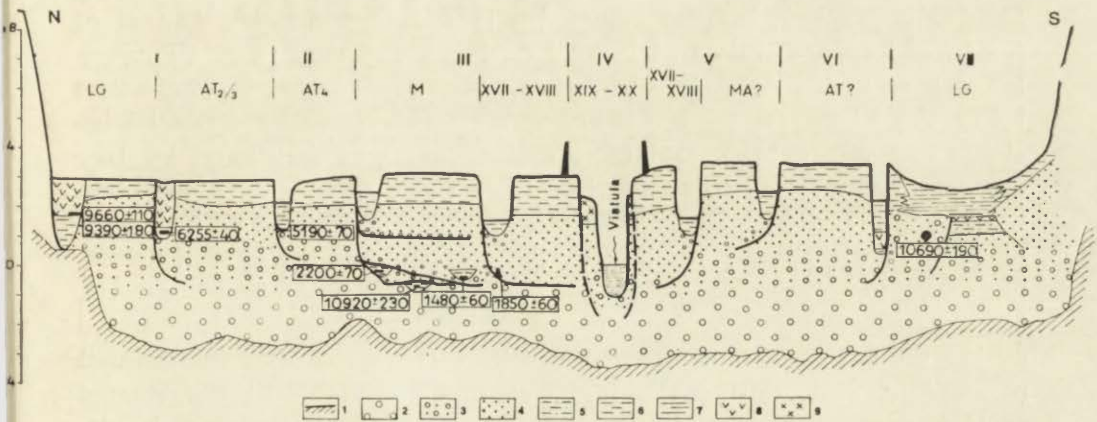

Fig. 7. Schematic cross-section of the Vistula valley downstream of Cracow (elaborated by T. Kalicki)

1 — Miocene clays; *2* — gravels; *3* — gravels with sands; *4* — sands; *5* — sandy silts; *6* — silty madas; *7* — clayey madas; *8* — peats; *9* — industrial madas; I—VII morphological zones described in the text; *LG* — Late Glacial; *AT* — Atlantic; *MA* — Middle Ages

The dissection of the alluvia underlaying the loess of the Vistulian terrace was likely initiated during the climax of the climate cooling and reached 1—2 m below the present water level (i.e. to the river bottom) in the Late Glacial as it is indicated by the paleochannel in Branice which was already filled in the Younger Dryas. The river has reached the coarse gravel level and has not been able to dissect them.

During the Younger Dryas there is a substantial aggradation because sands and gravels of that period with tree trunks reach in Brzegi up to 2 m above the present water level of the Vistula (only 2 m below the terrace plain). The mobility of the river in that period is evidenced by numerous meandering channels of the width exceeding 100 m and by the erosional benches incised in the Miocene clays found both under the loess terrace edge and on the opposite side of the valley floor. The Vistula had the regime of the transitional river meandering-braided, possibly it flew in a few channels.

The concentration of the channel was achieved in the period of 10 000—8500 years BP what indicates the lack of coarse deposits of the abandoned channel fills. Organic accumulation was interrupted during the period of the flood phase, at the beginning of the Atlantic, which is best known of the Wisłoka valley (Starkel 1981). The Vistula flew at the terrace edge in Pleszów in the Atlantic period (ca. 6500 BP). The filling of this channel should be related to the Vistula shifts during a period of intensified floods (ca. 6500—5900 BP — comp. Starkel 1981). A new system of channels known of Branice was initiated to be filled at the turn of the Atlantic period (5190 BP) during the following moister phase showing the tendencies to aggradation. The channel of the meandering Vistula was located during 2500—1500 years BP much lower than in the Atlantic, and reached the coarse gravel level (1—2 m below the Vistula water level) i.e. to the level of the Late Glacial incision and was subject to lateral shifts. That was facilitated by tree downcutting not only in the drainage basin but also on the flood plain itself. That resulted in a tendency to aggradation which was very pronounced in the Middle Ages, when the sediments of the laterally shifting channels occur at the height ca. 1 m above the present Vistula level, i.e. ca. 3 m above the channel bottom. That high level probably lasted during the entire Medieval period despite of an increase of the channel parameters. Just, during the last 300—400 years the Vistula started again to deepen its channel by a cutting down a deeper trough and cutting off the meanders which was related to an increase of the area of arable fields with more root crops. Simultaneously, the Vistula has produced, in a vicinity of the channel, wide not very distinct levees built of sandy madas which are higher by 0.5—1 m than the farther located depressions with preserved systems of channels at the turn of the Glacial. Almost all the substantial changes of climate of the Late Glacial and Holocene have been registered in the history of the discussed section of the Vistula valley downstream of Cracow while the lack of deepening in the Holocene should be explained by tectonically controlled lowering tendencies which are increasing downstream (Połtowicz 1967) as well as by the presence of the coarse gravels on the bottom the removal of which exceeded the Vistula capacity. However, the tendency to aggradation since the Roman period is associated with an increase of the sediment load due to a significant deforestation while the meander sweeping was facilitated by the clearing of forests on the flood plain.

Polish Academy of Sciences
Institute of Geography and Spatial Organization
Department of Geomorphology and Hydrology
31-018 Kraków, ul. św. Jana 22

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Geographical Studies
Evolution of the Vistula River Valley
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PIOTR GĘBICA, LESZEK STARKEL

EVOLUTION OF THE VISTULA RIVER VALLEY AT THE NORTHERN MARGIN OF THE NIEPOŁOMICE FOREST DURING THE LAST 15 000 YEARS

HISTORY AND ORGANIZATION OF THE STUDIES

Ten km long reach of the Vistula valley between Zabierzów Bocheński and Grobla comprises the area where the Vistula leaves its central position in the 6—7 km wide valley floor and undercuts a left-bank loess terrace and then an edge of Proszowice Upland (Fig. 1). Accord-

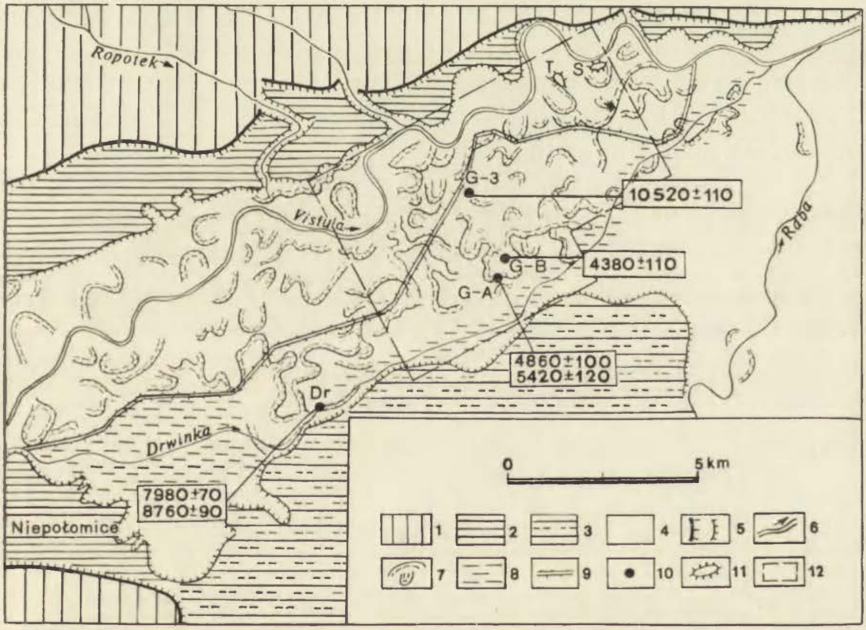

Fig. 1. Situational-geomorphological scheme of the Vistula valley floor at the northern fringe of the Niepołomice Forest

1 — plateaus; *2* — higher terrace level; *3* — sandy fan of the Raba river; *4* — Holocene valley floor; *5* — edges; *6* — Vistula channel; *7* — abandoned channels; *8* — marginal lowering of the Drwinka stream; *9* — main route; *10* — sites with the ^{14}C dates: G — Grobla, Dr — Drwinka; *11* — loess hills: T — Trawniki, S — Skała; *12* — area of detailed studies ing to Połtowicz (1967) this channel shift to the north is due to young subsidence movements being a continuation of the elder ones (Pleistocene gravels descend 50 m below the channel). Starkel (1967) relates isolated meander hills on the right bank to the loess terrace and explains their origin to be due to intensive erosion in the Youngest Holocene. Aggradation is evidenced by the Late Roman and early Medieval cultural sites (Zaki *et al.* 1970) which have been found under the madas at the foot of the Skala hill. The first detail studies in the region of the Grobla Forest were carried out by Bzowski (1973). Basing on the mapping of morphological forms and numerous drillings, he states the tendency to aggradation, and distinguishes, besides the Late Glacial lowering of the Drwinka stream, several generations of the Holocene paleomeanders. The oldest ones are in a form of fossil depressions of a medium age, and occur as a system cut off behind a levee while the youngest ones accompany the present channel. The avulsion of the Vistula to the north was supposed to occur a few hundred years ago. Simultaneous phytosociological, pedological and geomorphological studies indicate an agreement between differentiation of the types of forest communities and that of soils and various generations of the flood plain deposits, and between meadow communities in abandoned channels and age generations of paleochannels (Denisiuk 1976; Karkanis 1973; Bzowski 1973).

Basing on aerial photographs and old maps, Trafas (1975) distinguishes 3 generations of paleochannels in a chronological order from the smallest to the largest ones (the youngest). Trafas (1975) and Punzet (1981) state a channel deepening during the last 100 years by ca. 2.5 m in Cracow down to less than 1 m at the Raba outlet.

The presented stage of the studies was executed by the team under L. Starkel supervision. Geomorphological mapping and description of outcrops have been made by P. Gebica, geography student at the Jagellonian University (Starkel, Gębica 1984). Investigations of the abandoned channel fills have been performed by L. Starkel and T. Kalicki (1984) of the Department of Geomorphology and Hydrology, Polish Academy of Sciences (PAN), primary pollen analyses have been made by D. Nalepka of the Institute of Botany (PAN), molusca of the loess terrace have been studied by S. W. Alexandrowicz of the Geology Department, University of Mining and Metallurgy (AGH), physical and chemical analyses have been made by J. Gradowski and A. Podgórska-Tkacz of the Department of Geomorphology and Hydrology (PAN) while seven ^{14}C datings have been determined by M. Pazdur of the radiocarbon laboratory of the Polytechnical University in Gliwice.

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

LOCATION OF THE REACH

The studied reach is located between 110 km and 130 km of the river course, in the western part of Sandomierz Basin of the height of 180—190 m a.s.l. directly up the Carpathian tributary outlet — Raba river.

The wide, Holocene floor of the Vistula valley (6—8 km) is limited to the north by the edge of Proszowice Upland (220—270 m a.s.l.) and by the accompanying it ledge of the loess terrace of the last cold stage while to the south by systems of the Pleistocene terraces and fans of Raba at the Carpathian Foreland (Fig. 1). Larger tributaries are lacking, and except a compact forest Grobla the area is deforested and under cultivation.

PRESENT-DAY FLOOD PLAIN

An active part of the flood plain is a narrow 50—600 m band extending between the flood-control embankments (height 4—5 m) and elevated 2.5—3.5 m above mean water level in the channel (Fig. 2). Within that band the plain is diversified by bars up to 50 m wide and 50—200 m long protruding up to 1.2 m. The important morphological elements of the inundation level are flood troughs (length 200—500 m, width 10—20 m) among the point bar ridges. Among them some generations, from the present ones with definite edges and uneven bottoms (frequently filled with water) corresponding to the bend shape to the oldest troughs of gentle shapes in which clay material is deposited, are distinguished. Within the inter-embankment area the series of laminated and structureless madas of the thickness of 1—2 m rests on the channel facies sandy deposits in which "black oaks" are found.

CROSS-SECTIONS AND PARAMETERS OF THE PRESENT-DAY CHANNEL

The Vistula in the reach in question is channelized. Groynes occur at the whole thalweg along the concave banks of the bends. The channel width is 65—80 m and the radii of curvature are R = 370—900 m. The channel is incised down to the flood plain to the depth of 3—4 m. Up the reach between Wola Batorska and Grobla the Vistula is a sinuous river while down that section a meandering one (channel sinuosity — 1.4). The channel gradient (inclination of the mean water in the channel) over the 20 km long reach varies from 0.26—0.39‰ in the western part to 0.075‰ in the eastern part. Here, the Vistula cuts under the slopes of the Proszowice Upland — the channel is unstable and has a tendency for shifting to the north. The Raba fan and neotectonic movement of the substratum contribute likely to that shift (Poltowicz 1967).

HYDROLOGICAL REGIME CHARACTERISTICS

The regime of the Vistula reach between Wola Batorska and Grobla is under the influence of the variable regime of the Carpathian Vistula and its tributaries. Maximum annual discharge in the hydrological pro-

Vistula
TRAWNIKI
SKAŁA
WOLA ZABIERZOWSKA
Drwinka
186,0
195,7
182,6
185,9
186,1
181,5
185,8
183,5
183,0
184,1
185,2
184,2
184,2
182,7
0
1 km
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
183,1
N

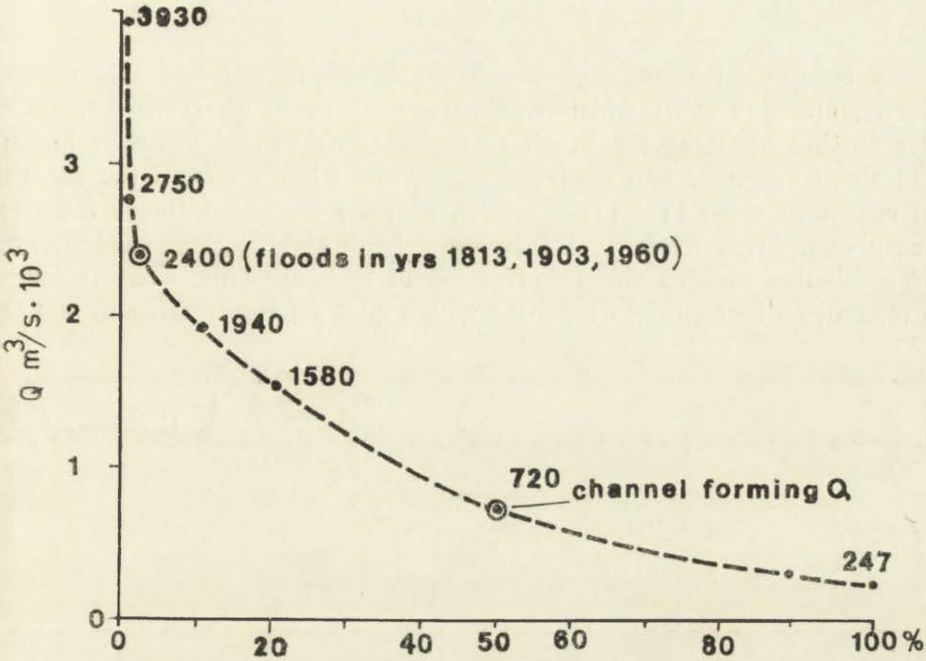

Fig. 3. Maximum discharges of the Vistula of a definite probability of occurrence in the profile Sieroslawice (1921—1970) according to Punzet (1978)

file in Sierosławice is 245 m^3/s in the period 1921—1970 (Punzet 1978). The channel forming discharge, it means, the discharge of the probability of 50% (Fig. 3) calculated for the Sierosławice profile equals to 720 m^3/s. Catastrophic floods, e.g. that of 1813, inundated a substantial part of the flood plain. Construction of the embankments contributed to a protection of the areas exposed to floods. However, it should be noticed that the high water constrained between the embankments breaks them frequently what was the case during the flood of 1970.

Fig. 2. Geomorphological map of the Vistula valley floor for the section Zabierzów Bocheński—Grobla

1—3 erosional edges: *1* — to 6 m; *2* — 6—10 m; *3* — above 10 m (broken line denotes indistinct edges); *4* — crevasse troughs; *5* — flood-water troughs; *6* — erosional valleys; *7* — plateau slope with landslides; *8* — loess terrace plains; *9* — slope of the Raba alluvial fan; *10* — rędzina terrace plain; *11* — decantation depressions; *12* — levees and point bars; *13* — slope of the convex bank of the bend (within the area of the point bars); *14* — water-logged depressions (former zones of flows); *15* — Dıwinka depression; *16* — zone of the raised levees; *17* — alluvial fans; *18* — flood-control embankments; *19* — melioration ditches; *20* — elevation posts

HYDROLOGICAL AND GEOMORPHOLOGICAL CHANGES IN THE 19TH AND 20TH CENTURIES

A substantial change of the hydrological regime has taken place during channelization which was performed in 1870s. However, meander cutting off due to a break of meander necks and meander sweaping along the river had occurred earlier what implies from the analysis of old maps since 1775 (Trafas 1975, Fig. 4a). Frequent floods favoured the above. River management included bank stabilization, straightening of particular reaches and construction of embankments. That triggered a tendency to a channel deepening which diminishes downstream and the

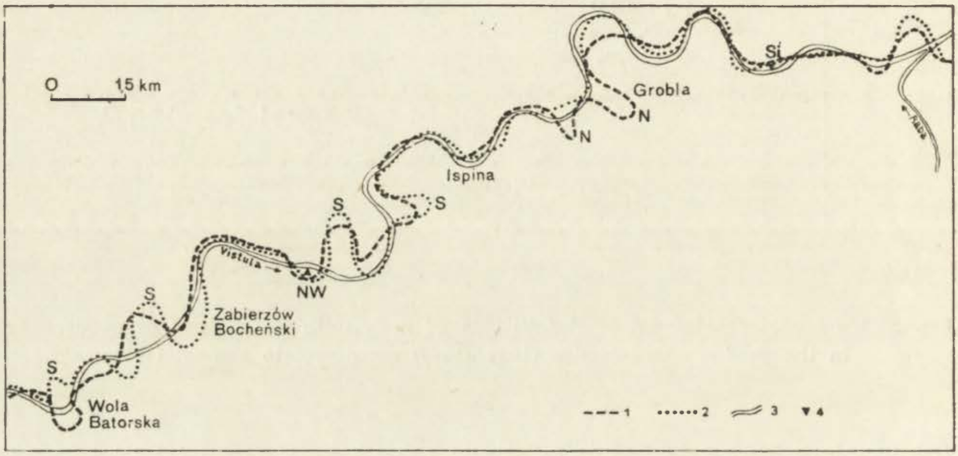

Fig. 4a. Changes of the course of the Vistula channel in the 18th and 19th centuries between Wola Batorska and Grobla (according to Trafas 1975)

1 — Vistula channel in the second half of the 18th century; *2* — Vistula channel course in the 19th century; *3* — Vistula channel in 1962; *N* — naturally cut off meanders; *S* — artificially cut off meanders; *4* — water level posts; *NW* — Nowa Wieś; *Sł* — Sierosławice

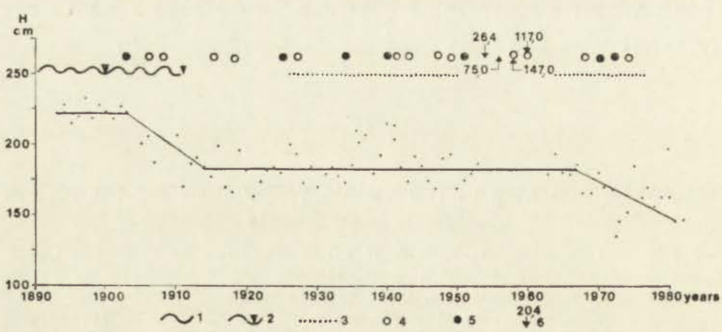

Fig. 4b. Pattern of the annual minimum water stages in 1893—1982 in the profile Sierosławice indicating the Vistula channel deepening

1 — the upper Vistula channelization; *2* — channelization of the study section; *3* — gravel exploitation; *4* — floods; *5* — catastrophic floods; *6* — single discharge measurements profile in Sierosławice down the studied area was deepened by 70 cm (Fig. 4b) in 1893—1978 only when compared to 2.5 m in the area of Cracow. According to Dembowski's studies (1984) down the Raba outlet both the erosion (8—107 cm at average) and accumulation (1—63 cm at average) took place in the inter-embankment zone in the 1937—1976. The dominance of erosion over accumulation indicates that the Vistula limited by embankments has a significant energy excess during the floods.

RELIEF AND STRUCTURE OF THE VISTULA VALLEY FLOOR

Some zones of a different paleochannel relief and structure can be distinguished in the valley cross-section. On the left (northern) bank the Holocene valley floor is limited by the loess terrace of the height of 195—200 m a.s.l. (15 m above the channel, at average) on which the cloister in Hebdów is located (Starkel 1967). The terrace flat is aggraded by alluvial fans of the streams dissecting the edge of the Proszowice Upland. The terrace is built of sands (up to 4 m above the river level), overtopped by 2 m of silts with sandy structures and 7 m of loess loams above. They contain the cold fauna of aquatic molusca which is characteristic of alases developed on a permafrost (according to primary studies of Alexandrowicz). The under-loess silts in Nowa Huta are dated at the end of the interpleniglacial (Mamakowa, Środoń 1977).

The actual valley floor elevated 2—4 m above the Vistula mean water level (descending from 190—187 m to 184—182 m a.s.l. along the river) is occupied by the complex terrace plain which had functioned as a flood plain until the channelization. The terrace plain is diversified due to a character of paleochannels and sediments building it.

The zone, located outside the interembankment area, of the width of 2 km is characterized by both fresh paleochannels and wide levees limiting this zone. Meanders frequently filled with water are usually wide (50—80 m), and of the radius of curvature of 245—400 m. Thus, they are similar to the present channel. The levee is well pronounced in a part of the Vistula bend to the north. Two meander hills, Trawniki and Skala (Starkel, 1967 — Fig. 2) protrude above the flood plain. That in Trawniki being of a table-like form, 350 m long and of the maximum height of 196.5 m (13 m above the Holocene plain) is undercut at 3 sides by the meander edges (the youngest one of the 18th century). It is built of the loess loams of the thickness of 8—9 m underlain by silts and sands with load structures and by sands (Kucia 1962). Thus, the structure is identical to that of the left-bank loess terrace (Fig. 5). The second hill, Skała (12 m above the plain), of the length of 300 m, is in a shape of a narrow ridge limited to the north by the undercut scar. The Medieval storage pits with ceramics occur in the loess loams at the top. At

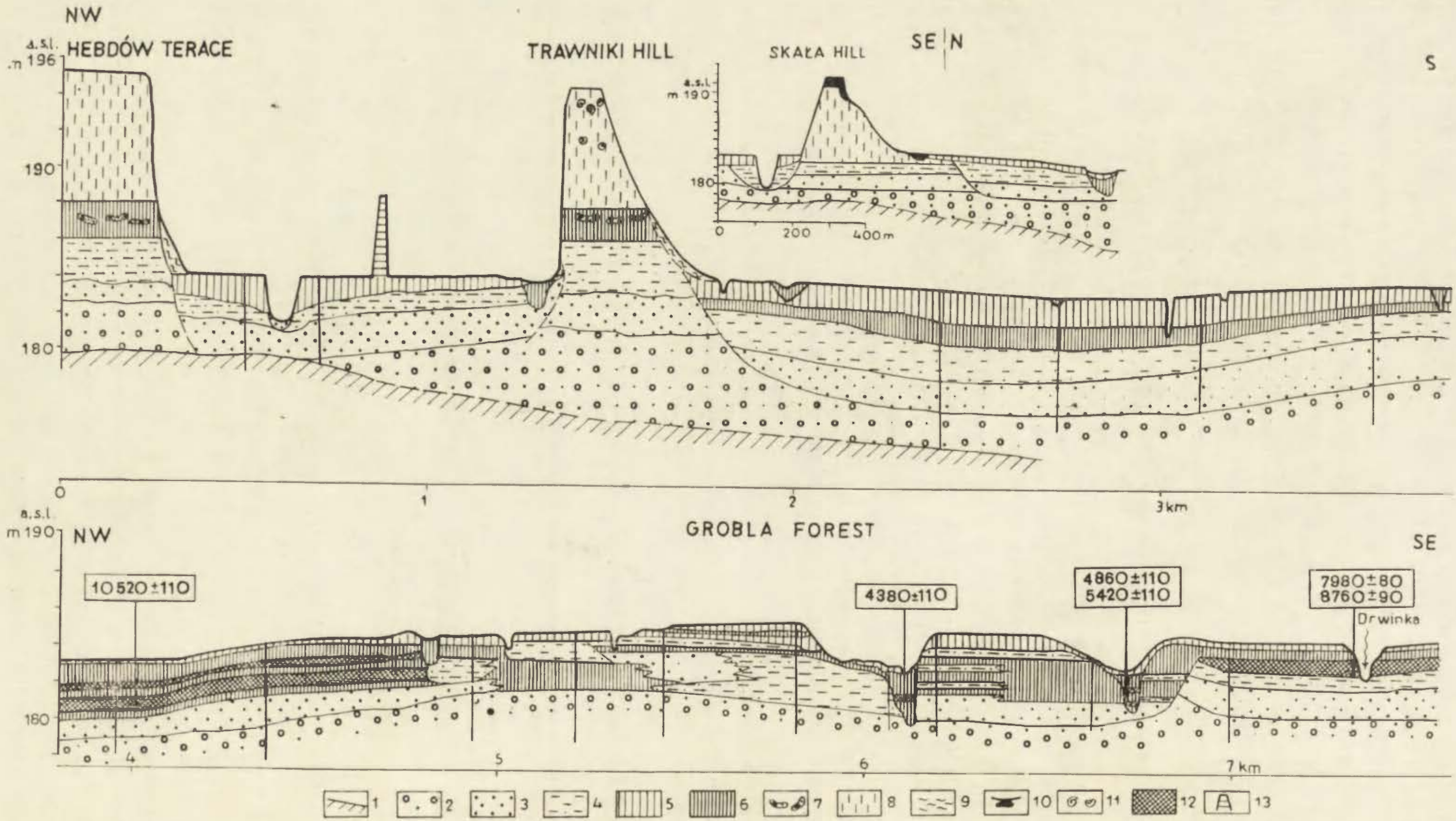

Fig. 5. Morphological-geological profiles of the Vistula valley floor in the region of the loess hills Trawniki and Skala (author's elaboration) and Grobla Forest (according to Bzowski 1973, partially modified)

1 — rocky socle (Miocene substratum); *2* — gravel and sand; *3* — medium and coarse sands; *4* — fine and loamy sands; *5* — loamy madas; *6* — clay and silts; *7* — involution structures; *8* — loess; *9* — colluvium; *10* — storage pits; *11* — mollusca shells; *12* — peats, gyttja and wood; *13* — flood-control embankment the southern foot, in the contact with the flood-plain, however, similar pits of the Late Roman and early Medieval period (Zaki *et al.* 1970) covered with 1—1.5 m thick madas have been found. These pits suggest that the area was not flooded and the Vistula channel and the flood plain accompanying it had lain much lower. The parameters of the meander limiting the hill from the south and filled with the 1.5 m layer of madas and lacustrine clay, are smaller (r = 290 m, width = = 46 m). Thus, the meander is older than the generation of the 18th—19th centuries (Fig. 6). Abandoned channels of similar sizes occur also

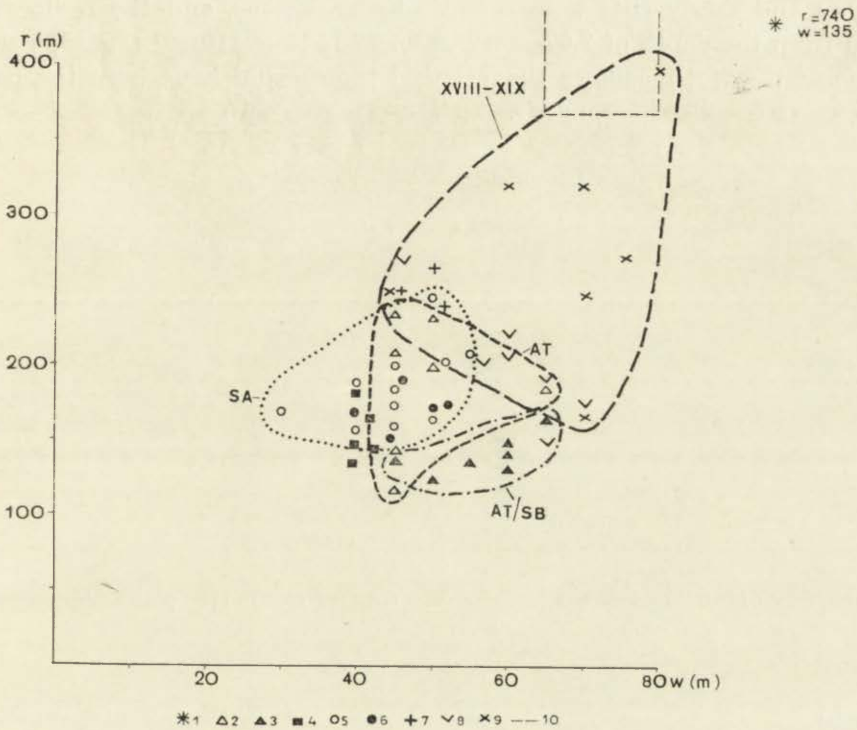

Fig. 6. Geometrical parameters of the vari-aged Vistula paleomeanders (r — radius, w — width)

Age of paleomeanders: *1* — Younger Dryas; *2* — Atlantic (Grobla Forest); *3* — Atlantic Sub-Boreal (Grobla Forest); *4* — Sub-Boreal (Sub-Atlantic?); *5* — Sub-Atlantic (Younger) — Zabierzów; *6* — Sub-Atlantic (Older) — Zabierzów; *7* — Middle Ages; *8* — paleochannels prior to the 18th century; *9* — 18th—19th century; *10* — parameters of the present-day Vistula channel

within a wide, higher by 1—2 m levee separating the present Vistula from the paleomeander system in the Grobla Forest (cf. Fig. 2). However, they are dissected there by crevasse troughs of the width up to several meters and the depth of 2—3 m. This zone widens upstream (to the west) and two systems of abandoned paleomeanders of similar parameters and of a small scattering which provide the evidence of a high discharge stability (r = 150—210 m, width 40—55 m) are found there.

The channels of smaller parameters (r = 150—220 m) occur to the south of the hills, further from the river, finally there is the area of wet plains being ca. 1—1.5 km wide and about 1 m lower. The latter one is built of silts and clays with peat intercalations. Bzowski (1973) assumes it to be of the Late Glacial. Here, the gleying soils dominate (Karkanis 1973). The drillings have confirmed the hypothesis that the backswamp sediments of the Younger Dryas (forest tundra vegetation) are found here. Sands are overlain by the 3 m layer of the alternating clayey and sandy silts with organic intercalations, and the radiocarbon date from the depth of 2.07—2.12 m was 10 520 ± 110 BP (Fig. 5, Tab. 1). Belts of the wet meadows suggest that those could have been the paleomeanders fossilized by madas.

Table 1. Collection of the radiocarbon datings

Site	Elevation	Zone	Depth	Type of material	Laboratory No.	Date BP	Comments
Drwinka		Drwinka depression					
Dr 10/75-79	185,2		2,29	peat	Gd-1849	8750±90	peat, possibly filling the abandoned channel
Dr 10/47-54	185,2		2,04	peaty mud	Gd-3135	7980±70	peat, possibly filling the abandoned channel
Grobla Forest		rised zone accompanying					
G 3 bis/1	185,0	meanders of the forest Grobla	2,32	clayish peat	Gd-1787	10520±110	peat lamina on the terrace
G A 7/1	183,0		2,23	mud with woods	Gd-2268	5420±110	bottom of the abandoned channel fill
G A 2/4	183,0		1,74	peat	Gd-2185	4860±110	peat intercalation in the abandoned channel fill
GB6/1,41--1,46	183,0		1,71	peat	Gd-2338	4380±110	peat intercalation in the abandoned channel fill
G A 7/2	183,0		2,48	wood	Gd-2269	3990±260	false date, small sample of wood in sands on the bottom of the abandoned channel fill

The elevated zone of paleomeanders of the "medium age" (Bzowski 1973) extends to the south of that depression and to the east of the levee dissected by the crevasse troughs. The zone consists of: a) system of meanders of the width of 45—55 m and radius of curvature of 120—

235 m which are cut off by b) a wider trough (45—70 m) but of a very variable radius of curvature (Fig. 2, 6). Besides the sinuous reacher ($r = 125—165$ m) the straight sections occur. This channel and the accompanying it sandy narrow levees provide the evidence of an increase of discharges (large width, straight sections) and simultaneously of a non-maturity of the channel. That suggests that all the system has been abandoned by the Vistula which shifted to the north. The gradient of this trough is also small. This plain is composed of sandy-silty madas on which brown soils and oak-hornbeam woods have been formed (Karkanis 1973). Drillings were performed in both the systems of paleomeanders (Fig. 5). The elder trough (Fig. 7), of the depth of 3 m is filled

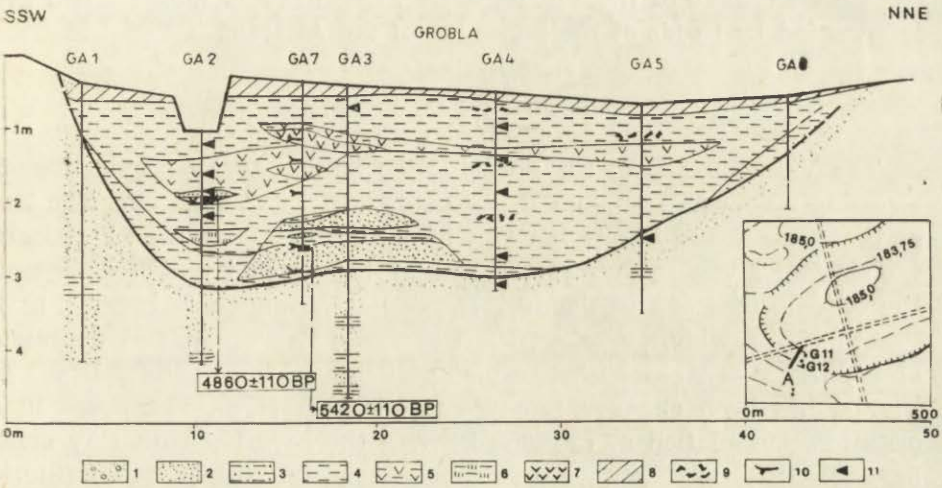

Fig. 7. Profile of the abandoned channel fill of the Grobla Forest (elaborated by Kalicki 1984)

1 — gravel with sands; *2* — sands; *3* — sandy clays; *4* — silts and clay; *5* — peaty silts; *6* — gyttja; *7* — peat; *8* — mada; *9* — levels with charcoal; *10* — wood; *11* — sampling sites

with silts containing peat and gyttja intercalations. The silts are overtopped by 1 m layer of gray clays. The date from the central part of the fill was here 4860 ± 110 BP while close to the lower face 5420 ± ± 110 BP. The above would denote that the channel was left before 5400 BP. However, in the younger trough of the depth above 4 m and width of 40 m silts intercalated with the 2 m thick peats occur under the similar layer of the upper face clay. The date in the middle part was 4380 ± 110 BP. Then, the Vistula likely stopped to flow here a few hundred years earlier, therefore, the avulsion had taken place at the beginning of the Sub-Boreal.

The southern part of the valley floor is occupied by a flat, the

1—2 km wide, wet depression of similar height which is used by the channelized Drwinka stream. The depression is built of sands covered at the top by ca. 1 m organic silt layer. An arc of the channel incised in this level of surprisingly large parameters (r = 750 m, w = 150 m) is visible in this zone near Zabierzów Bocheński. In the outcrop, at the base, there are sands and horizontally and cross-stratified gravels covered by intercalated series of paleochannel sediments of the thickness of 220 m. Below the sandy and clayey mada the 80 cm thick-peaty silt and 40 cm of gyttja lie. The date from the bottom of the peaty silt was 8760 ± 90 BP while that of the top 7980 ± 80 BP. A primary pollen analysis from gyttja suggests an early Holocene. Thus, the channel was active before the Holocene and its filling was associated with a change of the Vistula course. Organic accumulation had been interrupted by floods at the beginning of the Atlantic.

SEQUENCE OF EVENTS

The Vistula reach in the area of Niepołomice Forest provides an interesting sequence of events in the Late Glacial and Holocene. The level of the channel and of the flood plain of the Vistula in the Late Glacial was in the given section at the similar height as the present because the organic silts of the Younger Dryas lie on the sandy cover (Fig. 5). Traces of the wide, sinuous trough at the fringe of the flat depression of the Drwinka stream suggest that probably in the Younger Dryas the Vistula has been changed into the meandering river. The break in an organic accumulation at ca. 8000 BP and the covering with clay denote an increase of flood activity well known from the Wisłoka valley (Starkel 1981) and the San valley (Ralska-Jasiewiczowa and Starkel 1975).

During the Atlantic the Vistula flew along the axis of the present valley floor and was incised into the sandy cover and the river aggradated. Meandering channels started to be cut off at the turn of the Atlantic what should be related to the flood reactivation (Starkel 1983). Finally, a wide deeper channel of variable sinuosity had been left and the Vistula shifted to the north undercutting the edge of the loess terrace. Erosion in the neo-Holocene caused a destruction of the loess terrace over a several km long section. The primary extent of the terrace is evidenced by the meander hills. The processes of cutting off and the edge retreat had to be especially intensive in the Middle Ages what is indicated by a dense settling on the hill Skała and by the fact that villages and farmsteads being on the right bank (Zabierzów Bocheński, Trawniki) at present belong to the parishes located on the left bank of the river (cf. Bzowski 1973; Starkel 1967). The Late Roman storage pits covered with madas (Żaki *et al.* 1970) are the evidence of the progressing aggradation in the valley. The Vistula channel of the Middle Ages

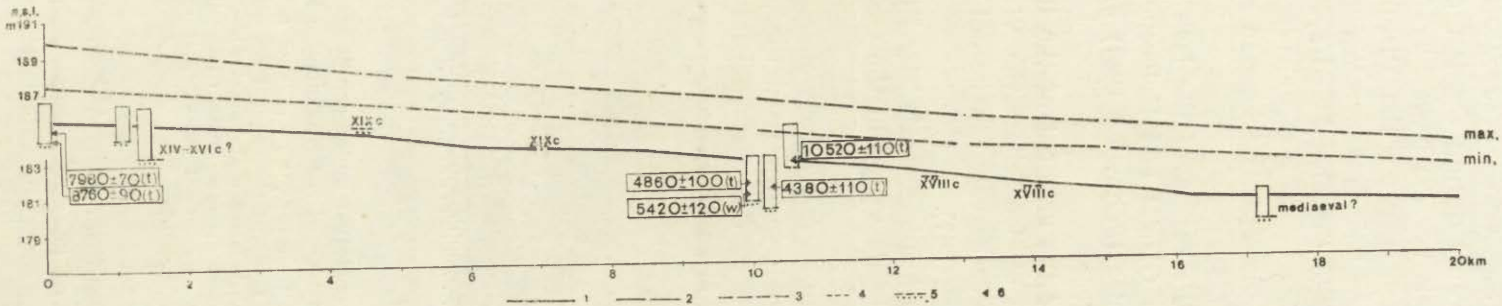

Fig. 8. Longitudinal profile of the chosen morphological elements of the Holocene floor of the Vistula valley in the section Zabierzów Bocheński—Grobla

1 — profile of the present-day Vistula channel; *2* — maximum height of the flood-plain; *3* — minimum height of the flood-plain; *4* — reconstructed height of the Late Glacial terrace plain; *5* — reconstructed heights of the paleochannels with the channel facies deposits; *6* — sampling sites and the ^{14}C dates; t— peat; w — wood was more narrow and with respect to the curvature it was similar to that of the Atlantic (Fig. 6). Just during the last centuries flood frequencies increased and channels became larger. Trafas (1975) computes that the channel forming discharges for the Vistula close to Cracow increased almost 3 times (from 268 to 762 m^3/s). The Vistula started to flood (e.g. in 1813) again into the abandoned system of channels of the turn of the Atlantic scouring crevasse troughs in the levee. Meander cut off and channelization of the Vistula triggered a new phase of the downcutting.

An open question is still the reason of the lack of the valley floor deepening at the end of Late Glacial and Holocene. That is probably related to subsidence tendencies (Poltowicz 1967) and to influence of the alluvial fan of the Raba river.

A characteristic decrease of the gradient of the flood plain and that of the river (cf. Fig. 8) at the section where the Vistula enters a deep basin (to 50 m) filled with river gravels can be only explained by the Quaternary tectonics (Połtowicz 1967).

Similar lack of a deepening has been stated by Niedzialkowska *et al.* (1985) at the section of the Vistula valley in the Oświęcim Basin being undoubtedly subsiding.

The avulsions of aggradating river are very characteristic of the studied section. That phenomenon is known from the areas of subsidence basins described among others of the eastern part of the Hungarian Basin (Borsy, Félegyházi 1983; Mike 1975).

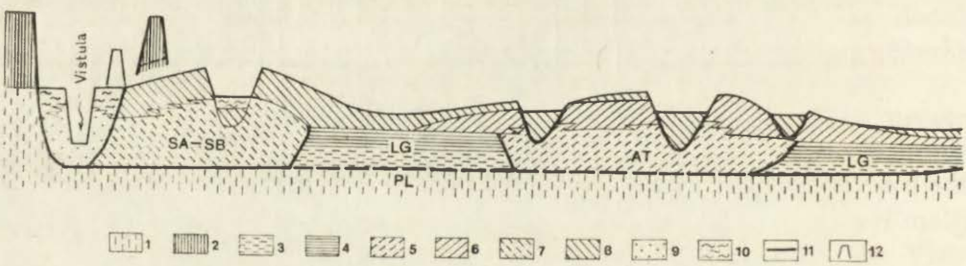

Fig. 9. Scheme of the Holocene aggradation under conditions of the channel shifts at the northern fringe of the Niepołomice Forest

1 — channel facies (pleniglacial); *2* — loess (PL), *3* — channel facies (Late Glacial); *4* — facies of the flood deposits (LG); *5* — facies of the channel deposits (Atlantic); *6* — facies of the flood deposits (AT); *7* — channel facies (Sub-Boreal—Sub-Atlantic); *8* — facies of the flood deposits (SB—SA); *9* — channel deposits facies (19th—20th century); *10* — flood deposits facies (19th—20th century); *11* — erosional surfaces; *12* — flood-control embankments

The whole bottom aggradates (Fig. 9) by the channel avulsions while the entire abandoned systems of channels preserve unchanged channel parameters to much greater extent than this is the case of the single, cut off bends. The latters are difficult to be compared since each bend can be of a different age.

Polish Academy of Sciences
Institute of Geography and Spatial Organization
Department of Geomorphology and Hydrology
31-018 Kraków, ul. św. Jana 22

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Evolution of the Vistula River Valley
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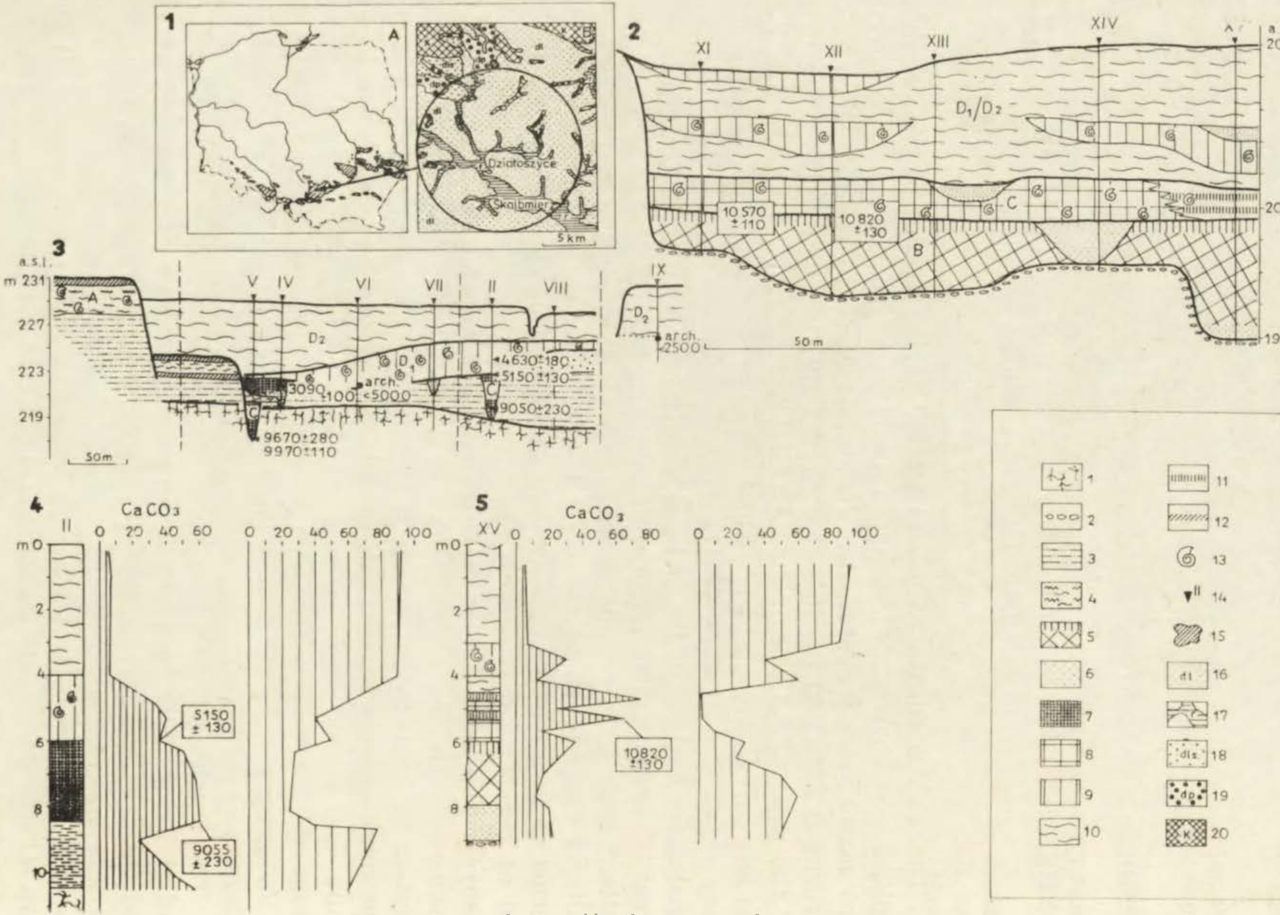
ZBIGNIEW ŚNIEŚZKO

THE LATE VISTULIAN AND HOLOCENE FLUVIAL DEPOSITS OF THE MIDDLE NIDZICA RIVER IN THE AREA OF DZIAŁOSZYCE

The middle Nidzica valley is located at the border of the Miechów Upland and the Nidzica Basin in the area of continuous loess covers. The major morphological directions are related to the Pre-Quaternary structural lines and the loesses conceal only the elder relief. Thus, most of the dry valleys, denudational basins and ravines, all formed within the loess cover, are located on the lines of depressions of the Sub-Quaternary relief. The surface of the Nidzica drainage basin in the area of Działoszyce is lacking the natural plant cover, and formerly continuous areas of brown soils and chernozems, at present occur in a patch-like pattern among the denudated areas. This is the result of prolonged agricultural exploitation of the loess terraines. Its origin is related to the period of the Neolithic "revolution" (Kruk 1983). The present-day channel of the Nidzica is narrow (3—4 m) and the river is channelized in many locations. The river is characterized by small and rather regular discharges. The minimum ones are in January, February, June and September while the maximum ones occur in February, May and August. The minimum discharges oscillate slightly about 1 m^3/s while the maximum ones exceed the value of 4 m^3/s. The specific runoff (for the water gauge in Skalbmierz, the area of 369 km^2) is small and is equal to 5 l/s/km^2 what, in connection with the regular discharges, indicates a large soil retention.

The studies of the geographical environment in the Late Vistulian and Holocene have been conducted in the valleys of the middle Nidzica and Sancygniówka since 1978 (Śnieszko 1983; Alexandrowicz, Śnieszko, Zajączkowska 1984; Śnieszko 1985). The obtained results allow for distinguishing the river series corresponding to the following phases: 1) the turn of the loess accumulation (Fig. 1—3A), 2) post-erosional phase of the Late Vistulian (Fig. 1—2B), 3) Eo- and Mesoholocene phase (Fig. 1—3C) and 4) the anthropogenic phase (Fig. 1-D_1, D_2). The oldest of the studied series represented by overbank muds with organic detritus and


1
A
B
Działoszyce
Skalbmierz
5 km
2
XI
XII
XIII
XIV
a.s.l.
205m
D_1/D_2
C
10 570
±110
10 820
±130
B
200
196
50 m
IX
D_2
arch.
<2500
3
a.s.l.
m 231
227
223
219
A
V
IV
VI
VII
II
VIII
D_2
D_1
4630±180
5150±130
3090
±100
arch.
<5000
9050±230
9670±280
9970±110
50m
4
II
CaCO3
0 20 40 60
0 20 40 60 80 100
m 0
2
4
6
8
10
5150
± 130
9055
± 230
5
XV
CaCO3
0 20 40 60 80
0 20 40 60 80 100
10820
±130
1
2
3
4
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the loess malacofauna was found in the upper face of the first overflood terrace. The other ones are forming the flood terrace. Due to the deep river erosion before the Bölling (Jersak 1965; Jersak, Snieszko 1983; Klatka 1968) the elder river deposits, preserved on the overflood terraces, were removed from the floors of the Nidzica and Sancygniówka valleys. As a result the Late Vistulian deposits of the post-erosional phase are overlaying the solid Sub-Quaternary substratum. These are the overbank river muds with an admixture of the weakly decayed peat-like substance overlain in the upper face with the wood-peat layer (wood-peat datings are 10 570 ± 111 (Gd 1149) and 10 820 ± 130 (Gd 1448). These deposits are correlated with the slope muds filling the floors of the dry valleys in the catchment.

The lateral erosion of the meandering channels, lasting since the beginning of the Holocene, resulted in a total removal of the deposits of the turn of the Vistulian in the Sancygniówka valley. The preserved fossil abandoned channels of the Early Holocene were filled with the organic-carbonate substance with the minimum admixture of the loess component. In the pollen spectra of these deposits the *Graminae* constitute from 37.4% to 59.5%. In terms of age they correspond to the thick humus horizons forming on the plateau and in the depressions of the dry valleys. In the case of the Nidzica valley the peat-carbonate deposits overlay all the surface of the fossil Late Vistulian valley floor giving the evidence for its water-logging at the beginning of the Holocene. Actually, there is no data indicating that there was a substantial change in the characteristics of sedimentation in the studied valleys during the Atlantic period. Still were accumulated peats and carbonates, only the content of calcium carbonate increased in the deposits. The Early Holocene chernozemic soils in the dry valleys are subject to the processes of turning into the brown soils. In all the types of forms there are no deposits indicating that the mechanical denudation took the active part.

The anthropogenic river series in the middle Nidzica and Sancygniówka valleys is developed as the overbank mineral-organic and orga-

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Fig. 1. The main river series of the valleys of the middle Nidzica and Sancygniówka rivers

1 — location of the study area: *A* — within the loess patches, *B* — in relation to the geological structure; 2 — cross-section of the deposits of the fragment of the Nidzica valley floor; 3 — cross-section of the Sancygniowka valley deposits; 4 — variation of the content (in per cent) of calcium carbonate and other mineral components in the core II; 5 — variation of the content (in per cent) of the calcium carbonate and other mineral deposits in the core XV; *1* — calcareous substratum; *2* — level of gravels; *3* — the Vistulian sands and silts; *4* — the Late Vistulian mada; *5* — Late Vistulian mada of the post-erosional phase; *6* — channel sands; *7* — organic-carbonate fillings of the abandoned channels; *8* — overbank organic-carbonate deposits; *9* — black muds, strongly carbonate; *10* — loess-like silts; *11* — wood-peat; *12* — levels of meadow soils; *13* — mollusca; *14* — localizations of the probes; *15* — loess in Poland; *16* — loess in the Działoszyce area; *17* — Holocene alluvia; *18* — sand loess; *19* — Pleistocene sands and gravels; *20* — Cretaceous limestones and marls

nic muds with peats intercalations. This series assumes the thickness of up to 8.0 m. The beginning of its sedimentation happened to occur about 5150 ± 130 BP (LO-14) and is related to the increasing activity of the Funnel Beaker culture with its center in Bronocice (Kruk, Milisauskas 1978). The fast rate of accretion of the overbank deposits is related to the progressing deforestation and increasing denudation of the surrounding plateaus. These processes resulted in the few meters thick slope deposits found in the dry valleys floors.

The distinguished river series differ in the content of the non-carbonate mineral material. Both the Late Vistulian and the anthropogenic deposits contain mostly the material originating from the mechanical denudation of the loess covers. In the Eo- and Mesoholocene deposits this material is only a small admixture, contrary to the calcium carbonate of the chemical denudation (Fig. 1-4,5). Such a differentiation is reflecting the evolution of the vegetation from the forest-steppe and the Eoholocene steppe, the latifolious forest of the Mesoholocene to the synanthropic vegetation of the Neoholocene. The human impact in the area of the middle Nidzica catchment has substantially influenced the changes in certain features of the loess displaced due to the denudation. The intensification of the processes of the surface and furrow washing, and an increased role of the flood discharges in the modelling of the river valleys resulted in a strong facial differentiation of the redeposited material (Fig. 2). When analysing the distributions of calcium carbonate, ferrous and ferric hydroxides and of organic substance in the various types of deposits it has to be stated that:

1. The overbank river deposits exhibit the largest facial differentiation and they are the most different from those of the primeval loess. The least modified loess is filling the fossil ravines. The deposits filling the dry valleys differ from the loesses in the substantially lowered carbonates content and an increased humus content (Fig. 2-I). This is due to the different courses of the morphological processes and the hydrological differences between the areas of deposition.

2. The overbank deposits of the Nidzica river are more differentiated than the synchronously accumulated deposits of the Sancygniówka river (Fig. 2-II). This may be explained as being related to the fact that the more narrow valley floor of the Sancygniówka (max. width of 500 m) was rapidly and as a whole accreted since the triggering of the ravine erosion. In the Nidzica valley (width of 2 km) the accumulation was more intensive in the areas of levees and at the ravine outlets what resulted both in the differentiated hydrological relations and deposition in the valley floor.

3. The overbank deposits of the Sub-Boreal period of these two valleys exhibit much less pronounced facial differences than the Sub-Atlantic deposits (Fig. 2-III). This is due to the fact that the rate of the side

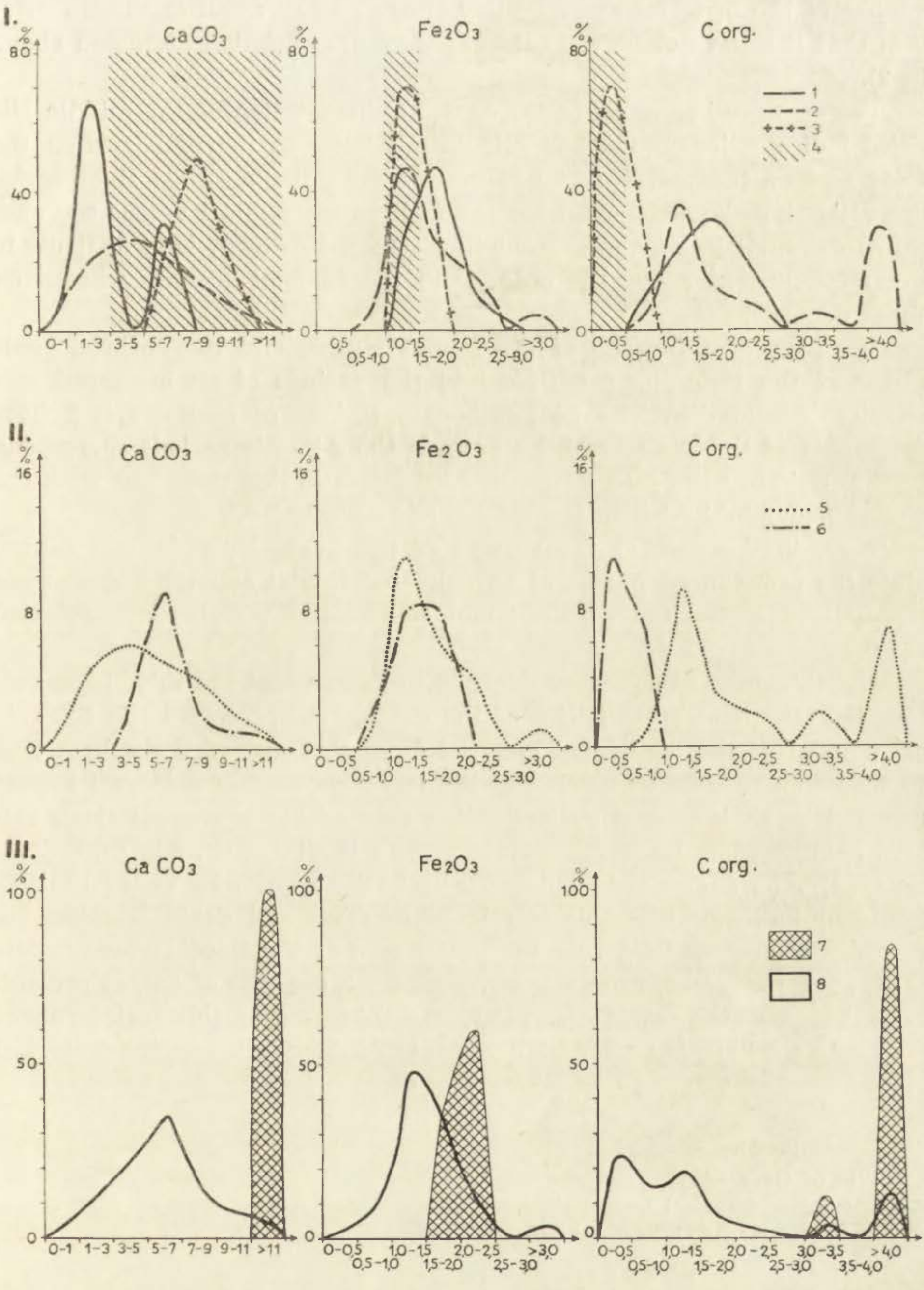

Fig. 2. Differentiation of the anthropogenic deposits in the middle Nidzica catchment

1 — slope deposits; *2* — overbank fluvial deposits of the Nidzica; *3* — fossil ravine deposits; *4* — loess; *5* — overbank deposits of the Nidzica; *6* — overbank deposit of the Sancygniowka; *7* — Sub-Boreal overbank deposit of the Nidzica and the Sancygniowka; *8* — Sub-Atlantic overbank deposit of the Nidzica and the Sancygniowka; x-axis — percentage of samples; y-axis — content in deposits (%)

supply of the material to the valley floors was so small in the Sub-Boreal that it could not be the cause of the differentiation discussed above in 2).

The changes in the character of the sedimentation of the middle Nidzica indicate the pronounced coincidence between the processes on the floor and on the plateau. The features of the distinguished river series are reflecting the changes in the ratio of the mechanical versus the chemical denudations on the surrounding slopes. However, it is difficult to draw conclusions about the changes in the channel geometry based on these deposits.

The overbank deposits of the Late Vistulian and the anthropogenic phase of the Holocene correspond to the periods of an increased mechanical denudation. The peat-carbonate fillings of channels and floor fragments of the Pre-Boreal, Boreal and the Atlantic periods correspond to the period of the intensification of the weathering processes with the simultaneous inhibition of the mechanical denudation.

Thus, in the case of the valleys of the Loess Uplands, one cannot state the pronounced phases of an animated fluvial activity known from the valleys of the Carpathian tributaries of the Vistula river (Starkel 1977).

The thickness of the river deposits in the area of the inter-loess valleys is a result of an intensity of the denudation processes and the rate of removal of the denudated material from the area of the valley. Due to the same reasons the period of the last 600 years of a human impact resulted in an increased sedimentation rate within the small river valleys (Klatka 1958; Kosmowska-Suffczyńska 1983; Jersak, Klatka, Śnieszko 1983). The analysis of the deposits in the Sancygniówka valley (Śnieszko 1985) indicates that this is related to dikes and dams catching the denudated loess. This is why the upper face of the flood terrace is formed, in many places, from a few meters thick deposits of the, at present, nonexistent water reservoirs. Thus, the thickness of this series cannot be used as a base for comparing the rate of denudation in the historical period.

Silesian University
Institute of Geography
Department of Physical Geography
41-200 Sosnowiec, ul. Mielczarskiego 60

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TADEUSZ SOKOŁOWSKI

VISTULA VALLEY BETWEEN THE OUTLETS OF DUNAJEC AND BREŃ RIVERS

HISTORY AND METHODS OF THE STUDY

At the beginning of the present century Łomnicki (1903) and Romer (1911) distinguished the fundamental terrace forms and discussed their structure as well as the development of the right-hand-side of the valley. Walczowski (1968, 1972) characterized the northern part of the valley. The entire section was synthetically presented by Starkel (1967, 1972) and Sokołowski (1981a, in press).

Hydrology and sediment load transportation in the Vistula channel were studied by Punzet (1972, 1981), Klimek (1979, 1983) and Kociszewska-Musiał (1969).

Archeological and historical studies on the settling in the valley (Cabalska *et al.* 1974, 1975; Mateszew 1974) are also helpful when the valley evolution is discussed.

This paper is based on the valley mapping in the scale 1 : 25 000 and on the already published geological maps and aerial photographs. In order to determine lithology of sediments, granulometric and petrographic studies of the gravel fraction (according to Rutkowski's method, 1977) as well as mineralogical ones in the case of fine sediments (madas and muds) have been performed. The archival drillings and cartographical materials have been utilized. The latter are especially useful when reconstructing the Vistula channel changes during the last 300 years.

This paper was realized and financially supported by the project MR I-25 "Changes of the geographical environment of Poland".

LOCATION OF THE STUDY AREA

The study reach of the Vistula river is located in the northern part of the Sandomierz Basin between the outlets of the Dunajec and Breń rivers, i.e. between 160 and 212 km of the river course. The valley width exceeds 20 km in some locations here. The valley is surrounded by plateaus, up to 100 m high, built of the Miocene clays (Sarmatian) covered with sandy and sandy-gravel glacial and fluvioglacial deposits of the South- and Middle-Polish Glaciations.

Following Starkel (1972) the middle sandy terrace protruding several meters above the Vistula channel can be distinguished. That form in the interbasin of the Vistula and Breń rivers is called Garb Szczuciński by the above author. The terrace in question between Opatów and Nowy Korczyn is accreted by loesses on the left bank.

The lower valley bottom is occuppied by the terraces: rendzina one (the overflood terrace) with a mada cover at the top, and the flood plain (meadow terrace) — younger than the former one. These two forms are subjects of the present study (Fig. 1).

The Miocene clays occur in the substratum of the Quaternary alluvia, the latter building the discussed terraces. The relief of the terrace tops is very diversified (Fig. 2). The fossil valley bottom at the Dunajec outlet is almost flat, and rises at the height 160—164 m a.s.l. More to the east, two almost parallel troughs, generally of the WE orientation, develop. They are separated to the east of Bolesław by a flat ridge built also of the Miocene clays. It appears as well in the remote valley parts along the plateaus and below the loess terrace between Opatowiec and Nowy Korczyn. Similar socle, sometimes higher by 6—8 m, occurs near Olesno. That relief does not correspond to the present one. The middle terrace is developed both above the socles and above the troughs. The lower terraces appear mainly in a range of the northern troughs.

Moreover, these two troughs extend downstream the river and are increasingly pronounced, and in the area of Tarnobrzeg have been described by Mycielska-Dowgiałło (1978). Their continuation is in the trough stated in the lower reach of the Dunajec river (Sokołowski 1981b).

The Vistula is the main river of the studied area. The tributaries are not without meaning for the valley modifications. The most important is the mountain river — Dunajec, especially during the floods. It influences a composition of alluvia, particularly of gravels, as well. The remaining tributaries are of the secondary importance due to their magnitudes.

HYDROLOGICAL REGIME OF THE VISTULA

The gradient of the Vistula channel in the studied fragment of the Sandomierz Basin is 0.28‰ what is a typical value of lowland rivers. The Vistula with the tributaries drains the area of 23 901 km^2 (up to the water gauge profile in Szczucin), the larger part out of which (43%) includes the Western Carpathians, i.e. the area with mountain and upland type relief. That is the region with precipitation of 700—1200 mm/yr which

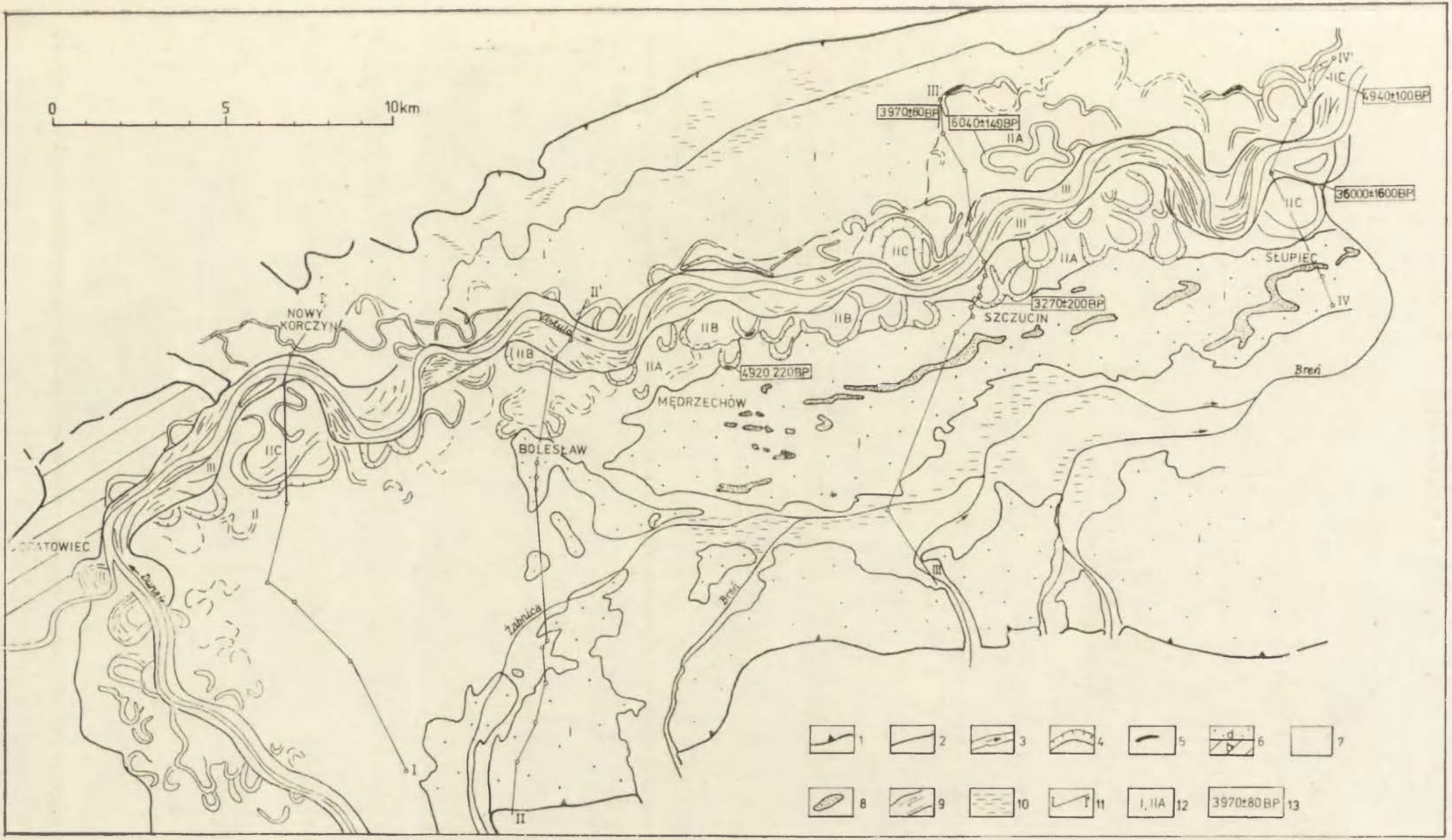
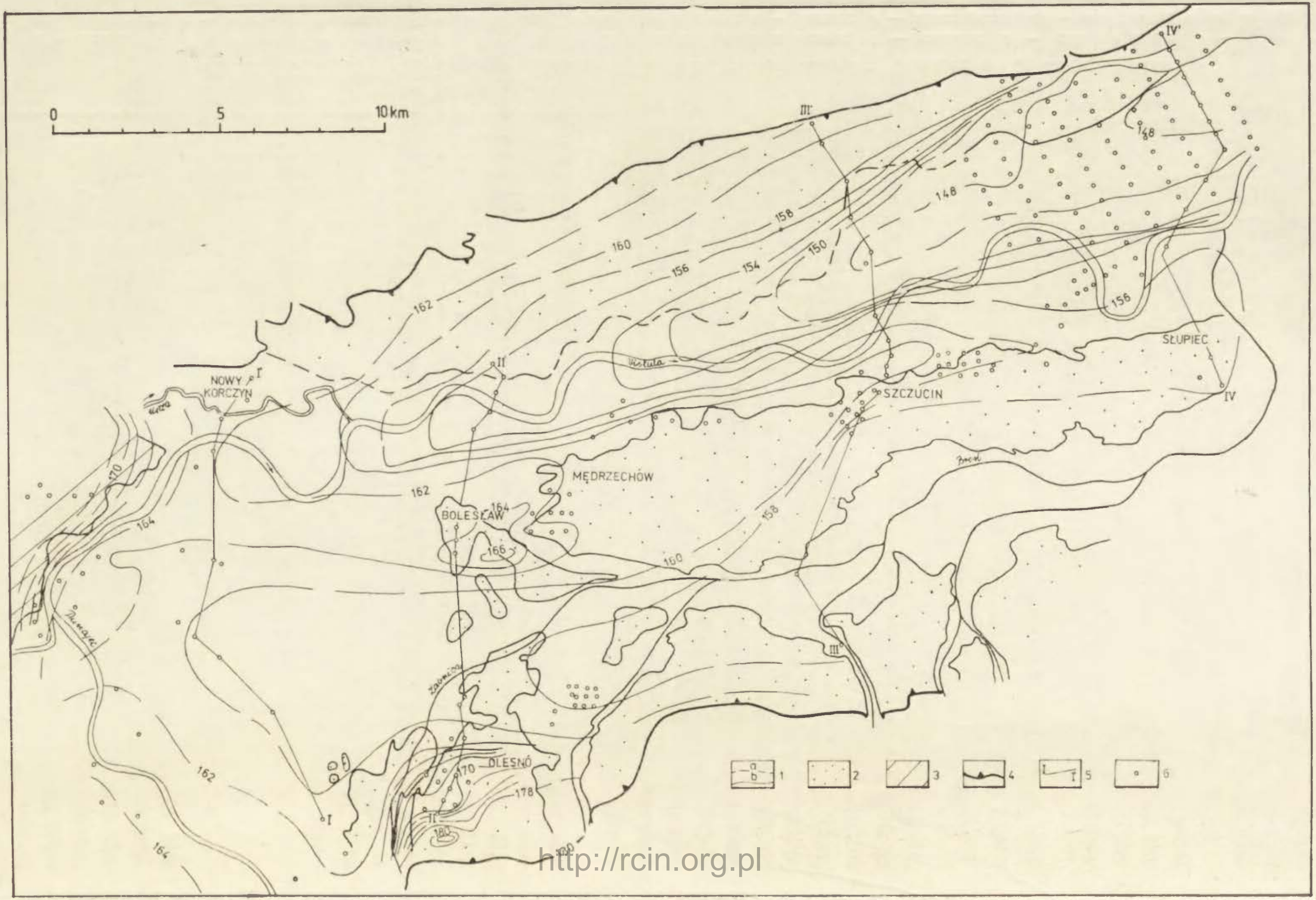


Fig. 1. Geologic-morphological sketch of Vistula valley between Dunajec and Breń mouths

1 — limits of valley floors; *2* — terrace edges; *3* — Vistula, Dunajec and Nida channels; *4* — oxbows; *5* — oxbows lakes; *6* — deposits of middle terrace, *a* — sands, *b* — loesses; *7* — muds on the rendzina terrace; *8* — dunes; *9* — flood plain; *10* — moisturing areas in the Breń and Kanał Strumień lows; *11* — geological cross-sections; *12* — numbers of terraces levels; *13* — dates of ^{14}C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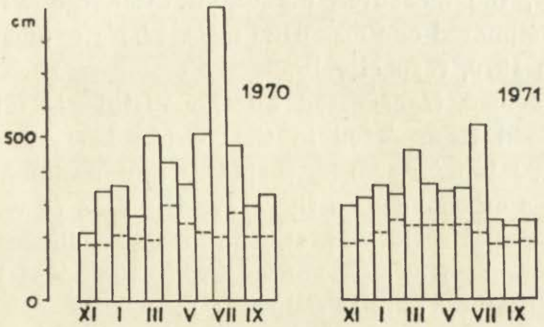

Fig. 3. Maximal and minimal water levels at Szczucin gauging station during 1970 (flood) and 1971

influences indeed the hydrological regime of the river. Catastrophic freshets with outstanding very high water stages and large discharges (Fig. 3) occur in summer. Snow-melt freshets (March — April) are much smaller.

The largest maximum water stages were recorded in 1960 (934 cm) and in 1934 (992 cm). The values for the maximum discharges are estimated because some water has not passed throughout the water gauge

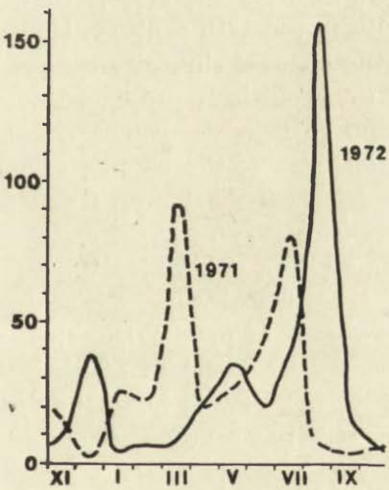

Fig. 4. Annual course of variability of transported material at Szczucin gauging station during 1971 and 1972 (flood)

Fig. 2. Relief of Miocene top surface in the Vistula valley

1 — isolinies of Miocene top surfaces (m a.s.l.), *a* — supposed, *b* — certain; *2* — sands of middle terrace; *3* — loess on middle terrace; *4* — limits of valley floors; *5* — geological cross-sections; *6* — boreholes profile. However, the measured maximum discharge was 4400 m^3/s in 1960 while the estimated one was 6100 m^3/s. These values were 4660 m^3/s and 6300 m^3/s in 1970, respectively.

The sediment load transported by the Vistula is fairly large. The total sediment load transported in the period 1971—1978 varied from 369 000 to 602 000 tons/yr. Mean turbidity and sediment yield exhibit similar tendencies of changes as these are the case of water stages and discharge in an annual scale (Fig. 4). The largest sediment transportation is during the summer freshets. For example, the flood in August 1972 carried 43% of the total annual sediment load.

PRESENT-DAY VISTULA CHANNEL AND ITS CHANGES DURING THE LAST 300 YEARS

The Vistula was a meandering river still in the 17th century as indicated by the plan of Michałowski (1678) which included some villages to the south of Nowy Korczyn. The Vistula is depicted as a straight river on the later topographic maps of the 18th and the beginning of the 19th centuries (maps of Mieg and Waldau, and of von Haldensfeld). The sinuosity of the river on those maps is 1.28, thus it is almost identical to that of the present-day channel. When interpolating the changes of the river sinuosity one can assume, therefore, that the Vistula became a straight river generally in the 18th century. However, the tendencies to the earlier changes of the channel sinuosity cannot be eliminated what is evidenced by straight undercuttings preserved to the west of Szczucin (Fig. 1). The topographic surveyings mentioned above have been made before the channelization. Hence, the change of the channel nature has resulted from an artificial river shortening frequently performed during a river management (Kędzior 1929).

Interchannel bars as well as point bars were fairly well pronounced within the channel of the 19th century. These bars concentrated more abundantly directly downstream of the Dunajec mouth. The channel width was most frequently 300—500 m at that time and sporadically reached 900 m. Therefore, the Vistula had a tendency to braiding.

The bars, predominantly the sandy ones, occur in the central parts of the stream current and close to the banks within the present-day, straight channel, the latter in a form of gentle bends. The presence of the bars is strongly related to that of groynes. Most of the bars, especially of the interchannel ones are permamently under the water, even during the low water stages.

The erosional tendencies of the river channels have been suggested many times in the case of the upper Vistula and its tributaries (Punzet 1981; Klimek 1983; Trafas 1975; Alexandrowicz *et al.* 1981). The permament lowering of the low water stages is considered to be a measure

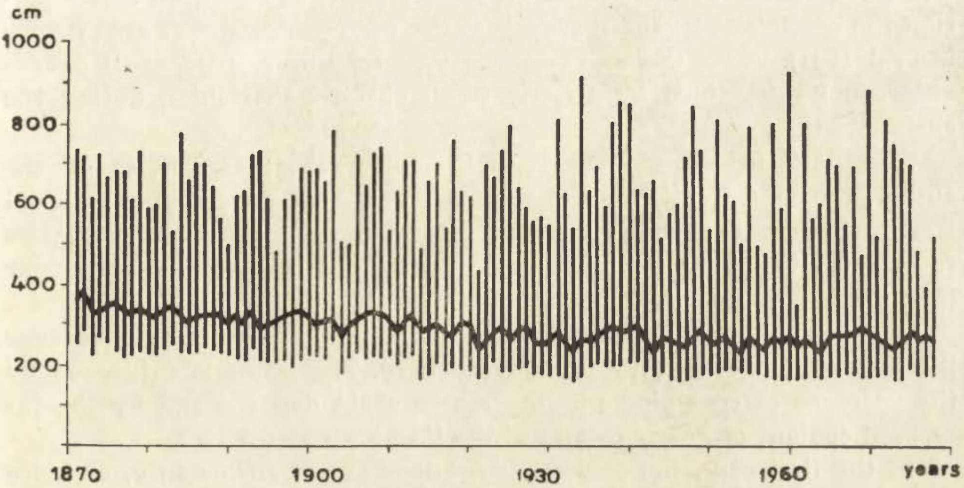

Fig. 5. Graph showing maximal, minimal and mean water levels at Szczucin gauging station in the years 1871—1978

of the above process. This process practically does not occur in the studied section when taking into account the profile in Szczucin (Fig. 5). Its rate is small, 0.9 cm/yr in the period of 1946—1975 according to Klimek's (1983) calculations. Similarly, the channel deepening is not registered at the water gauge profiles upstream the Dunajec mouth (Punzet 1981). However, the channel incision of the order of 0.31—

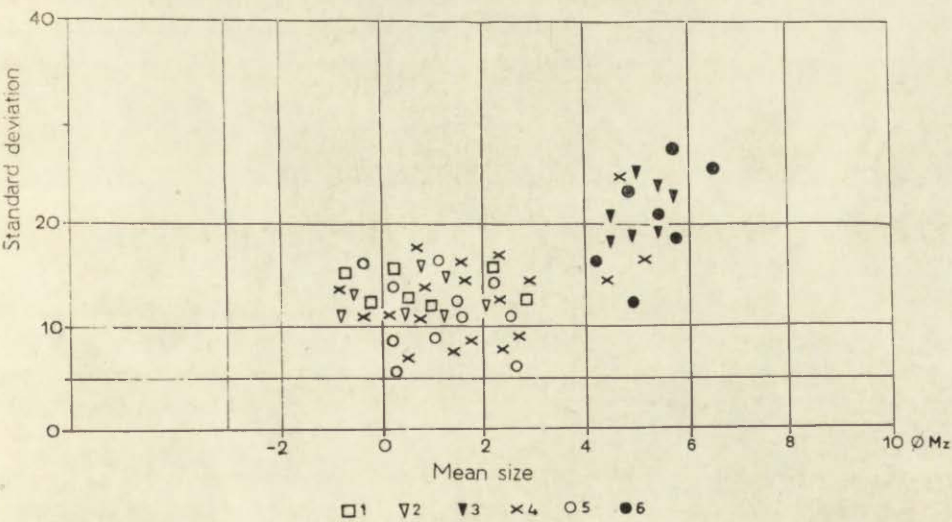

Fig. 6. Scatter plot of mean grain size (M_z) versus standard deviation (δ_1)

1 — sands and sands with gravels of middle terrace; *2* — sands and sands with gravels of rendzina terrace; *3* — muds of rendzina terrace; *4* — flood plain deposits; *5* — present channel deposits; *6* — oxbows deposits

0.64 m in 1937—1976 upstream the Dunajec mouth had been stated during the secondary levelling survey of the inter-embankment area (Dembowski 1981). Thus, the mean rate is 0.8—1.6 cm/yr. This small deepening can be explained by a fairly small channel shortening during the channelization.

According to Kociszewska-Musiał studies (1969) and those of the author, the sand fraction is the dominant one among the coarse material transported in the channel at present. Mean grain diameter varies from −0,3 to 2.3 ϕ (1.2—0.2 mm) and sorting is poor and very poor (Fig. 6).

The petrographic composition of alluvia is more interesting because the human impact is very pronounced here. The latter is evidenced by the presence of coal pieces in the coarse grain deposits and by the increased content of heavy metals in the fine grain deposits.

In the first case, the coal concentrations are at riffles only, or more precisely in shadows behind the plant thickets. Depending on the grain size composition the coal content can constitute up to 80% (Fig. 7 — Strojców B, Maniów B). Amount of coal in the sediment deposited in the river current is small or even minimum (Fig. 7 — Strojców A, Ma-

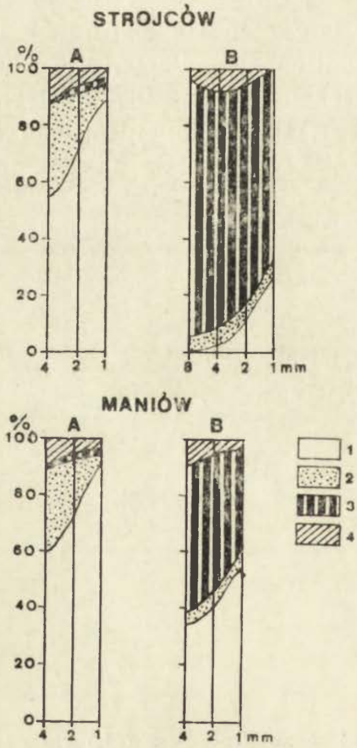

Fig. 7. Contens of coal clasts in recent Vistula deposits as a function of size grade
1 — quartz clasts; *2* — flysch sandstone clasts; *3* — coal clasts; *4* — other clasts

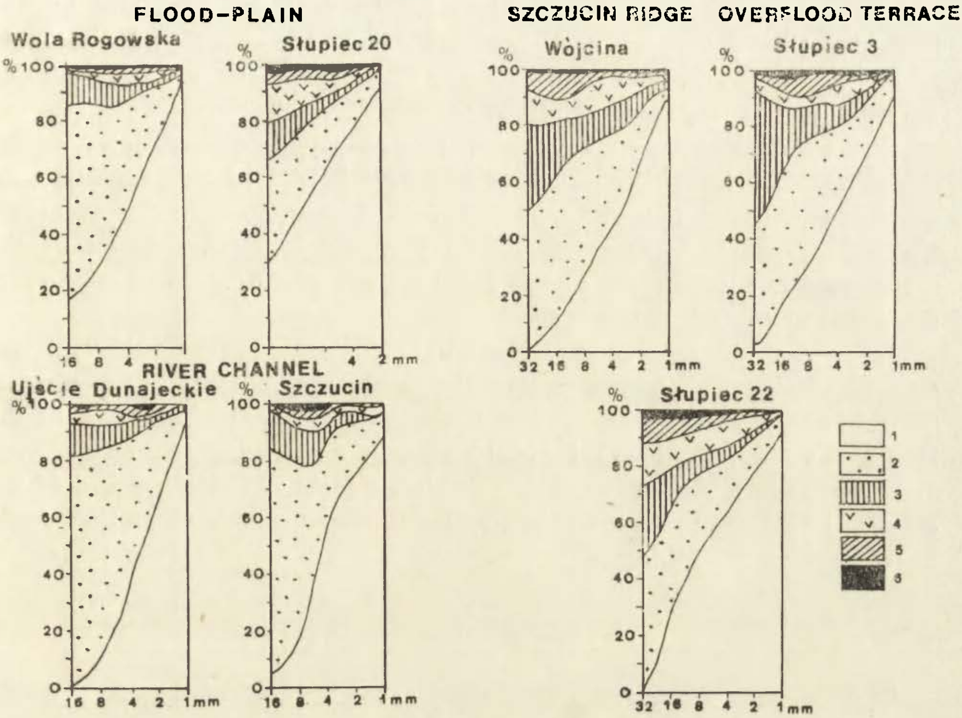

Fig. 8. Percentage variations in Vistula gravels compositions as a function of size grade

1 — quartz clasts; *2* — flysch sandstone clasts; *3* — flint clasts and silicified limestone clasts; *4* — igneous and metamorphic clasts; *5* — lydite, flysch chert and quartzite clasts; *6* — other clasts

niów A, Fig. 8 — Ujście Dunajeckie, Szczucin). That particular deposition of coal pieces is related to the ratio of its density versus that of the remaining material what is presented in details by Rutkowski (in press).

RELIEF OF THE RIVER TERRACES

MIDDLE TERRACE

The middle terrace constitutes the highest terrace level in the valley bottom of a very complicated structure. The higher patches are striking features of its relief. That one located in the interbasin areas of the Vistula and Breń rivers is called Garb Szczuciński by Starkel (1972). The remaining ones extend along the peripheral parts of the valley. These patches, including even the higher one in the area of Olesno, rise to the height of 8—10 m above the Vistula channel and 1—4 m above the overflood terrace. The patches in question are separated by slightly recessed (1—2 m), flat and fragmentarily water-logged depressions which are actually used by the Breń river in the southern part and by the Strumień Channel in the northern part. They are occuppied by the thin and discontinuous mada layer (Fig. 1, 9) in contrary to the remaining part of the terrace, being sandy at the top.

The terrace surface is covered with dunes which, in majority, form ridges parallel to the valley direction. The height of this terrace substantially increases between Opatowiec and Nowy Korczyn due to accretion by several meters thick loess layer, the latter developed in the valley facies, with a layer of the fossil soils of the Komorniki type (Jersak 1976) at the bottom.

The age of the terrace is difficult to be determined. Undoubtly, it was still fragmentarily formed during the younger Pleni-Vistulian what is indicated by the ^{14}C datings in the range of the analogical form in the Dunajec valley (Sokołowski 1981b) and in Opatowiec (Alexandrowicz, Jersak in press). The presence of the higher socle near Olesno and of the erosional troughs indicates that the fossil forms which formation could have reached the Middle-Polish Glaciation are masked in the terrace.

OVERFLOOD TERRACE (RENDZINA) II

The younger and lower overflood terrace is inserted into the middle terrace. Its extent is determined usually by the paleomeander traces. If the middle terrace is undercut by these paleomeanders the border separating those two levels is distinct, of a nature of bend-like fairly steep scarps. When they are lacking the border is uncertain, sometimes formed by a gently inclined low slope. In such a case the lithological limit between the madas on the overflood terrace and sands on the middle terrace was the criterion for distinguishing.

A variability of the terrace width is interesting. The latter is 2.5—4.5 km in the western part near Opatowiec and Nowy Korczyn. Farther to the east it narrows to 3 km, then to east of Szczucin it doubles its width reaching 6.5 km.

The paleomeanders within the area of the discussed terrace do not form so differentiated generations as those observed by Szumański (1972, 1982) in the San valley. The radii of the abandoned channels as well as their widths are similar. However, their division was attempted on the basis of certain changes of their nature distinguishing also 3 patches of the overflood terrace (A, B, C).

Overflood terrace II A. This terrace of the largest area occurs close to the Vistula channel and in the peripheral parts. The radii of the abandoned channels vary from ca. 150 to 630 m, ca. 330 m at average. The channel widths are 40—160 m. The change of their curvature is very uniform what results in regular channel forms, resambling circular bends. Actual depressions are almost always wet although to a various degree. Oxbow lakes are preserved in some of these depressions. Point bars are flat and the characteristic crescent-shaped ones are not pronounced either on aerial photographs or in the terrain.

Overflood terrace II B. The abandoned channels occurring on this terrace possess slightly larger radii of curvature, of 370 m at average. A diversity of their bend curvatures being a characteristic feature causes that these channels are not so regular as those on the terrace II A. Point bars are frequently flat, without the definite slopes in certain cases, hence it is sometimes impossible to separate them from the channel trace. This terrace forms only isolated fragments close to the river channel (Fig. 1) located 1—1.5 m lower than the terrace II A.

Overflood terrace II C. The overflood terrace II C, as the terrace II B, occurs in a form of isolated fragments in a range of paleomeanders of the largest radii of curvature up to 700 m provided the channel width of 300 m. The majority of these paleomeanders are irregular, sometimes with well pronounced traces of a channel migration.

One of these paleomeanders was undoubtedly active still in the 17th century what is indicated by a map of Michałowski (1678). The remaining paleomeanders are included here due to their geometrical affinity and direct neighbourhood with the lower flood plain.

The position and character of some indistinct bend-like traces marked on the aerial photographs close to the Dunajec mouth are questionable in that approach.

The present surface of the overflood terrace was being formed since the Atlantic period until the 17th century AD. The age limits are determined by the ^{14}C dates of the bottom of the abandoned channel fills. The dates 6040 ± 140 BP (Gd 2274) and 3970 ± 80 BP (Gd 1793) to the north of Szczucin, 3270 ± 200 BP (Gd 2293) in Szczucin and 4920 ± 220 BP (Gd 2292) near Medrzechów have been obtained. The tree trunk stuck in the channel deposits of the point bar in Słupiec has been dated as of 4920 ± 100 BP. The upper limit was determined by the above mentioned map of Michałowski (1678).

FLOOD PLAIN (III)

The flood plain forms narrow benches on the both banks of the present-day Vistula channel. In order to distinguish this flood plain the diverse relief of the surface, recognized from the aerial photographs and topographic maps (comp. Falkowski 1967 and Szumański 1972, 1977), has been adopted as a criterion.

The abandoned channels associated with a meandering river activity are lacking within its extent, however, an entire series of scarps being the limits of the cut-off channels, bars and islands related to the straight river activity, are marked on its surface. Their heights are fairly diversified. Besides the abandoned channels, sometimes filled with water, and laying at the level of the present-day stream current, there are bars and islands reaching up to the height of the overflood terrace. As indicated by the archival topographic maps the formation of this terrace should be related to the changes of the Vistula channel during the last 200—250 years.

LITHOLOGY OF THE SEDIMENTS BUILDING THE TERRACES

MIDDLE TERRACE

This terrace is mainly built of sandy and sandy-gravel deposits. Their thickness within the socles is usually 3—5 m. It reaches several meters in the troughs (Fig. 9). The sediments are diagonally and sometimes ho-

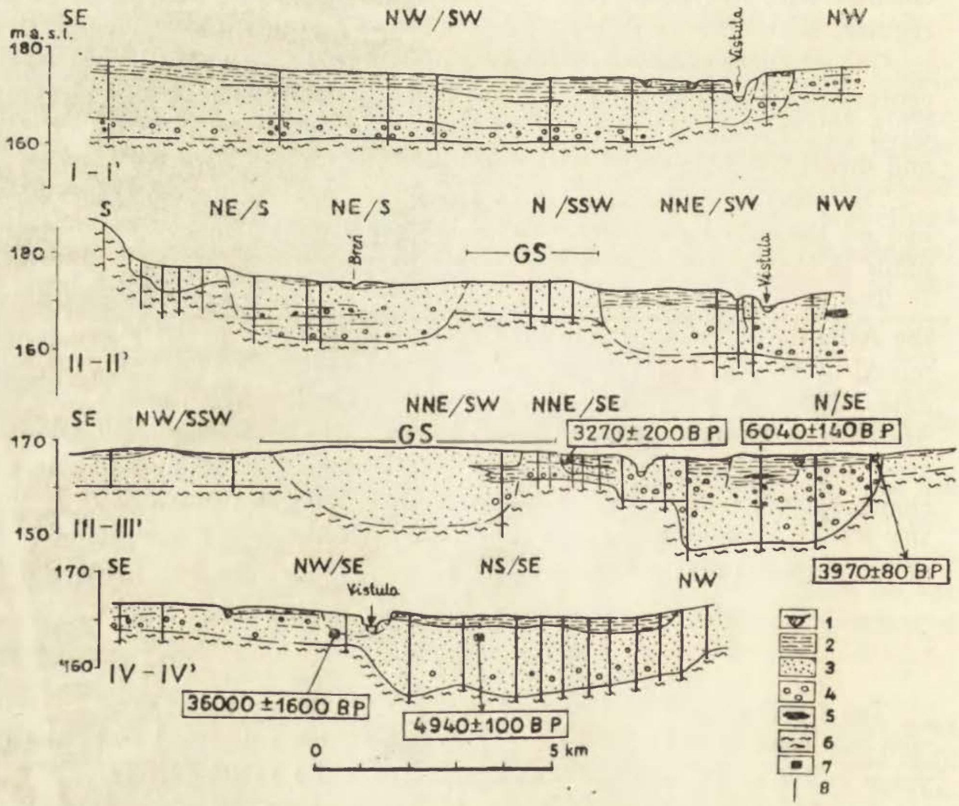

Fig. 9. Geological cross-sections of Vistula river valley

1 — oxbows deposits; *2* — muds; *3* — sands; *4* — sands with gravels; *5* — peat; *6* — Miocene clays; *7* — tree trunks; *8* — boreholes rizontally laminated. The sand fraction (40—90%) dominates in the grain size composition. The mean diameters are −0.9 to 2.0 ϕ (0.86—0.13 mm) provided poor sorting usually.

The variability of the petrographic composition of the gravel fraction reflecting the role of the supply areas of the Vistula catchment is very interesting. The dominating components are sandstones originating of the flysch Carpathians and their amount is rather constant being of ca. 35—45% (Fig. 8 — Wójcina). There is also a fairly large percentage of flintstones and silificated limestones originating of the Jurassic and Cretaceous rock outcrops of the Wyżyna Krakowska (Cracow Upland), Niecka Miechowska (Miechów Basin) and the fringe of Góry Świętokrzyskie (Holly Cross Mts). Their amount increases definitely in the coarsest fractions. The Tatric material, represented by granites and quartzites, can constitute a few per cent. The northern material (granitoides, metamorphic and effusive rocks), and Carpathian hornstones and lithides as well as the quartzites originating presumably from the Paleozoic socle of the Góry Świętokrzyskie Mts are in similar amounts. Quartz, undoubtedly of various origins, is present in several to over 70% and its amount increases in the finer fractions.

OVERFLOOD TERRACE

The overflood terrace is built of sediments of the channel, overbank and abandoned channel facies. The former ones are sands and sands with gravels of variable thickness. The profiles of drillings indicate that their thickness does not exceed 4 m in the area of Szczucin where the Miocene clays (Fig. 9) are present directly in the substratum. They overlie the elder sandy-gravel deposits of the northern trough on the left river bank. The channel deposits mainly representing the point bar deposits exhibit a poor horizontal lamination usually. The sandy intercalations, sometimes silty-sand ones, appear between the sandy-gravel deposits and are diagonally laminated. Mean grain diameters were most often from −0.9 to 2.1 ϕ (1.86—0.23 mm) provided a poor. sorting.

There is a some differentiation in a petrographic composition of the gravel fraction most pronounced in the coarsest, studied here, fraction of 16—32 mm. Gravels of the northern part of the valley (Fig. 8 — Słupiec 3) contain more flintstones in that fraction and less igneous and metamorphic rocks when compared to those of the southern part (Fig. 8 — Słupiec 22). Although two studied sites are located not far one from the other the differences are quite significant and denote that mixing and uniformity of the petrographic composition are lacking.

The flood deposits — madas — occur as a compact and almost continuous cover above the channel deposits. Their thickness is 1—5 m, and most frequently 1.5—2.5 m. Some of their vertical profiles are definitely dychotomous as described at the San river by Szumański (1972) and expressed in a differentiation of a grain size composition. The material of a higher clay content occurs at the bottom while that of silt at the top. These silts exhibit sometimes lamination of the climbing-ripple cross type and horizontal lamination which indicate an increased flood intensity.

The abandoned channel deposits constitute the cut-off paleomeander fills. Their thickness is variable (e.g. Fig. 10) and reaches slightly more

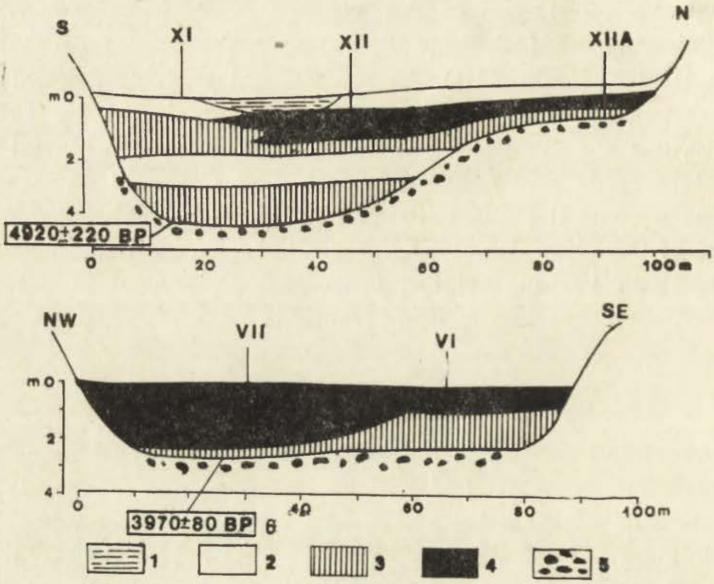

Fig. 10. Schematic cross-sections of paleomeanders

1 — oxbows lake; *2* — muds; *3* — muds with floral detritus; *4* — peat; *5* — channel deposits; *6* — dates of ^{14}C

than 4 m at maximum. Silts form usually the lowest part of the profile of the abandoned channel fills. They can contain some sand, or more rarely the plant detritus. Peats, strongly silty, appear above them in some profiles. The grain composition of the abandoned channel silts is almost identical to that of the madas described above (Fig. 6).

FLOOD PLAIN

The flood plain is built mainly of the channel facies consisting of sands, and less frequently of sands with gravels. Silts admixtures, or even mud inserts, are frequent. Typical diagonal laminations are pronounced here. Horizontal lamination dominates in the fine deposits.

The thickness of these sediments is difficult to be determined. Fine sands, slightly silty occurred at the outcrop near Slupiec (Fig. 1) below the sand-gravel deposits of the thickness less than 3 m. The age of the tree trunk stuck in these sands was 36 000 ± 1600 BP (Gd 1459). Although the trunk redeposition cannot be eliminated the whole complex of these sediments is located within the range of the erosional socle associated mainly with the middle terrace. Therefore, it seems possible that the deposits of the meadow terrace overtop the elder ones in some locations.

The grain size composition of the channel facies is diversified. Mean grain diameters are from −0.4 to 2.5 ϕ (1.4—0.18 mm) provided poor and medium sortings (Fig. 6).

The Carpathian sandstone material (Fig. 8, Wola Rogowska, Słupiec 20) with some flintstones, quartzites, hornstones and the northern material dominates in the petrographic composition of the gravel fraction. Quartz prevails in the fine fractions.

The madas occurring above the channel deposits are of a smaller thickness here which rarely exceeds 30 cm. Moreover, their occurrence is discontinuous and appears only above the fragments of bars and islands. With respect to the formation, these madas do not differ from those of the overflood terrace.

VISTULA VALLEY EVOLUTION

As it was already mentioned, the middle terrace in the studied section of the Vistula was under formation during the interglacial and younger pleniglacial of the Vistulian. It has been commonly accepted that the braided river had transported the large amounts of coarse unsorted material (Falkowski 1967; Szumański 1972, 1982). The coarse sediment load and lack of sorting of the Vistula deposits seem to be questionable. The sandy layers which appear within this terrace in some spots do not suggest a definite dominance of coarse deposits (Fig. 9). Similarly, statistical indices of sorting do not indicate other sorting than in the case of younger alluvia of the meandering river (Fig. 6).

The traces of erosion in the Late Vistulian are not visible although the presence of the Late Glacial dunes is the case for erosion (Wojtanowicz 1968; Izmaiłow 1975). It has been not excluded that the Vistula flew at that time in a wide, flat depression used actually by the Breń river. The analogical depression in the northern part of the valley drained by the Strumień Channel was possibly drained by the Nida river.

The stage of the river change from the braided into the meandering one cannot be reconstructed in the studied section. The ^{14}C datings of the abandoned channel fills indicate their age just from the Atlantic. It seems likely that per analogy to the upper Vistula reaches (Kalicki, Starkel in press) probably the elder abandoned channels lay lower and are buried by the overtopping younger ones.

The Atlantic and Sub-Boreal age of the paleochannel fills on the terrace II A (6040 ± 140, 4920 ± 220, 3970 ± 80 and 3270 ± 200 BP) together with their geometry suggest that these paleochannels have been formed by a river of a slowly migrating channel. Taking into account the fact that the younger abandoned channel deposits to the north of Szczucin appear in the peripheral parts of the valley (Fig. 1, 9) one can assume that the maximum widening of the contemporary flood plain bottom occurred also in the Sub-Boreal together with a general tendency to aggradation which seems to last until the turn of the Vistulian.

The upper limit of the functioning of these abandoned channels is more difficult to be determined. It cannot be eliminated that the single forms were still active in the first millenium AD. The presence of the earthwork located in the fork of the Vistula and Dunajec rivers, in the area of the point bar of the abandoned channel geometrically resambling the forms of the terrace II A, is behind the above statement. Based on the archeological finds Dąbrowska (1965) determines the earthwork formation for the 7th-8th century, or may be even for the 6th century. It seems that the natural conditions for defence were provided by the surrounding river channel.

The subsequent terace II B is incised into the terrace II A. The accumulation of the cover of the former one was probably preceeded by a slight incision. The terrace in question was modelled by somewhat different river what is indicated by a smaller regularity of the abandoned channels occurring within its extent. It seems that it was the river of more variable discharges. The traces of the point bar accretion suggest the river of a faster migrating channel. The timing of the terrace formation could be related to the 10th-15th centuries AD. The acceptance of such time limits is substantiated by the presence of the abandoned channels of another type on the terrace II A still in the first millenium AD. The upper time limit is determined by the presence of cutting the former ones which were undoubtedly still active in the 18th century. A certain additional datum can be the settlement development reconstructed by Mateszew (1974). According to that author's summaries the villages in the vicinity of these channels were formed relatively late (16th—18th centuries), i.e. 200—400 years later than those located within the terrace II A. Finally, the changes in the river hydrology can be expected in the more regional change of the land management of the catchment which took place mainly in the 13th—14th centuries (Dembińska 1972).

Moreover, the aggradation of the river was possible during this terrace accumulation what is evidenced by the presence of tree trunks on the point bar of one of the abandoned channel to the east of Szczucin. (Fig. 1, 9). One of these trunks has been dated for 4900 ± 100 BP. The young aggradation phenomenon is also known from the Vistula valley in the area of Cracow (Rutkowski in press; Kalicki, Starkel in press).

The Vistula river preserved its meandering nature in the discussed section, or at least in some fragments of this section, until the 17th century. The abandoned channel to the south of Nowy Korczyn was undoubtedly active at that time as indicated by the map of Michałowski (1678). Then, the Vistula was the river of variable discharges and of a relatively fast migrating channel which is evidenced by the traces of migration visible in the abandoned channel area and sometimes by a channel anabranching. The presence of silty, slightly sandy madas on the bar of one of these abandoned channels is interesting. That would confirm the opinion of Szumański (1982) that it is a young sediment formed during the last centuries.

The change from the meandering to the straight river took place at the turn of the 17th and 18th centuries, i.e. earlier than in the San valley (mid-18th century) or in the upper reaches of the Vistula (Szumański 1982; Trafas 1975; Rutkowski in press).

An increase of the supply of the slope material due to a farming intensification, and particularly an introduction of root crops (Gil, Słupik 1972), is considered to be the major cause of changing of the nature of the rivers in the Sandomierz Basin. The former change of the river pattern in the discussed section may be resulted from this section location below the Dunajec outlet. One has to remember that the Dunajec is the river of very variable discharges and rapid floods. It drains the large area what results in the supply of ca. 1/4 of the water flow to the Vistula during the freshet periods while the 17th century increase of the flood frequency could have played here a fundamental role.

The maximum horizontal channel shift reached 800 m during the last 200—250 years. The formation of the youngest flood plain (III) is also related to the above changes. The flood plain cover was packed into the elder deposits, presumably originating, at least fragmentarily, of the Last Glaciation.

The present Vistula channel downstream of the Dunajec outlet is almost totally enforced artificially and large amounts of the anthropogenic pollutions are transported in it. The channel does not exhibit erosional tendencies. The sediment supply to the channel can increase in the future due to destruction of the willow thickets and due to formation of arable fields in the interembankment area.

Technical University of Mining and Metallurgy
Institute of Geology and Mineral Deposits
30-059 Kraków, al. Mickiewicza 30

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ELŻBIETA MYCIELSKA-DOWGIAŁŁO

MORPHOGENESIS OF VISTULA VALLEY IN NORTHERN PART OF SANDOMIERZ BASIN IN THE LATE GLACIAL AND HOLOCENE

INTRODUCTION

The history of development of Vistula valley as well as that of all the northern part of the Sandomierz Basin (Fig. 1) caused particular interest in the period of mining activities related to two large open cast

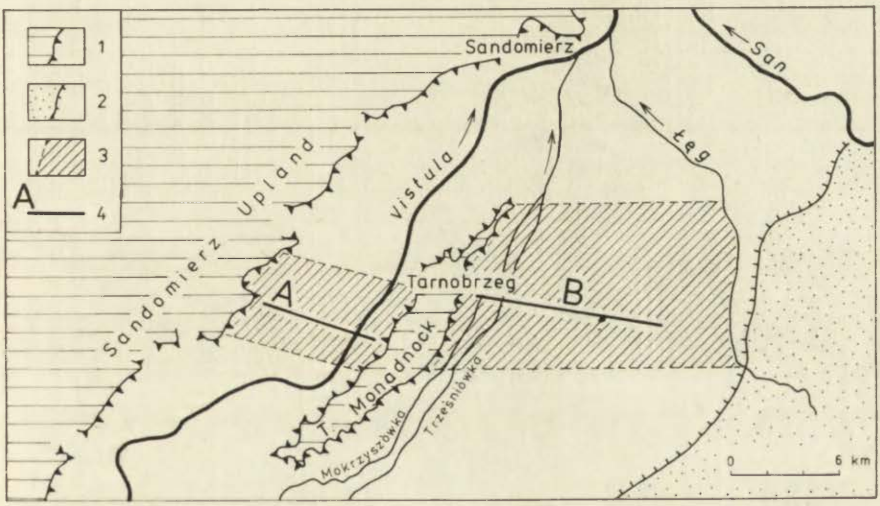

Fig. 1. Location of the study area

1 — edge of the Sandomierz Basin and of the Tarnobrzeg Ridge; 2 — edge of the accumulation terrace of the Middle Polish Glaciation; 3 — areas presented in the paper on the geomorphological sketches; 4 — profiles A and B presented in Fig. 2

mines in Piaseczno and Machów, located on both sides of the present Vistula channel. They have exposed the full alluvial series of the valley. The third mine, in Jeziórko, due to the dense network of drillings allowed to determine the stratigraphy and lithology of the alluvial series of depression of Trześniówka (Fig. 2). Thus, it was only the second half

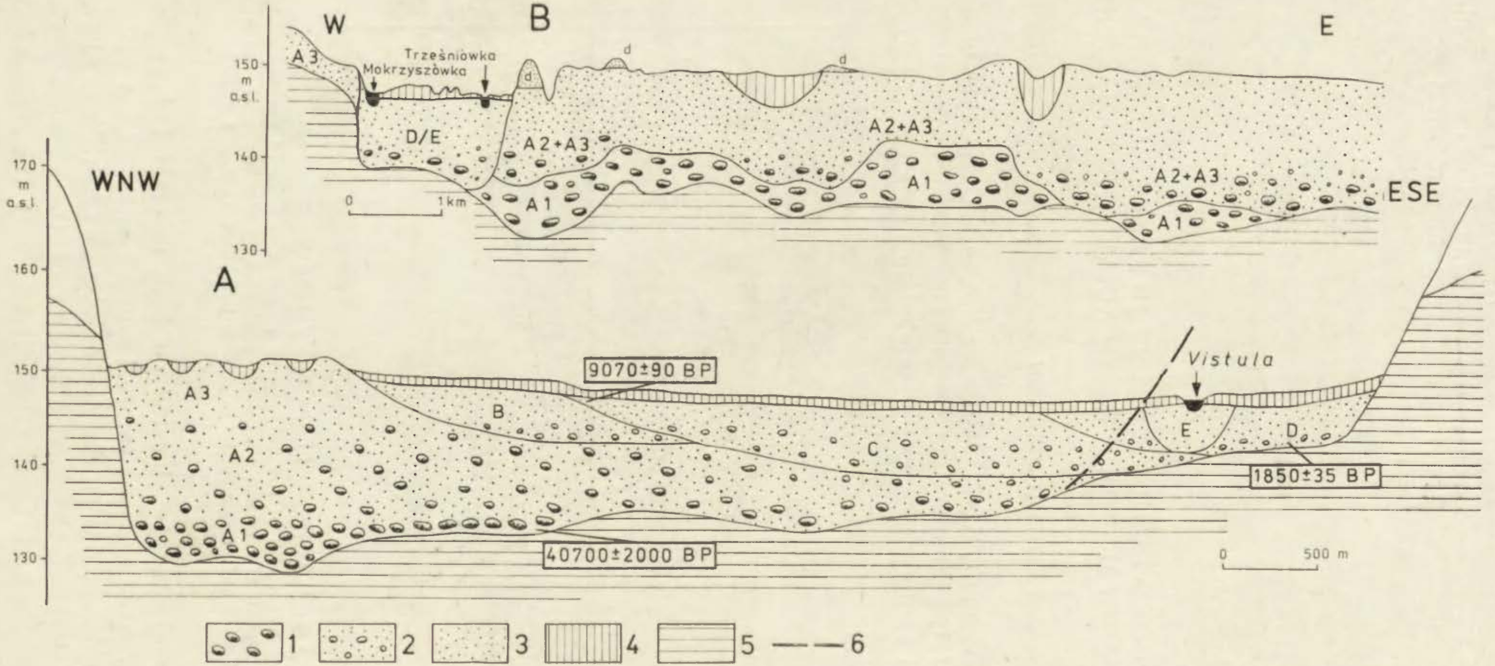

Fig. 2. Synthetic geological profiles of the Vistula valley floor in the area of Tarnobrzeg and in the northern **part of the** Sandomierz Basin

1 — gravel-pebble series; *2* — sandy-gravel series; *3* — sandy series and sandy-silt series; *4* — mada series; *5* — Krakowiec clays (Miocene); *6* — extent of the Vistula valley during the Last Glaciation. Main sedimentary series associated with channel development during the Last Glaciation and Holocene: *A1* — channel deposits of the early Pleniglacial; *A2* — channel deposits of the Late Pleniglacial; *A3* — channel deposits of the Late Glacial; *d* — levees dune-like at the top; *B* — channel deposits of the 1st meander generation (of large radii), of the Late Glacial (Allerod—Younger Dryas); *C* — channel deposits of the 2nd meander generation of the beginning of the Holocene (Pre-Boreal—Atlantic); *D* — channel deposits of the 3rd meander generation of the second half of the Holocene (Sub-Boreal—Sub-Atlantic); *E* — channel deposits of the present river of the 1960s when the whole series of publications, based mostly on materials related to the newly erected sulphur basin, was published (Buraczyński, Wojtanowicz 1966, 1967-1968; Mycielska-Dowgiałło 1967, 1969, 1977, 1978; Wojtanowicz 1970).

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

LOCATION OF THE STUDIED SECTION WITHIN THE DRAINAGE BASIN

The analysed section is located between the mouths of two large right tributaries — the Wisłoka and San rivers. It incorporates the part of Vistula valley from Machów to Tarnobrzeg as well as the depression of Trześniówka on the eastern slope of the Tarnobrzeg Ridge, up to the present-day channel of Łęg to the east. The Vistula river down to Tarnobrzeg is 255.3 km long and drains the area of 31 077 km^2.

The Vistula valley floor between the Opatów Upland and Tarnobrzeg Ridge is about 7 km wide. The NW edge of the valley which was formed in the reach in question by a braided river is straightened while the SE one is sinuous reflecting the meandering pattern of channels developed at its base.

The studied part of the Sandomierz Basin located to the east of the Tarnobrzeg Ridge is 12 km wide and reaches up to the Łęg channel in the east.

All the substratum of the studied region is built of the Krakowiec clays which thickness increases from the NW towards SE. It is only in the area of the Tarnobrzeg Ridge where the Sarmatian detritic deposits are exposed (conglomerates, sands and calciferous sandstones) as well as the Pliocene, Pre-Glacial and Glacial deposits — the latter ones related to the Cracow Glaciation (Elsterian). Valley lowerings, cut in the Krakowiec clays, are filled with the alluvia of the Vistulian and Holocene (Fig. 2).

THE OVERFLOOD TERRACE

The fragment of the overflood terrace (terrace 1) preserved at the western part may be included to the Vistula valley floor. This terrace is located at the height of 150—152 m a.s.l. (7.5—9.5 m above the mean water level of Vistula). It is characterized by a presence of the braided channel pattern, dunes and deflated sands and the alluvial cones descending to this level from the neighbouring Upland (Fig. 3). In the northern part of the Sandomierz Basin the surface of the overflood terrace is built from the extensive alluvial cones of some generations (Fig. 4).

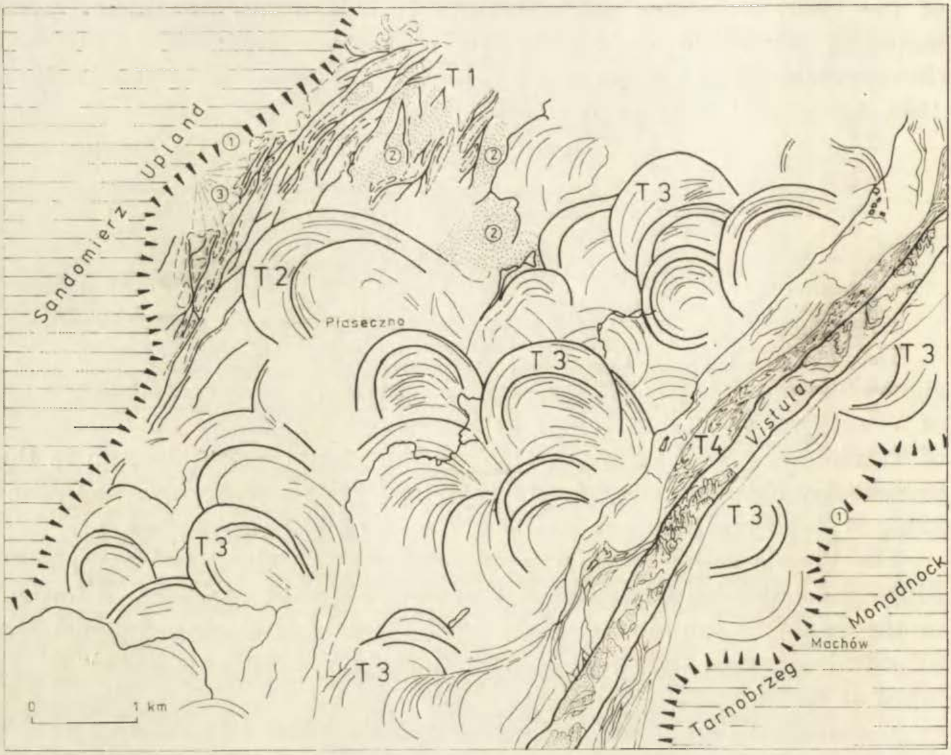

Fig. 3. Geomorphological sketch of the Vistula valley floor in the area of Tarnobrzeg

T1 — terrace with the braided river pattern of the Late Glacial; *T2* — high flood-plain with meanders of large radii, of the Late Glacial and Holocene; *T3* — middle flood-plain, with bends of small meanders, formed during the Holocene; *T4* — low flood-plain modelled by the present braided river; *1* — valley edge; *2* — dunes; *3* — alluvial fans

THE FLOOD PLAIN

Three steps in the level range 3.5—6.5 m above the Vistula mean water stage (high, middle, low flood plain) are distinguished.

The high flood plain (*T2*) of the Late Glacial with characteristic large meanders can be found in the Vistula valley only in a fragment at the level of 148.7—149 m a.s.l. (Fig. 3). Similar is the height of the bottom of the large meander, located in the eastern part of the studied fragment of the Sandomierz Basin (to the south of Grębów), which is related to the San river (Fig. 4). However, it has to be emphasized that the preserved form of the meander related to the San has the radius of curvature ($r \sim 2000$ m) more than twice that of the respective form from the Vistula valley floor.

The middle flood plain (*T3*) with traces of small meanders is, contrary to the former one, the best developed in the Vistula valley floor at the

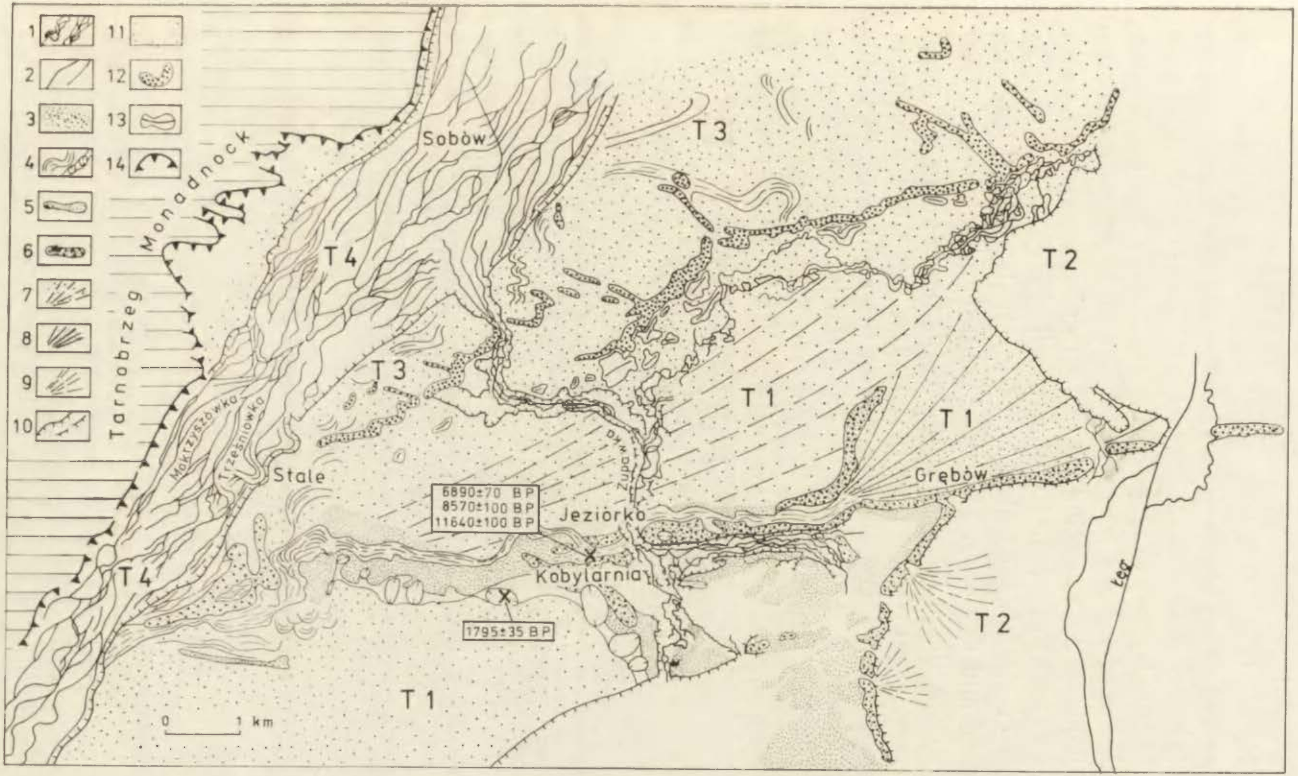

Fig. 4. Geomorphological sketch of the interbasin areas of the Trześniówka and Łęg rivers

T1 — terrace being formed during the Last Glaciation untill its turn, large alluvial fans contributed to its build-up; *T2* — high flood-plain of the turn of the Last Glaciation and Holocene with large meanders; *T3* — middle flood-plain, formed during the Holocene, with small meanders; *T4* — low flood-plain likely formed by flood water of the Wisłoka river of the braided channel pattern, at the present occuppied by Trześniówka and Mokrzyszówka rivers; *1* — traces of channels of the braided pattern of the period preceeding channelization; *2* — regulated channels; *3* — surfaces of the Pleistocene terrace; *4* — traces of channels in the area of the Pleistocene terrace; *5* — levees; *6* — levees dune-like at the top; *7* — alluvial fan of the oldest generation; *8* — alluvial fan of the intermediate generation; *9* — alluvial fan of the youngest generation; *10* — edge of the Pleistocene terrace; *11* — Pleistocene terrace, partially modified by meander channels of the Holocene rivers; *12* — dunes; *13* — deflation basins; *14* — edge of the Tarnobrzeg terrace elevation of 147—148.7 m a.s.l. (Fig. 3). Only single meanders are preserved on the eastern side of the present-day valley floors of the Mokrzyszówka and Trześniówka rivers (Fig. 4). The radii of curvature of the meanders on the Vistula valley floor are of 300—500 m.

The low flood plain (*T4*) limited by 1 m high edge is well developed both along the present-day Vistula channel and along the Mokrzyszówka and Trześniówka rivers. It is characterized by the braided channel pattern. The width of this terrace ranges from 1—1.25 km along the Vistula channel up to 1.5 km along the Mokrzyszówka and Trześniówka rivers. The pronounced denivelations ranging up to 3.5 m above the mean water stage (142.4—146 m a.s.l.) are found within the limits of this terrace as well as the series of straightened abandoned channels, both filled with water (oxbow lakes) and dry ones. The flood-control embankments follow the course of this edge. Some fragments of embankments along the reach of the Vistula river, from Wisłoka to San rivers, were constructed in 1872—1873 (Kędzior 1929). The embankments on the right-bank of Vistula were completed in 1889—1895 while those on the left-bank were completed in 1930s. Channelization of the lower Trześniówka, Mokrzyszówka and Łęg rivers was performed in 1886—1893. The upper reaches of these rivers were under flood-control management just in 1905—1930.

THE PRESENT-DAY CHANNEL

The present-day Vistula channel is substantially straightened, with sinusoity of 1.07 measured along the channel axis in the reach from Machów to Sandomierz. The channel width is here within 300—700 m. The mean water level is 142.4 m a.s.l. in Tarnobrzeg (Dzików). The channel banks are up to 3.5 m high at maximum. The gradient of the water level is of 0.27‰ over the reach between Dzików to Sandomierz. The channels of Mokrzyszówka and Trześniówka are a few meters wide, and are straightened due to the flood-control management.

HYDROLOGICAL REGIME

The mean annual precipitation total for the studied area is 800 mm (30—50% of that are in 3 summer month). The mean annual discharge of the Vistula in Sandomierz is 293 m^3/s while 13.1 km downstream of Tarnobrzeg — 296 m^3/s. Based on the data of the period of 1951—1971 the largest mean monthly discharges are those for 3 summer months with the maximum value in July (the maximum monthly mean discharge is 1470 m^3/s). The secondary maximum is related to the spring thawing period (in March, April) with a maximum monthly mean discharge of 991 m^3/s. Minimum monthly mean discharges are recorded in September and October (120 m^3/s). The maximum daily discharge in that period was 5690 m^3/s in July 1960. The maximum water stage amplitude is of 6.5 m. The river freezes periodically. The maximum thickness of an ice--cover was 33 cm in the period of 1972—1979.

The maximum of the suspended load transported by the Vistula is usually reached during a thawing period (Jan.—Apr.), occasionally in June. The values given below have been computed for the period of 1972—1979. The maximum monthly suspended sediment load is 165.6 g/m^3, minimum one is 18.9 g/m^3. The maximum daily values for turbidity were of 430 g/m^3 in that period. The calculated mean values of the transported bedload are 433 750 t and 388 700 t respectively for the winter and summer season, the former one being slightly higher.

CHANGES DURING THE LAST 200 YEARS

The interesting data have been provided by analysis of the 18th century maps, particularly with respect to the depression to the east of the Tarnobrzeg Ridge. An extensive channel oriented according to the parallel of lattitude which fragment is visible in the southern part of the studied area (Fig. 4) was marked on the map of Rizzi-Zannoni of 1772. This channel drained water both from the north (from Kobylarnia) as well as from the south. At present, that is a reclaimed land, drained in part to Żupawka, and in part to Trześniówka rivers. Another channel, oriented according to the parallel of latitude was marked on the map of von Mieg (1775—1783) — extending the Mokrzyszówka and Trześniówka valleys to Kobylarnia, then turning to the south and joining the above mentioned extensive channel. The aerial photographs indicate its course as a series of depressions (with the ^{14}C date of 1795 ± 35 in one of them, Fig. 4). The map of von Mieg shows the wide valley floor (with braided channel pattern) actually occuppied by Mokrzyszówka and Trześniówka rivers. One may not eliminate the possibility that the channel mentioned above was active only during the floods.

The change of the runoff direction is observed for all the rivers in the studied area. The western direction has been replaced with the northbound one during the last few hundred years. That is particularly clear in the case of the Żupawka river which originally flew towards NE along the range of dunes. It formed a meandering channel at that time. Contemporary to the formation of the extensive valley floor actually occuppied by Mokrzyszówka and Trześniówka rivers, the Żupawka river was beheaded, turning its flow towards NE.

The general change of the runoff direction in the studied area is related to the migrational tendencies of the channels of the Vistula and San, lasting since the climax of the Last Glaciation. The channel of San developed in the east, in the close vicinity of the studied area, was gradually shifted eastward, while the Vistula, forced by the fan of Koprzywianka (its left tributary) moved eastward and was approaching the studied area from the NW. Both, the extensive width of the valley floor actually occuppied by Mokrzyszówka and Trześniówka rivers and the braided channel system preserved there (Fig. 4) indicate water of large dynamics. One may not eliminate the possibility that it was water from the Wisłoka river which could have bifurcated periodically (during high floods) and some water flew to the Vistula, along the Tarnobrzeg Ridge to the north.

EVOLUTION OF THE RELIEF BASED ON THE ANALYSIS OF LANDFORMS AND DEPOSITS

VISTULIAN GLACIATION

The Vistula valley, as well as the northern part of the Sandomierz Basin, was formed after the retreat of the Riss Glaciation, presumably during the Eemian interglacial. The deepest dissections of the valley in the studied area reach the depth of 20—24 m below the present surface of the Vistula valley floor and the northern part of the Sandomierz Basin. They are filled with series of coarse gravel and pebbles (Fig. 2) which are characterized by tabular cross-stratification of the fairly thick sets and rather small scattering of directions of the lamina inclinations. The good sorting of the deposit is the striking feature (Mycielska-Dowgiałło 1978). The numerous synchronic structures of ice wedges and involutions indicate that this series was formed under the presence of permafrost (Mycielska-Dowgiałło 1967). The irregularly scattered large boulders of crystalline rock of diameters reaching 2.5 m can be found in the described deposit. Their presence, often relatively far (1—2 km) from the valley side, idicates that they were transported on ice floes of considerable thickness during the thawing periods. Relatively frequent scattering of boulders within the deposits indicates a considerable intensity of the denudation processes within the area of valley slopes. Boulders like the above are found in the Holocene deposits of the Vistula valley only in deposits occurring in the close vicinity of the erosional undercuts of the river bank where the intensive landslides are in progress. Intensive denudation precesses within catchments are also evidenced by the presence of crystalline rock fragments of sand fraction. It is more pronounced in the Vistulian deposits than in the Holocene ones.

Filling of the deepest erosional forms was performed by braided rivers of seasonal variability of hydrological regime and of positive alluvia budget.

It may be assumed, that at the beginning of the Vistulian Glaciation, at the level of the deepest erosional forms there were two separate rivers flowing on both sides of the Tarnobrzeg Ridge: the Vistula on the western and the Wisłoka on the eastern side. It was only about 40 thousand years ago when, due to a considerable lateral erosion of these rivers, they joined and created one common valley of the width of ca. 20 km (Mycielska-Dowgiałło 1978). In the upper climax of the glaciation, the northern part of the Sandomierz Basin was drained by channel networks of the Vistula and the Wisłoka (braided channel systems) which surrounded with their arms the Tarnobrzeg Ridge flowing towards the San valley. That extensive width of the valley floor of that period, the largest in all the Pleistocene history of the development of fluvial relief, was probably caused by thermal erosion of the braided river channels. The oldest and most extensive form of the alluvial cone (Fig. 4) which was produced at the limit of the San valley is related to the decline of the period in question. Simultaneously with the process of widening of valley floor the grain size composition of deposits was subject to modifications. In this period the gravel-pebble series changes into the sandy-gravel one in the Vistula valley (Fig. 2) what was caused by a decreasing dynamics of floods. The presence of ice wedges in these deposits in the Vistula valley indicates that the braided channel system was active under the presence of permafrost.

LATE GLACIAL

A gradual warming of the climate at the turn of glaciation resulted in a formation of a increasingly more compact plant cover (Wasylikowa 1964) and gradual decline of permafrost (Goździk 1973). Due to these factors the retentional capacity of soil increased and the energy of rivers during floods decreased. During that period the terrace at 150—152 m a.s.l., elevated 1.5—3.5 m above the valley floor with meander bends, was formed in the Vistula valley. There are preserved traces of braided channel systems, dune forms and alluvial fans at the outlets of the side valleys descending from the edge of the Sandomierz Upland. The sandy--gravel series gradually changes into the higher located sandy one with admixture of silts at the top. The fine, trough cross-stratification prevails in sandy deposits and horizontal lamination in silty sands and silts.

Wash-down was the major denudational process acting on slopes and plateaus (Kuydowicz-Turkowska 1975). Traces of its activity are visible in deluvial covers filling dry valleys within the Tarnobrzeg Ridge and the edge of the Upland as well as in the above mentioned alluvial cones. In the Vistula valley the fine-grained material was accumulated on the bars between the channels of the braided pattern. Further development of the terrace 1 progressed, in the eastern part behind the Tarnobrzeg Ridge, by the accretion of the next alluvial fan directed towards the San valley (Fig. 4), being smaller than the former one. The sedimentation series of the turn of the Glaciation are characterized by the occurrence of the alternating sand and silt laminae at the upper face. Large amount of well rounded grains of the sand fraction indicates intensive eolian processes acted at that time within plateaus and higher terrace surfaces.

As stated earlier, a few generations of alluvial fans orientated to the east, to the San valley, were formed in the northern part of the Sandomierz Basin during the Last Pleniglacial. One may not exclude the possibility that the fan of the 2nd generation, located near Grębów was formed when the Wisłoka river flew only periodically, during the large floods at the eastern part of the Tarnobrzeg Ridge towards the San valley.

The sizes of the above alluvial fans indicate a substantial efficiency of the river of that time, providing the evidence of the large transported sediment load exceeding the transportation abilities of the present-day rivers. Simultaneously the amount of material had to decrease what is proven by the sizes of fans of the next generation. A precise determination of the timing of their formation was possible due to ^{14}C datings of the peats filling a several meter wide channel formed in the valley orientated according to a parallel of latitude. The fan determined as the one of the 2nd generation (Fig. 4) has developed at the above valley outlet. In the area of Kobylarnia the channel is filled with 1.8 m thick peat underlain by fine sands and silts. Three dates on 3 levels have determined a continuous process of peat accumulation since the beginning of the Alleröd (11 640 ± 100 BP — layer from the depth of 1.8 m), throughout the Boreal (8570 ± 100 BP — layer from the depth of 1.3 m) until the Atlantic (6890 ± 70 BP — layer from the depth 70 cm). Thus, one can conclude that the channel ceased to function as a route leading the river water (may be flood water) at the beginning of the Alleröd what, in turn, caused that the fan of the 2nd generation ceased to form. Therefore, its formation is associated with the Older Dryas at least. The natural levees next accreted by dunes, were produced along the river channels. The braided river pattern prevailed at that time.

Due to the further climatic changes in the Alleröd and related to them changes of the compactness of the plant cover modification of the valley floors with the braided channel pattern towards those with the meandering one took place. Channel downcutting and lowering of the valley floors were associated with the above process. Meanders of the first generation were characterized by the largest, both, radii of curvature and widths as well as by small depths and vertical reworking of the alluvia (Mycielska-Dowgiałło 1978). Similar is the situation noticed in the Wisłoka valley (Starkel ed. 1981). At the formation period of the large meanders in the Wisłoka valley the erosional bottom was formed which provides evidence of the vertical extent of the channel activity of this time. Its formation is dated for the Alleröd. As in the case of the Vistula valley the vertical extent is rather small, definitely smaller than that in the following periods.

The largest meander is preserved in the San valley in the area of Grębów (radius of curvature — ca. 2 km). Szumański (1972, 1982) describes the forms with the radii of 1100 m and channel widths of 350 m at the slightly higher part of the San valley. Szumański relates their formation to erosion preceeding the Alleröd. Based on observations, the great paleomeander of the San river, visible in the presented map near Grębów (Fig. 4) emphasized by levee with a dune-like surface, was produced after the formation of the alluvial fan of the 2nd generation had been completed. Thus, one can assume that it was created during the Alleröd. At that time, due to the development of the plant cover the alluvia balance turned to be negative (Falkowski 1967, 1982) while the rivers started to downcut into substratum. Simultaneously, the presence of fans (of the 3rd generation) included into the great meander of the San indicates that periodical runoff to the east existed after this meander had been formed.

So explicit difference between the parameter of the first and second generations (Fig. 3) as in the San valley was not pronounced in the studied section of the Vistula valley. One can exclude that it was caused by a gradual change of the Wisłoka routes of outflow in the Late Glacial and Holocene. Initially, the Wisłoka river (may be partially with the Vistula) was joined with the San river at the eastern side of the Tarnobrzeg Ridge. Then, only its flood water used that route. The lack of the meanders of parameters being as large in the Vistula valley as those in the San valley is most likely to be explained by the above. Flood water, mainly forming the channel morphology, flew at that time only partially in the present day Vistula valley.

The depth of incision of the Vistula paleomeander of the 1st generation into the terrace 1 is small, of the order of 1.5—3 m. The channel facies is usually built of fine sets of medium and fine sands of the thickness of 5—10 cm and with cross-stratification of a trough type. The ice-wedges occurring in the underlaying Plenivistulian deposits terminate at the interface of the above sediments. It cannot be excluded that it is an erosional surface analogical to that recognized in the Wisłoka valley (Starkel ed. 1981).

The incision of the meandering Vistula resulted in a lowering of the groundwater table and, in turn, made the dune-forming processes at the higher level (terrace 1) possible.

PALEOHYDROLOGICAL CHARACTERISTICS OF THE VISTULA DURING THE PLENIGLACIAL AND THE LATE GLACIAL — UNTIL THE ALLERÖD

In order to obtain estimated data about paleohydrological conditions of the Vistula during the Pleniglacial and the Late Glacial the following statements contained in the works of Pardé (1957) and Davidov (1955) have served as the basis. According to those statements values of the mean specific runoff of the rivers of the present permafrost zone of the continental climate and these of the rivers of the temperate zone are of the same order of magnitude (5—10 l/s/km^2). Despite of the substantially lower precipitation within the cold zone (ca. 200 mm/yr) the presence of an unpermeable permafrost substratum and low evaporation caused the outflow coefficient to be very large (e.g. in the Chatanga catchment it is 9.3 l/s/km^2). The outflow of the rivers of the temperate climate is distributed throughout the whole year with some maxima. In the case of the river of the cold zone it is characterized by very low winter water stages and by very intensive and short-lasting spring floods due to thawing. A significant percentage of the outflow is recorded between June and August.

Two rivers, namely the Chatanga and Anabar, debouching into the Laptiev Sea between the Yenisei and Lena outlets were chosen in order to be compared with the Vistula (Mycielska-Dowgiałło 1969). The catchments of these rivers are similar to that of the Vistula with respect to the size and relief as well as the annual outflow is of the similar order.

Based on the similarity of the annual outflow of the rivers and knowing the distribution of the mean discharges of the Chatanga and Anabar rivers, the discharge values during the floods were estimated for the periglacial Vistula. Monthly mean discharges during the spring floods ranged from 800 to 2100 m^3/s at Sandomierz. Provided mean discharge values as the above the velocity of outflowing water had to vary from 0.9—1.2 m/s. This estimated value agrees with that which can be read from the Sundborg curve (1967/68) when the mean grain diameter of the alluvia of the Pleniglacial is used. Then, the value 0.8 m/s is obtained. By analogy to the Anabar river, one can presume that the periglacial Vistula was characterized by very large floods reaching even more than 8 m above the lower water stage.

HOLOCENE

Meanders of the 2nd generation within the middle flood plain (*T3*) started to form at the beginning of the Pre-Boreal. The ^{14}C analysis of the organic deposits filling one of the meander forms (9070 ± 90 BP) confirms the above. The depth of reworking of the lower laying alluvia reaches down to 10 m (Fig. 2). Meander arcs became smaller. Their radius of curvature varies between 300—500 m, and the channel width between 100—200 m. Hence, these are much larger than those of the San valley described by Szumański (1982). Probably, that idicates that the final take-over of the Wisłoka water by the Vistula occurred at that time. The channel pattern in the studied section of the Vistula valley was formed jointly by the Vistula and Wisłoka rivers.

The shift towards the present eastern edge is observed during the entire period of development of the Vistula channel. The straightening of meanders and decrease of the reworking depth (5—7 m) are noticed during the youngest stage. Concentrations of large oak trunks and, locally, of large crystalline blocks are visible at the bottom of channel facies of that meander generation, below the eastern edge, in Machów. These trunks managed to get into the channel due to the lateral undercutting of the western slope of the Tarnobrzeg Ridge. The obtained ^{14}C date of 1850 ± 35 BP indicates that the Vistula in the studied section still possessed the meandering pattern.

Due to large outcrops the lithographical structure as well as the particular stages of the channel development are well visible in the Vistula valley. The outstanding features of the channel facies deposits are: large scattering of the laminae inclinations, large amount of well rounded quartz grains of the sand fraction, poor petrographic composition (due to selective weathering) and significant admixture of organic remants. The distinguished properties of the deposits result from the decreased river energy as well as from the multi-year reworking of own alluvia under the conditions of the limited supply from the catchment. The abundant organic remnants in the alluvial deposits are the evidence of a compact plant cover which comprised valley floors of that time.

The overbank facies deposits are represented by the clayey madas.

Small meanders are very poorly pronounced along the Mokrzyszówka and Trześniówka valleys, at the eastern side of the Tarnobrzeg Ridge. Simultaneously, flood water had to flow sporadically eastward what is confirmed by the preserved channel, the latter being composed of a series of ripples. A fragment of the trunk, dated as of 1795 ± 35 BP, has been found in one of them.

The last few hundred years have resulted in a pronounced change of the direction and outflow character of the rivers at the eastern side of the Tarnobrzeg Ridge. A broad valley with a flat bottom and braided channel pattern (occuppied by the Mokrzyszówka and Trześniówka) and orientated directly northward was formed at that time. It beheaded the Żupawka river. The width of the valley floor and braided river pattern suggest that the valley was formed by floods of fairly large rivers. However, one may not eliminate a possibility that it is the last, subsequent episode of the seasonal bifurcation of the Wisłoka river along the eastern edge of the Tarnobrzeg Ridge. Channel deposits of this stage of the Vistula valley development do not differ substantially from the alluvia of the meandering phase. The difference refers mainly to the structure and composition of the overbank facies. The latter is built of a significantly thick silty deposits locally intercalated with sands. The above is the effect of an increasing soil erosion within a catchment and of substantial amount of suspended load transported during the present-day floods.

Warsaw University
Institute of Physical Geography Sciences
00-927 Warszawa, ul. Krakowskie Przedmieście 30

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ZDZISŁAWA SARNACKA

EVOLUTION OF THE VISTULA VALLEY BETWEEN THE OUTLETS OF RADOMKA AND ŚWIDER RIVERS IN THE LATE GLACIAL AND HOLOCENE

INTRODUCTION

The relief of the middle Vistula valley upstream of Warsaw has been presented in details by Lencewicz (1927). Sawicki (1923, 1935) has refered later to the Late Paleolithic archeological sites in Świdry Wielkie I, II, Świdry Małe III, being precisely investigated by Krukowski (1922a,b, 1939). The age and origin of alluvia were studied by Różycki (1972a,b).

The sequence of events at the turn of the Vistulian was established by Schild (1969, 1975). Biernacki (1968, 1970, 1971, 1975) has presented numerous geological profiles of the Late Pleistocene and Holocene alluvia with archeological sites discovered in the humus mada layers.

The author of the paper has carried out the multi-year investigations in the framework of the cartographical studies for the Detail Geological Map of Poland in the scale of 1 : 50 000 (Sarnacka 1964, 1978, 1982).

Stratigraphy of the Quaternary deposits has been established on the basis of geological drillings reaching down to the Quaternary. In the case of the profiles of river sediments, grain size analyses have been made, sorting coefficients and medians have been calculated, petrographic composition of the gravels occurring in these profiles and roundness of the quartz grains have been determined. The Late Glacial and Holocene deposits have been studied in the Vistula profile close to Magnuszewo, then in the Vistula valley in the area from Góra Kalwaria to Osieck as well as in the valley profile from Jeziorna to Otwock.

CHARACTERISTICS OF THE PRESENT-DAY VISTULA ENVIRONMENT

The Vistula river between the outlets of Radomka and Swider includes the section between 431.9 and 493.7 km of the river length counting from the Przemsza outlet. The river flows in the meridionally orientated valley. The main features of the latter were formed during the Eemian interglacial.

At that time Vistula dissected the plateau of Mazowsze down to 40—50 m; Warka plateau is located at the left bank and Siedlce plateau at the right bank (Różycki 1972b). The left tributaries of the Vistula are: Radomka and Pilica, and smaller ones: Czarna and Jeziorka. Small tributaries: Bączucha, Promnik, Wilga and Świder debouch on the right river side.

The Vistula valley in the discussed section is 12—15 km wide and constitutes a narrowing between Kozienice and Warsaw Basins. Różycki (1972b) has accepted the name "Masovian gap" for the section in question. The general tectonic conditions favouring the location of this section of the valley are pronounced since the pre-Pleistocene at least, and are related to the subsidence along the axis of the parallel lowering of the Marginal Depression (Synclinorium) (Różycki 1972b).

Fluvial deposits of the Vistulian period underlain by those of the Eemian interglacial occur on the basement of the sediments of the Vistula flood plain, 4—6 km wide (Fig. 1, 2, 3). At their bottom there are Masovian Interglacial alluvia deposited in the valleys being incised in the Pleistocene sediments, and fragmentarily covering glacial sediments and proglacial lake deposits of the South Polish Glaciation, those preserved in deep valleys of the Cromerian Interglacial. Due to erosion in the subsequent interglacials only fluvial deposits are present nowadays over extensive areas in the Vistula valley. During the subsequent interglacials not only the width of the valleys formed by the Vistula but also the alluvia thickness have decreased. Whereas the alluvia of the total thickness up to 50 m were deposited by the Vistula in the Masovian Interglacial, those deposited in the Eemian Interglacial reached the thickness up to 20 m only (Sarnacka 1978, 1982).

The present Vistula channel, 600—1000 wide, at the reach from the Radomka outlet to that of Świder is subdivided into numerous channels with many bars and broad interchannel islands. That is typical braided development of the river channel and the most branched off river reach from the outlet from uplands to Warsaw and downstream. The braided channel development is associated with accumulation of broad sand bars and islands, especially during the flood flows. Annual water discharges are very variable. Provided low water stages (NW) discharges decrease down to 100 m^3/s and reach 600 m^3/s at mean annual water stages while during the floods the discharges exceed 3000 m^3/s and sporadically 5500 m^3/s during the catastrophic floods. During the flood discharges of the order of 4000 m^3/s velocities are locally as large as 5 m/s. An average water velocity in Gusin at the gradient of 0.03 varies from 0.7 to 1.2 m/s. Water discharge variations result in vertical changes of the Vistula water table. Annually, the amplitudes are up to 4 or 5 m while

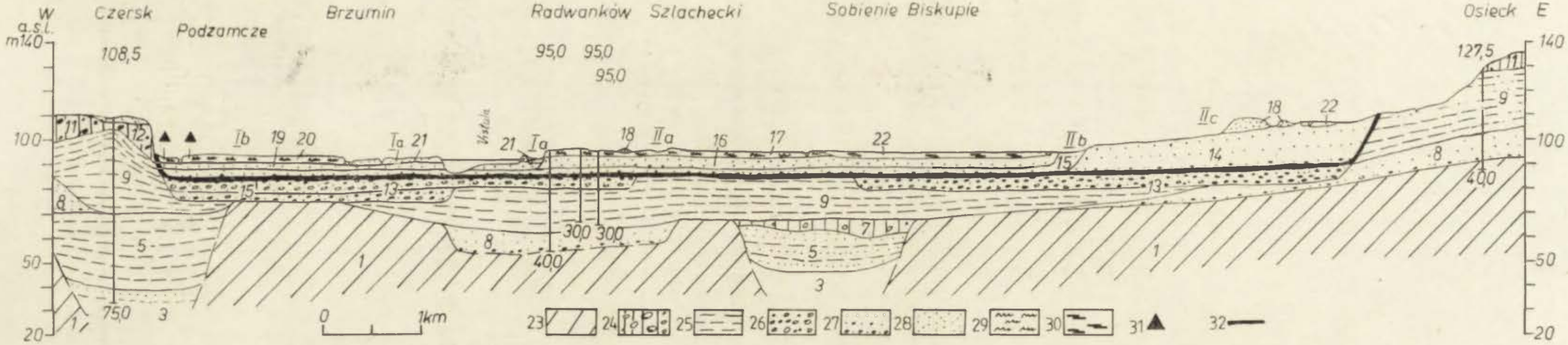


Fig. 1. Geological cross-section of the Vistula valley from Czersk to Osieck

Stratigraphic explanations: Pliocene: *1* — clay, silt and sands; Preglacial: *2* — sands with gravels and river silts; Cromerian interglacial: *3* — sands with gravels and river silts; Mindel Glaciation, Older stadial: *4* — glacial till; Younger stage, younger phase: *5* — sands, silts and glacilacustrine clays, *6* — glaciofluvial sands, *7* — glacial till; Masovian interglacial: *8* — sands with gravels and river silts of four sedimentation cycles; Middle Poland glaciation, Maximum stadial: *9* — clay, silts and glacilacustrine sands, *10* — glaciofluvial sands, *11* — glacial till; Warta stage: *12* — glaciofluvial sands; Eemian interglacial: *13* — sands with gravels and fluvial sits of 3 sedimentation cycles; Vistulian Glaciation: *14* — fluvial sands of the highest overflood Vistula terrace — the Otwock terrace IIc, *15* — fluvial sands of the higher overflood Vistula terrace — the Falenica terrace IIb, *16* — fluvial sands of the lower overflood Vistula terrace — the Praga terrace IIa, *16a* — Usselo type soil, *16b* — peats with charcoal, *17* — madas of the lower overflood Vistula terrace — the Praga terrace, *18* — eolian sands in dunes; Holocene: *19* — fluvial sands of the higher flood-plain Ib, *20* — madas of the Vistula higher flood-plain Ib, *21* — sands and madas of the Vistula lower flood-plain Ia, *22* — sands, sandy silts and peats of the valley floors and abandoned channels. Petrographic explanations: *23* — Pliocene deposits; *24* — glacial till; *25* — clay and varved silts; *26* — gravels; *27* — sands with gravels; *28* — sands; *29* — madas; *30* — peats; *31* — archeological sites; *32* — limits of the Vistulian deposits

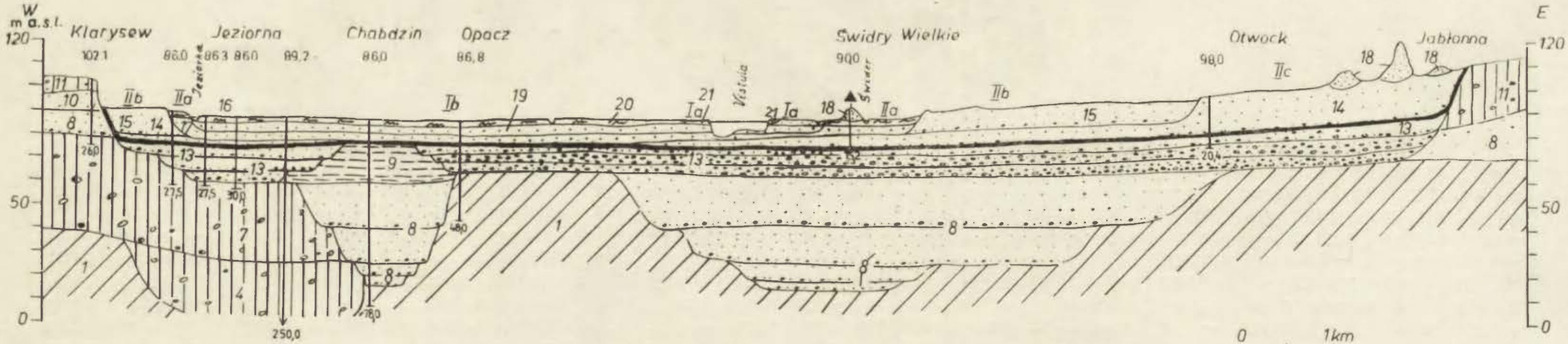


Fig. 2. Geological cross-section of the Vistula valley in the area of Całowanie (explanation in Fig. 1)

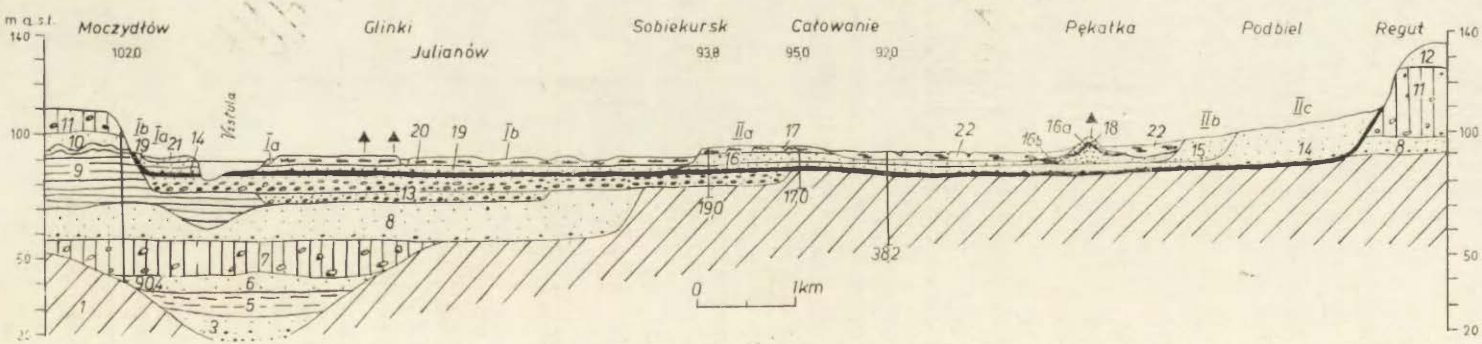


Fig. 3. Geological cross-section of the Vistula valley from Jeziorna to Otwock (explanations in Fig. 1)

the maximum ones exceed ca. 7 m. Water depth in the most dynamic current streams at low water stages is ca. 2 m while at high water stages ca. 7 m.

The Vistula river freezes every 2—3 years and the ice cover lasts 2 months.

Total sediment load transported by the Vistula consists of dissolved load (70%), suspended load (20%) and bedload (10%), the latter being mainly sandy and transported and accumulated at the bottom of current streams. According to the calculations of Skibiński (1963) sandy bedload carried by the Vistula river in the region of Warsaw is 45 000 m^3, i.e. 810 000 tons. Skibiński states that 58% of the bedload is transported at mean water discharges and 1/3 at high-water discharges. Silty suspension during the thawing floods reaches the concentration of 50 g/m^3 of water (Biernacki 1970). At average, 2.5×10^3 tons of suspended load per day is transported by the Vistula river (Biernacki 1970).

Flood discharges exceeding the channel capacity and reaching the water stage over 5 m above the "zero" of the Vistula (water stage gauge in Gusin) periodically overflood the valley limited by the flood-control embankments. Until the latters were not built, i.e. until the beginning of the 20th century, the Vistula river had flooded the whole flood plain and sometimes reached the lower steps of the upper terrace (the Pleistocene one).

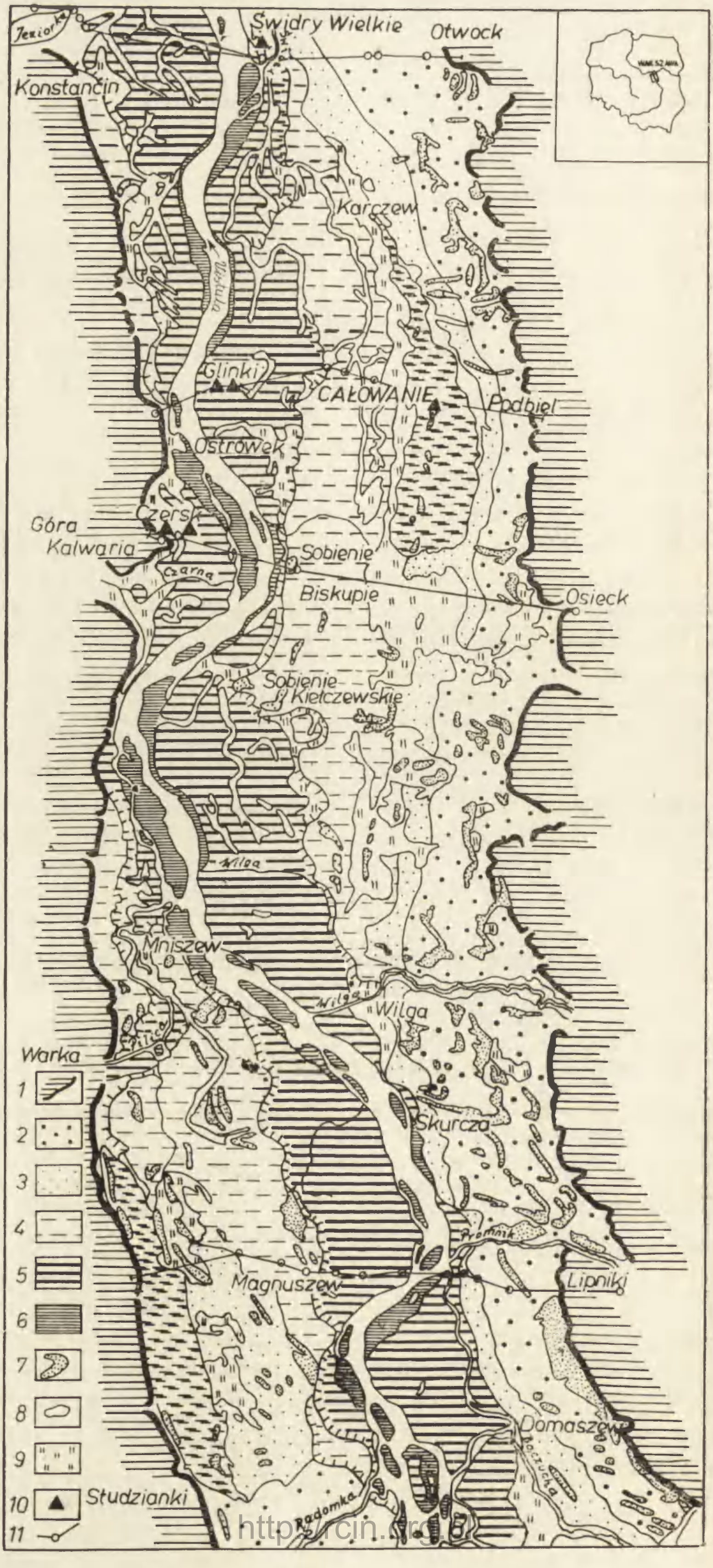
The braided nature of the Vistula channel results from floods and develops due to the excess of material over the transport ability of the current streams.

CHARACTERISTICS OF FORMS AND SEDIMENTS AT THE VALLEY FLOOR OF THE VISTULIAN AND HOLOCENE PERIODS

The Vistulian alluvia were deposited by the Vistula on the fluvial deposits of the Eemian interglacial. There are 3 overflood accumulation terraces: the highest — Otwock terrace — II c, upper — Falenica terrace — II b, lower — Praga terrace — II a (Fig. 4, 5).

OTWOCK TERRACE IIC

The overflood Otwock terrace — IIc has been preserved at the both sides of the Vistula (Fig. 4). Its surface in the valley cross-section is located at the height of 105.0—110.0 m a.s.l. in the southern part and at 95.0—100.0 m a.s.l. in the northern one. At the right side of the Vistula the terrace is preserved on the extensive terrains in the area from Domaszew to the Wilga river, and then northward from the Wilga outlet as a narrow belt at the foot of the plateau. At the left side the surface of the terrace in question is preserved at the Radomka and Pilica outlets into the Vistula. Here, it rises from 12.0 to 15.0 m above the Vistula



Jeziorka
Świdry Wielkie
Otwock
Konstancin
Karczew
Glinki
CAŁOWANIE
Podbiel
Ostrówek
Czersk
Góra
Kalwaria
Sobienie
Czarna
Biskupie
Osieck
Sobienie
Kiełczewskie
Wilga
Wilga
Wilga
Mniszew
Pilica
Warka
Skurcza
Promnik
Magnuszew
Lipniki
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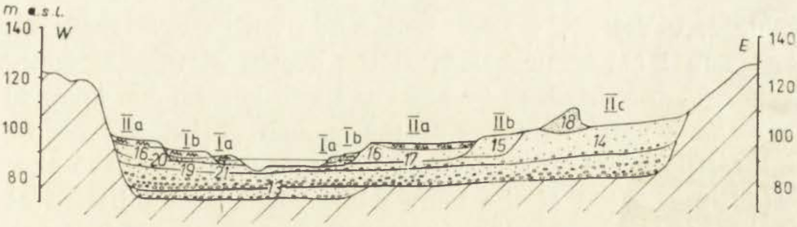

Fig. 5. Scheme of terraces in the Vistula valley south of Warsaw

Terrace levels: IIc — highest overflood terrace, Otwock one; IIb — higher overflood terrace, Falenica one; IIa — lower overflood terrace, Praga one; Ib — higher flood-plain; Ia — lower flood-plain; other explanations of stratigraphic levels as in Fig. 1

level. Numerous systems of parabolic forms, up to 20 m high, occur at the both Vistula banks.

During accumulation of the highest Otwock terrace sediments the Vistula has transported well sorted sandy material. The latter consists of various sands with a dominance of the medium ones with lenticles and intercalations of fine gravels being represented by crystalline rocks, sandstones, flintstones, and the Carpathian hornstones.

The roundness of the quartz grains of the fraction 0.5—1.0 mm indicated that the fluvial deposits of the period of the Otwock terrace formation are characterized by a higher degree of roundness compared with fluvial deposits of the elder interglacials. Roundness coefficient is 0.16—0.39. Good sorting is a characteristic feature of these sediments. The median is 0.26—0.67 mm. The thickness of the Otwock terrace at the discussed section of the Vistula valley does not exceed a few meters. The Vistula valley was filled with these deposits up to the height of 110 m a.s.l.

FALENICA TERRACE — IIB

The Falenica overflood terrace like the Otwock one has been preserved at the both Vistula banks in a form of a narrow bench of the width varying from several hundred meters to 1 km. The surface of the terrace in the southern part is located in the valley cross-section at the height 100.0—105.0 m while in the northern part at the height 90.0—95.0 m a.s.l. It rises from 7.5 to 10.0 m above the Vistula level. The terrace is limited by a distinct edge of the height of 5 m. Biernacki (1971, 1975) has found the fossil mud horizon deposited in the abandoned channel in the considered terrace profile in Skórcza. At the upper face there is 70 cm series of the dune sands with the 15—20 cm humus horizon

Fig. 4. Morphological sketch of the Vistula valley from Radomka to Świder outlet

1 — edge of glacial plateau; *2* — Vistula highest overflood terrace — Otwock terrace IIc; *3* — Vistula higher overflood terrace — Falenica terrace IIb; *4* — Vistula lower overflood terrace — Praga terrace IIa; *5* — Vistula higher flood-plain Ib; *6* — Vistula lower flood-plain Ia; *7* — dunes; *8* — abandoned channels; *9* — water logged and peaty depressions; *10* — archeological sites; *11* — cross-section lines being their top. Yellow, vari-grained sands with single gravels of the diameter up to 1 cm occur below, at the depths of 70—125 cm. At the top of sands, at the depth of 70—80 cm there is a humus layer in wich a single ceramic piece dated as of the Roman period has been found. According to Biernacki (1975) sand interbedding took place in the historical period. Formation of the humus layer had been initiated at least in the Younger Dryas. North of the Wilga river the Falenica terrace extends as a narrow belt to Falenica. There, its edge is degraded by eolian processes which also accreted the surfaces of IIb and IIc terraces.

Sandy deposits of the Falenica terrace lIb are lithologically identical to those of the Otwock terrace. Alluvia of this period consist of vari--grained sands with small amounts of gravels of the thickness of 8—10 m.

PRAGA TERRACE — IIA

The lower overflood terrace of the Vistula, called the Praga or Janów terrace (Baraniecka 1976) is limited at the whole length by a distinct edge of a relative height 2—5 m. The surface of the terrace is located at 100.0—102.5 m a.s.l. in the southern part of the valley and at 90.0—92.5 m a.s.l. in the northern one. The terrace forms an extensive evened out level, up to 3.5 km wide, with preserved numerous abandoned channels. Single, rather small dunes occur on this terrace surface. The dunes in shape of ridges are formed most frequently along the boundaries of the terrace edge and parallely to the former and present course of the Vistula bed among the extensive lowerings.

At the left bank of the Vistula the terrace surface extends as a wide belt up to the Pilica outlet (Fig. 4). Downstream the terrace is preserved only fragmentarily.

At the right bank of the Vistula the terrace extends as the 1.5 km wide belt up to Karczew. The terrace surface borders in the east with a broad, 1.5 km wide, lowering, the latter extending over the length of 25 km from Wilga to Karczew and marking the old Vistula bed related to the initial period of the dissection of the Praga terrace plain.

In the middle part of the abandoned Vistula bed the peatbog Całowanie (Schild 1969, 1975) was formed. A dune ridge was built within the latter (Fig. 4). Detail archeological studies related to geological investigations were carried out by Schild in 1963—1969 on one fragment of this dune ridge in Pękatka.

The wide belt of depressions, situated analogically as in Całowanie, occurs on the opposite side of the Vistula in the area of Magnuszewo. It extends at the foot of the edge of the upland indicating the abandoned channel bed of the Vistula or possibly, one of the branches of the Vistula of the length exceeding 15 km, with a peatbog with a dune ridge in its middle part as in Całowanie.

Both the dunes in form of dissected ridges and the series of peaty depressions orientated parallely to the channel course indicate that during the accumulation of the Praga terrace the Vistula river in this section was, as it is nowadays, orientated meridionally and its channel was rather straight and narrow.

Deposits of the terrace in question consist of alluvia of the channel and flood facies. The channel alluvia are medium and fine sands with a few coarse and fine gravels, 4—8 m thick. These are well sorted. Median is 0.33—0.94 mm. The good roundness of quartz grains is their characteristic feature. The rounded grains dominate and make up to 73.0%. The roundness coefficient is 0.26—0.38. Undoubtedly, it results from the influence of water environment on the grain roundness during a longlasting transportation of the grains which have been already rounded in the earlier periods. Moreover, one has to take into account that a significant part of the grains could have been blown to the valley, thus some number of grains which have been supplied to the river exhibit traces of eolian abrasion under periglacial climate conditions.

On these sediments the Vistula has deposited flood facies material represented by light silt-sandy and silty-clay madas which are known as brown madas (Biernacki 1968) or "old madas" (Kobędzina-Kaczorowska 1926, 1961). They differ from the other madas due to an intensive rusty colour and advanced development of soil processes frequently with illuvial horizon marked by iron concretions and hardpan (orstein). Contrary to the flood terrace madas they are characterized by a weak acidity pH = 6 (Biernacki 1968). Their thickness is ca. 0.6 m.

Alluvia of the Vistula lower overflood terrace and those of the Praga terrace IIa are the only deposits out of the discussed above sediments of the Vistula overflood terraces which age has been documented in Całowanie (Schild 1975) by palynological dating, by the ^{14}C method and archeological sites.

Before the discovery of the site Całowanie datings of the terraces have been exclusively attempted on a general stratigraphic-morphological basis. The latter have been related to particular recessional phases of the Vistulian glaciation.

S i t e   C a ł o w a n i e located in the middle of the 3 km wide channel, abandoned by the Vistula in the Alleröd, is an island protruding above the Holocene peatbogs and located close to the Pękatka hamlet. The island was strongly degraded by later eolian processes. Here, the fossil Vistula channel is filled with peats underlain by thin gyttja layers or fine silty sands in its northern part and with sands and peaty silts or sandy ones in the southern part (Fig. 6). Close to the southern bank, at the largest curvature of the depression arc, peats are up to 5 m thick.

In a geological profile of the island in Całowanie Schild (1975) has

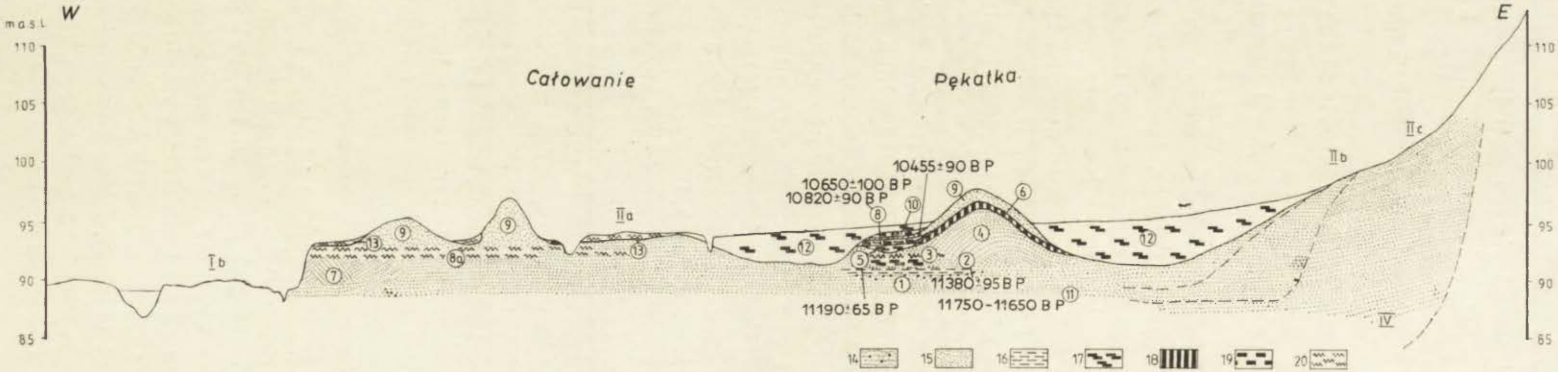

Fig. 6. Schematic cross-section of the right-bank of the Vistula valley in Całowanie

Stratigraphic explanations: *1* — sands and gravels of channel sedimentation of the Older Dryas; *2* — sands with silts, and gravels of the lower series of the alluvial island of the first half of Allerod; *3* — herbaceous peat and madas and sands of flood sedimentation; *4* — sands and silts of shoal island; *5* — peat of the second half of the Allerod changing into Usselo soil up-slope of the island; *6* — Usselo soil; *7* — sands with gravels of the channel facies of the younger part of the Praga terrce IIa; *8* — sandy gyttja with mada of early Younger Dryas covering Usselo soil; *8a* — sandy madas and sands of flood facies of the younger part of the terrace IIa of the pre-dune phase of the Younger Dryas; *9* — dunes of dune phase of the Younger Dryas; *10* — sandy gyttja of the post-dune phase of the Younger Dryas and Pre-Boreal; *11* — alluvia with gravels of the lower parts of the Praga terrace; *12* — Holocene peats; *13* — Holocene madas; IV — sands with gravels at the lower face of the terrace IIc. Petrographic explanations: *14* — sands with gravels; *15* — sands; *16* — silts; *17* — peats; *18* — soil; *19* — gyttja; *20* — madas distinguished two sedimentation members: the lower one — that of shallow central bar, and the upper one — that of dunes. Both the members are interlinked with organogenic sediments occurring in the vicinity (Fig. 6).

Sands and gravels of the channel sedimentation (*1*) constitute the lowest known horizon. They are overlain by the bottom of the shoal series which consist of the laminated sands and sandy silts (*2*). The upper part of the shoal series is represented by laminated sands only (*4*). They form a bar in the northern side while in the NW part they overtop the flood deposits (*3*), which were most likely formed simultaneously with the sediments of the bottom part of the bar (*2*). The flood deposits composed of a thin gravel horizon (*3a*) covered with a thin layer of the compressed peat of herbaceous plants (*3b*) and a thin sand layer (*3d*). The latter separates the peat from the overlaying sandy mada containing some detritus gyttja and peat intercalations (*3c*). Above, there is fine brown sand (*3f*) and above it, in turn, coarse sand with gravel (*3g*). At the NW part of the island, the deposits of the alluvial sedimentation are covered with a dichotomous herbaceous-brown-moss peat with charcoal concentrations at the bottom (*5a*). The upper part of the peat changes gradually into the soil of the Usselo type towards the head of the island. This top part of the peat has been humificated (*5b*). On the shoal island, fluvial sands are covered with the Usselo soil which descends also onto the terrace surface outside the island slopes. In the northern part of the shoal island, in the uppermost fragments, this soil is not preserved due to deflation during the dune sedimentation. In the northern boundary zone the Usselo soil is covered with the clay-sandy gyttja filled with coal (*6*).

Almost all the deposits discussed above are covered by sands of the dune sedimentation (*7a*). These sands are the thickest in the central part of the island. Dune sands in the boundary zone are covered with a thin gyttja layer (*8*).

Basing on the data given above Schild (1975) assumed that during the sedimentation of the shoal island the Vistula main current was at the eastern side of the island. That is confirmed by the morphology of the peat substratum which fills the dead channel, the latter descending in a distance of ca. 300—400 m to the NE of the island. Close to the western bank of the Vistula channel the shoal island was formed during the spring high water stages of the Vistula. The island was widened towards the N and NW, and moreover accreted in its northern part according to the river current. In the initial phase of the shoal island formation, the shortlasting sedge peatbogs covered with flood sands and fluvial mada have been formed to the NW of the island. These sediments deposited on a flat surface surrounding the island became covered with sands in the final phase of the island accretion towards the NW-direction. A new peatbog which has been formed again in a small depression at the NW end of the island terminated the sedimentation of the island in question.

Basing on the ^{14}C datings and palynological profiles Schild (1975) considered that the date 11 380 ± 95 BP obtained from the bottom of the upper portion of the shoal island sediments indicates that the shoal island was formed during the Alleröd and is related to the settling of the III cultural level. The date 11 190 ± 65 BP obtained from the concentrations of the charcoal of the bottom of the peat (*5a*), the latter deposited just after the island sedimentation has been completed, determines the age of that event as the second half of the Alleröd. That indicates that the portion of the upper shoal series of the island has been deposited during ca. 200 years. Accumulation of the lower part of a greater thickness lasted probably much longer, ca. 300—400 years. The beginning of the shoal island sedimentation took place in the early Alleröd (ca. 11 800—11 700 BP) while sands with gravels of the channel facies originate of the Older Dryas.

The termination of the fluvial sedimentation (11 190 ± 65) denotes also the initial stage of the pedological process at a bar surface. The processes of the Alleröd soil formation in the final stage has comprised the upper peat layer what resulted in its strong humification. The process provides also the evidence for a further lowering of groundwater in the Vistula paleochannel and indirectly for a deepening of a new shifted Vistula channel (ca. 300—400 years before the end of the Alleröd).

The age of the termination of the pedological process after 400 years is determined by the dates 10 820 ± 90 and 10 650 ± 100 BP, the latter obtained from a thin gyttja layer (*6*) covering the soil in the boundary zone. The palynological gyttja profile indicates that it originates from an early phase of the Younger Dryas. The Usselo soil on the island is cover with a dune of the Younger Dryas. Basing on the results of Całowanie the final stage of the dune sedimentation was completed in the middle of the Younger Dryas what is documented by the date 10 450 ± 90 obtained from the charcoal excavated out of the gyttja (*8*) overtopping the dune sands in the NW part of the island. These charcoals are associated with the settlements of the Masovian cycle.

Borówko-Dłużakowa (1961) has also carried out the palynological studies of the Całowanie peatbog. At the bottom of the profile of the Łukowiec area, silts have occurred at the depth of 3.4—3.5 m. Peat of the thickness of 0.5 m was deposited over these silts. Above, at the depth of 2.3—2.9 m calcareous gyttja occurs covered with a new peat layer from the surface to 2.3 m. Three climatic phases are distinguished in the palynological diagram. The first one is the evidence of the mild climate, the second of a cooling (in the latter one the stenothermal forms disapeared in favour of pine and birch with grasses) and the third phase much warmer than the previous one. According to Borówko-Dłużakowa the bottom of the profile can be related to the Alleröd. The second zone corresponds to the Younger Dryas cooling while the reoccurrence of the stenothermal forms in the third zone provides the evidence of the following post-glacial warming.

Sites Świdry Wielkie and Świdry Małe. Świdry Wielkie is a fairly small dune located at the spit of the Praga terrace edge at the Świder river outlet into the Vistula. That profile was described by Krukowski (1922a,b, 1939) and Sawicki (1923, 1930, 1935). The dune Świdry Wielkie I, II comprises 3 soil horizons (Schild 1975) and lies directly onto the sand of the IIa terrace. The B-horizon of the lowermost fossil podsol contained the material of the turn of Paleolithic Masovian cycle.

The site Świdry Małe is located on a strongly wasted ridge dune, 1 km to the north of Świdry Wielkie; Sawicki (1923) discovered some small accumulation of the Masovian cycle materials in the SE part of the dune.

Based on the current knowledge on the chronology of the Praga terrace Schild (1975) considered that all the materials from the sites Świdry Wielkie I, II and Świdry Małe III collected by Krukowski and Sawicki are younger than the early phase of the Younger Dryas. That is evidenced by hypsometry of this part of the terrace, by madas below the dunes, and continuous transition of the terrace sedimentation into the dune one.

With respect to hypsometry, the sites in Świdry Wielkie are located at the height of 90.0—92.0 m a.s.l. what altitudinally corresponds to the upper part of the IIa terrace of Całowanie (95.0 m a.s.l.). Thus, it can be assumed that the late Paleolithic settling, located at the B-horizon of the lowermost soil, the latter covering the flat dunes in Świdry, is younger than the dune sedimentation, and according to Schild (1975) it should be related to the final phase of the Younger Dryas and early Pre-Boreal.

When analysing the profile of Całowanie Schild (1975) assumes that the change in the Vistula bed position has occurred directly after the sedimentation of the central bar when the latter was covered with pine forest. The shift of the river did not take form of a meander cut off because the preserved bend of the inactive channel is small. According to Schild the Vistula river functioned likely in the existing lateral shallow flood scour with a flat channel. The shift was rapid because the fossil bars of the period preceeding the river shift are preserved along the whole old bed. Różycki (1972a) considers that the bed cutting off was caused by a formation of levees in the area of Karczew. The Vistula channel was shifted to the west in the second half of the Alleröd and deepened by the end of the Alleröd. The presence of the thin gyttja horizon, the latter covering the island slopes, indicates the rise of ground water table in the initial phase of the Younger Dryas. That was related to the high water stages of the Vistula river which overflooded the channel banks and deposited sand and flood madas in the lower parts of the IIa terrace to the west of the site Całowanie. High stages in the area of Całowanie reached at least up to 95.0 m a.s.l. at that time, i.e. ca. 10 750 BP.

Biernacki (1971) has also pointed out the Alleröd age of the initial deposition of madas of the Praga terrace because they are locally covered by the boundary ridge dunes being related to the Younger Dryas. The Late Pleistocene age of the Praga terrace madas is documented by the neolithic settlement stated among the others in Kępa Radwankowska and Sobienie Biskupie (Biernacki 1971; Krukowski 1920).

Formerly, the mada formation on the Praga terrace IIa was related to the Holocene ice-jam floods (Różycki 1972a) occurring since the Atlantic. Based on the chronicle documents Biernacki (1971) states that since the 15th century the ice-jam floods entered the Praga terrace only sporadically, and since the 18th century more frequently — once per a few dozen years. However, the amount of muddy material deposited by those floods was negligible. Thus, the madas of the Praga terrace are undoubtedly older than the contemporary accumulated Holocene madas.

The age of the upper series of alluvia of the Praga terrace which has been documented in Całowanie allows one to presume that the Vistula downcutting to the lower face of the IIa terrace occurred during the Bölling interphase and the alluvia accumulation lasted until the Alleröd — when the shift of the Vistula channel took place.

According to Biernacki (1971) the dissection of the plain of the Falenica terrace IIa could occur after the Pomeranian phase and before the Bölling.

HOLOCENE

At the beginning of the Holocene the Vistula cut the Late Pleistocene alluvia of the Praga terrace IIa initiating this way bottom and lateral erosion as well as accumulation of the Holocene alluvia.

The higher flood plain Ib and the lower one Ia have been formed by the Vistula within the 6 km wide Holocene valley.

Higher flood plain — Ib. That flood plain is located along the whole river and its total width occuppies the Holocene valley. Its surface is flat, with preserved abandoned channels occurring mainly at the foot of the edge of the Praga terrace IIa, and indicating Vistula flow at this level. The terrace surface riser 2—3 m above the mean Vistula water stage and its height descends over the discussed section from 100.0 to 85.0—87.5 m a.s.l.

Alluvia of the Ib flood plain consist of fine sands with a few percent of medium ones and their thickness is up to several meters. During numerous floods the Vistula has deposited on those sediments the madas which cover the flood plain almost as a uniform layer. These are heavy, silt-clay compact madas of the following colours: brownish-gray and blueish-gray, spotty rusty-yellowish-gray of the thickness of 0.5—3.9 m and sometimes to 5.0 m. They are usually neutral, of pH close to 7 (Biernacki 1968) what is associated with slightly alkaline Vistula water (pH = 7.5—8.0), being more alkaline in summer at low water stages. In that layer, to the south of Czersk in Królewski Las the author has discovered a concentration of the black tree trunks which were inserted in the present-day bank of the Vistula bed. The trunks have not been dated by the radiocarbon method. Smólska (1963) has indicated these trunks as oaks (*Quercus pendunculata* Ehrh.) and as linden (*Tilia parvifolia* Ehrh.). Flood levees, probably associated with the ice-jam floods, were formed in many locations in the near-bed zones on the considered madas of the IIa terrace. On one of the fossil levees occurring at the fringe of the abandoned channel in Czersk (Fig. 4), 0.3 m thick humus layer of mada with numerous ceramic pieces of the period of the 7th — 5th century BC to the 14th century AD, i.e. over 2000 years, was discovered by Biernacki (1968, 1975) at the depth of 0.5—9.8 m under a thin layer of surface madas and coarse sands. Above, 2000 pieces primarly dated as of the Middle Ages (majority of the 14th century, some of the 12th, 15th centuries), and of the 16th century (Roman period/beginning of AD) and of the La Tene period (from the 5th century BC until the beginning of AD) have been collected from that cultural layer and from the surface of the area.

Prehistoric burial grounds, graves and settlements of various archeological periods have been discovered by Biernacki (1968, 1975) at the levee analogical to that of Czersk, limiting from the west the cutoff in Glinki (Fig. 4) and Julianów and in its vicinity at the surface, in a humus layer of the mada of the terrace Ib. The ceramic of the prehistoric burial grounds of the period of bell graves dated tentatively as of the 3rd century BC, the crematory burial ground of the Przeworsk culture, dated as from the turn of the 1st and 2nd century AD, an early Medieval ceramics, tentatively dated for the 12th century AD, two Medieval settlements possibly of the 14th to 16th century have been found. In the part of the burial ground, of the early Roman period, neighbouring the grave, 20 pit graves and cinerary urn graves have been found dated for the first half of the 1st century AD. Single Roman coins dated exactly for 3rd and 4th century AD have been found in the neighbourhood of the described burial ground in Kępa Gliniecka and Ostrówek.

According to Biernacki (1968) the accumulation of multichronological finds in one cultural layer is the indirect evidence of the fact that for the period of at least 2000 years, from the 7th to 5th century BC until the middle of the 14th century AB, the Vistula did not annually flooded the zones of the described flood plain lb. That process lasted so long that humus soil was formed in Glinki and Julianów on the madas previously deposited by the Vistula. That soil was later covered by younger flood deposits. Sporadic floods of the 10th century occurred most likely irregularly in a several tens of years intervals. Due to infrequent floods and due to smaller amount of material carried by the flood waters in a period from the 7th—5th BC until the 15 century AD the Vistula was not able to form a definite mada layer at the surface of the flood plain lb. Probably, it caused an increase of the thickness of the fossil humus layer of the earlier accumulated mada by few cm only.

Based on the detail analysis of the discussed finds, Biernacki (1968, 1970, 1971, 1975) assumes that madas of the Vistula flood plain lb were accumulated in the second half of the Sub-Boral phase and at the beginning of the Sub-Atlantic phase. When a mada accumulation cycle had been completed and after stabilization in the Vistula valley the flood plain lb within the range of the discussed section of the Vistula was occupied by settlements of the Lusatian culture by the end of the youngest (V) period of the Bronze age or at the beginning of the Iron age.

Flood frequency increased at the beginning of the 15th century. Due to these floods the upper face of mada of light brownish colour with a small amount of clay fraction of the thickness of 0.3—0.5 m has been accumulated. The Vistula channel started to change its meandering pattern towards its present-day straight and also braided nature. The increasing number of floods caused a shift of settlements towards the higher and higher ridges of the flooded Vistula valley. Aggradation known from the upper sections (Falkowski 1967) has started. Effects of climate changes were enhanced due to forest clearing associated with a development of agricultural practicies. Because of numerous floods settling concentrated since the 18th century mainly at the near-scarp portion of the overflood terrace IIa.

Flood plain 1a. That part of the flood plain at the discussed section of the Vistula valley forms small benches between the embankments and the Vistula. The plain is eroded by the present-day Vistula river. Its surface rises from 1 to 1.5 m above the Vistula level. The plain is located at the height of 95.0—100.0 m a.s.l. in the southern part and at 85.0—90.0 m a.s.l. in the northern part of the valley. The plain width varies from several to some hundred meters, sometimes ca. 1 km.

During accumulation of the lower flood plain deposits the Vistula transported fine sands with single gravels while a few mm thin layers of madas were accumulated during floods. The thickness of these alluvia is very differentiated (0.5—1.5 m). The uppermost parts of the lower flood plain la are located in the interchannel fully developed islands and on the edge of the channel zone being for a longer time period under the influence of dynamic channel processes.

Present-day alluvia of the Vistula channel zone are of the thickness varying up to 10 m. They are subject to a repeatative reworking. A depth of this overworking is marked in the profile by distinct erosional gravel horizons of an amplitude of a few meters and sloping according to the river gradient. The depth of the reworking indicates a low channel position in various phases of the Sub-Boreal and Sub-Atlantic periods.

PALEOGEOGRAPHIC RECONSTRUCTION OF THE VISTULA VALLEY

History of the Vistula valley development at the turn of the Pleistocene is associated with a recession of the Vistulian ice-sheet. Before the Pomeranian phase the Vistula functioned as a marginal channel. Recession of the ice-sheet of the Pomeranian phase has caused an outflow of the Vistula water to the Baltic sea and enabled a valley deepening. Due to an increased gradient the Vistula has cut down to the lower face of alluvia of the Falenica terrace (IIb) and accumulated sandy alluvia. Because of rapid changes of the Vistula runoff in that period and due to shortening of the outlet to the Baltic the Vistula stared to cut down to the bottom of the Praga terrace IIa already in Bölling. According to Biernacki (1970, 1971) the Vistula at the discussed section has flown in an initial stage in a wide, straight channel. Formation of the cover of the terrace IIa took place during the Older Dryas and lasted to the mid-Alleröd.

During accumulation of the upper face of the Praga terrace shoal islands were formed which enforced a sinuous stream pattern at low water stages. The Usselo type soil formed at the shoal island of the terrace IIa in Całowanie provides evidence that the Vistula has shifted to the west already since the mid-Alleröd while at the turn of the Alleröd a former Wilga bed to Karczew was abandoned. A gyttja lamina varnishing the Usselo soil (Schild 1975) indicates that ground water table rised up at the beginning of the Younger Dryas what, in turn, was associated with high water stages of the Vistula. The latter has deposited sands and flood madas on the Praga terrace IIa. In the final accumulation phase a discharge and material supply to the channel decreased due to climatic changes. At that period, the Vistula channel was narrowed several times (to 300—400 m) and was of a meandering nature.

Madas of the Praga terrace deposited during the period shorter than 400 years (ca. 11 200—10 800 BP) reached the thickness of 0.6 m. Thus, mean annual rate of the mada accumulation was over 1.5 mm, and was faster than the present rate. People inhabiting dunes made their living on hunting and did not invade madas of the terrace IIa. The latters were valued by the people of the Neolithic age (Krukowski 1920, Biernacki 1971).

In the Younger Dryas sands were drifted, probably from braided channels, onto the surface of the terrace IIa. They were also drifted on the island in Całowanie which had been already stabilized by vegetation. Fairly low and small sized dunes were formed at that ime. Simultaneously there was a transformation of the dunes which had been formed earlier in the Older Dryas on the higher terraces of the Vistula (IIb and IIc).

Gyttjas, and then the Holocene peats started to form in the abandoned channels of the Vistula at the turn of the Younger Dryas.

Due to an increased gradient the Vistula initiated an incision of the Praga terrace forming a flood plain Ib at the beginning of the Holocene. The process of the present-day Vistula flood plain formation was initiated at that time. Major features of the actual valley were formed in the Atlantic period. The channel of the river of that time was of a meandering nature. During the climatic optimum in the Atlantic period meanders of the Vistula were up to 1.5 km wide which classic example is the meander in Sobienie Kiełczewskie (Fig. 4). Simultaneously, flood accumulation has developed. Numerous trunks of deciduous trees, among the others oaks and lindens, provide evidence of large discharges. These trees discovered at the river bed within the discused area in 1963 could not have been studied by a poorly known at that time ^{14}C-method.

The percentage of clay fraction in the madas of the flood plain Ib larger than that in the present-day madas indicates a smaller supply of coarse material from the catchment, and indirectly, provides the evidence of a smaller intensity of denudational processes and of the compact vegetation cover in the Vistula catchment upstream of the discussed section.

Based on the analogy of the water level changes of the present Vistula one can presume that the amplitudes of the stages of water accumulating the alluvia of the supra flood plain Ib were smaller and erosion of the Vistula did not reach as deep when compared to the present ones.

The occurrence of archeological finds in the madas of the flood plain Ib allows one to indicate that the madas of this plain were deposited between 5200 and 2500 BP (Biernacki 1970). Probably they have been accumulated in the second half of the Sub-Boreal and at the beginning of the Sub-Atlantic. After the cycle of mada sedimentation had been completed and decline of flooding, the flood plain Ib was locally occuppied by settlements of the Lusation culture. The discussed Sub-Boreal period has finished ca. 1000 BP and since then until the beginning of the 15th century the Vistula valley was stabilized.

Archeological sites of various ages and dated for the period from the 7th—5th century BC until 15th century AD concentrated on the flood plain Ib below 0.5 m thick layer of the present-day madas indicate that floods were not frequent in the period lasting ca. 2000 years. Therefore, these madas possess a well developed 0.2—0.3 m thick humus layer.

Reoccurrence of the annual floods in the 15th century is mostly associated with forest clearing and synchroneous period of a moister climate. Settling retreats onto the higher and higher levees and ridges in the flood plain, and since the 18th century to the bluffs of the higher Pleistocene terrace. Wild channel development was initiated since the 15th century while a definite braided pattern on the channel started to form at the beginnig of the 18th century.

The extent of the channel zone of the Vistula during some hundred years is based on a spot sedimentological studies of alluvia. Evolution of the discussed section of the Vistula valley is associated with the development and sequence of events occurring in the upper and middle reaches of the Vistula. Until the flood-control embankments had been constructed the Vistula changed its bankline after each flood.

Geological Institute
00-975 Warszawa, ul. Rakowiecka 4

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MARIA DANUTA BARANIECKA, KRYSTYNA KONECKA-BETLEY

FLUVIAL SEDIMENTS OF THE VISTULIAN AND HOLOCENE IN THE WARSAW BASIN

GEOLOGICAL BACKGROUND

The Warsaw Basin occuppies the area along the Vistula river in the section 100 km downstream of Góra Kalwaria to Wyszogród. Numerous tributaries of the Vistula join here (Fig. 1). The basin is surrounded by glacial plateaus. The form in question is controlled by the substratum, i.e.: chalk basin descending in the Tertiary and older Quaternary, and filled with the Tertiary deposits. The sediments of the Older and Middle Pleistocene are of variable thickness and of a very complex structure. Sand series of running water were deposited several time during the Quaternary in the Warsaw Basin. Multi-cycle sedimentation of the fluvial deposits of the Masovian interglacial (Fig. 2) is to be emphasized.

Glacial plateaus arround the Warsaw Basin were formed due to the Middle Polish Glaciation, including the recessional — Warta and Wkra stages. According to TL datings of the bottom of the Eemian series in the open cast mine Bełchatów this area is ca. 140 000 years old (Baraniecka 1982a; Butrym *et al.* 1982).

Numerous lakes developed on the glacial plateau during the Eemian interglacial. Lacustrine sediments are known of many sites subjected to studies by geologists and paleobotanists (Fig. 1,2). According to Sarnacka (1982), Karaszewski (1975) and Janczyk-Kopikowa (1975) the sites in Ossów and Passy are of the particular importance since the Eemian sediments are there covered with the varved clays of the Warsaw ice-marginal lake which age was related to the recession of the Middle-Polish Glaciation until recently. The site of Kaliska near Lubień Kujawski is also worth to be mentioned (Domosławska-Baraniecka 1965; Janczyk-Kopikowa 1965). There the Eemian sediments with the Amerstfort and the Rodebaek at the top are covered with the till of the Last Glaciation. River valleys of the Vistula and its tributaries have been formed in the axial part of the Basin. The Eemian in the valleys consists of the lag layer at the bottom overlied by the series of fluvial sands with some gravels.

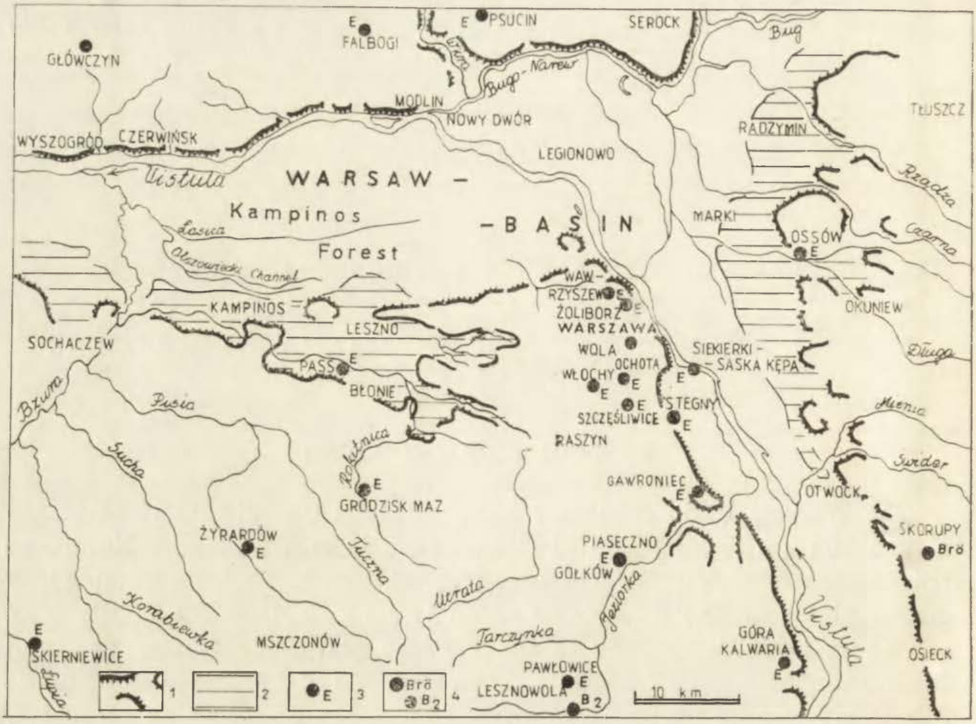

Fig. 1. Situational sketch

1 — edges and limits of the glacial plateau; *2* — varved clays; *3* — sites of the lacustrine sediments of the Eemian interglacial (E); *4* — organic sites of the Brorup (Bro) and of the Middle Vistulian (B_2). The sites of the organic deposits which are not discussed in the further text are given according to the following works. Due to the paper limitation the full bibliography notes which are in the general literature on the Quaternary of the Polish Lowland are not cited in the list of references. Główczyn — Ruszczyńska--Szenajch 1964, Niklewski 1968; Falbogi — Baraniecka, Janczyk-Kopikowa 1974; Psucin — Nowak 1961; Wawrzyszew — Morawski 1975; Żoliborz — Różycki 1929, Raniecka 1930; Wola — Różycki 1967, Borówko-Dlużakowa 1960; Włochy — Morawski 1978, 1980; Ochota — Morawski 1978, 1980; Szczęśliwice — Ślusarski 1893; Stegny — Sarnacka 1979, 1980; Grodzisk — Nowak 1973, Janczyk-Kopikowa 1973; Żyrardów — Krupiński 1978; Gawroniec — Wicik 1973, Borówko-Dłużakowa 1973; Skierniewice — Karaszewski 1972a; Pawłowice — Baraniecka 1979, 1980a; Góra Kalwaria — Sarnacka 1961, Sobolewska 1961; Gołków — Gadomska 1966, Janczyk-Kopikowa 1966, Różycki 1968

The only site where the Eemian oxbow lake deposits rest on the 10-m series of fluvial sands are found among the valley deposits. The site in question is located in Warsaw, below the Vistula bottom (Fig. 2/6), between the city quarters — Siekierki and Saska Kępa (Baraniecka and Gadomska 1965; Borówko-Dlużakowa 1985).

The top of the Eemian sediments in Passy near Błonie is dated for 108 000 BP (Prószyński in: Karaszewski 1975).

The warm period Brörup took place in the Early Vistulian. Based on the studies of the loess profiles that period lasted between 95 000 and 90 000 BP (Maruszczak 1980) or between 85 000 and 80 000 BP according to various comparative studies (Wysoczański-Minkowicz 1982). The

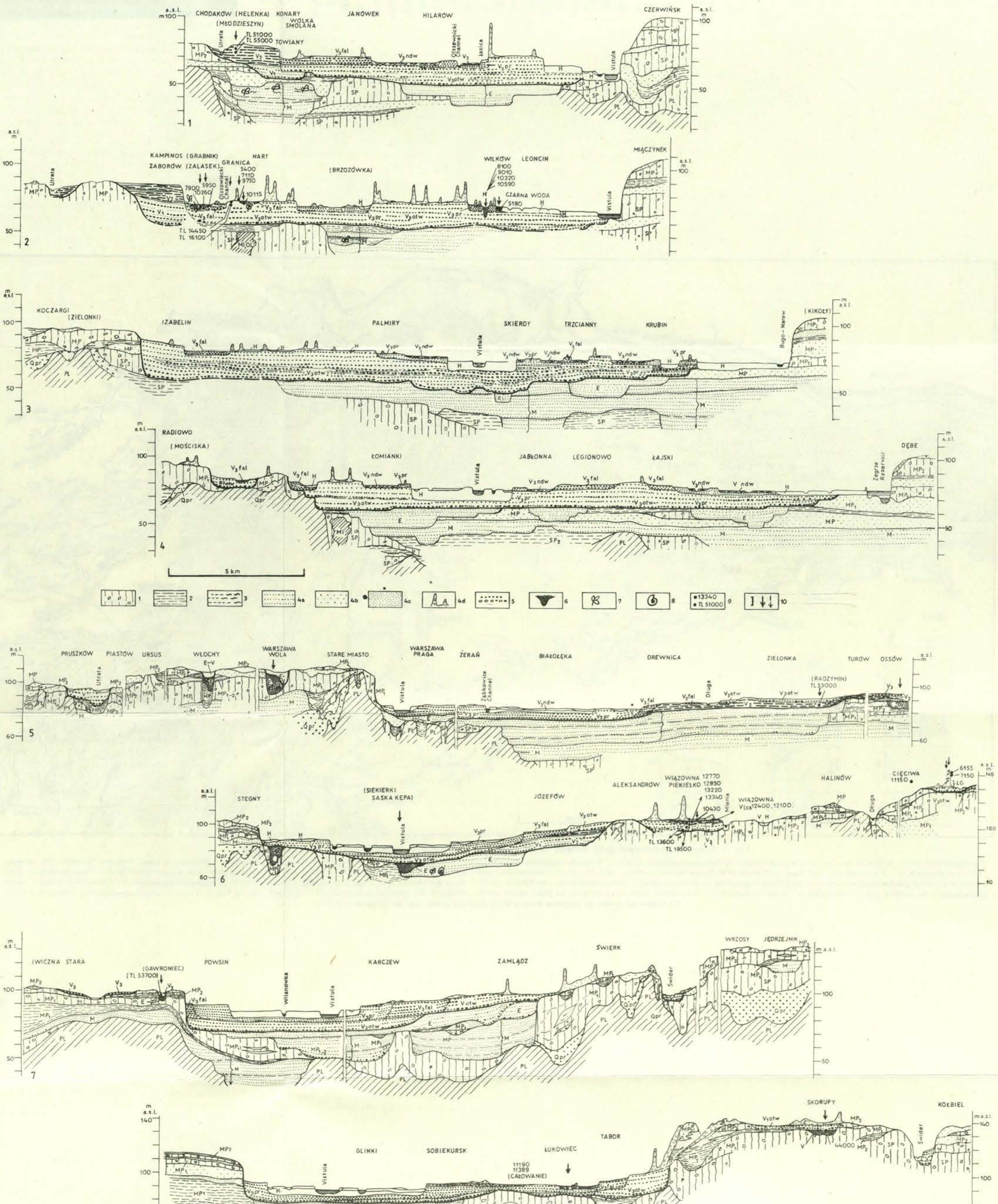

Fig. 2. Geological cross-sections 1–8

The cross-sections summarized in 1985 by Baraniecka (1, 3, 4, 5, 7, 8) and by Baraniecka and Konecka-Betley (2, 6) on the basis of the following works: 1 — Nowak 1974a, Kopczyńska 1960, Kopczyńska-Żandarska 1970, Brzeziński 1984; 2 — Kaczorowska 1926, Nowak 1960, 1964, 1974a, Konecka-Betley 1981, 1983, Konecka-Betley and Stefaniak 1983, Czępińska-Kamińska (in press), Kopczyńska 1969, Kopczyńska-Żandarska 1970; 3 — Nowak 1974, Morawski 1978; 4 — Nowak 1974a, b, 1978, Morawski 1978, 1980; 5 — Morawski 1978, 1980, Domosławska-Baraniecka, Gadomska and others 1965, Sarnacka 1979, 1980, 1982, Prószyński 1985; 6 – Sarnacka 1979, Baraniecka and Gadomska 1965, Baraniecka 1976, Baraniecka and Konecka-Betley 1980, Konecka-Betley 1981; 7 — Sarnacka 1974, 1976, Baraniecka 1973, Wicik 1973, Prószyński 1985; 8 — Baraniecka 1973, 1976, 1982, Sarnacka 1974 (the study are not cited in the list of references). Location of cross-sections in Fig. 3. *1* — glacial till; *2* — clays; *3* — silts; *4* — sands (*4a* — fluvial sands, *4b* — glacifluvial sands, *4c* — glacilacustrine sands, *4d* — dune sands); *5* — gravels and boulders; *6* — gyttja, peat, organic mud and lacustrine chalk as well as the levels of fossil soils; the sediments discussed in details are marked by bold signs; *7* — floristic remnants with elaborations or primary palynological identifications; *8* – molusca shells; *9* – age determinations by ^{14}C and termoluminscence (TL) methods; *10* — major study sites.

Abbreviations: OL — oligocene; Mi — Miocene; PL — Pliocene; Q — Older Quaternary; SP — South Polish Glaciations (SP_1, SP_2); M — Masovien Interglacial; MP — Middle Polish Glaciations (MP_1, MP_2); E — Eemian Interglacial; V — Vistulian (V_1, V_2, V_3); LG — Late Glacial; H — Holocene; otw — Otwock terrace fill; fal — Falenica terrace fill; pr — Praga terrace fill; ndw — Nowodworski terrace fill. The names of settlements of which materials projected onto cross-sections originate are given in parentheses.

Brörup profile in the Warsaw Basin (Fig. 2/8) has been obtained from the site Skorupy (Baraniecka 1976). The palynological diagram, being of an interstadial type, has been compared to the Brörup profile of Podgłębokie II (Janczyk-Kopikowa 1969). The top of peat in Skorupy was older than 44 000 BP (Pazdur 1983: Gd 1073) according to the radiocarbon method.

LAST GLACIATION — VISTULIAN

Geomorphological levels lower than the glacial plateaus (Fig. 3) had been formed in the Vistulian. There is the conventional subdivision of the stratigraphy of sediments into: lower, middle and upper Vistulian, and late Vistulian.

Lower Vistulian. The post-Eemian erosion and denudation are pronounced by a substantial erosional phase. A several meters deep incision, the largest in the Younger Quaternary, and accumulation of fluvial deposits in the valleys (Fig. 2/1, 2-B_1) are measures of the erosion in the valleys. Unfortunately, these deposits are not dated.

Middle Vistulian. This period was characterized by erosion, stagnation and change of fluvial sandy accumulation into fluvial-limnic facies. Frequent, small changes of the lithology and sediment facies, rhythmically laminated or of a varved nature, are typical. Two facial-paleogeographical types of sediments differing with respect to a formation period have been distinguished. These are: glacilacustrine and fluvial-lacustrine deposits.

Deposits of the Warsaw ice-marginal lake, which extended over the area of the river valley, were formed in the northern zone, closer to an ice-sheet. The lacustrine sediments have been preserved in the area of Radzymin—Marki. Many bays and gulfs of the ice-marginal lake have entered into the valleys of the Vistula tributaries: of the Bzura, Utrata, Długa, Czarna and Rządza rivers. Geomorphological expression of this glacilacustrine accumulation are plains — the Błonie level and the Radzymin—Marki level (Fig. 3).

The age of the Warsaw ice-marginal lake was questionable since long ago. Actually, the site Passy with the Eemian deposits (Janczyk-Kopikowa 1975; Karaszewski 1975) below the varved clays of the Błonie level (Karaszewski 1975) as well as the site Ossów (Sarnacka 1982) with the Eemian sediments (Borówko-Dłużakowa in: Sarnacka 1982) below the varved clays of the Radzymin-Marki level indicate the age younger than the Eemian. Despite of the Warsaw ice-marginal lake, the varved clays of same older, Middle Polish glacilacustrine levels are exposed at the surface near Warsaw.

The correlation between maximum advance of the Vistulian ice-sheet in the Płock Basin and fluvial and fluvial-glacifluvial levels in the Kampinos Forest indicates that the varved clays of Blonie are older than the maximum advance of the Vistulian ice-sheet. These clays are dissected while the sediments correlated with the maximum development of the glaciation have been deposited in a incised channel. The varved clays of the western part of the Warsaw Basin are also dated for 51 000 and 53 000 BP (Brzeziński 1986) according to TL analyses of Butrym of Lublin (in Młodzieszyn, Fig. 2/1), those of the brick-yard in Radzymin, in the eastern part of the Basin (oral information by Prószyński, paper of 18 Apr., 1985) for 53 000 BP.

With the time, the tendencies of the erosion stagnation and of fine--grained accumulation have shifted the area of the ice-damned lake upstream of the rivers flowing into this lake. Fluvial lacustrine sediments are formed to the south of the Warsaw Basin, in the side valleys and isolated basin on the upland. Sandy-silts, silts or clayey silts contain numerous admixtures of the organic humus matter in forms of: peat intercalations, layers of the mineral-organic flood deposits (muds) or lacustrine silts. The profile of the drilling Lesznowola 2 of the area of Grójec (Baraniecka 1979, 1980a) has provided one of the more complicated sequences. There are present 7 organic levels. These are levels partially of a marshy accumulation and partially of initial soil accumulation or of the scattered organic matter. The levels in question are separated by deposits which do not contain the organic matter, namely by sands and silts of a loess character. The palynological analysis (Janczyk-Kopikowa 1978) of the humus layers indicates vegatation phases of the arctic tundra, subarctic associations as well as fragmentarily boreal forest, probably. The section dated by the ^{14}C method for $38\,000 \pm {}^{3200}_{2300}$ BP (Pazdur 1978: Gd 551) has been compared to the Hengelo interstadial by Janczyk-Kopikowa (1978). The amount of spruce is particularly large with a culmination of 42%. The section is dated as of $30\,300 \pm {}^{2560}_{1940}$ BP (Gd 527); compared with the Denekamp is characterized by large amounts of pine, birch and by a small percentage of the NAP. The remaining cooler sections of the profile, almost without trees, indicate the dominance of the NAP.

The sediments of the Middle Vistulian in the analogical facies are dated like those in the other locations on the Polish Lowland. That is: in the area of Łomża (Straszewska and Goździk 1978) as of 37 800 ± 1220 BP (Lod 25); in Maliniec I near Konin (Stankowski and Tobolski 1979) as of over 36 000, 42 500 and 42 900 BP (Pazdur and Walanus 1979; Gd 647, 1076, 1077). The Middle Vistulian is also determined in the mine of Bełchatów by 6 dates (Baraniecka 1980b) in the range of $43\,000 {}^{+3700}_{-2400}$ BP and 21 970 ± 810 BP (Baraniecka and Pazdur 1980; Gd 1072).

A pronounced phase of denudation took place at the turn of the

Middle and Upper Vistulian. Residual gravel-stony levels are reflections of this phase on the plateau. The downcutting in the depressions has dissected the glacilacustrine levels of the plateau down to several meters.

U p p e r V i s t u l i a n. The bottom of the Upper Vistulian is determined by the mentioned above date of 21 970 BP from the mine of Bełchatów as well as by the date from Maliniec II (Stankowski and Tobolski 1979) referring to the sediments laying on the almost direct bottom of the glacial till of the Vistulian. The latter date is 22 230 ± 480 BP (Pazdur and Walanus 1979; Gd 646). The top of the Upper Vistulian is ca. 14 000 BP. The most important episode of the Upper Vistulian was the maximum advance of the ice-sheet to the Płock Basin. In the case of the Middle Poland, that was the coldest period of the Last Glaciation. It was expressed by an increased number of permafrost structures (ice-wedges, pattern ground) occurring abundantly in the top part of the silty-sandy series of the Middle Vistulian, e.g. in Bełchatów (Goździk 1973, 1980).

Sandy accumulation of a thick series took place during the maximum extent of the ice-sheet and when it melted. The material was transported from 2 directions into the Warsaw Basin. Glacifluvial material (Fig. 2/1, 2, 3, 4), which had been mixed with fluvial one (Nowak 1964, 1974a, 1978), was transported by extraglacial rivers from the NW of the ice--sheet lobe, from the Płock Basin. Fluvial sandy series (Sarnacka 1974, 1976, 1979, 1980; Baraniecka 1973, 1976) were deposited (Fig. 2/1, 6, 7, 8) from the S and SE. The accumulation surfaces (Fig. 3) formed at that time are differently called: the Otwock terrace at the south, and the dune terrace at the north of the Warsaw Basin. As the capacity of the valleys was not sufficient for so large accumulation, the latter included also the areas outside these valleys. The lower parts of the lacustrine levels, especially in the vicinity of Radzymin—Marki, were filled up. The system of numerous shallow valleys and accumulation zones along the rivers was formed on the upland. The valleys on the upland, later abandoned by the rivers, e.g. Zabieżki—Celestynów valley (Baraniecka 1976, 1982b) as well as the known system of the Góra Kalwaria—Konstancin—Dąbrówka—Raszyn valley (Lencewicz 1927) contributed also to the above system. Accumulation sands of the Otwock terrace and the series correlated with the latter are dated by TL methods. The border and top parts of the sandy series of the site Wiązowna—Piekiełko (Fig. 2/6) were dated as of 19 500 ± 2900 BP (Butrym, Laboratory in Lublin).

The accumulation of the sand series in two regions of the Warsaw Basin, in the south near Wiązowna and in the north in the western part of the Kampinos Forest terminates with a silty levels and a clayey one sometimes. These sediments in two study sites are dated by TL method. In the site Granica, the layer with the dominating silt fraction (Fig. 2/2) is dated for 16 100 ± 570 BP and the higher located sands for

14 450 ± 300 BP (Laboratory in Warsaw, Stańska-Prószyńska, Prószyński 1985). In the case of the site Wiązowna—Piekiełko (Konecka-Betley, Baraniecka 1983) the layer of very fine sands in the described silty level (Fig. 2/6) is dated for 13 600 ± 1700 BP (Laboratory in Lublin, J. Butrym).

A decrease of an accumulation rate and finally its ceasing as well as vegetation development complete the Vistulian, initiating simultaneously the Late Glacial. Because of thermal and moisture changes multiple changes of the tendencies of erosion and fluvial accumulation processes are pronounced from time to time. The soils developing under more favourable thermal and moisture conditions, and being preserved in fossil forms, are of the great importance for the dating of the sequence of events.

The Late Vistulian. The downcutting initiating the turn of the Vistulian has contributed to the dissection of the broad level of the fluvial and fluvial-glacifluvial accumulation down to several meters. That level (Fig. 3) is preserved until now in forms of the Otwock terrace (Różycki 1972; Baraniecka 1973, 1976; Sarnacka 1974, 1976), some islandic complexes of the dune terrace in the fork of the Vistula and Bug—Narew rivers (Nowak 1974a, b, 1978), the Bielany terrace (Morawski 1978, 1980) and two wide belts of the dune terrace in the Kampinos Forest (Kaczorowska 1926; Kobendzina 1961, 1982; Borówko-Dłużakowa 1961a, b). The dissection took place in some stages.

The Falenica terrace (Różycki 1972; Sarnacka 1974, 1976), or the Karczew terrace (Baraniecka 1973, 1976) was formed below the Otwock level after the first phase of erosion and accumulation. The height of this terrace to the north becomes almost equal to the lower Praga terrace. This terrace can be distinguished (Baraniecka 1982b) on the basis of the properties of the terrace surface, but not on the height differences (Fig. 3). The Falenica terrace in the Kampinos Forest changes most likely into the southern belt of marshes and swamps while the northern one is related to the younger terrace (the Praga level).

The sandy Praga terrace, called the Praga higher one (Lencewicz 1927; Sawicki 1960; Różycki 1972; Nowak 1964; Biernacki 1975; Sarnacka 1979, 1980), was formed after the dissection of the Falenica terrace and the following accumulation. The Praga terrace (Fig. 3) is known as a continuous geomorphological element within the Warsaw Basin.

After the partial dissection of the Praga terrace its lower part covered with light madas is formed. This mada terrace is (Fig. 3) either the Nowy Dwór one (Sawicki 1960) or the Praga lower terrace. The madas are younger than the erosional dissection as well as than the terrace surface. These are the Holocene madas (Nowak 1964, 1974b, 1978), so called older ones, usually light (silts, muds, and silty sands), rarely clayey and heavy. The madas in question in the area of Otwock (Baraniecka 1973, 1976) are considered as the final element of the accumulation of the overflood terrace, the latter called locally the Janów terrace, and are regarded as of the Late Pleistocene.

The Praga higher and lower terraces were dissected at the turn of the Vistulian and Holocene. This dissection is emphasized in some locations by meander bends (Fig. 3). The edges of large meanders (radius ca. 1—2 km) are known as fragments to the south of Karczew and in the area of the lower Wilanówka stream. However, a compact system of meander bends is characteristic of the dissection of the Pleistocene terrace in the Bug—Narew valley over more than the 20 km long section.

The meandering process was gradual. Its initial stage was the transitional braided-meandering phase which geomorphological reflection is the over-flood level within the flood terrace (Fig. 2-H_o, Fig. 3). The terrace surface of this type, being very diverse with respect to geology and geomorphology, occurs between Zegrze and Nowy Dwór at the Bug—Narew river. There, the systems of uni-shaped meander depressions separated by the lower and lower levels are characteristic. The second equally complicated area is found at the Vistula, to the north of the Kampinos Forest, close to Leoncin where the abandoned channels form a network of fork-like depressions.

Stages of the downcutting, accumulation of geomorphological levels are dated indirectly (Fig. 1)). The series of dune eolian accumulation, separated by the accumulation levels A_1 of the fossil soils served that purpose. Organic matter was dated by ^{14}C method (Tab. 1).

There is the specified sequence of events which occur successively one after the other, and which overlap only partially. These are: accumulation of the fluvial series, formation of soils or organic deposits, bottom erosion exposing the fluvial series as a terrace, and development of eolian processes (Tab. 1, 2). Determination of the age of particular sediment members confirms that sequence and allows to determine the duration of sedimentation and time of formation of geomorphological surfaces.

Accumulation of the Otwock series was completed ca. 14 000 BP. The soil of the Wiązowna I level, known of the stratotype profile of Wiązowna—Piekiełko (Fig. 2/6), has developed at the surface part of silts. That is dated by ^{14}C-method, starting from the bottom upward, for: 13 340 ± 130 (Gd 1377), 13 320 ± 120 (Gd 1376), 12 860 ± 190 (Gd 1375), and 12 770 ± 130 (Gd 1327) BP. That is hydrogenic gley soil (Konecka-Betley 1981, 1982) with a pronounced intercalation of organic matter. The layer of strongly compressed peat corresponds fragmentarily to that soil horizon A_1. According to Mörner scheme (1976) the soil horizon Wiązowna I can be paralleled with 2 oldest warm oscillations of

Table 1. Datings of the Late Vistulian and Holocene of the Warsaw Basin area

Stratigraphy		^{14}C and TL dates (BP)	Name of settlement	Dated substance	Soils
1	2	3	4	5	6
S A	NEOHOLOCENE	2430±100	Wda outwash	wę A_1	soil degradation, podzolic soils, relic podzols, rusty soils, continuation of peaty soils
2800					
S B	NEOHOLOCENE	3610±120	Liszyno	wę A_1	younger podzolic soils continuation of peaty soils (soils degradation)
5100					
A T	MEZOHOLOCENE	5180±40	Czarna Woda	t	podzolic soils and humus podzols, ferrous, and ferrous-humus soils, gley-podzols
		5400±250	Nart	t	
		5950±80	Zalasek	t	
		6155±270	Cięciwa	tm	
		7110±320	Nart	t	
		7150±150	Cięciwa	s.org. B_{HS}	
		7900±120	Grabnik	gy	
		8100±140	Wilków	t	continuation of peaty soils
		8360±75	Całowanie	tp	
8400					
B O	EOHOLOCENE	8750±100	Liszyno	wę A_1	rusty and podzolic soils and
		9010±100	Wilków	t	
9300					
P B	EOHOLOCENE	9550±85	Całowanie	wę	rusty soils
		9750±120	Nart Pożary	t	
		9935±110	Całowanie	gy	
		10115±55	Nart	t	and peaty soils
10250					
DR_3 10600*		a, b, c, d, e, f, 10590±360	Wilków	t	
10900					eolian processes
A L		11150±1300	Cięciwa	wę A_1	
		11190±65	Całowanie	wę	
		11380±95	Całowanie	wę	
11800					
DR_2					eolian processes
12100					
B O		? 12150±110	Wiązowna Cięciwa	(A_1)	initial soil
12400					

1	2	3	4	5	6
Bolling-Agard	LATE VISTULIAN	12770±130	Wiązowna (Piekiełko)	s.org. A_1	eolian processes
		12860±190	Wiązowna (Piekiełko)	s.org. A_1	gley soils
		13200±120	Wiązowna (Piekiełko)	s.org. A_1	eolian processes
		13340±110	Wiązowna (Piekiełko)	s.org. A_1	gley soils
		13600–TL	Wiązowna (Piekiełko)	v.fine sands	initial soils
		14450 TL	Granica	silty sands	
DR_1		16100 TL	Granica	silts	
		19500 TL	Wiązowna	sands	

x - - - — proposed change of the Pleistocene-Holocene limit for the Warsaw Basin, a — -10260 ± 160, Olszowickie Błoto t, b — 10320 ± 100, Wilków t, c — 10400 ± 180, Liszyno wę; d — 10430 ± 450 Wiązowna s. org.; e — 10460 ± 90 Całowanie gy; f — 10455 ± 90, Całowanie gy, t — peat, tm — peatbog, tp — sandy peat, gy — gyttja, wę — charcoal, s. org. A_1 — organic matter of the accumulation level, s. org. B_{Hs} — organic matter of the illuvial humus-ferrous level.

the climate in the period conventionally called the Oldest Dryas, i.e. with Vintapper and Agard. These two oscillations were most likely separated by a cooler period of the so-called Lower Baltic.

The palynological analysis of the organic layers of the soil horizon Wiązowna I (Borówka-Dłużakowa in: Konecka-Betley and Baraniecka 1983) indicates the plant associations which, despite of the admixture of the Tertiary sporomorphes, characterize a temperate cold climate. The forest-tundra association occurs in silts, in the lower part. *Pinus* and *Betula* (up to 70%) dominate among the trees, and *Alnus* and *Larix* are also present. This is a significant percentage of pollens of the plants of the forest-less areas. The palynological spectra in the top section, in the upper part of the horizon A_1 indicate the tundra-steppe associations. There is a substantial decrease of the pollens of arborescent plants (to 26%), among which *Pinus* and *Betula* with the presence of *Betula nana* occur. The pollen of the light-seeking vascular plants dominates. The amount of grasses and sedges reaches up to 75%.

The presence of the ferrugineous fibers being the evidence of the latter oscillations of the ground water, related probably to the bottom erosion dissecting the Otwock terrace, is pronounced in the soil profile of the stratotype Wiązowna I below A_1 horizon.

After the organic accumulation the bottom erosin took place. The latter reached the socle of the Falenica terrace and initiated gradual accumulation of the Falenica series. The surface of the Otwock terrace was dried out and the first stage of eolian activity — deflation of sands

Table 2. Scheme of the sequence of fluvial processes (accumulation and erosion) soil-forming and organic accumulation at the turn of the Vistulian

Age			Series of fluvial sedimentation	Soils and organic accumulation	River bottom erosion	Eolian accumulation
Holocene			Nowy Dwór series madas sands	peat, gyttja, lacustrine chalk and Holocene soils		
pleistocene	Late Vistulian	Younger Dryas				phase of the Younger Dryas
					incision to the socle of the Nowy Dwór terrace	
				soil of the Cięciwa I bottom part of peat Całowanie and Łukowiec		
		Alleröd	Praga series sands			
		Older Dryas				phase of the Older Dryas
					incision to the socle of the Praga terrace	
				soil of the Wiązowna II level		
		Bölling	Falenica series sands			
		Oldest Dryas				phase of the Oldest Dryas
					incision to the socle of the Falenica terrace	
		Agard		soil of the Wiązowna I level and pressed part		
	Upper Vistulian		Otwock series silts sands			

including the silts available arround — took place under climatic conditions. The sandy-silty cover known of the profile Wiązowna "at a road" was formed.

The fluvial Falenica series had been finally deposited due to the change of climate to the moister one.

Poor vegetation was developed and the soil of the level Wiązowna II (Fig. 2/6) represented by the profile Wiązowna "at a road" was formed under the favourable local conditions due to a slight warming of the climate. The initial soil, weakly gleyed, with 2—4 cm thick humus horizon of the black-brown colour (Konecka-Betley 1981) lies on the sandy--silty layer in that profile. The lower laying silty-sandy deposits are strongly cemented by ferrugineous-aluminium-siliceous fibers. The ferrugineous layer, in a form of fine fibers directly underlies the initial horizon A_1. The soil level Wiązowna II is parallelized with the Bölling (ca. 12 300—12 100 BP).

A new phase of the bottom erosion, being the more intensive than the previous one, took place after the formation of the soil of the level Wiązowna II. The Falenica series was totally dissected and the dissection of the Otwock series (Fig. 2/5, 6, 7) was overdeepened.

The downcutting had caused a drying of the Falenica terrace and draining out of the Otwock terrace.

With the subsequent cooling and drying of the climate the Otwock terrace plain became a terrain of a dune-forming phase the latter incorporated to the Middle Dryas, i.e. 12 100—11 800 BP (Starkel 1977).

The changes of the grain sizes and those of the eolian transport directions (Baraniecka and Konecka-Betley 1980) are noticed. The dunes of this age (Baraniecka 1976, 1982b) occur both on the Otwock terrace (Fig. 2/7) as well as in the abandoned river valleys on the plateau (Fig. 3).

After the main dune-forming phase, under the conditions of a moister climate, the Vistula channel was widened and the Praga fluvial series was accumulated. The development of the compact vegetation and preservation of the relief forms, as well as the development of the soil covers both on the dunes and in the Vistula valley (Konecka-Betley 1974, 1981) had taken place first time in the Last Glaciation decline. Alleröd soil level of the Cięciwa has been called the Cięciwa I level and considered as a stratotype for the profiles in the dunes. Various types of this soil have been distinguished on the fossil slopes of the dune of the Older Dryas depending on the gradient and exposure.

A weakly developed podzol with a marked A_1 horizon and with small charcoals at the top is found at the upper part of the slope. The soil possesses initial A_2 and B horizons while C-horizon has its prior lamination. The soil complex with some humus levels of a light gray colour occurs on the lower part of the slope. The Alleröd soil has developed at the foot of the Middle Dryas dune under the conditions of an increased moisture. That soil possesses some gley features which allow one to distinguish weakly pronounced horizons AG (Baraniecka, Konecka-Betley 1980).

The soil level Cięciwa I, and more precisely its top, is dated on the basis of the charcoals for 11 150 ± 1300 BP (Lod 30).

The stratotype of the Alleröd soil is developed in the Vistula valley on a shoal island of the Praga terrace in Całowanie (Schild 1969, 1975, 1982; Konecka-Betley 1974). The age is determined for 11 380 ± 95 BP and for 11 190 ± 65 BP. The entire shoal island is surrounded by a peatland. According to the palynological diagram the bottom part of peat in the study profile in Łukowiec also indicates the Alleröd (Borówka-Dłużakowa 1961a,b). Analogically to the level Cięciwa I in dunes, the level Całowanie is the Alleröd stratotype for the Vistula valley in the Warsaw Basin. The incorporation of the underlaying dune series to the Older Dryas and the overtopping one to the Younger Dryas are confirmed for the Warsaw Basin by the Alleröd stratotypes of Cięciwa I in the dune and of Całowanie in the Vistula valley. A cartographical distinction of the dune complex (Fig. 2/7) near Otwock (Baraniecka 1976) and of the younger dunes near Legionowo (Nowak 1974b, 1978) as well as a generalization of the distribution of the Younger Dryas dunes on the Praga terrace in the Warsaw Basin (Baraniecka 1976) allows to determine a relation to the terraces and erosional dissections. The sequence of events is as follows: accumulation of the Older Dryas dunes — accumulation of the Praga fluvial series — development of soils and peats of the levels Cięciwa I and Całowanie — initial dissection of the Praga terrace — accumulation of the Younger Dryas dunes — changes of channels and flood inundation on the Nowy Dwór terrace.

The dune-forming phase of the Younger Dryas caused a reactivation of eolian processes on the plateau. The layer of the dune sands with the rusty soil, included to the Pre-Boreal, at the bottom was formed at that time. That soil is called the level Cięciwa II. The stratotype for this soil in the Warsaw Basin is the relevant fragment of the dune profile in Cięciwa (Baraniecka, Konecka-Betley 1980; Konecka-Betley 1981).

The final stage of the fluvial activity in the Vistula valley at the turn of the Vistulian manifestates in several changes of the course of the Vistula dissecting the Praga terrace and in accumulation of sands and madas of the Nowy Dwór series. The above took place under the moist and chilly conditions with a tendency to warming. The Nowy Dwór terrace consists of four main ridges extending in a fan-like pattern to the north: 3 ridges in the fork of the Vistula and Bug-Narew rivers and the 4th one along the Vistula to the west of it, reaching up to the northern border of the Kampinos Forest.

HOLOCENE

D e v e l o p m e n t o f e r o s i o n a n d a c c u m u l a t i o n p r o c e s s e s. The period of the bottom erosion in the Eoholocene, accumulation of the main series of the fluvial sediments: madas and sands of the higher flood terrace, subsequent bottom erosion in the Subboreal and the fluvial accumulation of the lower flood-plain in the Sub-Atlantic can be distinguished in the Vistula functioning during the Holocene (Starkel 1977). This paper does not deal with the historic period for which the investigations of an actual stage, and especially of the causes of events, require other study methods and should be considered in a different time scale.

The beginning of the Holocene in the Warsaw Basin is characterized by a fast stabilization of the older terraces (Pleistocene ones) by vegetation. Numerous ^{14}C dates are obtained for the bottom of peats or for the organic matter of the mineral soils. These datings (Fig. 2/2, 6, Tab. 2) are as follows: 10 115 ± 55 BP (GroN 6068) in the peatland Nart (Borówka-Dłużakowa 1982), 10 260 ± 160 BP (Gd 2063) for peat below the lacustrine chalk in Olszowieckie Błoto (Konecka-Betley 1986), 10 430 ± 450 BP (Lod 32) for charcoals of the mineral soils under the dune in Wiązowna (Baraniecka and Konecka-Betley 1980), 10 590 ± 360 BP for the peat bottom in Wilków (Pazdur 1983). The datings in the areas directly neighbouring with the study area are analogical: in the south 10 455 ± 90 BP (GroN 5409) peat in Całowanie (Schild 1982) and in the NW 10 400 ± 180 BP charcoal in the dune in Liszyno, in the Płock Basin (Kamińska *et al.* 1986). Two similar dates can be also mentioned here: 9935 ± 110 BP (GroN 5254) of Całowanie (Schild 1982) and 9750 ± 120 BP (Gd 2065) of the peatland Pożary-Nart (Konecka-Betley 1986). The above dates refer usually to the Younger Dryas. However, the development of the organic accumulation would have indicated the Holocene beginning. The above can suggest that the dune period of the Younger Dryas has been completed earlier. The accumulation of the organic matter characteristic of the Holocene, which lasts until nowadays in some cases, has started much earlier. Thus, the lower limit of the Holocene should be changed to ca. 10 600 BP.

The peat accumulation dated for 10 260 BP (Gd 2065) and occurring in the southern belt of the marshes in the Kampinos Forest, in the Olszewskie Błoto in Grabnik (Fig. 2/2) has been interrupted due to formation of the backswamps of the Pra-Vistula in which the lacustrine chalk deposition has been initiated (Konecka-Betley and Stefaniak 1983; Alexandrowicz 1983; Konecka-Betley 1986). The formation of the lacustrine chalk was closely associated with a leaching of the glacial and glacilacustrine deposits surrounding the Warsaw Basin.

The soils and peatlands on the older (Pleistocene) terraces continued their development since the Alleröd throughout the Younger Dryas (Konecka-Betley 1981). The dune-forming processes were limited in the Younger Dryas to fairly small areas. The main proof of the local meaning of the eolian processes of the Younger Dryas is a lack of sandy pollutants in the central parts of the peatlands in Całowanie (Łukowiec) and most likely in Pożary-Nart. The accumulation of these peatlands continues since the turn of the Pleistocene and Holocene until nowadays.

However, one has to state that a slight eolian activity did not ceased totally in the Younger Dryas but was continued as "last blows" in the Pre-Boreal and Boreal periods.

The Holocene beginning was characterized in the Vistula valley by the erosion dissection of the Praga terrace. However 4 belts of depressions (Fig. 3) within the above terrace, called the Nowy Dwór terrace, became the area of multiple floodings which resulted in the so-called older mada deposition. The floods inundated even the margin of Praga terrace.

The presence of thin eolian sand covers, most likely of the Younger Dryas, on the madas in the area of Wilków, Karczew and other locations, is the evidence of a relatively earlier beginning of the mada accumulation in certain spots and of the overlapping processes of the flood accumulation and the eolian one.

The western belt of the madas of the Nowy Dwór terrace (Fig. 3) is undercut at the northern border of the Kampinos Forest near Wilków by the edge of the Early Holocene. Below, there is the overflood level of the flood terrace. The 1 m thick peat bog Czarna Woda (Fig. 2/2) is located on the above. The dating of the peat bottom is 5180 ± ± 40 BP.

The lateral and bottom erosion dominated in the Vistula valley in the Pre-Boreal and Boreal. Besides the transitional overflood level of the flood-plain (vicinity of Zegrze and Leoncin — Fig. 2/1, 2, 4) the Vistula has formed a broad, 2—4 km wide valley due to the channel shifts and undercuttings. The valley depth with respect to the Praga terrace is 8—9 m (Fig. 2/1—8).

When characterizing the Holocene valley floor its substantial narrowing in the area of Warsaw (Fig. 2/5 and Fig. 3) is to be emphasized. The Holocene valley in the meridional section to the south of Warsaw is shifted maximally to the west while in the latitudinal section to the north (Fig. 3).

The largest fluvial accumulation of fine sands, and especially of heavy silty madas building the surface of the higher flood-plain took place in the Atlantic period. During the increased bottom erosion in the Sub-Boreal, the higher flood-plain was ca. 2.5 m above the mean water level, while the lower flood-plain started to form.

The Holocene soil formation. Fluvial sediments, and moreover those of the fluvial erosion phase are not dated directly. Thus, in order to determine the absolute age of processes as well as the environmental conditions one has to refer to sediments outside the Holocene Vistula valley where are the evidences of the vegetation and soil development.

The processes of an intensive physical weathering dominated over a chemical one during the Younger Dryas and Pre-Boreal. Then, the translucent forests prevailed. The dominating grasses influenced positively the mobility of the fulvic acids in effect of which podzolization process was intensified. Hence, the podzols were lacking in the Pre-Boreal while rusty soils developed commonly over the extensive areas. The latter were subject to further changes in the Boreal and Atlantic. The Pre-Boreal rusty soil is rarely known as an individual soil as well as the organic matter which could be dated by the ^{14}C-methods is seldom preserved in it. Such a soil is described by Manikowska (1982). The data 9380 ± 50 BP was obtained from the charcoals of A_1 horizon of such soil.

The Pre-Boreal rusty soil occurs also in Cięciwa (II level). This horizon is considered as the stratotype for the Warsaw Basin. In the Boreal the dunes are progressively occuppied by pine forest vegetation with a large amount of an acidic ecto-humus what results in a process of an intensive podzolization. The earlier rusty soils change into rusty podzols.

Both, the rusty podzol and podzol occur individually in a fossil form or could have been subject to further soil-forming processes on the surfaces. The rusty podzol has been described in Liszyno, in Płock Basin where it was dated for 8750 ± 100 BP (Kamińska *et al.* 1986). The stratotype for the rusty podzol in the Warsaw Basin can be the outcrops in Cięciwa where this soil occurs in a fossil isolated form and it incorporates sometimes into the B_H horizon of the humus-ferrous podzol of the Atlantic. The rusty pedostratigraphical horizon as independent one is called horizon Cięciwa III.

The process of podzolization became more intensive in the initial phase of the Atlantic, and humus podzols and ferrous-humus podzols with a characteristic translocation of the organic matter and free iron into B_H horizons, the latters dated for 7150 ± 350 BP (Lod 47), and to B_s horizons had been formed. Some of these soils, as it is the case of one of the outcrops in Cięciwa, are capped with a shallow peat. The latter was formed by the end of the Atlantic what is confirmed by the ^{14}C dating of the peat for 6155 ± 270 BP (Lod 37) (Baraniecka and Konecka--Betley 1980; Konecka-Betley 1982). The palynological analysis of this peat (Janczyk-Kopikowa) indicates the younger part of the Holocene while the presence of pollen of cultivated plants indicate the possibility of the beginning period of man activity. The profile of the humus--ferrugineous podzol is considered as the stratotype for the dunes of the Warsaw Basin and is called the level Cięciwa IV.

Two layers of peat interbedded with dune sands were deposited in a boudary zone of the peatland in Nart. These peat layers are dated for 7110 ± 320 BP (Lod 34) and 5400 ± 250 BP (Lod 91) (Baraniecka and Konecka-Betley 1980; Konecka-Betley 1982). They provide the evidence of the rise and changes of the ground water table when the B_{HS} horizons of the podzol in Cięciwa was formed.

In the western part of the southern belt of marshes in the Kampinos Forest in the Olszowickie Błoto, the supply of the carbonates decreased in the Atlantic after the accumulation of the lower part of the lacustrine chalk. The organic material had been deposited in a form of gyttja dated for 7900 ± 120 BP (Gd 2059). The lacustrine chalk was accumulated again after that episode. Finally, the peatland entered the area of the shallowed basin and invaded the surrounding. The peat of this layer is dated for 5950 ± 80 BP (Gd 1584). These events correspond to hydrological changes distinguished by Starkel (1982).

Since ca. 5000 BP the human impact on the natural environment of the Warsaw Basin is intensified. Due to the anthropogenic deflation of the dunes the plant cover and soils — the Atlantic podzols — became degraded what is the case of Liszyno, or became covered with deflated sand in Cięciwa. In Liszyno, on the deflated material or on that formed of the Atlantic soil degradation, and sometimes on the older deposits, the younger podzolic soils, but not the podzols for which the date 3610 ± 120 BP was obtained (Kamińska *et al.* 1986) were formed. The presence of the rusty soil (Prusinkiewicz and Bednarek 1983) dated, for example, on the Wda outwash for 2430 ± 100 BP has been stated in other situations. The qunqest soils of the Neoholoceno formed on the deflated dune sands and fluvial deposits in the Warsaw Basin differ typologically. The degree of the old soil degradation as well as the stage of the development of the youngest soil-forming processes depend on the local factors, and especially on the human activity. According to the detail carthographical studies on the river terraces and dunes of the Warsaw Basin, however, the older soil-forming processes which acted during the last 10 000 or 14 000 years are preserved in the actual soils in numerous locations.

CONCLUSIONS

The new insights onto the chronostratigraphy of the fluvial deposits and the paleogeography of the Vistula valley in the area of the Warsaw Basin (Fig. 1, 2, Tab. 1) have been presented. The study has been based on the detail geological maps and numerous cross-sections of the Quaternary deposits as well as on the physico-chemical and palynological analyses and datings by ^{14}C and TL methods (Tab. 2). The spatial distributions of erosional phases and that of thickness, stage of formations and of fluvial deposit facies, especially of the Last Glaciation have been obtained.

The following Vistula terraces have been characterized: the Otwock, Falenica, Praga, Nowy Dwór ones and the flood plain and the belonging to it overflood level of the area of Leoncin (Fig. 2, 3). The oldest Otwock series has been related to the maximum extent of the Vistulian Glaciation (ca. 20 000 years). Thus, two older stratigraphic members of the Vistulian: fluvial-basin deposits of Lesznowola (35 000—38 000 years) and the Warsaw ice-marginal lake deposits (ca. 50 000 years), have been determined in a consequence.

The following pedostratigraphic levels have been distinguished and dated: Wiązowna I (Agard), Wiązowna II (Bölling), Cięciwa I (Alleröd), Cięciwa II (Pre-Boreal), Cięciwa III (Boreal) and Cięciwa IV (Atlantic) determining the soil type and providing the characteristics of climate conditions. That has enabled one to determine the age of the fluvial series and Vistula terraces.

The review of the Vistulian and Holocene events presents 3 separate erosional-aggradation cycles the 1st one — of the Lower and Middle Vistulian, the 2nd one — multi-phase cycle of the Upper Vistulian and Late-Glacial and the 3rd one — the Holocene cycle. The Pleistocene--Holocene limit should be placed at 10 600 BP in the Warsaw Basin.

M. D. Baraniecka
Geological Institute
00-975 Warszawa, ul. Rakowiecka 4

K. Konecka-Betley
Agricultural University
Department of Pedology
02-528 Warszawa, ul. Rakowiecka 26/30

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EDWARD WIŚNIEWSKI

EVOLUTION OF THE VISTULA VALLEY BETWEEN WARSAW AND PŁOCK BASINS DURING THE LAST 15 000 YEARS

HISTORY OF STUDIES

Since 1927, when Lencewicz had published his work "Dyluwium i morfologia Środkowego Powiśla" (Pleistocene and morphology of the Middle Powiśle) in which stated the presence of glacial relief and sediments in the eastern part of the Płock Basin a more recent study of the Vistula valley between the Warsaw and Płock Basins was lacking. That part of the Basin was the author's interest of study due to the fact that without cognition of geomorphology of that area it would be difficult to present an opinion on the timing and the mechanism of the exposure by the Vistula its old valley to the west of Płock after unblocking of the river course by the Vistulian ice-sheet.

First, more recent papers dealing with the Vistula valley between Wyszogród and Płock are those of Skompski (1960, 1961) and Borówko-Dłużakowa (1961). The first author has described geological structures near Gąbin and geological position of some peatlands on the terrace of the left-bank part of the Vistula valley down of Płock while Borówko-Dłużakowa has performed the palynological studies of organic deposits.

Two papers of Laskowska-Wysoczańska and Ruszczyńska-Szenajch were published in 1964. The geological cross-section of the Quaternary sediments between Wyszogród and Sochaczew was presented in the former of the above papers while the terraces of the Vistula valley and their age were described in the second one.

Geological profile through the Vistula valley, to the SE of Płock, near Dobrzykowo, was described by Makowska and Skompski (1966). Three years later Skompski (1969) published a broad study dealing with the stratigraphy of the Quaternary deposits in the eastern part of the Płock Basin.

Since 1967 the author initiated his investigations on geomorphological development of the Vistula valley between Warsaw and Płock Basins which results are presented in this paper. Some of the results have been already published (Wiśniewski 1983, 1984).

PRESENT-DAY ENVIRONMENT

LOCATION OF THE STUDY AREA

A characteristic feature of the lower Vistula valley, starting from Warsaw, is the presence of the alternating valley broaden areas and narrowings of the nature of gaps along the river.

Between Warsaw and Fordon, over the distance ca. 200 km, there are 3 such broaden areas called: Warsaw Basin, Płock Basin and Toruń Basin. The length of these basins varies from ca. 50 km to almost 100 km in the case of Toruń Basin while their width is 20—25 km. Two sections linking the basins are ca. 25 km each and their widths are from 7 to 10 km, while the section linking the Warsaw and Płock basins is wider.

During the Vistulian Glaciation, the ice-sheet coming from the north reached to Gąbin, the latter located at the eastern margin of the Płock Basin. If it took place in the oldest phase, i.e. Leszno phase or in Poznań phase (Galon 1961a, 1972; Galon, Roszkówna 1961; Kotarbiński 1966; Mojski 1960, 1969; Roszkówna 1968; Skompski 1969) is questionable. Thus, the Warsaw Basin and valley section linking it with the Płock Basin were behind the ice-sheet extent.

Geomorphological events during glaciation and deglaciation of the valley section between Płock and Toruń basins have been described in the author's former papers (Wiśniewski 1976a, b, 1982). In order to clarify some questionable problems the studies on the section linking the Warsaw and Płock basins between Wyszogród and Płock, i.e. between 585 and 632 km of the river course, being behind the extent of the Vistulian glaciation (Fig. 1) were undertaken.

PRESENT-DAY CHANNEL

Until 1969 when the Vistula had not been dammed near Włocławek its channel developed under the conditions of undisturbed water flow. Actually, undisturbed flow of the Vistula is only to Kępa Polska where backwater effects of the Włocławek reservoir reach.

In the discussed section the Vistula is almost a braided river. It flows in a few wider and more narrow branches which surround numerously occurring here islands and bars. The widths of the branches are diversified. The most narrow ones are 30—40 m wide. The largest widths in

Fig. 1. Geomorphological map of the Vistula valley between the Warsaw Basin and Płock Basin

1 — morainic plateau; *2* — valley level built of glaciolacustrine sediments; *3* — Ciechomice level; *4* — level built of fine sands, silts and clays; *5* — outwash plain; *6* — eskers; *7* — accumulation terraces; *8* — valley floor — flood terrace; *9* — dunes; *10* — peat; *11* — elevations a.s.l.; *12* — location of geological cross-sections

the discussed sections are 800—900 m. Between Wyszogród and Dobrzykowo the Vistula channel is characterized by numerous islands called "kępa" (holm). They occur most frequently in the central part of a channel, however, lateral holms are also present here. Besides these holms numerous shoals called bars are found here as well. The Vistula has a nature of a braided river of a chaotic pattern of bars and holms being the evidence of variable hydrodynamic conditions.

PRESENT-DAY CHANGES

The Vistula valley floor between Wyszogród and Płock rather did not changed during the last 100 years. Although channelization of the Vistula had started in that period a substantial progress was not achieved. However, hydrological regime of the river between Kępa Polska and Płock had been changed due to a construction of the dam near Włocławek being the first one out of 10 projected dams of the lower Vistula cascade. The dam in question is located at the 675 km of the Vistula and limits the drainage basin of the area of 171 250 km^2.

Damming of the river was initiated in 1969 and completed in the mid-1970. The backwater reaches 58 km upstream and terminates up of Płock near Kępa Polska. The water level rised by 10.7 m at the dam and by 2.5 m in Płock with respect to the mean water level of the period of 1959—1968 (Glazik 1978). Water level changes do not exceed 1.5 m (Banach 1983). At the normal level of damming up the area of the Włocławek reservoir is 70.4 km^2. Damming of the Vistula at Włocławek was a major reason of an increased frequency of a formation of ice-jams on the reservoir itself and upstream of it, and in effect that of floods. According to Grześ (1983) during 13 years of the reservoir operation 16 ice-jams formed during 9 winter seasons.

Following Grześ and Banach (1983) natural jamming factors in the discussed section of the Vistula valley are: small river depths, large variability of the current stream, numerous interchannel holms, planting of holms and interembankment area with trees and changes of the river course direction, for example at Dobrzykowo. According to these authors susceptibility for jamming increased after the river dam up due to a lowering of the hydraulic gradient, presence at the dam head of numerous holms of the ordinates similar to the dam up level, and acceleration of the freezing timing by 23 days when compared to the free flowing river.

Particularly catastrophic ice-jam flood took place in January 1982 when water level in Płock had been 948 cm and exceeded the mean stage by 359 cm. Water level in Kępa Polska was 682 cm and in Wyszogród 756 cm (400 cm above the mean water level) at that time. During the flood water had broken low left embankments and inundated the area of almost 10 000 ha.

FORMS AND DEPOSITS OF THE FLOOD PLAIN

The flood plain occuppies ca. 50% of the valley area. Located at the height of 65—66 m a.s.l., close to Wyszogród it is 2 km wide, however, it rapidly widens downstream the Vistula to almost 7 km. It becomes again more narrow (to 2.5 km) close to Płock at the height 58 m a.s.l.

On the right hand side near Wyszogród the river undercuts directly the morainic plateaus of the height of 100—105 m a.s.l. most frequently. The flood plain at this river side is in a form of 3 larger fragments. The first fragment is located between Wyszogród and Kępa Polska. Its length is ca. 13 km and maximum width ca. 2.5 km. The second fragment of the flood plain is 8 km long and 1.7 km wide. The third larger fragment of the right-bank flood plain occurs few km to the SE of Płock, in the vicinity of Dobrzykowo, where the Vistula rapidly changes its course and forms a bend. A flood terrace, 7 km long and up to 2 km wide, has formed inside this bend.

The Vistula comes closer to the morainic plateau in Płock and the lowermost located fragments of the flood terrace have been submerged.

At the left hand side the flood terrace, 1—4.5 km wide, accompany the river over almost the entire discussed valley section excluding the area near Dobrzykowo where the river, forming a bend as mentioned above, undercuts the overflood plain over 2 km long distance. Downstream of Dobrzykowo the flood terrace again occurs over the distance of 12 km. In this section an island of the overflood terrace, 8 km long and 300—1300 m wide, on which the left-bank part of Płock — Radziwie is located, protrudes above the surface of flood terrace.

When analysing the relief of the flood plain the traces of old wide channels, frequently with peat, which extend over several km at the foot of the upper terraces have been stated on it. Besides the mentioned forms a network of narrow (20—30 m) and shallow depressions, mainly parallel to the valley axis, is common in the flood plain relief. Such relief proves best the braided character of the river.

Geological structure of the flood-plain is uniform. Down of Wyszogród, fine sands of the thickness sometimes up to 3 m or silty-clay layer

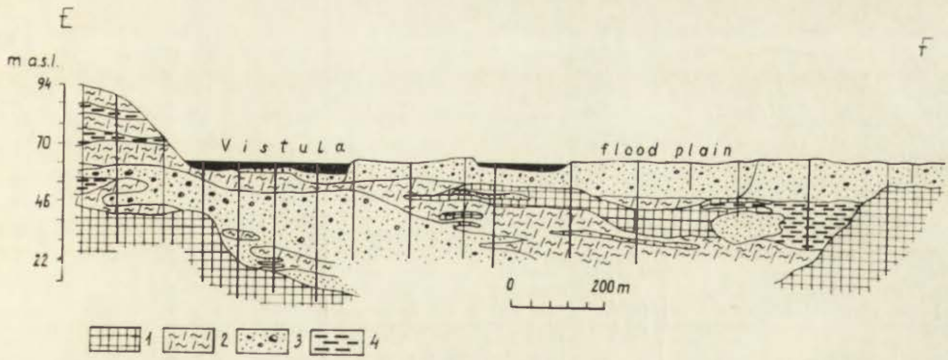

Fig. 2. Geological cross-section of the Vistula valley along the line E—F (according to Laskowska-Wysoczańska (1964) modified by the author)

1 — Pliocene deposits; 2 — till; 3 — sand and gravel deposits; 4 — glaciolacustrine deposits

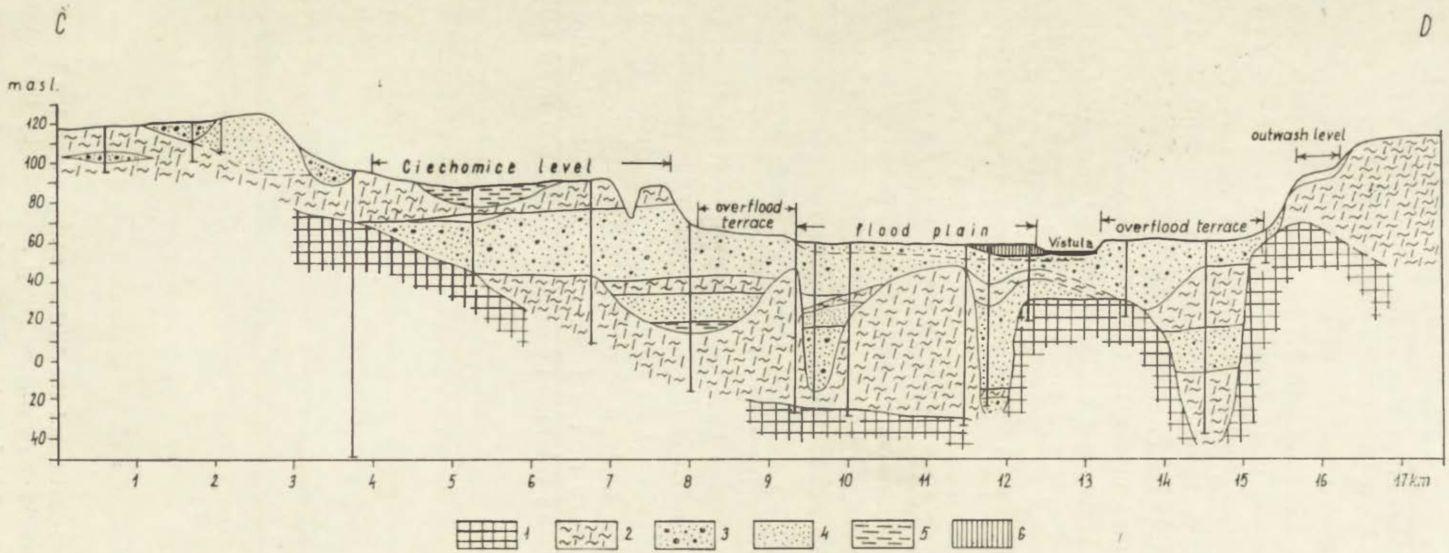

Fig. 3. Geological cross-section of the Vistula valley along the line C—D

1 — Pliocene deposits; *2* — till; *3* — sandy and gravel deposits; *4* — fine sands; *5* — glaciolacustrine deposits; *6* — alluvium of the thickness up to 1 m occur. Below, there are channel deposits: vari-grained sands, gravels and pebbles. The thickness of these deposits is very variable what is shown in Fig. 2. Sometimes it is 1.5 m only while there are locations where the thickness of fluvial deposits reaches several m. The erosional socle, i.e. till or Pliocene clays, occur below the fluvial sediments. The flood facies are up to 3 m thick near Borowiczki, west of Płock.

The broad left-bank flood terrace near Dobrzykowo, i.e. close to the Vistula bend is also built of medium sands, gravels and pebbles of the thickness of 12 m (Fig. 3). Here, the Vistula paleochannel, filled with organic deposits and flood facies of the thickness up to 5 m, is found at the edge of the overflood terrace.

Geological structure of the left bank of the fragment of the flood terrace south of Płock is shown in Fig. 4. Channel deposits of the thickness from 3.7 to 13.2 m lie directly onto the Pliocene deposits and, in turn, are covered with flood deposits up to 3 m thick. Although alluvia near Wyszogród reach sometimes the thickness of 17 m the Vistula flows directly on the morainic till or Tertiary deposits. According to the analysis of numerous archival drillings these deposits are very strongly glacitectonically deformed (Fig. 2). Hence, a deeper Vistula incision is not stated here. Larger thickness of fluvial sediments can be explained by a filling of depressions in the river channel, i.e. overdeepened areas and pools. The pools in shapes of furrows have a tendency to migrate downstream and are filled during high water stages.

Similarly to the above, the thickness of medium and fine sands in the Vistula channel near Płock varies from 0.6—11 m. The Pliocene deposits are below (Fig. 4).

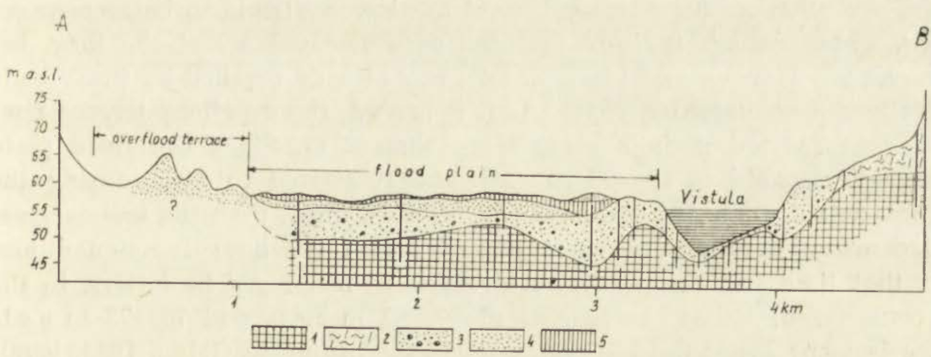

Fig. 4. Geological cross-section along the line A—B

1 — Pliocene deposits; 2 — till; 3 — sandy and gravel deposits; 4 — fine sands; 5 — alluvium

AGE AND ORIGIN OF THE VALLEY

The age of the river downcutting to the present level (Wiśniewski in press) is one of the most important problems refering to the geomorphological development of the Vistula valley between the Warsaw and Płock basins. Skompski in 1969 was of opinion that the Vistula overflood terrace in the eastern part of the Płock Basin is of the Older Dryas. His statement was based on the results of the palynological studies of peatlands to the south of Płock, Ciechomice and Dzierzązna performed by Borówko-Dłużakowa (1961) as well as on archeological evidences. Organic deposits in the Vistula abandoned channels onto the overflood terrace started to accumulate since the Pre-Boreal, i.e. since the beginning of the Holocene. Taking into account archeological findings on dunes of this terrace being in a form of the Paleolithic flintstone tools of the Younger Dryas and Alleröd Skompski concluded that these dunes could not have been formed later than the Alleröd.

Meanwhile, Manikowska published in 1982 the results of the fossil soil datings of the Vistula valley south of Wyszogród. The dunes, up to 13 m high, which cover the top of the overflood terace, the latter dated by ^{14}C method for 14 590 ± 270 BP (Lod.-85), have developed in the settlement of Kamion, on the left-bank overflood terrace elevated slightly more than 2 m above the flood plain. Second, thin humus layer with charcoal, dated for 12 235 ± 260 BP (Lod.-43) occurs above the first dune series of the thickness of 2—3 m. That soils should be related to the Bölling. It is covered by the second dune series of the Older Dryas as the soil dated for 10 830 ± 250 BP (Gro.-828), i.e. in the Alleröd, has formed in it. That soil is overtopped by the third, upper dune series.

Results of datings of the sub-dune deposits obtained by Manikowska are of great importance and cause numerous problems with respect to the evolution of the entire valley of the lower Vistula to be reconstructed. These datings indicate that the present-day level of the flow, between the Warsaw and Płock Basins, was already reached by the Vistula during the Pomeranian phase. As it is known, the overflood terrace rises above the flood plain slightly more than 2 m. Since the flood plain near Wyszogród is 65—66 m a.s.l. and it started to form during the Pomeranian phase, as it should had been assumed, then the ice-marginal streamway of the Drwęca—Noteć—Warta (pradolina) functioned also at that time and the pradolina levels were forming. The latters, in the Toruń Basin, are of the heights of 80—81 m a.s.l., and 70—72 m a.s.l., the last one being the bifurcation level (according to Galon, 1953, levels XI, X and IX, respectively). Therefore, the floor of the Toruń Basin was located at the level several meters higher than the contemporary flood plain located 140 km upstream of the valley! Hence, a new difficult problem arises which will require a thorough examination through the analysis of known facts and findings as well as considering of various possibilities when solving it.

The earlier ^{14}C datings of the organic deposits of the overflood and flood terraces, obtained by the author (Wiśniewski 1985), allow to assume that the Vistula descended to the actual level between Wyszogród and Płock at the end of the Late Glacial. The bottom of the gyttjas from the depth of 3.95—4.2 m, which fill the abandoned channel ca. 5 km to the SW of Wyszogród — in Nowa Wieś — on the overflood terrace, at the left bank of the Vistula, have been dated. The age of these sediments 9640 ± 100 BP (Gd.-1202) confirms their deposition since the Pre-Boreal. Actually, considering the datings by Manikowska, the age of the initiation of the formation of the Vistula flood plain between the Warsaw and Płock Basins should be modified from the end of the Late Glacial to its beginning.

At the moment when the Vistula had reached the present level, as it never did flow lower than that — what has been already shown, it started to form a broad flood plain by lateral erosion. In order to recognize changes of channel position 4 samples of organic deposits have been taken from this plain for the ^{14}C datings. The bottom layer of peat from the depth of 1.52—1.72 m which fills the abandoned channel, in Wola Ładowska, ca. 3 km to the north of Iłów, has been taken for datings. Below, only the channel deposits in form of medium sands occur. The obtained date was 8450 ± 105 BP (Gd.-1199) what indicates that the Vistula has shifted closer to the Wyszogród Plateau in the Boreal period. The Vistula flows in the middle of the flood plain in a section Wola Ładowska—Podgórze and the flood terrace widths at both the river sides are similarly of 2 km. The sample of the bottom of peat from the depth of 0.8—1.0 m, below which only sandy sediments occur, has been taken for datings from the shallow abandoned channel in the settlement Podgórze, ca. 500 m from the plateau slope. The age of the bottom of peat is 6295 ± 65 BP (Gd.-1204) what indicates that overgrowing with vegetation and filling of the abandoned channel started since the Atlantic. The left-bank flood terrace occurring 15 km downstream of the Vistula is ca. 4 km wide, and the abandoned channel located at the terrace in question undercuts the latter at 63—72 m a.s.l. as well as the overflood terrace. That abandoned channel is filled to the depth of 4.25 m by organic deposits (peat, gyttja) resting on fluvial coarse sands. The sample of the bottom of gyttja, i.e. from the depth of 3.95—4.25 m, has been taken for dating. The processes of the abandoned channel filling and overgrowing with vegetation were initiated at the turn of the Atlantic and Sub-Boreal what confirms the gyttja age — 5255 ± 245 BP (Gd.-740). At the right bank of the Vistula in Wykowo the fragments of the flood terrace of the width ca. 750 m are present, the age of the bottom of gyttja from the depth of 3.77—3.95 m is 3850 ± 100 BP (Gd.-735). Based on the above

4 datings of the organic deposits of various locations at the Vistula flood terrace between Wyszogród and Płock which have proven different age of particular abandoned channels occurring on this terrace one can conclude that the formation of a broad floor by the river migrations has continued since 14 500 BP likely until nowadays.

PALEOGEOGRAPHICAL PROBLEMS OF THE VISTULA VALLEY BETWEEN THE WARSAW BASIN AND PŁOCK BASIN

As mentioned in the introduction, the entire Płock Basin was under the ice-sheet during the maximum extent of the Vistulian Glaciation. The consequence of the ice-sheet advance was blocking of the Vistula and formation of the ice-marginal lake which extent up-valley towards Warsaw as well as its level were not exactly known up-to-date.

The studies carried out recently in the vicinity of Warsaw by Karaszewski (1974), Morawski (1979) and Sarnacka (1982) have provided new and valuable results which allow one to form more precise opinions. The studies proved that clays of the Warsaw ice-marginal lake, which position was related to the ice-sheet stoppage at the line of the Wkra stage — Middle Polish Glaciation (Różycki 1961, 1967a, 1967b, 1972), are much younger because the organic deposits of the Eemian interglacial occur below these clays. The sites analysed by Karaszewski were located at the left-bank of the Vistula, on the so-called Błonie terrace, at the heights of 87.4—87.6 m a.s.l. and 102.2—102.6 m a.s.l. in the vicinity of Ożarów while those studied by Sarnacka on the equivalent of that terrace, i.e. on the Radzymin terrace (Otwock terrace IIc, according Różycki 1967a, 1967b, 1972) located at the height of 92—95 m a.s.l. at the right hand side of the Vistula valley.

So high level of the Vistulian clays in the area of Warsaw, i.e. that of the bottom of the former ice-marginal lake is not the evidence of the water level it that lake, however allows to consider a possible outflow from this lake via the Warsaw-Berlin Pradolina (ice-marginal streamway) which floor, on the water divide between the Ner and Bzura rivers, is located at present at the height 102 m a.s.l.

Undoubtedly, the reason and rate of the ice-marginal lake outflow belong to difficult geomorphological questions. Up to now the author only has attempted to determine the Vistula incision between Wyszogród and Płock down to the present level after the unblocking of the ice-marginal lake on the basis of radiocarbon datings of the organic deposits of the valley lower terraces. Hence, the mechanism of the ice-marginal lake disappearence is still to be explained.

Five levels and terraces of the following heights occur in the Vistula valley between Warsaw Basin and Płock Basin: a — level 82—83 m a.s.l., b — level 73—78 m a.s.l., c — terrace 63—72 m a.s.l., d — terrace 60—69 m a.s.l., e — terrace 58—65 m a.s.l. (Fig. 5).

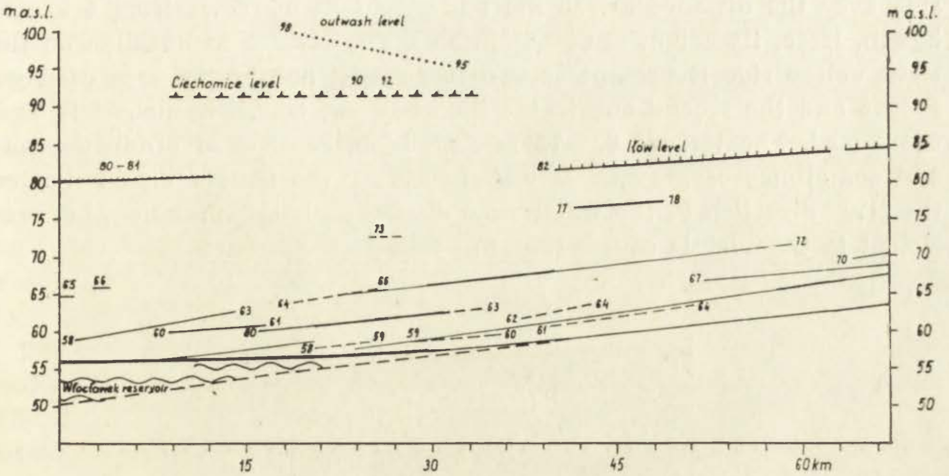

Fig. 5. Longitudinal profile of the Vistula valley terraces between the Warsaw Basin and Płock Basin

Continuous line — left-bank terraces; broken line — right-bank terraces; thick line — terraces on both sides of the Vistula river

The level 82—83 m a.s.l., called the Iłów level, is present exclusively on the left side of the Vistula. It is equivalent of the Błonie terrace on the left side of the Vistula or the Radzymin terrace on its right side within the Warsaw Basin. The level in question is built of the Pleistocene clays, covered with fine sands over extensive areas. Considering its geological structure it is no of a nature of a river terrace. According to the literature that level was formed by the final stage of the Riss Glaciation, in the Wkra stage, when an extensive ice-marginal lake was being formed in the Vistula valley (Ruszczyńska-Szenajch 1964; Laskowska--Wysoczańska 1964). Based on the results of the recent studies of Karaszewski and Sarnacka, what has been already mentioned, the interpretation of the clay deposits as well as that of the form itself is questionable. It seems likely that the clays building the Iłów level, or at least their top part, are also younger. Thus, they could be deposited in the ice-marginal lake during the Vistulian Glaciation.

The level located at the lower elevation in the analysed part of the valey is 73—78 m a.s.l. and is present as two narrow fragments. It extends along the highest level on the left side of the Vistula in a form of a narrow, 0.5 km wide and 7 km long bench. Its tantamount form on the right side of the Vistula is probably 2 km long, narrow level of the height 73 m a.s.l., occurring ca. 8 km to the SE of Płock. Both fragments of the level to the depth of 2 m are built of horizontally laminated fine sands usually, however, cross-laminated ones are sporadically present.

The first typical river terrace of an accumulational character in the Vistula valley between the Warsaw and Płock Basins is 72 m a.s.l. high close to the Bzura river mouth. It extends continuously on the left valley side over the distance ca. 38 km and gradually narrows from 4 km to 300 m. Here, its height is 64—65 m a.s.l. The terrace in question on the right valley side is present as two fragments: one in the area of Kępa Polska and the second one to the SE of Płock, where its height is 63—64 m a.s.l. The terrace 63—72 m a.s.l. high, consists of sandy deposits and sometimes of gravels. Measurements of the lamina dips indicated the NW direction of the water flow during their accumulation, i.e. consistent to the Vistula course (Fig. 6).

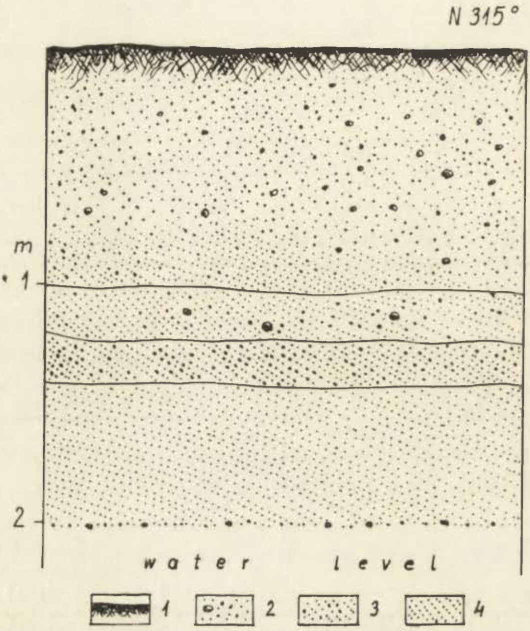

Fig. 6. Example of the geological structure of 63—72 m a.s.l. terrace east of Iłów
1 — soil; 2 — medium sand with some gravel; 3 — vari-grained sand with dominating coarse sand; 4 — fine sand

According to Ruszczyńska-Szenajch (1964) the discussed terrace had to be formed due to river accumulation because of blocking of the Vistula outflow to the north during the Vistulian Glaciation. Moreover, one more terrace of the height 60—69 m a.s.l. occurs below that of 63—72 m a.s.l. That is the overflood terrace which, between Wyszogród and Płock, is preserved on the left hand side of the Vistula close to the Bzura river mouth and on both the valley sides, from the line Wąsosz—Wykowo due to NE. The traces of the abandoned channels, filled with organic deposits, are preserved in all the fragments of the overflood terrace with dunes in numerous locations.

When reconsidering the age of the terrace of 63—72 m a.s.l. between Wyszogród and Płock one should refer to Różycki's opinion (1967a,b, 1972) about the age of its equivalent in the Warsaw Basin. According to

Różycki the highest terrace is located at the height of 92—97 m a.s.l. That is the earlier mentioned terrace IIc — the Otwock terrace, called also that of Radzymin or of Błonie. Accumulation of sands covering the clays on this terrace is related by Różycki to the Leszno phase. The lower terrace in the area of Warsaw, i.e. IIb one, called the Falenica terrace, is 83—84 m a.s.l. high and originates of the Poznań phase. According to Różycki the terrace of the Pomeranian phase in the Warsaw Basin is 82 m a.s.l. high. Following Ruszczyńska-Szenajch (1964) and Baraniecka (1982) the terrace of 63—72 m a.s.l. between Wyszogród and Płock is an extention of the terrace IIb — the Falenica one.

Therefore, considering the heights of the terraces in the Warsaw Basin and in the section linking the latter with the Płock Basin it is difficult to relate them to the highest terrace of the gap section of the Vistula valley between the Płock and Toruń Basins (here, the highest terrace is 70—72 m a.s.l. high) and, moreover, to the even higher two levels (80—81 m a.s.l. and 75—77 m a.s.l.) in the Toruń Basin.

Now, it is reasonable to discuss geomorphological relations in the eastern part of the Płock Basin. Skompski has distinguished the sandur level of the height of 98 m a.s.l. and assumed that the meltwater was directed to the east, to the Warsaw Basin, only at this height. It should be recalled that the above author indicates the meltwater outflow to the north, to the Toruń Basin, on the lower level at the height of 92—93 m a.s.l. (i.e. Ciechomice terrace). The level of 92—93 m a.s.l. has not been modelled by rivers according to the author's investigations. Various glacial forms and deposits present here indicate that the level was glaciarized. The SE part of the Ciechomice level is limited by the area located 2—3 m higher and built of sands and gravels. That area has been modified by kettles. The studies had proven that it is a small outwash which was formed on the ice.

When the Płock Basin, i.e. the Ciechomice level as well, was covered with ice the outflow of the outwash water to the east, to the ice-marginal lake, took place 5—6 m higher at the fringe between the ice-sheet margin and the moraine plateau, at the height of 98 m a.s.l. The above is confirmed by the geological structure of this level as well as by textural measurements of the deposits. The bench of the level of 98 m a.s.l. extends as far to the east as the barricade had reached, i.e. to the ice--sheet margin.

Between the slope of Ciechomice level and the moraine plateau the Vistula valley is only 4 km wide. This is the place where the northbound outflow of water from the ice-marginal lake had been initiated. The beginning of this event has not to be indicated at the Ciechomice terrace but at the lower height. However, the latter cannot be determined precisely because the event in question has not been reflected in the relief of that area. The causes of the overflooding of the ice-dammed lake to the north through the Płock Basin have to be found in the following facts. Many finger lakes, kames and eskers occur in the Płock Basin. Thus, numerous crevasses in which water could have started to flow northward were present in the dead ice filling that Basin. During the outflow from the ice-dammed lake the conditions favouring the formation of the terrace plains in the valley between the Warsaw and Płock Basins were likely not to prevail. Such conditions were fulfilled when the water descended and formed the linear river flow. The first terrace which is likely to be related to that event between Warsaw and Płock Basins is the terrace of 63—72 m a.s.l.

However, taking into account the up-to-date findings that the development of the Drwęca—Noteć—Warta ice-marginal streamway (pradolina) took place in the Pomeranian phase, what is the opinion established during several years based mainly on geomorphological analysis by numerous researchers (Galon 1961b, 1968; Kozarski 1962, 1965; Niewiarowski 1968; Wiśniewski 1971), the formation of the above mentioned terrace due to its low location is difficult to be related to the Pomeranian phase or Poznań phase as considered by Różycki (1967a, 1967b, 1972), Ruszczyńska-Szenajch (1964) and Baraniecka (1982). According to Manikowska's studies (1982), however, the formation of the even lower terraces between Wyszogród and Płock should be related to the Pomeranian phase. The latter studies invite to re-examine the opinions. However, the effect of such a re-examination will depend on a confirmation of the results obtained by Manikowska in other locations in the valley.

Based on the actual results one can state with a fairly large probability that after the ice-sheet retreat from the northern part of Poland the process of the Vistula incision down to the present level took place in a short time interval in the Late Glacial period.

Nicholas Copernicus University
Institute of Geography
87-100 Toruń, ul. Fredry 8

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ELŻBIETA FLOREK, WACŁAW FLOREK,
ELŻBIETA MYCIELSKA-DOWGIAŁŁO

MORPHOGENESIS OF THE VISTULA VALLEY BETWEEN KĘPA POLSKA AND PŁOCK IN THE LATE GLACIAL AND HOLOCENE

HISTORY OF THE STUDY

The studied section of the Vistula valley was not thoroughly studied up-to-date. Former analyses were either related to the studies of larger areas and the Vistula valley was treated rather marginally there (Lencewicz 1927; Galon 1953; Mojski 1960; Słowański and Skompski 1965), or their subject was the geological structure of the area, especially with respect to the Pleistocene stages of glaciation and deglaciation (Skompski 1961, 1969; Ruszczyńska-Szenajch 1964; Mojski 1960, 1980a,b; Makowska, Skompski 1962, 1966). Some works are dominated by their authors interest in the dune environment (Mojski 1960; Urbaniak-Biernacka 1969).

Makowska and Skompski (1966) have distinguished the flood plain, the overflood terrace and three glacifluvial levels in the valley in question.

Kotarbiński and Urbaniak-Biernacka (1975) have studied the water outflow from the western part of the Płock Basin, covering with the analysis the small western part of the considered area. Following the works of Makowska and Skompski (1966) and Skompski (1969) the former authors have distinguished the Pleistocene supra-flood terrace and the Holocene flood plain.

The most recent paper of Wiśniewski (in press) brings a few ^{14}C datings — two of them are related directly to the area in question. These new data allowed Wiśniewski for verification of findings of Skompski with respect to the age and number of the river terraces in the studied section of the Vistula valley. According to Wiśniewski there are three terraces here and three morphological levels of unknown origin.

The statement that the supra-flood terrace in the studied section of the Vistula valley was built in the Older Dryas is common for the mentioned authors (Makowska and Skompski 1966; Kotarbiński and Urbaniak-Biernacka 1975; Wiśniewski in press). The interpretation of the palynological profiles on the left-bank of the Vistula by Borówko-Dłużakowa (1961) was the base for datings. Similarly the statement of S. Skompski that the Vistula has descended down to the present-day level already in the Late Glacial (what was based on archeological finds) was supported recently by Wiśniewski (in press) having only an indirect proof — the Holocene date (Wola Ładowska — 8450 ± 105 BP).

One has to mention also the photointerpretational map made under the supervision of Falkowski (1979) as well as numerous remarks on the geological structure of the Vistula valley in the Płock area (in papers of 1975—1980) among the evaluations of the studied section.

The studies, results of which are presented here, were carried out in 1981—1984 and were coordinated by the Institute of Geography and Spatial Organization of the Polish Academy of Sciences. Alexandrowicz (the malacofauna analyses), Konecka-Betley (fossil soils analyses), Pazdur (^{14}C analyses) and Zachowicz (palynological expertise) contributed also to the work of three authors.

Two M. S. theses dealing with the development of the relief in the studied section have been made in the Department of Geomorphology, of the Institute of Physico-geographical Sciences, of the Warsaw University (Krajewska 1983; Jancewicz 1984).

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

The 26 km long section of the Vistula valley from Kępa Polska to Płock was a subject of the present study. This section is located at the southern border of the Płock Basin. The width of the Vistula valley floor ranges from 4.5 km to 9 km. The edge of the glacial plateau limiting the valley is up to 30 m high on the left bank in the western part while in the eastern one it is lower and dissected. The right-bank edge is higher — it reaches the height of 40—50 m and is more pronounced.

The valley floor is composed of 3 Pleistocene levels and of 4 Holocene ones (Fig. 1, 5):

— the TP-0 level, located on the NW side of the valley floor — up-to-date it was not subject to a thorough study;

— TP-1 — the Late Glacial higher level, with numerous large dunes and longitudinal lowerings of the abandoned channels filled with peat and gyttja to the depth of 2.5—3 m;

— TP-2 — the Late Glacial lower level, dichotomous one: one part with dunes and areas of deflated sands dissected by fine flood-troughs, with no organic fills and with elongated depressions filled with organic deposits up to 2.5 (with peat and gyttja) and part two located in the level of the flood plain. The extensive depressions filled up to 3 m with peat are included into part two;

— TH-1 — the zone with the traces on an activity of the sinuous channel, with paleochannels filled with organic deposits, mainly with peat up to 5 m thick;

— TH-2 — the zone with traces of well developed splays and crevasse troughs overlaying the relief of the TH-1 and TP-2 levels. The organic deposits of the thickness up to 1.5 m are found in the straightened abandoned channels;

— TH-3 — the zone with traces of numerous, thick sandy bars dissected by the flood water channels, with small backswamps in the deepest places (Fig. 4);

— TH-4 — the area limited by flood-control embankments, featuring numerous young bars and dissections due to flood-waters.

The width of the Vistula channel is 0.5 to 2 km in the studied reach. There are numerous bars ranging from the small sandy ones to the large, accreted and even inhabited ones (Kępa Tokarska), in the channel.

HYDROLOGY

The annual mean temperature in the period 1971—1980 was 7.7°C in the studied area. The minimum monthly mean temperature is in January: −2.7°C. The average number of days with the temperature below 0°C is 104. The total annual precipitation is 576 mm (1971—1980). The hydrological conditions were evaluated based on records from 2 water-gauge posts. The water gauge Kępa Polska is installed at the 606.5 km of the course of the Vistula and terminates the drainage basin of 168 862 km^2 while the one in Plock is located at the 632.4 km of the river course closing the drainage basin area larger by 519 km^2. The river gradient is of 0.17‰ in the vicinity of Kępa Polska and of 0.05‰ at Płock.

Regular occurrence of relatively high and long-lasting melt-floods (in March—April) and low water stages in autumn were typical of the Vistula before its damming-up. Rain floods are irregular and occur mainly in July and in August. The maximum water stages were recorded during the rare summer floods, often being higher than their spring analogues.

The water stage amplitudes in the years 1958—1968 were of 593 cm in Płock, and 699 cm after the water-gauge was installed. The maximum amplitudes of 570 cm occur in June and July either due to large rain floods or, in some years, due to low water stages. During the spring floods the amplitudes were lower, to 440 cm, due to increased minimum stages.

The maximum water discharges were 1260 m^3/s in February at Kępa Polska and 1840 m^3/s at Płock in April. The minimum mean discharges are related to a period of the lowest mean water stages. They occur in September and are of 649 m^3/s in Kępa Polska and 494 m^3/s in Płock.


Vistula
Słupianka
Wołów
TP-0
TH-3
TH-4
TP-1
TP-2
TH-1
TH-2
TP 2
Datings ^{14}C
1 - Liszyno - 10400±180 B.P.
8750±100 B.P.
3610±120 B.P.
2 - Wykowo - 3850±100 B.P.
3 - Piaski - Wąsosz - 5255±245 B.P.
4 - Wymyśle a - 6360±150 B.P. b - 5180±80
5 - Wymyśle 2 - 4680± 80 B.P.
6 - Nowosiadło - 990±120 B.P.
7 - Słupno - 9620 ±300 B.P.
8 - Bończa - 11900±500 B.P.
9 - Troszyn Polski - 5650±120 B.P.
10 - Juliszew 10500±270 B.P.
11. Borki 4880± 260 B.P.
12. Budki Ciechomickie 14390± 160 B.P.
Vistulian Gl.
Płock
1
2
3
4
5
6
7
8
9
10
11
12
13
0 1 2 km

After the Włocławek reservoir has been built there are still large amplitudes of water stages observed in the studied reach of the Vistula river.

Here, the Vistula is the river of large amplitudes of water stages (the amplitudes are up to 6.5 m) and of variable discharges: from 189 m^3/s in the period of ice-phenomena up to 6900 m^3/s during the floods. The ratio $Q_{max}:Q_{mean}:Q_{min}$ is 7.6:1.0:0.2 for the water-gauge in Płock. The probabilities of occurrence of discharges are given in Table 1. The melt-

Table 1. The maximum annual discharges of given probability (years 1921—1963) computed for the Płock profile

Probability of occurrence [%]	Recurrence interval [years]	Discharge [m^3/s]	Mean error [m^3/s]
1.0	100	9280	1430
2.0	50	8460	1190
5.0	20	7520	883
10.0	10	6410	656
25.0	4	5090	420
50.0	2	3900	300

-floods in the winter/spring period may take a form of the ice-jam floods (in February—March). The ice-cover appears already in December and sometimes lasts until March. The maximum thickness of the ice-cover is up to 40 cm.

The ice-jam floods are usually dangerous due to difficulties in predicting them and violent occurrence (e.g. the flood of 1982).

Less frequent are summer floods related to the torrents. The largest flood occurred in the studied area in July 1844 (the highest stage in summer — 850 was observed then in Płock), another summer flood, of July 1924, has caused significant morphological modifications on the major part of the flood plain.

Fig. 1. Location of the study area versus the extent of the Last Glaciation and the geomorphological map of the Vistula valley from Kępa Polska to Płock (with ^{14}C datings, position no. 2 and 3 after Wiśniewski, in press)

1 — morainic plateau; *2* — glacifluvial level; *3* — edges of the higher morphological levels; *4* — esker; *5* — dissections of the valley sides and alluvial fans; *6* — distinct and indistinct edges of the terrace levels; *7* — dune forms; *8* — areas of deflated sands and irregular dune forms; *9* — traces of crevasse troughs; *10* — present-day hydrographic network; *11* — post-channel depressions with peat and bog accumulation; *12* — traces of compact sinuous channels; *13* — flood-control embankments; *TP-0* — oldest Pleistocene terrace; *TP-1* — older Pleistocene terrace; *TP-2* — younger Pleistocene terrace; *TH-1* — the oldest segment of the Holocene terrace; *TH-2* — channels and crevasse fans overlaying the terraces TP-2 and TH-1; *TH-3* — segment of the Holocene flood-plain formed during the flood of 1924; *TH-4* — the youngest segment of the flood-plain related to the present-day channel activity

CHANGES OF THE VISTULA CHANNEL AND THE FLOOD PLAIN DURING THE LAST 200 YEARS

The youngest stage of evolution of both the flood plain and the channel of the Vistula could be studied by an analysis of the archival maps. The oldest map, which may be used for this purpose, is the map of Textor of 1808 in the scale 1:150 000 (Fig. 2). 180 years ago the bank of the Vistula river was irregular with numerous point bars gradually transforming into more stable forms — holms. The point bars and holms were dissected by numerous channels, some of them up to 0.5 km wide. Such a situation is visible also on the Topographic Map of The Polish Kingdom of the year 1839 (the scale 1:126 000). The plan of the Vistula channel made in the years 1860—1866 is depicting the river channel with smaller number of larger holms and point bars.

At the beginning of this century the Vistula was subject to channelization. The numerous former bars and holms have been incorporated into the flood plain, and the channels separating them have been partly filled.

The effects of channelization were not long-lasting. The map of the years 1929—1930 indicates the changes of the bankline due to erosion and accumulation. The large summer flood of 1924 took place in this period, which modified the stable for a long time surface of the right-bank part of the flood plain in the area of Rydzyno. This flood has deposited sandy bars of the thickness sporadically exceeding 1 m, on the fertile madas (Fig. 3). Simultaneously the deep erosional dissections were formed reaching the limits on the meander filled with the clayey mada and terminating there. They are visible again on the opposite side of the bend. The discontinuous erosional forms at the bend border may be explained due to the lithological differences. The area surrounding the meander bend is built of sands and sandy silts while the meander itself is filled with clayey mada resistant to erosion. The morphological effects due to this flood are shown only in the maps of the end of 1920s, the German topographical map in the scale 1:25 000 edited in 1942, and maps edited after the Second World War.

The consecutive major changes can be noticed when comparing the topographical maps of 1959 and 1974 (Fig. 2). These changes are mostly related to the effects of the Włocławek reservoir. Other bars have been incorporated into the flood plain in the vicinity of Kępa Polska and the separating them arms of the Vistula became permanently cut-off from the active river.

During the ice-jam flood in 1982 the flood-control embankments have been broken in some localities, and the flood water has eroded deep troughs of the length of some hundred meters in the areas of breakages. In the vicinity of these breakages the sandy bars of the thickness of se-

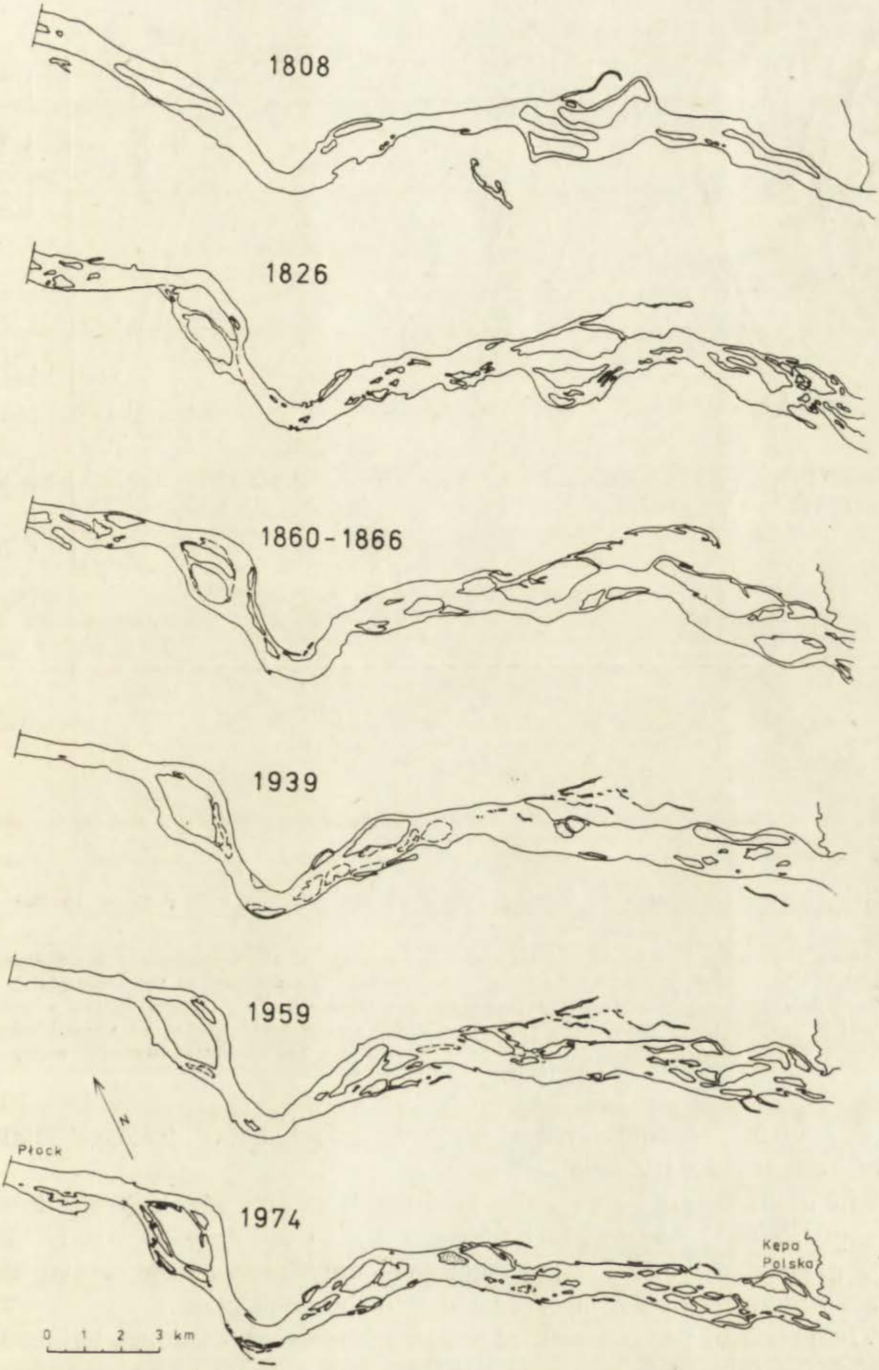


Fig. 2. Changes of the Vistula channel in the section from Kępa Polska to Płock depicted on the maps of the period of 1808—1974

1808 — map of Textor J. Ch., original's scale ca. 1:150 000; 1826 — map of the Quartermaster Department, original's scale ca. 1:126 000; 1660—1866 — plans of the Vistula river, original's scale ca. 1:40 000; 1939 and 1959 — topographic map in the scale 1:25 000, 1974 — topographic map — original's scale 1:50 000

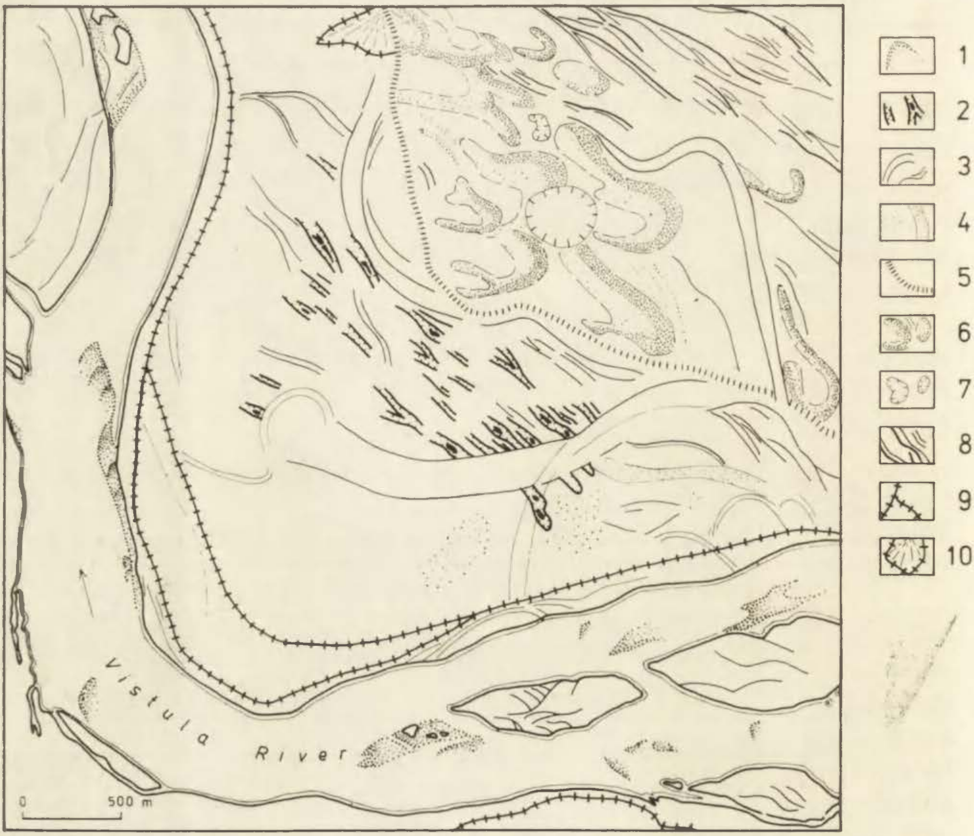


Fig. 3. Photointerpretational tracing paper of the Vistula valley floor to the SE of Płock

1 — sandy-gravel channel bars; *2* — traces of the activity of the sinuous and braided channels on the flood-plain; *3* — traces of the young post-flood dissection on the flood-plain; *4* — areas of the sandy post-flood accumulation on the flood-plain; *5* — edges of the overflood terrace; *6* — dunes; *7* — deflation forms; *8* — traces of the braided channel activity on the overflood terrace; *9* — embankments; *10* — fans of the organic-mineral material accumulation in the sedimentation basins

veral tens of centimeters have been deposited. Some drainage ditches have been filled with sand.

The areas described by Falkowski (1979) as being formed due to the ice-jam floods turned out to be formed due to the development of bars, their gradual stabilization by vegetation and subsequently turning into holms which have been incorporated into the flood plain.

The origin of the complex of splays and crevasses troughs within the level TH-2 (Fig. 1) is only questionable. The described above results of the summer flood of 1924 give the substance for a supposition, that the above mentioned crevasse forms were created due to an influence of summer floods, the latter being not frequent but more extensive than the others.

The contemporary Vistula channel is significantly differentiated morphometrically in the analysed reach of the Vistula (Fig. 4) what enhances floods, mainly the ice-jam ones. Their occurrences result in flooding of the entire valley floor excluding the higher surfaces of the Pleistocene terraces (Fig. 4).

ORIGIN AND AGE OF THE DEPOSITS AND FORMS ON THE VALLEY FLOOR

The series of geological probes have been performed in order to characterize the textural features of alluvial deposits on the vari-aged surfaces of the terraces and in the abandoned river channels. All the outcrops located in the studied area have been also analysed. Over 200 samples have been collected for the detail analysis of the grain size composition and abrasion of the quartz grains of chosen fractions. More than 50 samples were analysed mineralogically.

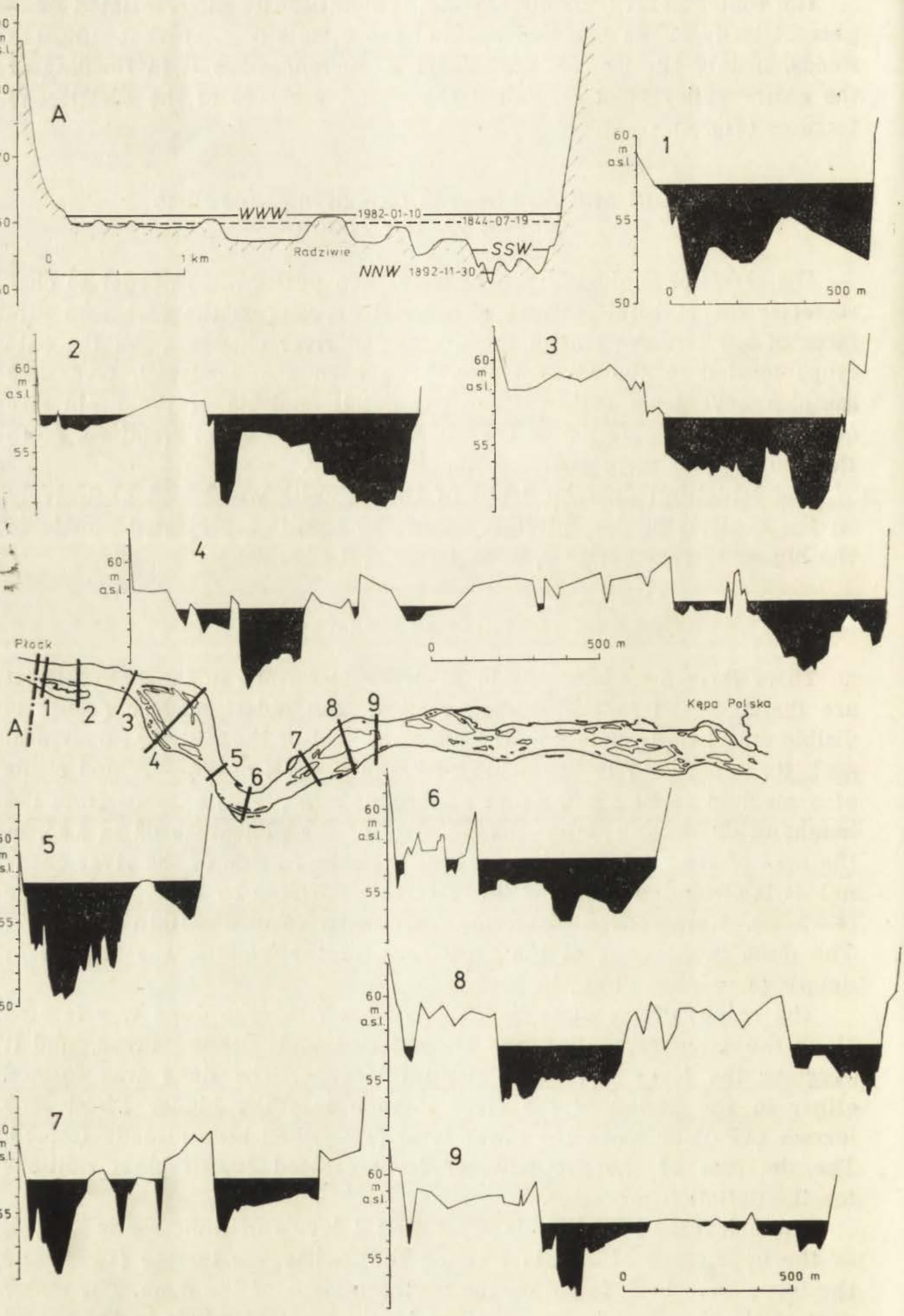
The structural characteristics of the deposits was based exclusively on the analysis of the outcrops. Thus, the results are related mostly to the higher terrace surfaces, dune forms and edge zones.

LATE GLACIAL TERRACES

Three terrace surfaces (TP-0, TP-1, TP-2) formed in the Late Glacial are distinguished in the studied section. The oldest surface (TP-0) is visible only in a fragment in the northern part of the valley at 65—75 m a.s.l. Its upper face to the depth of 2.5 m is built of fine-grained sands of a medium sorting. The other terrace surface (TP-1) extends from the height of 69 m a.s.l. under the SE edge of the plateau to 62 m a.s.l. in the area of the preserved islands on the northern side of the river channel. It is separated from the lower terrace surfaces by a very high edge (4—5 m). Numerous dune forms have been formed within this area. The dune in Liszyno, at the right-bank of the Vistula was studied in details (Kamińska *et al.*, in press).

The height of the dune in Liszyno is of 7 m. The dune was formed along the edge separating the overflooded and flooded areas, and it overlays the levee developed along this edge. The dune was formed etiher in the period of the river incision into the higher Pleistocene terrace (TP-1) or when the lower level (TP-2) had been already formed. The decrease of the groundwater level created favourable conditions for the deflation processes.

Three levels of fossil soils separating 4 levels of dune sands as well as the upper face of alluvia forming the Pleistocene terrace (TP-1) and the levee have been found on the northern slope of the dune. The major part of the dune sands was piled up by the western winds in the period


A
90 m a.s.l.
80
70
60
50
WWW
1982-01-10
1844-07-19
Radziwie
SSW
NNW 1892-11-30
0 1 km
1
2
3
4
5
6
7
8
9
55
0 500 m
Płock
Kępa Polska

preceeding the forming of the oldest fossil soil. The latter, dated with ^{14}C as of 10 400 ± 180 BP was, the most probably, formed on a dune of the Older Dryas. This soil started to form in the Alleröd interstadial and was covered with eolian sands after the fire (indicated by the presence of a charcoal) in the second half of the Younger Dryas. The second soil, formed, in part, on a dune of the Younger Dryas and, in part, on deflated sands of the Pre-Boreal period has been dated based on a charcoal in the upper part of the humus horizon. The date ^{14}C of 8750 ± 100 BP indicates the forming period as of the mid-Boreal. The period of the youngest soil formation has been determined based on the ^{14}C method (3610 ± 120 BP) as of the middle phase of the Sub-Boreal.

The dune sands have been subjected to a complex textural analysis of the alluvia. Due to a common occurrence of material of an earlier eolian abrasion in the fluvial deposits of the turn of the Glaciation and the Holocene the roundness coefficient of quartz grains, and the percentage of the γ group (the best rounded grains, formed in a process of eolian abrasion, Mycielska-Dowgiałło 1980) have been determined. The analysis of the quartz grains abrasion, performed by means of the automatic graniformametr, indicated that both in the substratum, as well as in the lower dune series the better rounding of grains of the coarse fraction (0.75—1.02 mm) prevails and the percentage of the grains of the γ group is higher in this fraction. In the highest of the analysed series the better rounded are the grains of finer fractions (0.6—0.75 mm) and, again, the percentage of grains of the γ group is larger there. In the middle series of dune sands the pronounced variability is found. Basing on the ^{14}C datings one may conclude that, in general, the larger eolian abrasion of the quartz grains of coarser fractions is characteristic of the Late Glacial while the same applied to the finer was characteristic of the Holocene (especially to its second half).

The accumulation of deposits forming the Pleistocene terrace TP-1 must have been ended before the Older Dryas. Both the study of the dune in Liszyno and the analysis of deposits filling the channel depression within the same terrace at Bończa (Fig. 1) seem to support this conclusion. There is the peat layer of 70 cm in the axis of the form, underlain to the depth 2.96 m by gyttja with an abundant malacofauna. The presence of the malacofauna indicates the permanent reservoir, stagnant or of a negligible flow, with an abundant vegetation. The beginning of accumulation in this reservoir has been established for 11 900 ±

Fig. 4. *A* — cross-section of the Vistula valley in the area of Plock; extents of mean and extreme water stages are marked.

1—9 — exemplary cross-sections of the present-day Vistula Channel made in 1983 and 1984 at mean water stages (channel soundings performed by "Hydroproject")

500 BP based on the analysis of gyttja of the depth 2.83—2.96 m. It may be assumed, then, that the accumulation of the fluvial deposits forming the described terrace level ceased before the Mid-Dryas period. Just after this paper has been sent for publication the authors have obtained 3 extra ^{14}C datings of the organic fills of the abandoned river channels. One of these datings is related to the silt deposits with macroremnants of the bottom of the abandoned river channel in Budki Ciechomickie, in the area of TP-1 terrace. The abandoned channel deposits, silty-sandy sediments with gyttja and peat intercalations are reaching the depth of 3 m there. The sample of the depth of 2.83—3.0 m was dated for 14 390 ± 160 BP. If this material was not redeposited one may assume that by the end of the climax and the turn of the Vistulian glaciation the process of filling of the abandoned channels on the terrace TP-1 has already begun and that the main phase of accumulation of this surface is related to an earlier period. The structural measurements indicated that this terrace was formed by streams of a dynamic regime (large-scale tabular and trough cross-stratification) of a braided channel system, outflowing in the NW direction and with a large contribution of water flowing from the edge of the plateau. The overtopping with deposits of the alluvial fans is visible in the alluvia deposits.

The surface of the TP-1 terrace is dissected and separated with a high edge (4—5 m) from the lower terrace surface (TP-2). The heights within this latter surface vary from 63 m a.s.l. to 59 m a.s.l. The large alluvial fans (e.g. the Słupianka fan) and the abandoned river channels filled with peat and with gyttja at the bottom (e.g. Słupno and Juliszewo) (Fig. 1). The malacofauna which may be occasionally found in gyttjas indicates that it was inhabiting a shallow reservoir of stagnant water, with abundant vegetation, being subjected to filling with deposits and in the stage of gradually progressing eutrophization. The sample taken at the lower face of the mineral-organic deposits in Juliszewo at the depth of 2.7—2.8 m was dated for 9620 ± 300 BP. Basing on the results of the ^{14}C analyses one may assume that the accumulation of fluvial deposits forming the terrace (TP-2) was terminated at the turn of the Late Glacial and Holocene. It is evident that in the period between 11 900 ± 500 and 10 500 ± 270 BP the very strong bottom erosion ceased in the Vistula valley (the high edge separating both the terrace surfaces). With reference to the studies in the Vistula valley in the vicinity of Tarnobrzeg (Mycielska-Dowgiałło 1978) and to the profile in Całowanie (Schild 1982) one may assume that this period is characterized, in general, by the bottom erosion.

The mutual relation of the abandoned channel formed in the area of Słupno, filled with organic deposits, to the size of the alluvial fan of the Słupianka river, which blocks this channel over an extensive reach, serves as evidence for the processes in the Vistula valley at the level of

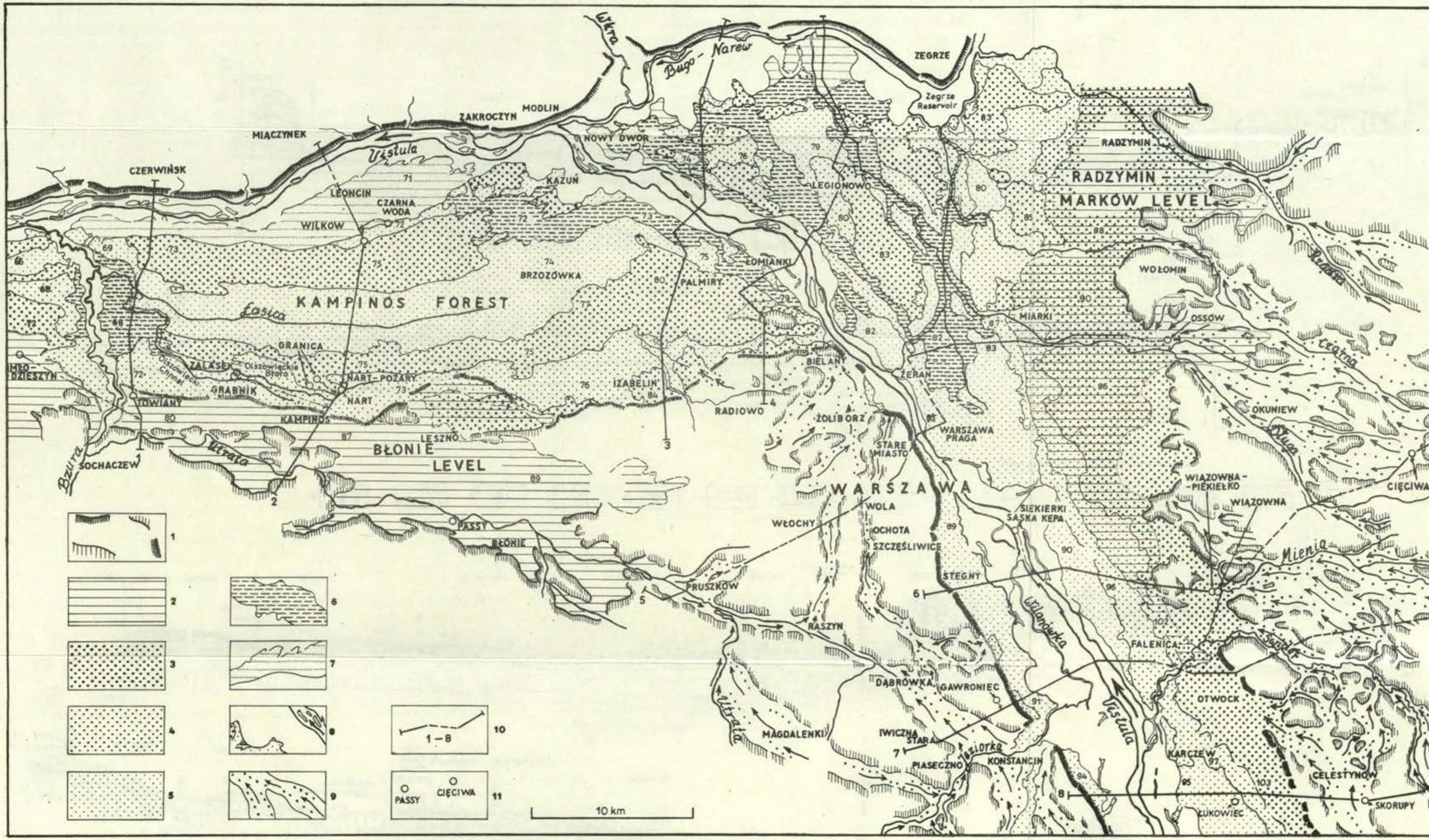


Fig. 3. Maps of geomorphological surfaces of the river and glacilacustrine accumulation in the Warsaw Basin

Summarized by Baraniecka based on the detail geological maps elaborated in the Geological Institute for the areas of: Wyszogród (Makowska i Ruszczyńska 1960), Czerwińsk (Kopczyńska 1960), Legionowo (Nowak 1974b), Sochaczew (Brzeziński in press), Warszawa (Morawski 1978, Sarnacka 1979), Okuniew (Nowak 1976), Raszyn (Sarnacka 1976), Piaseczno (Sarnacka 1974), Otwock (Baraniecka 1973). *1* – edge of the glacial plateau and older accumulation and denudation levels; *2* – Warsaw ice-marginal lake accumulation (Błonie level, Radzymin-Marki level); *3* – fluvial accumulation of the Otwock terrace and of glacifluwial accumulation of the dune terrace (fragmentarily on the older surfaces); *4* – fluvial accumulation of the Falenica terrace; *5* – fluvial accumulation of the Praga terrace (overflood terrace); *6* – the fluvial-backswamp accumulation of the Nowy Dwór terrace; *7* – fluvial accumulation of the overflood plain; *8* – flood-plain; *9* – fluvial accumulation and flow direction in the valleys dissecting the glacial upland, partially abandoned; *10* – geological cross-sections; *11* – major study sites. The heights of terraces and geomorphological levels are given in m a.s.l. The broken line denotes the projection direction of the study site profiles onto the geological cross-section

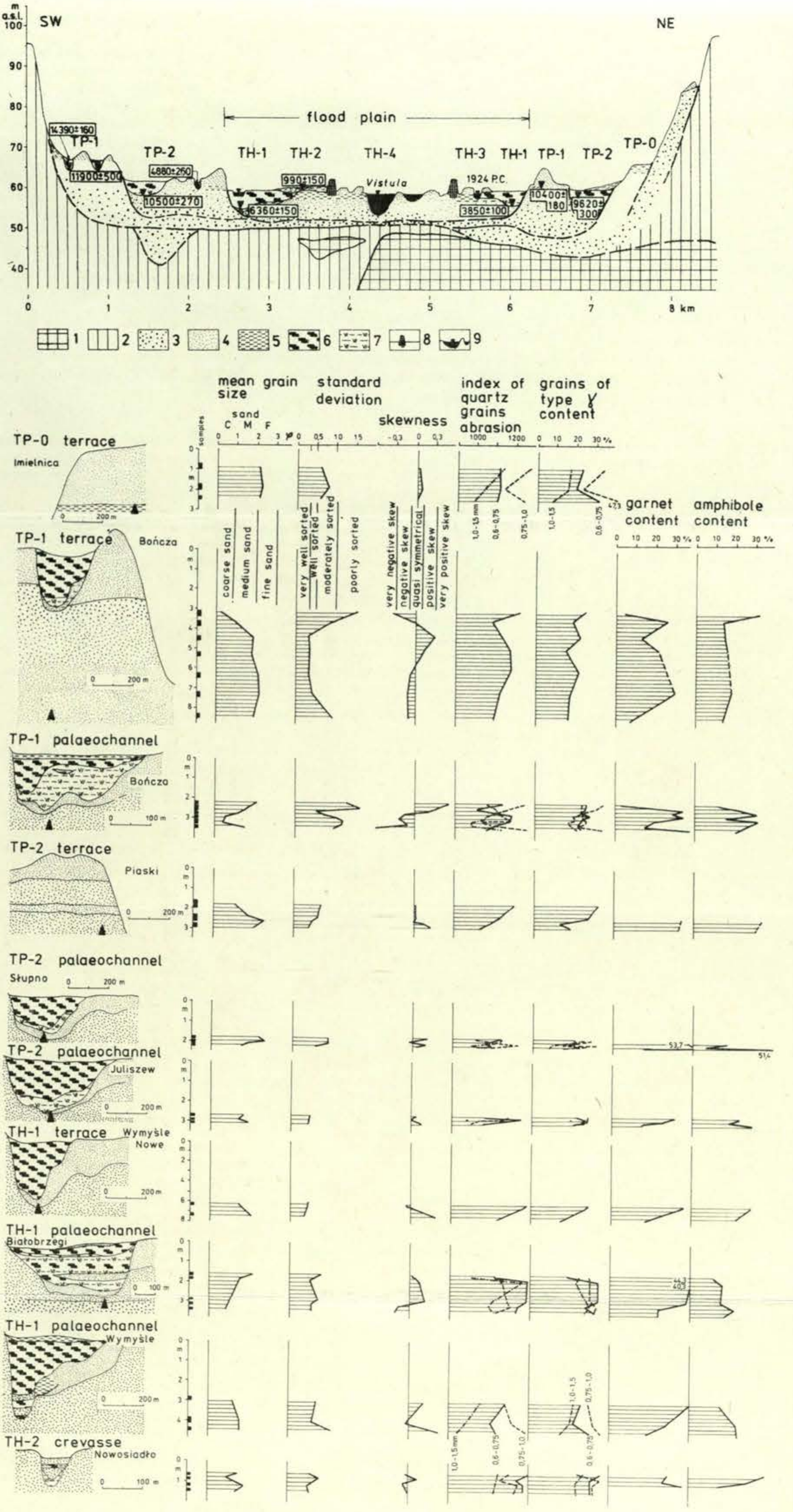


Fig. 5. Synthetic geological section of the fluvial deposits of the studied section of the Vistula valley floor and lithological properties of the mineral deposits of the investigated terrace levels (including those underlaying the dated paleochannels)

1 – Tertiary sediments, unseparated; *2* – Pleistocene sediments, sands; *4* – fine sands; *5* – silts of levees, backswamps, and alluvial fans; *6* – peats filling the channel depressions; *7* – gyttja; *8* – flood-control embankments; *9* – water. Date of 3850 ± 100 BP is of the paper of E. Wiśniewski (in press). The graphs presented illustrate the variability of the statistical measures of the grain size composition: mean grain diameter (M_z), standard deviation (δ_1) and skewness (Sk_1); abrasion of the quartz grains of the fractions of 0.6—0.75 mm, 0.75—1.02 mm, and 1.02—1.5 mm; abrasion coefficient W_a; content of the γ group grains in %; content of garnets and amphibolites in the fraction of 0.1— 0.25 mm terrace TP-2 (Fig. 1). It may be assumed that, in the Late Glacial, the dynamics of the Vistula was that large that the deposits transported into the Vistula valley by the Słupianka river were successively removed. Only the modification in the hydrological regime at the beginning of the Holocene resulted in the change in the balance in favour of deposits transported by the Słupianka river. Its growing alluvial fan had dammed an outflow through one of the channels being possibly one of the Vistula braided channel system. Additionally, the traces of shallow, of the depth 1—1.5 m, straight or braided channels are found within the area of the TP-2 terrace (Borki, Płock-Radziwie). These channels are filled with peat and muds with an admixture of organic remnants. New ^{14}C datings were obtained for the bottom of the abandoned channels just after this text has been written. The results obtained indicate similar age of the forms in question (Borki — 4880 ± 260 BP, Płock-Radziwie — 4560 ± 70 BP). The site in Borki is of particular interest as in its immediate vicinity, although on the hipsometrically lower level, a deeply incised meander bend is located within the area of the Holocene terrace (TH-1); the bend being of a similar formation period (Wymyśle, Piaski--Wąsosz). One may assume that these two channel systems, located on two different hipsometric levels, represent the forms developed by the Vistula in different phases of the flow: the flood water formed the shallow straightened channels, incised into the elder terrace (TP-2), while at low and medium stages the water flew in deep, meandering channels.

In order to find some additional criteria for distinction of alluvial deposits forming the vari-aged terrace surfaces the study of their textural features have been performed (grain size analysis, analysis of quartz grains abrasion of the fractions of 0.6—0.75 mm, 0.75—1.02 mm and 1.02—1.5 mm and heavy minerals analysis in the fraction of 0.1—0.2 mm). The collected data are not fully evaluated yet. Certain general features, repetitively occurring for the deposits of particular terrace surfaces as well as local features are found. The latter ones are usually due to a lateral erosion and supply of extraneous deposits of different properties. In the table (Fig. 5) the profiles of various terrace levels have been chosen in order to characterize both the features distinguishing the particular terraces as well as the local features.

The largest percentage of well rounded quartz grains (γ) in the fraction of 0.75—1.02 mm is one of the most pronounced textural features of the Pleistocene terrace deposits. The mean values calculated of all the analysed samples have shown the following percentages of the γ group within particular fractions: 19.5% for the fraction of 0.6—0.75, 23.6% for 0.75—1.02 mm, 15.6% for 1.02—1.5 mm. It can be stated, when analysing the initial data, that the values related to the left-bank of the Vistula are not differentiated while those related to the Vistula right--bank are both extremely high and extremely low. This is probably related to different sources of deposits: the sandur sands, of rather low abrasion in general, forming the northern edge of the valley and eolian sands which locally had to strongly enrich the alluvial deposits. The fact that the abrasion coefficient of the quartz grains from the fraction of 0.75—1.02 mm is larger than the corresponding value for the fraction of 0.6—0.75 mm indicates a substantial dynamics and power of the winds forming the dunes.

The analysis of the heavy minerals content in the alluvia forming the Pleistocene terraces (Bończa, Piaski) have shown an enormous variability in the percentage of particular minerals, often in the case of the neighbouring series. There is, in general, a lack of indications for the sorting processes, which are usually pronounced by the enrichment in the minerals more resistant to the mechanical abrasion (e.g. garnet) and decrease of amount of the least resistent ones (e.g. amphibolites). This is clearly visible in the paleochannels of Bończa and Slupno (Fig. 5). The only exception for the above principle is the paleochannel in Juliszewo which is probably due to localization of this channel under the southern valley side, thus it could be active for a long period of time and the sorting process could take place here.

HOLOCENE TERRACE

There are 4 segments distinguished within the Holocene terrace: TH-1, TH-2, TH-3 and TH-4. While there is a lack of the altitudinal differentiation, they differ with respect to a relief. The oldest segment of this terrace is a surface with preserved sinuous abandoned river channels (TH-1). The substantial original depths of these channels are indicated by the preserved abandoned channels filled with peats and flood deposits to the depth of ca. 5 m. Then, they are much deeper than the abandoned channels on the elder Pleistocene surfaces. The results of 5 datings by ^{14}C allow for an assumption that the TH-1 surface was formed since the initial phases of the Holocene until the turn of the Sub-Boreal period (Fig. 1). In the Sub-Atlantic period the subsequent change in the hydrological regime caused by an increase in both the flood frequency and in the sediment load took place. The system of meandering channels and, in part, the lower terrace of the Late Glacial were overlain with the flat alluvial fans of the type of the crevasse splays of the braided channel system (TH-2). The ^{14}C analysis, performed for the deposits filling one of the dissections, indicated the age of 990 ± 150 BP (Fig. 1).

The subsequent segment of the Holocene terrace (TH-3) is characterized by the presence of erosional dissections of the braided nature, filled often with water. The historical data and interviews with local inhabitants indicate, that they were formed during various floods in the 20th century. The contemporary forms are overtopping those formed in the earlier stages of the Holocene terrace development (Fig. 3). The elder forms of the bends are often preserved non-dissected due to the filling with silty material.

The youngest segment of the flood plain is composed of interchannel bars and the plain between the river channel and the flood-control embankments. The contemporary flood deposits of the silty-sandy type overlie the alluvial clay (mada) deposits (beeing the river flood deposits at the level TH-1) within the area in question. The influence of the backwater of the Włocławek reservoir is observed within the area of this youngest segment of the Holocene terrace.

The studies of textural properties of the deposits indicated that the homogeneity in the grain size composition is substantially more pronounced in the Holocene deposits when compared with the Pleistocene ones. With respect to the abrasion of quartz grains the larger percentage of the γ group is pronounced in the fraction of 0.6—0.75 mm, what is well illustrated for the deposits filling the abandoned channel in Białobrzegi (Fig. 5). There are only few exceptional cases when the maximum values of the abrasion coefficient are found in the fraction of 0.75—1.02 mm. It is usually the case to the places where the channel undercuts the strongly unified Pleistocene terraces (e.g. the abandoned channels in Wymyśle, Fig. 5) or where the channel eroded the underlaying deposits of the Pleistocene terrace (e.g. the abandoned channel in Nowosiadło, Fig. 5). The larger percentage of the γ group in the fraction of 0.6—0.75 mm is, likely, indicating an intermediate connection to the eolian processes. As it was stated earlier, the dune sands formed in the Holocene have the best rounding of quartz grains of the fraction of 0.6—0.75 mm.

The analysis of the heavy minerals content in the channel deposits within the Holocene terrace indicates that the higher the series the higher the content of the garnet and simultaneously the lower the content of amphibolites (e.g. the abandoned channel deposits in Białobrzegi and in Wymyśle, Fig. 5). This phenomenon indicates the pronounced sorting processes and for multiple reworking of its own alluvia by the river. It is only the ephemeral crevasse channel in Nowosiadło where this phenomenon is not observed (Fig. 5).

The collected results of the heavy mineral content analysis, grain size composition and the abrasion of the quartz grains indicate that the channel deposits of the Holocene terrace (especially those deposited before the active influence of a man — i.e. earlier than the last 1000 years) were accumulated by water of more steady discharge. The pronounced ability for sorting of alluvia was its characteristic feature. The flood deposits of that period are usually heavy madas with a large content of the clay fraction.

E. Florek, W. Florek
High School of Pedagogy
Department of Geography
76-200 Słupsk, ul. Arciszewskiego 22b

E. Mycielska-Dowgiałło
Warsaw University
Institute of Physical Geography Sciences
00-927 Warszawa, ul. Krakowskie Przedmieście 30

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ANNA TOMCZAK

EVOLUTION OF THE VISTULA VALLEY IN THE TORUŃ BASIN IN THE LATE GLACIAL AND HOLOCENE

HISTORY AND ORGANIZATION OF STUDIES

The region of Ciechocinek, located in the SE part of the Toruń Basin, was not a subject of any special studies until the work of Kucharski (1966) despite of the fact that it was presented in some morphological studies (Sonntag 1916; Lencewicz 1923; Galon 1934, 1961; Mrózek 1958). Kucharski presented the course of events in the Quaternary based on the thorough knowledge of the geological structure of 7 terrace levels distinguished in the left-bank part of the Vistula valley in the region of Ciechocinek, correlating them with those described earlier by Galon (1934, 1961) in the lower Vistula valley, and with those in the Toruń Basin described by Mrózek (1958) in his paper on dunes.

The significant progress in the studies of the reach of the Vistula valley in question was brought by papers of Wiśniewski (1976, 1982). The latter presented both the process of forming of the highest levels of melt-water outflow between the basins of Płock and Toruń as well as the development of the Vistula valley. Wiśniewski distinguishes 7 consecutive terraces below the earlier mentioned levels. The avulsion of water from the Płock Basin to the Toruń Basin has been related by Wiśniewski to the terrace level of 72 m a.s.l. (IX). The evolution of the Vistula valley between Włocławek and Ciechocinek is presented in his paper of 1982. The same author assumes that the overflood terrace may be related to the Alleröd, basing this assumption on the datings in the sites located elsewhere (Drozdowski 1974; Andrzejewski 1984). Relating the deepest incision of the Vistula valley to the Yoldia Sea period, Wiśniewski states the depth of 17 m as the deepest deposition of the alluvial series, at the same time he assumes the existence of the fossil Holocene terrace.

The current work is a continuation of the studies on the evolution of the Vistula valley in the Toruń Basin conducted earlier between Toruń and Solec Kujawski (Tomczak 1982). This work is based on the field and laboratory studies, aerial photographs, old topographic maps and archival papers. Additional sedimentological (K. Lankauf) and palynological (B. Noryśkiewicz) analyses have been performed in the Institute of Geography of the Nicolaus Copernicus University in Toruń especially for this study. The absolute age analyses have been performed in the ^{14}C Laboratory in Gliwice.

The collected materials and correlating them with the results obtained earlier by the author for the western part of the basin allowed for a reconstruction of the evolution of the Vistula valley at the turn of the Pleistocene and in the Holocene in the entire Toruń Basin. It allowed also for correlating the references about an age of the terraces with the opinions expressed in the papers dealing with the other parts of the Vistula valley and with the valleys adjacent to it (Galon 1934, 1953, 1961, 1968; Roszko 1968; Drozdowski, Berglund 1976; Niewiarowski, Noryśkiewicz 1983; Andrzejewski 1984).

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

LOCATION OF THE SECTION IN THE DRAINAGE BASIN

The studied section of the Vistula valley (Fig. 1A) between the outlets of right tributaries — the Mienia and Drwęca rivers — is of the length of 25 km and extends over the SE part of the Toruń Basin. Only the Tążyna river debouches into the Vistula on the left-hand side. The water divide between the catchments of the Vistula and Odra rivers is passing just 26 km to the SW of Ciechocinek. The river, between Płock and Fordon, flows along the eastern flank of the Kujawy-Pomeranian Anticlinorium and reacts to the upheaval of its Mesozoic structures which occur not deeply, occasionally only between 10—20 m below the surface.

The Vistula channel drains the area of 173 420 km^2 up to the profile of Nieszawa, and of 180 580 km^2 at that in Toruń (according to the Hydrological Annual Records).

VALLEY FLOOR

The valley floor, including the channel, is of the width of 1.3 km between Bobrowniki and Nieszawa where the valley is narrow (Fig. 3). The valley floor gradually widens northward to 5.5 km in the vicinity of Ciechocinek, and further, at the Drwęca outlet its width is of 2.6—3.0 km. The flood plain forms a continuous bench of a very variable width on both sides of the river, while the overflood terrace occurs exclusively on the right-hand side of the Vistula out of the region of Ciechocinek.

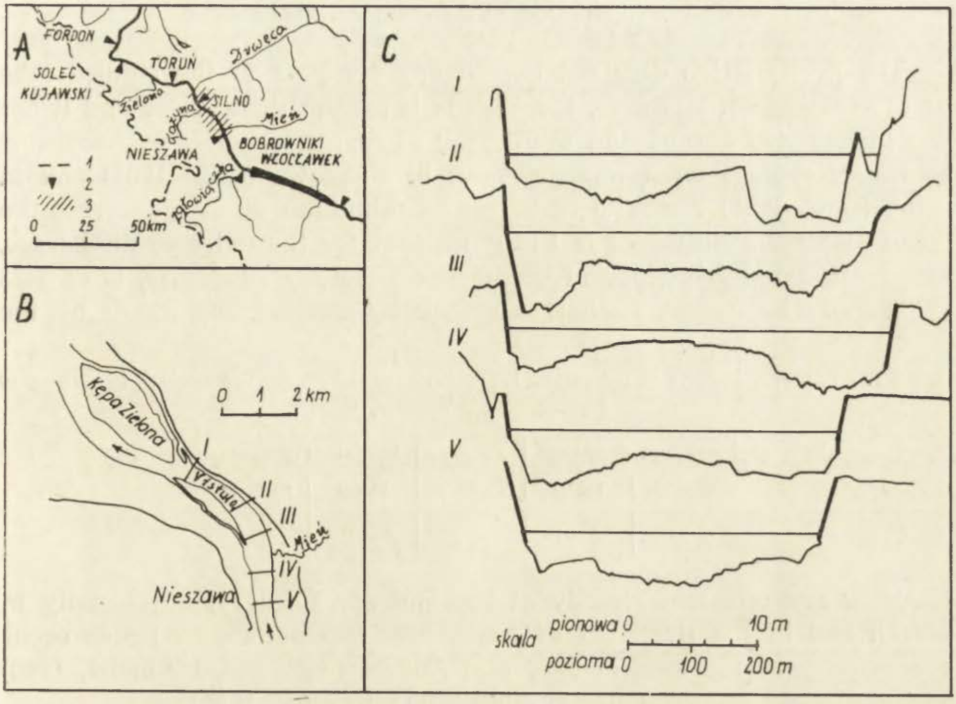


Fig. 1. Location of the study area (*A*), of the probe profile (*B*) and cross-sections of the Vistula channel (*C*) according to the soundings by "Hydroprojekt" in Włocławek on 13 September 1978

1 — water divide between the Vistula and Odra drainage basins; 2 — water level gauges; 3 — study area

PROFILES AND PARAMETERS OF THE PRESENT-DAY CHANNEL

The Vistula channel is only partly straightened with the groynes up to the Tążyna outlet and is of the width of 420 to 900 m, while further, up to the mouth of the Vistula at Baltic Sea, it is regulated to the constant width of 350 m. Down of the valley narrowing at Nieszawa, the channel is divided into arms which are separated by 3 large holms: Kozia Kępa (61 ha), Zielona Kępa (323 ha) and Dzikowska Kępa (207 ha) (Koc 1975) which are stabilized in the channel. The main trunk is 500—600 m wide and the lateral arms are of 25—125 m, in this reach.

The channel profile, according to the sounding on the 13th of September, 1978 (Fig. 1C) between Zielona Kępa and Nieszawa, exhibits 2 marginal troughs separated with a convex bar. The stream current is shifting from one to the other bank over the length of the regulated section.

The forms of convex sandy bars intensively migrate in the channel. The sediment movement is intensified since 1969 due to the influence of the water dam in Włocławek (Babiński 1984).

The gradient of the Vistula between Nieszawa and Toruń is of 0.172‰.

SOME PROPERTIES OF THE HYDROLOGICAL REGIME

The precipitation does not exceed 500 mm/year in the studied area of the catchment. However, the Vistula is a transitional river and it has the pronounced annual and multi-year discharge amplitudes. According to the recordings on 2 water gauges: in Nieszawa (since 1901) and in Silno (since 1905) the ratio of the mean minimum discharge versus the mean maximum discharge is 1 : 13 and that for the extreme discharges, of an estimated frequence of occurrence once per 100 years, is of 1:33 (Table 1). The largest discharges caused by melting, sometimes by the

Table 1. Discharges in m^3/s in the period 1951—1970 for the profile Ciechocinek (according to „Hydroprojekt" Warsaw, 1978)

Maximum discharge		Average discharge	Minimum discharge	
extreme	mean		mean	extreme
6900	4060	930	313	209

ice-jams are recorded already at the end of February, but usually in March and in the first half of April. The maximum rain floods occur sporadically at the turn of July and August (e.g. on 3rd August, 1960) and absolutely exceptionally in June (e.g. 11th June, 1962).

HYDROLOGICAL AND GEOMORPHOLOGICAL CHANGES

The Vistula valley in the vicinity of Ciechocinek was not subject to a human impact. The channel of a very irregular bankline, with numerous holms was of the braided, aggrading river (Fig. 2). Changes due to the human impact occurred differently up- and downstream of the Tążyna outlet. Downstream, the river management practices initiated after 1856 lasted until the beginning of the 20th century, being the most intensive in the years 1880—1901. The construction of groynes resulted in straightening of the channel, eradication of holms, majority of which extended the surface of the flood plain (Babiński 1984). Many abandoned channels subject to eutrophization have been created. Upstream of the Tążyna river the Vistula remained, up-to-date, almost natural. The banks downstream of Nieszawa have been partly straightened due to a construction of the up-current groynes at the beginning of the 20th century, what was done in order to diminish the sediment load supply to the regulated part of the channel (Koc 1975). Other groynes were constructed in the years 1948—1949, in the reach between Warsaw and Ciechocinek after the catastrophic flood in 1947.

The flood plain is rather narrow here and did not need protection against flooding and only the valley floor in the immediate vicinity of Ciechocinek is protected with the flood-control embankment since 1872.

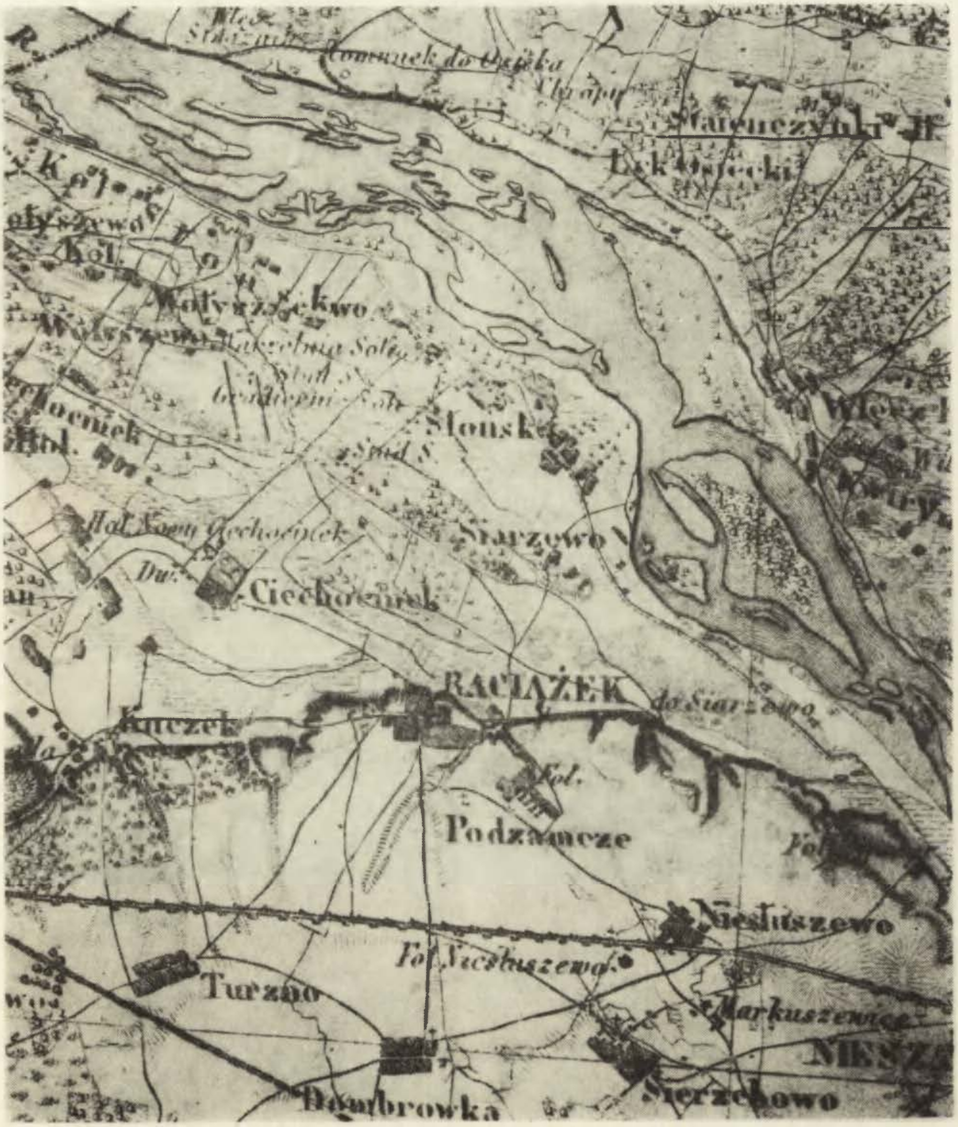


Fig. 2. Vistula valley in the region of Ciechocinek on the topographic map of 1839—1843 (state of the channel of 1822—1827)

PROBLEM OF THE NUMBER OF TERRACES IN THE TORUŃ BASIN AND THEIR GENERAL CHARACTERISTICS

After the studies of Galon (1934, 1953, 1961, 1968) the system of 11 terrace levels (including 9 pradolina and valley terraces) has been commonly accepted. All other authors (Mrózek 1958; Tomczak 1965; Kucharski 1966; Niewiarowski 1968; Niewiarowski, Tomczak 1969; Wiśniewski 1976, 1982) referred to this scheme. However, every author defined somewhat differently the heights and courses of the terrace edges. An attempt has been made in this paper to study thoroughly the terraces in the basin again. Assuming the pronounced edge as a base for distinguishing a level, all the inflections have been found and this way, omitting only the highest (above 73 m a.s.l.) — only 5 terraces have been distinguished in the Toruń Basin (Table 2; Fig. 3). Thus, a conclusion may be

Table 2. Terraces in the Toruń Basin

Region	Mean Vistula level	Terraces				
		I	III	IV	VI	IX
Solec Kuj.	30	32–33 (2–3)	35–39 (5–9)	45–46 (15–16)	51–54 (21–24)	70 (40)
Toruń	35	37–38 (2–3)	–	46 (11)	53–57 (18–22)	70–72 (35–37)
Silno	37	40 (3)	43–44 (6–7)	48–54 (11–17)	–	70 (33)
Ciechocinek	39	42–43 (3–4)	46 (7)	53–57 (14–17)	61 (22)	72–71 (32–33)
Nieszawa	49	44–45 (3–4)	47–48 (6–7)	55–57 (14–16)	67 (26)	73–71 (32–30)

Altitudes are in m a.s.l. Relative heights are given in parentheses

drawn that only the strongest impulses have been morphologically reflected here and that they indicate the major phases of the valley evolution. This does not eliminate the occurrence of the remaining terrace levels in the lower part of the Vistula valley. Each of the terraces is characterized by the differentiating geomorphological features like: an extent, a longitudinal and cross gradient, character of a slope, type of lateral valley and fans entering the given terrace, size and shape of the dunes occurring at the surface and, finally, the presence or lack of the relief of former channels and holms. These features indicate the different hydrological conditions of formation of the consecutive terraces.

The terrace IX is preserved in large fragments, in the entire valley on both sides of the Vistula and over all its length, it is characterized by the lack of a pronounced incision. Its size — the width changing from 7—8 km in the valley narrowing at Nieszawa to 18 km in the basin — as well as the lack of any traces of fluvial forms all over its surface indicate that its primeval surface has been formed by a non-linear outflow but rather by a surface runoff under the conditions of abundance of water and the presence of permafrost in the substratum. This terrace is of a character of an indicator level, what results from the fact that in the level of the terrace IX (Wiśniewski 1976) the water outflow from the Płock Basin to the Toruń Basin has been initiated. The water from the Toruń Basin directed itself to the west, to the Noteć-Warta ice-marginal valley (pradolina).

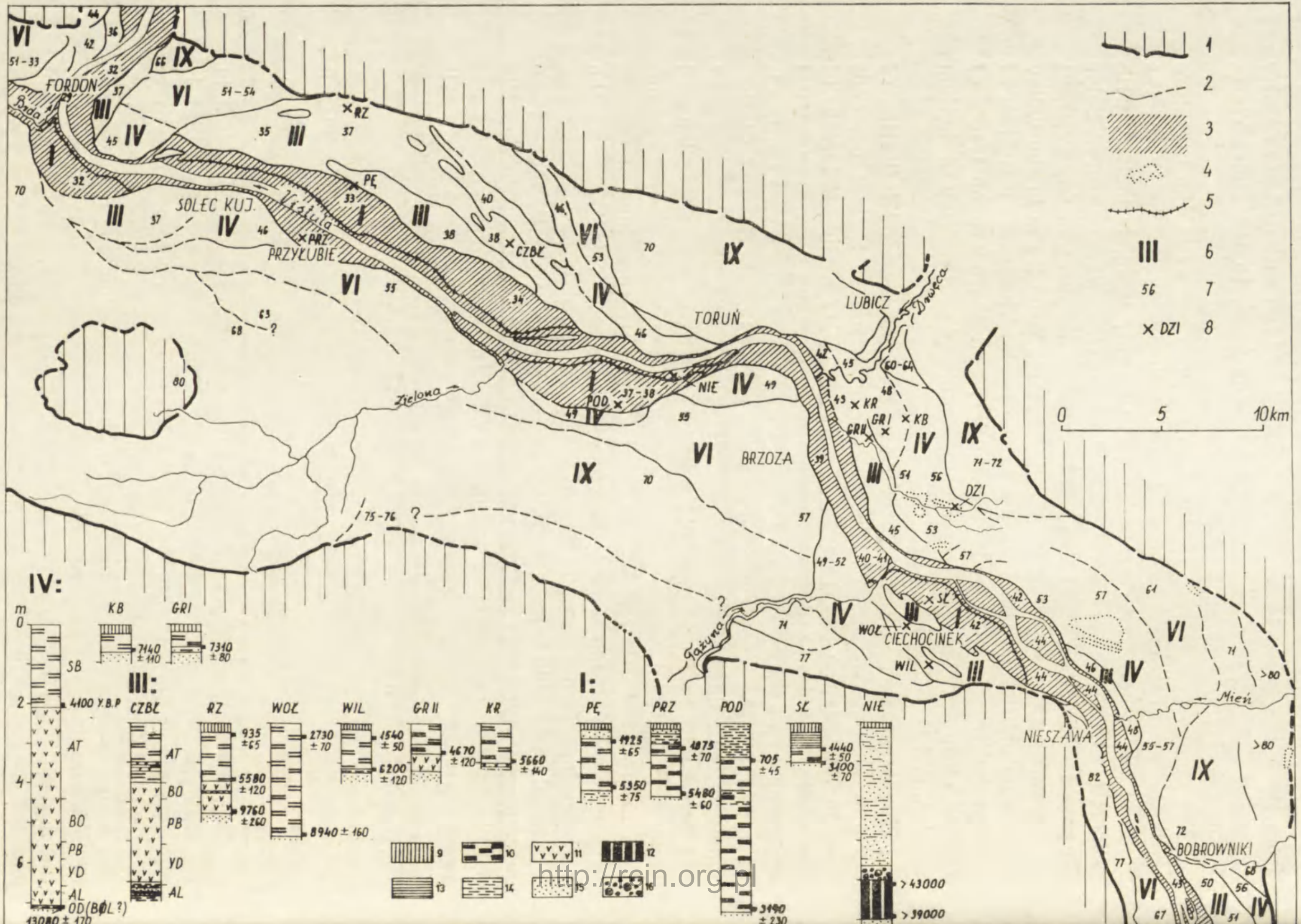
The consecutive terrace (denoted as the number VI in the literature until the present), corresponding hypsometrically to the height of the floor of the Noteć-Warta pradolina (Galon 1961, 1968), is incised, with respect to the IX terrace level, from 6 m at Nieszawa to 19 m at Solec Kujawski. This 13 m level descend is close to the present-day gradient of the valley floor. The terrace width increases from 2 km in the valley narrowing at Nieszawa to 7—8 km in the Basin. The upper inflection of a slope indicates a gently sinuous outline, and there are no traces of former channels. These features indicate a rather pronounced bottom erosion, and then the lateral one.

The terrace IV, limited from the top by a pronounced inflection of a slope, exhibits a rather large cross-inclination (the surface descends 6—7 m towards the river) and is of a character of a slip-off terrace of the width 6—8 km and 1.8—3.0 km in the narrows only. The spatial arrangement of the terrace IV indicates that the river formed the bends of large radii (the best developed one is preserved to the west of Ciechocinek on both sides of the Tążyna river). The morphological features of the terrace IV indicate an initial action of a strong lateral erosion and channel migration and then the lowering of the valley floor by about 6—7 m. This is the lowest terrace level of the surface lacking any traces of the former channels, and the course of the upper inflection of the terrace slope is not parallel to the present-day river course. The age of the plain of this terrace (Bölling) is indicated by the datings of the organogenic deposits filling the meltwater basin at Dzikowo (the deposits 7.18 m thick have been found; Fig. 3 IV DZI). Other more shallow depressions on its surface are, in some places, covered with a peaty soil (Kopanińskie Bagno; Fig. 3 IV KB; Grabówiec Fig. 3 IV GR I; Wilcze Kąty and Kwirynowo to the NE of Nieszawa).

CHARACTERISTICS OF FORMS AND DEPOSITS ON THE VALLEY FLOOR

MORPHOLOGY OF VALLEY FLOOR

The lowest two terraces: the overflood one (III) and the flood plain (I) may be assumed as being the valley floor because their relief is substantially different from that of the higher levels. The overflood terrace, elevated 6—9 m above the mean Vistula level, is separated from the higher terrace step by a distinct 4—5 m inflection, the linear course of which indicates a propensity to a rather concentrated river outflow, and consequently to the narrowing of the valley floor. The pronounced braided development of the channel of that time is evidenced by for-


FORDON
Brda
SOLEC KUJ.
Vistula
PRZYŁUBIE
TORUŃ
LUBICZ
Drwęca
Zielona
BRZOZA
DZI
Tążyna
CIECHOCINEK
NIESZAWA
Mień
BOBROWNIKI
RZ
PĘ
PRZ
CZBŁ
NIE
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III 6
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IV:
m
KB
GRI
SB
AT
BO
PB
YD
AL
OD (BØL?)
4100 Y.B.P
7140 ± 110
7310 ± 80
13080 ± 170
III:
CZBŁ
RZ
WOŁ
WIL
GR II
KR
935 ± 65
5580 ± 120
9760 ± 260
2730 ± 70
8940 ± 160
1540 ± 50
6200 ± 120
4670 ± 120
5660 ± 140
I:
PĘ
PRZ
POD
SŁ
NIE
1925 ± 65
5350 ± 75
1875 ± 70
5480 ± 60
705 ± 45
3490 ± 230
1440 ± 50
3400 ± 70
> 43000
> 39000
9
10
11
12
13
14
15
16

mer channels of various widths mid-channel bars and holms accreted in the top part by small elongated dune hills. The fluvial forms are best developed on the so-called Ciechocinek Lowland where, besides the peaty bottoms of the former channels (43 m a.s.l.) are preserved the former river islands: Woluszewska Kępa and Siarzewska Kępa, both of the height of 47 m a.s.l., thus being located 4 m higher. This was the reason why, sometimes, two terrace levels have been distinguished within this level (Kucharski 1966; Wiśniewski 1976, 1982).

The widths of the former channels are usually of 200—400 m and 500—700 m in the places of junctions of several arms, the most narrow of these arms are of the widths of merely some tens of meters. The characteristic hills — being the former mid-channel bars — are pronounced in the cross-profiles of the former channels. The overdeepened areas filled usually with peat of maximum thickness of 3.8 m and in most cases 1—2 m occur between these hills (Fig. 4A and 4B). The parameters of the fossil channels (width, depth, bottom relief) are close to those of the present-day Vistula channel at Ciechocinek and the morphology of the terrace surface III indicates a braided pattern of the channel development similar to that shown in the oldest detail map of 1820s (Fig. 2). The terrace III at Ciechocinek is developed analogically to the Vistula valley below Toruń (Tomczak 1982).

Also the flood plain morphology indicates the braided channel pattern. The former channels (located at 40 m a.s.l. in the vicinity of Ciechocinek) and the mid-channel bars (42—43 m a.s.l.), occurring there as well exhibit, however, smaller denivelations and their outline is not underlined by inflections. The channels are narrow about 200 m wide and only up to 1 m deep. The largest elevations to 44.5 m a.s.l. are found in the vicinity of a natural levee.

Denivelations reach up to 5 m on the surface of the holms currently located in the Vistula channel: Kozia Kępa, Zielona Kępa, and Dzikowska Kępa (Fig. 5) and the forms there, shaped by various water stages, indicate a gradual accretion, emerging and stabilization of holms. The diversity of the relief is maximum in those places of the flood plain

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Fig. 3. Terrace levels in the Toruń Basin and location of the dated sites and their geological profiles with the age determined palynologically and by radiocarbon method

1 — plateau edge; *2* — edges of terraces; *3* — flood-plain; *4* — meltwater basins; *5* — flood-control embankments; *6* — numbers of terraces; *7* — elevations a.s.l.; *8* — dated sites. Abbreviations of the dated sites: *Dzi* — Dzikowo; *KB* — Kopańskie Bagno; *Gr I* — Grabowiec I; *CzBł* — Czarne Błota; *Rz* — Rzęczkowo; *Woł* — Wołuszewo; *Wil* — Wilkowyje; *Gr II* — Grabowiec II; *Kr* — Krusz; *Pę* — Pędzewo; *Prz* — Przyłubie; *Pod* — Podgórz; *Sł* — Słońsk; *Nie* — Nieszawa. Explanations to lithological signs for geological profiles: *9* — mada; *10* — peat; *11* — gyttja; *12* — brown coal; *13* — clayey silt; *14* — silt; *15* — sand; *16* — gravel and pebbles

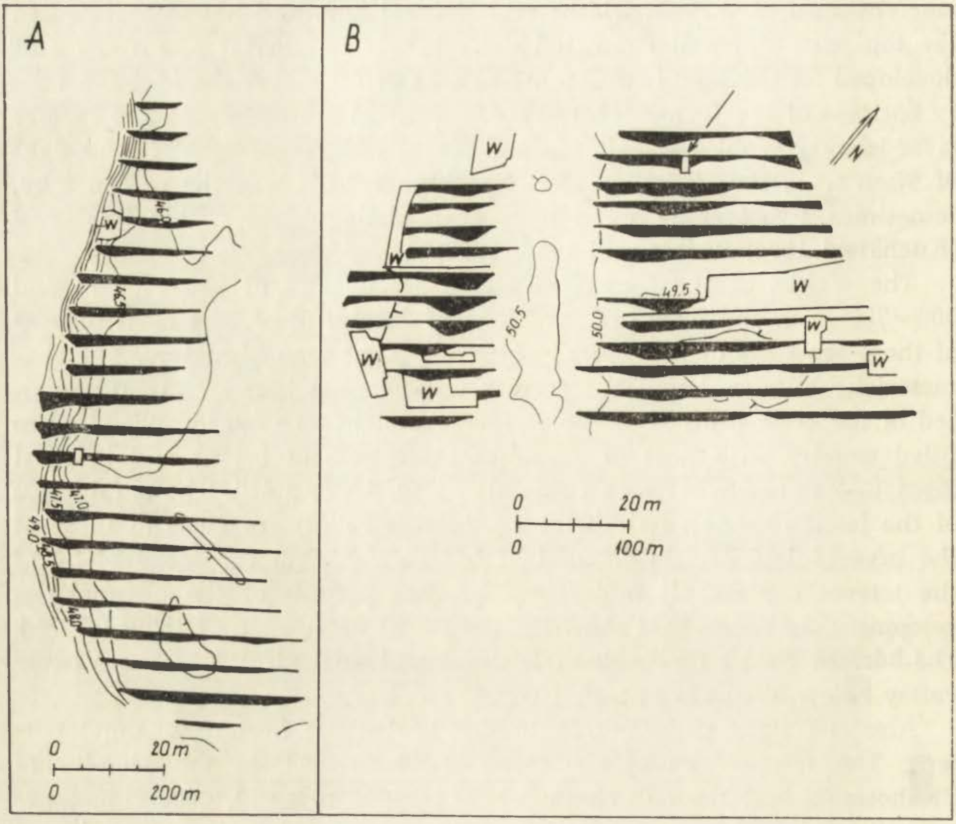


Fig. 4. Peat fills of the former channels on the flood-plain: *A* — Wilkowyje, *B* — Wołuszewo. Location of the areas *A* and *B* in Fig. 5 (Śmieciszewski 1954)

where, due to channel management practicies, all the holms and mid--channel bars detached from the channel became a part of the flood plain.

Characteristics of the alluvial series of the flood plain. The alluvial series filling the lowest floor of the present-day Vistula valley (Fig. 6) has been distinguished based on the analysis of several outcrops and a few hundred drilling profiles supplemented with the grain-size analyses. The depth of the first erosional level has been assumed to be the lower face of this series, the former being indicated by either the pavement or by a layer with a larger amount of the coarse material. The erosional pavement usually occurs on the sandy Pleistocene deposits. The bottom of the alluvial series does not descend below 28 m a.s.l. and in many places is located higher, maximum 39 m a.s.l., what evidences the 11 m denivelations of the erosional bottom in the flood plain substratum. The erosional pavement lies directly

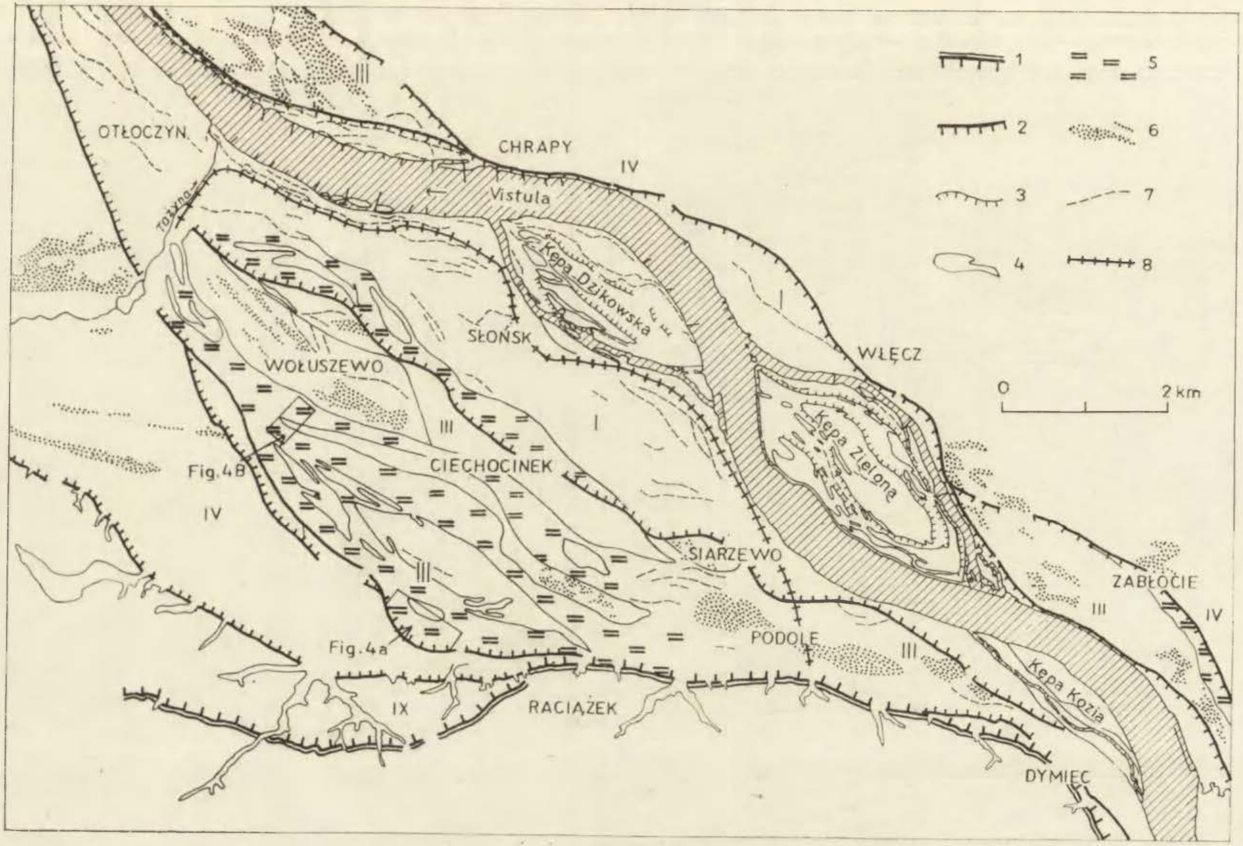


Fig. 5. Fluvial relief of the valley bottom in the region of Ciechocinek

1 — plateau edge; *2* — edges of terraces; *3* — secondary inflections; *4* — holms and mid-channel bars; *5* — bottoms of the former outflow routes; *6* — dunes; *7* — paleochannels; *8* — flood-control embankments

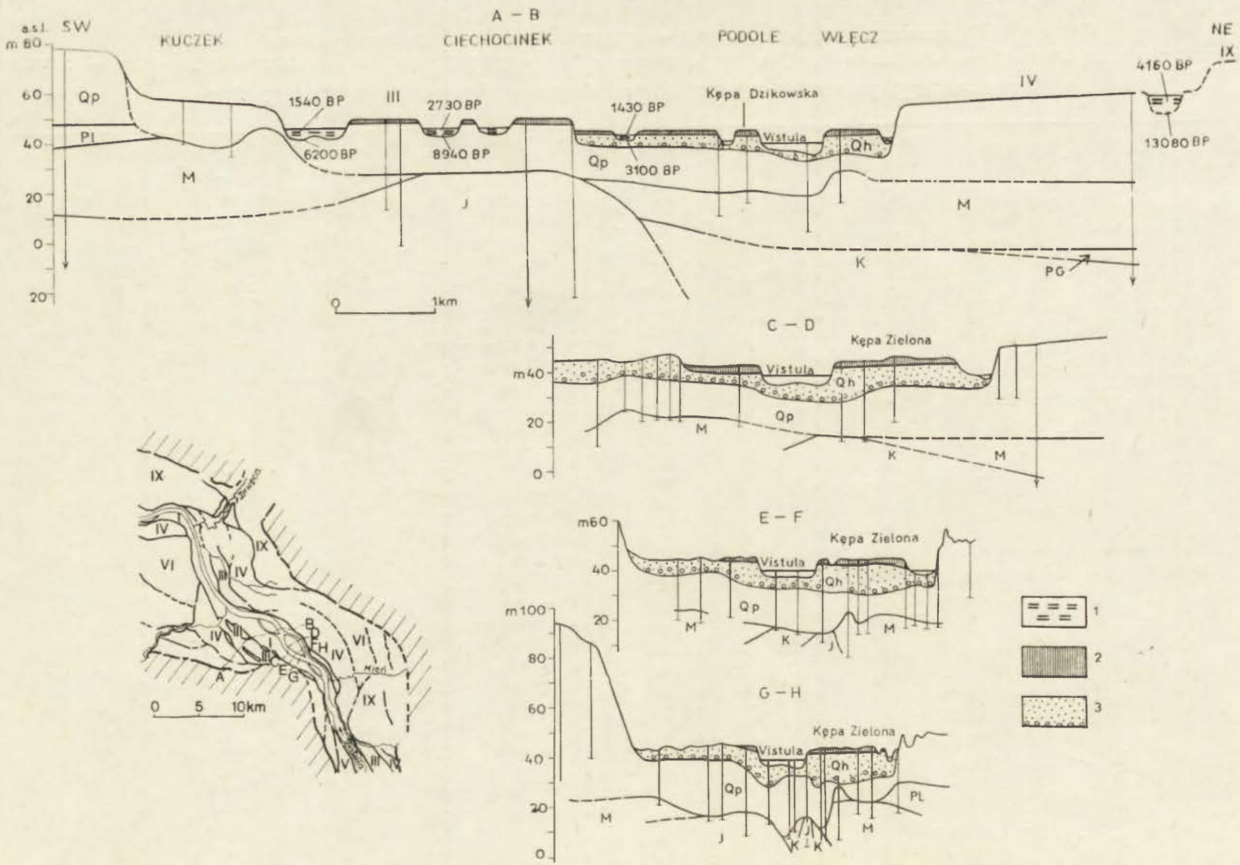


Fig. 6. Geological profiles of the Vistula valley floor in the region of Ciechocinek and their location

1 — peat; 2 — mada; 3 — sand and gravel; *J* — Jurassic; *K* — Cretaceous; *PG* — Paleogene; *M* — Miocene; *PL* — Pliocene; *Qp* — Pleistocene; *Qh* — Holocene. Arabic numbers denote ^{14}C dates and Roman numbers denote terraces on the cross-section A—B

on the Tertiary clays at the height of 31—34 m a.s.l., what has been confirmed by drillings in the narrow part of the valley at Nieszawa.

The thickness of the alluvial series is usually 10—12 m, however, it reaches up to 15—16 m in the places of the deepest incision (similar values were given by Wiśniewski 1982) while in the places where the bottom of the series occurs relatively high the series thickness does not exceed 3—4 m. The largest thickness of the alluvial deposits is found in the NE part of the valley and it is where the erosional bottom occurs at the lowest depth. The above may indicate that the channel of that time eroded, similarly as nowadays, in the vicinity of the right bank.

The entire alluvial series being evidently of the Holocene age consists of 4 members: a pavement, sand with an admixture of gravel, organogenic deposits and of a mada cover.

The erosional pavement consists of the pebbles of crystalline rocks and limestones of the diameter from a few to over 30 cm and of 42—61% of gravel.

The well washed deposit consisting in 70—98% of a sand fraction with an admixture of gravels and pebbles forms the substantial part of the alluvial series. These admixtures happen to occur most often in the substratum of the present-day valley axis, frequently as irregular intercalations, the latter being the result of the prolonged reworking of the alluvia in the channel.

The peat inserts occur in the flood plain series. Their thickness is small due to the fact that an intensive accumulation took place in the channel which was wide but shallow. Thus, there were no conditions for a forming of deep lateral arms where the peat could have been accumulated.

Peats occur only under the mada cover what evidences a change of sedimentation conditions. In the case of the Słońsk profile (Fig. 3, I SŁ) peat has been found in the shallow arm of the former channel over the silty-sandy deposits and under the cover of clay muds of the thickness of 0.6 m. The datings obtained for both the lower and the upper face of 0.4 m thick peat layer determine its accumulation time for the period between 3100—1440 BP. The first date is close to the earlier obtained one for the analogically situated profile Podgórz in Toruń (Fig. 3, I POD), and the second date indicates the earlier beginning of the accumulation of madas (the corresponding date for Podgórz is 705 BP).

The peat occurs also in the vicinity of Siarzewo, where it was found and described by Wiśniewski (1976). The thickness of the peat is here of 1.3 m. Moreover, the peat is covered with the 4.22 thick glacilacustrine deposit series, and higher with the sands of the levee. The age of this peat has been determined palynologically to be of the Atlantic and Sub--Boreal periods. The lower face of this peat is laying only 2.5 m lower than the present-day mean Vistula level. Thus, it may be assumed that the peat fills a rather shallow arm of the same, continually aggrading channel which has formed the present-day flood plain. Undoubtedly, this channel was incised deeper at that time, relatively stabilized, and at least to the beginning of the Sub-Atlantic it was not susceptible to floods. This is evidenced by the quoted above datings of Słońsk as well as those of the beginning of the flood sedimentation of Pędzewo and Przyłubie (Fig. 3, and 8) and by the numerous archeological sites (of the Funnel Beaker Culture and of the Lusatian Culture) situated just at the bank of the Vistula and known also from Siarzewo (Cwetsch 1978). This interpretation is different from that of Wiśniewski who assumes the peat from Siarzewo to be the evidence of the fossil terrace.

The mada cover occurs in the upper face of the entire surface of the flood plain. Silty madas occur below while upward they are more differentiated with respect to the grain size composition what is related to a surface topography and a distance from the channel. Clay madas are deposited in depressions while the sandy ones in the higher locations. Under natural conditions, with an increase of the relative altitude of a surface the fraction increases and the thickness decreases in the accreting layers while within the flood-control embankments particular intercalations are definitely thicker what is due to the post-channelization narrowing of the flooded area.

Geological structure of the overflood terrace. The structure of the overflood terrace is known from numerous drillings and mainly from the outcrops, among the others, in the gravel pit close to Wołuszewo and Siarzewo. The sediment forming the edge of this terrace has no connection with the accumulation of the present-day Vistula valley. The coarse material prevails being very strongly weathered and poorly rounded, often with sharp edges due to the secondary cracking, with stony-gravel intercalations, where the boulders of several tens of meters are found. The material originates from igneous and metamorphic rocks and includes also the pebbles of limestones and the silicified fossils, a relatively large contents of the black and yellowish coloured flintstones as well as clay-balls and mud-balls. The deposit of this type occurs down to the depth of 20—30 m and overlies the erosional surface which cuts the Miocene formations underlaying in the substratum as well as the outcrops of the anticlinal Jurassic and Cretaceous structures (Fig. 6, A-B).

The geological situation suggests that in the line of the present-day Vistula valley the river outflow and erosion related to it supposedly a multiple one, took place before the Last Glaciation already. The erosion reached the Quaternary substratum while the material occurring in the overflood terrace substratum originates from the dissection of the local Jurassic, Cretaceous and Tertiary deposits, and also from the washing-away of the elder Pleistocene sediments deposited here earlier. The present-day Vistula cut its overflood terrace in the developed this way substratum in the Older Dryas. Deposits at the surface of this terrace were subject to the frost weathering under periglacial conditions after the terrace had been formed what is indicated by strongly weathered pebbles *in situ*. Silts and very fine sands of a poor lamination with ferruginous strips, of the thickness of 2—3 m, occur in the uppermost fragments of the terrace. This is mada cover of the period when the Vistula functioned in this terrace level with eolian reworking fragmentary or accreted with dunes of the Younger Dryas period. The age of the dunes is evidenced by the site of the Swider Culture of the turn of the Paleolithic (Prinke 1975) found in Woluszewo.

Peat filling the channel branches of the maximum depths of 3.0 m at Woluszewo and of 3.6 m in the Wilkowyje peatland (Fig. 4A and 4B) occurs at the surface of the overflood terrace. Peat overlies directly the mineral deposits, often the coarse ones, and only in the SE part of the peatland Wilkowyje the 35 cm layer of a silty-gyttja has been found. This is a sedge-reed peat with macro-residues of alders, horsetails and reed-mace. The palynological study of the lower face of the peat from Woluszewo of the depth of 2.3 m has indicated that the beginning of its accumulation is of the late Pre-Boreal period and the ^{14}C dating for the lower face of the peat of another profile of the depth of 2.78—2.83 m indicates a similar age, namely 8940 ± 160 years BP. The date for the upper face at the depth of 0.25—0.30 m is of 2730 ± ± 70 years BP (Fig. 3, III WOŁ).

The sample of the peat from the Wilkowyje peatland, taken from the lower face from the depth of 1.15—1.20 m has been dated as of 6200 ± 150 years BP. It is possible that this peatland might have a slightly different history as it is profusely alimentated by ground water from the adjacent slope of the terrace IV. The date for the upper face, from the depth of 0.30—0.35 cm is of 1540 ± 50 years BP (Fig. 3, III WIL).

FOUNDATIONS OF THE ABSOLUTE AND RELATIVE CHRONOLOGIES

Twenty-three datings by the ^{14}C method of the organogenic deposits of the lower (IV, III, I) terraces in the Toruń Basin (Fig. 3) served, in the first place, for establishing the chronology of events. Twelve dates out of those are related to 8 sites in the Ciechocinek region and the remaining 11 dates to 5 sites in the Vistula valley between Toruń and Solec Kujawski (Tomczak 1982).

The pollen diagrams of 2 sites: Czarne Błota located in the western part of the basin (Tomczak 1982; Niewiarowski Noryśkiewicz 1983) and Dzikowo in the eastern part were the essential base for establishing the age of the deposits. The diagram of Czarne Błota is undoubtedly the evidence of the Alleröd age of the deposits filling the former channels, and possibly the meltwater basin in the terrace III. An interpretation of the Dzikowo diagram of the meltwater basin on the terrace IV is more difficult as the age of the lower face of the deposits is of 13 080 ± ± 120 BP (the beginning of the Bölling) when determined by the ^{14}C method what, in turn, is not supported by the palynological analysis (Fig. 7). The small admixtures of the redeposited material have been stated in the lowest part of the diagram what could result in an elder ^{14}C dating. However, there is a change of the climatic conditions to the colder ones indicated in the diagram for the deposits below those of being definitely of the Alleröd period what might indicate the end of the Older Dryas. Then, it was finally assumed that the bottom part of the organogenic deposits of this meltwater basin is younger than the Bölling.

Also the archeological sites have contributed to the chronology determination. The oldest of those, of the turn of the Paleolithic period (Świder culture), is known from the terrace III at the vicinity of Wołuszewo (Prinke 1975). There are no definite Mesolithic sites in the Toruń Basin, however, there are numerous sites of the Neolithic and younger cultures as the Funnel Beaker Culture, the Lusatian and Przeworsk Cultures (Cwetsch 1978). Some of these sites, located close to the Vistula channel (Siarzewo, Podgórz, Nieszawka, Stary Toruń) are good indicators of an extent of floods and of vertical changes of the river channel bottom.

The mutual relation of particular forms and deposits, all the data related to their absolute age as well as the status of recognition of both the stages of the last deglaciation of the northern Poland and the stages of the South Baltic development (Kępińska *et al.* 1979) have been also taken into account when determining the chronology of events.

EVOLUTION OF THE ENVIRONMENT AND VALLEY DEVELOPMENT DUE TO CLIMATIC CHANGES AND HUMAN IMPACT

PALEOGRAPHICAL BACKGROUND

The Vistula flows in the Toruń Basin in the valley cut down to 40—50 m into the surface of the surrounding plateaus formed during the recession of the Baltic ice-sheet of the Poznań stage (18 400 years BP) and the Chodzież-Kujawy one (about 17 200 years BP, Kozarski in press). An outflow along the present-day route was not formed in one instant. The beginning of the outflow in this part of the lowland is indicated by the meltwater erosional levels at the heights of: 88—89 m, 80—84 m and 78 m a.s.l. (Wiśniewski 1976). The present-day Toruń Basin was formed as a widening in the eastern end of the Noteć-Warta pra-

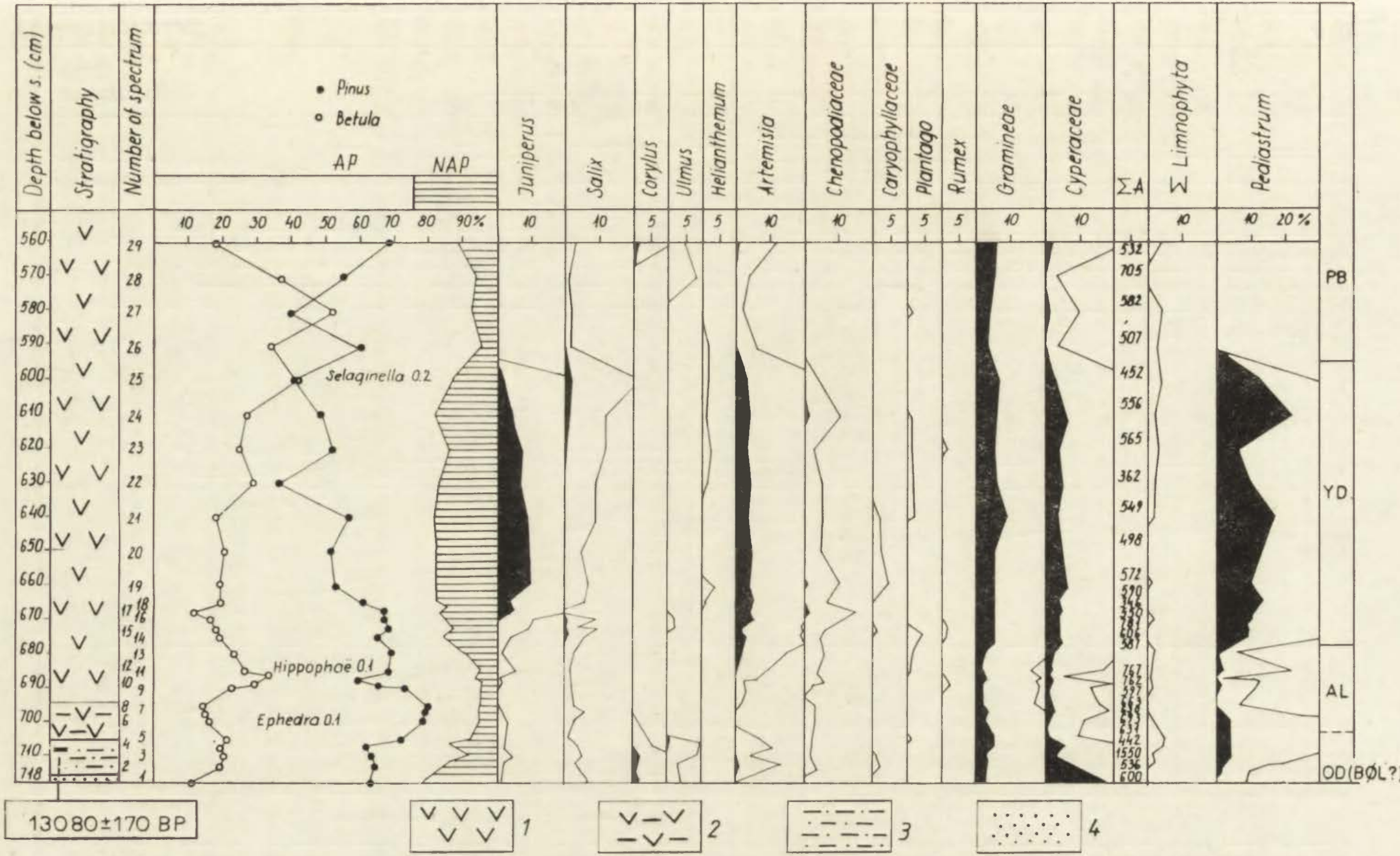
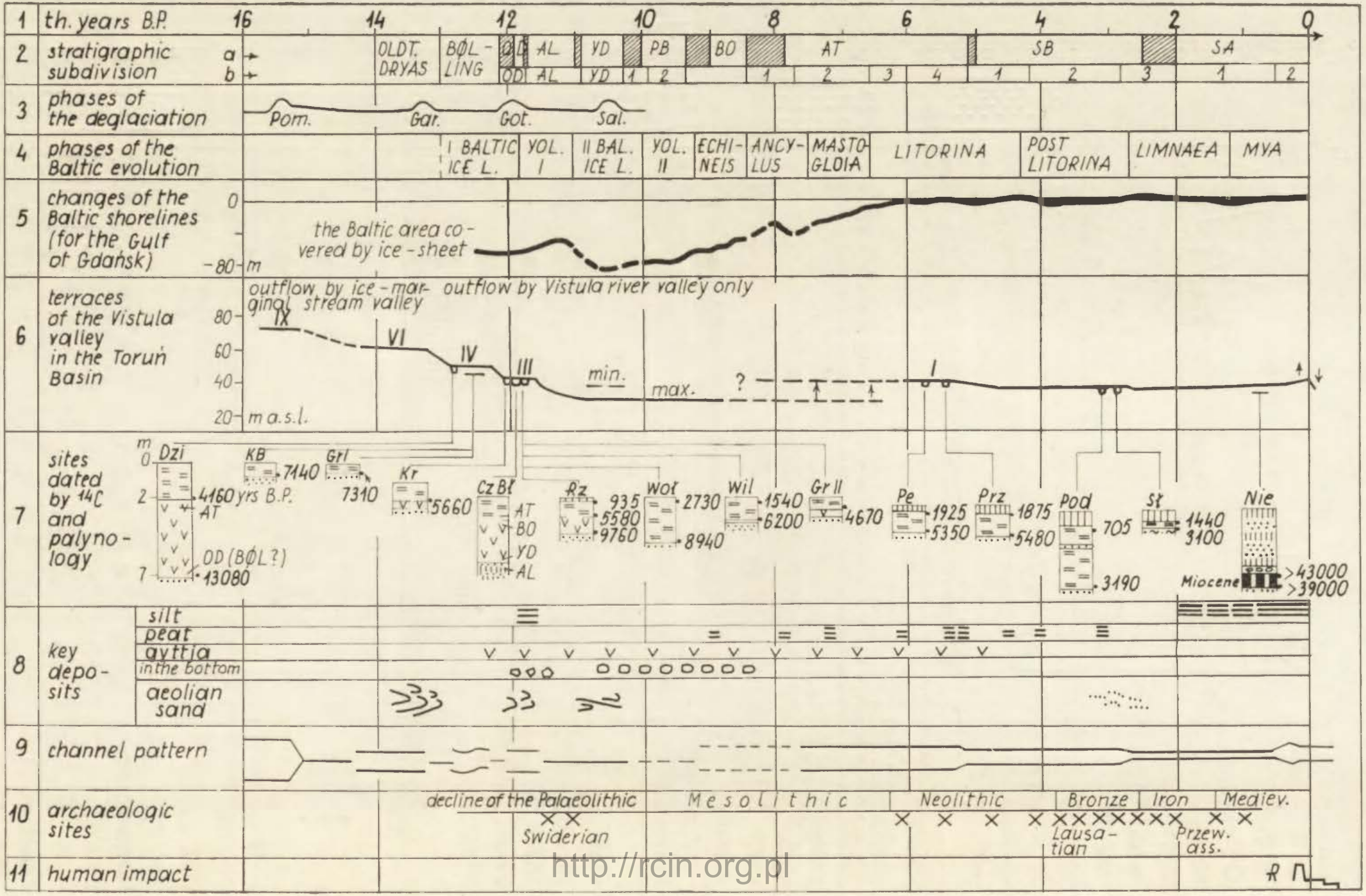


Fig. 7. Shortened and simplified pollen diagram of the bottom part of the meltwater basin in Dzikowo (elaborated by Noryskiewicz)

1 — dark gray gyttja; *2* — black gyttja with abundant organic matter; *3* — silt with organic detritus; *4* — fine sand


1 th. years B.P. 16 14 12 10 8 6 4 2 0
2 stratigraphic subdivision a b
OLDT. DRYAS
BØL-LING
OD AL YD PB BO AT SB SA
OD AL YD 1 2 1 2 3 4 1 2 3 1 2
3 phases of the deglaciation
Pom. Gar. Got. Sal.
4 phases of the Baltic evolution
I BALTIC ICE L.
YOL. I
II BAL. ICE L.
YOL. II
ECHI-NEIS
ANCY-LUS
MASTO-GLOIA
LITORINA
POST LITORINA
LIMNAEA
MYA
5 changes of the Baltic shorelines (for the Gulf of Gdańsk)
0
-80 m
the Baltic area co-vered by ice-sheet
6 terraces of the Vistula valley in the Toruń Basin
outflow by ice-mar-ginal stream valley
outflow by Vistula river valley only
80 60 40 20 m a.s.l.
IX VI IV III I
min. max. ?
7 sites dated by 14C and palynology
m 0 2 7
Dzi 4160 yrs B.P. AT OD (BØL?) 13080
KB 7140
Grl 7310
Kr 5660
Cz Bł AT BO YD AL
Rz 935 5580 9760
Woł 2730 8940
Wil 1540 6200
Gr II 4670
Pe 1925 5350
Prz 1875 5480
Pod 705 3190
Sł 1440 3100
Nie Miocene >43000 >39000
8 key deposits
silt
peat
gyttja
in the bottom
aeolian sand
9 channel pattern
10 archaeologic sites
decline of the Palaeolithic
Mesolithic
Neolithic
Bronze
Iron
Mediev.
Swiderian
Lausa-tian
Przew. ass.
11 human impact
R

dolina in the place where the latter one collected the meltwater from the sandurs of the Mienia and Drwęca rivers and that flowing from the north from the sandurs of the Wąbrzeźno moraines.

The Mesozoic, Jurassic and Cretaceous as well as the Tertiary deposits underlay the Quaternary ones (Wilczyński 1978) what is due to the multiple valley incisions reaching the elder substratum during the Quaternary. The course of these valleys was, however, inconsistent with the present-day shape of the valley thus, the small patches of the vari-age morainic clays are preserved among the deposits filling the latter. At first, that meltwater flew out through the Toruń Basin. After the water inundation from the Płock Basin to the Toruń Basin what took place at the level of terrace IX (Wiśniewski 1976) the latter basin became the part of an outflow route of the Vistula river being under formation. The outflow to the west had been discontinued at the level of the terrace VI what was followed by a downcutting to the terrace IV and by the outflow following the path prepared earlier (according to Galon (1961) in the bifurcation phase) exclusively to the north through the gorge at Fordon, supposedly of a character of a trough (Mojski 1980). The way of development of this terrace is expressing the first phase of a formation of the present-day shape of the Vistula valley.

EVOLUTION OF THE VALLEY SECTION IN THE LATE GLACIAL AND HOLOCENE

The presented here evolution of the valley section covers the period of the last 13 000 years. It is presented graphically in Fig. 8 (section 6) together with the most important geological evidences and datings (sections 7, 8) as well as with the archeological evidences (section 10) and with conclusions related to the channel development (section 9). The definite correlation with other events in the Late Glacial and Holocene, given in Fig. 8 as the paleogeographical background (sections 2—5), appears here.

Fig. 8. Evolution of the Vistula valley in the Toruń Basin in the background of chosen events in the Late Glacial and Holocene

1 — absolute age scale; *2* — stratigraphic division: *a* — for Scandinavia according to Berglund, Tauber and Mangerud, hachured areas denote the time limits according to different authors, *b* — for Poland according to Starkel; *3* — deglaciation phases: *Pom* — Pomeranian, *Gar* — Gardno, *Got* — Gotland, *Sal* — Salpausselka; *5* — according to Rosa (in: Kępińska *et al.* 1979); *6* — minimum and maximum depth of the fossil erosional surface of the bottom, arrows indicate tendency to aggradation or erosion; *7* — abbreviations of the names of dated sites and explanations of lithological signs as in Fig. 3; *8* — key deposits and, their formation time (more detailed explanations in the text); *9* — period of the river incision denoted by broken line, braided river channel or that of a very gentle sinuosity (as in terrace IV) denoted by double line, channel width shown symbolically determines its content; *10* — X — age ordering of finds occurring in the study area; *11* — R — changes in the valley floor due to flood-control and due to the future dam constructions

The Late Glacial evolution of the river — as a distinct of the pradolina phase of the Vistula valley development — begun at the level of the terrace IV, which had been definitely formed already in the Older Dryas and originated most likely from the Bölling what could have been suggested by the ^{14}C dating of 13 080 BP for the bottom of the profile in Dzikowo (Fig. 3 and 8). In any case, a pronounced inflection of the slope between the terraces VI and IV was formed, at the latest, in the early Bölling. This period of the strong downcutting, found also in the middle and lower reaches of the Elbe and Odra valleys (Brose, Präger 1983), occurred after the recession of the ice-sheet from the Gardno moraine phase (Fig. 8, section 3) when the possibility of an outflow to the north emerged. The river begun to flow to the I Baltic Ice Lake (Fig. 8, section 4) what resulted in a substantial shortening of its course when compared to that of the pradolina period.

A significant change of the direction of the contemporary valley axis from the western to the northern one (Fig. 3) took place in the terrace IV level, likely due to a decrease in the amount of water supplied there by the routes of Drwęca and Mienia rivers. The way the terrace IV is developed in the Toruń Basin clearly indicates a propensity to a gentle sinuosity of the channel (Fig. 8, section 9) and to a lateral erosion and, consequently, to an increase in the valley floor of that day. The decrease of a gradient due to an ascend of the contemporary erosional base level was the most probabl rason for that.

The blocks of dead ice left on the surface of the terrace IV were the places of formation of the water-logged depressions. The palynological record (Fig. 7) indicates the continuity of this accumulation. The shallow depression, preserved throughout the Alleröd and Younger Dryas, deepened rapidly at the beginning of the Pre-Boreal (the *Pediastrum* curve falls down to zero, Fig. 7) after the final melting of the dead ice had taken place. Until that time the deposit accretion was of 125 cm consisting of gyttja, evidently enriched in organic substances in the Alleröd. Accumulation of gyttja was continued during the Pre-Boreal, Boreal, and Atlantic periods and it was only at the beginning of the Sub-Boreal that the shallowing of the basin took place (*Pediastrum* became extinct) and the accumulation of the 2 m peat layer begun 4100 years BP.

The evened out shape of the inflection of the slope between the terraces IV and III in the Ciechocinek region indicates a propensity to a straightening of the river course and a shifting of a valley axis towards its present-day position. The incision down to the terrace III probably took place at the turn of the Bölling and Older Dryas as a reaction to a lowering of the erosional base level at the progressing cooling down of the Gotland phase of the ice-sheet (Fig. 8, section 3). This erosional impulse has been transferred, in a weakened form, up to the Toruń

Basin where it totally ceased in the vicinity of Nieszawa because the terrace III does not occur further to the south (Wiśniewski 1976).

The outflow of the Vistula at the terrace level III is definitely of the Older Dryas. This is evidenced, first of all, by the early Alleröd age of the bottom of the profile of Czarne Błota (Fig. 3, 8) and confirmed by the periglacial reworking of this terrace material at Ciechocinek. In the Older Dryas under the conditions of permafrost and scant vegetation the Vistula formed a wide, braided channel, not deeply cut into the substratum, with holms and mid-channel bars (Fig. 5). The large amplitudes of water stages resulted in covering of the surface of the terrace III with a series of sandy-silty flood deposits. This mada cover was subject to eolian accumulation probably only in the Younger Dryas phase of the dune formation what is evidenced by the presence of a poorly developed fossil soil.

Earlier, in the Older Dryas phase of the dune formation, the extensive dune fields were developed on the higher, previous terraces.

The successive downcutting to the lowest fossil valley floor is the next stage of the evolution of the Vistula valley recorded in the Toruń Basin. This level is found in the Ciechocinek region at 32—28 m a.s.l., at 33 to 28—29 m a.s.l. in the Toruń region (Tomczak 1971) and 34—27.5 m a.s.l. to the west of Toruń (Tomczak 1982). The differences in the heights result from the evident denivelations of the bottom and the values given indicate a small but steady gradient.

The descent of the Vistula to this lowest level in its evolution was connected in time with the Younger Dryas phase of the deglaciation, the Salpauselkä (Fig. 8, section 3) and the lowest level in the history of the Baltic Sea which was 80 m below sea level and possibly, even lower (Fig. 8, section 4, broken line) in the period of the II Baltic Ice Lake. This erosional impulse has reached the Toruń Basin substantially weakened, as one may infer both from the small gradient of the contemporary floor and from the relatively small differences (7—13 m) of positions of the present-day and contemporary floors.

Possibly, the downcutting as such was delayed upstream because the dates of the same terrace III in the western part of the basin are earlier (Fig. 3).

Terrace II, being distinguished in the lower Vistula valley (Galon 1934; Roszko 1968) of the age of 11 630 years BP (Drozdowski, Berglund 1976; Drozdowski 1982) is not found in the Toruń Basin. Probably the impulse that caused the 2 m downcutting in the Grudziądz Basin has decayed before reaching the Toruń Basin.

The gradual accumulation and filling of the valley with a rather uniform alluvial series is the further stage of the valley evolution. Its beginning was likely somewhat delayed with respect to the rise of the Baltic level since the beginning of the Pre-Boreal (Fig. 8, section 5).

The accumulation series have reached the maximum level, corresponding roughly to the present-day surface of the flood plain about the half of the Atlantic period. The oldest paleochannels on this surface are filled with peat which bottom possesses a repetitive dating of about 5500 years BP (Fig. 8, section 7). This is of the second half of the Atlantic (Fig. 8, section 2) and corresponds to the final phase of growth of the *Litorina* transgression. The peat accumulation lasted until the second half of the Sub-Boreal and not only on the flood plain but also in various geomorphological situations and on various heights (former channels, deflational depressions and other concave forms). In the depressions where the gyttja was accumulated up-to-date the change to a peat sedimentation took place at the same time. Subsequent, frequently close dates of the beginning of occurrences of peat in various phases indicate the following five periods of increased humidity (in years BP): 7300—7100, 6200, 5700—5300, 4700—4200 and 3200—3100.

There are two generations of the braided abandoned channel systems in the flood plain. The elder one is of about 5500 years BP and the young one of about 3200—3100 years BP. They mark two phases of concentration and straightening of the channel what evidences that, at least until the end of the Sub-Boreal, the river drained gradually diminishing amount of water. The channel was cut down deeper than at present and freshets did not endanger the overbank settlements.

In the Sub-Atlantic the ground water level gradually decreased as the peat accumulation ended. The precise dating of this period is rather difficult to perform despite several dates from the peat bottom. It is because the lack of certainty whether the deposition of the clayey mada cover overlaying the peat begun immediately after ceasing of the peat accumulation. It is known, however, that until the early Middle Ages the permament settlements persisted in the direct vicinity of the river (Cwetsch 1978). Thus, it was probably the second half of the Sub--Atlantic when the danger of floods emerged, certainly as a result of aggradation of the channel bottom. This tendency intensifies with time what may be explained as related to the deforestation in the catchment. Due to an increased denudation the supply of the load to the river exceeded its transport capacity (Falkowski 1980). The elevation of the channel bottom may be estimated to be at least of 2 m higher when compared to the level of the early Middle Ages.

The flood-control embankments decreased only the extent of floods. An increased accretion of the flood deposit facies is pronounced in the profile in the interembankment area, dependent on the topography and relative height of the flooded surface, on the vegetation cover and on the year season (spring or summer) of the flood (Tomczak 1971).

The river management activities on the Vistula river below the mouth of Tążyna at the end of the 19th century and partly in the 20th century further upstream were an impulse for a deepening of the channel and to an accretion of the flood plain (Babiński 1984).

Constructing of the dam in Włocławek resulted in pronounced changes in the channel pattern (Babiński 1984). Intensified erosion and drastic increase in both the amount of the bedload and the rate of its transportation occur downstream of the dam.

The facts presented here indicate that all the major, Late Pleistocene and Holocene stages of the Vistula valley development in the Toruń Basin were a reaction to the changes of the erosional base level and the shortening of the lower part of the river course due to a change in a flow direction to the northward one. The changes in the level of the Baltic Sea were, in turn, the cumulated effect of the climatic oscillations, progressing deglaciation and the isostatic movements of the earth crust. Also the oscillations of the ground water table took place in the valley as well as the eolian and slope processes of various intensity. The morphology of the terrace surface indicates that the nature of the Vistula channel in the Toruń Basin was always close to the braided one. In any of the periods none developed form of meanders have been formed contrary to some cases of the valleys of smaller rivers (Kozarski, Rotnicki 1978; Falkowski 1982; Starkel *et al.* 1982; Szumański 1982). This was not favoured by the morphologically non-uniform character of that part of the Vistula valley where the narrowing of a larger gradient confines the basin-like widening to the length of some tens of kilometers.

All the energy of the river was consumed by the necessity of adjusting of the longitudinal profile of the channel and the bedload transportation downstream. The sinuosity of the stream current in the very channel is, under the conditions of a wide and rather shallow channel, an equivalent of a natural propensity to a meander formation by the river.

Geological Institute
81-740 Sopot, ul. Kombatantów 62

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WŁADYSŁAW NIEWIAROWSKI

EVOLUTION OF THE LOWER VISTULA VALLEY IN THE UNISŁAW BASIN AND AT THE RIVER GAP TO THE NORTH OF BYDGOSZCZ-FORDON

INTRODUCTION

The lower Vistula valley is characterized by an occurrence of a basin--like widenings and narrowings. The largest narrowing (gap) in the meridional valley section is located to the north of Bydgoszcz-Fordon where the valley width is only 3.5—5.0 km and the depth of incision into a morainic plateau is 60—65 m. The valley width in the widening to the north of the gap — in the Unisław Basin — reaches up to 9 km while the valley incision is down to 70 m.

The detail studies performed in the Unisław Basin and completed by the general studies in the gap section were carried out under the IGCP-158A programme. The investigated, 26 km long, valley section is located between 778 and 804 km of the Vistula course (Fig. 1). It is situated between the section of the Vistula valley in the Toruń Basin (Tomczak 1982) and the Chełmno and Grudziądz Basin (Drozdowski 1982) which have been already elaborated under this programme.

This Vistula valley has developed after the retreat of the last Scandinavian ice-sheet in the Late Vistulian. The outflow of the glacial water at the valley fringe during the ice-sheet retreat from the Świecie Plain and during the Pomeranian stage (ca. 17—15 thousand years ago) can be considered as the beginning of the valley formation. However, the lower Vistula valley in a more precise sense can be assumed since the period when the outflow of the Vistula has been initiated from the Toruń Basin to the north, into the Baltic Sea under development that took place probably ca. 14 000 years ago. Not all the stages of the valley formation have been evidently marked here. The lower river terraces are best developed. Therefore, the problems of the Vistula valley evolution by the end of the Late Glacial and in the Holocene focus the most attention.

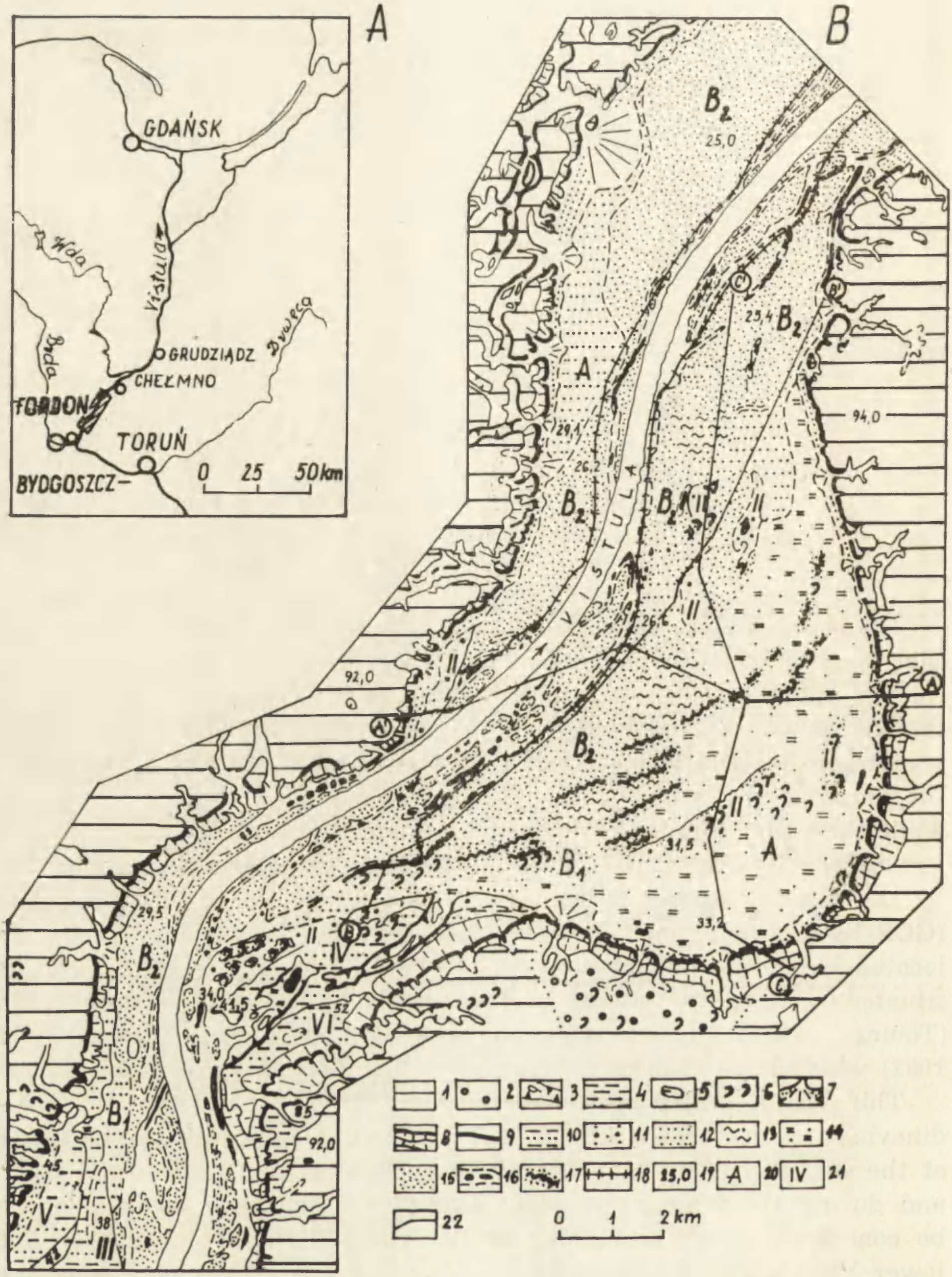

Fig. 1. *A* — Location of the study area. *B* — Geomorphological sketch of the Unisław Basin and of its surrounding

1 — morainic plateau; *2* — sandur; *3* — subglacial channels; *4* — meltwater erosional plains; *5* — kettles; *6* — dunes; *7* — valleys dissecting the Vistula valley slopes, alluvial fans and deluvial-colluvial covers; *8* — slopes with edges of various origin; *9* — main edges of slopes, of the height above 10 m; *10* — erosional-accumulational river terraces; *11* — sandy-graely accumulational river terraces. Flood plain built at the surface of: *12* — sands; *13* — clayey silts; *14* — silts and organic deposits; *15* — fine sands and silts. *16* — former side channels, abandoned channels and lakes; *17* — natural levees; *18* — flood-control embankments; *19* — height spots; *20* — levels of the flood-plain; *21* — terrace numbering; *22* — lines of geological profiles

OUTLINE OF THE HISTORY OF STUDIES

Geological and geomorphological investigations in the lower Vistula valley are dated since the end of the 19th century. However, the first complete study dealing with the origin and development of the valley was the work by Galon (1934). That author has distinguished there 8 terraces besides the flood plain, including 4 of them in the gap section to the north of Fordon and 1 in the Unisław Basin, the latter being associated with the rise of the Baltic level during the *Littorina litorea* phase. The commonly accepted system of 11 terraces has been distinguished by Galon in his later papers on the valley and outwash of the Brda river (Galon 1953), on the Noteć-Warta ice-marginal streamway (Galon 1961) and on the valleys associated with the latter (Galon 1968). The terrace numbers in this paper follow those of the above system. However, it has to be mentioned here that the full complex of 11 terraces was stated only in the Brda valley (Galon 1953) and in Drwęca valley (Niewiarowski 1968).

New details with respect to geomorphology in the gap section and in the Unisław Basin have been provided due to the detail geomorphological mapping (Niewiarowski, Olszewski) while the dune in the Unisław Basin has been elaborated by Niewiarowski (1970). These studies have not resulted in a change of opinions about the age of these dunes and terraces due to the lack of an absolute age determination at that time.

More recent geological and geomorphological investigations in the region of the lower Vistula provided new data with respect to the Last Glaciation stratigraphy and to the age of higher terraces. Palynological studies and ^{14}C datings contributed to the above (Kępczyński and Noryśkiewicz 1968; Roszko 1968; Drozdowski and Berglund 1976; Tomczak 1982; Niewiarowski and Noryśkiewicz 1983). The stated Late Glacial age of the overflood terrace II (Drozdowski and Berglund 1976; Tomczak 1982; Niewiarowski and Noryśkiewicz 1983) has also required the age verification of the terraces in the discussed valley section. Hence, the further detail geological studies have been carried out besides the geomorphological ones. The age of organic deposits has been determined in the ^{14}C Laboratory of the Institute of Physics of the Polytechnical University in Gliwice under the supervision of dr hab. M. Pazdur while the age of some sandy samples has been determined by TL-methods in the Chair of Geomorphology and Quaternary Geology of the Gdańsk University by mgr S. Fedorowicz. Some palynological expertises have been made by dr B. Noryśkiewicz, and grain size composition as well as quartz abrasion have been analysed by mgr K. Lankauf and Z. Zygora. The author is grateful all the above persons.

CHARACTERISTICS OF THE PRESENT-DAY ENVIRONMENT

As mentioned above the studied section of the Vistula valley is located between 778 and 804 km of the Vistula course. Thus, the river drains the catchment of the area ca. 187 000 km^2. The Vistula is the transitional river as none of the larger tributaries joins it here (Fig. 1A). Water from the morainic plateau, mainly the ground water, flows out mainly through a network of drainage ditches while during the high water stages water is pumped over by the pumping station. It is obvious that the water regime of the studied section is influenced by natural conditions and human impact in the whole catchment.

The lower Vistula valley is mainly incised in the Quaternary deposits which thickness is of the order of 50—100 m. The valley bottom within the area of low terraces and a flood plain is incised in the Pliocene and Miocene deposits while the channel is developed in the alluvia of the Holocene age.

The morainic plateau of the Last Glaciation, differentiated with respect to morphology, occurs in the valley surroundings at the height of 80—100 m a.s.l.

The Vistula river is characterized by a very variable hydrological regime in a multi-year period. The closest water stage gauging posts are in Fordon and Chełmno where records are obtained since 1896. The water stage amplitude of the Vistula river, known up-to-date, was 846 cm in Chełmno (958 cm — 13.03.1948 and 112 cm — in 1896). The highest Vistula stages are related either to melting season and ice-jams (in March and at the beginning of April) or to precipitation in the south of Poland (in July and August). The water stages in Chełmno exceed 900 cm during the catastrophic floods. According to Siebauer (1947) computations water discharge is 7970 m^3/s provided water stage of 908 cm in Chełmno while the maximum theoretical stage, occurring once per 150 years, can reach to 1000 cm and then the discharge can exceed 10 000 m^3/s. The lowest water stages occur usually in November, December or in January and during dry years — also the summer season. At a very low water stage of 137 cm in Chełmno the discharge is only 225 m^3/s. At the annual mean water stage the discharge is 1005 m^3/s while the mean water stage of the Vistula in 1971—1975 was 338 cm in Chełmno. The mean river gradient between Fordon and Chełmno is then 0.18‰.

The present-day character of the Vistula river was strongly influenced by channelization which was performed here by the end of the 19th century and at the beginning of the current century (the most intensive river management was in 1880—1892). The regulation of the channel included its straightening and narrowing, as well as the constructing of groyones and dikes. Now, the channel width is usually 400—425 m while the average depth is 3—5 m at the mean water level. Flood--control embankments have existed locally prior to the channelization. However, these embankments have been heightened and restored in many locations. The embankments are lacking in the gap section where the flood plain is more narrow and the higher terraces are adjacent to it whereas they are continuous in the Unisław Basin while the distance between them varies from 0.8—2.0 km. According to Babiński (1981, 1984) the Vistula channelization resulted in an accelerated runoff and in a channel deepening of the order of 0.5—1.0 m. The channel as such has changed from that of the braided nature to the type of a limited meandering. The mid-channel bars occurred chaotically prior to the channelization. After the latter, diagonal bars of the lengths of 1—2 km and widths of 0.2—0.4 km as well as pools of the similar lengths, widths of 0.1—0.3 km and depths of 4—13 m have become the dominating mesoforms. The rate of the channel mesoform migration is 0.2—0.6 km annually. The material eroded from the channel floor as well as a transitional bedload are largely deposited between the groynes what results in accretion of bars and their change into the lateral bars which, in turn, change into a new flood plain during the channel deepening. This new flood plain is lowered with respect to the flood-plain prior to the channelization.

The limitation of the flood extent due to the flood-control embankments in the Unisław Basin results in increased water stages during floods what in turn enforces one to heighten the embankments and causes a more intensive accumulation of alluvia in the inter-embankment area, pronounced mainly as levée accretion. The height differences are very pronounced when the hypsometric maps, the current ones and those of the end of the 19th century are compared.

After the water dam and electric power plant were constructed in Włocławek in 1970 the Vistula discharge downstream of the dam started to be regulated artificially. Diurnal water stage variability, related to the electric power plant operation, can reach 3 m and its extent is noticeable to 200 km downstream (Babiński 1984), i.e. much farther than the analysed section of the Vistula channel. The water dam limits the floods due to ice-jams, the latter being destroyed by the icebreakers.

Moreover, human impact onto the hydrological conditions in the Unisław Basin is dated since the 13th century. The more intensive settlement started here on the overflood terrace in the 13th and 14th centuries while the Dutch colonists who were involved in land reclaiming and in flood-control practices came in the 15th and 16th centuries. Actually, the analysed section is under management. The sandy terrace levels are usually overgrown with forests, mainly the pine ones, while the primeval willow-poplar forests are preserved only in reserves in the neighbourhood of Ostromecko and Chełmno. Arable fields and gardens occur on the fertile soils on the flood plain. However, meadows and pasture grounds dominate.

FLOOD PLAIN AND FORMS OCCURRING ON IT

The obtained datings of the organic sediments in the Unisław Basin cause one to revise the previous opinions onto an extent of the flood plain. Galon (1934) has distinguished only one overflood terrace in the Unisław Basin and stated 2 overflood terraces farther to the north: the higher one — 5—9 m, and lower one of the height 3 m above the flood plain. Following the presence of more numerous terraces in the Brda and Drwęca valley that author has started to distinguish (Galon 1968) also 3 overflood terraces (I—III) in the Vistula valley at Fordon and in Grudziądz Basin. The presence of these terraces in the latter Basin has been confirmed in numerous papers by Drozdowski (among others: Drozdowski and Berglund 1976; Drozdowski 1982). Tomczak (1982) has discussed only 1 overflood terrace, 6—8 m high above the mean Vistula level, in the Toruń Basin. The author distinguished in 1970 two levels of the overflood terrace in the Unisław Basin: the higher one — 6—7 m high (ca. 31 m a.s.l.) and the lower one 3—4 m above the mean water level of the Vistula (28—29 m a.s.l.). According to the lithology of sediments and ^{14}C datings of the organic deposits it is certain that the so--called "lower level of the overflood terrace" being the equivalent of the overflood terrace I of Galon (1968) is genetically a part of the flood plain in the Unisław Basin and in the gap section. The problem of the higher level, 6—7 m high, being the equivalent of the overflood terrace II according to Galon (1968) is much more complicated. The reason for that is the presence of 2 vari-aged levels in the uniform hypsometric level in the Unisław Basin, i.e. the Late Glacial overflood terrace and the higher level of the flood plain. Therefore, the author has distinguished within the flood plain the levels A, B_1, B_2 (Fig. 1B) which slightly differ with respect to hypsometry, although definite inflection lines between them are lacking and with respect to a geological structure. Indistinct scarps (1.0—1.5 m) occur mainly between the levels A and B_2.

Within this approach the flood-plain is 2.0—2.5 km wide in the gap section and widens to 5—8 km in the Unisław Basin. It descends (from 30 to 25 m a.s.l.) over the distance of 26 km and the gradient of 0.18‰ is similar to that of the river. The flood plain is 2—4 m above the mean water level of the Vistula, as in the Toruń Basin (Tomczak 1982), however, it ascends to 6—7 m at the level A.

The flood plain morphology can be subdivided into:

a) present-day levées occurring along the actual Vistula channel and forming the ridges, 1—2 m high, dissected by the lateral branches of the river. The width of the levée zone is 250—375 m while they are alternating on the both river banks. Their height is larger in the area where flood-control embankments were constructed by the end of the 19th century. That proves an intensive accumulation of the Vistula after these embankments have been made. The flood plain surface is inclined towards the valley side in some locations or towards the river channel, in the other ones;

b) former levées, developed along the main primary Vistula channels. These forms are best developed in the eastern part of the Unisław Basin. They are 0.5—2.0 km long and 100—300 m wide, rise slightly (1—2 m) above the flood plain. The upper part of these levée sediments is composed of eolian sands overlying the fluvial sands. The elongated dunes, up to 2 m high, occur on them locally;

c) flood plain, occuppying the largest areas, lithologically differentiated;

d) former, main Vistula channels of flat bottoms, 0.5—1.0 km wide, without abandoned channels, best developed in the eastern part;

e) elongated, lateral channels of the Vistula, definitely more narrow (50—175 m), occurring along the actual river channel, filled with water during the floods. Some of them have been cut off after the constructing of the flood-control embankments. The largest oxbow lake is Jezioro Starogrodzkie of the area of 27.3 ha, 2.6 km long and of the maximum width of 175 m and depth of 5.2 m;

f) eolian covers forming gentle undulations, developed at the top of former bars and sandy holms;

g) anthropogenic forms — flood-control embankments, drainage ditches and channels, earthworks and a few piles related to the building grounds.

The flood plain is directly adjacent to the valley slopes of the height of 50—60 m. The latters are dissected by a dense network of deep erosional and denudational forms with some denudational edges. At the foot of the valley slopes there is a deluvial plain, up to 200 m wide, and there are alluvial fans of various sizes and thickness of deposits up to 5—6 m.

Flood plain deposits. The thickness and nature of the flood plain deposits are depicted in cross-sections in Fig. 2—4. The bottom of fluvial sediments is at the height of 20—25 m in the southern part of the Unisław Basin and descends towards the north down to the height of 5—10 m a.s.l. According to the cross-sections in Fig. 2, 4 the bottom of these sediments descends also gently to west what suggests the channel shift in that direction.

The alluvia series is 8—20 m thick. The thickness of these sediments

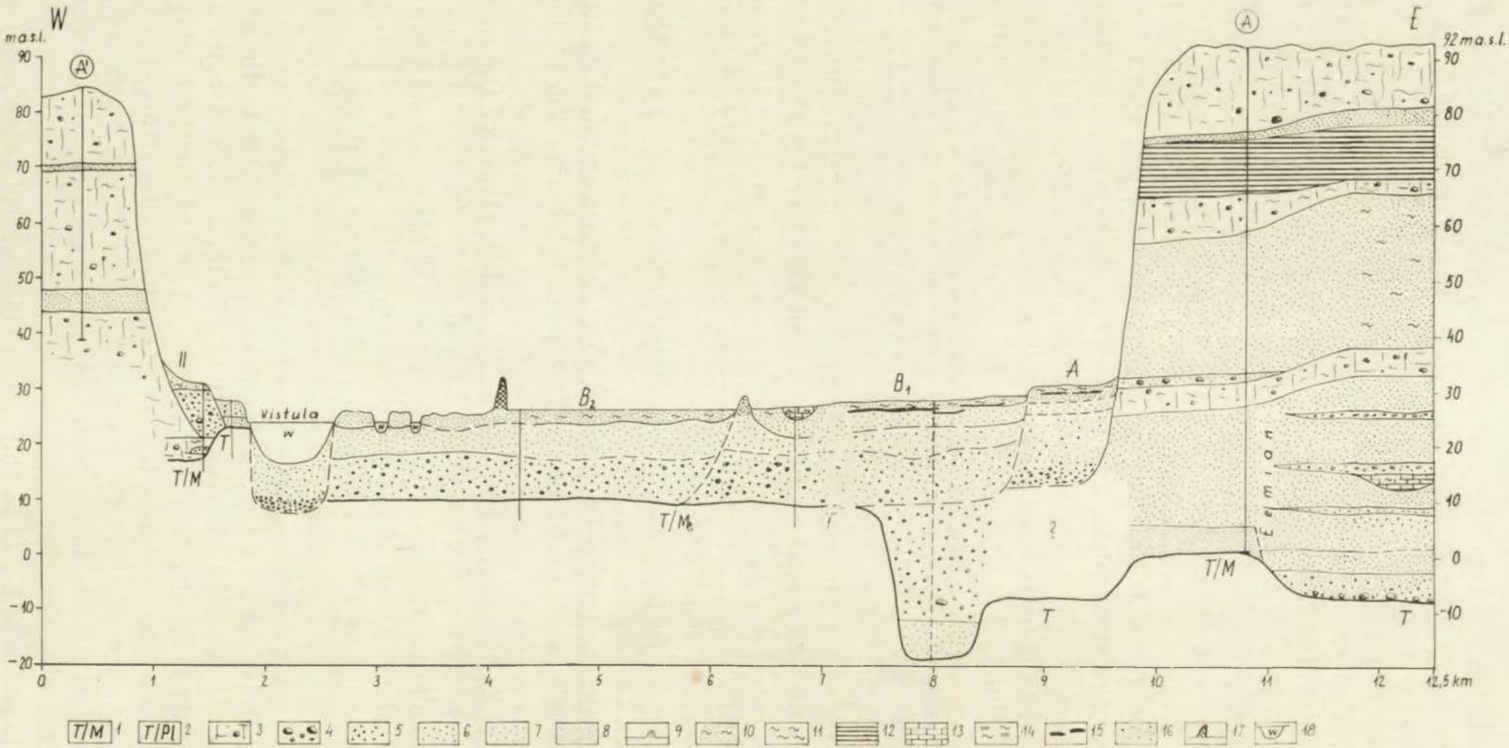

Fig. 2. Geological profile A—A′

1 — Miocene deposits; *2* — Pliocene deposits; *3* — till; *4* — pebbles; *5* — gravel; *6* — coarse sands; *7* — medium sands; *8* — fine sands; *9* — dune sands; *10* — silty sands and silts; *11* — clays; *12* — varved clays; *13* — gyttjas; *14* — organic silts; *15* — peat; *16* — deluvial deposits; *17* — levees; *18* — water

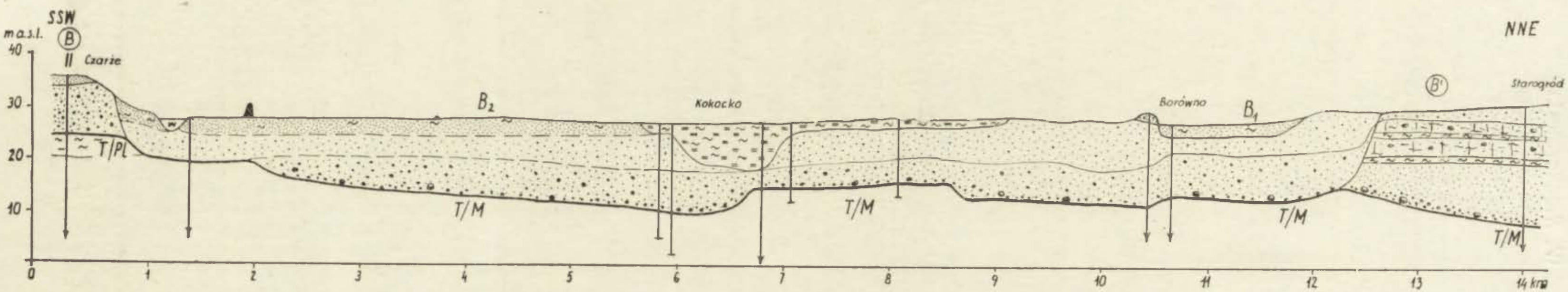

Fig. 3. Geological profile B—B′ (Explanations as in Fig. 2)

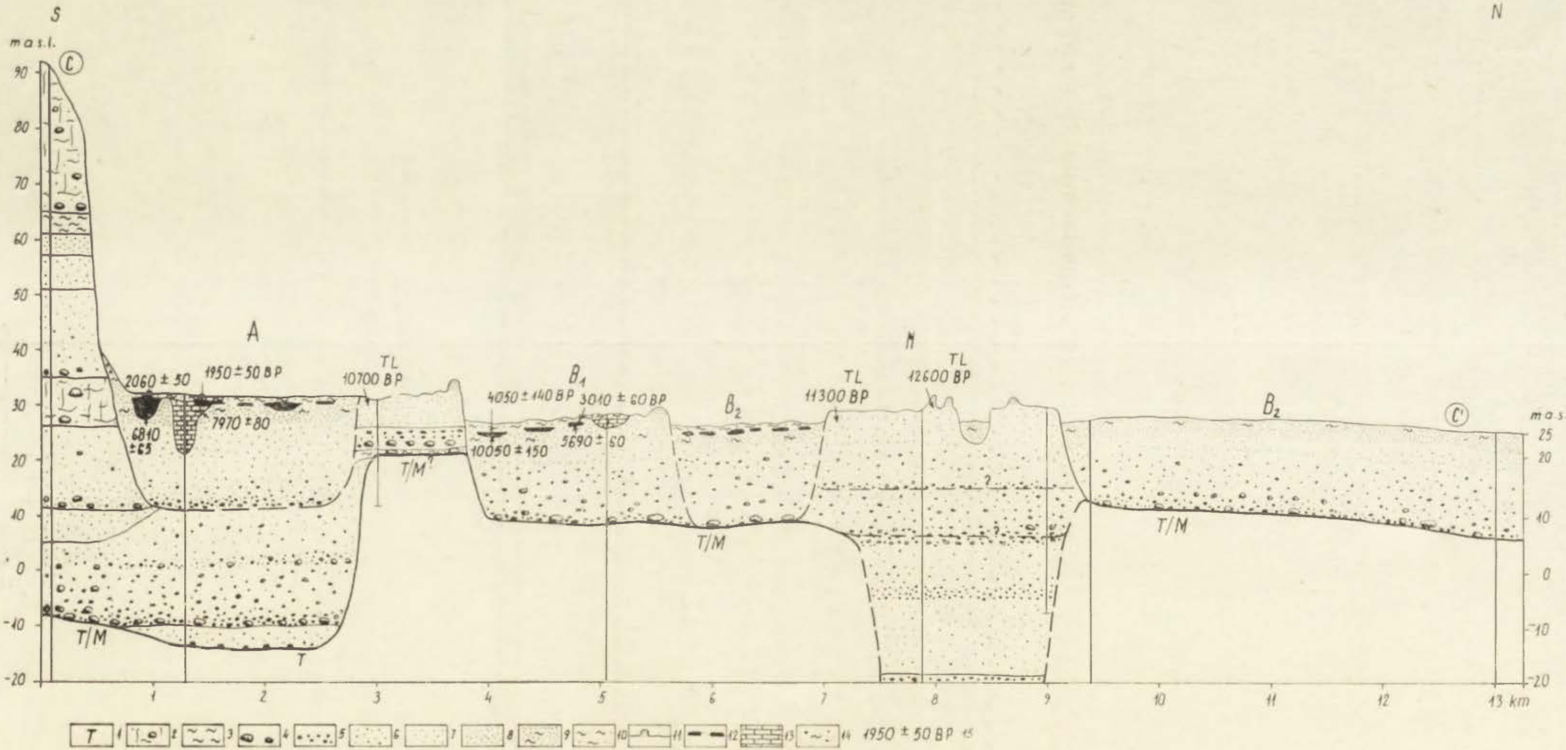

Fig. 4. Geological profile C—C′

1 — Tertiary deposits; 2 — till; 3 — clays; 4 — pebbles; 5 — gravel; 6 — coarse sands; 7 — medium sands; 8 — fine sands; 9 — dune sands; 10 — silty sands and silts; 11 — levées; 12 — peat; 13 — gyttjas; 14 — deluvial deposits; 15 — radiocarbon datings

is slightly larger here than in the Toruń Basin (Tomczak 1982) and similar to that of Grudziądz Basin (Drozdowski 1982). Thus, there is a substantial affinity in their formation Therefore, the following deposits occur here:

1) channel facies deposits (bar facies) — built of sands with gravels and pebbles in the lower part, of the thickness up to 12 m frequently with the channel-lag deposits at the bottom. They are overlain by the medium sands with an admixture of coarse sands and gravels, 3—5 m thick;

2) overbank facies deposits — among which the following are distinguished:

a) levée facies deposits; the older levées are built of medium sands with some coarser sands while the present-day ones — of fine sands;

b) flood facies, of the thickness of 0.5—3.0 m, occurring commonly on the surface of the flood plain, spatially differentiated with respect to lithology. The fine sandy and silty deposits dominate in the vicinity of the present-day channel (level B_2). Here, the thickness of the flood-facies is the largest of the order of 1—3 m. The fine sandy deposits occur on the surface on the level B_1 in the gap section while the silty-sandy and silty-clay deposits, 0.5—1.5 m thick, are found in the Unisław Basin. In the case of the level A the sandy-silty deposits occur in the western part of the Unisław Basin while silty-clay deposits, 0.5—1.0 m thick, are found in the eastern part;

c) facies of organic deposits — occurring mainly in the eastern part of the Basin, on the levels B_1 and A_0 below the silty-clay cover of the flood-facies deposits usually (comp. Fig. 4). The facies include mainly peats, to 1.0 m thick, on the level B_1 and over 3 m thick in some locations on the level A, reaching the surface locally. The gyttjas usually underlay the peats, however, there are found at the surface as well. The thickness of the gyttjas is rather small although 9 m of these deposits have been stated in one drilling. The organic deposits (peats, organic muds) on the level B_2 occur in the abandoned channels. The alluvial fan deposits of the levels A and B_1, of a diversified thickness (0.5—6.0 m), and deluvia occur commonly on the surfaces of the levels A and B_1 at the foot of the valley slopes.

OVERFLOOD TERRACE — FORMS AND DEPOSITS

The overflood terrace corresponds hypsometrically to the overflood terrace II, according to Galon's numbering system (1968), however, it is indeed the first overflood terrace as it has been proven above. When the level B_2 is adjacent to the terrace in question, the latter is separated from the flood plain by the edge while in the eastern part of the Unisław Basin it is at the height of level A of the flood plain. The terrace is preserved only fragmentarily on the left and right hand sides of the present-day Vistula channel. This terrace corresponds undoubtly to that one 6—8 m above the mean water level of the Vistula in the Toruń Basin and probably to the terrace II in the Grudziądz Basin. The difficulties associated with a terrace interpretation in the Grudziądz Basin result from the fact that Drozdowski (1982), as Galon (1934, 1968), determines the relative height of the terraces with respect to the flood plain instead of to the mean water level of the Vistula.

The common elements of the terrace morphology, especially in the eastern part of the Unisław Basin, are dunes in forms of hills and elongated ridges, up to 2—5 m high, exceptionally up to 6—8 m. The lack of distinct parabolic dunes and ridges with asymmetric slopes indicates that these dunes have not been subjected to migration. They have been formed due to deflation of fluvial sands and to vertical accretion upwards. That is the evidence of the lacking diagonal stratification and that of the stratification following shapes of the dune formes.

The thickness of fluvial deposits is smaller than that on the flood plain and does not exceed 10 m. The typical flood facies is lacking on the surface and the terrace is built of the channel facies, i.e. coarse sands and gravels in the lower part and medium sands with a small admixture of gravels in the upper part.

The analysis of the grain composition of the fluvial deposits to the depth of 2 m has indicated (data of 24 samples) that the clay fraction is absent and there is a small amount of the gravel fraction with the grain diameter above 2.0 mm (exceptionally 6.11%). Medium sands (0.25—0.50 mm) constitute 50—75%. The grain size composition of the dune sands is similar, as M_z of the fluvial sands is 1.57 φ while M_z of the dune ones is 1.69 φ.

The analysis of the quartz grain abrasion (W_0) of the diameters of 0.8—1.0 mm performed using the graniformameter of Krygowski (1964) has indicated that the fluvial sands of the discussed terrace are of the medium abrasion index W_0 — 1125 (data of 16 samples) and the mean heterogeneity index of abrasion is Nm — 5.7 while in the case of the dune sands laying on this terrace the appropriate values are W_0 — 1063 and Nm — 6.2. Based on the comparison of the grain size composition and grain abrasion (Fig. 5) it may be concluded that the dune occurring on the overflood terrace have been formed out of the fluvial sands of the terrace in question and the eolian transport of sands has been performed over a short distance.

AGE AND CHRONOLOGY OF SEDIMENTS OF THE FLOOD PLAIN AND THE OVERFLOOD TERRACE

Despite of 10 datings obtained for the peats of the flood plain of the levels A and B_1 by the ^{14}C methods and 3 datings by TL of the overflood terrace the age of the deposits can be determined only approxima-

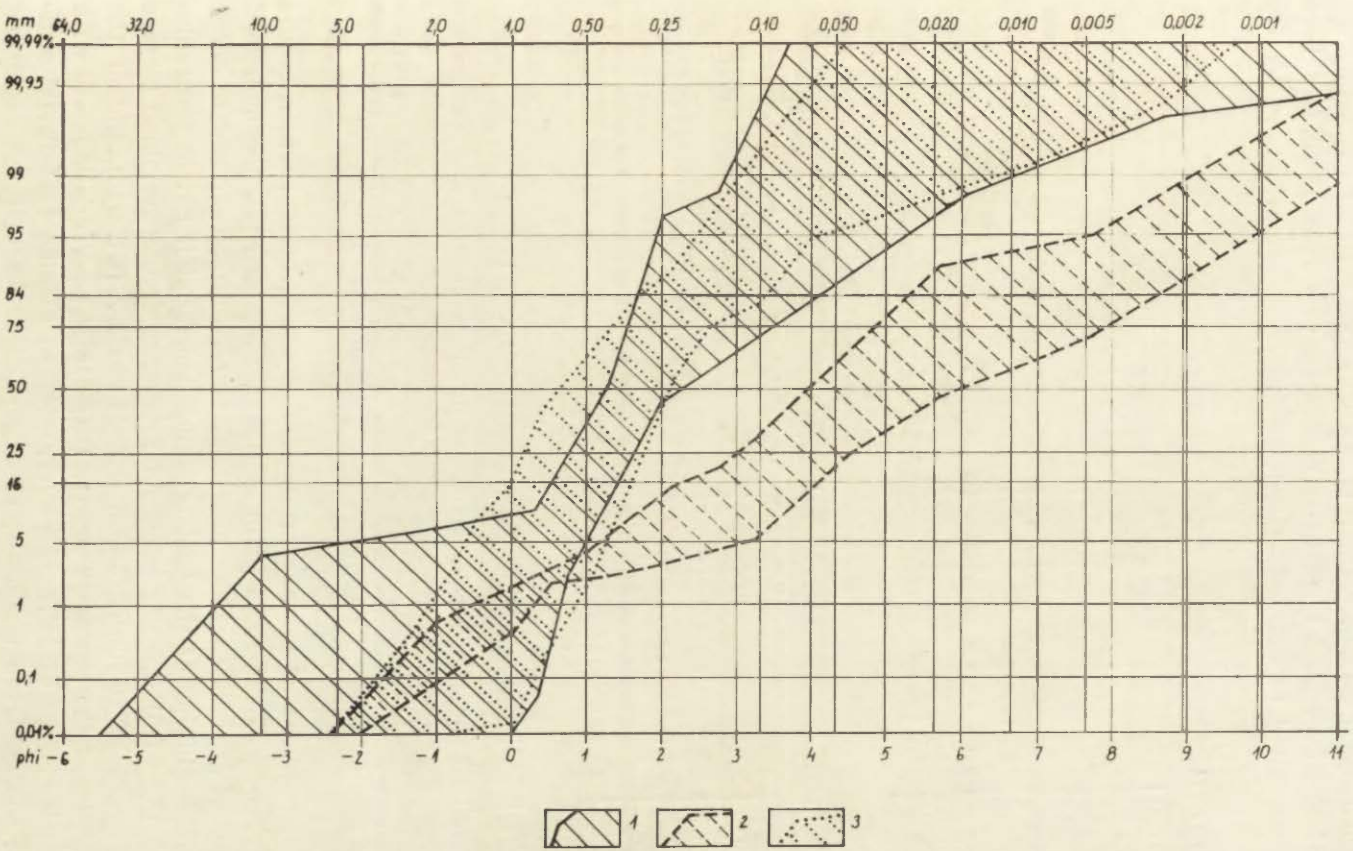

Fig. 5. Distribution of the grain size composition of sediments in the Unisław Basin

1 — of the overflood terrace; 2 — of the flood plain of the level A and B_1 (flood facies); 3 — of the eolian sands on the overflood terrace

tely. Nevertheless, the obtained data enforce one to reconsider certain opinions. Both, the TL datings of the overflood terrace and these of the ^{14}C methods of the flood plain (Fig. 6) have proven that the sandy deposits of the overflood terrace (II according to Galon 1968) had been already deposited in the Late Glacial period. That is evidenced by the

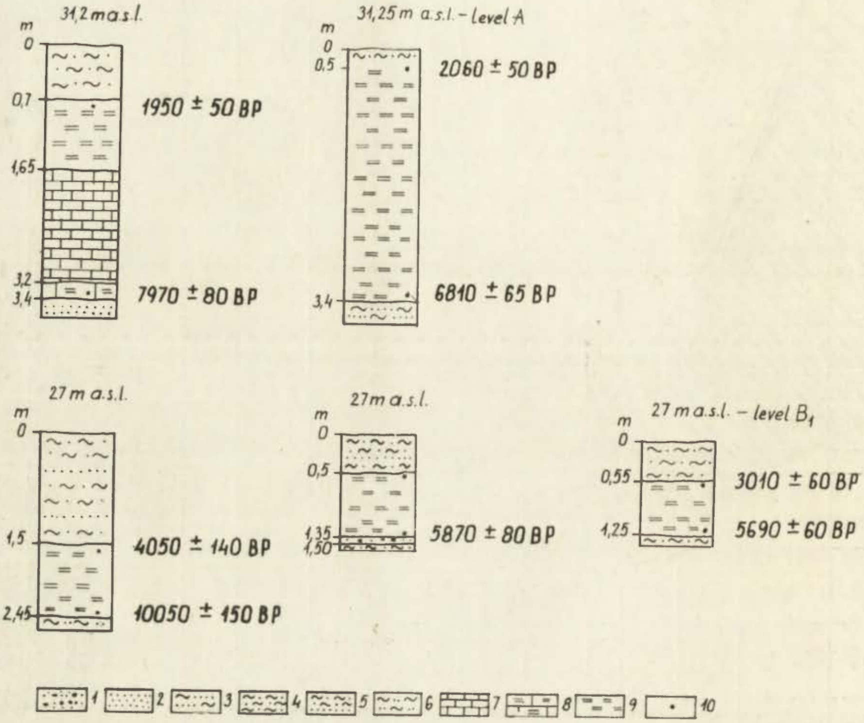

Fig. 6. Profiles of the flood plain sediments (levels A and B_1) with radiocarbon dated organic deposits

1 — sands with gravel; *2* — fine and medium sands; *3* — silty sands; *4* — sandy silts; *5* — clayey silts with admixture of fine sands; *6* — clayey silts; *7* — gyttja; *8* — gyttja with peat intercalations; *9* — peat; *10* — sampling sites for the ^{14}C datings

bottom of the peat of the age of 10 050 ± 150 BP (Gd-905) which occurs on the level B_1 of the flood plain in Bruki, 1—2 m below the overflood terrace. It is obvious that the overflood terrace dissection had to occur before the beginning of the peat accumulation. That is not in contradiction with the TL datings of the fluvial deposits of the overflood terrace of the TL age of 10 700 (UG-220) and 11 300 BP (UG-218), and of the dune deposits of the age of 12 600 BP (UG-218). The TL datings are with an estimation error of 15%. However, one can assume that fuvial sediments of the analysed terrace were deposited at least at the beginning of the Alleröd, or likely in the Older Dryas already, based on the datings of the organic sediments on the equivalent of this terrace (6—8 m above the mean Vistula level) in the Toruń Basin (Tomczak 1982; Niewiarowski and Noryśkiewicz 1983) and on the possible terrace equivalent (terrace II) in the Grudziądz Basin (Drozdowski and Berglund 1976; Drozdowski 1982). One can also assume that the age of the dunes developed on this terrace, disregarding the top part of their sediments in which fossil soils and younger eolian sands occur, are also of the Late Glacial, most likely of the Younger Dryas.

The dissection of the overflood terrace had to be initiated in the Alleröd already and could last still in the Younger Dryas. Based on the elevation of the bottom of the Late Glacial and Holocene fluvial sediments in the Unisław Basin one can assume that the migration of the main Vistula channel took place from the east to the west. Based on the above one can also consider that the oldest deposits of the channel facies on the flood plain are on the level A, and the respectively younger ones on the levels B_1 and B_2. It is unquestionable that different segments of the alluvial series on the flood plain are of various age. Infering from the ^{14}C date of the peat bottom — 10 050 ± 150 BP on the level B_1 — it is possible to assume that the channel facies of the levels A and B_1 were deposited still in the Late Glacial (Alleröd, Younger Dryas) while the Vistula channel descended to the lowermost level within the flood plain in the Pre-Boreal and it was related to the lowest water level in the Baltic Sea at that time, to the Yoldia Sea (Rosa 1968). Therefore, the entire fluvial sediments are of the Holocene age on the level B_2 only.

A fairly common presence of autochthonous deposits of peats and gyttjas, locally, on the flood plain on the levels A and B_1 confirms that during the peat formation, i.e. 10 000—3000 BP on the level B_1 and ca. 2000 BP on the level A (Gd-902, 905, 1361, 1362, 1578, 1579, 1785), the Vistula running water did not reach to the peats, and the formation of the latters was associated with an overgrowing of the oxbow lakes and with a rise of the ground water table. As the peats are as a rule covered with fine deposits (sandy and clayey silts) of the flood facies on both the levels one can conclude that the Vistula flood water initiated to reach the level B_1 ca. 3000—4000 BP while the level A ca. 2000 BP. That is the evidence of the rising water stages of the Vistula, increased discharges, and more frequent occurrence of the high flood stages. In order the flood water of the Vistula could reach the level A of the flood plain (6—7 m above the mean water level) the floods had to have been much larger than those recorded here during the last century. The accretion of the Holocene organic deposits and flood facies deposits younger than 2000 year on the level A has resulted in the same height in the eastern part of the Unisław Basin as that of the Late Glacial overflood terrace. Thus, two levels of the age difference of ca. 10 000 years are here on the same hypsometrical level.

Although the beginnings of the peat formation within the flood plain in the Toruń and Unisław Basin are of various ages the majority of the profiles indicate the peat initiation for 7000—5000 BP. Tomczak (1982) states the beginning of the upper face of the peat to be covered with the flood facies deposits in the profiles Przyłubie and Pędzewo in the Toruń Basin for the period of 1800—1900 BP.

HIGHER ELEMENTS OF THE VALLEY RELIEF

The terraces higher than the overflood one are lacking in the Unisław Basin while the benches of the terraces III, IV, V and VI are preserved in the gap section adjacent at the south to the Basin. These are erosional--accumulation terraces with a sand-gravel fluvial sediment cover of the thickness 2—4 m at average. They are inclined towards the present direction of the Vistula outflow. The fragments of the subglacial channel, which peaty bottom is 12 m below the terrace surface, are preserved within the terrace IV (41—40 m a.s.l.). The eutrophic finger lake Skrzynka of the area of 4.93 ha and depth ca. 3 m occuppies the channel bottom. As this terrace lies ca. 50 m lower than the neighbouring morainic plateau, thus, one should assume that this channel was over 60 m deep in the past. The preserved terrace with this channel confirms that the latter was conserved by a buried ice during the terrace formation. The presence of this ice is also evidenced by the kettles occuring on the terrace VI.

The terraces VII—XI distinguished in the neighbouring Toruń Basin are lacking in the gap section. The bench of the erosional level, built of the till and thin cover of sandy deposits, occurs at the foot of the edge of the Chełmno Moraine Plateau at the height of ca. 85 m a.s.l. That level is the evidence of the southward outflow of glacial water along the line of the present-day valley.

STAGES OF EVOLUTION OF THE SECTION OF THE LOWER VISTULA VALLEY

One of the problems of the earliest development of the lower Vistula valley is its dependence on the former conditions. The analysis of the Quaternary sediment substratum as well as the formation of these deposits in the discussed valley section and in its vicinity indicate the presence of the narrow fossil valley, which bottom is 20 m below sea level, in the substratum of the Unisław Basin. Drozdowski (1982) suggests that it is the fossil valley of the Eemian interglacial. However a wide, well documented (Makowska 1977) valley of the Eemian age extends to the east of the present-day Vistula valley in the discussed section, within the morainic plateau and enters the Vistula valley just in the Grudziądz Basin. As follows from the Fig. 2 its bottom lies higher than that of the narrow fossil valley. Thus, this deeper narrow valley cannot be of the Eemian age and originates likely of the Masovian interglacial. Moreover, the form is covered with younger deposits and it is too small to provide a substantial foundation for the formation of the lower Vistula valley here. Therefore, one should assume that the analysed valley section is a new form which has been produced after the retreat of the last ice--sheet and its formation has been favoured by the contemporary glacial relief which has enabled the glacial water outflow along this line, and later that of the Vistula river. The fragment of the erosional surface preserved in the gap at the height of 85 m a.s.l. indicates that the glacial water flew southward at the line of the present-day valley at the time when the ice-sheet margin was in the neighbouring Świecie Moraine Plateau.

The glacial water flow out in that direction also during the Pomeranian stage what is evidenced by the outwash plains of the Wda and Mątawa rivers reaching the Vistula valley. The traces of that ouflow are not preserved in the valley — they have been destroyed later.

The period, when the Vistula started to flow out of the Toruń Basin to the north first time, should be considered as the initiation of the Vistula valley formation. According to Galon (1934, 1961), and to the other authors, the above took place at the level of the terrace IX in the so-called bifurcation phase when the ice-sheet front was at the area of the Gulf of Gdańsk. It can be approximately determined for 14 000 BP. The cause of the Vistula flow to the north has not been thoroughly known yet.

The terraces IX—VII are lacking in the analysed section. On the basis of the preserved fragments of the subglacial channel in the gap on the terrace IV and of the kettles on the terrace VI, however, one can presume that the partial Vistula flow to the north could have been triggered by an early melting of the ice not deeply buried into the glacial deposits and may be by a lower elevation of the areas at the ice-sheet foreland at that time (isostaticaliy lowered) and by the isostatic uplift of the areas located far from the ice-sheet margin.

The main cause of a diversified formation of the Vistula valley to the north of Fordon and in the Unisław Basin is another question. The narrowing of the Vistula valley at the gap and its widening in the Unisław Basin result, according to the author, from differences of the geological structure. The Pliocene clays, which top is at the height of 40—50 m a.s.l., occur below the Quaternary deposits. The thickness of these deposits together with the clays at the Miocene top can reach up to 30 m. The Pliocene clays are lacking in the vicinity of the Unisław Basin. The clay deposits hindered the Vistula channel migration and the valley widening during the bottom erosion at the gap. That was not the case of the Unisław Basin. Provided this approach the narrowing of the Vistula valley to the north of Fordon is of the nature of the structural river gap.

In order to explain the Grudziądz Basin origin Drozdowski (1974, 1982) assumes the presence of the preserved dead glacier ice prior to the ice-sheet in the Vistulian. In the case of the Unisław Basin and the gap section there are no proofs for the presence of large masses of the dead ice here besides the buried ice in the subglacial channel and in the kettles. Therefore, the author considers the Unisław Basin in the present form to be the result of the Vistula erosion.

The occurrence of the overflood terrace fragments in the Unisław Basin on the both sides of the present-day Vistula channel indicates that the general shape of the actual basin was formed in the level of this terrace, i.e. in the Late Glacial period (Older Dryas—Alleröd most likely) The further modifications of the Basin took place in the Holocene because the youngest level of the flood plain B_2 is directly adjacent to the valley slopes in some locations. It is likely that the Vistula leaving the narrowed section at the gap was divergent into some branches what can explain the conservation of this terrace at the foot of both the valley slopes.

As in the neighbouring sections, the lower Vistula had a propensity to intensive erosion during the Pleniglacial and part of Late Glacial time although the river was undoubtly of the braided nature at that time. Drozdowski (1982) assumes that the above erosion rate was ca. 18 mm/yr. The Vistula downcutting was identical or of a similar order in the analysed section and in the Toruń Basin (Niewiarowski and Noryśkiewicz 1983). The above is mainly related to the lowering of the base level due to the ice-sheet recession and exposing of the low bottom of the Gulf of Gdańsk and to isostatic movements eventually. The presence of the terraces in other sections indicates that the above incision was not uniform but occurred in some stages.

Despite of the further erosional propensity in the Alleröd in the Younger Dryas and at the beginning of the Pre-Boreal (incision of the order of 20 m) the erosion rate was almost twice lower, of the order of 9—10 mm/yr, when compared to that of the preceeding period.

Although the Vistula was still of the braided nature during the overflood terrace formation the water concentrated largely in the main channel the latter being of a sinuousity of large radii, what is indicated by the character of the spatial development of the overflood terrace in the Toruń Basin and in the Unisław Basin. The above suggests a certain change of the hydrological regime. The Vistula channel in the gap section was usually straight.

The lack of the well preserved former Vistula channels within the overflood terrace as well as within the flood-plain does not allow to calculate discharge in particular periods. It is commonly accepted that the propensity to accumulation dominated durig the entire Holocene after the deepest incision of the lower Vistula valley at the beginning of the Holocene.

There are contradictory opinions about the development of the river channel of the lower Vistula in the Holocene. According to Drozdowski (1982) the lower Vistula river was of a meandering nature since the mid-Atlantic while Tomczak (1982) is of opinion that the Vistula was permamently a braided river in the Toruń Basin. The results of the author's studies confirm the opinion of Tomczak. Despite of the propensity to the natural large-radius sinuousity of the river, being substantially pronounced from the overflood terrace, the lower Vistula has never reached the full meandering river development both at the gap section and in the Unisław Basin what is evidenced here by the lack of free meanders and distinctly formed meandering channels.

River discharges and magnitude of floods increased during the last 3000—4000 years what is evidenced by the elevation and thickness of deposits of the flood facies. The largest flood stages, larger than those recorded in the last century, occurred in the Unisław Basin at the beginning of AD when floods reached up to the level A of the flood plain (6—7 m above the actual mean water level of the Vistula). The silty-clay sediments deposited on peats originate of the above floodings. The more precise datings of these floods are still lacking. The cause of the so large freshets is not yet fully explained if it is related to a moister climate in the initial phase of the Sub-Atlantic or to a more intensive farming development and deforestation. Based on the maximum increase of the water level in the Kuyawy and Brodnica lakes stated at that time (Niewiarowski 1976, 1978) the author assumes that both the causes can overlap, however, the main reason for these large floods is the moister climate.

Nicholas Copernicus University
Institute of Geography
87-100 Toruń, ul. Fredry 8

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