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GEOGRAPHICAL STUDIES
SPECIAL ISSUE No. 8

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

PART V

WYDAWNICTWO
Continuo

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ГЕОГРАФИЧЕСКИЕ ТРУДЫ

СПЕЦИАЛЬНОЕ ИЗДАНИЕ № 8

ЭВОЛЮЦИЯ ДОЛИНЫ РЕКИ ВИСЛЫ НА ПРОТЯЖЕНИИ ПОСЛЕДНИХ 15 000 ЛЕТ

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PART V

Editor:
LESZEK STARKEL

WYDAWNICTWO
Continuo

WROCŁAW 1995

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LESZEK STARKEL*

INTRODUCTION

This collection of papers presents in some sense a continuation of research realised in the framework of the IGGCP project 158A – Palaeohydrology of the temperate zone during the last 15 000 years. Their result were 4 volumes on the evolution of the Vistula valley during the last 15 000 years (Starkel ed. 1982, 1987, 1990, 1991). These studies inspired various supplementary studies, some of them extending the problems or the area.

In 1991 in the upper Vistula basin the team from the Department of Geomorphology and Hydrology in Cracow supported by Dr Marek Krąpiec, dendrochronologist, started to realise the project (supported by national grant No. 6-0783-91-01-P2) entitled "Paleohydrological changes in the river valleys of southern Poland during last 20 000 years on the background of global changes".

The present volume includes 9 papers of regional or local charakter not only from the upper Vistula valley, but also from the middle and lower Vistula, as well as tributary Wisłoka valley (Fig. 1). It will be followed by the last volume VI summarising the results of the granted project mentioned above.

I'd like to express cordial thanks to all authors for cooperation. Especially I should mention senior Professor Władysław Pożaryski, who pressented his valuable data collected 40–50 years ago and after several supplementary borings, sedimentological analyses and radiocarbon dating filled the gap in our knowledge on the middle Vistula valley.

I'd also like to thank mgr Maria Klimek for most of the presented drawings, mgr Teresa Mrozek for translation to English, Prof. Jacek Rutkowski and Prof. Teresa Madeyska for valuable editorial comments and Dr Tomasz Kalicki for some help in editorial work.

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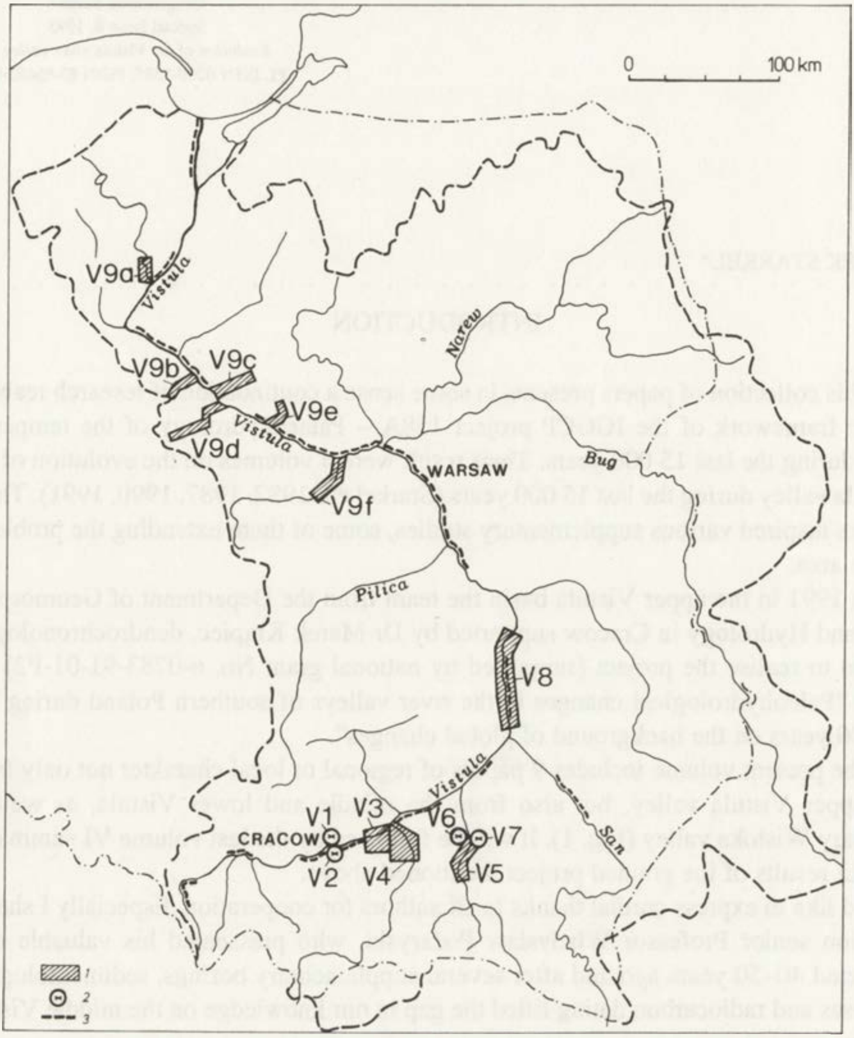

Fig. 1. Valley reaches and sites presented in the 5-th volume on the Evolution of the Vistula valley (V1–9)

1 – valley reaches (V3 – by Gębica, V4 – by Sokołowski, V5 – by Starkel, V8 – by Pożaryski and Kalicki, V9 – by Andrzejewski), 2 – investigated sites (V1 – by Kalicki and Zernickaya, V2 – by Kalicki and Krąpiec, V6 – by Granoszewski and Starkel, V7 – by Starkel and Krąpiec), 3 – valley reaches elaborated before and presented in the 1-st, 2-nd and 4-th volume on the Vistula valley

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Geographical Studies
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TOMASZ KALICKI*, VALENTINA P. ZERNICKAYA**

PALEOGEOGRAPHY OF THE VISTULA VALLEY NEAR CRACOW BASED ON SEDIMENTS AND PALYNOLOGY OF THE ALLERØD PALEOCHANNEL FILL

INTRODUCTION

The site located near Plac Centralny has already been described in details (Kalicki 1984, 1987, 1988b; Kalicki, Starkel 1987), and was recently correlated with the site Łęg B. This allowed to hypothesize that both profiles represent the filling of the Allerød paleomeander located under the margin of Pleistocene Dłubnia fan (Fig. 1, 3) (Kalicki 1992a, c).

The purpose of the palaeobotanical studies, undertaken under the grant 6-0783-91-01 "Paleohydrological changes in the river valleys of Southern Poland in the last 20 000 years on the background of global changes", was to determine the age of the series of silts underlying peats at site Nowa Huta and, therefore, conclusively to decide on the age of the abandoned channel. An early attempt to date a fragment of reed in the bottom of these silts assigned to it a younger age (9660±180 BP, Gd-4041) (Kalicki 1988a), which was identical to the age of peaty silts lying above which started an organic series (Fig. 1). In the ongoing studies the emphasis is also on the way flood frequency and the distance from the active river channel are reflected in deposits and in a pollen diagram of the abandoned channel filling.

METHODS

The drilling in the paleomeander in Nowa Huta was made using the K. Więckowski core-drill at the distance ca 200 m to the west of the profile dated earlier. Despite some differences in the thickness, when compared to older drillings, the sequence of three main members (the lower member silts, peats, the upper member clayed peats)

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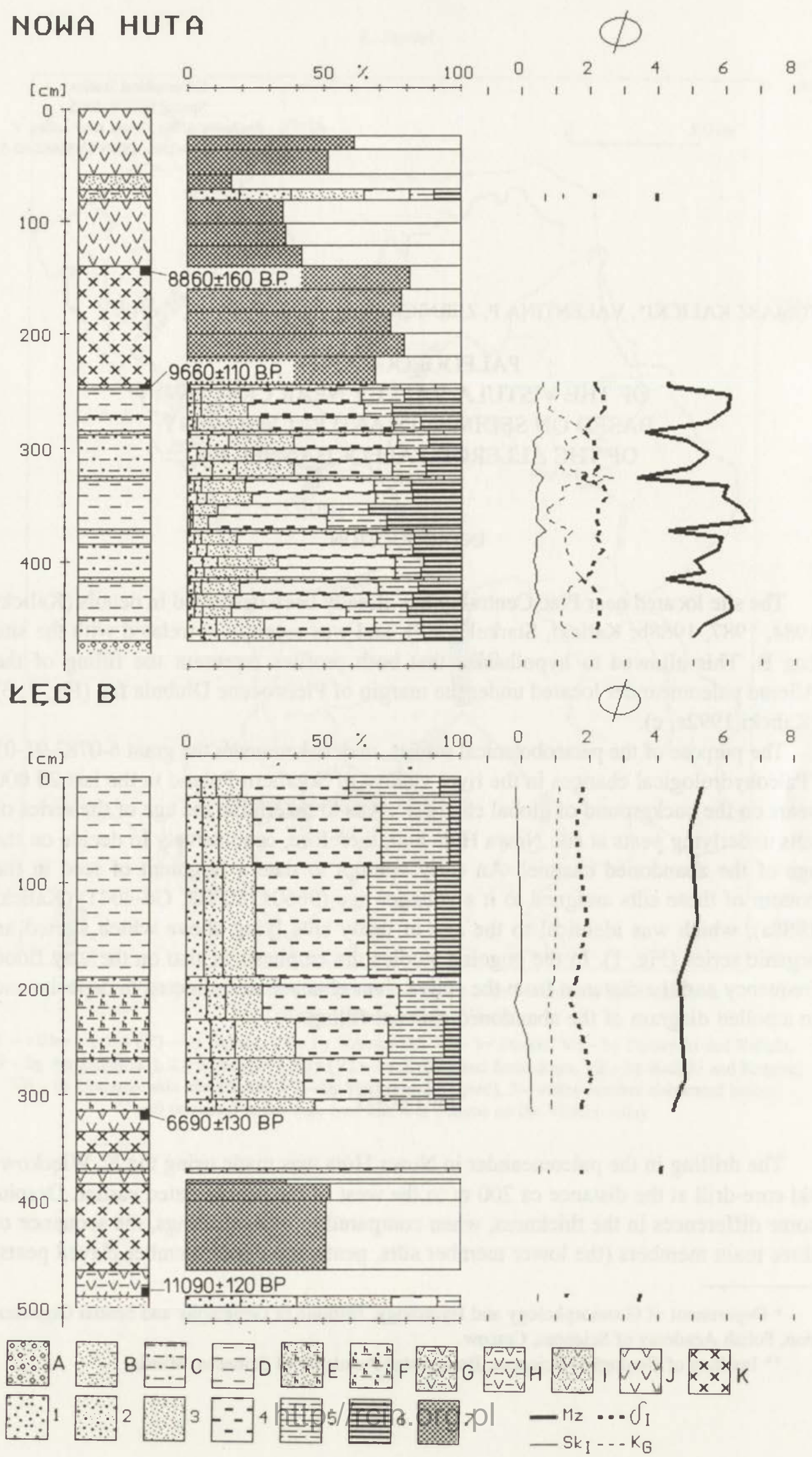

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filling the paleomeander is identical (cf. Fig. 1 and 2). This allows for a good correlation with earlier studies.

Samples for palynological analysis were taken every 5 cm. The laboratory processing was performed in the 10% KOH solution. In order to separate pollen from mineral parts "heavy water", obtained from the mixture of KJ and CdJ_2 with the distilled water, was used. Specific weight of the obtained solution was 2.25 $g \cdot cm^{-3}$. Methodology of G. Erdtman was used for the processing of sediments. Concentration of pollen and spores in 1 g of sediment was calculated according to M. Kabajlene's method (1969). Percentage values in the palynological diagram were calculated according to the formula: AP + NAP = 100‰ (Fig. 2).

VEGETATION DEVELOPMENT AND FILLING OF THE ABANDONED CHANNEL

At the lower part of the filling silty deposits interlaminated with fine sands are found. This is zone NH-1 representing the turn of Allerød (Fig. 2). This zone corresponds to the phase *Pinus-Betula* which has been distinguished by D. Nalepka (1993). There was a predominance of *Pinus* and *Betula*, probably *Betula t. alba*, among the tree pollen. Forests with pine and birch trees overgrowing high terraces did not form compact complexes and alternated with open habitats overgrown with *Hippophaë* and *Ephedra distachya*. Mesophytes of the *Poaceae, Ranunculaceae, Rosaceae* families predominated among the grasses while *Artemisia* – among the plants of drier habitats. By the end of Allerød swamp plants – *Cyperaceae, Sphagnum* – became more abundant at the site. *Selaginell selaginoides* was also stated. *Potamogeton* and *Myriophyllum virtieillatum* predominated among hygrophytes. This provides evidence that the depth of abandoned channel was not smaller that 3–4 m. In all the samples of the zone NH-1 water weeds *Pediastrum* were stated. In this period the abandoned channel was still in contact with the active Vistula channel that is indicated by sandy interlayers and the corroded Tertiary pollen and spores occurring in the sediments.

Zone NH-2 *(Pinus–Salix–Juniperus)* refers to the development of vegetation in the Younger Dryas and has been distinguished in silty muds, which are peaty at the upper part, at the depth of 3.3–4.3 m. At the lower limit of the zone pollen concentration increases in 1 g of deposits which is related to the change in the sediment type. The boundary of plant complexes (AL/YD) has been established slightly higher which can be explained by the lag in vegetation changes with respect to climatic changes. In the

Fig. 1. Grain size composition, content of organic substance and Folk, Ward grain size distribution parameters of Nowa Huta and Łęg B profiles of abandoned channel filling (by T. Kalicki)

A – sands with gravels, B – loamy sands, C – sandy silts, D – silts, E – organic loamy sands, F – organic sandy silts, G – peaty silts with sand, H – peaty silts, I – peats with sand, J – clayey peats, K – peats; Fractions: 1 – coarse sand (–1 to 1∅), 2 – medium sand (1 to 2∅), 3 – fine sand (2 to 4∅), 4 – coarse and medium dust (4 to 6∅), 5 – fine dust (6 to 8∅), 6 – clay (above 8∅), 7 – content of organic substance made by Tiurin's method; *Mz* – mean grain size in phi scale, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis

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Younger Dryas the amount of tree pollen decreased and the role of bush pollen increased. The pine dominated among the trees. The amount of *Populus, Salix* and *Juniperus* increased when compared with the Allerød period, the pollen of *Betula nana, Ephedra dist.* were also found, and the significance of bushes of the *Caprifoliaceae* family increased as well. A similar composition of tree species in the Younger Dryas has been described of the abandoned channel profile of Rondo Mogilskie site (Mamakowa 1970). The composition of grass species became more diversified. Communities with xerophytes – *Artemisia, Chenopodiaceae, Thalictrum* expanded. Pollen of *Viscaria* and *Seleranthus*, of the *Caryophyllaceae* family, were identified and pollen of the photophillic plants *Plantago lanceolata, Heliathemum* appeared. Tall herb grassland communities of *Ranunculus, Filipendula, Umbelliferae* covered moister places on the Vistula floodplain. Among water plants *Myriophyllum, Potamogeton, Lemna* grew in the abandoned channel. Due to the overgrowing of a water body the significance of the species of a shore zone (*Typha latifolia*) and those of swampy areas (*Menyanthes trifoliata, Sphagnum*) increased. Spores of *Selaginella selaginoides* were also identified. In the studied deposits the contents of the corroded and redeposited pollen was gradually diminishing, while pollen disappered totally in the top peaty silts. This indicated progressing isolation of the abandoned channel from the active Vistula channel and a final separation by the end of the Younger Dryas, so the abandoned channel started to be overgrown with peats.

Zone NH-3 (*Betula–Pinus*), distinguished in peats at the depth of 2.8–3.3 m, corresponds to the Preboreal. The composition of tree species indicates that birch and pine-birch forest grew in the region of Nowa Huta. The occurrence of *Ulmus* pollen was characteristic. Among bushes occurred pollen of *Juniperus* while that of *Salix* had disappeared. Composition of grass species has changed. The role of *Cyperaceae, Artemisia, Chenopodiaceae, Helianthemum* decreased while significance of *Poaceae* and spores of *Polypodiaceae* increased. The increased amounts of pollen of *Menyanthes trifoliata* and of spores of *Sphagnum* indicate a progressing development of marshes in the abandoned channel. However, small exposed water surfaces where *Potamogeton* and *Typha latifolia* grew, existed in the discussed period. The lack of corroded and redeposited pollen indicates autonomous, isolated development of marsh ecosystem.

Zone NH-4 (*Pinus–Ulmus*), distinguished in peats which are slightly clayed at the top at the depth of 2.3–2.8 m, corresponds to the Boreal. The amount of *Betula* pollen decreased, the role of *Pinus* and *Picea* increased. A continuous curve of *Ulmus* began. Again pollen of *Populus* and *Salix* appeared. Pollen of *Corylus* was found by the end of Boreal. A similar composition of tree species of that period has been stated in Podgrodzie where the occurrence of *Ulmus* precedes the expansion of *Corylus* and of thermophilic species (Mamakowa, Starkel 1977). *Poaceae* predominated among grasses, the role of xeric grassland communities with *Artemisia, Cichoriaceae, Crucifereae* increased and *Chenopodiaceae* were found. Tall herb communities with *Filipendula, Umbelliferae, Rubiaceae* were typical of moister location. A similar composition of grassland communities with maximum *Poaceae* has been stated in this period in the profile of Rondo Mogilskie (Mamakowa 1970), and a very high maximum of *Gramineae* is characteristic of all the profiles in the Sandomierz Basin

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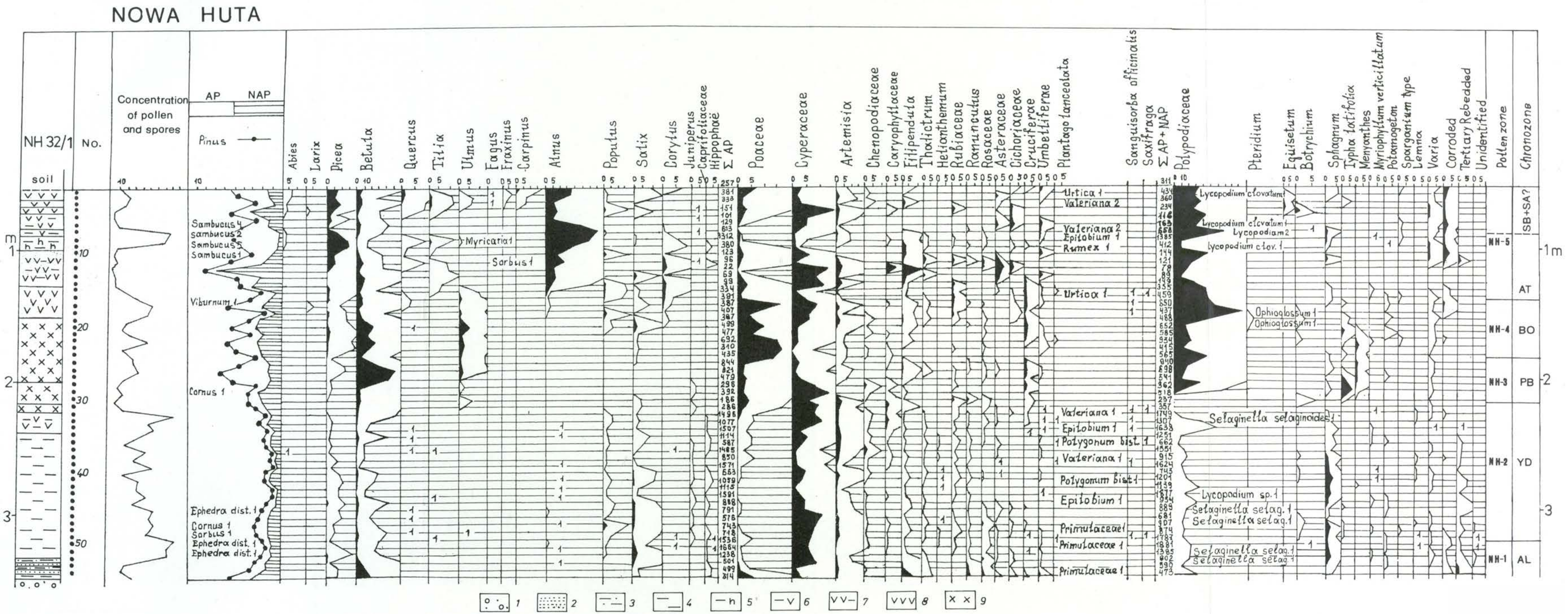

Fig. 2. Pollen diagram of Nowa Huta abandoned channel fill (by V. P. Zernickaya)

1 – gravels and sands, 2 – sands, 3 – sandy silts, 4 – silts, 5 – organic silts, 6 – peaty silts, 7 – strong clayey peats, 8 – clayey peats, 9 – peats

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(Mamakowa 1962). The above could be related to the vicinity of loess areas where forests were not compact as evidenced by the early Holocene chernozems developed in this region (Jersak, Śnieszko 1987). A significant percentage of spores of *Polypodiaceae* and admixture of pollen of *Pteridium, Ophioglossum, Botrichium,* however, evidences the expansion of woodland in the vicinity of the studied abandoned channel. By the end of the Boreal the role of hygrophites (*Potamogeton*) among the water--swamp vegetation increased, which indicates increased moisture of the peat-bog. Differentiation of vegetation in relation to lithologic-morphological conditions manifested in the Boreal. Pine forests with birch, which overgrew upland and high terraces, alternated with open steppe fragments. Forests with elm (*Ulmus*) and poplar (*Populus*), and the thickets formed by willow (*Salix*) and hazel (*Corylus*) occurred on moister habitats in the Vistula valley. The floodplain was covered with grassland communities.

A climatic change at the turn of the Preboreal/Atlantic has been reflected in a change of the deposit type and in accumulation of slightly clayed peats, and then of strongly clayed ones. Moreover, corroded pollen appeared in deposits. This provides evidence of floods reaching the peat-bog. At the palynological diagram the BO/AT border lies slightly above the change of sedimentation type. The border was drawn at the beginning of the continuous curve of *Alnus* and *Corylus* and the permanent presence of pollen of *Quercus* and *Tilia* in the spectra. At this border the role of *Poaceae* decreased and the amount of xerophytes diminished as well.

The determination of vegetation zones as well as the detailed age determination of the top sediments is impossible, although the presence of pollen *Carpinus, Fraxinus* and *Fagus* allows to correlate them to the Neoholocene (SB-SA). These sediments are formed by organic silts interlayered with peaty silts and strongly clayed peats. The origin of these sediments is associated with floods reaching the area of the peat-bog from the beginning of the Atlantic. In the spectra there are observed discrete changes in the amount of pollen of trees and grasses, a definite increase in the amount of pollen of the corroded and redeposited Tertiary spores. Thus, a more stable percentage of *Alnus* pollen should be emphasized, which can be associated with edaphic rather than with climatic conditions (cf. Brown 1988). An alder belongs to hygromesophites but it does not like excessive moisture. Numerous species of alder belong also to pioneering plants entering new alluvia and abandoned pastures. Therefore, alder thickets have overgrown loamy soils on the Vistula floodplain since the Atlantic. A significant amount of alder in the Neoholocene has also been stated in the diagram of the deposits filling the abandoned channel in Pleszów (Wasylikowa 1989)

CONCLUSIONS

The palaeobotanical studies on the filling of the abandoned channel in Nowa Huta have fully confirmed the earlier conclusions based on geological, and geomorphological data, and C-14 datings (Kalicki 1992a, c).

In the Allerød period the Vistula flew in large meanders on the northern side of the valley and was undercuting the Pleistocene terraces and alluvial fans of the Dłub-

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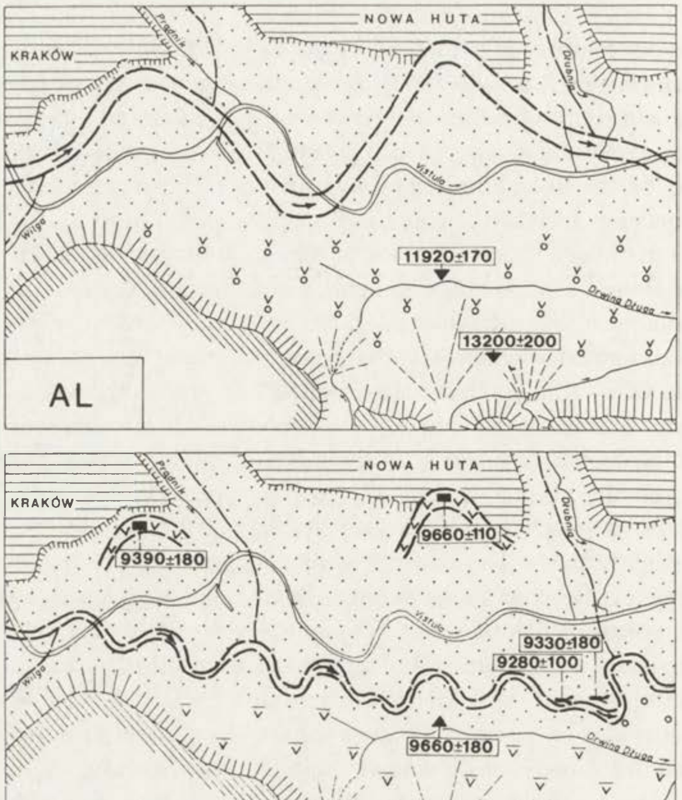

Fig. 3. Palaeogeographical reconstruction of the Vistula river valley near Nowa Huta and present situation (by T. Kalicki)

1 – morphological edges, 2 – overflood terraces of the Vistula river, 3 – Gdów Divide, 4 – active braided alluvial plain, 5 – older braided alluvial plain overgrowing by peat, 6 – peat-bogs on the older braided alluvial plain cover by muds, 7 – older braided alluvial plain cover by muds, 8 – flood plain, 9 – modern flood plain (inter-dike area), 10 – alluvial fans, 11 – dikes, 12 – present Vistula channel, 13 – reconstruction of the

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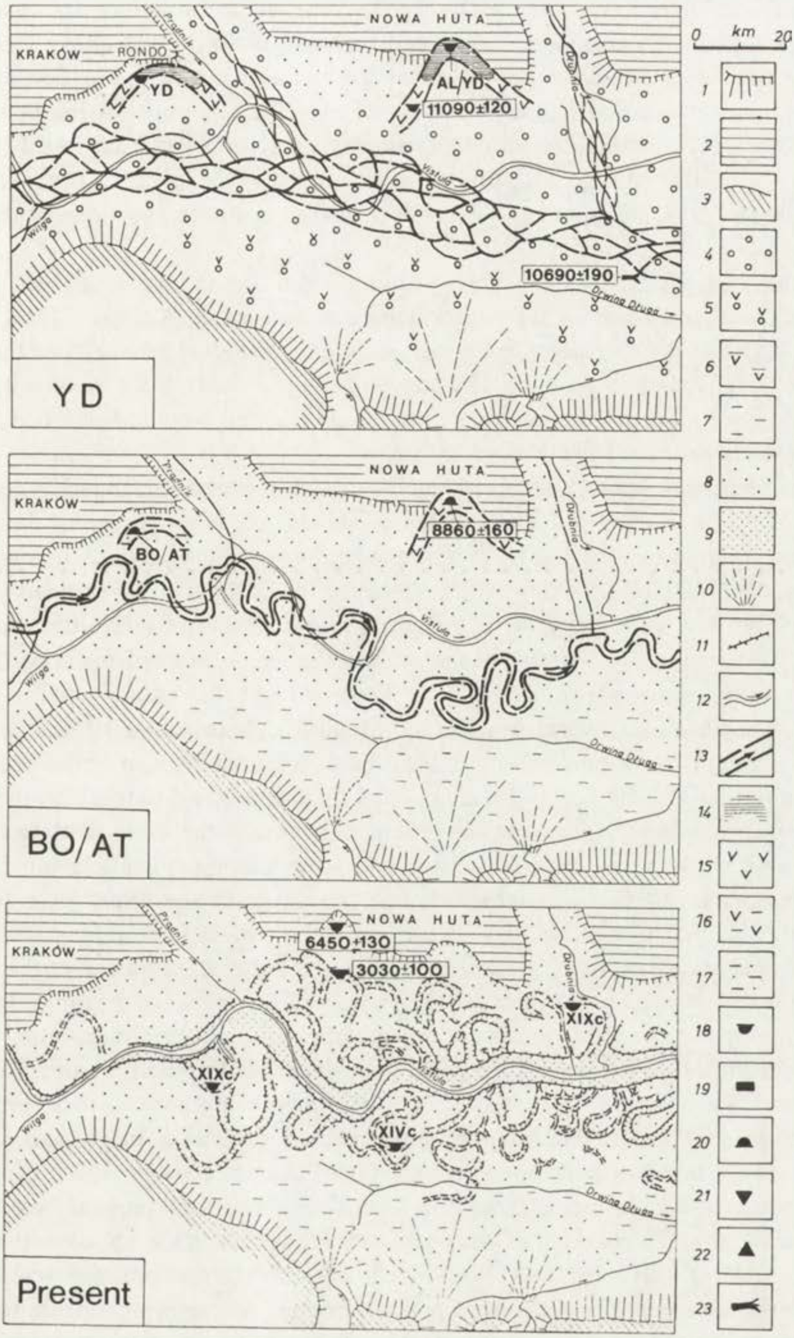

Vistula channel, 14 – oxbow lakes, 15 – peats, 16 – clayey peats, 17 – sandy muds, 18 – cut off radiocarbon, palynological (letters), historical and cartographical datings, 19 – peat initiation in abandoned channels radiocarbon datings, 20 – superposition of the muds and clayey peats on peats in abandoned channels radiocarbon and palynological (letters) datings, 21 – peat initiation on braided alluvial plain radiocarbon datings, 22 – superposition of the muds on peats on braided alluvial plain radiocarbon datings, 23 – channel deposits radiocarbon datings AL – Allerød, YD – Younger Dryas, PB – Preboreal, BO – Boreal, AT – Atlantic

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nia and Prądnik rivers (Kalicki 1991b; Fig. 3). Similarly to the abandoned channels of Rondo Mogilskie (Mamakowa 1970), and of Branice–Stryjów (Kalicki 1991b) the paleomeander in Nowa Huta was cut off by the end of this period. The deepenings in the abandoned channel occupied by water bodies of the depth not smaller than 3–4 m were initially filled with silts with sandy interlayers (Nowa Huta; Fig. 1). Peaty silts (Łęg B – 11 090±120 BP, Gd-2666) were accumulated first and then peats started to overgrow (Kalicki 1992a, c; Fig. 1, 3) in the shallower marshy sections of the channel.

In the Younger Dryas the Vistula was a braided or anastomosing river, and the active alluvial plain was in the southern part of the valley (Kalicki 1991b, 1992a; Fig. 3). In this period the larger and larger isolation of the abandoned channel in Nowa Huta as well as the overgrowing of water bodies progressed. Silty muds with sandy interlayers, which provide evidence of the floods reaching to the abandoned channel (Fig. 1), were deposited in these water bodies.

At the beginning of the Holocene the Vistula channel was meandering again and the Vistula flew ca 2 km south of the abandoned channel in the region of the Drwień depression (Kalicki 1991a, b; Fig. 3) until the beginning of the Atlantic. In this period, from 9660±110 BP (Gd-1791) to 8869±160 BP (Gd-2518), non-clayed peats (Kalicki 1987, 1988b; Fig. 1, 2) overgrew in the abandoned channel in Nowa Huta which was isolated from the active Vistula channel. In the Preboreal, in the deepest parts of the abandoned channel small, water bodies still existed and they disappeared in Boreal. At that time peats also owergrew at Rondo Mogilskie (Mamakowa 1970; Fig. 3).

The phase of intensified activity of the Vistula began at the turn of the Boreal and the Atlantic (Kalicki 1991b). In the abandoned channel at Rondo Mogilskie the covering of peats with sandy alluvial loams (overbank deposits-madas) took place (Mamakowa 1970) which was associated with the proximity of the Vistula channel. In the paleomeander in Nowa Huta, which is more distant from the river, more frequent floods inundating the whole valley bottom caused the peats to be clayed (Fig. 1–3). The contents of clay particles in these peats increased after the avulsion of the Vistula channel from the south to the north, to the vicinity of Czyżyny and Łęg in ca 8000 BP (Kalicki 1991a, b; Fig. 2, 3). During the period of the channel functioning in this region, the clayed peats grew in the abandoned channel. As shown by the profiles of Łęg B and Nowa Huta (Fig. 1) the amount of mineral substance in these peats was inversely proportional to the distance from the active channel of the Vistula (Kalicki 1992a). At the beginning of the intensified phase of river activity which caused the abandonment of the channel in Czyżyny (Kalicki 1991a, b) an increased frequency of floods resulted in the covering of the peats with sandy silts in the abandoned channel (Łęg B – 6690±130 BP, Gd 2951; Fig. 1, 3). It was only the case of the closest vicinity of the Vistula as the strongly clayed peats were still overgrowing farther from the active channel in Nowa Huta (Kalicki 1992a). It cannot be rejected that sanded peats (Fig. 1), which can provide evidence of a proximity of a channel or of larger floods, are associated with this period.

The proximity of the channel and related floods frequently inundating the peat-bog from the Atlantic already, i.e. since the moment of the Vistula avulsion from the south,

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hindered overgrowing of peats during the whole Meso- and Neoholocene (Fig. 3). Therefore, determination of the stratigraphy of their upper parts is impossible (Fig. 2).

Sedimentological and palynological records of the changes in accumulation conditions in the floodplain are found in the filling of the abandoned channel in Nowa Huta. A detailed analysis of the geomorphological layout (Kalicki 1991a, b; 1992a, b) allows for stating which changes were related to climatic oscillations and flood frequency and which ones to changes in local conditions such as location and distance from the active channel of the Vistula. However, there is also an overlap between these factors when climatic impulse was reinforced after the change of the channel position or when it disappeared due to predominance of the local conditions. In the first case, in the phase of intensified activity of the river at the turn of the Boreal and Atlantic peats became clayed more significantly after the avulsion of the Vistula channel to the north towards the abandoned channel. In the second case, during the whole Meso- and Neoholocene the proximity of the active channel caused the peats to be strongly clayed. This proximity was probably a cause of breaks in accumulation which, in turn, make impossible the reading of the climatically conditioned periods of more frequent floods from the profile.

REFERENCES

B r o w n A. G., 1988, *The palaecology of Alnus (alder) and the Postglacial history of floodplain vegetation. Pollen percentage and influx data from the West Midlands, United Kingdom*, New Phytol. 110, 425–436.

J e r s a k J., Ś n i e s z k o Z., 1987, *Zmiany środowiska geograficznego w późnym vistulianie i holocenie na obszarach lessowych Wyżyny Miechowskiej i Opatowsko-Sandomierskiej (Changes in the geographical environment in the Late Vistulian and Holocene at loess areas of the Miechowska and Opatowsko-Sandomierska Upland)*, [in:] *Wybrane zagadnienia paleogeografii czwartorzędu – holocen*, Prace Nauk. UŚl. 712, 7–24.

K a b a y l e n e M. V., 1969, *Formation of the pollen spectra and methods of reconstruction of paleovegetation* (in Russian), Trudy Inst. Geol. 2, Vilnius.

K a l i c k i T., 1984, *Budowa starorzecza Wisły w rejonie Placu Centralnego (Nowa Huta–Zalew)*, Materiały sympozjum „Holocen okolic Krakowa", 18–20 VI 1984 Kraków, 39–41.

– 1987, *Late Glacial paleochannel of the Vistula river in Kraków–Nowa Huta*, Studia Geomorph. Carpatho-Balcan. 21, 93–108.

– 1988a, *Dolina Wisły między Krakowem a Niepołomicami w późnym glacjale i holocenie*, (typewrite PhD-thesis) IGiPZ PAN, Kraków.

– 1988b, *The Late glacial abandoned channel in Nowa Huta*, Excursion Guide Book Symposium „Lateglacial and Holocene environmental changes – Vistula Basin 1988", 15–21 June 1988 Cracow, 47–52.

– 1991a, *Holoceńskie generacje paleomeandrów Wisły w rejonie Krakowa (Holocene Generations of the Vistula Paleomeanders near Cracow)*, Kwart. AGH, Geol. 17, 1–2, 25–66.

– 1991b, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

– 1992a, *Zmiany rozwinięcia Wisły pod Krakowem w późny Vistulianie w świetle nowych stanowisk w Pleszowie i Łęgu (Changes of the pattern channel of the Vistula near Cracow during*

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Late Vistulian in the light of new sites at Pleszów and Łęg), Folia Geogr., Ser. Geogr.-Phys. 23, 111–124.

– 1992b, *The structure and age of the Drwień depression interrupting the Vistula flood-plain east of Cracow (South Poland)*, Studia Geomorph. Carpatho-Balcan. 25–26, 89–113.

– 1992c, *Nowa Huta–Central Square site – Lateglacial large paleomeander*, Excursion Guide-Book, Symposium Global Continental Paleohydrology, Kraków-Mogilany 8–12 IX 1992, 36.

K a l i c k i T., S t a r k e l L., 1987, *The evolution of the Vistula river valley downstream of Cracow durign the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley durign the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 51–70.

M a m a k o w a K., 1962, *Roślinność Kotliny Sandomierskiej w późnym glacjale i holocenie (The vegetation of the Basin of Sandomierz in the Late-Glacial and Holocene)*, Acta Palaeobot. 3, 2, 1–57.

– 1970, *Late-glacial and early-holocene vegetation from the territory of Kraków (Poland)*, Acta Paleobot. 11, 1, 3–12.

M a m a k o w a K., S t a r k e l L., 1977, *Stratigraphy of Late Glacial and Early Holocene alluvia at Podgrodzie on the Wisłoka river (S Poland)*, Studia Geomorph. Carpatho-Balcan. 11, 101–110.

N a l e p k a D., in print, *Historia roślinności w zachodniej części Kotliny Sandomierskiej w czasie ostatnich 15 000 lat*, Wiad. Bot.

W a s y l i k o w a K., 1989, *Paleoecological characteristics of the settlement periods of the linear pottery and lengyel cultures at Cracow–Nowa Huta (on the basis of plant material)*, Przegl. Archeol. 36, 57–87.

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"BLACK OAKS" IN THE RECENT CENTURIES ALLUVIA OF THE VISTULA RIVER AT WOLICA NEAR CRACOW (SOUTH POLAND)

INTRODUCTION

The site in Wolica is a subsequent site in the Vistula valley between Cracow and Niepołomice in which detailed geological-dendrochronological studies have been carried out. The methods of studies and of interpretation were developed in the previous investigations (Kalicki, Krąpiec 1991a, b, 1994, 1995). Therefore, complete characteristics of the site and an outline of the complicated structure of the floodplain are possible.

The gravel pit is located ca 20 km to the east from the centre of Cracow, on the left bank of the Vistula opposite to Niepołomice. At the distance of 3 and 5 km upstream there are found the gravel pits in Branice–Stryjów and in Grabie (Kalicki, Krąpiec 1991a, b), discussed in the previous papers. The studies carried out in the 1990s were the continuation of the IGCP-158A project and were performed under the grant 6-0783-91-01 "Paleohydrological changes in the river valleys of Southern Poland during the last 20 000 years on the background of global changes".

MORPHOLOGY AND DEPOSITS

The gravel pit is located in the zone of point bars of the abandoned channel of the radius of ca 350 m (Fig. 1) which is well pronounced in morphology. In the eastern part the ca 80 m wide channel is well preserved and limited by the scarps up to 3 m high. In the western part there is a series of parallel scars which provide evidence of the channel migration downstream. These are the traces of the decline of the 18th

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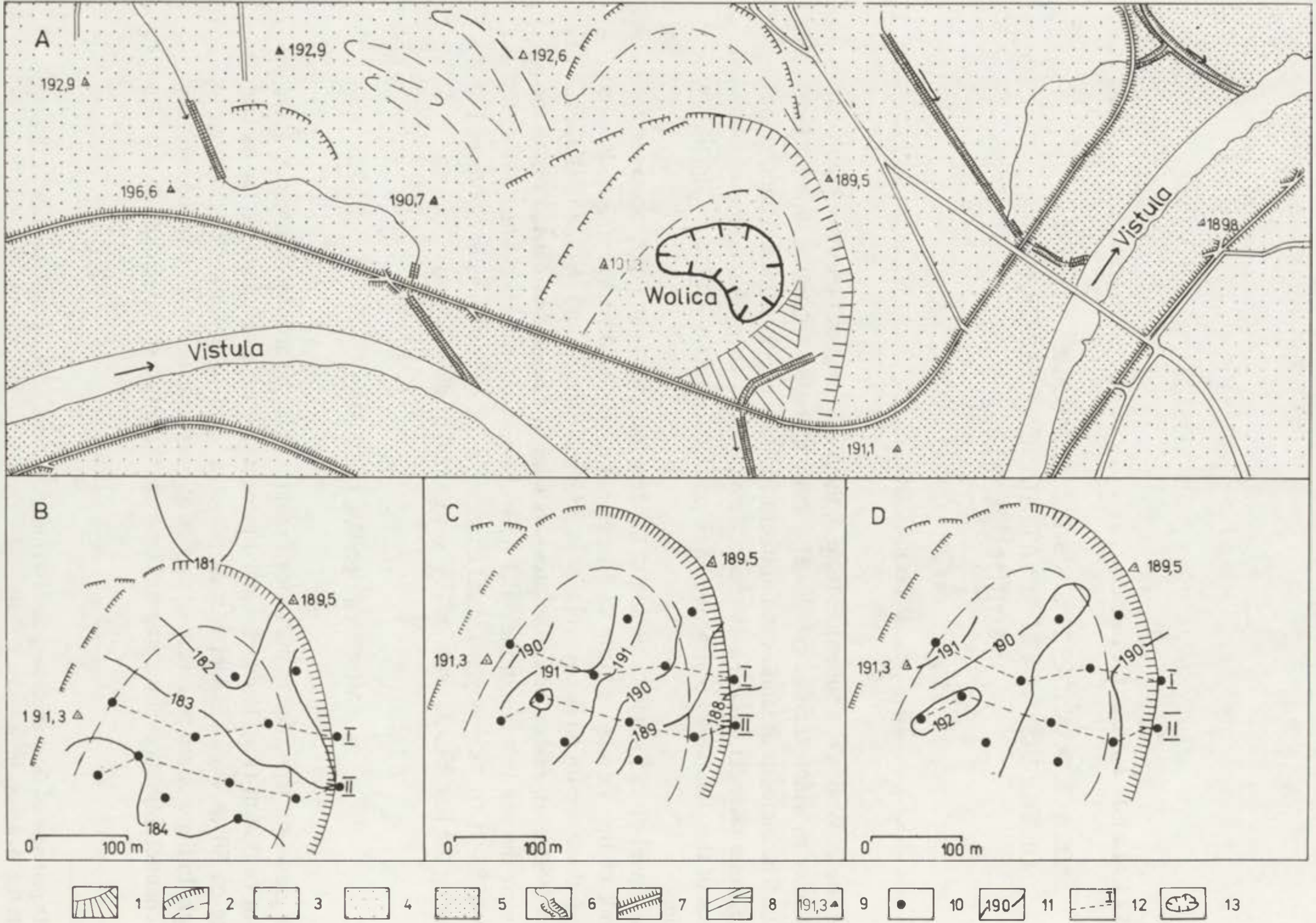

Fig. 1. Geomorphological map of the Vistula flood plain near Wolica site (A) and relief of the top of the Miocene clay (B), top of the sandy-gravel sediments (channel facies) (C), bed of overbank and abandoned channel sediments (D) (by T. Kalicki)

1 – slope of the convex meander-side, 2 – paleomeander, 3 – older flood plain (OFP), 4 – young flood plain (YFP), 5 – modern flood plain (inter-dike area), 6 – streams, 7 – dikes, 8 – roads, 9 – altitude (m), 10 – borings, 11 – isohypses (m a. s. l.), 12 – cross-section (see Fig. 2).

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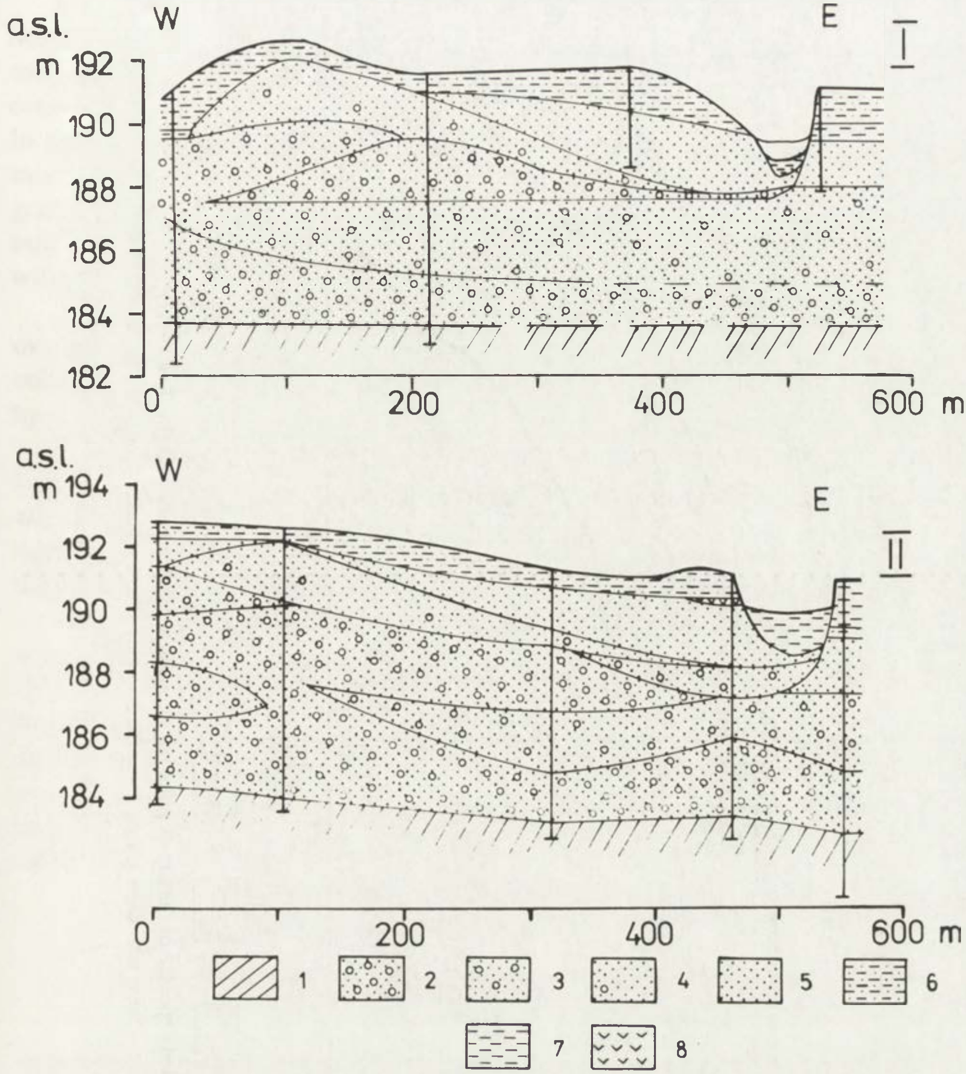

Fig. 2. Geological sections I and II across the gravel pit at Wolica site (comp. Fig. 1) (by T. Kalicki)

1 – Miocene clay, 2 – gravels and sands, 3 – sands with admixture gravels, 4 – sands with single gravel, 5 – sands, 6 – sandy silts, 7 – silts, 8 – peats

century, when the meander was moving downstream according to the "theory of wave" and reached the largest width, length, radius of curvature and extent in ca 1812, and was cut off after 1817 (Trafas 1975). During the lateral migration this channel undercut the older fragment of the floodplain preserved in the eastern part of the site. Absolute altitudes of the older fragment of the plain are lower by ca 1 m than the central part of the meander bars of the 19th century abandoned channel.

The Subquaternary relief is weakly differentiated. The top of the Miocene clays declines to the north from 184 to above 182 m a. s. l. (Fig. 1B).

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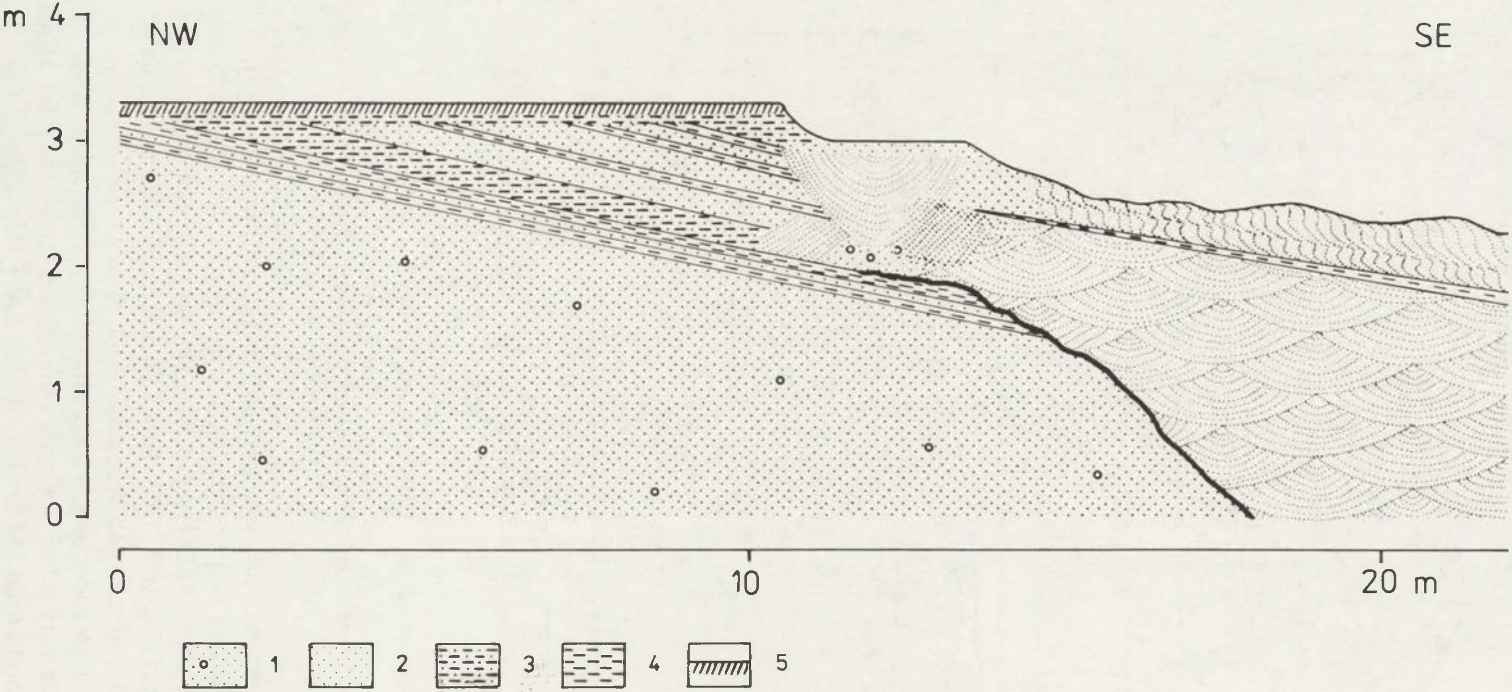

Fig. 3. Detailed exposure of the top of point bar deposits at Wolica gravel pit (by T. Kalicki)
1 – sands with single gravel, 2 – sands, 3 – sandy silts, 4 – silts, 5 – soil

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The thickness of alluvia is small and amounts to ca 8 m. The gravel-sandy member lies at the bottom of these alluvia. The top of this member corresponds well to the morphology of the abandoned channel reaching maximum (above 192 m a. s. l.) in the centre of point bars and declining towards the channel to 188.3 m a. s. l. at maximum. In the east of the site within the fragment of the older floodplain undercut by the meander the top is lower by 0.5–1 m (187.5–188.1 m a. s. l.) (Fig. 1C). On the gravel-sandy member there are sands whose thickness does not exceed 1–2 m. The sands occur in the border part of the point bar near the abandoned channel as well as within the older floodplain.

Analogously to the top of the gravel-sandy member the surface occurring under overbank deposits – mada (the top of channel deposits) is developed. It reaches its culmination in the central part of the bars and declines in the abandoned channel bed by ca 1 m (189 m a. s. l.) (Fig. 1D).

The thickness of sandy-silty alluvial loams in the zone of the abandoned channel bars is small and does not exceed several tens cm, that is typical of the youngest alluvia (cf. Kalicki, Krąpiec 1991b). The case of the older floodplain where the thickness of alluvial loams exceeds 1.5 m and silty muds are covered with sandy-silty muds is different.

Geological profiles indicate that the erosional level of the 19th century channel was ca 187.0–187.5 m a. s. l. It shows up in the deposits as a gravel enriched level (Fig. 2). Below, there is a gravel series of an unknown age. Due to a high groundwater level only the deposits of the uppermost parts of the ponit bars were available for direct observation. These bars are formed by sandy deposits of fine cross-stratification and sandy silts interlayers dipping to the channel (Fig. 3). Local washing-away horizons and erosional layers which separate the meander bars and which provide the evidence of aggradation and lateral migration of the channel are also observed here.

DENDROCHRONOLOGY

In the gravel-pit in Wolica there are numerous trunks of "black oaks" which have been dredged out of sandy-gravel and sandy channel deposits of the abandoned channel. Among subfossil trees relatively young species (60–120 years old) predominate. The oldest analysed tree was only 210 years old (it had 197 tree rings). In addition, the sizes of the trunks occurring in the deposits are "small" when compared with the neighbouring sites in Branice–Stryjów and Kujawy, and reach up to 0.9 m in diameter, and 0,5–0,7 m at average.

The subfossil oak trunks differ also as to the hue of the cross-section. Most of the trunks are characterized by dark, greyish-black colour. These trunks are lacking sapwood while on their surfaces are traces of reworking by material transported in the river. The traces are in the form of hollows and provide evidences of redeposition. Majority of trunks have a reworked root system and branches. According to the workers dredging the subfossil trunks, oaks with intensive hue lie at the depth of 5–6 m.

In the gravel-pit have also been stated the trunks and stumps of the oaks which

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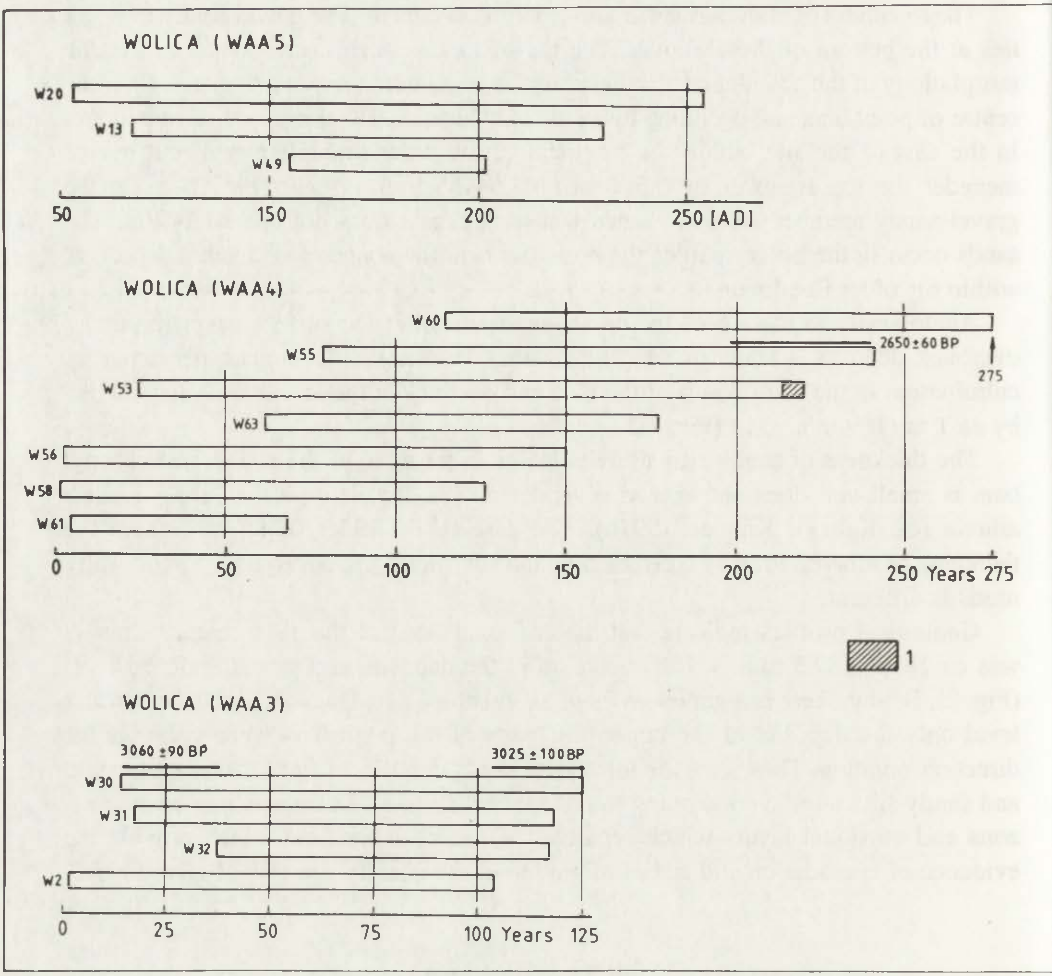

Fig. 4. Tree-ring series of the subfossil oak trunks from chronologies: WAA3, WAA4 and WAA5 (by M. Krąpiec)
1 – sapwood

were cut down with an axe and which were of almost unchanged, natural colour. The sapwood and, in most cases, the bark of these trunks are completely preserved. The stumps bear distinct traces of cutting with axes at the height of 80–90 cm above the hypocotyl. They have been dredged up from the depth of ca 2–2.5 m.

During the ongoing studies 63 samples in a form of slices were taken for an analysis. On each slice 2 to 4 core radii were selected along which the widths of annual rings with the accuracy of 0.01. mm were measured in the laboratory of the Chair of Stratigraphy and Regional Geology, Cracow University of Metallurgy and Mining. For the elaboration of the measured sequences a package of TREE-RING programmes by A. Krawczyk and M. Krąpiec were used. The performed analysis based on equal-aged samples allowed to compile chronologies which were dated by the radiocarbon method in the first stage of the studies.

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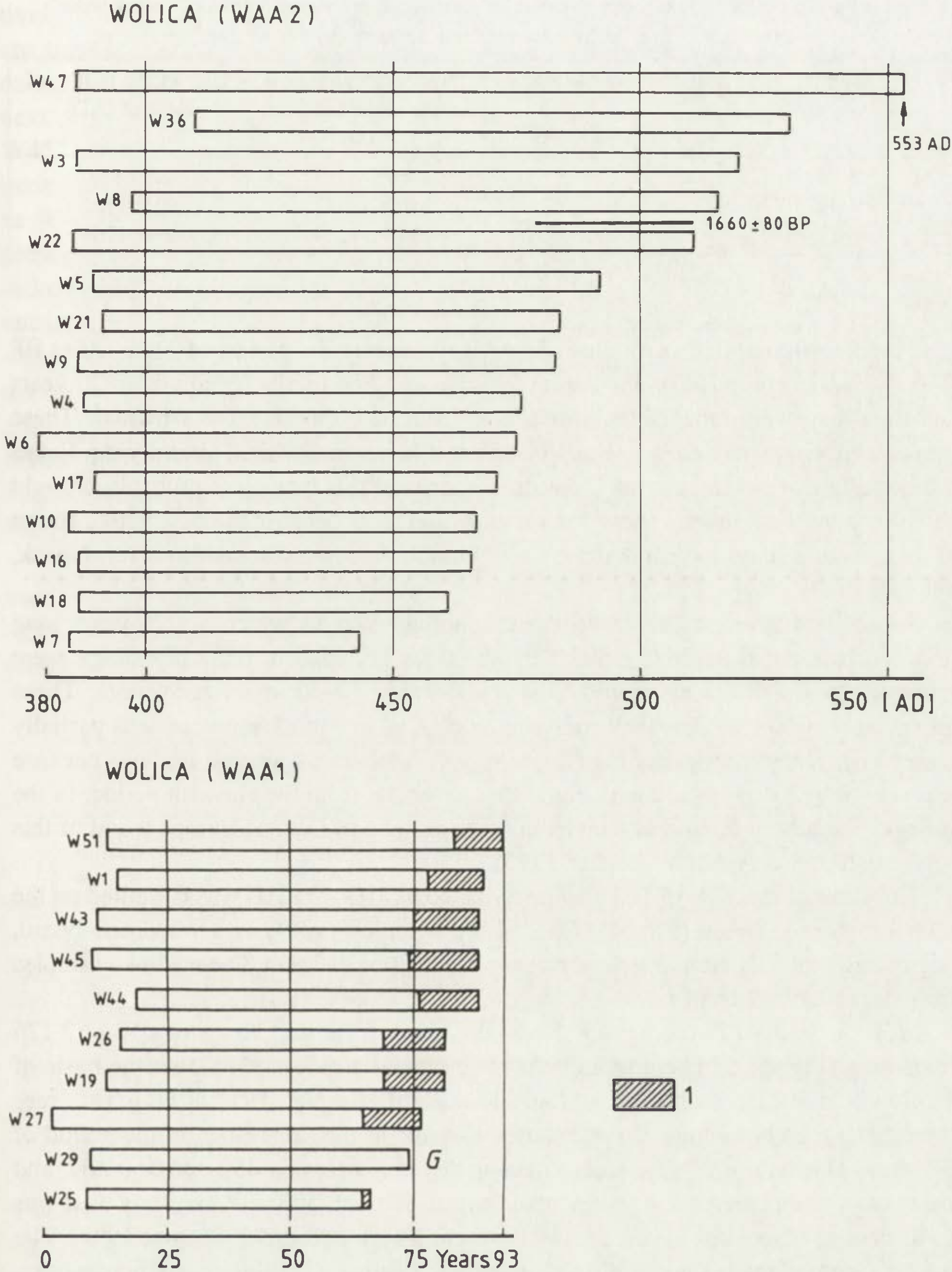

Fig. 5. Tree-ring series of the subfossil oak trunks from chronologies: WAA1 and WAA2 (by M. Krąpiec)

1 – sapwood

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T a b l e 1. Results of dendrochronological dating of the remaining trunks of "black oaks" on the basis of the Southern Poland standard (by M. Krąpiec)

Sample	Number of rings	Dendrochronological dating of the sequence (AD)	Date of the falling of the tree (AD)
W24	126	695–821	after 831
W42	106	1006–1111	after 1121
W12	91	1168–1259	after 1266

The oldest compiled chronology WAA3 represents the period of 3125–3000 BP (Fig. 4). It was compiled on the basis of 4 samples. The trunks felled within 20 years and then they were redeposited which is evidenced by the lack of sapwood. These trunks were characterized by a changed external hardwood which, after drying, flakes off into a few or several cm thick pieces. Changes of this type were probably brought about by periodical resting above the groundwater table because the destructive action of bacteria and fungi in sediments is only possible under such conditions (cf. Noack, Schwab 1983).

Subsequent seven trunks build the chronology WAA4 which is 275 years long (Fig. 4). It is dated as 2875–2600 BP. The trees included in this chronology were successively felled during almost 200 years, every 30–50 years at average. These trunks were redeposited as well (only in the case of one trunk sapwood was partially preserved). The trunks indicating chronology WAA4 are interesting findings because – as shown by the radiocarbon dating – they originate from the Halstadt period. In the valleys of southern Poland as well as in other regions of Central Europe wood of this period is found very rarely (Becker 1993).

The chronology WAA5 103 absolutely dated as 103–254 AD was compiled on the basis of three samples (Fig. 4). One of the samples (W49) is a reworked board, originating probably from a side of a canoe made after 212 AD. The next two samples are redeposited oak trunks.

Most numerous (15 pieces) are the trunks which form the chronology WAA2 176 years long (Fig. 5). This chronology has been dated at 378–553 AD on the basis of the Southern Poland dendrochronological standard (Krąpiec 1992, 1994). The trees comprising the chronology WAA2 started to grow at the same time, in the period of 20 years. The falling of subsequent trees took place between 450 and 560 AD, and majority of trees entered the sediments between 470 and 500 AD, similarly as it was in the case of other sites in southern Poland, i.a. Kujawy (Kalicki, Krąpiec 1992). The lack of sapwood made impossible a more detailed dating of falling the particular oaks. As the presented figure shows, however, the trees were accumulated successively, 1–2 every several years. Visible traces of reworking of the root system and trunk surfaces indicate that the trunks were redeposited as well.

Basing on 10 trunks and stumps of cut down oaks the chronology WAA1, 93 years long (Fig. 5), has been compiled. All samples had sapwood; it was fragmentarily and completely preserved in the case of the two oldest and the remaining samples, respec-

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tively. The oaks growing in the vicinity of the contemporary channel, whose remnants are trunks and stumps, did not complete their vegetation simultaneously. First two oaks (W27 and W25) were cut down in 77 relative year, of this floating chronology next two (W19 and W26) – five years later. In relative year 88 two oaks (W44 and W45) felled down while one was cut down by men (W43). In the next year the river undercut another tree (W1). The last of the analysed oaks was cut down 4 years later in 93 relative year. The root system in the samples felled down with an axe is preserved very well; besides the main roots there are also present those of a lower order which provide evidence that stumps rested *in situ* from the moment of their cutting down to dredging out. Two samples (outer and core rings) of the stump W27 were subjected to a radiocarbon dating. The results of dating turned out to be identical, giving a negative age (Kr-118, Kr-119; Krąpiec 1992). As there is not a definite similarity between the chronology WAA2 and rocks, elaborated from the regions distant by a few kilometres, covering the period 474 BC-1529 AD (Krąpiec 1994) and 1760–1980 AD (Bednarz 1987), one should assume that it originates from the period from the 16th to the first half of the 18th century.

Basing on the Southern Poland standard: 474 BC-1529 AD, three subsequent samples were dated (Table 1). The sample W12 comes from the beam of a triangular shape with circular bungholes, which was made after 1266 AD and whose functional purpose is difficult to determine. The remaining samples are trunks of "black oaks".

CONCLUSIONS

At Wolica site the trunks of "black oaks" of various age are found in the alluvia of the recent centuries. The frequency of the trunks in the deposits correlates well with the phases of intensified activity of the Vistula river distinguished hitherto (cf. Kalicki 1991). The first generation (WAA3) were felled during 20 years at the end of the Subboreal in the phase discussed in details in the case of the site Grabie (Kalicki, Krąpiec 1991b). In the Halstadt period trees (WAA4) gradually felled. This can be interpreted as a period of relative calmness and gradual undercuting of banks by the river and not, as it was considered by Środoń (1952), as a period catastrophic floods at the beginning of the Subatlantic. Next trunks originate from the Roman period (WAA5). The trunks of this period are common in the Vistula alluvia near Cracow (Kalicki, Krąpiec 1991a; Krąpiec 1992). At it is known from the site of Branice–Stryjów (Kalicki, Krąpiec 1991a) the Vistula channel was deeply incised at that time. This resulted in the lowering of the groundwater level on the floodplain. The trunks of generation WAA3 lying at the upper part of the Subboreal channel deposits were above the groundwater table and were exposed to destructive action of bacteria and fungi. By the end of the 3rd and 4th centuries the frequency of floods decreased which can be evidenced by the lack of trunks in alluvia and the placement of the settlement on the floodplain 3 km NW of Wolica near Wyciąże. The subsequent phase of felling the trees (WAA2) was at the turn of the 5th and 6th centuries and coincides with the older generation of trunks (KAA2) at Kujawy site (Kalicki, Krąpiec 1992). The

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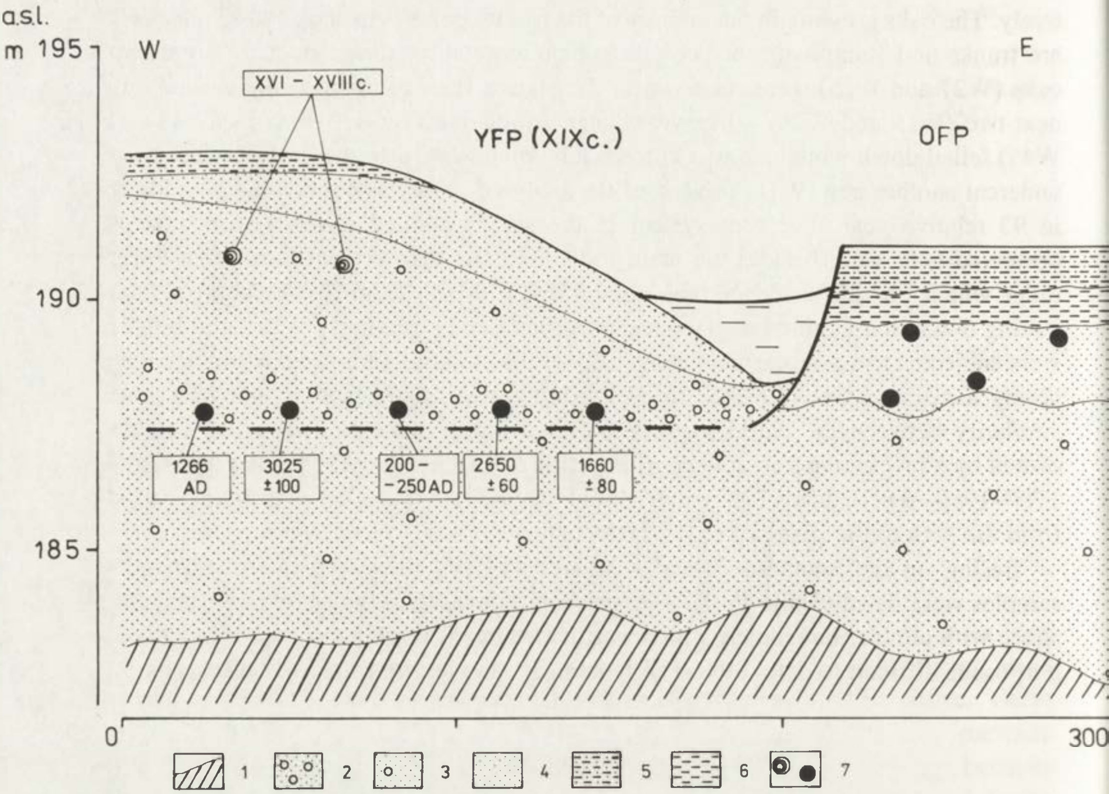

Fig. 6. Stratigraphical scheme of alluvia exposed in the gravel pit at Wolica site (by T. Kalicki)
1 – Miocene clay, 2 – gravels and sands (lag deposits), 3 – sands with admixture gravels, 4 – sands, 5 – sandy silts, 6 – silts, 7 – subfossil oak trees: young (light) and old (black), OFP and YFP – see Fig. 1

youngest generation (WAA1) is associated with the Little Ice Age. Similarly as in the case of Kujawy and Branice–Stryjów sites (Kalicki, Krąpiec 1991a, 1992) aggradation lasting since the early Middle Ages allowed for preservation of the fossil, 16th–18th centuries floodplains with standing stumps. It is the evidence that the aggradation tendency lasted until the 19th century and just then changed to the opposite one.

At Wolica site in the alluvia of the recent centuries the redeposited trunks of oaks from the period from 3000 BP to the Medieval together with the trunks of the modern age (16th–18th C.) resting *in situ* are found (Fig. 6). This is a classic example of “simulate aggradation” (cf. Kalicki, Krąpiec 1994, 1995). The older, redeposited trunks lie at the depth of ca 5–6 m. They were washed out of the older alluvia and, being heavier than water, accumulated secondarily at the lag level of the 19th century channel. The younger trunks resting *in situ* were accumulated in the upper parts of the point bars at the depth of 2–2.5 m. As a result, in the channel alluvia two “trunk horizons” rest one above another – the older at the lower part and younger at the upper part. The patterns of this type were interpreted in former papers as two series of alluvia of different age, providing evidence of aggradation (e.g. Awsiuk *et al.* 1980; Alexandrowicz *et al.* 1981). However, this is one series of alluvia in which two horizons of

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trunks are found, namely in the lag level and in the upper part of channel deposits. Such series is exclusively formed by lateral migration of a meandering channel and by the washing of the older alluvia by a river.

REFERENCES

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E., Pazdur M., Starkel L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, (L. Starkel ed.), Folia Quater. 53, 1–91.

Awsiuk R., Niedziałkowska E., Pazdur A., Pazdur M., Starkel L., Walanus A., 1980, *Preliminary results of studies on the age of the Holocene alluvia at the left bank of the Wisłoka river near Dębica*, Studia Geomorph. Carphatho-Balcan. 14, 33–42.

Becker B., 1993, *An 11.000 year German Oak and Pine chronology for Radiocarbon calibration*, Radiocarbon 35, 1, 201–213.

Bednarz Z., 1987, *The 225-years tree-ring chronology of the oak (Quercus robur L.) in the Niepołomice Forest near Kraków*, Dendrochronologia 5, 59–68.

Kalicki T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

Kalicki T., Krąpiec M., 1991a, *Black oaks and Subatlantic alluvia of the Vistula in the Branice–Stryjów near Cracow*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 39–61.

– 1991b, *Subboreal black oaks identified from the Vistula alluvia at Grabie near Cracow (South Poland)*, Kwart. AGH, Geol. 17, 1–2, 155–171.

– 1992, *Kujawy site – Subatlantic alluvia with black oaks,* Excursion Guide-Book, Symposium Global Continental Paleohydrology, Kraków-Mogilany 8–12 IX 1992, 37–41.

– 1994, *Problemy datowań form i aluwiów za pomocą metody dendrochronologicznej na przykładzie doliny Wisły koło Krakowa (Problems in dendrochronological dating of alluvial sediments – selected examples from the Vistula river valley near Cracow)*, Zesz. Nauk. Polit. Śl., Mat.-Fiz. 71, Geochronometria 10, 173–189.

– 1995, *Problems of dating alluvium using buried subfossil tree trunks: lessons from the "black oaks" of the Vistula Valley, Central Europe,* The Holocene 5, 2, 243–250.

Krąpiec M., 1992, *Skale dendrochronologiczne późnego holcenu południowej i centralnej Polski (Late Holocene tree-ring chronologies of South and Central Poland)*, Kwart. AGH, Geol. 18, 3, 37–119.

– 1994, *Subfossil oak chronology (474BC-1529AD) from Southern Poland*, Abstracts International Conference on Tree-Rings, Environment and Humanity: Relationships and Processes, Tucson 17–21 V 1994, 39.

Noack D., Schwab E., 1983, *Technological properties of archaeological woods*, Mitt. Bund Forsch-Anst. Forst-Holzw. 141, 103–121.

Środoń A., 1952, *Ostatni glacjał i postglacjał w Karpatach (Last Glacial and Postglacial in Carpathians)*, Biul. PIG 67, Z badań czwartorzędu w Polsce 3, 27–76.

Trafas K., 1975, *Zmiany biegu koryta Wisły na wschód od Krakowa w świetle map archiwalnych i fotointerpretacji (Changes of the Vistula river bed east of Cracow in the light of archival maps and photointerpretation)*, Prace Geogr. UJ 40, 5–85.

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EVOLUTION OF THE VISTULA VALLEY AND OF ALLUVIAL FANS OF THE RABA AND USZWICA RIVERS BETWEEN UŚCIE SOLNE AND SZCZUROWA IN THE VISTULIAN AND HOLOCENE

OUTLINE OF THE PROBLEM

Channel avulsion is a typical feature of valleys of wide bottoms, gently sloping basins and alluvial fans in subsiding areas at a mountain foreland (Kvitkovic, Vanko 1972; Mike 1975; Borsy, Felegyhazi 1983; Borsy 1990). The concept of the structure of the fans of the Wisłoka, Wisłok and San rivers, consisting of a few inserted series of alluvia has been presented by L. Starkel (Starkel 1960; Alexandrowicz *et al.* 1981; Starkel *et al.* 1991) and by U. Schreiber (1985) and G. Schellman (1990) in the case of the Alps foreland. In the Sandomierz Basin, avulsion of channels refers to the wide alluvial plains abandoned by the Vistula river and by the outlet reaches of the Carpathian tributaries in the Plenivistulian and in the late Vistulian (Mycielska-Dowgiałło 1978; Gilot *et al.* 1982; Niedziałkowska *et al.* 1985; Sokołowski 1987; Kalicki 1991) as well as to the 1–1.5 km wide alluvial ridges which accompany the system of the Holocene paleochannels (Strzelecka 1958; Gębica, Starkel 1987; Starkel *et al.* 1991) known in literature as meander belts (Allen 1965; Gradziński 1973).

The aim of the paper is to learn the structure and evolution of relief of the Vistula valley section and of the outlet reaches of the Raba and Uszwica rivers in the Vistulian and Holocene. A particular attention has also been paid to learning the mechanism of alluvial fan formation. The typology of the alluvial fans and the sections of the Vistula valley bottom in the western part of the Sandomierz Basin was attempted.

Under the IGCP-158A programme entitled "Paleohydrology of the temperate zone during the last 15 000 years" and CPBP 03.13 programme entitled "Evolution of the environment of Poland", both led by Prof. L. Starkel, the section of the Vistula valley between Cracow and the Raba mouth (Kalicki, Starkel 1987; Gębica, Starkel 1987; Starkel *et al.* 1991; Kalicki 1991) and the section between the Dunajec and Breń

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outlets (Sokołowski 1987) have been studied. The studies that have been carried out hitherto in the section between Uście Solne and Szczurowa referred to the Witów series and the Pleistocene fans of the Raba and Dunajec rivers (Łomnicki 1903; Łyczewska 1948; Dżułyński *et al.* 1968; Izmaiłow 1975; Sokołowski 1988).

A broad range of methods were used in this work; in addition to geomorphological mapping at the scale of 1:10 000, several outcrops were examined and 30 geological drillings were performed with the help of the "Geomeres" drill. About 250 grain size analyses were made in the laboratory of the Department of Geomorphology and Hydrology, Polish Academy of Sciences in Cracow. For lithological characteristics grain-size indices were calculated according to R. L. Folk and W. C. Ward (1957). In order to determine the age and origin of deposits paleobotanical, paleontological and petrographic expertises as well as 17 radiocarbon datings were made (Table 1).

STUDY AREA

The study area comprises the 13 km long section of the Vistula valley and the alluvial fans of the Raba and Uszwica together with the outlet reaches of small tributaries of the Gróbka and Uszewka streams (Fig. 1). The Vistula undercuts the scarp of Działy Proszowskie hills. This scarp is built of the Miocene clays which, at the valley bottom, are overlain with the lower Quaternary Witów series, and some moraine till of the San Glaciation as well as with the loess in which there are some layers of fossil soils. On the left bank of the Vistula river there is a small fragment of the terrace with the loess cover of the height of 13–15 m above the river level while on the right bank there is a fragment of the young Pleistocene terraces of the Vistula river which are 6–10 m and 15–20 m above the channel level. The extent of the Dunajec alluvial fan is marked by gravel-sandy outliers surrounded by floodplain deposits occurring on the left bank of the Uszwica river and the dunes located at the margin of the Radłowska Plain. In this section the Uszwica river flows along the splayed surface of the Dunajec fan and forms the 4 km wide and 5 km long alluvial fan at the outlet to the Vistula river. Near the outlets of the upland tributaries the alluvial fans are absent because they have been undermined by the Vistula channel. The Vistula flood plain at the section down from the Raba mouth is only 2 km wide. This is a subsequent section of the Vistula valley down of the Cracow Gate where the floodplain is so narrow. Within the floodplain there are singular abandoned channels cut off due to breaking of a meander neck. Upstream the Raba mouth as well as to the east of the Uszwica river the floodplain width increases to 4–7 km. In these wide sections of the floodplain there occur the systems of the Holocene paleochannels which have been abandoned due to avulsion and which are separated by wide depressions.

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Table 1. Collection of the radiocarbon datings

Profile No.	Type of material	Deph [m]	Laboratory No.	Date B.P.	Comments
Włoszyn					
Wł –1	peaty mud	2,05–2,10	Gd–5704	39 100±3000	alluvial fan
Gróbka					
Gr – 1–1	peat	2.45–2.50	Gd–6248	11 860±160	floodplain
Gr – 1–2	peat	1.89–1.94	Gd–5730	10 820±120	floodplain
Gr – 1–3	peat	1.78–1.82	Gd–6656	10 020±140	floodplain
Strzelce Małe					
STM – 10–1	peat	3.53–3.58	Gd–5729	11 560±120	floodplain
STM – 11–1	peat	1.85–1.90	Gd–6279	8090±120	floodplain
STM – 11–2	peat	2.23–2.30	Gd–5835	9480±120	floodplain
STM – 11–3	peat	2.90–3.00	Gd–6499	11 800±170	floodplain
STM – 4–1	peat	4.30–4.35	Gd–5726	7210±80	paleochannel filling
STM – 4–2	peat	3.57–3.64	Gd–6661	6670±130	paleochannel filling
STM – 8–1	peat	1.95–2.00	Gd–6348	2620±100	paleochannel filling
STM – 8–2	sticks in mud	3.10–3.15	Gd–4822	3670±110	paleochannel filling – possible redeposition
Szczurowa					
Sz – 1	peat	4.03–4.08	Gd–2927	10 440±200	floodplain
Sz – 2	peat	4.28–4.33	Gd–5411	11 300±140	floodplain
Uście Solne					
US – 1–6	peat	2.20–2.25	Gd–5960	2710±60	paleochannel filling
US – 2–7	peat	3.55–3.60	Gd–5961	10 640±110	floodplain
US – 3–7	tree trunk	3.10–3.25	Gd–5974	7220±80	channel deposits – possible redeposition

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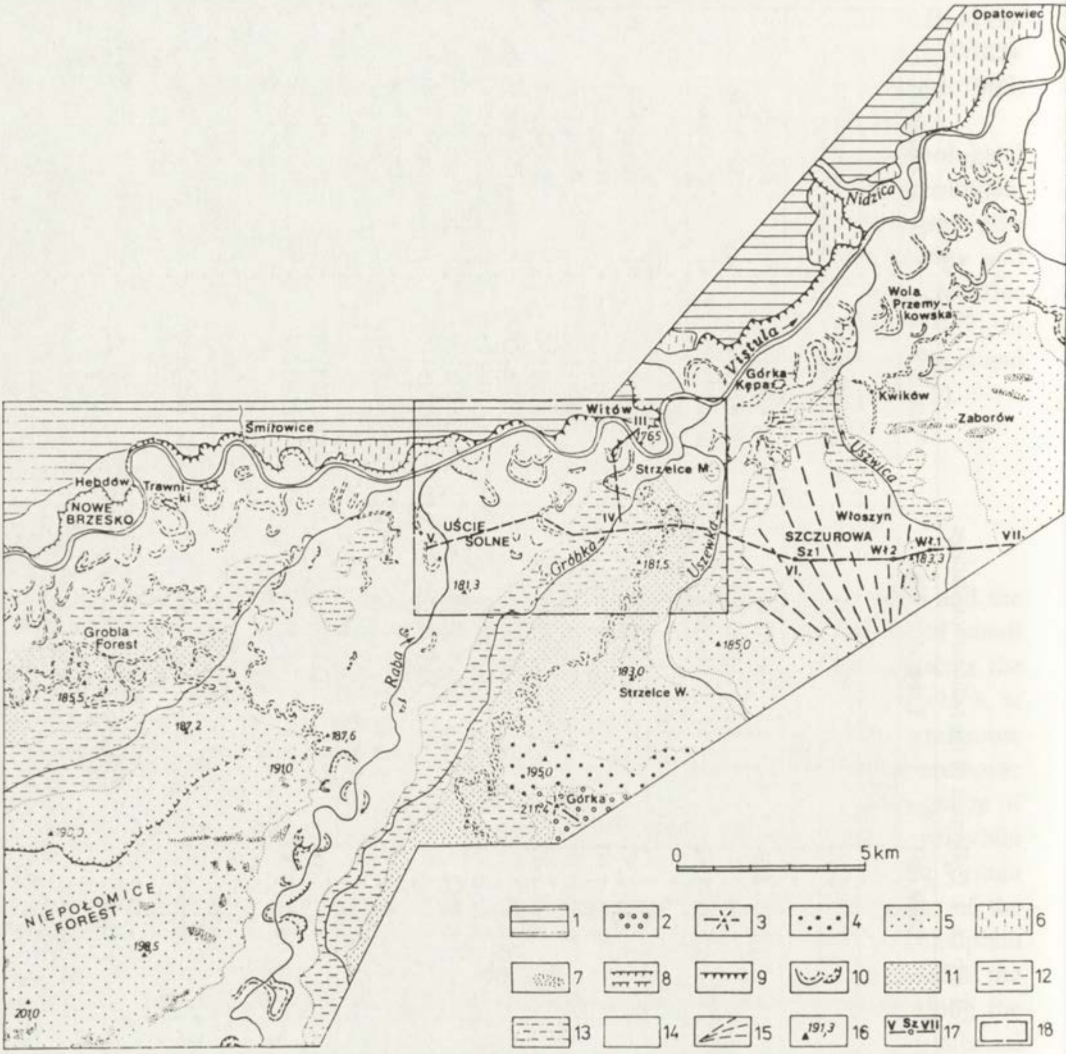

Fig. 1. Geomorphological map of the Vistula valley between Nowe Brzesko and Opatowiec

1 – Działy Proszowskie Upland covered by loess, 2 – denuded morainic and glacifluvial plateaus from the Sanian glaciation, 3 – residual hills, 4 – middle terrace (Odranian or Wartanian?), 5 – Vistulian terraces and fans, 6 – Vistulian loess-covered terrace, 7 – dunes, 8 – erosional scarps below 10 m, 9 – erosional scarps, above 10 m, 10 – paleochannels, 11 – old alluvial ridges with paleochannel abandoned by avulsion, 12 – depressions of Late Vistulian age, 13 – swampy floodbasins, 14 – contemporaneous alluvial ridges, 15 – Holocene alluvial fan of Uszwica, 16 – elevations in metres, 17 – geological transects with localities described in text, 18 – area of detailed studies

RELIEF AND THE PLEISTOCENE DEPOSITS OF THE VISTULA VALLEY TERRACES AND OF THE DUNAJEC ALLUVIAL FAN

On the left bank of the Vistula river there is a fragment of the terrace which is 13–15 m high above the river level. In Trawniki the lower face of the terrace is built of sands which are TL dated to be of the lower Plenivistulian (Gębica 1993). These

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sands are overlain by silts and the upper Plenivistulian loess with terrestrial malacofauna and aquarius malacofauna in places (Alexandrowicz, Jersak 1991). In the Vistula valley, in the settlement of Górka–Kępa there is a sandy-gravel outlier which occurs within the extent of the floodplain and which is 4 m high above the channel level. A petrographic analysis has shown that the limestone gaizes occur among gravels of the grain size class of 8–16 mm. The gaizes discussed originate from the Szreniawa drainage basin and were deposited at the river mouth when the Vistula channel was ca. 1.5 km farther to the east. By analogy to the TL dated sands of Trawniki the sandy-gravel cover of the outlier should probably be related to the lower Plenivistulian. In Włoszyn, on the Dunajec alluvial fan, at the height of 6.5 m above the river level the rivers have accumulated peaty muds in the Interplenivistulian. These peaty muds are dated as 39 100±3000 BP. The composition of a pollen spectrum points to the presence of open birch-pine forests in this area.

THE STRUCTURE AND AGE OF THE VISTULA FLOODPLAIN

The structure and the age of the Vistula floodplain is exemplified by profile US18 which is located 1.2 km south of the present Vistula channel (Fig. 2). The thicknesses of the channel alluvia in the cross-section of the valley bottom is 7–9 m while that of the overbank deposits is 2–4 m. The oldest deposits in profile US18 are the pre-Allerød sands with gravels and silty muds located 2 m below the present level of the Vistula channel and covered with peat which, at its upper face, at the depth of 3.55–3.60 m, is dated as 10 640±110 BP (Fig. 3B). The overtopping is formed by the member of the 3.5 m thick overbank deposits which is lithologically tripartite. The floodbasin clays occur at the lower face, the floodplain silts – in the middle, and the clays occur again found at the top face.

THE RABA ALLUVIAL FAN

The Raba river builds the 12 km wide, 10 km long alluvial fan of the gradient of 0.6–0,7‰ in the outlet section to the Vistula river. Within this fan, on the right bank three 1–1.5 km wide meander bands are found. The first band includes the present-day channel-marginal zone of the Raba river while two others accompany the system of the Holocene paleomeanders abandoned due to avulsion. In the region of Strzelce Małe the system of such paleomeanders, exceeding 10 km in length, consists of the older meanders which are 24.1 m wide on the average and whose mean radius of curvature is r = 119 m as well as of the sinuous paleochannel located centrally (w = 24.6 m, r = 91 m). On the both sides of the abandoned system of the paleomeanders there are flat bottom depressions of Gróbka and Uszewka where there are not any traces of paleochannels. On the left bank of the Raba, below the edge of the Pleistocene fan there is the 3.5 km long paleochannel undermining the system of paleochannels in the Grobla Forest.

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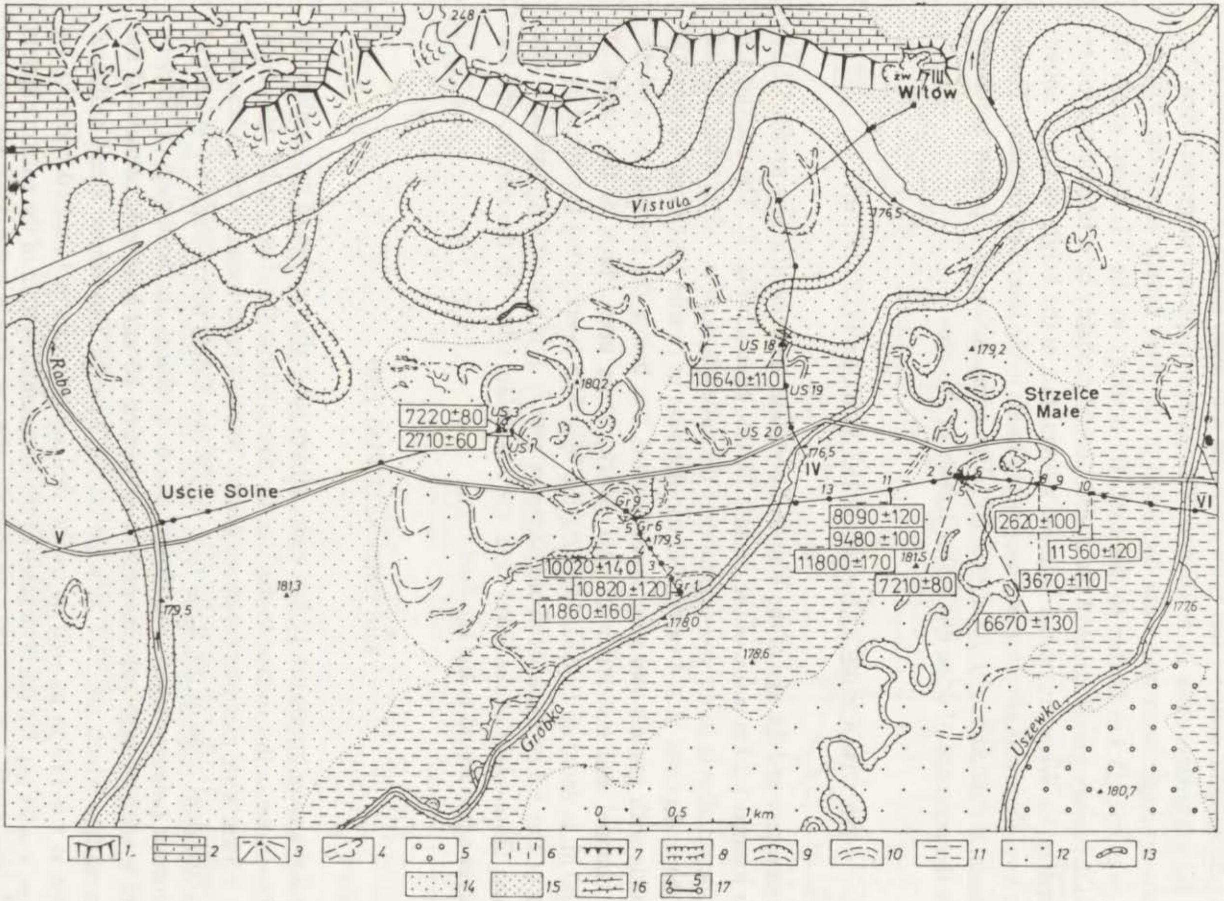

Fig. 2. Geomorphological map of the Vistula floodplain and Raba alluvial fan east of Uście Solne

1 – Upland edges, 2 – Działy Proszowskie Upland covered by loess, 3 – residual hills, 4 – erosional valleys, 5 – Vistulian terrace, 6 – Plenivistulian loess covered terrace, 7 – erosional edges, 5–10 m, 8 – erosional edges, below 5 m, 9 – paleochannels, 10 – crevass troughs, 11 – Late Vistulian Gróbka and Uszewka depressions, 12 – old alluvial ridges with paleochannel systems abandoned by avulsion, 13 – levees, 14 – contemporaneous alluvial ridges, 15 – floodplain between embankments, 16 – embankments, 17 – line of the detailed geological transects (with numbers of borings)

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STRUCTURE OF THE FLOOD PLAIN AND THE AGE OF THE ABANDONED SYSTEM OF THE RABA PALEOMEANDERS IN UŚCIE SOLNE

Between the present-day channel-marginal zone of the Raba river and the depression of Gróbka there is a fragment of the plain where a redeposited tree trunk rests on channel sands at the depth of 3.10–3.25 m. This trunk has been dated as 7220±80 BP (Fig. 3A). Silty-sandy and silty overbank deposits (drillings US2 und US3), building the levee of the paleochannel which is 28 m wide on the average and has a large radius of curvature (r = 145–315 m), rest over the sands. The fill of the paleochannel, at its lower face, is formed of silty muds and gyttia with sand inserts and of peat resting ca. 1 m above the lower face. This peat is dated as 2710±60 BP (drilling US1). Thus, one can infer that the channel was cut off and abandoned before 2700 BP.

STRUCTURE AND STRATIGRAPHY OF THE ALLUVIA OF THE GRÓBKA DEPRESSION

In profile Gr1, located in the central part of the depression, the sands with an admixture of gravels as well as the medium and fine sands are covered with sandy and silty muds containing plant detritus. Peat of the thickness of 0.62 m lies above. Dark, floodbasin, humus clays and gray clays, which are 1.78 m thick, form the overtopping. The sample from the lower face of the peat, from the depth of 2.45–2.50 m has been dated as 11 860±160 BP, while that from the top of the peat, from the depth of 1.89–1.94 m has been dated as 10 820±120 BP. Therefore, the peat corresponds to the inerstadial Allerød. The next peat overlying the clays, at the dept 1.78–1.82, has been dated as 10 020±140 BP, which corresponds to the beginning of the Holocene. The pollen analysis confirms the results of the ^{14}C-datings. A similar sequence of sediments occuring in profile STM11 (cf. Fig. 3A) in the 0.85 m thick peat has been dated at the lower face as 11 800±170 BP and at the upper face – as 9480±100 BP, which indicates that organogenic accumulation progressed continuously until the Younger Preboreal. The next layer of the 0.15 m thick peat, dated at the upper face as 8090±120 BP, overlies the 0.2 m thick layer of clays. Above there is the 0.9 m thick layer of floodplain silts muds with an admixture of sands. This layer indicates increased flood accumulation at the beginning of the Atlantic. At the top of the discussed profile there are clays.

THE STRUCTURE AND THE AGE OF THE ABANDONED SYSTEM OF THE RABA PALEOMEANDER IN STRZELCE MAŁE

In the wide meander band the oldest are the sediments filling the fossil abandoned channel (drillings STM4) and resting on the channel alluvia ca. 5 m below the present-day Raba channel. The fill embodies silty muds and peat with fragments of wood. This peat is dated at the lower face as 7210±80 BP, and at the upper face as 6670±130 BP.

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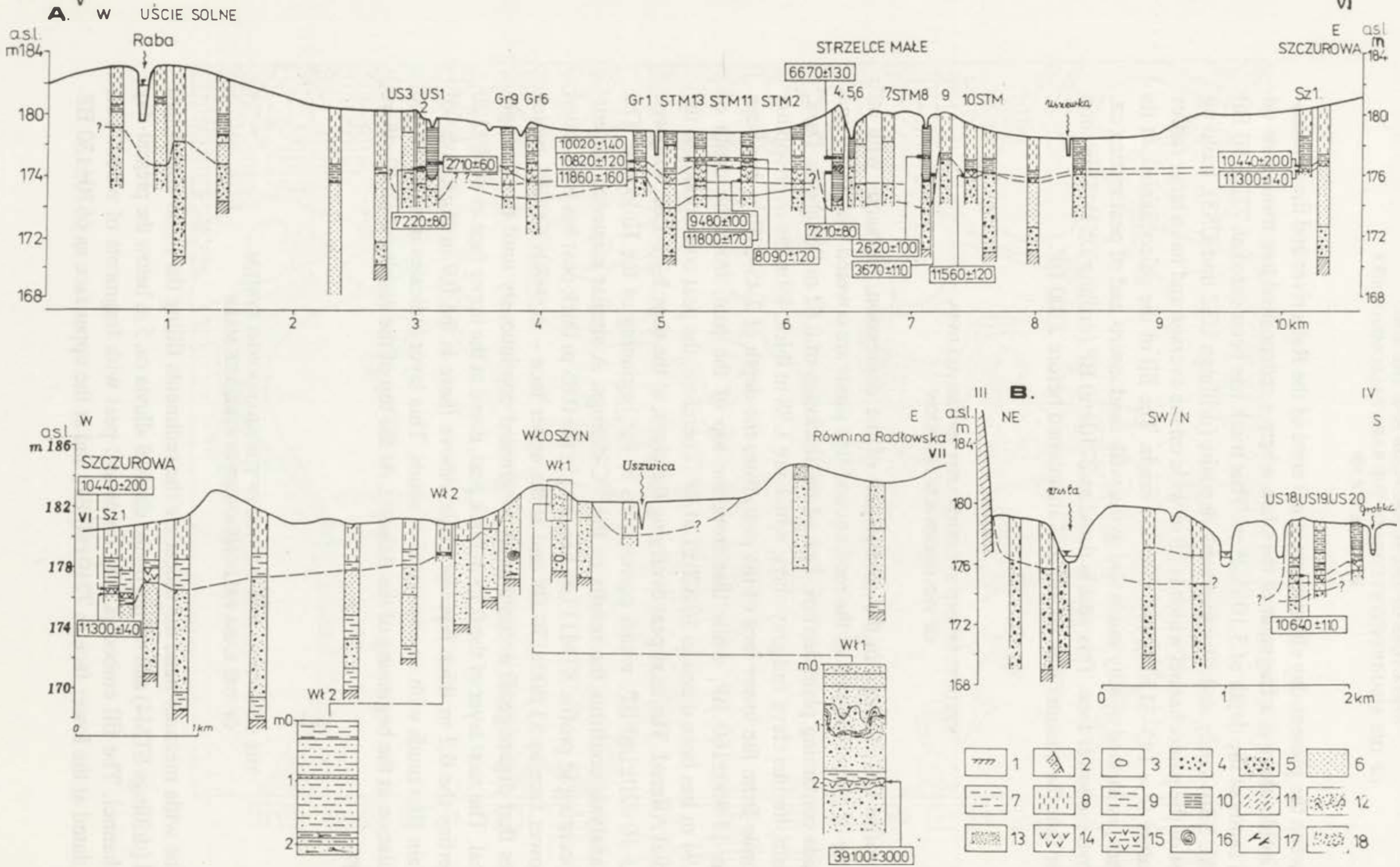

Fig. 3. A. Geological section across the Raba and Uszwica alluvial fans between Uście Solne and Szczurowa.
B. Geological section across the Vistula floodplain near Uście Solne

1 – Miocene clay, 2 – Lower Quaternary Witów series, 3 – erratics, 4 – gravels, 5 – sands with gravels, 6 – sands, 7 – sandy muds, 8 – silty muds, 9 – silty clays, 10 – clays, 11 – alluvial fan deposits, 12 – involutions, 13 – dune sands, 14 – peat, 15 – peaty muds, 16 – tree trunks, 17 – detrit plant, 18 – Holocene soil

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The latter date marks the beginning of accumulation of the levee deposits. The formation of the levee is associated with the functioning of the paleochannel of the older generation (drilling STM5) in which the upper face of the channel sands is 2 m below the present-day level of the Raba channel. The sinuous channel which extends over 10 km constitutes the youngest generation. In drilling STM8, the fill of the paleochannel at its lower face consists of silty muds and fine sands with fragments of redeposited pieces of wood dated as 3670±120 BP. Above there are peaty muds and the peat dated at the lower face as 2620±100 BP.

THE STRUCTURE AND THE AGE OF THE USZEWKA PLAIN

The structure of the Uszewka plain is very similar to that of the Gróbka depression. In the drilling STM10, directly on sands and gravels of the diameters up to 4 cm rests the 0.35 m thick peat, sanded at the lower face, dated at the depth of 3.53–3.58 m as 11 560±120 BP, which is also confirmed by the results of the palynological analysis. Clays and dark steel-blue clayey silts occur over the peat, and above it there are silty and silty-sandy levee deposits.

THE STRUCTURE AND STRATIGRAPHY OF THE USZWICA FAN

At the outlet to the Vistula valley the Uszwica river builds the alluvial fan which is 4 km wide, 5 km long and of the gradient of 1.4‰. The fan slopes gently towards the Vistula floodplain (cf. Fig. 1).

In the outcrop at Szczurowa (Sz1), at the lower face exposed are the channel sands with singular gravels (cf. Fig. 3A). The 0.35 m thick peat with fragments of pine wood rests on the sands. From the archive drillings it results that the peat and organic silts occur both to the north and south, in the distance of 300–400 m, of the discussed outcrop and merge with the peat of the Uszewka depression in the west. The 2.05 m floodbasin clays occur over the peat. These clays are humus clays dark steel-blue at the lower face and grayish above. At the upper face of the outcrop there is the 1.4 m thick gray-brown silty-sandy floodplain (35% of sand) at its lower face and silty--clayey at its upper face. The sample from the lower face of the peat, from the depth of 4.23–4.28 m has been dated as 11 300±140 BP while that from the upper face as 10 440±200 BP. The accumulation of the peat took place in the Allerød and the Younger Dryas. The beginning of the peat deposition is synchronous with the beginning of the organogenic accumulatioin in the Uszewka depression. The peats dated at their lower faces as 11 300 BP indicate the pre-Allerød age of the wide alluvial plain being the extension of the Gróbka and Uszewka plains to the east. The deposits building the alluvial plain are not related to accumulational action of the Uszwica river. The silty and silty-sandy floodplain deposits of the Uszwica alluvial fan were deposited in the late Atlantic and Neoholocene (per analogy to the dated profiles from Strzelce Małe).

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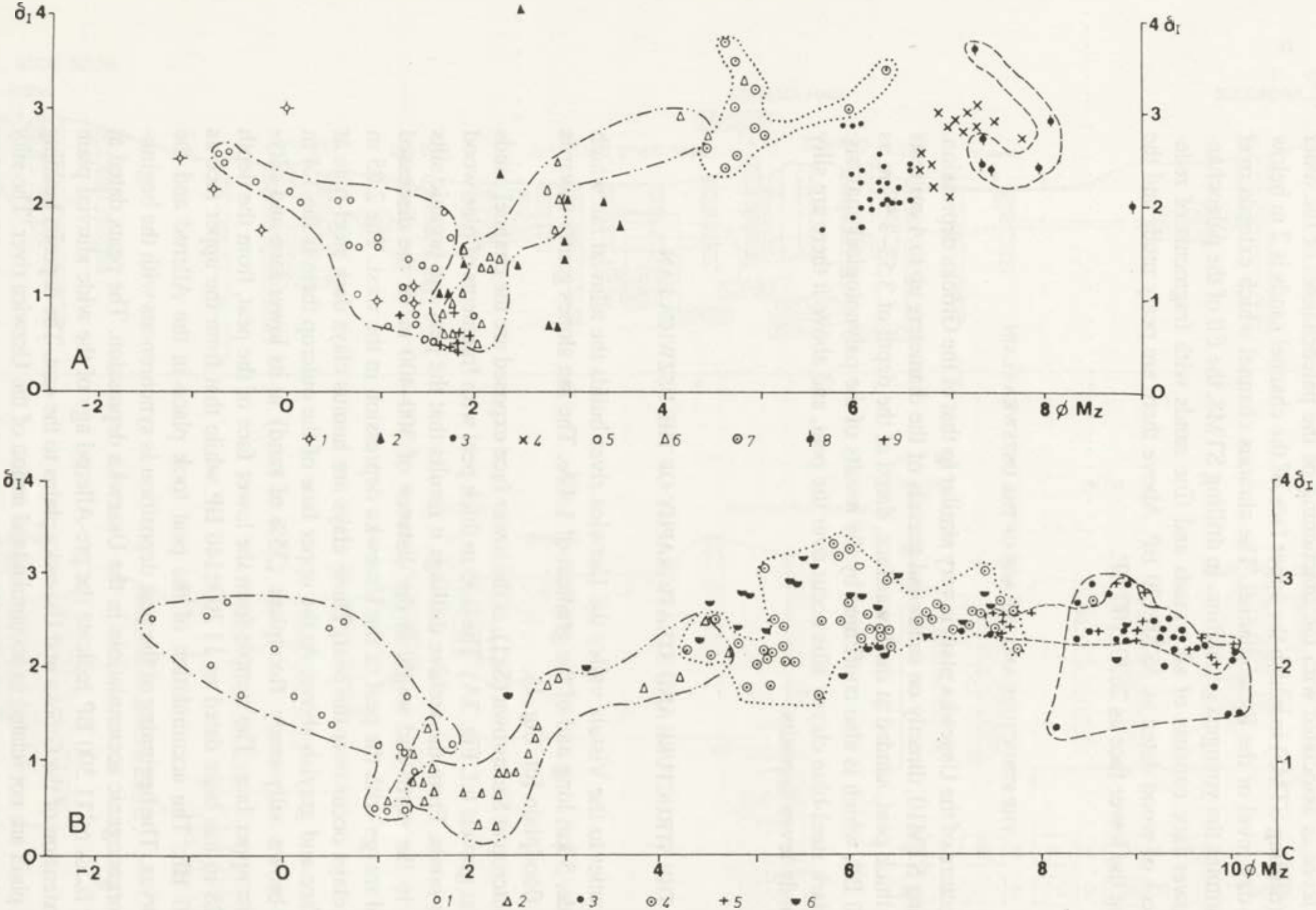

Fig. 4. Sedimentological characteristics of different types of sediments. Ratio of mean diamiter *Mz* to standard deviation δ_I

A. Deposits of Vistulian age. PLV: 1 – channel lag, 2 – channel sand bars, 3 – loess, 4 – silty clay; pAL: 5 – channel lag, 6 – channel sand bars, 7 – silty muds; YD: 8 – floodbasin clay, 9 – eolian sands.

B. Deposits of Holocene age. PB-SB: 1 – channel lag, 2 – point bar sands; PB–BO: 3 – floodbasin clay; AT–SB: 4 – silty muds; SB–SA: 5 – floodbasin and floodplain silty clay and clay, 6 – paleochannel fill deposit, different age. PLV – Plenivistulian, pAL – pre–Allerød, YD – Younger Dryas, PB – Preboreal, BO – Boreal, AT – Atlantic, SB – Subboreal, SA – Subatlantic

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SEDIMENTOLOGICAL CHARACTERISTICS OF THE FACIES DEPOSITS OF VARIOUS AGES

In the graphs presenting the relationship between the standard deviation (δ_I) and the mean diameter (*Mz*) channel deposits, overbank deposits and channel fill deposits have been distinguished according to Allen's classification (1965). Eolian deposits make a separate class (Fig. 4).

The deposits of the terraces and alluvial fans of the Carpathian tributaries are very differentiated with respect to their grain size composition. The Plenivistulian channel aluvia of a braided river are characterized by a large diversity *Mz* from –1,1 to 3.5∅. In the site Strzelce Wielkie the predominating sediments are sandy-gravel deposits with large proportion of the grain size larger than 8 mm. The sediments filling the paleochannels of a braided river are silts and silty sands (*Mz* = 2.8–3.5∅). The above indicates large diversity of water flow dynamics in various parts of braided channels on an alluvial plain (Kozarski *et al.* 1988).

The pre-Allerød deposits comprise channel alluvia which are composed of fine gravel with sand (*Mz* = –0,8–1.7∅), and the channel sands, which become finer (*Mz* = 1.5–3.0∅) towards the upper face. The overbank deposits are silty and sandy muds (*Mz* = 4.5–6,5∅). Of the younger Dryas there are clayey silts and dark, steel-blue, humus clays (*Mz* = 7–9∅) deposited during slight and infrequent floods in wide backswamps.

The Holocene channel deposits of the Raba meandering system of Strzelce Małe comprise channel lag deposits (*Mz* = –1.5–1.7∅) and sandy pointbars (*Mz* = 1.2–4.7∅) which are best sorted among the alluvial deposits (Rotnicki, Młynarczyk 1989).

The Holocene overbank deposits comprise the dark, floodbasin, humus clays (*Mz* = 8–10∅) whose beginning of the sedimentation has been dated as 10 000 BP. During the Mesoholocene, from ca 8000 BP, there were formed silts (*Mz* = 5–7∅) accumulated in the area of the wide levee zones and of the Uszwica alluvial fan as well as clays (*Mz* = 7–10∅) deposited far from the active meandering channel in the backswamps (the Drwinka stream). In the Neoholocene floodbasin clays silts were formed within the area of the abandoned zones of the paleomeanders which were rarely inundated in the later periods as well as floodplain silty-sandy deposits in the zones of the present-day meander bands of the Vistula and Raba. The abandoned channel fills are built of both the mineral and organic deposits (*Mz* = 2.5–9∅).

The author has not stated significant differences in grain size and shape indices between the alluvial deposits of various ages which were deposited in the Vistula valley and on the Raba fan. Slight differences in the grain size of the overbank deposits manifest in the floodplain and on the alluvial fan of the Uszwica river where silty *madas* accumulated in the late Atlantic and Neoholocení predominate. The overbank deposits of the Uszwica river are slightly coarser, it means that the value of *Mz* is on the average 1–1.5∅ smaller than in the case of the overbank deposits of the Vistula and Raba rivers. It is related to the small discharges of the Uszwica river and to the small catchment area which is built of silty deposits of the Pogórze Wielickie Upland mainly in its upper parts. In the Vistula valley and in its Carpathian tributaries,

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in the werstern part of the Sandomierz Basin E. Niedziałkowska (1991) has evidenced the lack of relationship between the grain size composition of the overbank deposits and the climatic factors controlling magnitudes and frequency of floods. The influence of the climate and changes in vegetation on grain size differentiation of the overbank deposits manifests only at the turn of the late Vistulian and the Holocene, when the floodbasin clays deposited during slight and infrequent floods were formed. On the other hand, the influence of the distance form the active channel of the Vistula river and its tributaries on the grain size differentiation of the overbank deposits is very pronounced. The silty-sandy levee deposits were formed in the vicinity of levees and their slopes, floodplain silts – farther out, and clays – in the backswamps. Spatial differentiation of the grain size of the overbank deposits is observed only in the case of the meandering river in the Holocene and it is not observed in the late Vistulian overbank deposits when braided rivers functioned.

CONCLUSIONS

The oldest element at the bottom of the Vistula valley is the sandy-gravel cover building the terrace outliers of the height of 1.5 m high above the floodplain in the settlement of Górka–Kępa (cf. Fig. 1). By analogy to the TL dated sands at the lower face of the loess terrace in Trawniki these deposits should probably be related to the lower Plenivistulian (Gębica 1993). At that time, vast alluvial fans of the Raba and Dunajec rivers were accumulated. The alluvial fan of the Dunajec reached beyond the contemporary Uszwica channel in the west, which is evidenced by the gravel-sandy cover of the outlier in Włoszyn (Fig. 5).

This cover is composed with Dunajec gravels (sandstone, granit and quartzite clasts (Sokołowski 1981). The accumulation of peaty muds at the height of 6.5 m above the river level, on the Dunajec fan in Włoszyn in the Interplenivistulian, which have been dated as 39 100±3000 BP points to the abandonment of the plain by the Dunajec and to the erosional deepening of the channels known from other sections of the valleys in Poland (Mycielska-Dowgiałło 1987; Rotnicki 1987; Harasimiuk 1991).

In the upper Plenivistullian, on the left-bank terrace of the Vistula, the youngest loess was accumulated (Alexandrowicz, Jersak 1991). The aquarius malacofauna commonly occurring in Trawniki indicates, according to Alexandrowicz, the presence of shallow alases. The inserts of sands and gravels in Śmiłowice provide evidence of the formation of the loess terrace with contribution of slope material. The deepest incision into the Vistula valley and the Raba fan must have taken place before the Allerød because the wide alluvial plain of Gróbka and Uszewka located 1–3 m below the present-day channels has been covered with the peat dated from 11 800 to 11 300 BP (cf. Fig 5). The Uszwica river flew over the dissected surface of the Vistulian fan of the Dunajec river and was depositing organic silts on the channel deposits. In the younger Dryas, 10 800–10 400 BP, the organogenic accumulation on the Raba fan and in the Vistula valley was interrupted by the deposition of clays. At the period, the Raba river probably flew in the braided channel to the west of the Gróbka depression. In the

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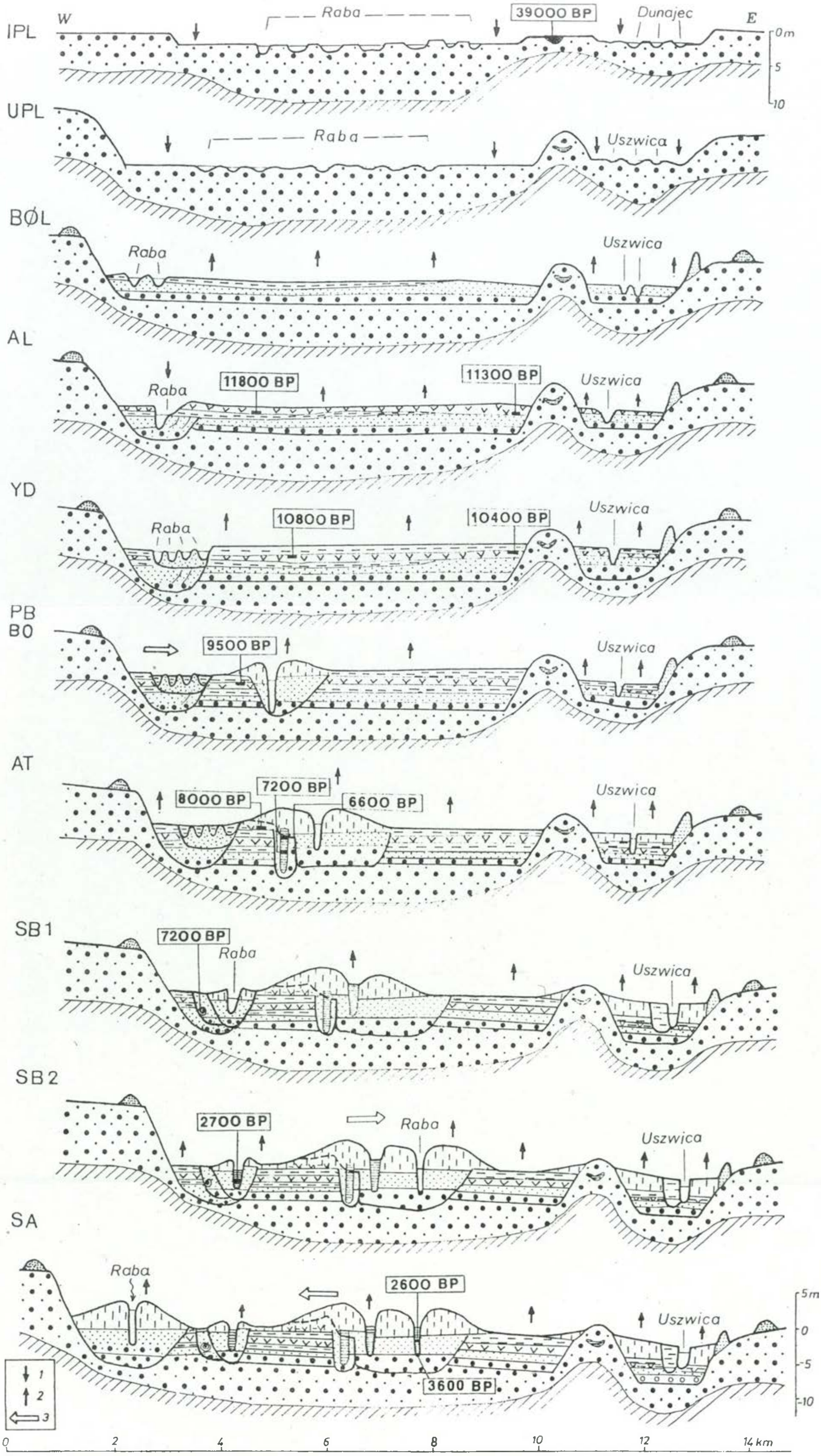

Fig. 5. Evolution stages of the Raba and Uszwica alluvial fans during Vistulian and Holocene

IPL – Interplenivistulian, UPL – Upper Plenivistulian, BOL – Bölling, AL – Allerød, YD – Younger Dryas, PB – Preboreal, BO – Boreal, AT – Atlantic, SB1 – Older Subboreal, SB2 – Younger Subboreal, SA – Subatlantic

Lithological signs see fig. 3. 1 – erosion, 2 – accumulation, 3 – channel avulsions

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farther located sites which were not inundated the peat accumulation lasted continuously until 9500 BP. In the older Holocene due to the change from the channel pattern to the meandering one wide depressions in the Vistula valley were abandoned (Starkel *et al.* 1991; Kalicki 1991). The plains of Gróbka and Uszewka in the vicinity of the Vistula and Raba channels have been dissected and infilled with the younger alluvia. The oldest fossil abandoned channel had been incised into the plain 2 m deep and was abandoned before 7200 BP. On the Gróbka plain silty floodplain deposits covering the peats dated as 8090±120 BP accumulated (cf. Fig. 5).

In the Atlantic period both the Vistula (Gębica, Starkel 1987) and the Raba river aggraded and were forming the alluvial ridges located by 1–1.5 m above. On the Raba fan the accumulation of levees was marked from ca 6700 BP. At that time the Uszwica river started to heap up its alluvial fan accreting the late Vistulian-early Holocene plain of the Vistula river. This caused the Vistula to be pushed to the edge of the upland. The evidences of the above can be found upstream the Raba outlet where the system of the paleochannels was abandoned because of the intensified flood activity of the Vistula due to the channel shift before 5100 BP (Gębica, Starkel 1987; Starkel *et al.* 1991). In the older Subboreal period the Raba channel was abandoned and Raba shifted to Strzelce Małe where is the second paleochannel system abandoned by avulsion before 2600 BP (cf. Fig. 5). From that time the Raba channel migrated towards the west, which is evidenced by numerous abandoned channels of larger and larger geometric parameters, by arc-like undercuttings and meander scars cut off from the edge of the dunified Raba fan. After the avulsion of the Raba channel to the west, within the abandoned zones of the paleomeanders which were rarely flooded in the later periods, floodbasin silty-clay deposits were forming. During on avulsion of the Raba channel to the west, to the margin of the Pleistocene fan the undercutting of the Vistula paleomeanders in the Grobla Forest took place and, then, the meanders became covered with the Raba overbank deposits. The progressing aggradation in the valley bottoms is evidenced by the covering of the late Roman and early Medieval storage pit occurring on the slope of the Skała hill (Starkel 1967; Żaki *et al.* 1970) with the Vistula overbank deposits. In the few recent centuries the curvature and widths of the meanders increased due to the larger flood frequency, and then the meanders were cut off (Trafas 1975). The wide, present-day alluvial ridges of the Raba and Vistula rivers, built mainly of the silty-sandy overbank deposits, have been formed. Due to channelization in the mid 19th century, cutting the meanders off and setting the embankments the river downcutting reached 0.7 m in the region of the Raba mouth (Punzet 1981). Predominance of erosion over accumulation in the interembankment area of the Vistula river is documented by R. Dembowski (1984). Only the largest floods (eg those of 1934, 1972) break through the embankments and inundate the whole area.

FINAL REMARSK

The phenomenon of the channel avulsion and the accompanying permanent migration of the Vistula channel to the north onto the edge of the Małopolska Upland is

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characteristic of the western part of the Sandomierz Basin. Such phenomena are typical of the wide valley bottoms and of the basins of small gradients as well as of the alluvial fans, especially in the subsiding areas at the mountain foreland. However, channel shifts are insufficient evidence of descending neotectonic movements assumed by S. Połtowicz (1967) and K. Mike (1975). As early as the decline of the Vistulian already, the wide plain braid of the Vistula and of the outlet reaches of the Carpathian tributaries were abandoned and changed into swampy depressions (Mycielska-Dowgiałło 1978; Gębica, Starkel 1987; Sokołowski 1987; Kalicki 1991). Analogous forms have been described by W. Schirmer (1988) from the Rheine river.

The author seeks the cause of the Vistula channel migratioin in the alluvial fans which sloping at the gradient of 0.6–0.7‰ and supplying significant amounts of material were pushing the Vistula onto the edge of the upland. In the sections narrowed by the fans of the Raba and Uszwica the modelling of the 2 km wide Vistula flood plain consisted in cutting off the singular meanders. In the 5–7 km wide sections of the Vistula valley and on the alluvial fans, during intensified flood activity there were: fast accretion of levees, formation of the meander bands accompanying the Holocene system of meandering channels and, as a result, avulsion of the channels.

The avulsion occurred at the beginning of the Holocene, 8400–8000 BP, 6500–6000 BP, 5400–5000 BP and 3000–2800 BP, which corresponds to the moister periods and to the large and more frequent floods (cf. Starkel 1983; Kalicki 1991). The last avulsion of this type occurred on the Wisłok fan due to huge floods in the historic period (Strzelecka 1958). The phase 8400–8000 BP distinguished on the Raba fan is associated with the beginning of the formation of the alluvial ridges within which accumulation of levees started from ca 6700 BP. These phases are in agreement with the phases of intensified river activity in the temperate zone distinguished by Starkel (1983).

When analysing the study reach and when comparing it with other parts of the Sandomierz Basin the author has distinguished two types of alluvial fans and two types of the sections of the Vistula valley bottom (Fig. 6, 7).

A. The type of the wide alluvial fan from the mountain foreland. Such a fan is up to several kilometers wide and its gradient is 0.60–0.70‰. Within the area of the fan there is the Holocene system of paleomeanders which primarily dissected the late Vistulian plain. As aggradation was progressing wide alluvial ridges were formed and then became abandoned due to avulsion. The alluvial ridges are separated by depressions. The examples are the fans of the Raba, San and Wisłok rivers (Strzelecka 1958; Starkel 1960) as well as the fans of the Wisłoka and Dunajec rivers at the outlet to the Vistula valley. In the sections where the fans are developed the bottom of the Vistula valley is narrowed.

B. The type of the narrow alluvial fan of the width up to 5 km and gradient of over 0.70‰ at the direct Carpathian foreland. Within the area of this fan the younger alluvia of the Holocene terraces were deposited in dissections of the older terraces as the zone of the river activity became narrower. The examples are outlets of the terraced valleys of the Wisłoka, Dunajec and Soła rivers (Starkel *et al.* 1982; Klimek 1987; Sokołowski 1988).

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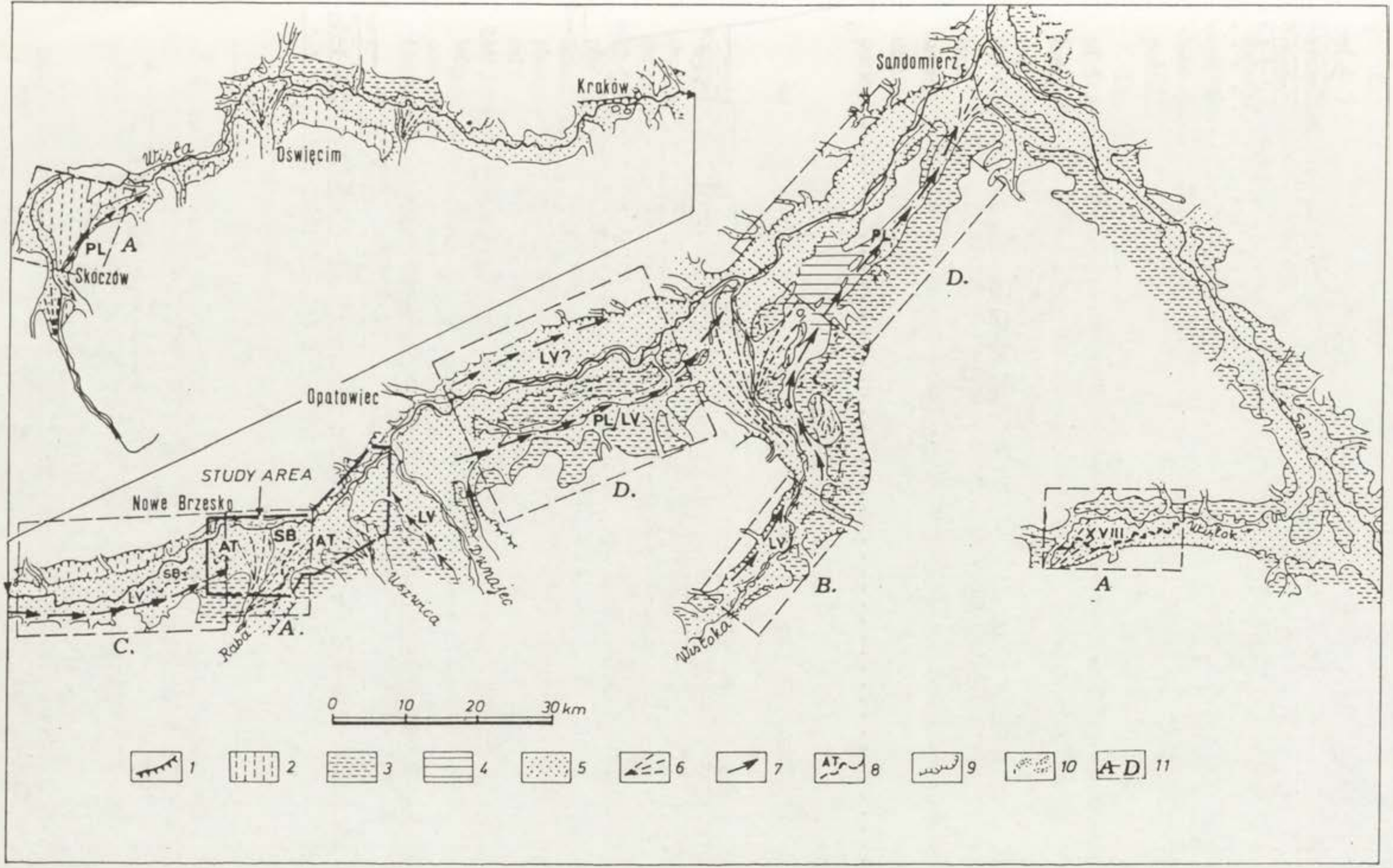

Fig. 6. Geomorphological sketch of the Upper Vistula valley (by L. Starkel 1990, modified by Gębica 1993)

1 – plateau edges, 2 – loess-covered Vistulian terrace, 3 – Vistulian alluvial fans and terraces, 4 – Late Vistulian terrace, 5 – Holocene alluvial plain, 6 – Late Vistulian and Holocene alluvial fans, 7 – depressions used by Vistula and tributaries in Upper- and Late Vistulian, 8 – paleochannel systems abandoned by avulsion, 9 – terrace edges, 10 – dunes, 11 – types of alluvial fans and sections of the Vistula valley bottom (explanations see text); PL – Plenivistulian, LV – Late Vistulian, AT – Atlantic, SB – Subboreal

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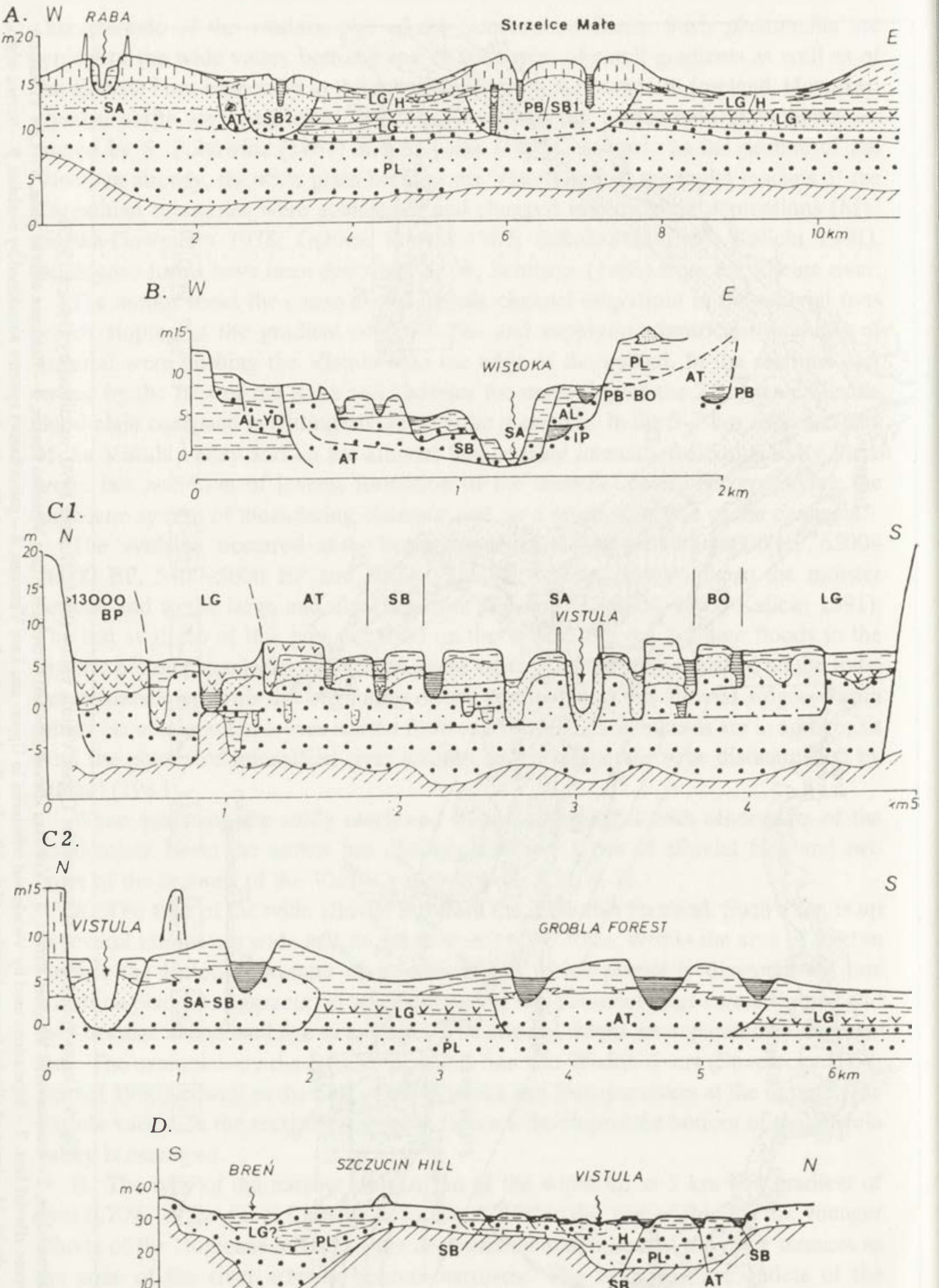

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C. The type of the bottom of the main valley (of the Vistula valley) of the width of 4–7 km and of the gradient of 0.27‰. Within the area of this valley, among the systems of paleomeanders abandoned due to cutting off the singular meanders or shifts there are found flat depressions of the Late Vistulian braided channels which are located close to the margin in the narrower sections of the floodplain – subtype C1 – (region of Cracow – Kalicki 1991) and which, in the wider parts of the floodplain, take from of the outliers located in the centre – subtype C2 – (region of the Niepołomice, Forest–Gębica–Starkel 1987).

D. The type of the bottom of the main valley (of the Vistula valley) of the width of 5–8 km and of the gradient smaller than 0.27‰ with the traces of the outlet 2–5 km wide reaches of the tributaries flowing parallel to the valley. The example is the depression of Breń which was used by the Dunajec flowing on the southern side of the Garb Szczuciński ridge (Sokołowski 1987) in the Plenivistulian and in late Vistulian. The second example is the depressions of Trześniówka and Mokrzyszówka which are located farther to the east and are used by the Wisłoka which shortened its course directly towards the Vistula river probably due to bifurcation, in the later period, during the large floods (Mycielska-Dowgiałło 1978).

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Fig. 7. Types of alluvial fans and sections of the Vistula valley bottom in the Sandomierz Basin (explanations see text)

A. Geological section across the Raba and Uszwica alluvial fans between Uście Solne and Szczurowa (by Gębica 1993). B. Alluvial fills in the Wisłoka fan near Dębica (by Starkel in Alexandrowicz *et al.* 1981)

C1. Schematic section across Vistula floodplain between Cracow and Niepołomice (by Kalicki 1991)

C2. Schematic section across the Vistula valley floor at the northern margin of Niepołomice Forest (by Gębica, Starkel 1987). D. Geological section across the Vistula valley and Breń depression near Szczucin (by Sokołowski 1987); PL – Plenivistulian, IP – Interplenivistulian, LG – Late Glacial, H – Holocene

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REFERENCES

A l e x a n d r o w i c z S. W., K l i m e k K., K o w a l k o w s k i A., M a m a k o w a K., N i e d z i a ł k o w s k a E., P a z d u r M., S t a r k e l L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, (L. Starkel ed.), Folia Quater. 53, 1–91.

A l e x a n d r o w i c z S. W., J e r s a k J., 1991, *Profil lessów w Opatowcu nad Wisłą*, [w:] *Podstawowe profile lessów w Polsce (Loess section at Opatowiec on Vistula River*, [in:] *Main sections of loesses in Poland)*, Lublin, 19–93.

A l l e n J. R., 1965, *A review of the origin and characteristics of recent alluvial sediments*, Sedimentology 5, 89–191.

B o r s y Z., 1990, *Evolution of the alluvial fans of the Alfold*, [in:] *Alluvial fans. A field approach*, Chichester, 229–242.

B o r s y Z., F e l e g y h a z i E., 1983, *Evolution of the network of water courses in the end of Pleistocene to our days*, Quater. Stud. in Poland 4, 115–125.

D e m b o w s k i R., 1984, *Erozja i sedymentacja w międzywalu Wisły pomiędzy ujściem Raby i Uszwicy (Erosion and sedimentation in the Vistula interembankment area between Raba mouth and Uszwica)*, Mat. Symp. „Holocen okolic Krakowa", Kraków, 26–29.

D ż u ł y ń s k i S., K r y s o w s k a - I w a s z k i e w i c z M., O s z a s t J., S t a r k e l L., 1968, *O staroczwartorzędowych żwirach w Kotlinie Sandomierskiej (On Lower Quaternary gravels in the Sandomierz Basin)*, Studia Geomorph. Carpatho-Balcan. 2, 63–76.

F o l k R. L., W a r d W. C., 1957, *Brazos river bar, a study in the significance of grain-size parametres*, J. Sedim. Petrol. 29, 3–27.

G ę b i c a P., 1993, *Ewolucja doliny Wisły pomiędzy Nowym Brzeskiem a Opatowcem w vistulianie i holocenie (Evolution of the Vistula valley between Nowe Brzesko and Opatowiec in the Vistulian and Holocene, South Poland)*, Praca doktorska w archiwum Biblioteki IG i PZ PAN.

G ę b i c a P., S t a r k e l L., 1987, *Evolution of the Vistula river valley at the northern margin of the Niepołomice Forest during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 71–86.

G i l o t E., N i e d z i a ł k o w s k a E., S o b o l e w s k a M., S t a r k e l L., 1982, *Pleniglacial alluvial fan of the Biała stream*, Studia Geomorph. Carpatho-Balcan. 15, 115–124.

G r a d z i ń s k i R., 1973, *Wyróżnienie i klasyfikacja kopalnych osadów rzecznych (Distinguish and classification of the fossil river sediments)*, Postępy Nauk Geol. 5, 57–112.

H a r a s i m i u k M., 1991, *Vistulian glacial cycle of the fluvial processes development in the valley of the middle Wieprz river (SE Poland)*, Ann. UMCS 46, 5, 81–109.

I z m a i ł o w B., 1975, *Geneza i wiek wydm Puszczy Niepołomickiej (Origin and age of the sand dunes i the Niepołomice Primeval Forest)*, Folia Geogr., Geogr.-Phys. 9, 43–60.

K a l i c k i T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

K a l i c k i T., S t a r k e l L., 1987, *The evolution of the Vistula river valley downstream of Cracow during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 51–70.

K l i m e k K., 1987, *Vistula valley in the eastern part of the Oświęcim Basing during the Upper Vistulian and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15000 years, II*, Geogr. Stud., Spec. Issue 4, 13–29.

K o z a r s k i S., G o n e r a P., A n t c z a k B., 19988, *Valley floor development and paleohydrological changes: The Late Vistulian and Holocene history of the Warta river (Poland)*, [in:] *Lake, mire and river environments*, 185–203, Rotterdam.

K v i t k o v i c J., V a n k o J., 1972, *Recent crustal movements in the region of Eastern Slovakia*, Geogr. Časop. 24, 2, 151–161.

http://rcin.org.pl

Łomnicki A., 1903, *Atlas Geologiczny Galicji*. Mapa 1:75 000 i tekst do zeszytu 15 (arkusz Ujście Solne) (Erläuterungen zur geologischen Karte Galiziens).

Łyczewska J., 1948, *Sprawozdania z badań geologicznych w północno zachodniej części arkusza Brzesko Nowe (1:100 000) (Report from the geological research in the western part of Nowe Brzesko sheet, 1: 100 000)*, Biul. Państw. Inst. Geol. 42, 46–75.

Mike K., 1975, *Utilization of the analysis of ancient river beds for the detection of Holocene crustal movements*, Tectonophysics 29, 359–368.

Mycielska-Dowgiałło E., 1978, *Rozwój rzeźby fluwialnej w północnej części Kotliny Sandomierskiej w świetle badań sedymentologicznych (Development of the fluvial relief of the northern part of the Sandomierz Basin in the light of the sedimentological investigations)*, Rozpr. Uniw. Warsz. 120, 7–148.

– 1987, *Morphogenesis of Vistula valley in northern part of Sandomierz Basin in the Late Glacial and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 115–129.

Niedziałkowska E., 1991, *The textural diversity of upper Quaternary fluvial deposits in the Carpathian foreland*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 119–146.

Niedziałkowska E., Gilot E., Pazdur M. F., Szczepanek K., 1985, *The Upper Vistula valley near Drogomyśl in the Late Vistulian and Holocene*, Folia Quater. 56, 101–132.

Połtowicz S., 1967, *Młode ruchy tektoniczne przedgórza Karpat i okolicy Krakowa i ich wpływ na ewolucję dolin Wisły i Raby (Young tectonic movements in the Carpathian foreland vicinites of Cracow and their influence upon the evolution of the Vistula and Raba rivers)*, Kwart. Geol. 11, 699–706.

Punzet J., 1981, *Zmiany w przebiegu stanów wody w dorzeczu górnej Wisły na przestrzeni 100 lat (1871–1970) (Changes in the course of water stages in the upper Vistula basin over a century 1871–1970)*, Folia Geogr., Ser. Geogr.-Phys. 14, 5–29.

Rotnicki K., 1987, *Main phases of erosion and accumulation in the middle and lover Prosna valley in the last glacial – interglacial cycle*, Geogr. Pol. 53, 53–65.

Rotnicki K., Młynarczyk Z., 1989, *Późnovistuliańskie i holoceńskie formy i osady korytowe środkowej Prosny i ich paleohydrologiczna interpretacja (Late Vistulian and Holocene channel forms and deposits of the middle Prosna river and their paleohydrological interpretation)*, Ser. Geogr. 43, 1–76.

Schellmann G., 1990, *Fluviale Geomorphodynamik im jungeren Quartar des unteren Isar- und angrenzenden Donautales*, Düsseldorfer Geogr. Schr. 29, 1–131.

Schirmer W., 1988, *Holocene valley development on the Upper Rhine and Main*, [in:] *Lake, mire and river environments*, 153–160, Rotterdam.

Schreiber U., 1985, *Das Lechtal zwischen Schongau und Rain im Hoch-, Spät- und Postglazial*, Sonderveröff. Geol. Inst. Köln 58, 1–192.

Sokołowski T., 1981, *Uwagi o terasach doliny Dunajca koło Tarnowa (Remarks on the terraces of Dunajec valley near Tarnów, Southern Poland)*, Rocz. Pol. Tow. Geol. 51, 3–4, 579–594.

– 1987, *Vistula valley between the outlets of Dunajec and Breń rivers*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 95–114.

– 1988, *Utwory czwartorzędowe współczesnych den dolin Wisły i Dunajca regionu tarnowskiego i ich znaczenie surowcowe (Quaternary deposits of the Vistula and Dunajec valleys bottoms in the Tarnów region, South Poland)*, Praca doktorska w archiwum Biblioteki AGH.

Starkel L., 1960, *Rozwój rzeźby Karpat fliszowych w holocenie (The development of the Flysh Carpathians relief during the Holocene)*, Prace Geogr. IG PAN, 22.

– 1967, *Wisła wśród gór i wyżyn. Przewodnik geologiczny z biegiem Wisły (Vistula among the mountains and uplands. Guide book along the Vistula river)*, Warszawa, 31–159.

http://rcin.org.pl

– 1983, *The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15 000 years*, [in:] K. J. Gregory, J. Wiley (ed.), *Background to palaeohydrology*, 213–234.
– ed., 1990, *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5.
Starkel L., Gębica P., Niedziałkowska E., Podgórska-Tkacz A., 1991, *Evolution of both the Vistula floodplain and Lateglacial – early Holocene palaeochannel systems in the Grobla Forest (Sandomierz Basin)*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 87–99.
Starkel L., Klimek K., Mamakowa K., Niedziałkowska E., 1982, *The Wisłoka river valley in the Carpathian foreland during the Late Glacial and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 41–56.
Strzelecka B., 1958, *Historyczna dokumentacja niektórych młodszych zmian hydrograficznych na brzegu Karpat (Historical documentation of some hydrographical changes at the Carpathian border)*, Czas. Geogr. 29, 4, 455–472.
Trafas K., 1975, *Zmiany biegu koryta Wisły na wschód od Krakowa w świetle map archiwalnych i fotointerpretacji (Changes of the Vistula river bed east of Cracow in the light of archival maps and photointerpretation)*, Prace Geogr. UJ 40, 5–85.
Żaki A., Fraś M., Olszowski J., 1970, *Stanowisko wczesnośredniowieczne w Grobli, pow. Bochnia (Early Medieval site in Grobla, Bochnia district, South Poland)*, Spraw. z Posiedz. Nauk. PAN 14, 2, 486.

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DEVELOPMENT OF THE LOWER REACH OF THE DUNAJEC RIVER IN THE VISTULIAN AND HOLOCENE

INTRODUCTION

The study area, which includes the Dunajec valley down the gorge at Olszyny in the outskirts of the Carpathian Foreland to the junction of the Vistula and Dunajec rivers and a fragment of the Vistula valley west of the Dunajec outlet, is located in the western part of the Sandomierz Basin (Fig. 1).

In the Sandomierz Basin the Dunajec valley, being over 20 km wide and mainly incised in the Miocene clay deposits, is surrounded by 40–70 m high plateaus covered with glacial, fluvioglacial and fluvial deposits of the San 2 glaciation.

The discussed area or certain parts of the have already been studied by A. Łomnicki (1903), M. Klimaszewski (1937), L. Starkel (1972), T. Sokołowski (1981, 1987), W. Cabaj (1989), M. Żółkiewski (1989), A. Walczowski (1979) and P. Radzki *et al.* (1992).

This paper is based on: the results of cartographic materials of the scale 1:25 000, the interpretation of air photos of the scale 1:5000 and 1:10 000, the analyses of several thousand shallow drillings and of the published cartographic materials as well as on the grain size analyses (sieve and aerometric methods), the petrographic composition of the gravel size fraction according to the method of J. Rutkowski (1977) and on the mineralogy of fine sediments determined by the X-ray difractometry. The author has been provided with some absolute age datings. The datings have been determined by M. Pazdur from the C-14 Laboratory, Silesian Technical University in Gliwice and by J. Butrym from the Institute of Earth Sciences, Maria Curie-Skłodowska University (TL-datings). Some of these studies, especially absolute datings, were financially supported by the MR I-25 Project „Evolution of the natural environment of Poland".

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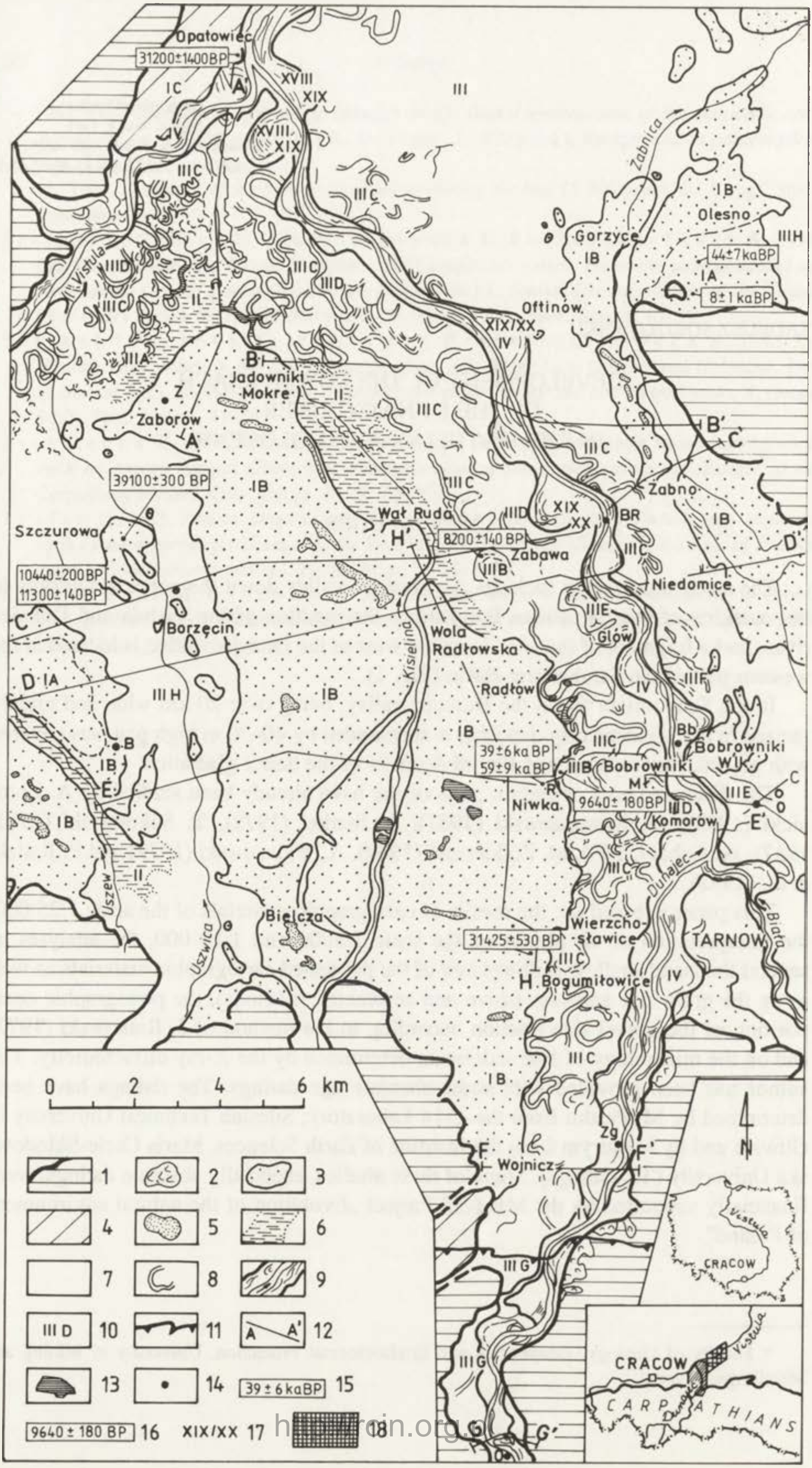

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HYDROLOGICAL REGIME OF THE DUNAJEC RIVER

The gradient of the Dunajec channel is variable. It is mainly typical of mountain rivers, and from Olszyny near Zakliczyn the gradient amounts to 1‰ while down to Niedomice – to 0.7‰. Downstream of Niedomice, the Dunajec river becomes a lowland river whose gradient is even 0.23‰ down of Otfinów, i. e. the gradient is smaller than that of the Vistula at its junction with the Dunajec.

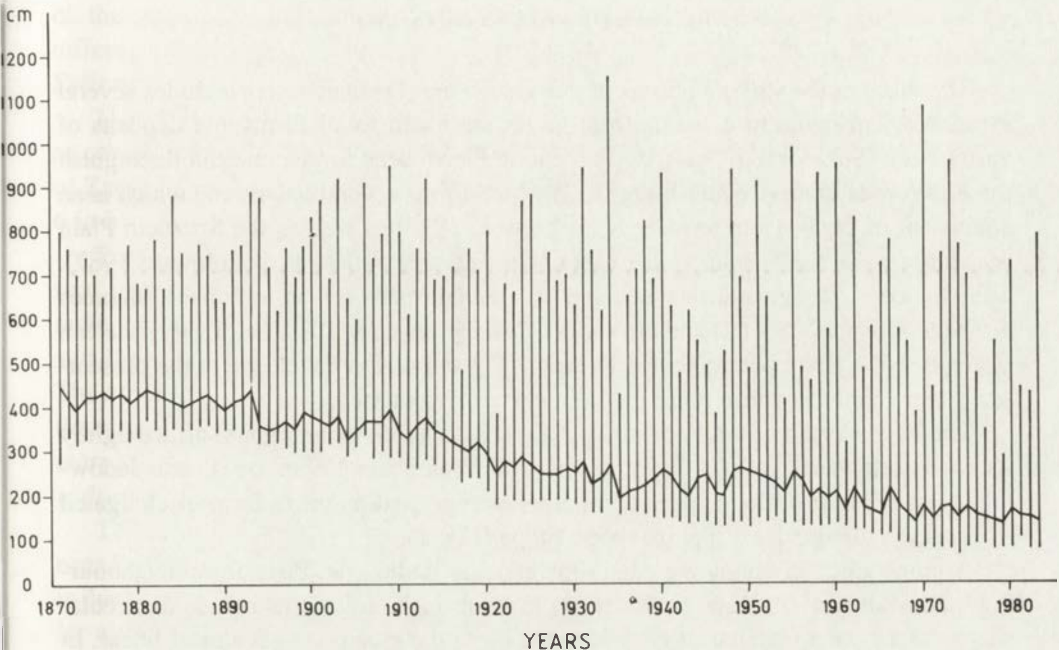

Fig. 2. Graph showing maximal, minimal and mean water levels at Żabno gauging station in the years 1870–1984

The sinuosity of the present-day channel does not practically change, and in the upper part it is 1.13 up to the outlet of the Biała river and 1.15 down of this outlet. A gentle, meandering channel, which rarely exceeds 100 m in width, is 0.7–1.1 m depp on average.

The Dunajec river is characterized by very large variation in water stages, reaching maximum 10.5 m. The largest water stages, in the profile of Żabno, were recorded in

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Fig. 1. Geomorphological sketch of the lower reach of Dunajec valley
1 – plateaus, 2 – slides, 3 – sands of Radłów plain and Szczucin Plain, 4 – loesses, 5 – dunes, 6 – marginal depressions, 7 – alluvial loams (*madas*), 8 – oxbows, 9 – flood plain, 10 – numbers of zones, 11 – Carpathian overthrust, 12 – geological cross-sections, 13 – water basins, 14 – localization of gravels petrographic composition samples, 15 – dates of TL, 16 – dates of ^{14}C, 17 – age (in centuries) of shorten anthropogenic cut of meanders, 18 – studied area in Vistula valley (Sokołowski 1987). (dates in Opatowiec and near Szczurowa by Alexandrowicz, Jersak 1985, 1991; Radzki *at al.* 1992; Gębica 1991, 1995)

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1934 (1150 cm) and after the water reservoirs had been constructed in 1970 (1077 cm, Fig. 2). The largest, corresponding discharges are 4500 $m^3 \cdot s^{-1}$ and 3500 $m^3 \cdot s^{-1}$, respectively. The summer floods are particularly important, on the contrary to spring ones, thawing induced floods, which are less significant in the Dunajec catchment (Soja 1992).

Rapid floods are characteristic for the Dunajec catchment because more than 90% of the catchment is represented by mountain and upland relief with high rainfall duration and intensity.

RELIEFE OF VALLEY BOTTOMS

The relief of the valley bottoms of the Vistula and Dunajec rivers includes several morphological units. In these uniform levels are hiden fossil forms and deposits of various age (Sokołowski 1981, 1987). Among Pleistocene forms, one can distinguish the Radłowska Plain (Region I, Fig. 1, 3) which forms several ledges and which is an equivalent of the 8–15 m terrace (Klimaszewski 1937) as well as the Szczucin Plain which occurs in the Vistula valley east of the Dunajec outlet (cf. Sokołowski 1987). The Holocene, rendzina terrace covered by alluvial loams (mada in Polish), includes a region of depressions (II) and the zones of paleomenaders (III). And finally, one can distinguish the flood plain (Region IV, Fig. 1) as the region developed at the present--day river channels whose relief is likely most differentiated.

The largest patch of the Radłowska Plain (IB) is a flat, monotonous surface lightly inclined northwards, from c. 205 m a. s. l. near Wojnicz to 179 m a. s. l. near Jadowniki Mokre. From place to place there are superimposed dunes in form of elongated ridges and sporadically of the parabolic shape (Fig. 1).

A pronounced morphologic edge separates the Radłowska Plain from neighbouring areas. South of Radłów, the scarp up to 10 m high, adjusts its course to circular shapes of meander undercutting while in the north the escarpment is almost linear. In other locations, the escarpment is not pronounced and takes form of a gently steeping, low (to 3 m) slope. In certain locations, especially along the Vistula and Uszwica valleys the escarpment is invisible because it is burried under alluvial loams (*madas*).

West of Borzęcin there is an outcroping fragment of the level higher by 3–5 m (IA) which corresponds to a similar form near Olesno in the Vistula valley (cf. Sokołowski 1987). On the left bank of the Vistula near Opatowiec the next ledge (IC) is accreted with loesses whose height locally increases up to c. 20 m. The steep scar of this ledge is partially covered with landslides (Walczowski 1975).

It is likely that a similar ledge also occurs south-west of Wojnicz. One of the drillings provides evidence of gravels and sands with gravels present there under the 12.5 m thick layer of loess.

The marginal depressions (II) apear in some locations although in different positions. The most pronounced depressions extend along the straight escarpment of the Radłowska Plain between Wola Radłowska and Jadowniki Mokre, and are identified as a slight, 1–2 m deep wetland lowering in the Holocene surface. There are several paleomeanders in the area of this depression. Small radii of the paleomeanders (to 80 m) and

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narrow channels (to 25 m) provide evidence of their links to the activity of the Kisielina river (once being a tributary of the Dunajec river) which was artificially diverted to the Vistula in the 19th century.

A subsequent, short and narrow depression surrounds the Radłowska Plain from the north.

Both of the forms remined the Late Glacial, flat lowerings known of the Vistula valley east of Cracow (Bzowski 1973; Kalicki, Starkel 1987; Gębica – this volume; Kalicki 1991).

The most important feature of the next (III) unit in the valley floors is the presence of the meandering abandoned channels which exhibit a definite, although not so differentiated as e. g. in the case of the San river, variability of geometric features. Differences in parameters allow to distinguish a few zones here.

The first zone (IIIA) consists of the forms which only show up on the air photos as concenrtic darker bands, not coinciding with the pattern of arable fields north-west of Zaborów. Thesa are point bars which are recognized by K. Trafas (1975 – pohoto 6 in his paper).

Two, relatively small and isolated patches near Radłów and Zabawa belong to the next zone (IIIB). These are patches with singular paleomeanders of relatively large radii, reaching 450 and 550 m, and of the widths of the cut-off channels reaching 100 and 170 m. The traces of these abandoned channels are preserved to a varying degree. The channel near Radłow is shallow (up to c. 0.5 m) and its presence is evidenced by the seepage and meadows. The abandoned channel near Zabawa is well marked in morphology and the height of the scar at the concave slope exceeds 1 m. This channel is drier than the previously mentioned one.

The layout of the zone IIIC, corresponding to the terrace IIA of the Vistula valley near Szczucin (cf. Sokołowski 1987), is the largest. On the surface of this zone there is developed a dense network of abandoned channels characterized by generally smaller although differentiated radii. The succession near Radłów starts with abandoned channels of relatively large radii reaching ca. 400 m. These channels intersect with other abandoned channels whose smallest radii are 90–100 m and which undercut the escarpment of the Radłowska Plain in some locations. The subsequent generation is the most numerous. The abandoned channels of this generation undercut not only the older forms but the escarpment of the Radłowska Plain as well. The varying radii of those are in the range of 120–460 m. A very interesting feature is preservation of relatively long channel sections in some locations. The longest (13 km) is the fragment between Bobrowniki Małe and Radłów, whose sinuosity is 3.2. The characteristic feature of all the paleomeanders of this zone is their stability which manifests in a regular shape resembling circular arcs and in the lack of migratioin traces in the forms of meander bars or concentric scars at the convex bend. In the next zone IIID the radii of the abandoned channels are frequently slightly larger and reach 300–500 m. A characteristic feature of these channels is varying curvature of bends. Here the point bars are sometimes low, occasionally without pronounced scars. The outer sides are more pronunced and can exceed 1 m. This zone forms several patches. Due to its location it corresponds to the terrace IIB near Szczucin (cf. Sokołowski 1987).

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The following zone (IIIE), forming the isolated patches as well, corresponds to the terrace IIC distinguished on the Vistula river. In the area of the patches the radii of the abandoned channels can even reach 700 m. These channels are often irregular and sometimes exhibit pronounced traces of channel migration. Out of the other zones related to the Holocene bottom covered with alluvial loams (*madas*) one can also distinguish: narrow strips with almost straight linear udercuttings (IIIF), the Carpathian reach of the Dunajec valley where the traces of abandoned channels which do not reveal features of paleomeanders (IIIG) appear, and, finally, bottoms of small valleys (of the Kisielina, the Uszwica rivers etc.) with the traces of abandoned channels of small radii in some locations. The present-day floodplain (IV) extends along the present channels. The forms typical of linear development predominate this floodplain although the bends of the 18th–19th century paleomeanders of relatively large radii (to 500–600 m) are preserved in some locations, especially down of Żabno on the Dunajec river.

SUBQUATERNARY RELIEF

The Carpathian flysch deposits underlie the Quaternary deposits in the southern part. North of the Carpathian thrust there are found shale-sandy Miocene deposits which change into clays and silts to the north. In some parts of the river valley slopes as well as in the southern part directly in the Dunajec channel where the sandstone outcrops form low steps the bedrock deposits come to the surface. The relief of the Quaternary bedrock is very diversified (Fig. 3; Sokołowski 1981, 1987). The relief interpretation differs from that presented in the maps by other authors (i. a. Bożym-Rogalska 1964; Jawor *et al.* 1982; Nowak, Żółkiewski 1989) which is the result of different documentary data used (deep drillings of oil industry and geophysical materials). The author is of the opinion that deep drillings of the oil industry are not reliable as to the thickness of the Quaternary deposits.

The interpretation presented below is exclusively based on the profiles of a few thousand shallow drillings, including geological ones for finding deposits, natural break-stones and ceramic resources and shallow hydrogeological drillings. The non-uniform spatial distribution of drillings results in varying exactness of the studies of the bedrock. The zones of the natural break-stones are best documented. These areas are presented in the map in Fig. 3.

The analysis of the map and geological cross-sections (Fig. 3, 4) indicates that one of the most extensive forms is the erosional base occurring at the height of 196–173 m a. s. l. (i. e. at the level of the present Dunajec channel), extending from Wojnicz to Jadowniki Mokre and reaching up to the region of Borzęcin and Zaborów in the

Fig. 3. Relief of subquaternary top surface
1 – plateaus, 2 – range of Radłów and Szczucin Plains, 3 – isolinies of subquaternary top surface, 4 – range of areas of best documentation, 5 – selected boreholes, 6 – geological cross-sections, 7 – Carpathian overthrust

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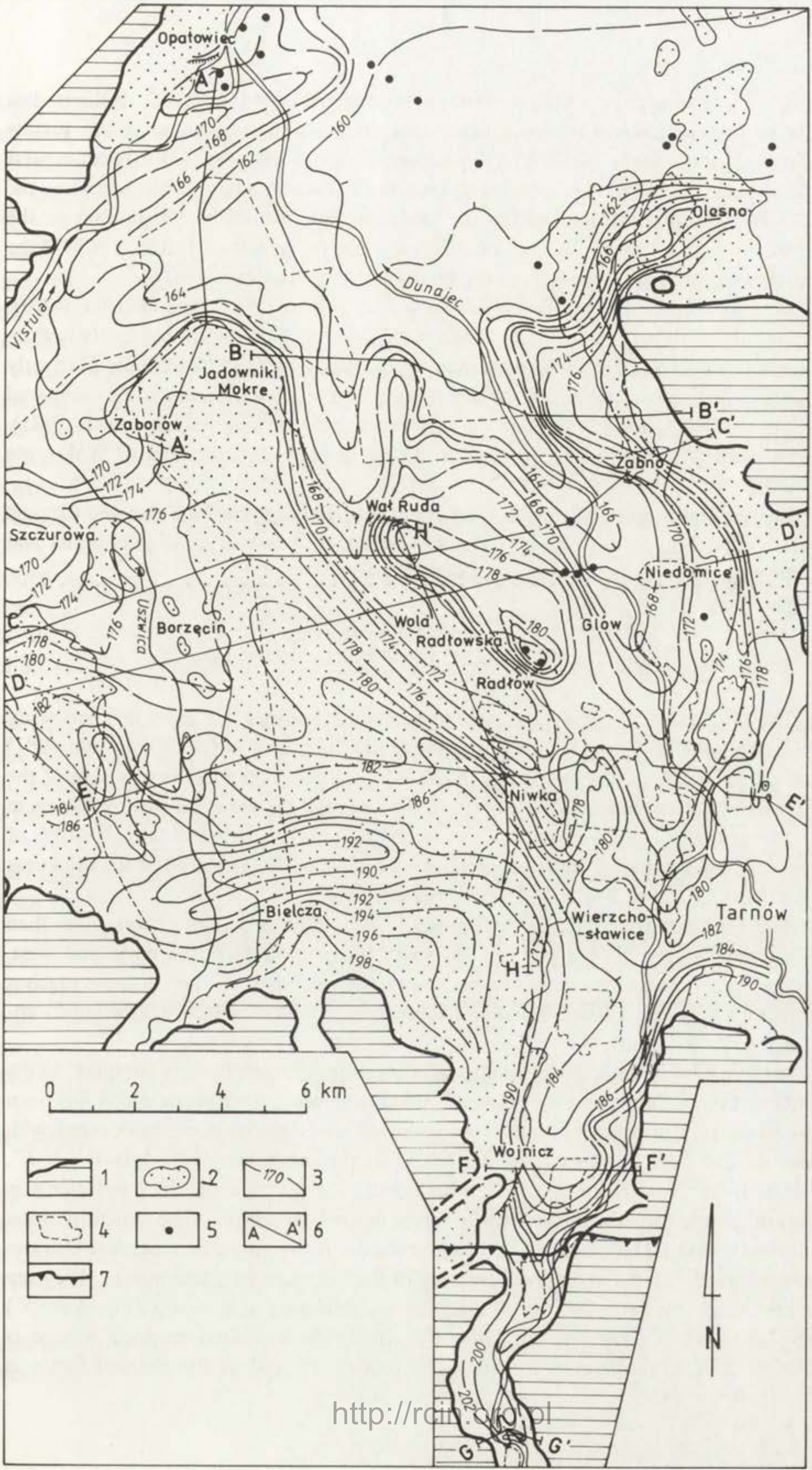

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west. This base appears in the eastern part of the valley. More recent drillings data indicate that the erosional base is bisectional, similarly to the situation in the Vistula valley (cf. Sokołowski 1987). The upper section of this base (by 3–4 m) occurs west of Borzęcin (Fig. 3). It should be mentioned that a few secondary forms, including the SE–NW hollow, are found within the erosional base while the flat bottom of the Vistula valley is 5 to 8 m below, descending from the height of 168 m a. s. l. at the Uszwica outlet to 160 m a. s. l. in the vicinity of the Dunajec outlet.

The discussed erosional base is dissected by two troughs in the Dunajec valley. The western trough extends from Wierzchosławice to Jadowniki Mokre. Its bottom reaches down to 8 m below the upper face of the base and its width exceeds 2 km only in the northern part. The course of this trough requires modification when compared with the previous one described in the former paper of the author (Sokołowski 1981). This trough does not turn to NW but to the north near the settlement of Wał–Ruda (Fig. 3).

The second trough (eastern trough) is almost parallel to the first one and extends probably from Wojnicz to Żabno. The second trough, however, is slightly wider and a few meters deeper in some locations (Fig. 3, 4).

SELECTED PROBLEMS OF ALLUVIAL LITHOLOGY

The obtained drillings data as well as soundings allowed at a more detailed study and completion of previous knowledge about alluvial lithology (cf. Sokołowski 1981) and especially about channel fillings. The information related to the structure of the Radłowska Plain was relatively scarce. In the extent of the ledge IA west of Borzęcin the Miocene clays are overlain with sand and gravel (i. e. deposits with 30–70% of grain size coarser than 2 mm) of the thickness of 0.5–3 m. The sand of the thickness not exceeding 2.5 m (Fig. 4 D–D') can occur above.

The most extensive path (IB) of the Radłowska Plain is built of gravel (more than 70% grains coarser than 2 mm) in the southern part which, to the north and west, changes into sand and gravel with sand inserts. Silty deposits whose thickness reaches sometimes 5 m (Fig. 4 E–E') and whose genesis is unknown (channel fillings?) appear in some locations.

In the extent of the troughs mentioned above the structure is more complex. In the northern trough, in the section between Niwka and Wola Radłowska which has been best studied by drillings there are two series of sandy-gravel deposits covered with sands of the total thickness reaching 20 m at the maximum (Fig. 4 D–D', E–E', H–H'). In the eastern trough, near Niedomice, the division of older sediments is doubtful due to the flow of the Dunajec river in the later periods. The structure of the hollows (region II) has been learned fragmentarily. At the lower face of these hollows there are sandy-gravel and gravel deposits of the thickness of a few meters. They are covered with silts (alluvial loams) reaching the thickness of 8 meters (Fig. 4 A–A') north of Zaborów. The structure of the formerly distinguished rendzina terrace is differentiated. In the southern, Carpathian part of the valleys the channel facies is

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formed by gravels and sporadically by sands with gravels of the thickness not exceeding 5–6 m (Fig. 4 G–G'). North of the boundary of the Carpathians, the thickness of deposits increases to 8–11 metres, and at maximum to 13–14 metres. These deposits are gravels which change into sands with gravels. Starting from Wierzchosławice these deposits are twofold at some locations, Sands appear above sandy-gravel deposits. The sand thickness increases downvalley and in the northern part of the valley (near Jadowniki Mokre) these sands become predominant. Moreover, the sand associated with the extent of the zone IIIC is most likely to form the upper part of the pointbars.

Alluvial loams occurring above channel deposits are twofold in numerous locations. The lower laying clayey alluvial loams may contain up to 30% of clayey grain size particles, while the upper laying silty alluvial loams contain sometimes over 30% of sand grain size and a few percent of clay grain size particles. Their mineral composition which has been studied by the X-ray method indicates the presence of quartz, feldspar, mica (muscovite, chlorite), calcite and dolomite, and probably that of smectite, i.e. the mixed-assize mineral of the illite-montmorillonite type. This composition, which seems typical of the material originating from the Carpathian weathering waste, does not outstand that described from the lower reaches of the Vistula (Myślińska *et al.* 1982) or from the clay pit at Radłów (Baranowski, Ratajczak 1977). The thickness of alluvial loams is rather variable (0.3–6 m), and reaches 2.5–3 m most frequently.

The sediments, which have been learned from the soundings and which are filling the paleomeanders, are characteristically differentiated with respect to the thickness due to the asymmetry of the channels. The maximum thickness rarely exceeds 3.5–4 m, and only in the abandoned channel of the zone IIIB near Radłów it reaches almost 7 meters. In the last case the upper part of the profile, to the depth of ca 5 m, is built of silted up peats with silt interbeddings. Below there are silts containing plant detritus. In some profiles of the other abandoned channels, mainly of the zones IIIC and IIID, there are only silts which are noticeably sanded up in some locations.

The determination of the thickness of the present-day floodplain deposits (region IV) is very complicated. The thickness of the floodplain deposits is 5.5 m at maximum only in these sites where the floodplain deposits have been laid down on the substratum. In the part of the valley farther to the north, within the range of the flood plain, there are local lowerings of the upper face of the Miocene. Thus, it cannot be excluded that the reworking and redeposition of alluvia reache the upper face of the Miocene, i. e. the depth of 6–11 m from the ground surface, that is 3–8 m below the Dunajec bottom.

The floodplain deposits, being gravely in the southern part and sandy-gravely to the north, contain inserts of silty sands and silts as well. The overtopping alluvial loams form a discontinued cover which usually does not exceed 3 metres. These alluvial loams are strongly sanded up, especially in the Carpathian part of the valley. They also frequently contain inserts of sands or even inserts of sands with gravels.

Only few conclusions can be drawn from the grain size analysis of the outcrops and drillings taken in arbitrary locations. Basing on the grain size analysis the statistical parameters of distribution, i.e. the mean diameter standard deviation, have been

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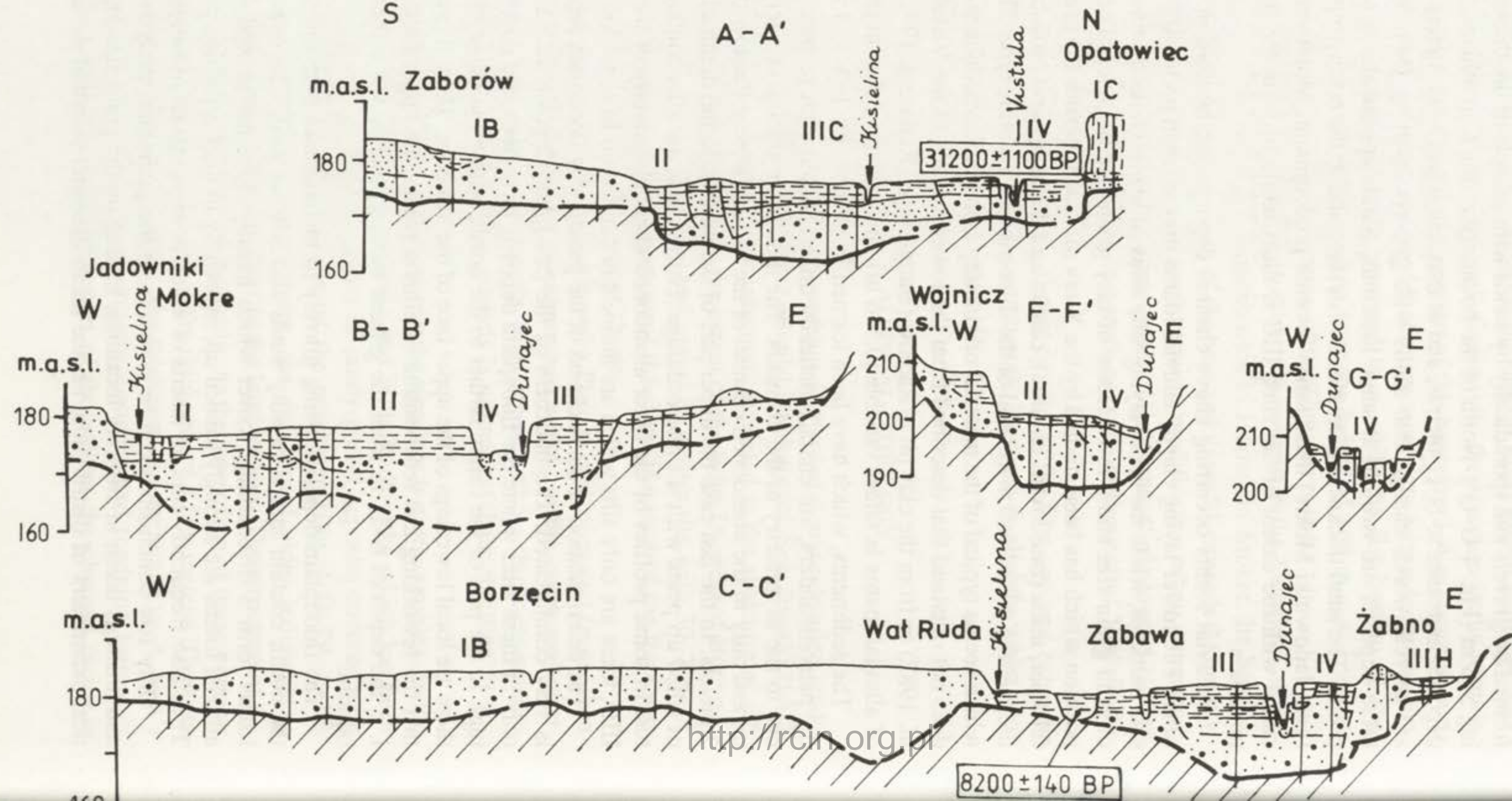

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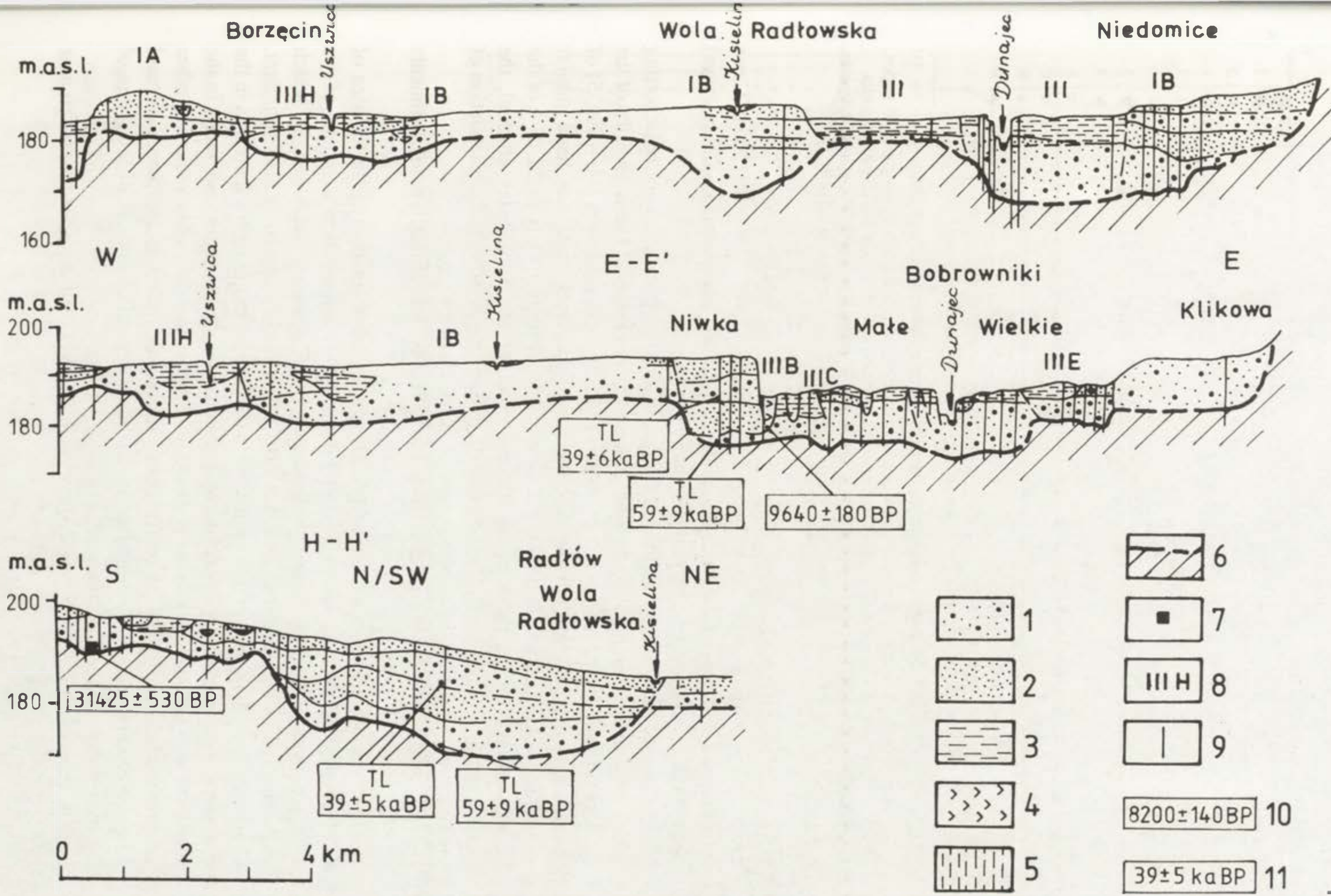

Fig. 4. Geological cross-sections of Dunajec and Vistula valleys

1 – sands with gravels and gravels, 2 – sands, 3 – alluvial loams and oxbows muds, 4 – organic deposits, 5 – loesses, 6 – top of subquaternary deposits, 7 – tree trunks, 8 – numbers of regions and zones, 9 – boreholes, 10 – dates of ^{14}C, 11 – dates of TL

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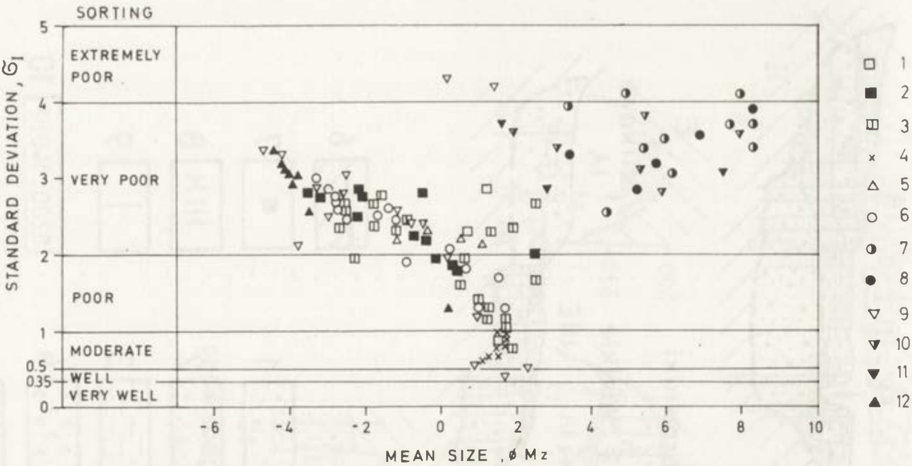

Fig. 5. Scatter plot of sorting index (δ_I) versus mean grain size (*Mz*)

1 – deposits of IA region, 2 – deposits of IB region (without troughs), 3 – deposits in troughs of IB region, 4 – dune sands, 5 – deposits of marginal depressions, 6–8 deposits of III region: 6 – channel deposits, 7 – floodbasin deposits, 8 – oxbows deposits; 9–11 deposits of IV region (flood plain): 9 – channel deposits, 10 – floodbasin deposits, 11 – oxbows deposits; 12 – recent channel deposits

calculated according to the formulae of R. L. Folk and W. C. Ward (1957). These formulae were not only used to calculate the distribution parameters of sandy-gravel deposits but also those of silty and silty-clayey ones.

In general, the Dunajec alluvia are characterized by a poor and very poor sorting which particularly well refers to the fine grained deposits (alluvial loams and silts of the channel fillings). Numerical indices of sorting (δ_I) and mean diameters (*Mz* – Fig. 5) of the deposits originating from the discussed morphological areas can have similar values and, therefore, are not reliable in stratigraphical studies. Only in the case of the youngest deposits, i.e. those of the floodplain or of the present-day channel, the coarsest grains are frequently missing which, in turn, could indicate the attenuation of the river energy during the accumulation of the discussed deposits.

In general, dune sands are better sorted, which is typical of this type of sediments (cf. Kolasa *et al.* 1956).

The petrographic composition of gravels is even more interesting. In the area of the Radłowska Plain, the south–west of Borzecin, this composition is typical of the Dunajec river (Fig. 6A). There predominates the Carpathian sandstone, in which particular grains size classes can reach 50%. The Tatric material is also abundant. Granites are predominant in fine grains while the content of quartzites increases in the coarsest grain size classes. Quartz is also present in larger quantities, especially in the smallest grain size class, while the northern materials, flintstone, silica rocks and other materials amount to a few percent in total. Among the silica rocks there are found singular crumps of cherts of menilite layers being typical of gravels of the rivers of the eastern part of the Carpathians.

The composition of the gravels of both sandy gravel complexes of the trough near

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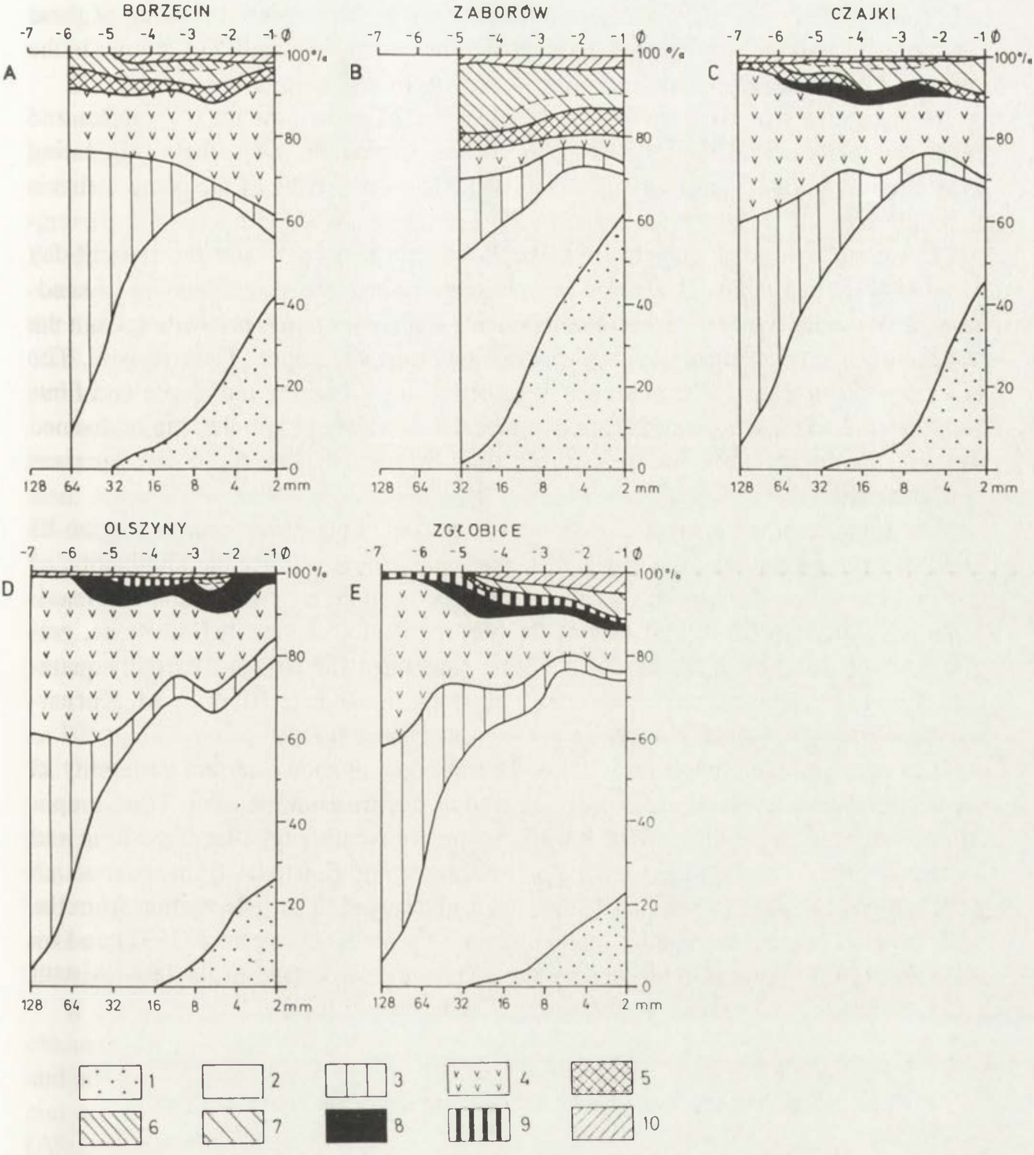

Fig. 6. Petrographic compositions of Dunajec valley gravels strom in number percentages as a function of size grade

1 – quartz, 2 – flysch sandstones, 3 – Tatra quartzities (quartzitic sandstones), 4 – Tatra granites, 5 – others igneous and metamorphic, 6 – flintstones, 7 – others siliceous clasts, 8 – limestones, 9 – shales and marls, 10 – others

Radłów is similar. In the part farther to the north the mixing of waters of the Vistula and Dunajec took place. That is evidenced by the larger proportion of flinstone and sandstone delivered by the Vistula at the expense of the Tatric material (Fig. 6B).

The gravel material of the Radłowska Plain is weathered, especially in the case of

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sandstone and granite. This phenomenon manifests in the increased soaking of these components, and in the presented diagrams by the increased quantity of granite in the fine grain size classes due to crumbling as well as by leaching of limestones.

In the gravels of the zone III, in Czajki (Fig. 6C), the amount of granites and sandstone increases in the coarser grain classes. Limestone most likely originating from the Pieniny Klippen Belt appears as well. The weathering of the components is less intensive.

The composition of gravels from the floodplain (Fig. 6D) and the present-day channel (Fig. 6E) indicates a slight but progressing increase in the amount of sandstone and granite. Weakly resistant components – shales or marls originating from the not remote flysch members or the Miocene outcrops can appear there as well. The other components, as lydite and chert together with the Pieniny radiolarite and flintstone, amount to a few percent. Singular rounded boulders or pebbles can be formed of volcanic and metamorphic rocks originating from exotic Flysch, or can represent northern material.

The samples of the present-day channel as well as of the lower terraces (region III and IV) having been taken in larger distances apart, one can trace the elimination of components as the distance of transportation becomes longer. This elimination manifests in a fairly typical degradation of the less resistant components (sandstone, granite) and the enrichment of the most resistant components: quartz and partially quarzites. Similar phenomena have been observed along the Dunajec river by M. Kucharska-Słupikowa (1964), K. Nawara (1964) and R. Unrug (1957).

The petrographic composition of the Dunajec gravel shows certain variability in the accumulation levels of various age as well as downstream the river. This composition is dependent on the time of transportation, on weathering after deposition and on redeposition of the northern rocks, part of quartz and flinstones from areas which were within the range of the San 1 and San 2 glaciations. The redeposition from the older alluvial levels was smaller than suggested by M. Klimaszewski (1937) and by R. Unrug (1957). This is evidenced by the increasing percentage of the less resistant rocks, sandstone and granite, in the younger and younger levels.

AGE OF FORMS AND DEPOSITS – EVOLUTION OF THE VALLEYS

The Sub-Quaternary surface, together with the overlying deposits, was mainly formed by the lateral shifting of the channels of the Dunajec, Vistula, Biała and other rivers in different periods. Undoubtedly, it took place in the Vistulian, but the extent of socle and its nonuniformity indicate that the socle formation started earlier.

The lateral migration was interrupted by more pronounced downcutting and the troughs were incised at that time. The presence of two troughs here shows that these troughs must be of different age. The eastern trough is deeper, wider, and therefore the author is of the opinion that it formed in a longer period, as in the case of the Vistula valley near Tarnobrzeg (Mycielska-Dowgiałło 1978), at the decline of the Middle Poland glaciation (the Warta glaciation) and in the initial phase of the Eemian

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interglacial. The southern trough in the Vistula valley downstream of the Dunajec outlet is of similar age (cf. Sokołowski 1987).

The western trough as well as the northern one in the Vistula valley downstream of the Dunajec outlet (cf. Sokołowski 1987) are larger, slightly shallower and seem to have been formed in a short period when headward erosion was fast. These troughs could have been formed in the period directly preceding the accumulation of sandy--gravel deposits in Radłów whose lower face is dated by the TL-method as 59±9 ka BP (Lub-1215). The date, taking into account the error (68–50 ka BP) involved, corresponds to the climax or decline of the older pleni-Vistulian. The magnitude of the dissection must have been fairly significant (several meters) if the sands dated as 69±9 ka BP in the west of the discussed terrain, in the Vistula valley, occur 4–6 m above the present-day channel (Gębica 1991).

In the light of the datings obtained the interpleniglacial of the Vistulian (50–30 000 years ago) is generally the period of aggradation with phases of slight channel incision. Aggradation and lateral migration of channels took place in the period of ca. 44–36 ka BP, as of that period are the deposits on the socle near Olesno (44±7 ka BP, Lub-1213 – Fig. 1) and east of Szczucin (Sokołowski 1987). The first of this dates originates from the upper face of sands overtopping the step mentioned above. However, its position can suggest that it is older and the dated deposits are only the younger, overlaid cover.

One of the phases of the channel incision is probably determined by the date 39±6 ka BP (Lub-1214) of the higher series at the trough near Radłów (Fig. 4E–E', H–H', 7). Organic deposits (peaty silts dated as 39 100±3000 years BP – Gębica 1991, 1995) were partially accumulated in the abandoned channels. The slightly lower position of the channels is also evidenced by the tree trunk (*Larix* sp.) in Szujec near Wierzchosławice dated as 31 425±530 years BP (Hv-9708, Sokołowski 1981). This trunk lay under the gravel layer of the thickness of a several meters (Fig. 4 H–H') and almost at the same time the soils dated as 31 200±1400 years BP (Alexandrowicz, Jersak 1985, 1991) were formed on sands under loesses.

It cannot be excluded that the subsequent but more pronounced incision of the channel took place at the turn of the interpleniglacial. The low position of channels and attenuation of the river transporting power, which lasted in the younger pleniglacial as well, conditioned the accumulation of loesses partially in the valley facies (Alexandrowicz, Jersak 1985, 1991; Gębica 1991).

In the climax of the younger pleni-Vistulian, in the bottoms of the contemporary river valleys there formed fine-grained deposits – silts, known among others from the Wisłoka valley (Mamakowa, Starkel 1974). It cannot be stated whether the Dunajec energy decreased as much as to transport fine-grained material while it is possible that the silts south of Szczucin correspond to this level (cf. Sokołowski 1987, Fig. 9, III–-III'), especially as the upper face of the overtopping sands is dated as 17±2 ka BP (Lub-1211). The sands with admixture of some gravels which build the upper face of the Radłowska Plain west of Borzęcin are of similar age (19±3 ka BP – Lub-1216). These data denote, therefore, the final stage of aggradation and of the accumulation of the coarse-grained deposits.

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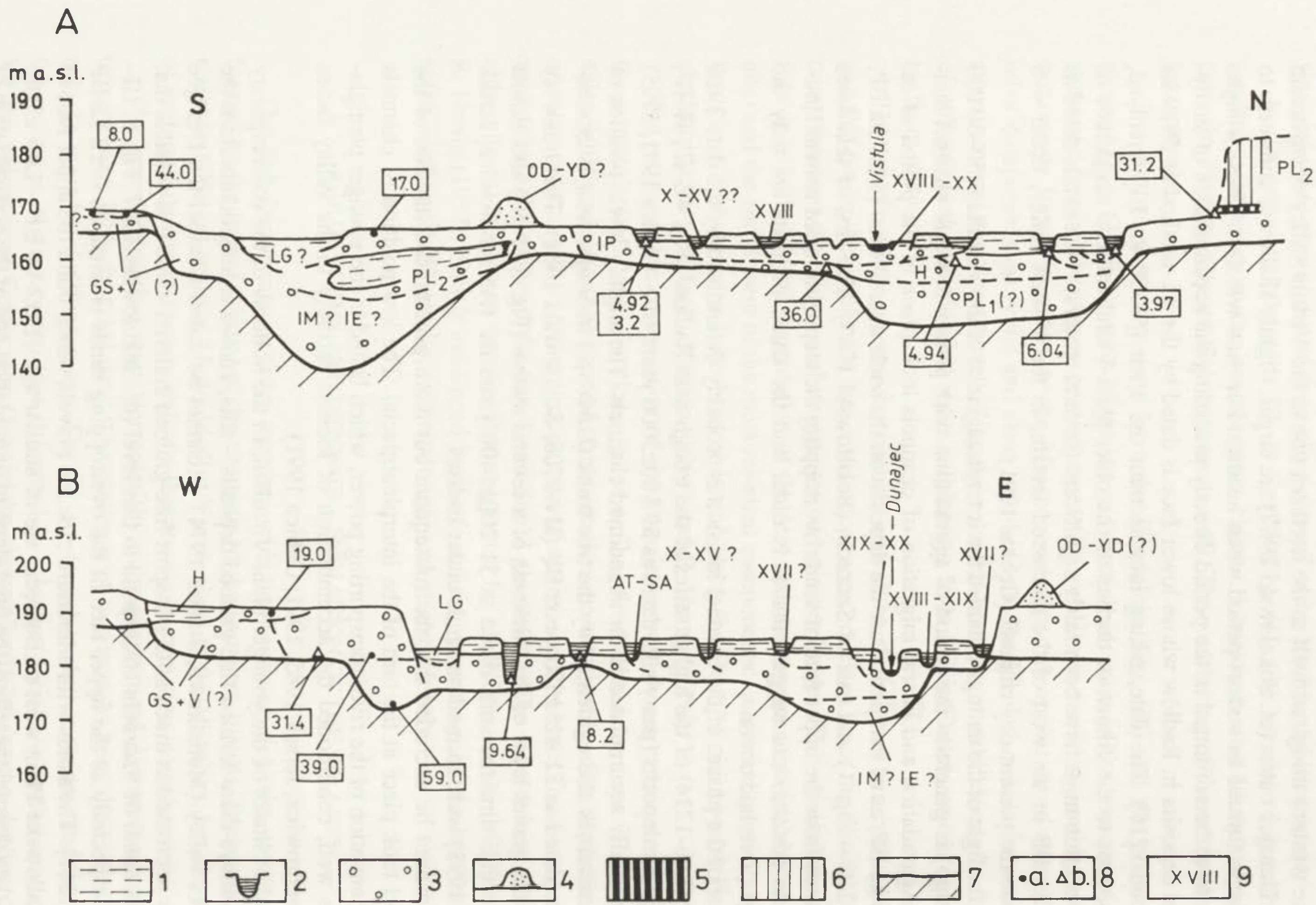

Fig. 7. Schematic sections across the Vistula valley east of the Dunajec outlet (A) and lower reach of the Dunajec valley (B)

1 – floodbasins facies, 2 – oxbows facies, 3 – channel facies, 4 – aeolian deposits, 5 – fossil soils, 6 – loesses, 7 – Miocene top surface, 8 – dates (ka BP): a – TL, b – ^{14}C; 9 – age in centuries; IM, IE – interglacials: Mazovian (Holstein) and Eemian, GS – Middle Polish Glaciations (Saale, Warta), $PL_{1,2}$ – Pleniglacials, IP – Interpleniglacial, LG – Late Glacial, OD – Older Dryas, YD – Younger Dryas, H – Holocene, AT – Atlantic, SA – Subatlantic

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The clear stage of channel deepening, known from the area of Poland, is of the final period of the younger pleni-Vistulian (ca. 15 000 years BP). This stage is linked to the retreat of permafrost and precedes intensive, late-Vistulian dune-forming activity (Manikowska 1988; Kalicki 1991; Rutkowski 1991; Starkel, Gębica 1992).

In the area discussed this stage is not documented, but it is supported by the presence of dunes which formed in the Sandomierz Basin in the late glacial (Wojtanowicz 1968; Izmaiłow 1975). Peats are formed in the deflation depressions accompanying the dunes. The beginning of the dune accumulation falls within the Younger Dryas (Radzki *et al.* 1992). In addition the low position of the river channels can be evidenced by peats occurring at the depth below 4 m in the southern part of Szczurowa and west of this settlement (out of the map). The period of their formations determined by C-14 datings is Allerød and the Younger Dryas (Gębica 1991; Radzki *et al.* 1992).

Finally, the low position of the channel in the Late Glacial is evidenced by the presence of wide depressions without paleomeanders. Similarly, T. Kalicki and L. Starkel (1987) and by P. Gębica (1995) link the forms in the Vistula valley east of Cracow with the Late Glacial (the Older and Younger Dryas). The straight linear edges are the evidence of the braided or at least linear development at that time.

The documented stage of transformation of the channels into the meandering ones, at the persisting low position of the river channels (except for the mentioned above trace of the zone III), took place in the early Holocene. This can be supported by the pre-Boreal age of the beginning of filling the paleomeander of the zone IIIB near Radłów (9640±180 years BP, Gd-2423 – Fig. 1, 4E–E'). The Dunajec channel lay in a low position at that time, ca. 2 m below the present-day position. The small thickness of the underlying channel deposits shows that the reworking of them probably reached the upper face of the Miocene. Thus, the fact that the change in the Dunajec development was earlier than suggested by L. Starkel (1990) is evident.

However, the beginning of the transformation of the channel development in the Vistula valley close to the Dunajec outlet is unknown. The datings of the fillings of the outermost meanders indicate only their Atlantic or sub-Atlantic age (Sokołowski 1987). However, if the early Holocene meandering channels lay low, as was in the case on the Dunajec river, their traces could have been buried.

In the Dunajec valley the pattern of meandering channels of slightly larger radii had probably been preserved until the early Atlantic period because the accumulation in the cut-off channel near Zabawa, found also in the zone IIIB, started 8200±140 years BP (Gd-2422 – Fig. 1, 4C–C'). Aggradation must have taken place earlier if the bottom of this abandoned channel is located here 1–1.5 m higher than the present-day one, and if the almost 2 m thick layer of silts forms the lower part of the filling at Radłów. In addition, delluvia accrete the fragments of the sandy plains near plateaus. Sandy deposits of this type, with the admixture of silts, occur guite often along the edges of surrounding plateaus. Near Olesno they have been dated as 8±1 ka BP (Lub-1212 – Fig. 1, 7).

Just from the Atlantic period there is a more distinct change in the character of paleomeanders occurring in the subsequent zone (IIIC). They are becoming small-

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radii meanders and of narrower channels. Their curvature, being rather regular, and the lack of distinct traces of meander bars indicate that they were formed by the river of stable discharges and slowly moving channel. The small river energy can be evidenced by the straightening of the long series of bends near Radłów, close to the withhold of the Miocene clays of the substrate. Finally, the sands stated in the profiles of the archive drillings within the extent of meander bars provide also an evidence of the attenuation of energy of the Dunajec river. The upper time limit of the functioning of the abandoned channels is probably the first millennium of our era (cf. Sokołowski 1987).

A different geometry of the abandoned channels of the zone IIID (slightly larger radii, smaller regularity of curvature) supports a change in hydrological conditions during the abandoned channels formation which could take place in the 10th–15th century, as it was in the case of the terrace IIB in the Vistula valley downstream the Dunajec outlet (Sokołowski 1987) or the terrace IID in the Wisłoka valley (Alexandrowicz *et al.* 1981).

In the subsequent zone (IIIE), typical of the abandoned channels are the traces of fairly intensive channel migration and even sometimes the traces of channel splitting (in the vicinity of Glów and Czajki). Analogously to the previously described abandoned channels of the Vistula valley (terrace IIC – Sokołowski 1987) it seems that these channels still functioned in the 17th century. The high position of the Miocene upper face above the abandoned channel in Czajki (Fig. 4E–E') helps to presume that the Dunajec aggraded at that time.

In the case of the Dunajec river the shift in the channel development from the meandering to the linear one, which occurred in the Vistula valley downstream the Dunajec outlet at the turn of the 17th century, is less striking. Disregarding the channel reach upstream of Wojnicz, where it has not probably reached typical meandering development, then downstream of the Biała outlet the Dunajec preserves its singular meanders which were artificially shortened at the turn of the 18th century as well as in the second half of the 19th century. These meanders are still depicted in the map of C. Kummerer (1855). The turn of the 18th century is marked by intensified channelization of the Dunajec, Vistula as well as of the Biała and Breń rivers (Stoksik 1986; Trafas 1992).

The preservation of the more sinuous development of the Dunajec channel is striking, as it has already been mentioned, the river is characterized by the very large oscillation of water stages and discharges, i.e. the phenomena in which the reasons of changes in the channels development were sought (cf. Falkowski 1971). The reasons of the preservation of such a river character must be have been more complicated. The author would not exclude here the links to the slight channel gradient in the lowest river reach as well as possibility of the perching of the Dunajec water by that of the Vistula during flood periods and, thus, the attenuation of the energy of the rivers.

In the present-day channel of the Dunajec which is channelized and reinforced with groyne there is bar migration which has been exemplified by K. Klimek (1986).

On the other hand, the analysis of the minimum water stages pinpoints to various tendencies of the deepening of the present-day channels of the Vistula and Dunajec

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rivers. The Vistula is characterized by a larger stability of the channels as for as downcutting is concerned (Punzet 1981; Klimek 1983; Sokołowski 1987). In the case of the Dunajec the tendencies are different. According to the recorder of the water stage in Żabno the uplifting of the channel to ca 0.5–0.8 m in 1870–1890 was followed by pronounced erosion. The largest deepening – by ca. 9 cm/year – took place in the 1910–1921, a slightly smaller one (ca. 5 cm/year) in 1891–1900 and 1961–1970. Considering the extreme positions of the low water stage the total incision in Żabno in 1871–1980 slightly exceeded 3 m. After 1974 the deepening stopped. It is lileky that the Dunajec river reached a certain equilibrium stage. A similar process is observed upstream in Zgłobice (cf. Punzet 1981).

REFERENCES

Alexandrowicz S. W., Jersak J., 1985, *Profil terasy lessowej Wisły w Opatowcu*, Spraw. z Pos. Komis. Nauk. PAN. Krak. 29, 1–2, 386–388.

– 1991, *Profil lessów w Opatowcu nad Wisłą (Loess section at Opatowiec on the Vistula River)*, [in:] *Podstawowe profile lessów w Polsce (Main sections of loesses in Poland)*, UMCS, Lublin B. 91–93.

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E., Pazdur M., Starkel L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, (L. Starkel ed.), Folia Quater., 53, 1–91.

Bahranowski K., Ratajczak T., 1977, *Skład mineralny glin aluwialnych z Radłowa nad Dunajcem (The mineralogical composition of alluvial clay from Radłów on the river Dunajec)*, Zesz. Nauk. AGH, Geologia 3, 3, 75–85.

Bożym-Rogalska A., 1964, *Rzeźba podczwartorzędowa Kotliny Sandomierskiej (The sub--Quaternary relief of the Sandomierz Basin)*. Zesz. Nauk. UJ, 88, Prace Geogr. 10, 7–10.

Bzowski M., 1973, *Rzeźba i stosunki wodne dna doliny Wisły w rejonie północnej części Puszczy Niepołomickiej (The relief and hydrology of Vistula river bottom in the region of Niepołomice forest)*, Studia Naturae, Ser. A 7, 7–37.

Cabaj W., 1989, *Czwartorzędowe osady doliny Wisły w obrębie Kotliny Oświęcimskiej i Sandomierskiej (Quaternary deposits in the Vistula valley within the Oświęcim and Sandomierz Basins)*, Studia Ośr. Dokum. Fizjog. 17, 33–53.

Falkowski E., 1971, *Historia i prognoza rozwoju układu koryt wybranych odcinków rzek nizinnych Polski (History and prognosis for the development of bed configurations of selected sections of Polish lowland rivers)*, Biul. Geol. UW 12, 5–110.

Folk R. L., Ward W. C., 1957, *Brazos river bar: A study in the significance of grain size parameters*, Journ. Sedim. Petrol. 27, 1, 3–26.

Gębica P., 1991, *Vistulian Kotliny Sandomierskiej między Niepołomicami a Opatowcem*, Spraw. z Pos. Komis. Nauk. PAN. Krak. 35, 1–2, 310–314.

– 1995, *Evolution of the Vistula valley and of alluvial fans of the Raba and Uszwica rivers between Uście Solne and Szczurowa in the Vistulian and Holocene*, [in:] L. Stakel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, V*, Geogr. Stud., Spec. Issue 8, 31–50.

Izmaiłow B., 1975, *Geneza i wiek wydm Puszczy Niepołomickiej (Origin and age of sands dunes in the Niepołomicka Primeval Forest)*, Folia Geogr. Ser. Geogr.-Phys. 9, 43–62.

Jawor E., Jucha S., Kruczek J., Sas-Korczyński S., Wdowiarz S., Witek K., 1982, *Wykształcenie górnej części utworów miocenu i czwartorzędu w zapadlisku przedkarpackim między Krakowem a Tarnowem (On the development of upper part of Miocene*

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and Quaternary deposits in the Carpathian Foredeep between Cracow and Tarnów), Kwart. Geol. 26, 3/4, 647–661.

K a l i c k i T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

K a l i c k i T., S t a r k e l L., 1987, *The evolution of the Vistula river valley downstream of Cracow during last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 51–70.

K l i m a s z e w s k i M., 1937, *Morfologia i dyluwium doliny Dunajca od Pienin po ujście (Morphologie und Diluvium des Dunajectales von den Pieninen bis zur Mündung)*, Prace Inst. Geogr. UJ, 18.

K l i m e k K., 1983, *Erozja wgłębna dopływów Wisły na przedpolu Karpat (Vertical erosion of Vistula tributaries on the Carpathian foreland)*, [in:] *Ekologiczne podstawy zagospodarowania Wisły i jej dorzecza*, 97–108, Kraków.

– 1986, *Fluvial processes in the temperate zone: present day examples from Carpathian and Fore-Carpathian rivers, stop 1: Zgłobice*. IAS 7 European Regional Meeting, Exc. Guide-book, 71–73, Wrocław.

K o l a s a M., C h m u r a K., S m o r ą g i e w i c z W., 1956, *Z badań nad piaskami wydmowymi z obszaru położonego w widłach Wisły i Dunajca (Notes on the dune sands in the fork formed by the rivers Vistula and Dunajec)*, Zesz. Nauk. AGH, 9, Geologia 1, 155–170.

K u c h a r s k a - S ł u p i k o w a M., 1964, *Analizy żwirów z pokryw czwartorzędowych w dolinie Dunajca (Analyses of gravels from Quaternary Covers in the Dunajec valley)*, Zesz. Nauk. UJ, 88, 13–43.

K u m m e r e r R i t t e r v o n K u m m e r s b e r g C., 1855, *Administration Karte den Königreichen, Galizien und Lodomerien*, Wien. Bibl. Jagiell. Kraków.

Ł o m n i c k i A., 1903, *Atlas Geologiczny Galicyi*, 15. Akad. Umiejętności, Kraków.

M a n i k o w s k a B., 1988, *Dunes occuring in the Vistula valley near Wyszogród*, Exc. Guide-book: Lateglacial and Holocene environmental changes Vistula basin, 129–133, Kraków.

M a m a k o w a K., S t a r k e l L., 1974, *New data about the profile of Young Quaternary deposits at Brzeźnica in Wisłoka Valley*, Studia Geomorph. Carpatho-Balcan. 8, 47–59.

M y c i e l s k a - D o w g i a ł ł o E., 1978, *Rozwój rzeźby fluwialnej północnej części Kotliny Sandomierskiej w świetle badań sedymentologicznych (Development of the fluvial relief of the northern part of the Sandomierz Basin in the light of the sedimentological investigations)*, Rozpr. Uniw. Warsz. 120.

M y ś l i ń s k a E., H o f f m a n E., K u l e s z a - W i e w i ó r a K., 1982, *Zróżnicowanie litologiczne mad w wybranych odcinkach doliny Wisły (Lithological differentiation of muds in selected sections of the Vistula valley)*, Przegl. Geol. 9, 474–479.

N a w a r a K., 1964, *Transport i sedymentacja współczesnych żwirów Dunajca i niektórych jego dopływów (Recent transport and sedimentation of gravels in the Dunajec and some of its tributaries)*, Prace Muz. Ziemi 6, 3–111.

N o w a k W. A., Ż ó ł k i e w s k i M., 1989, *Kopalna rzeźba stropu miocenu pod doliną Wisły w obrębie Kotliny Oświęcimskiej i Sandomierskiej (Fossil relief of the Miocene roof under the Vistula valley within the Oświęcim and Sandomierz Basin)*, Studia Ośr. Dokum. Fizjogr. 17, 55–85.

P u n z e t J., 1981, *Zmiany przebiegów stanów wody w dorzeczu górnej Wisły na przestrzeni 100 lat (1871–1970) (Changes in the course of water stages in the Upper Vistula Basin over a century 1871–1970)*, Folia Geogr., Ser. Geogr.-Phys. 14, 5–28.

R a d z k i P., Ł o p u s i ń s k i L., W i d z D., 1992, *Objaśnienia do szczegółowej mapy geologicznej Polski, ark. Borzęcin (976)*, Państ. Inst. Geol. Warszawa.

R u t k o w s k i J., 1977, *On petrographic variability of Holocene gravels in the Polish Carpathians*, Studia Geomorph. Carpatho-Balcan 11, 53–65.

http://rcin.org.pl

– 1991, *Osady vistulianu w dolinach Wisły i Skawinki w Skawinie*, Spraw. z Pos. Komis. Nauk. PAN. Krak. 35, 1–2, 308–310.

S o j a R., 1992, *Charakterystyka hydrologiczna Wisły od Przemszy do Sandomierza*, [in:] *Wisła w dziejach i kulturze Polski, Zmiany biegu górnej Wisły i ich skutki*, 9–29, Wyd. Uniw. Warsz. Warszawa.

S o k o ł o w s k i T., 1981, *Uwagi o terasach doliny Dunajca koło Tarnowa (Remarks on the terraces of Dunajec valley near Tarnów. Southern Poland)*, Rocz. Pol. Tow. Geol. 51, 3–4, 579–594.

– 1987, *Vistula valley between the outlets of Dunajec and Breń rivers*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 95–114.

S t a r k e l L., 1972, *Kotlina Sandomierska*, [in:] *Geomorfologia Polski*, 2, PWN, Warszawa, 138–166.

– 1990, *The upper Vistula Valley*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5, 97–102.

S t a r k e l L., G ę b i c a P., 1992, *Osady rzeczne i ewolucja dolin w okresie 18 000–8000 lat BP w Południowej Polsce*, Przegl. Geol. 10, 589–591.

S t o k s i k J., 1986, *Zagadnienia regulacji rzek w Galicji (1772–1918) w zbiorach Archiwum Państwowego w Krakowie (The problem of river regulation in Galicia (1772–1918) in the collection of the National Record Office in Cracow)*, Zesz. Nauk. AGH, 1093, Sozol. i Sozotech. 24, 91–112.

T r a f a s K., 1975, *Zmiany biegu koryta Wisły na wschód od Krakowa w świetle map archiwalnych i fotointerpretacji (Changes of the Vistula river bed east of Cracow in the light of archival maps and photointerpretation)*, Prace Geogr. UJ 40, 5–85.

– 1992, *Zmiany biegu Wisły pomiędzy ujściem Przemszy a Sandomierzem*, [in:] *Wisła w dziejach i kulturze Polski, Zmiany biegu górnej Wisły i ich skutki*, 31–61, Wyd. Uniw. Warsz. Warszawa.

U n r u g R., 1957, *Współczesny transport i sedymentacja żwirów w dolinie Dunajca (Recent transport and sedimentation of gravels in the Dunajec valley, Western Carpathians)*, Acta Geol. Pol. 7, 2, 217–257.

W a l c z o w s k i A., 1975, *Objawy współczesnych procesów suffozyjno-erozyjnych w rejonie Opatowca (Symptoms of recent-erosion processes in the vicinity of Opatowiec)*, Biul. Inst. Geol. 283, 189–209.

– 1979, *Objaśnienia do szczegółowej mapy geologicznej Polski, ark. Bejsce (949)*, Inst. Geol. Warszawa.

W o j t a n o w i c z J., 1968, *Wydmy międzyrzecza Sanu i Łęgu (The dunes of the area between the San and Łęg rivers)*, Ann. UMCS. Sec. B 20, 4, 89–124.

Ż ó ł k i e w s k i M., 1989, *Rzeźba doliny Wisły w obrębie Kotliny Oświęcimskiej i Sandomierskiej (Relief of the Vistula valley in the Oświęcim and Sandomierz Basins)*, Studia Ośr. Dokum. Fizjogr. 17, 87–100.

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NEW DATA ON THE LATE VISTULIAN AND HOLOCENE EVOLUTION OF THE WISŁOKA VALLEY NEAR DĘBICA

PREVIOUS CONCEPTS ON THE EVOLUTION OF THE WISŁOKA VALLEY FLOOR

In the 1950s the author investigated several sites in the Wisłoka and other valleys at the Carpathian foreland (Starkel 1957, 1960). The author distinguished 3–5 parallel fills in the Holocene alluvial plain. The oldest among them, imbedded in the pleniglacial deposits, was composed of gravels and sands with pine trunks and was connected with Allerød. The sparse pollen analyses indicate that the younger and shallower fills were connected with the Atlantic and Subatlantic phases, considered to have been more humid at that time. From the existence of fossil soils in the thick overbank deposits it has been concluded that in the peripheral parts of the floodplains more or less continuous aggradation took place.

In the 1970s new studies showed that old overbank deposits and soils are frequently preserved on the surface, and in the marginal parts older paleochannels exist – then there exist parallel alluvial fills (Klimek, Starkel 1974; Kowalkowski, Starkel 1977; Alexandrowicz *et al.* 1981; Starkel *et al.* 1982). From the existence of erosional benches at the base of the Younger Dryas, at the level of 2–4 m above the present Wisłoka level, the author has concluded that the late glacial incision was much shallower (Mamakowa, Starkel 1974, 1977). A distinct aggradation progressed in the Middle Ages (Grabiny–Latoszyn site – cf. Awsiuk *et al.* 1980). Finally the radiocarbon dating made it possible to localize the phases of increased fluvial activity (Fig. 1, 2).

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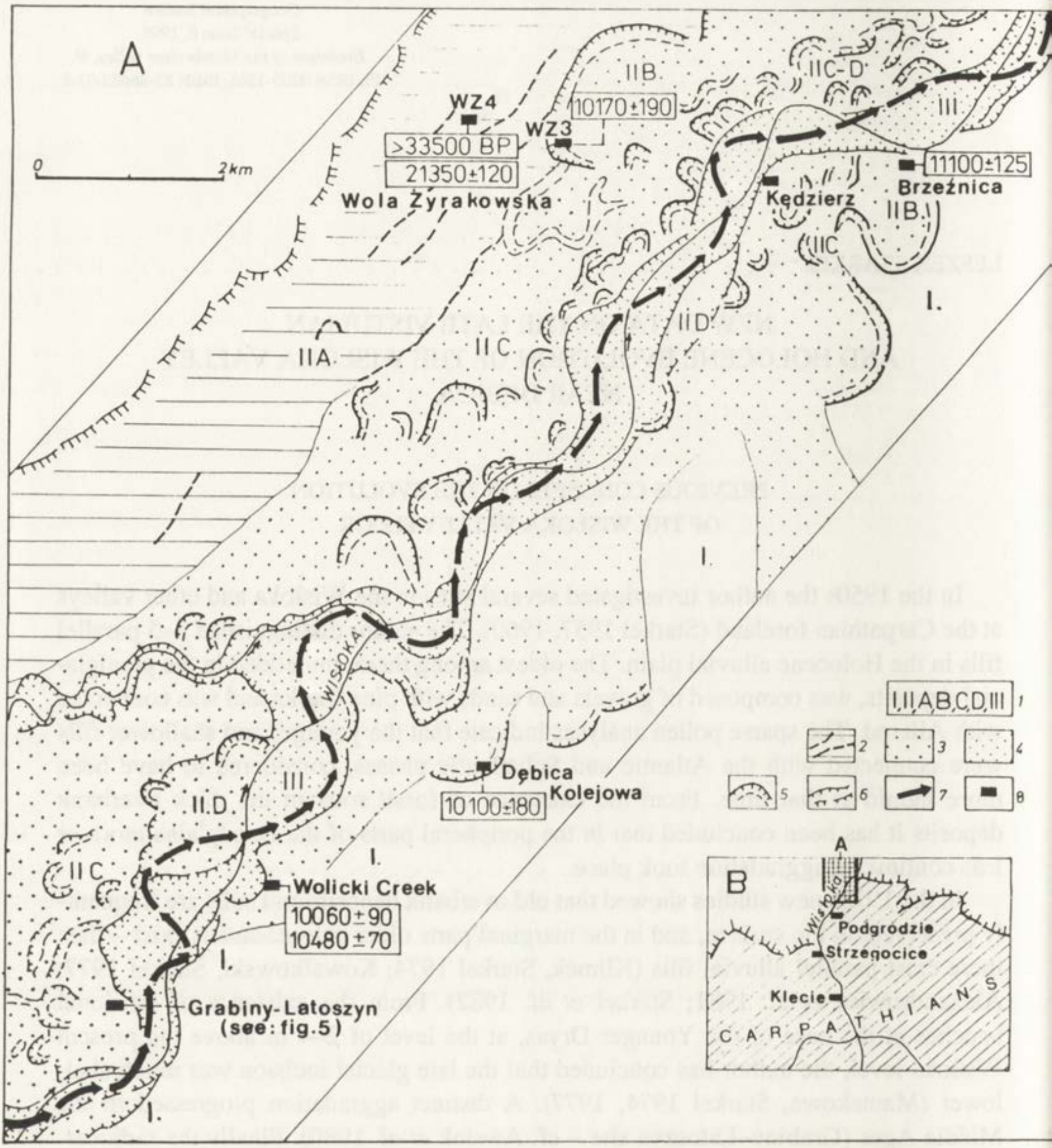

Fig. 1. Geomorphological map of the fragment of the Wisłoka valley (A) with investigated localities (partly after Starkel *et al.* 1982). B. Position of this area at the foreland of the Carpathians (with 3 other localities mentioned in the text)

1 – terrace levels (represented by separate fills), 2 – terrace IIa 11–12 m high with remains of braided pattern, 3 – terrace fills IIB, IIC, IID, 4 – flood-plain, 5 – paleomeander, 6 – terrace scarp, 7 – position of the Wisłoka channel in 1780, 8 – localities described or mentioned in the text

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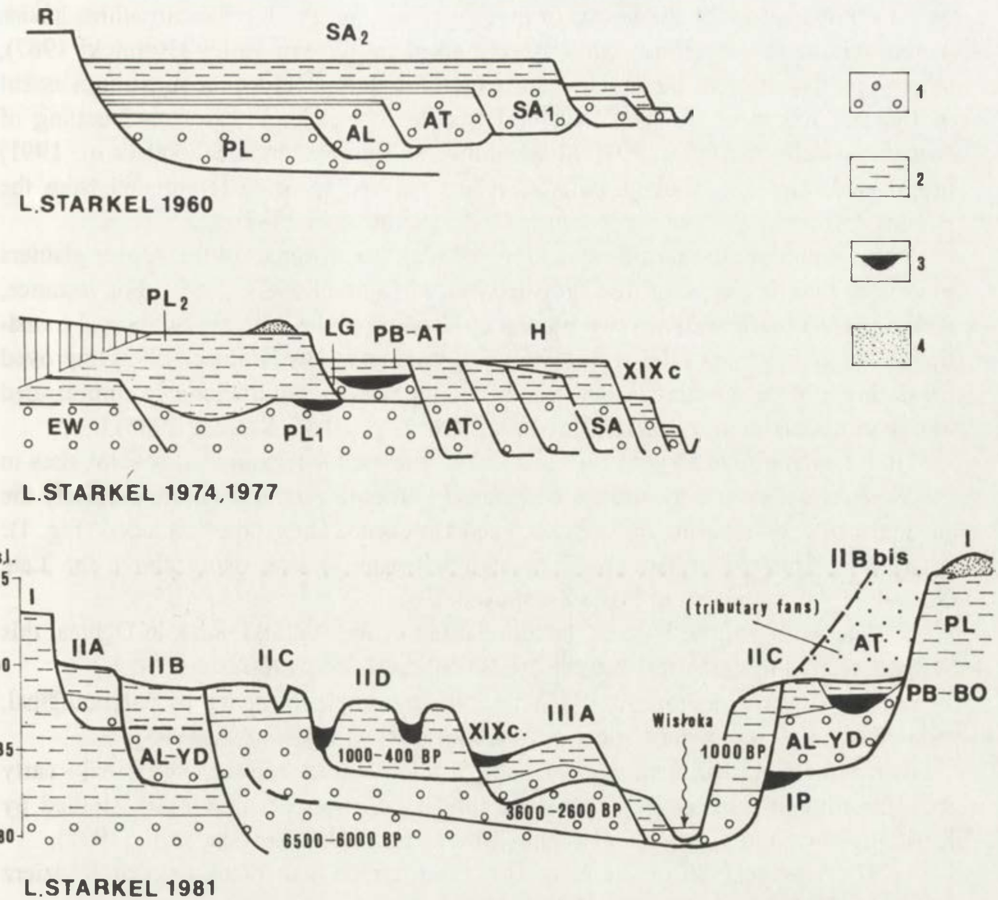

Fig. 2. Previous concepts on the evolution and alluvial fills of the Wisłoka and other valleys at the foreland of the Carpathian Foothills

1 – channel facies, 2 – overbank facies, 3 – paleochannel fills, 4 – dunes; R – Riss, EV – Early Vistulian, PL – Pleniglacial (1, 2), LG – Late Glacial, AL – Allerød, YD – Younger Dryas, H – Holocene, PB – Preboreal, AT – Atlantic, SA – Subatlantic

NEW RESULTS AND NECESSITY OF REVISIONS

The investigations in the Vistula valley carried in the IGC project no. 158 (cf. Starkel 1990) provided many new data which inspired the revision of the previous opinions and triggered some supplementary investigations within the framework of the national grant no. 6-0783-91-01-P2.

The borings in the San valley downstream and upstream of Przemyśl showed that deep channels sloping below the present channel may be not only of the pre-Allerød age (Mamakowa 1962) but even older than 15 ka BP (Klimek 1992). In the Vistula valley downstream of Cracow the oldest buried channel was abandoned before 13 250 BP (Kalicki 1991). Last year a similar opinion was presented (Starkel 1994) basing

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on the comparison with the results of investigations north of the Subcarpathian basins in the Wieprz valley (Harasimiuk 1991) and in the Prosna valley (Rotnicki 1987), where the dissection of the main Vistulian terrace started before the maximum extent of the last ice sheet. In the Younger Dryas a distinct aggradation and cutting of erosional shelfs (Kalicki 1991; Alexandrowicz, Klimek 1985; Starkel *et al.* 1991) progressed. The age of large paleomeanders seemed to be differentiated from the Bølling (Klimek 1992) to the Younger Dryas (Szumański 1983).

The number of alluvial fills synchronised with the advances of the Alpine glaciers is greater than it has been distinguished before (Starkel 1983, 1990). For instance, Kalicki (1991) differentiates two phases of flooding at the Atlantic-Subboreal transition. The introduction of the dendrochronological method by Krąpiec (1992) improved the dating of phases with frequent floods and, moreover, simultaneously commanded to pay more attention to the rebedded older trunks (Kalicki, Krąpiec 1995).

Under such circumstances (in 1992–1994) the author reexamined several sites in the Wisłoka valley and looked for new ones in order to establish moore precisely the sequence of events during the Vistulian and Holocene. The studies included (Fig. 1):

a) The structure of the 11–12 m high left-bank terrace rising above the Late Glacial–Holocene plains in Wola Żyrakowska.

b) The dating of the base of the alluvial fan of the Wolicki creak in Dębica; this fan was related to the Allerød in the 1950s (Starkel 1957, 1960).

c) The largest paleomeander in Wola Żyrakowska, investigated by palynological, radiocarbon and sedimentological methods (Starkel, Granoszewski 1995).

d) The detailed sedimentological study of flood sequence in the late Boreal – early Atlantic alluvial fan, by E. Czyżowska (under preparation), previously studied by K. Mamakowa and L. Starkel (1977) as well as E. Niedziałkowska *et al.* (1977).

e) The youngest fill of the main Holocene terrace with black oaks at Kędzierz (paper by Starkel and Krąpiec – 1995).

f) The supplementary studies of historical alluvial fills and paleomeanders in Grabiny.

g) The dendrochronological datings of black oaks from the gravel pits in Strzegocice and Klecie (cf. Krąpiec 1992, in print).

THE 11–12 M HIGH LEFT-BANK TERRACE IN WOLA ŻYRAKOWSKA

This 1–2 km wide terrace is elevated 11–12 m above the mean water level of the Wisłoka river. It is 3–4 m lower than the right-bank terrace at Brzeźnica, including the late interpleniglacial and the early, upper pleniglacial sequence. In its middle part the Dryas flora was dated at ca 28 ka BP (Mamakowa, Starkel 1974).

The discussed terrace is elevated 188–189 m a. s. l. Near the valley side it is covered by deluvial loam (Fig. 1, 3), closer to the river-dissected by sinuous channels to 1.5 m deep. Only the central part of the terrace preserved its original relief. There are discontinuous strips of shallow (0.2–0.5 m) channels characteristic for the braided pattern. The lack of overbank loams, so typical of the Holocene floodplain, is replaced

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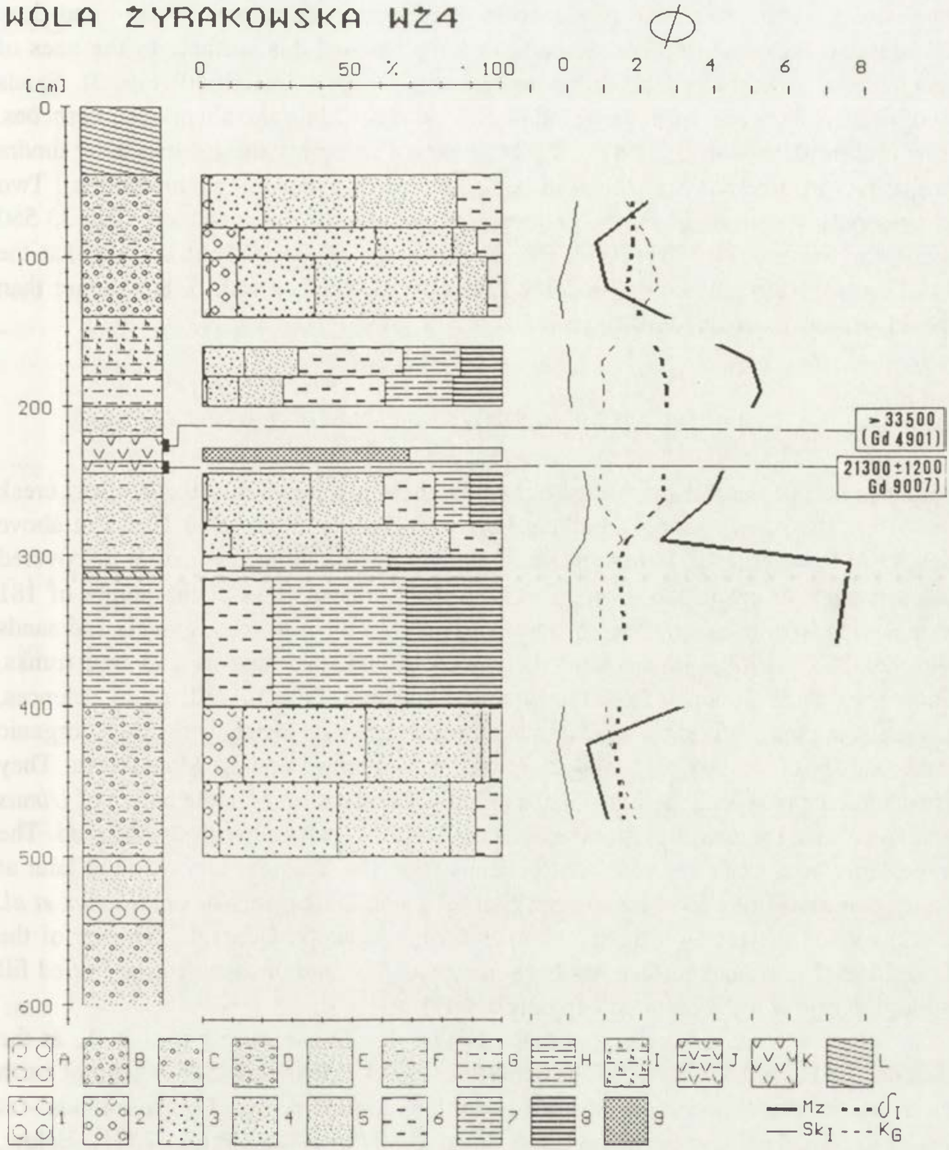

Fig. 3. Boring WŻ 4 at the 11–12 m high terrace of the Wisłoka river at Wola Żyrakowska (of Fig. 1)

A – gravel, B – gravel with sand, C – sand with single gravel, D – loamy sand with gravel, E – fine sand, F – loamy sand, G – sandy silt, H – silt with clay, I – sandy silt with organic material, J – peaty mud, K – peat, L – soil. Grain sizes in phi scale: 1 – below 4∅, 2 – –4 to –1∅, 3 – –1 to +1∅, 4 – 1–2∅, 5 – 2–4∅, 6 – 4–6∅, 7 – 6–8∅, 8 – above 8∅, 9 – carbon content; *Mz* – mean grain size in phi scale, δ_I – standart deviation, Sk_I – skewness, K_G – kurtosis

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by a sandy cover, even with fine gravels. This indicates a relatively rapid and deep incision, so the younger floods could not have reached this surface. In the axes of paleochannels the remaining sediment sequence is very diversified (Fig. 3). Sands with gravels alternate with muds and organic layers, filling the abandoned branches. The preliminary investigation by K. Mamakowa indicates the existence of tundra probably with tree patches (this will be the theme of a separate communique). Two close samples were dated by the radiocarbon method: the upper is more than 33 550 a BP, the lower – 21 300±1200 a BP. At this stage of the study it is clear that the 11–12 m high terrace is older than the Late Glacial, yet as a form it is younger than the 15 m high extensive terrace plain.

THE LATE GLACIAL AT THE BASE OF THE FAN OF THE WOLICKI CREEK

Upstream of the railway bridge in Dębica there is the outlet of the Wolicki creek dissecting the scarp of the Carpathian Foothills. The fan is elevated 10–15 m above the Wisłoka water level. Below the sandy–loamy fan the author has earlier discovered a fossil channel cut in the older gravels to the Miocene clays at the height of 181 m a. s. l. (14–15 m deep). The channel is filled with the 4 m thick gravels and sands (Starkel 1957, 1960). In the sand there were found macrofossils and tree trunks, among which M. Reyman from the Botanical Institute, Polish Academy of Sciences, recognised *Pinus silvestris, Larix* and *Betula*. Higher up there were found organic muds and peat, studied palynologically by W. Koperowa and K. Mamakowa. They connected the peat with the Late Glacial – Holocene transition (single pollen of *Ulmus* and *Corylus*). The lower gravel member the author correlated with the Allerød. The interpleniglacial beds and erosional benches from the Younger Dryas found later at the higher elevations (cf. Mamakowa, Starkel 1974; Starkel in: Alexandrowicz *et al.* 1981) caused the revision of the author's former concept. General existence of the Late Glacial erosional surface has been accepted. The author assumed the buried fill with pine trunks to be older (interpleniglacial?).

Finally, in 1992 a boring was made at the elevation of 195.5 m a. s. l., at the distance of 10 m from the previous exposure (Fig. 4). Below the 5.5 m heap of earth there appeared silts and sands of the alluvial fan, and the peat and organic muds – at 188–186.5 m. The base of the peat was dated at 10 060±90 a BP (Gd-7304). Below, the sandy member passing into gravels begins. In the upper part we drilled across two pine trunks of over 10 cm diameter each. The lower trunk, from the depth of 9.83–9.94 m was dated as 10 480±80 a BP (Gd-7311).

Both radiocarbon datings have shown that the filling of the paleochannel, at least in its upper portion, is of the Younger Dryas age. At that time the bottom of the late glacial Wisłoka was 1.5 m below the present Wisłoka water level, and 4–6 m below the erosional benches at the margin of the Wisłoka valley floor. The first opinion about the Late Glacial age of the deeper paleochannels has been confirmed.

The continuation of this paleochannel has been stated by borings farther to the east (Fig. 4, Starkel in: Alexandrowicz *et al.* 1981), where its width exceeds 80–90 m and

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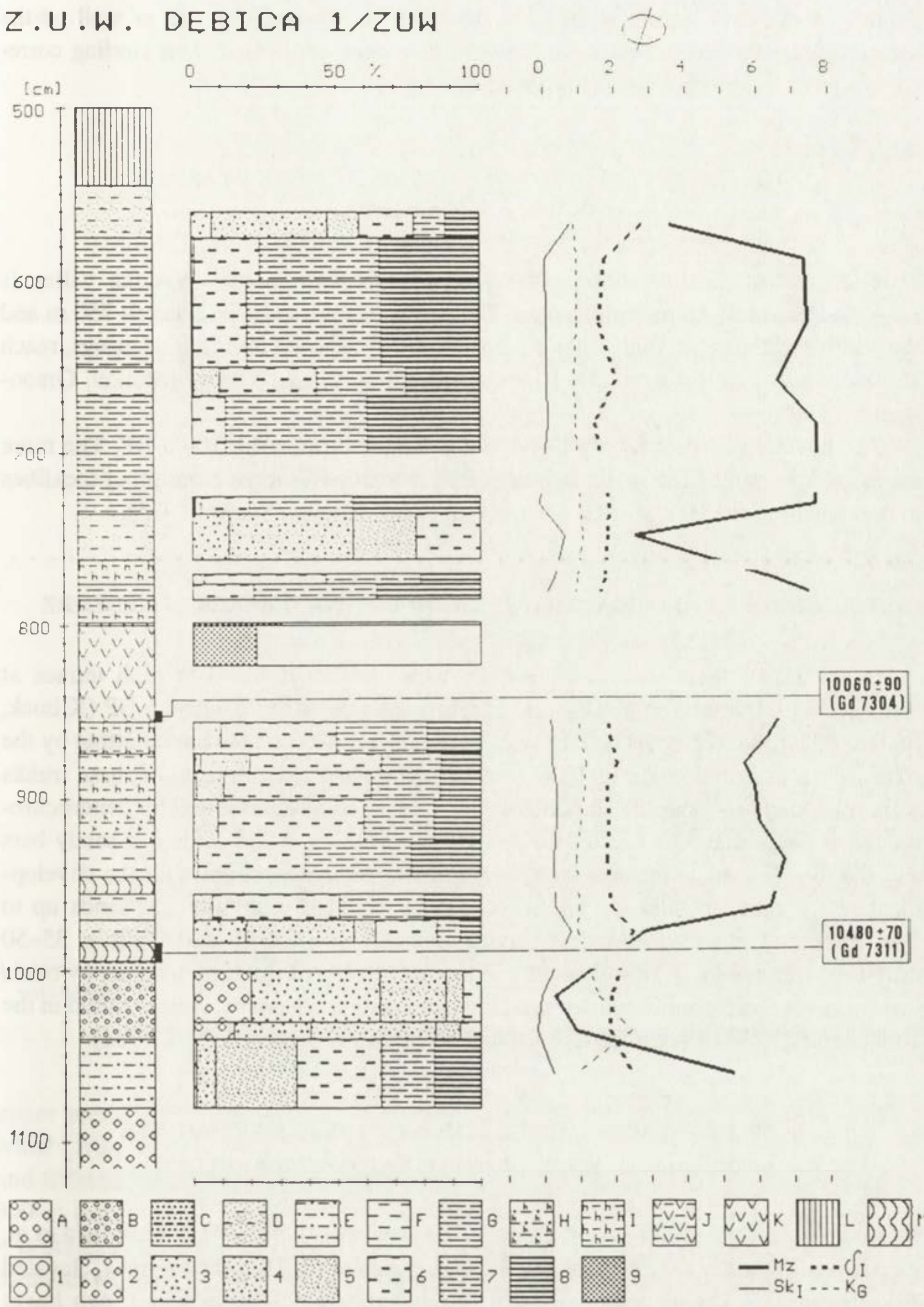

Fig. 4. Boring 1-ZUW in Dębica at the outlet of the Wolicki creek with well developed transition from the Younger Dryas to Holocene

A – gravel, B – gravel with sand, C – sand intercalated with mud, D – loamy sand, E – sandy silt, F – silt, G – silt with clay, H – sandy silt with organic material, I – organic silt, J – peaty mud, K – peat, L – debris, M – wood, Other explanations as at Fig. 3

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depth – 4 m. The decline in fluvial activity in the early Holocene as well as the upbuilding by the Boreal–Atlantic fan have also been confirmed. This finding corresponds to those of other sites (Podgrodzie).

THE GREAT PALEOMEANDER OF THE YOUNGER DYAS AGE IN WOLA ŻYRAKOWSKA

The greatest meander among the Late Glacial ones in the Wisłoka valley is preserved on the 7–10 m high terrace. The radius of this meander exceeds 750 m and the width and the depth (below the overbank *mada*) exposed during the borings, reach 125 m and 2–4 m, respectively. It is described in a separate paper (Starkel, Granoszewski 1995).

The covering of peat by the flood loams started after 9040±100 a BP. The more sandy middle part of the mada indicates frequent floods known from other localities at the transition the Boreal–Atlantic (Ralska-Jasiewiczowa, Starkel 1975).

THE YOUNGEST ALLUVIAL FILL OF THE HOLOCENE TERRACE AT KĘDZIERZ

In the 1950s there was described the bank profile of the 9 m high terrace at Kędzierz with buried tree trunks, one of which was dated at 1670±80 a BP (Klimek, Starkel 1974; Starkel in: Alexandrowicz *et al.* 1981). After a new undercutting by the river it was explored again in 1992 (Starkel, Krąpiec 1995). Several of these trunks were rebedded (4–5 ka old) and one of the younger trunks was dated by dendrochronological method at 550 AD (ca 1400 a BP) or younger. The bedding of sandy bars and the direction of the trunks indicate a simultaneous deposition with the development of the paleochannel farther to the east. It is filled with silts and sands up to 5 m thick and has the following parameters: radius = 120 m and width = 35–50 m. The abandonment of this channel and the upbuilding of the Kędzierz site by mada was probably synchronous with aggradation of overbank deposits, which started in the 10th century AD in Brzeźnica (Kowalkowski in: Alexandrowicz *et al.* 1981).

SUPPLEMENTARY INVESTIGATIONS OF THE PALEOCHANNELS AND BLACK OAKS AT GRABINY–LATOSZYN GRAVEL PIT

In the gravel pit explored in the late 1970s (Awsiuk *et al.* 1980; Mamakowa *et al.* in: Alexandrowicz *et al.* 1981), below the higher step of the Holocene terrace, elevated 191–193 m a. s. l. with traces of small paleochannels (20–30 m wide), two lower niveaus were found: IID – 190–191 m high, with the medium size paleochannels (width 45–55 m) and level III – 187–188 m high with wide braided channels from the 18–19th centuries (Fig. 5). The buried channel deposits include black oaks dated back to ca 6 ka and 3–2 ka BP. In 1986, the other trunk was dated at 3720±50 BP. The

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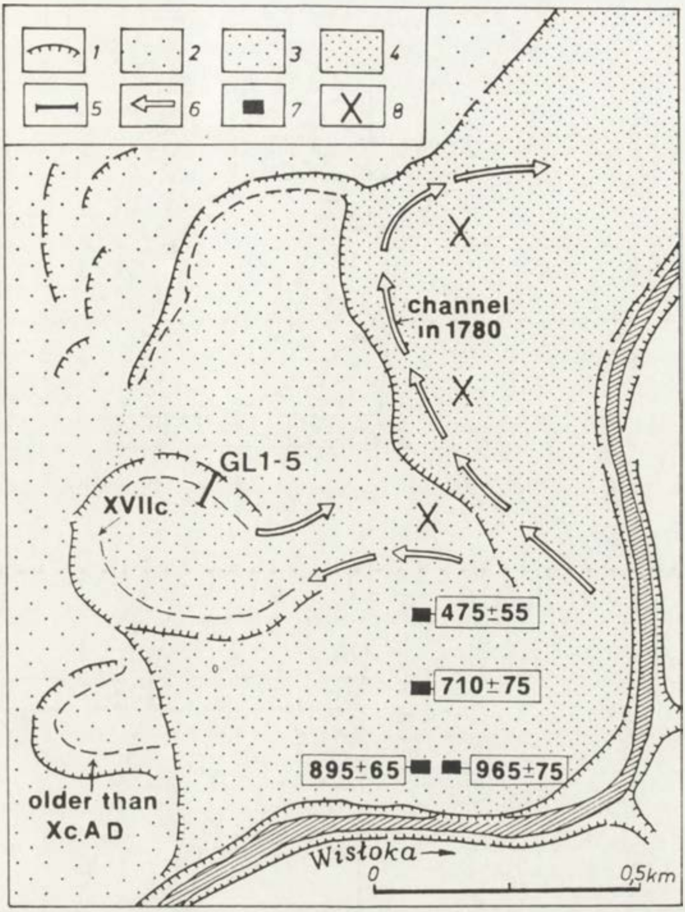

Fig. 5. Terrace levels and paleochannels of Wisłoka river in the area of Grabiny – Latoszyn gravel-pit

1 – terrace scarp, 2 – terrace plain 8–9 m high IIB–IIC, 3 – terrace IID, 4 – floodplain-level 5 – cross section with borings, 6 – direction of flow, 7 – position of trees dated by the radiocarbon method, 8 – area from which the oaks for dendrochronological datings derive

upper member of the aggrading bars at the IID level contained several tree trunks which, from the south to the north, show an interesting time sequence from 965±75 and 895±65 through 710±75 up to the youngest 475±55 BP over the distance of ca 300 m (tree with branches buried just below the river bank). Farther to the N there was preserved a paleochannel older than 1780 because it was drown as the abandoned meander (Klimek in: Alexandrowicz *et al.* 1981).

In spring 1994 in order to provide a better determintion of the events of the last millennium there were made several borings across this paleochannel and many black oaks were dated by the dendrochronological method.

The paleomeander in Grabiny (Fig. 6) undercuts the higher step and has a very regular form. It is elevated 187 m a. s. l., its width fluctuates between 45 and 55 m,

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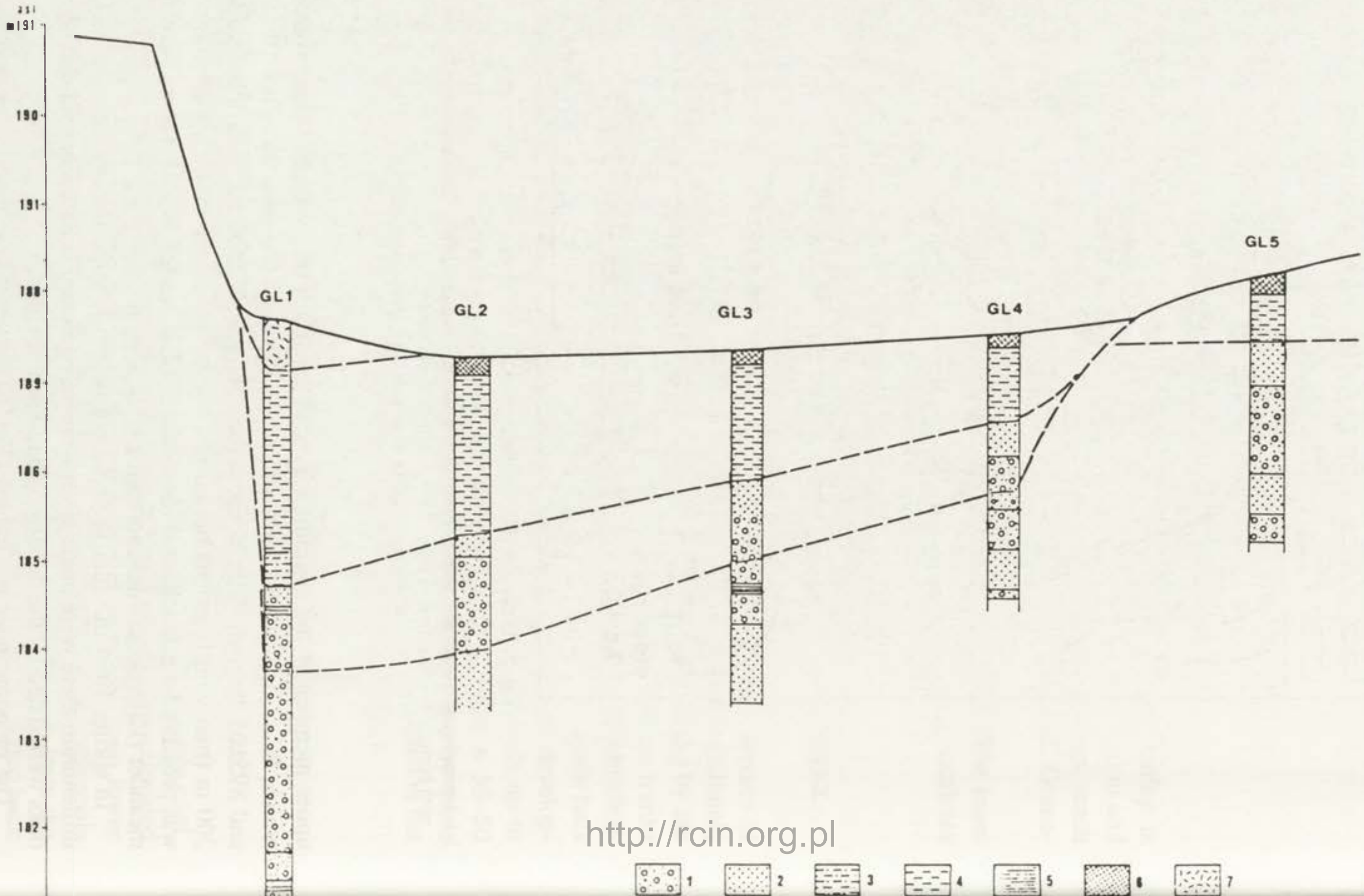
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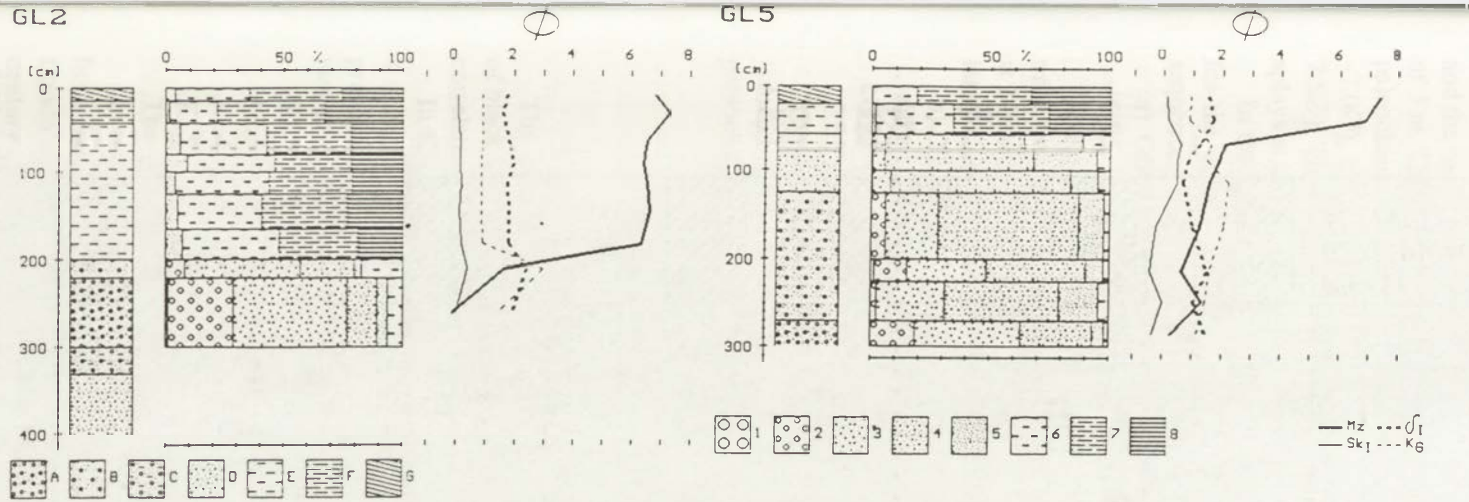

Fig. 6. Cross-section and profiles in the paleomeander from 17–18th century at Grabiny

Signs for cross-section: 1 – gravel and sand, 2 – sand, 3 – sandy silt, 4 – silt, 5 – clay, 6 – soil, 7 – debris. Signs for profiles: A – gravels with sand, B – sand with gravel, C – loamy sand with gravel, D – fine sand, E – silt, F – silty clay, G – soil; Grain sizes in ph scale: 1 – below 4, 2 – –4 to –1∅, 3 – –1 to +1∅, 4 – 1–2∅, 5 – 2–4∅, 6 – 4–6∅, 7 – 6–8∅, 8 – above 8∅; *Mz*, δ_I, Sk_I K_G – see Fig. 2

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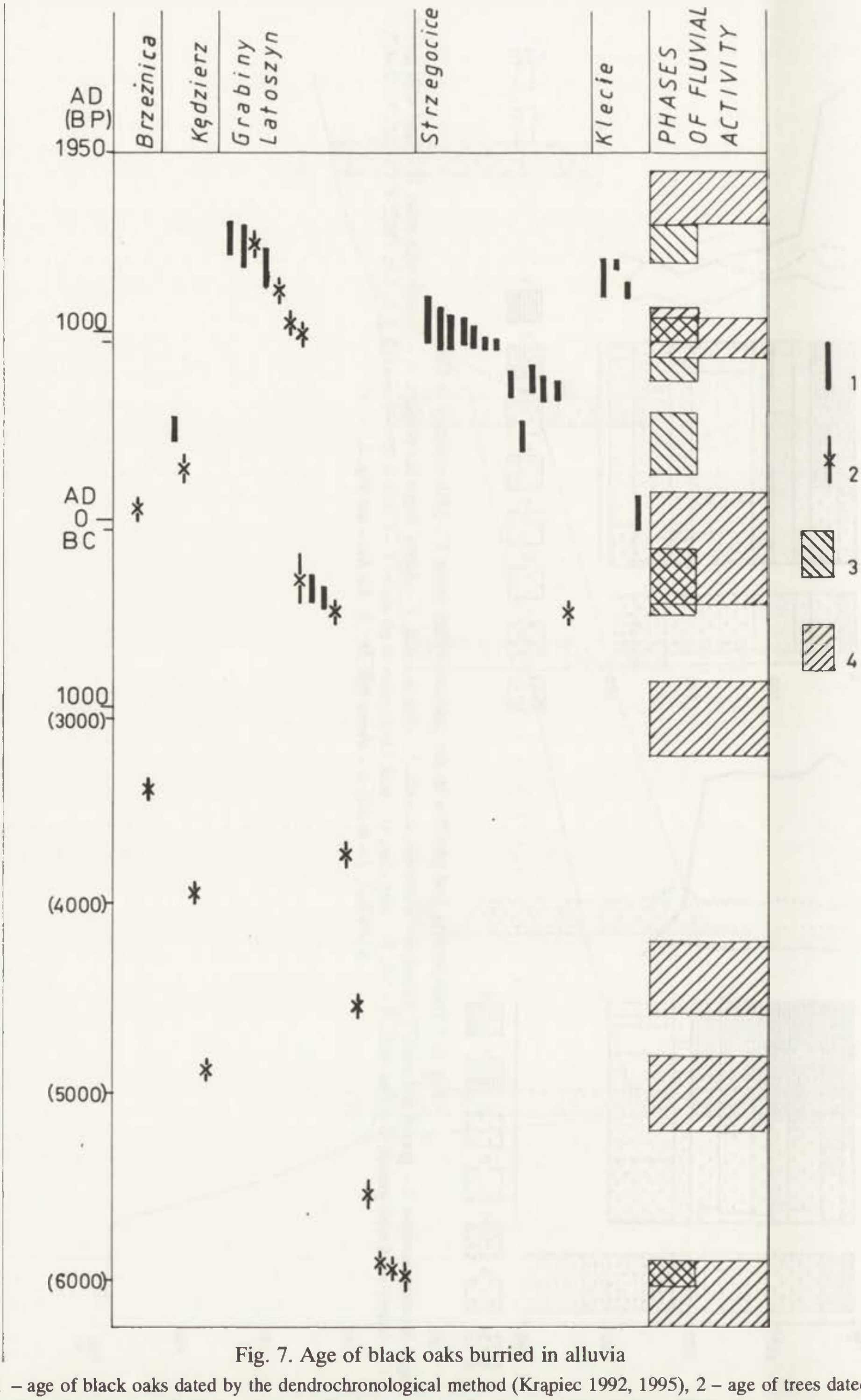

Fig. 7. Age of black oaks burried in alluvia

1 – age of black oaks dated by the dendrochronological method (Krąpiec 1992, 1995), 2 – age of trees dated by the radiocarbon method, 3 – phases of fluvial activity (after Starkel 1990; Kalicki 1991), 4 – phases of tree falling in the Wisłoka valley

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and the radius of curvature is 170 m. Five borings registered the log layer at the depth of 3 m. The top points bars rise to 188–189 m. The reconstructed depth of the studied paleochannel is 4–5 m. The channel is filled with the silty-sandy *mada* (*Mz* = 6.5–7.0∅), slightly coarser than the overbank deposits covering the pointbars (*Mz* to 7.5∅). The previously described (Niedziałkowska 1991) sandy silts of the crevasse splays at the top of the level IID farther to the south are much coarser (*Mz* = 3.5–6∅).

In the last years M. Krąpiec took samples from the gravel pit (to the E and NE) for the dendrochronological datings and recognised that these belong to two time sequences (Krąpiec 1992, in. print; Fig. 7):

a) GB1 – 453–333 a BC (fallen after 323 BC).

GB5 – 449–295 a BC (fallen after 285 BC).

These oaks correspond to the older (and lower) gravel member represented by the trunk from the exposure dated at 2420±55 BP, below which was an organic detritus dated at 2730±70 BP (Awsiuk *et al.* 1980; Alexandrowicz *et al.* 1981). This gravel unit may be interpreted as the unit of the higher fluvial activity and of the aggradation in 5–3 century BC.

b) Three trunks are from the 15–16th century:

GB – 1230–1432 AD (fallen about 1441 AD).

GB3 – with the sapwood dated at 1550–AD.

GB2 – 1380–1553 AD (fallen about 1563 AD).

These trunks correlate well with the radiocarbon dating from the upper gravel-sandy member (475±55 BP) and shift the period of the activity of the described paleochannel to the late 16th and 17th centuries.

THE YOUNG ALLUVIAL FILLS WITH "BLACK OAKS" IN KLECIE AND IN STRZEGOCICE GRAVEL PITS

The aim of the reconnaissance made 15–30 km upstream was not only the dating of black oaks (Krąpiec 1992, in print) but also the dating of the younger fills and their correlation with localities near Dębica.

In Klecie, upstream of Brzostek (ca 30 km south of Grabiny) trees buried in the 4 m high alluvial plain were found in 1992. Below the 1.5 m thick sandy mada, in the gravel being up to 5 cm in diameter, there are lying long trunks connected with the two existing oak chronologies:

KL2 – fallen after 129 a AD.

KL3 – fallen after 1263 AD (1175–1256 AD).

KL4 – fallen after 1392 AD (1340±1385 AD).

KL5 – fallen after 1397 AD (1172–1387 AD).

The last trees document the floods at the end of the 14th century.

In the northern gravel pit at Strzegocice, since the long time the black oaks have been found in the younger part of the 6–8 m high terrace as well as below the active floodplain over which the Wisłoka channel shifted as late as in the 18th and 19th century (Klimek, Starkel 1974).

In 1986, a single trunk from this locality was dated at 6779±90 BP (Gd-5058).

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During the last years M. Krąpiec and the author took ca 20 samples which show clustering in three phases (Fig. 7).

a) two trees belong to the chronology STA 2 which, according to ^{14}C dates, may be assigned between 2760±70 and 2440±70 BP (cf. Krąpiec 1992).

b) three trunks from the chronology STA 3 after the dendrochronological correlation have fallen between 470 and 560 AD, e. g. at the time of deposition of the youngest dated tree at Kędzierz (Starkel, Krąpiec 1995).

c) seven oaks represent the youngest chronology STA 1 which last year got the radiocarbon date of 970±50 a BP. This changed the previous opinion (Krąpiec 1992) and helped in the correlation with the standard scale VISTULA 2 (Krąpiec 1992) indicates that tree rings represent the period 904–1177 AD and trees have fallen between 960 and 1185 AD.

The two other trees, found in 1992, match the existing standard chronology very well and were buried simultaneously with trees of the STA 3 group:

ST22 – 361–521 AD (fallen after 531 AD).

ST23 – found in the gravels 650–788 AD (fallen after 798 AD).

The gravel pit is mainly located on the floodplain. The datings of trees support the opinion about the alluvial sequence at Grabiny–Latoszyn gravel pit that the Medieval and younger alluvia reworked the older ones from the 3rd–2nd millennia BP.

CONCLUSIONS

The last findings in the previously explored reach of the Wisłoka valley floor have shown several new elements which cause the author to modify the previous interpretation (Starkel 1960; Klimek, Starkel 1974; Starkel in Alexandrowicz *et al.* 1981, Fig. 8).

Below the 15 m high terrace (level I) dated ca 30–25 ka BP and above the Late Glacial fill with large paleomeanders (level IIB) there was found the 11–12 m high terrace with traces of braided channels. The lack of overbank *mada* indicates a rapid incision of the terraces. The organic intercalations are dated 21300±1200 BP at least.

During the Late Glacial the rivers eroded 1–2 m below the present water level as it is shown near the outlet of the Wolicki creek (Fig. 4). It means that the author's first interpretation was correct (Starkel 1957, 1960). The above is supported by the new findings in the Vistula valley (Kalicki 1991), San valley (Klimek 1992) and Jasiołka valley (Wójcik 1987). During the Younger Dryas the river aggraded and large paleochannels cut erosional benches 3–4 m above the present water level known from Brzeźnica (Mamakowa, Starkel 1974), Podgrodzie (Niedziałkowska, Starkel in Alexandrowicz *et al.* 1981) as well as from the large paleomeander in Wola Żyrakowska described above (Starkel, Granoszewski 1995).

The Holocene history is well documented by the alluvial fan with the sequence of deposits from the Boreal–Atlantic transition in Podgrodzie which has been previously described. This phase also manifests in the coarsening of *mada* in the paleochannel fills (Wola Żyrakowska, the Wolicki creek).

The new findings also document the Subatlantic phases of the Wisłoka valley

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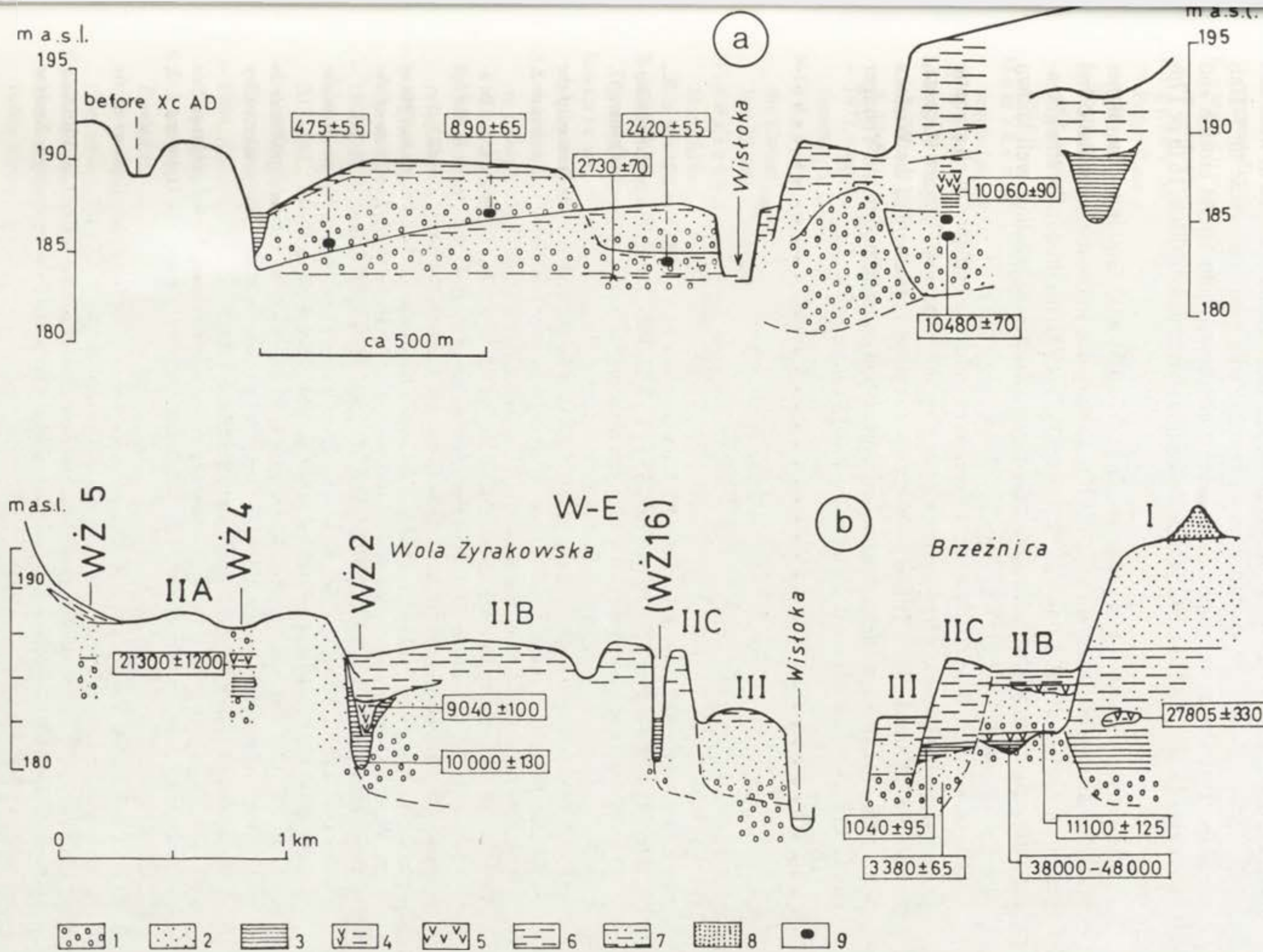

Fig. 8. Structure of alluvial plains of the Wisłoka river at two cross-sections:
a – Grabiny–Latoszyn – Wolicki creek, b – Wola Żyrakowska–Kędzierz–Brzeźnica
1 – gravels, 2 – sands, 3 – paleochannel fills, 4 – organic muds, 5 – peat, 6 – overbank loams, 7 – silty-sandy muds, 8 – eolian sand, 9 – burried tree trunks

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evolution which is supported by a great number of subfossil oaks. The last fill of the main Holocene terrace (IIB-C) with accompanying paleochannels 20–40 m wide and of the radius of 100–120 m started to be covered with overbank *mada* in 7–10th centuries. This was accompanied by incision which turned into lateral erosion and formation of a new, 1–2 lower fill whose deposition started in the 10th to 16 th or 17th centuries.

The paleomeanders of that phase are large (r = 170 m at Grabiny). The higher flood frequency which started in the 16–17th century due to combined climatic and anthropogenic factors (cf. Klimek 1974; Starkel 1983, 1990) resulted in the straightening and incision of the channel, accompanied by a tendency to braiding, well known from the San valley (Szumański 1977).

The outlet of the Wisłoka river did not preserve so clear an evidence of all climatic fluctuations which were observed in the Vistula river downstream of Cracow (Gębica, Starkel 1987; Kalicki 1991). This is probably due to the larger gradient of the Wisłoka river and more extensive lateral erosion and aggradation concentrated in the Younger Dryas, Boreal–Atlantic transition and in the last 15 centuries.

REFERENCES

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E,. Pazdur M., Starkel L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, (L. Starkel ed.), Folia Quater. 53, 1–91.

Alexandrowicz S. W., Klimek K., 1985, *Latoszyn on the Wisłoka river Section of the Vistulian pleniglacial strata: stability stages of the Wisłoka river bed. Guide to Excursion 5*, Carpatho-Balcan. Geological Association XVIII Congress, Cracow 117–121.

Awsiuk R., Niedziałkowska E., Pazdur A., Pazdur M., Starkel L., Walanus A., 1980, *Preliminary results of studies on the age of the Holocene alluvia at the left bank of the Wisłoka river near Dębica*, Studia Geomorph. Carpatho-Balcan. 14, 33–42.

Gębica P., Starkel L., 1987, *Evolution of the Vistula river valley at the northern margin of the Niepołomice Forest during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Studies, Spec. Issue 4, 71–86.

Harasimiuk M., 1991, *Vistulian glacial cycle of the fluvial processes developmwent in the valley of the Middle Wieprz River (SE Poland)*, Ann. UMCS Sec. B 46, 5, 81–109.

Kalicki T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

Kalicki T., Krąpiec M., 1995, *Problems of dating alluvium using buried subfossil tree trunks: lesson from the "black oaks" of the Vistula valley, Central Europe*, The Holocene 5, 2, 253–260

Klimek K., 1974, *The structure and mode of sedimentation of the flood-plain deposits in the Wisłoka-valley (South Poland)*, Studia Geomorph. Carpatho-Balcan. 8, 137–151.

– 1992, *The age of transformation of subcarpathian river channel pattern during Late Vistulian*, Papers and Abstracts of Papers. Symposium on Global Continental Palaeohydrology, Kraków and Mogilany.

http://rcin.org.pl

Klimek K., Starkel L., 1974, *History and actual tendency of flood-plain development at the border of the Polish Carpathians*, Nachrichten Akad. Göttingen. Report of Committee on present-day Processes IGU, 185–196.

Kowalkowski A., Starkel L., 1977, *Different age of soil cover at the Holocene terraces in Carpathian valleys*, Folia Quater. 49, 63–74.

Krąpiec M., 1992, *Skale dendrochronologiczne późnego holocenu południowej i centralnej Polski (Late Holocene tree-ring chronologies of South and Central Poland)*, Kwart. AGH, Geol. 18, 3, 37–119.

– 1995, *Dendrochronology of black oaks in the river valleys of Southern Poland*, [in:] L. Starkel (ed.), *Evolution of the Vistula rivers valley during the last 15 000 years, VI*, Geogr. Stud., Spec. Issue 9.

Mamakowa K., 1962, *Roślinność Kotliny Sandomierskiej w późnym glacjale i holocenie (The vegetation of the Basin of Sandomierz in the Late Glacial and Holocene)*, Acta Palaeobot. 3, 2, 1–57.

Mamakowa K., Starkel L., 1974, *New data about the profile of Young Quaternary deposits at Brzeźnica in Wisłoka valley, Sandomierz Basin*, Studia Geomorph. Carpatho-Balcan. 8, 47–59.

– 1977, *Statigraphy of the Eo- and Mesoholocene alluvia in Podgrodzie upon Wisłoka river*, Studia Geomorph. Carpatho-Balcan. 11, 101–110.

Niedziałkowska E., 1991, *The textural diversity of Upper Quaternary fluvial deposits in the Carpathian foreland*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud. Spec. Issue 6, 119–146.

Niedziałkowska E., Skubisz A., Starkel L., 1977, *Lithology of the Eo- and Mezo-holocene alluvia in Podgrodzie upon Wisłoka river*, Studia Geomorph. Carpatho-Balcan. 11, 89–100.

Ralska-Jasiewiczowa M., Starkel L., 1975, *The basic problems of palaeogeography of the Holocene in the Polish Carpathians*, Biul. Geol. Uniw. Warsz. 19, 27–44.

Rotnicki K., 1987, *Main phases of erosion and accumulation in the middle and lower Prosna valley in the last glacial – interglacial cycle*, Geogr. Pol. 53, 53–65.

Starkel L., 1957, *Rozwój morfologiczny progu Pogórza Karpackiego między Dębicą a Trzcianą (Morphological development of the escarpment of the Pogórze Karpackie between Dębica and Trzciana)*, Prace Geogr. IG PAN 11.

– 1960, *Rozwój rzeźby Karpat fliszowych w holocenie (The development of the Flysch Carpathians relief during the Holocene)*, Prace Geogr. IG PAN, 22.

– 1977, *Last Glacial and Holocene fluvial chronology in the Carpathian valleys*, Studia Geomorph. Carpatho-Balcan. 11, 33–51.

– 1983, *The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15 000 years*, [in:] K. J. Gregory (ed.), *Background to palaeohydrology*, J. Wiley 213–234.

– ed. 1990, *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5.

– 1994, *Frequency of floods during the Holocene in the Upper Vistula Basin*, Studia Geomorph. Carpatho-Balcan. 27–28, 3–13.

Starkel L., Gębica P., Niedziałkowska E., Podgórska-Tkacz A., 1991, *Evolution of both the Vistula floodplain and Late Glacial – early Holocene palaeochannel systems in the Grobla Forest (Sandomierz Basin)*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 87–99.

Starkel L., Granoszewski W., 1995, *The Younger Dryas paleomeander of the Wisłoka river at Wola Żyrakowska near Dębica*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, V*, Geogr. Stud., Spec. Issue 8, 91–100.

http://rcin.org.pl

S t a r k e l L., K l i m e k K., M a m a k o w a K., N i e d z i a ł k o w s k a E., 1982, *The Wisłoka river valley in the Carpathian foreland during the Late Glacial and the Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 year, I*, Geogr. Stud., Spec. Issue 1, 41–56.

S t a r k e l L., K r ą p i e c M., 1995, *Profile of the alluvia with "black oaks" in Kędzierz on the Wisłoka river*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, V*, Geogr. Stud., Spec. Issue 8, 101–110.

S z u m a ń s k i A., 1977, *Zmiany układu koryta dolnego Sanu w XIX i XX wieku oraz ich wpływ na morfogenezę terasu łęgowego (Changes in the course of the Lower San channel in XIX and XX centuries and their influence on the morphogenesis of its floodplain)*, Studia Geomorph. Carpatho-Balcan. XI, 139–154.

– 1983, *Paleochannels of large meanders in the river valleys of the Polish Lowland*, Quater. Stud. Pol. 4, 207–216.

W ó j c i k A., 1987, Late-Glacial lacustrine sediments from Roztoki and Tarnowiec near Jasło, (Jasło–Sanok Depression), Acta Palaeobot. 27, 1, 27–41.

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THE YOUNGER DRYAS PALEOMEANDER OF THE WISŁOKA RIVER AT WOLA ŻYRAKOWSKA NEAR DĘBICA

INTRODUCTION

On the left bank of the Wisłoka river, opposite to the lateglacial paleochannel at Brzeźnica (Mamakowa, Starkel 1974; Mamakowa *et al.* in: Alexandrowicz *et. al.* 1981) there exists paleomeander the largest one in this reach, belonging to the lateglacial category described from various parts of the Sandomierz Basin (cf. Szumański 1983; Starkel ed. 1990). This paleochannel was located just at the northern margin of previous detailed explorations (Starkel 1960; Alexandrowicz *et al.* 1981).

The information about the findings of peat layer 2 m thick in the well of Mr. J. Dziadowiec's farm inspired the core drilling in August 1992 and later on – a series of 10 borings in the cross-section of the abandoned channel on Mr. S. Kuszowski's field. The samples from 4 borings were investigated by laser and sewing methods for granulometry by mgr J. Sala at the laboratory of Geomorphology and Hydrology Department. 4 organic samples dated by radiocarbon method at the Laboratory of the Silesian Technical University and the organic member from boring WŻ3 were studied by palynological method by W. Granoszewski from the Botanical Institute of the Polish Academy of Sciences. The research was sponsored by the grant of the Committee of the Scientific Research no. 6-0783-91-01-P2.

LOCATION AND RELIEF OF THE AREA

The mentioned paleomeander is located at the border of 2 villages: Wola Żyrakowska and Bobrowa, about 6 km north of Dębica. In this section in the left-bank valley floor of the Wisłoka river 3 main units may be distinguished:

a) The terrace plain elevated 188–189 m a. s. l. (11–12 m above the mean Wisło-

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ka level) is 1–2 km wide. The narrowest is the part undercut by paleomeander in Wola Żyrakowska, the widest in the south where its margin is undulated by narrow sinuous and shallow paleochannel depressions. Its central zone is flat but modified by a parallel only 0.2–0.5 m deep furrow SW–NE. This plain is built fully of sands from the top. It is 3–4 meters lower than the 15 meter high right-bank terrace at Brzeźnica with the organic horizon dated back to 28 ka BP and with the dunes on the top (Mamakowa, Starkel 1974). The organic and clay intercalation at the depth of 1–3 m in the boring WŻ4 in one of such shallow furrows indicates the existence of braided channels under the forest-tundra vegetation. Two samples were dated by ^{14}C method at 21 300±1200 yrs. Bp and > 33 500 BP. This locality will be the object of a separate paper.

b) The main terrace plain of the Holocene age is about 1.5 km wide and includes various fills. It is elevated 185–187 m a. s. l. (7–9 m above the river level). The flat surface is bordered by a great paleomeander of ca 1.5 km in diameter with a scarp of the higher terrace only 1–1.5 m high. Closer to the river it is modified by discontinuous sinuous channels ca 1 m deep and farther by several deeper paleomeanders, undercut from the side of floodplain. These channels are 2.5–4 m deep, their width reaches 15–30 m only and the radius of curvature is 120 m. A single drilling has shown 2 m thick silty unit and the gravels at the depth of 2.40 m. The bottom of this paleochannel drops below the floodplain level (181.5 m).

c) The floodplain surface to 0.5 km wide elevated 182–184 m a. s. l. It consists of sandy bars formed by the active shifting channel mainly before the channel regulation in the 19-th century, later on built up by mada during the succeeding incision (cf. Klimek 1974; Klimek, Starkel 1974).

SHAPE AND GEOLOGY OF THE PALEOCHANNEL

The great meander in Wola Żyrakowska (Fig. 1, 2) has a very clear outer scarp, but on the opposite side the plain is very flat, only the meadow belt extends to 100–150 m. The meander radius exceeds 750 meters.

Outside the basic profile near the well, 11 borings were made along the paleomeander transect, denser at its margins, to determine the limits (Fig. 2). In this cross-section the plain is limited by the scarp 1–1.2 m high and 2–5% steep, smoothed by deluvial sands and the embankment. The former channel was ca 125 m wide and its deeper part with two branches was less than 60 m wide and 5.75 m deep. The paleochannel undercuts the higher sandy terrace. The sands in comparison to the Holocene channel deposits are very loamy (5–10% of clay and 5–32% of silt) and poorly sorted (*Mz* = 1–2).

The paleochannel fill may be divided into 3 members. The lower one, 2 m thick, is sandy and silty with organic intercalations deposited during floods before or after the cut off of the paleochannel. The shallow part is filled with point-bar deposits. The middle unit of peaty muds and gyttya, 0.5–1.1 m thick, is silty clayey with peat on the top. It represents the shallowing and overgrowing of the oxbow lake which ended ca 9360±40 a BP (Gd–7549). This flat surface is covered by 2.5 m thick overbank mada.

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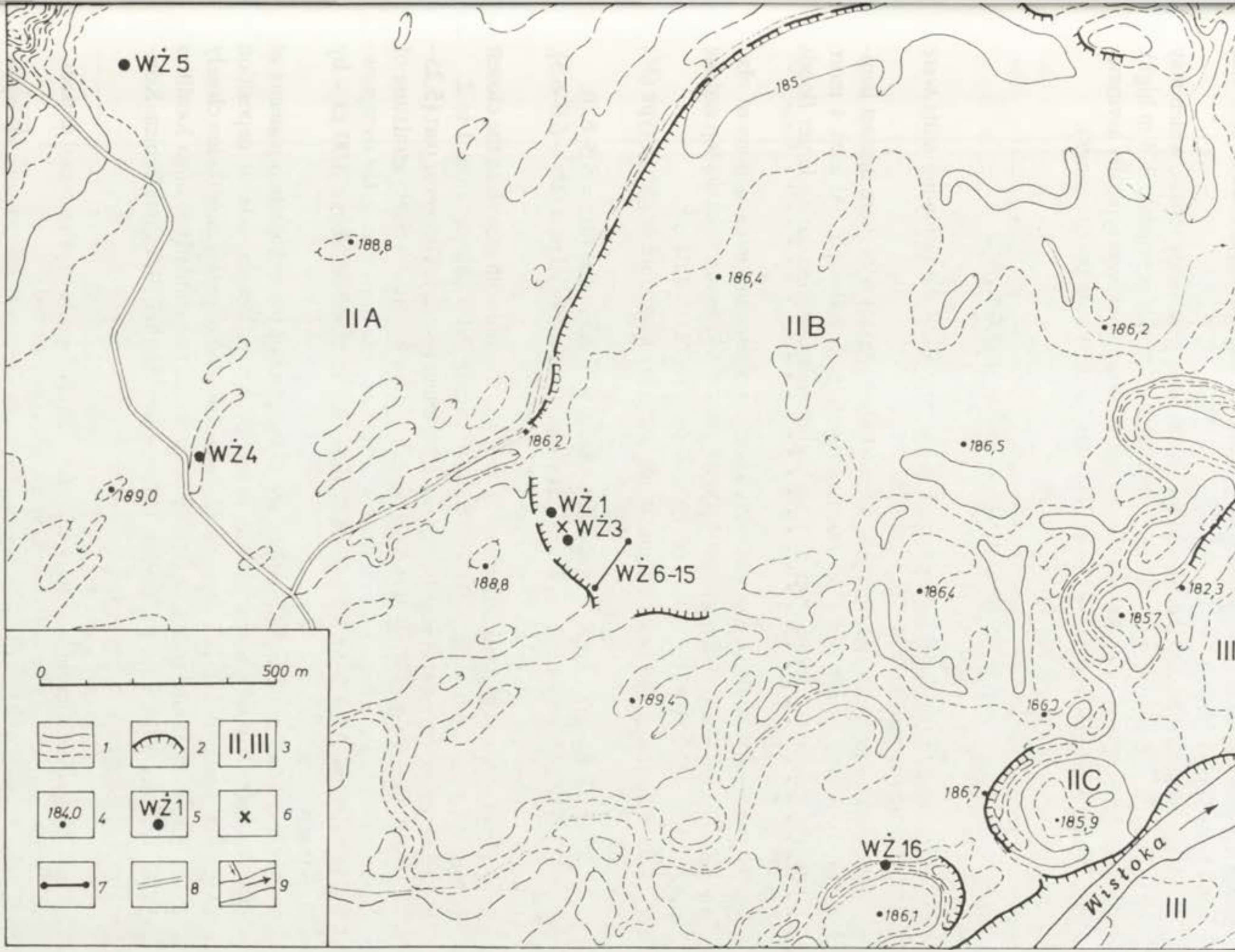

Fig. 1. Fragment of the alluvial plain at the left bank of the Wisłoka river near Wola Żyrakowska

1 – isohypses 5, 2.5 and 1.25 m, 2 – erosional scarps, 3 – number of the terrace level (cf. Alexandrowicz *et al.* 1981), 4 – elevation a. s. l., 5 – borings with number, 6 – location of well, where the peat was found for the first time, 7 – series of borings across meander (Fig. 2), 8 – main road, 9 – rivers

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In the vertical section it starts with the bottom silty clay (*Mz* = 7–8 phi) through silty sand (5–6 phi) up to finer at the top (6–8 phi). The mada of the axial deeper part is slightly coarser (5–7 phi), than that farther from the scarp where the water flow was weaker (6–8 phi).

At the base of the scarp the alluvial loams alternate with sandy lenses, which may be explained as the slope-wash fan or slumps (this scarp was previously 3–4 m high).

The reconstructed paleochannel (below the mada member) was typically asymmetric and its primary mean depth was ca 2 meters (up to 4 m in overdeepings).

SEQUENCE OF STRIATA IN THE MAIN CORE WŻ3

In the axis of the fossil paleochannel in the core WŻ3 the following units were drilled from the surface (Fig. 3).

0–3.43 m – grey-rusty, deeper grey alluvial loam (*mada*) with more distinct lamination. The mean grain size (*Mz*) fluctuates between 5 and 7 phi. At least 4 more sandy horizons in the middle part indicate higher sediment load during larger floods (15–25% of sand).

3.43–4.35 m – dark-brown peat with wood fragments and intercalations of clay and silt. The radiocarbon date of 9040±100 BP (Gd–4997) comes from the top and the date of 10170±190 BP (Gd–9008) from the lower part (4.02–4.04 m).

4.35–4.56 m – grey-brown organic muds with clay admixture of gyttya type (*Mz* > 7 phi).

4.56–5.07 m – grey organic muds silty-sandy, well laminated (*Mz* = 5.5–6.0).

5.07–5.25 m – grey-black organic muds with intercalations of peat (*Mz* = 6.0–6.5), dated at the base at 10 000±130 BP (Gd–6872)

5.25 m – coarse grained sand deeper passing in to sand with gravel. In the closest boring WŻ1 the *Mz* rises from 0.0–1.0 phi and sorting index changes from 1 to 2.

The section represents the filling of the abandoned channel. The lower part (5.25–4.56 m) indicates the filling of the oxbow lake partly by flood waters (admixture of sand 10–20%). Then there follows finer sediment passing to peat, e. g. the overgrowing of the oxbow lake. At 3.43 m starts more active flooding, above 3.00 m – by transfluent waters.

The two lower radiocarbon datings are in the zone of the radiocarbon plateaux at the Younger Dryas–Preboreal transition and do not reflect the rate of deposition (Ammann, Lotter 1989). The upper date localises the end of peat accumulation closely to the Preboreal–Boreal transition. It may be expected that similarly to other localities in the Wisłoka valley e. g. Podgrodzie (Mamakowa, Starkel 1977) and Dębica–Kole-

Fig. 3. Main research boring WŻ3 analyzed by the sedimentological and palynological methods, as well as dated by the radiocarbon method

A – sand, B – sandy silt, C – silt, D – silty clay, E – clay, F – silt with organic matter, G – clay with organic matter, H – muddy gyttia, I – sandy peaty mud, J – peaty mud, K – peat, L – soil, M – fossil wood; grain sizes in phi scale: 1 – –1 to +1, 2 – 1–2, 3 – 2–4, 4 – 4–6, 5 – 6–8, 6 – over 8; *Mz*, δ_I, Sk_I, K_G see Fig. 2

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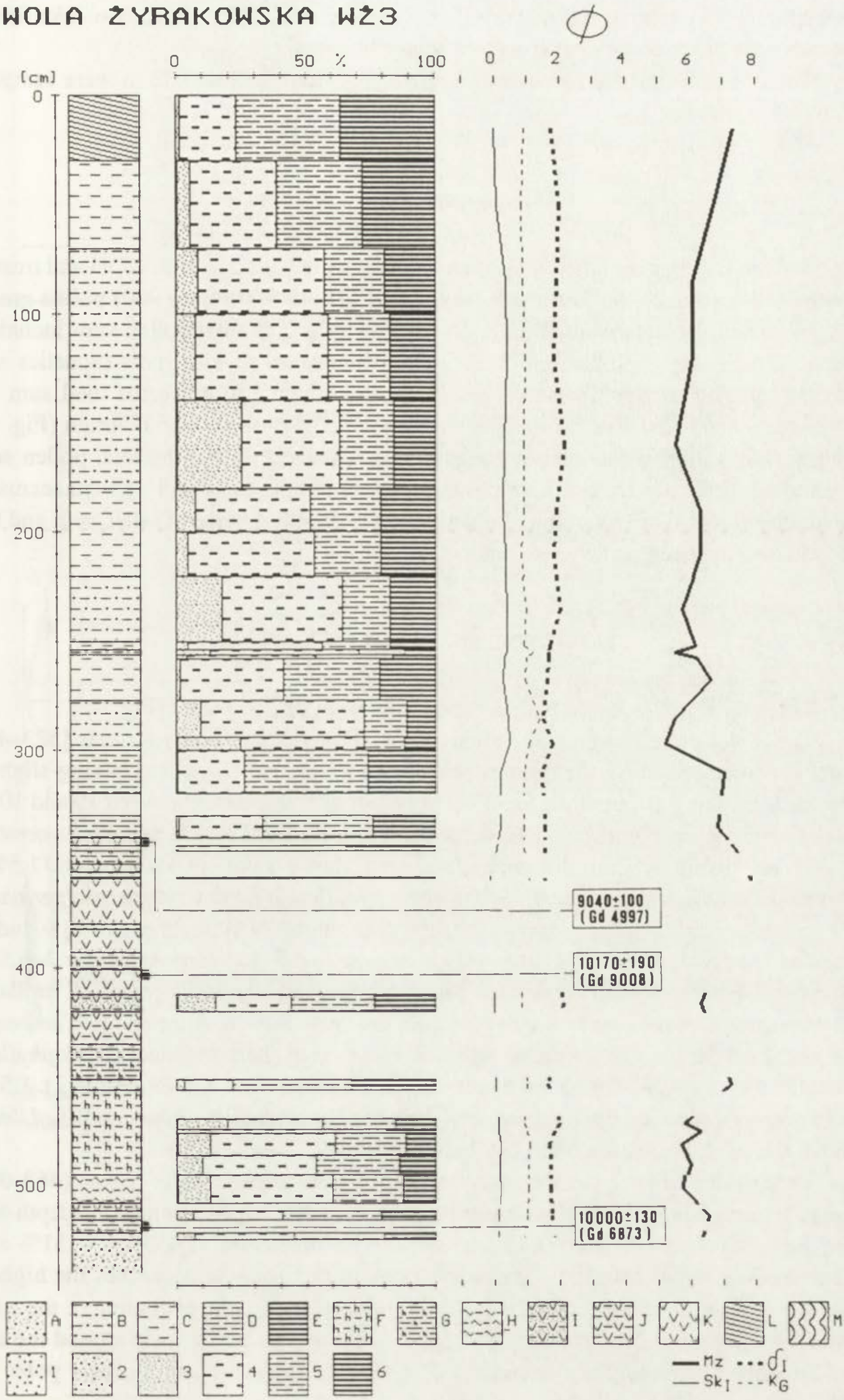

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jowa Street (Mamakowa, Starkel in: Alexandrowicz *et al.* 1981) the oxbow-lake filling startes near the boundary of Younger Dryas–Preboreal.

To get a more detailed stratigraphy the layers from 3.33 to 5.23 m were sampled for pollen analysis.

POLLEN ANALYTICAL STUDY

Sixteen samples designed for pollen analysis were boiled in 10% KOH and treated with hot HF prior to the Erdtman's acetolysis. At least 300 (up to 900) pollen grains from terrestrial plants were counted in each sample. The total pollen sum includes: trees, shrubs, dwarf shrubs and herbs. The percentages of local taxa (aquatics and reedswamps), *Pteridophyta* and *Bryophyta* were counted to make the total sum increased by the respective taxon. The results are given in the pollen diagram (Fig. 4); Fig. 5 shows the curves of trees and shrubs calculated to make the total pollen sum excluding *Alnus* pollen, as its local overrepresentation at the depth 353 cm seems to be quite evident. The excluding of alder pollen makes the course of other trees and the boundaries between zones more distinct.

LOCAL POLLEN ASSEMBLAGES ZONES

Three local pollen assemblages zones have been distinguished (Fig. 4).

The lower pollen assemblage zone WŻ3-1 *Pinus–Pinus cembra–Larix* [523–463 cm] is characterized by the highest amount of *Pinus* undiff. pollen, having slightly upwards tendency (from 40 up to 52%). *Betula* undiff. fluctuates between 19 and 10%. Relatively high percentages of *Larix* pollen from nearly 2 to 5% and *Pinus cembra* 2–9% are distinctive for the zone. *Juniperus* shows small maximum (ca. 1,5%), whereas *Populus, Hippophaë, Ephedra distachya, Betula nana* t., *Myricaria germanica* and *Alnus viridis* t. are present with very low values. NAP reaches 22–38% and is formed chiefly by *Cyperaceae* 6.5–16%, *Gramineae* 4,5–12% and *Artemisia* 3–6.5%. Some of the herbs are only present in this zone: *Saxifraga oppositiofolia* t., *S. stellaris* t., *Helianthemum nummularium* t., *Gentiana pneumonanthe* t., *Anemone* t., *Campanula* and *Ficaria*. At the depth of 488 cm there have their maxima: *Myriophyllum verticillatum* 3,2%, *Potamogenton* sect. *Eupotamogeton* – 2% and *Phragmites* t. 1,5%. The drop of *Larix* and *Pinus cembra* and rise of *Betula* undiff., *Pinus* undiff., *Ulmus* and *Salix* marking out the boundary between zones.

The middle pollen assemblage zone WŻ3-2 *Pinus-Betula-Salix-Ulmus* (463–375 cm). AP increasing to 94%, *Pinus* undiff., excluding 28,5% pessimum at the depth 453 cm increasing to 80%. *Betula* undiff. starts with maximum at 453 cm – 31% and afterwards is rather constant – around 9–11%. In this zone *Salix* reaches the highest percentages in the entire sequence 2–6.5%. *Ulmus* comes at the beginning of the zone with a low value (0.2%), increasing to 5.5% in the middle and to 14% around the end of the zone. *Picea* slightly exceeds 1%. *Quercus, Fraxinus* and *Corylus* polen in

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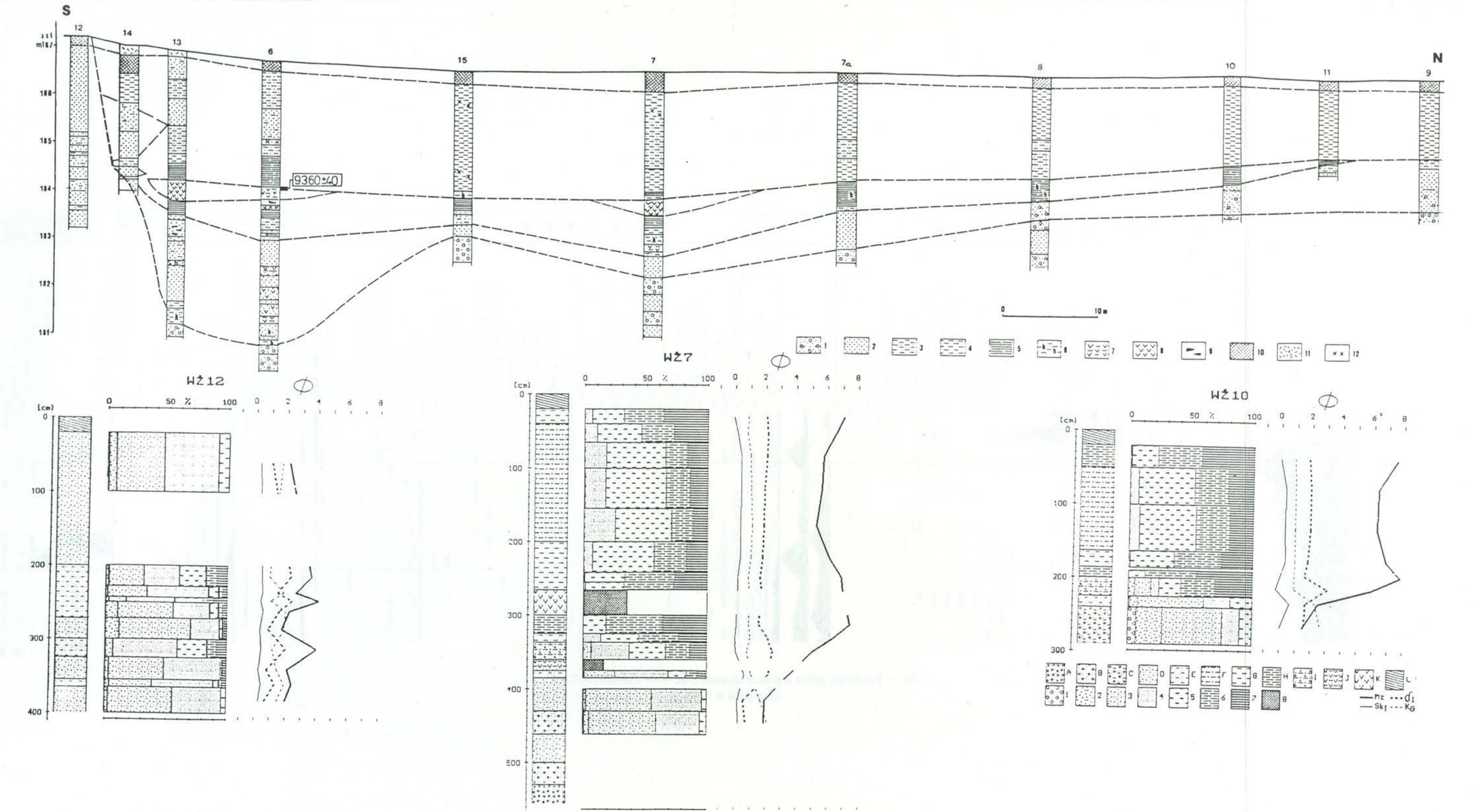

Fig. 2. Cross-section of the large paleomeander and selected profiles

Signs for the cross section: 1 – gravels and sand, 2 – sand, 3 – sandy silt, 4 – silt, 5 – clay, 6 – silt or clay with organic detritus, 7 – organic muds, 8 – peat, 9 – wood fragments, 10 – soil (humus layer), 11 – rubble, 12 – iron concretions.

Signs for profiles: A – gravel with sand, B – sand with single gravels, C – sand with gravels and silt, D – coarse and fine sand, E – sand with silt admixtures, F – sandy silt, G – silt, H – silty clay, I – mud with organic detritus, J – peaty mud, K – peat, L – soil; grain sizes in phi scale: 1 – -4 to -1, 2 – -1 to +1, 3 – 1–2, 4 – 2–4, 5 – 4–6,

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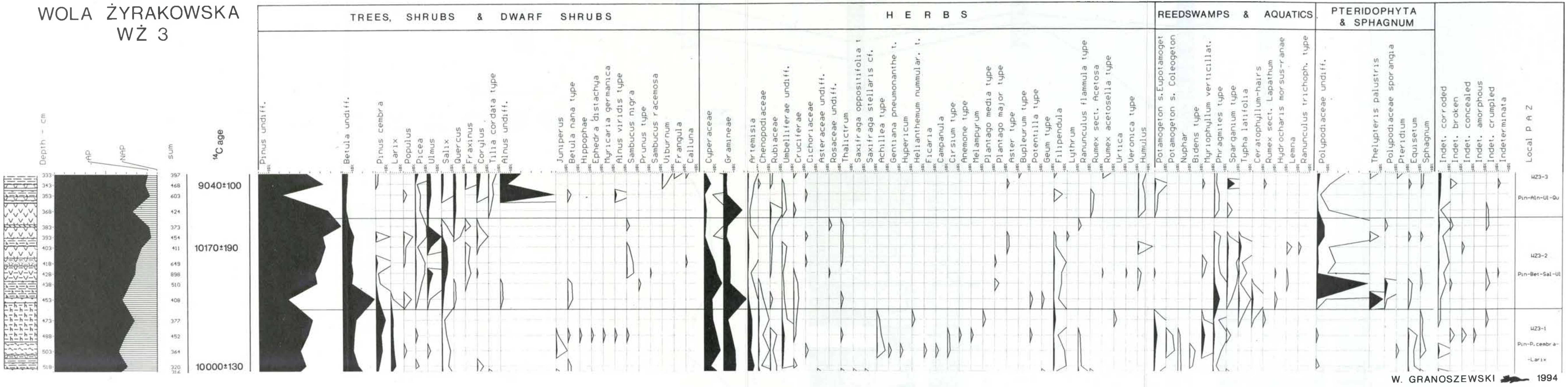

Fig. 4. Percentage pollen and spore diagram from Wola Żyrakowska 3 site
Lithology as in Fig. 3

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traces. *Gramineae* curve starts with 22% at 453 cm and decreases to 4.5%; *Cyperaceae* curve has a maximum 17% at 438 cm, but then decreases upwards to 2%. Local taxa e. g. *Phragmites* t. shows small maximum 6%. *Polypodiaceae* undiff. approaching 50%, *Thelypteris palustris* exceeds 10%; sporangia of *Polypodiaceae* and *Ceratophyllum* hairs are noted. The boundary between the succeeding zones is based on the fall of *Pinus* undiff. and the gradual occurrence of thermophilous trees and shrubs e. g. *Quercus, Corylus, Tilia cordata* t. and *Alnus* undiff.

The upper zone WŻ3-3 *Pinus–Alnus–Ulmus–Quercus* (375–333 cm). AP constitutes around 90% of the pollen flora, only at 368 cm decreases to ca. 75%. *Pinus* predominates 23–67%. *Betula* in decline; 14% maximum *Ulmus* at 393 cm is followed by the gradual occurrence and expansion of thermophilous trees: *Quercus* 0,7–2.6%;

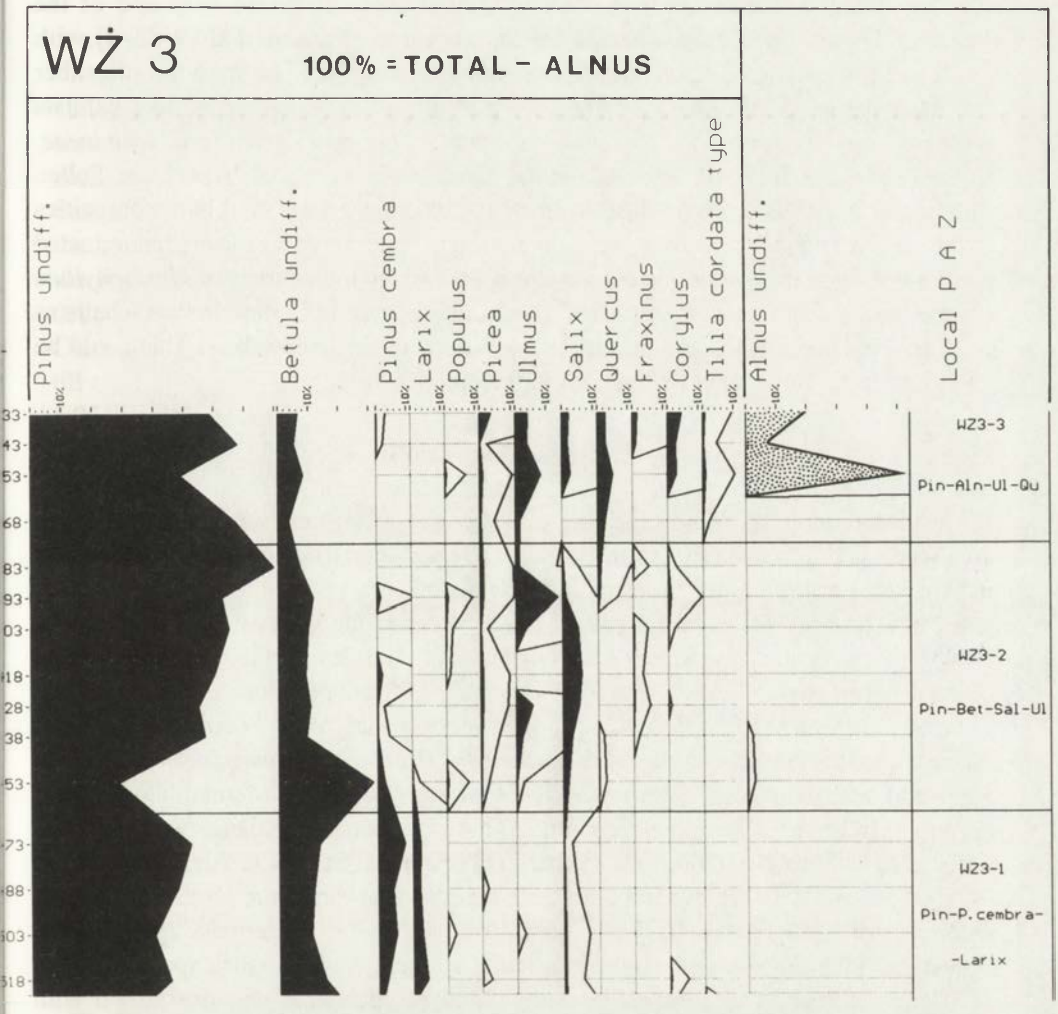

Fig. 5. Curves of some trees and shrubs calculated on the total sum excluding *Alnus* pollen

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Corylus 1–4%; *Fraxinus* 1,5%; *Tilia cordata* t. less than 1%. *Picea* rises to 3%. At 353 cm *Alnus* appears with a striking proportion – 53% and then diminishes to 7,3% and rises to 20% (Fig. 5). There is no upper boundary for this zone.

DESCRIPTION OF VEGETATION

On the ground of the obtained pollen diagram and its relation to radiocarbon datings three chronozones have been distinguished in the course of the developing of the vegetation.

THE TRANSITIONAL YOUNGER DRYAS/PREBOREAL PERIOD

The filling of the abandoned channel started probably at the very end of the Younger Dryas. Open *Pinus–Betula* forests appeared at that period (WŻ3–1) with *Larix* as an important component. *Pinus cembra* grew not very far from the site either (cf. Mamakowa, Starkel in: Alexandrowicz *et al.* 1981). Open steppe-like habitats were occupied by *Juniperus, Ephedra distachya, Hippophaë, Artemisia, Gramineae, Chenopodiaceae, Helianthemum nummularium* t., *Anemone* t. and *Hypericum.* Pollen of *Myricaria germanica* could be a proof for existing gravel-sand bars comunities along the river banks. As for the local vegetation at that time in the basin predominated comunities from the *Potamogetonetea* Class. Relatively high curves of *Myriophyllum verticilltum, Nuphar, Potamogeton* sect. *Eupotamogeton* and *Ceratophyllum* – hairs as well may indicate mezo- and eutrophic conditions in the oxbow-lake. This could be an evidence for improving the climate in the area.

THE PREBOREAL PERIOD

In the Preboreal (WŻ3–2) the role of *Larix* and *Pinus cembra* diminished in the area whereas the contribution of tree birches (*Betula* undiff.) in the forest composition increased for a while in the oldest part of the period. After *Betula* drop, *Pinus* was the main tree forming forest communities in the area. In the upper habitats *Picea* was established a regular component of the forest communities. In the river valley there could develop aspen – willow riverside communities from *Salicion* Alliance with tree willows (*Salix*) and aspen (*Populus*). As an admixture there grew *Fraxinus* and *Ulmus*; in undergrowth: *Sambucus nigra, S. racemosa, Prunus* t.; *Artemisia, Urtica* in the floor and with *Humulus. Ulmus* was the first element of the thermophilous forest springing in the area in reliable quantity. That is in good accordance with previous pollen and radiocarbon data from the area (Mamakowa, Starkel in Alexandrowicz *et al.* 1981) as well as with general Holocene plant succession in the south–east Poland (Mamakowa 1962; Ralska-Jasiewiczowa 1980, 1983, 1991; Harmata 1987, 1989). Forest communities were strongly expanding, so there was not much space for open herb communities. The swampy bottom of the paleochannel was overgrown with communities similar to those of *Phragmitetea* Class contained *Salix, Sparganium,*

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Phragmites, Typha latifolia, Rumex sect. *Lapatum* and *Thelypteris palustris* and of *Bidentetea* Class as well.

THE BOREAL PERIOD

Pinus and *Ulmus* were the main components of forest communities. Gradually there became more and more important thermophilous trees like *Quercus, Fraxinus, Tilia cordata* t. and shrubs e. g. *Corylus, Viburnum* and *Frangula*. In the river valley the apparently existed forest alnus-carr-like communities composed of: *Alnus, Fraxinus, Salix* and possibly *Ulmus*. *Picea* was spreading in the upper habitats. Open habitats were getting more and more restricted.

CONCLUSIONS AND DISCUSSION

The exact date of the abandonment of the greatest paleochannel in the Wisłoka valley is difficult to determine due to coincidence in time with the radiocarbon plateaux (Ammann, Lotter 1989; Goslar *et al.* 1993). However, the age of abandonment corresponds in general to the data from other localities (Mamakowa, Starkel 1977; Starkel ed. 1990), and the character of vegetation places it in the uppermost part of the Younger Dryas. The change of channel parameters to much smaller ones during the Holocene may be explained by the expansion of the dense forest vegetation, the decline in the flood frequency and the decline in delivery of sediment from the Carpathians slopes (Szumański 1983; Starkel 1983). The zone of ^{14}C plateaux lasted till the mid-Preboreal, as it is indicated by the date 10 170±190 a BP at the depth of 4.02–4.04 m. During that time probably ca. 500–1000 years long the early oxbow-lake was overgrown. The upper part of Preboreal is represented by undisturbed peat deposition. Then at the transition to Boreal and at the arrival of broadleaved trees the paleochannel floor started to be flooded again. The date 9040±100 a BP from the highest peaty intercalation seems to be too old if we correlate with the vegetational succession. A similar picture is observed at the Podgrodzie alluvial fan (Mamakowa, Starkel 1977; Niedziałkowska *et al.* 1977). Sandy layers above 3 m deep probably represent the first Holocene phase with frequent floods which started about 8600–8400 a BP (Starkel 1983, 1991). Later on the floods flattened the paleochannel and the bar system by deposition of thick mada (Fig. 2). Therefore at present only one geomorphic feature, the 1–1.5 m high external scarp, is visible in the landscape.

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REFERENCES

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E., Pazdur M., Starkel L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, L. Starkel (ed.), Folia Quater. 53, 1–91.

Amman B., Lotter A. F., 1989, *Late-glacial radiocarbon – and palynostratigraphy on the Swiss Plateau*, Bores 18, 109–126.

Goslar I., 1993, *The varve chronology of the late glacial and early Holocene parts of laminated sediments of Lake Gościąż (in Polish, English summary)*, Polish Bot. Stud. Guidebook, Series 8, 145–155.

Harmata K., 1987, *Late-Glacial and Holocene history of vegetation at Roztoki and Tarnawiec near Jasło (Jasło–Sanok Depression)*, Acta Palaeobot. 27, 1, 43–65.

– 1989, *Type Region P-d: The Jasło–Sanok Depression*, [in:] M. Ralska-Jasiewiczowa (ed.), *Environmental changes recorded in lakes and mires of Poland during the last 13 000 years. Part three*, Acta Palaeobot. 29, 2, 25–29.

Klimek K., 1974, *The structure and mode of sedimentation of the flood-plain deposits in the Wisłoka valley (South Poland)*, Studia Geomorph. Carpatho-Balcan. 8, 137–151.

Klimek K., Starkel L., 1974, *History and actual tendency of flood-plain development at the border of the Polish Carpathians*, Nachr. Akad. Göttingen, Report of Commission on Present Day Processes IGU, 185–196.

Mamakowa K., 1962, *Roślinność Kotliny Sandomierskiej w późnym glacjale i holocenie (The vegetation of the Basin of Sandomierz in the Late-Glacial and Holocene)*, Acta Palaeobot. 3, 2, 1–57.

Mamakowa K., Starkel L., 1974, *New data about the profile of Young Quaternary deposits at Brzeźnica in Wisłoka valley, Sandomierz Basin*, Studia Geomorph. Carpatho-Balcan. 8, 47–59.

– 1977, *Stratigraphy of the Late glacial and early Holocene alluvia at Podgrodzie on the Wisłoka river (S. Poland)*, Studia Geomorph. Carpatho-Balcan. 11, 101–110.

Niedziałkowska E., Skubisz A., Starkel L., 1977, *Lithology of the Eo- and Meso-holocene alluvia in Podgrodzie upon Wisłoka river*, Studia Geomorph. Carpatho-Balcan. 11, 89–100.

Ralska-Jasiewiczowa M., 1980, *Late-glacial and Holocene vegetation of the Bieszczady Mts. (Polish Eastern Carpathians)*, PWN, Warszawa–Kraków.

– 1983, *Isopollen maps for Poland: 0–11000 years B. P.*, New Phytologist 49.

– 1991, *Ewolucja szaty roślinnej w holocenie*, [in:] L. Starkel (ed.) *Geografia Polski – Środowisko Przyrodnicze*, PWN, Warszawa.

Starkel L., 1960, *Rozwój rzeźby Karpat fliszowych w holocenie (The development of the Flysch Carpathian relief during the Holocene)*, Prace Geogr. IG PAN, 22.

– 1983, *The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15000 years*, [in:] K. J. Gregory (ed.) *Background to palaeohydrology*, J. Wiley, 213–234.

– ed., 1990, *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5.

– 1991, *Environmental changes at the Younger Dryas-Preboral transition and during the early Holocene: some distinctive aspects in central Europe*, The Holocene 1, 3, 234–242.

Szumański A., 1983, *Paleochannels of large meanders in the river valleys of the Polish Lowland*, Quater. Stud. Pol. 4, 207–216.

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PROFILE OF THE ALLUVIA WITH "BLACK OAKS" IN KĘDZIERZ ON THE WISŁOKA RIVER

HISTORY AND THE AIM OF THE STUDIES

The undermining of the rendzina terrace north of the village of Kędzierz and NW of the village of Kozłów (both villages being the quarters of the Dębica city) was one of the outcrops where the black oaks have been stated (Friedberg 1903; Starkel 1957, 1960).

Prior to the Symposium of the INQUA Holocene Commission in 1972 there was generally described the site in Kędzierz where in the 8.5 m thick series of alluvia (on the Miocene clays?) under 2.5 m of alluvial loams and 2 m of sand bars ca 10 interlocking tree trunks had been found in gravels and sands. The dendrochronological analysis made by B. Pawlikowa of the Institute of Botany, Polish Academy of Sciences in Cracow provided evidence of the presence of the following species: *Quercus, Ulmus, Alnus* and *Acer campestre* (Starkel in: Alexandrowicz *et al.* 1981). The age of one of the trunks was determined by the radiocarbon method as 1670±80 BP (Gd-121) – cf. Ralska-Jasiewiczowa and Starkel (1975).

Also in the 1970s, the lying at the distance of 1.5 km profile in Brzeźnica was studied in detail. In this profile, within the rendzina terrace, out of the socle of the Late Glacial abandoned channel built of the interpleniglacial deposits there was found a younger insert, with the *Carpinus* trunk dated at 3380±65 BP (Hv-4901) and overlying organic silts dated at 1040±95 BP (Hv-5522) which in the pollen diagram pinpoint to the progressing in the Medieval deforestation of the valley bottom (Mamakowa, Starkel 1974; Alexandrowicz *et al.* 1981). This indicates that some parts of the rendzina terrace accreted by inserts until the Middle Ages (so called IIC layer).

A discovery of another site in Grabiny, 10 km upstream the Wisłoka valley, provides the evidence that the youngest fill of the rendzina terrace, forming the 1–1.5 m lower bench, is built of channel alluvia dated at 900±475 BP, i. e. at the decline of

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the Medieval. (Mamakowa *et al.* in: Alexandrowicz *et al.* 1981). Therefore, the site at Kędzierz did not belong to the youngest inserts of the rendzina terrace. In addition, in Grabiny at the larger depths tree trunks, dated as 2200–2400 BP, 5900–6000 BP and others by the C-14 method were found which indicates possible redeposition of the trunks.

In the recent years, the collaborated studies of Kalicki and Krąpiec performed in the Vistula valley near Cracow, in which the dendrochronological method was used (Kalicki 1991; Krąpiec 1991, 1992) allowed to show the presence of series of trees of various ages within one horizon. Thus one has to be critical about the datings of the alluvia, which up to now have been obtained on the basis of the black oaks.

The bank of the Wisłoka near Kędzierz had overgrown and became exposed later on, during one of the floods. In spring 1992 a discovery of a fresh cliff with the trunks

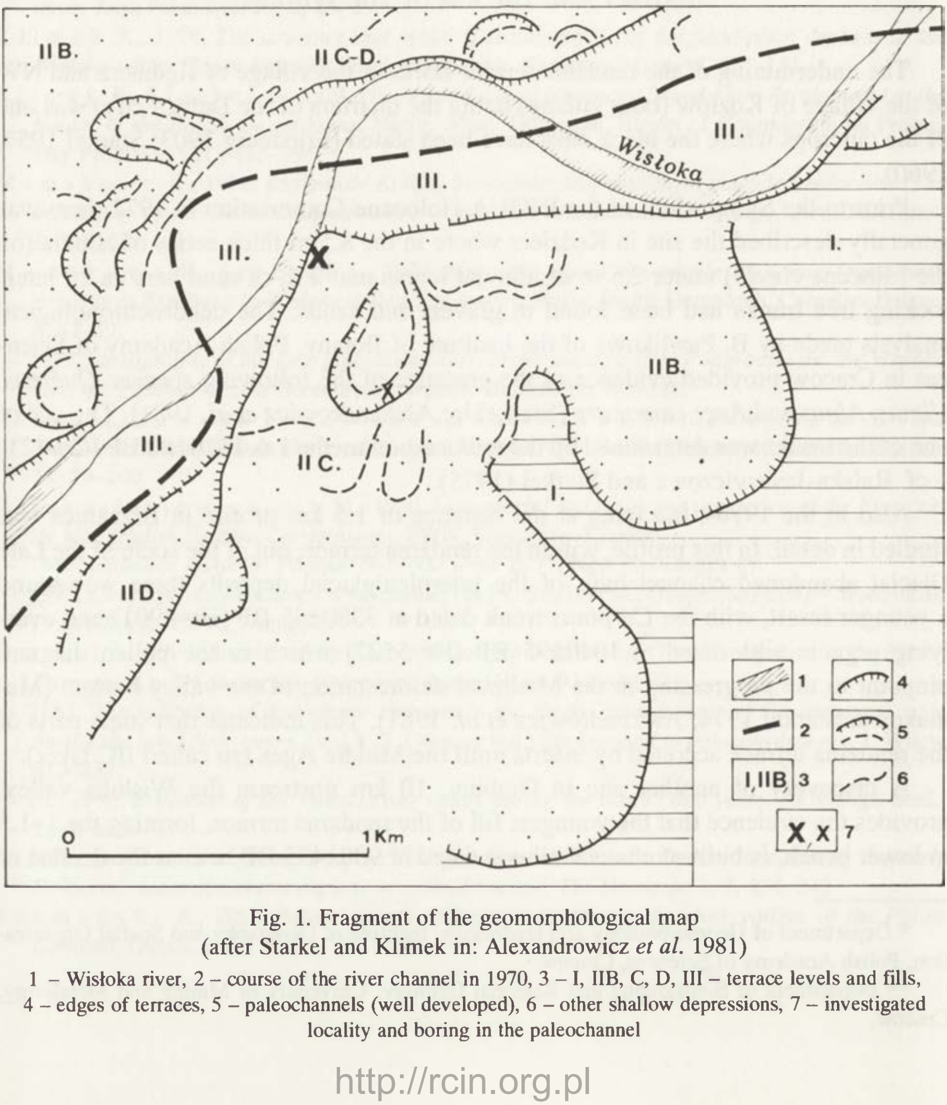

Fig. 1. Fragment of the geomorphological map
(after Starkel and Klimek in: Alexandrowicz *et al.* 1981)
1 – Wisłoka river, 2 – course of the river channel in 1970, 3 – I, IIB, C, D, III – terrace levels and fills, 4 – edges of terraces, 5 – paleochannels (well developed), 6 – other shallow depressions, 7 – investigated locality and boring in the paleochannel

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occurring in it enabled another, detailed study of this outcrop using sedimentological methods simultaneously with the dendrochronological and radiocarbon dating methods. The investigations aimed at the study of sedimentation of deposits and at a more detailed age determination of the insert within the lower terrace in Kędzierz.

RELIEF

The right-bank plain of the Wisłoka rendzina terrace, north of Kędzierz and Kozłów, is flat, 1–1.5 km wide, without traces of the steps of inserts. It is elevated 184.5–186 m a. s. l. and protrudes 10 m above the mean water level of the Wisłoka (Fig. 1, 2). Beside the Late Glacial meander undercutting at the foot of the upper, sandy pleniglacial terrace there are found shallow traces of channel of which only the one occurring 200–400 m from the terrace edge is pronounced. This is the 50–60 m wide paleomeander which is incised 2–2.5 m in the terrace plain (Fig. 2). The curvature radius of this paleomeander is ca 150 m. So, it is slightly smaller than the Late Medieval one of the Grabiny (180 m) and definitely smaller than the 18th century meanders (240–300 m; cf. Alexandrowicz *et al.* 1981). The reconnaissance drilling in the abandoned channel indicated the presence of the channel deposits at the depth of 4.78 m, under alluvial loams and clayey silts. Thus, the bottom of the paleochannel is at the level of 177.7 m, which corresponds to the level by 1 m higher than the present-day, low water level of the Wisłoka river (recording of July 1, 1992).

The location of the NNE–SSE outcrop, at the distance of 200 m west of the meander, elongated in the direction of the meridian of longitude gives the opportunity to expose the bar structure of the channel which was shifting during the development of the system of free river meanders (Fig. 1).

In the north of the outcrop and on the opposite bank there is a sandy floodplain which is 3 m lower and which was being formed by the Wisłoka river in the 17th–18th centuries, i. e. at the time prior to channelization when the river had properties of the braided one (Klimek 1974).

GEOLOGICAL STRUCTURE OF THE OUTCROP

In the abrupt, straight linear, 9–9.5 m high, bank of the Wisłoka river, over the distance of 150 m the structure of the terrace with jutting out tree trunks is exposed. These tree trunks show up over 110 m long section. The surface of the terrace descends by ca 1 m over the distance of 110 m. For a terrace face a sequence of sediments has been described in 4 vertical profiles, and in the case of the profile A detailed grain size analyses of 19 samples have been carried out. The position and directions of fifteen trunks protruding out of the face (Fig. 3) were determined. In the vertical profile three distinct members of the deposits show up. These are: lag deposits and bars occurring within the shifting channel, pointbars and floodplain deposits (Fig. 4). On the local clay socle (probably the Miocene one) at the height of ca 177.5–178

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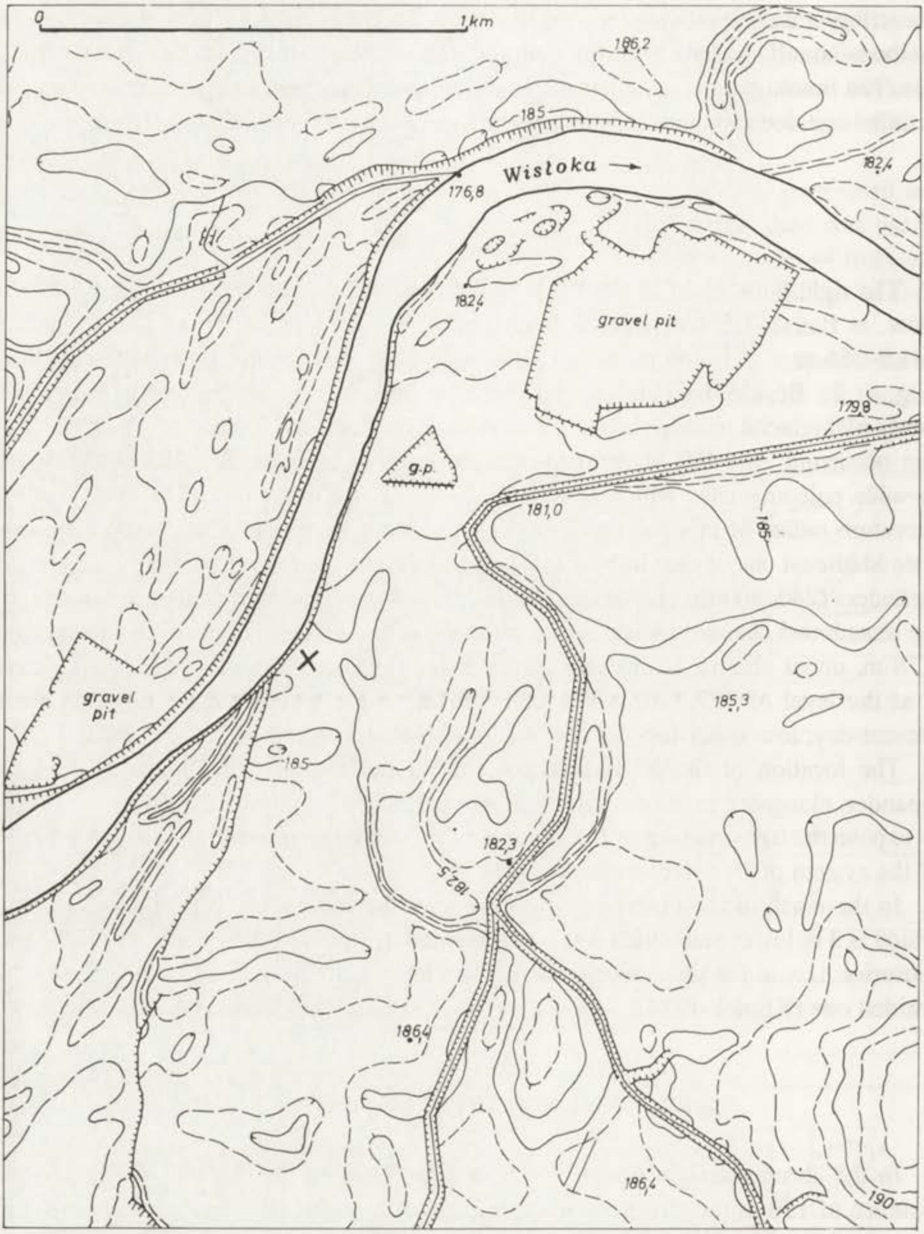

Fig. 2. Hipsometry of the Holocene terrace with palaeochannel (after topographic map), x – investigated locality

m a. s. l. (7.5–8 m down of the surface) there is a 3 m thick member of gravels and sands. These are alternating beds of sands and gravels (of the diameter to 5 cm) which are sorted to a various degree (0.5–2.0), and which are often cross-bedded and dipping to the north. Occurring silty-clay lenticels (*Mz* ca 5phi) indicate alluvial loam ac-

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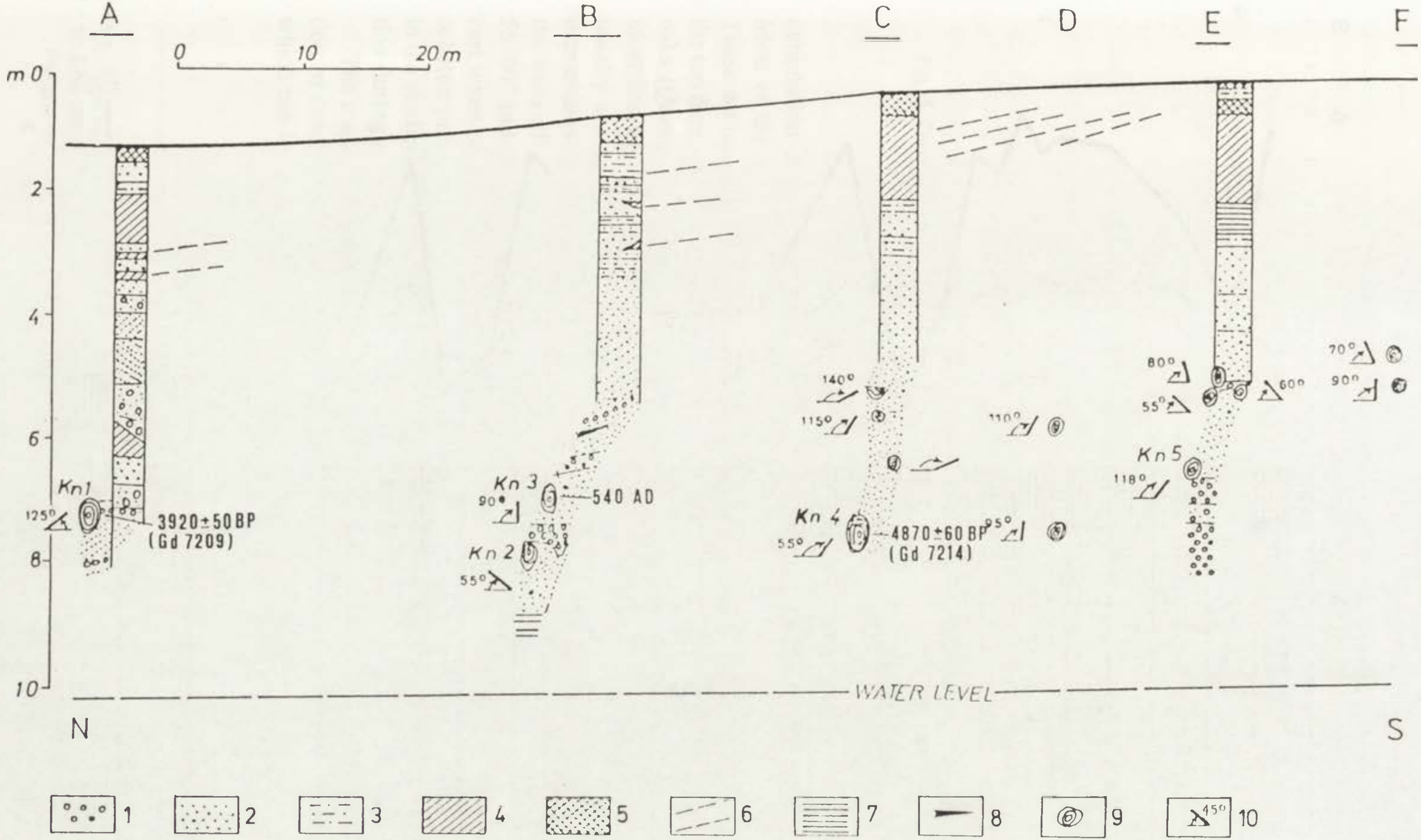

Fig. 3. Geological cross-section of the Holocene terrace at Kędzierz (by L. Starkel)

1 – gravels, 2 – sands, 3 – sandy silts, 4 – loams (over-bank deposits), 5 – humus soil horizon, 6 – bedding in the overbank deposits, 7 – clays (at bottow Miocene?), 8 – organic layers, 9 – fossil trunk, 10 – direction of tree trunk; Kn1 to Kn5 – oaks sampled for dendrochronological dating (two of them dated by radiocarbon method, one – by dendrochronologic one)

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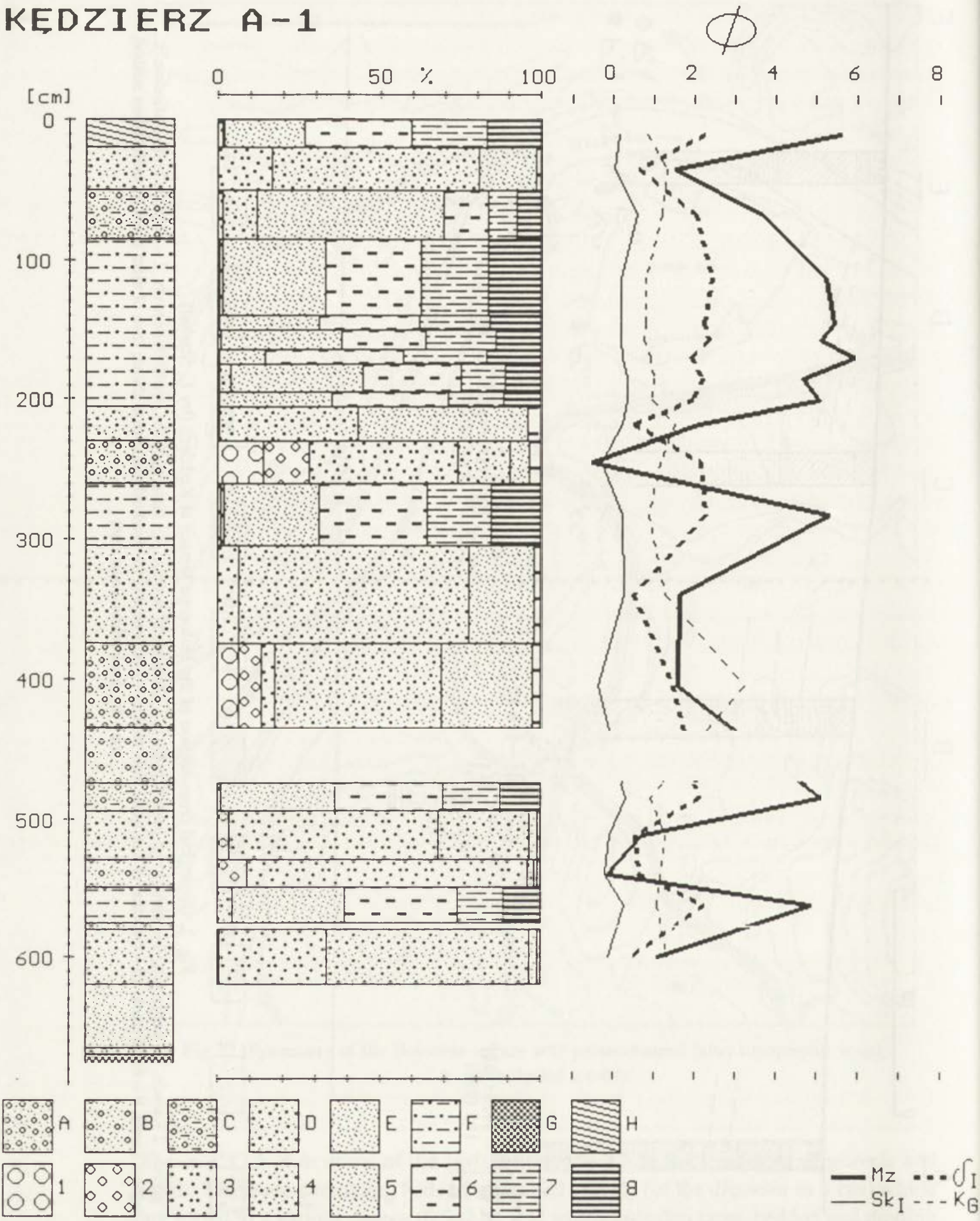

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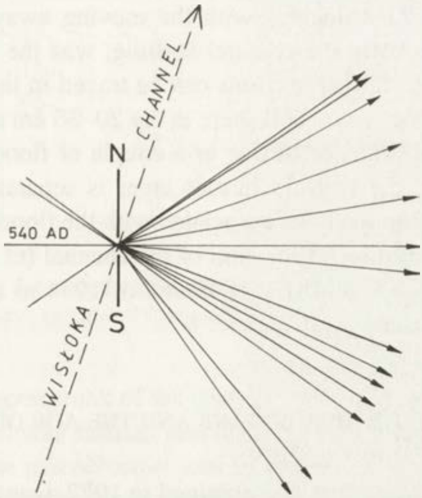

Fig. 5. Direction of orientation of tree trunk in exposure in relation to present river channel (by L. Starkel)

cumulation in the abandoned depressions which usually accompany the tree trunks. Most of the trunks occur closer to the lower face (5.5–7 m deep) of this member. These are usually the larger tree trunks of the 50–80 cm in the diameter and, closer to the top face, the smaller trunks of the 20–30 cm in the diameter. Among the tree trunks oaks (*Quercus robur* and *Quercus petraea*) predominated and only one trunk was identified as elm (*Ulmus* sp.) The trunks occur separately or as 2–3 pieces together, usually at some distance from each other (15–30 m) as if they were deposited in the depressions between the ridges of the bars. There is a characteristic arrangement of the axes of the trunks from 55 to 140°E, the most frequent strikes are 110–125°, 55–60° and 90–95°E (Fig. 5), so they were deposited by water flowing from west to east when river current was shifting to the north. This direction of the cross-bedding is better pronounced in the member of the middle sands which are poorly represented in the studied profile A and which have gravel inserts providing evidence of aggradation during a large flood. This member in the profiles B–E is to 2–2.5 m thick.

The transition to the alluvial loam member is gradual and indicates the accumulation of sand beds which is characteristic for the point bars. The surface of the bars, which can be traced easily, is tilting 5–10° to the north and indicates lateral accretion

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Fig. 4. Granulometry of the profile A (analysed by J. Sala)

A – sand with gravels, B – sand with single gravels, C – loamy sand with gravels, D – medium size sand, E – fine sands, F – sandy silt, G – clays, H – soil; Grain sizes in classes: 1 – coarse gravel, 2 – medium and fine gravels, 3 – coarse sand, 4 – medium sand, 5 – fine sand, 6 – coarse and medium silt, 7 – fine silt, 8 – clay; *Mz* – mean grain size, δ_I – standard deviation, Sk_I – skewness K_G – kurtosis

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on the terrace slope which coincides with the moving away and deepening of the channel. The next stage, after the channel shifting, was the formation of a mature, meandering trough whose farther sections can be traced in the meander preserved in the east (Fig. 1). Under the loamy soil there is the 20–30 cm thick, well sorted (0.63) sandy layer which is the evidence of one or a couple of floods. In the southern part, within the same terrace, the twofold humus layer is separated by the 10 cm thick silty-sandy layer, which can likely be associated with the floods of the recent centuries when, provided the 2–2.5 m lower incision of the channel (cf. Klimek in: Alexandrowicz *et al.* 1981), the floods of 1813, 1845 and of 1934 as the last one entered the plain of the rendzina terrace.

DATINGS OF THE BLACK OAKS AND THE AGE OF DEPOSITS

The date 1670±80 BP, the first one obtained in 1972, was the basis for linking the channel facies of the Wisłoka river with the Late Roman period.

In 1992 the slices for the dendrochronological analysis were cut with the chainsaw out of the five thickest oak trunks of the diameters from 40 to 80 cm. None of the sampled trunks had sapwood. The traces of the reworking by the river driven material occurring at the surface, in forms of depressions, provide evidence of either trunk or sediment redeposition. These trunks are characterized by a dark, brown-black colour with an exception of the trunk marked KN3 which is lighter, gray-brown in a cross-section.

From the measurements of the widths of the tree rings along 3–4 selected core radii (in each slice) with the accuracy of 0.01 mm five, 70 to 170 years long, dendrochronological sequences were obtained. The lack of similarity between the studied sequences indicate that they originated from the trees which had grown at the various time. These sequences have been compared with the Southern Poland dendrochronological standard covering the period of 474 BC–1529 AD (Krąpiec 1992), which allowed the absolute dating of one trunk – KN3 (the last preserved tree ring corresponds to 540 AD, cf. Fig. 6). As the sapwood has not been found in the sample KN3 it was only possible to determine the earliest possible date of the tree felling – as after 550 AD. The four remaining sequences (KN1, 2, 4, 5) neither do significantly correlate with the Southern Poland standard nor with the older "floating" chronologies, dated by the radiocarbon method (Krąpiec 1992) which impelled the authors to the age determination by the C-14 method. The following radiocarbon age determination of the outer parts of the trunks: KN4 (tree rings 120–170): 4870±60 BP (Gd-7214) and KN1 (tree rings 120–128): 3920±50 BP (Gd-7209), indicate that these trunks originate from the hitherto dendrochronologically unidentified periods in the vicinity of Cracow. These trees are much older and probably were redeposited over a small distance or the material around them was washed out and they, as being heavier than water, remained almost at their initial place of deposition. This could be inferred from their position at the lower face of alluvia and from their strike of ca 125E, diverting from the majority of trunks lying above (which are also thinner).

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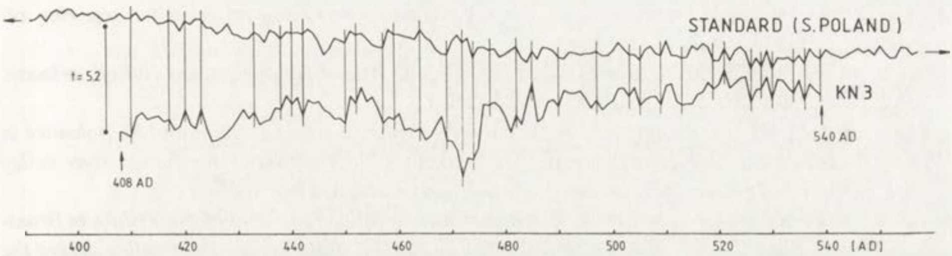

Fig. 6. Cross-matching for calendar dating of subfossil oak KN3 by Krąpiec chronology for Southern Poland (t-value, calculated using a high pass filter, as in Baillie and Pilcher 1973)

The date of the youngest trunk of the middle of the 6th century AD would indicate that the Wisłoka channel was shifting and deposited bars in the 6th century and later on. If we assume that the paleochannel east of the outcrop is evidently older than the 16th–18th centuries, and if the lower terrace bench is lacking, the paleochannel may be older than the 11th century (by comparison with the discussed above site at Grabiny) and the sediments above the fossil trunks could be deposited between the 6th and the 10th centuries.

The dating of the fragments of wood in the paleochannel from the depth of 2.48 m as 140±100 BP (Gd-4996) provides invalid information. It may be wood from a root, after the calibration curve it may represent 16th to 18th century AD. Moreover, it was sampled 2.3 m above the lower face of the clayey filling and dont Late the aboundance of the channel.

The outcrop in Kędzierz well documents the structure of one of the youngest fills within the rendzina terrace which was formed by the shifting of the meandering river channel. The flatness of the terrace plain is misleading and if these were not the preserved paleomeanders there would not be evidence of the presence of some inserts. In addition, the profile in Kędzierz confirms the facts known from Grabiny and from the series of sites on the Vistula that the presence of the black oaks of various age in one member often makes impossible the more precise dating of the channel alluvia on the basis of singular dates (cf. Kalicki, Krąpiec 1991, in print).

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REFERENCES

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E., Pazdur M., Starkel L., 1981, *The evolution of the Wisłoka valley near Dębica during the Late Glacial and Holocene*, (L. Starkel ed.), Folia Quater. 53, 1–91.

http://rcin.org.pl

Baillie M. G. L., Pilcher J. R., 1973, *A simple cross dating program for tree-ring research*, Tree-Ring Bull. 33, 7–14.

Friedberg W., 1903, *Objaśnienia do zeszytu 16-go Atlasu Geologicznego Galicji, arkusze: Dębica, Rzeszów, Rudnik*, in Polish, PAU, Kraków.

Kalicki T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

Kalicki T., Krąpiec M., 1991, *Black oaks and Subatlantic alluvia of the Vistula in Branice–Stryjów near Cracow*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 39–61.

– in print, *Problems of dating alluvium using buried subfossil tree trunks: lesson from the "black oaks" of the Vistula valley, Central Europe*. The Holocene 5, 2, 253–260.

Klimek K., 1974, *The structure and mode of sedimentation of the flood-plain deposits in the Wisłoka valley (South Poland)*, Studia Geomorph. Carpatho-Balcan. 8, 137–151.

Krąpiec M., 1992, *Skale dendrochronologiczne późnego holocenu południowej i centralnej Polski (Late Holocene tree-ring chronologies of South and Central Poland)*, Kwart. AGH, Geol. 18, 3, 37–119.

Mamakowa K., Starkel L., 1974, *New data about the profile of Young Quaternary deposits at Brzeźnica in Wisłoka valley, Sandomierz Basin*, Studia Geomorph. Carpatho-Balcan. 8, 47–59.

Ralska-Jasiewiczowa M., Starkel L., 1975, *The basic problems of palaeogeography of the Holocene in the Polish Carpathians*, Biul. Geol. Uniw. Warsz. 19, 27–44.

Starkel L., 1957, *Rozwój morfologiczny progu Pogórza Karpackiego między Dębicą a Trzcianą (Morphological development of the escarpment of the Pogórze Karpackie between Dębica and Trzciana)*, Prace Geogr. IG PAN 11.

– 1960, *Rozwój rzeźby Karpat fliszowych w holocenie (The development of the Flysh Carpathians relief during Holocene)*, Prace Geogr. IG PAN, 22.

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Evolution of the Vistula river valley, V
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EVOLUTION OF THE GAP SECTION OF THE VISTULA VALLEY IN THE LATE GLACIAL AND HOLOCENE

STUDY AREA

The study reach between the towns of Zawichost and Puławy, of the length of 70 km (390–475 km of the river vourse), is located in the Vistula gap through the southern Polish Uplands (Fig. 1). In this reach only minor tributaries yield into the Vistula from the Kielce–Sandomierz Upland and from the Radom Plain (the Kamienna, Iłżanka, Zwolenka rivers) as well as from the Lublin Upland (the Wyżnica, Chodelka rivers). The Vistula catchment upto Zawichost is 50 732 km^2 and the mean annual discharge is 450 $m^3 \cdot s^{-1}$ (in 1951–1980) while in Puławy these values increase to 57 264 km^2 and 477 $m^3 \cdot s^{-1}$, respectively. In the discussed area the Vistula regime is pluvialnival. The Carpathian tributaries have influence on two periods of floods, i. e. the spring (March) nival flood period (absolute maximum discharge 5440 $m^3 \cdot s^{-1}$) and the summer (June) pluvial flood period (absolute maximum discharge 7459 $m^3 \cdot s^{-1}$). The amplitude of water stages is about 5 m and maximum floods cause water level to increase by 6 m (Zawichost). In the considered section maximum discharges decrease probably due to the strong infiltration into the substratum which is additionally promoted by the long duration of the floods lasting 16–20 days (Jankowski, Stolarska 1978; Soja, Mrozek 1990).

HISTORY AND AIM OF STUDY

N. Krishtofovich (1896, 1904) was the first to present the structure of the lowest terrace (3–3.5 m) consisting of two layers of silts separated by sands. In the gorge L. Sawicki (1925, 1933) has distinguished the Pleistocene middle terraces (25 and 15 m) as well as the Holocene lower terraces (5–8 and 2–4 m) besides the Pliocene erosional

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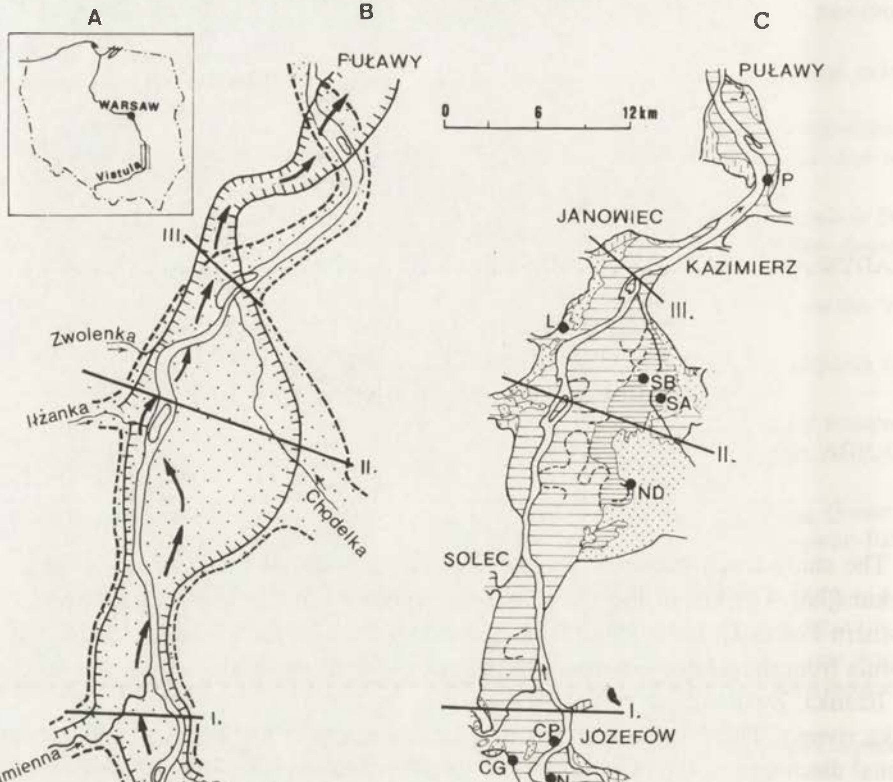

Fig. 1. Location (A), geological (B) (Pożaryski *et al.* 1994, modified) and morphological (C) (Pożaryski 1955, modified) maps of stude area

1 – pre-Odranian Vistula valley, 2 – axis of pre-Odranian Vistula valley, 3 – post-Odranian Vistula valley, 4 – section across the valley (see Fig. 2), 5 – Pleistocene high terraces (III), 6 – Late Glacial middle terraces (II), 7 – Holocene "old mada" flood plain (I), 8 – Holocene "young mada" flood plain (I), 9 – palaeomeanders, 10 – sites: B – Basonia, CG – Ciszyca Górna, CP – Ciszyca Przewozowa, L – Lucimia, N – Nieszawa, ND – Niedźwiada, P – Parchatka, Ś – Świeciechów, SA – Szczekarków A, SB – Szczekarków B

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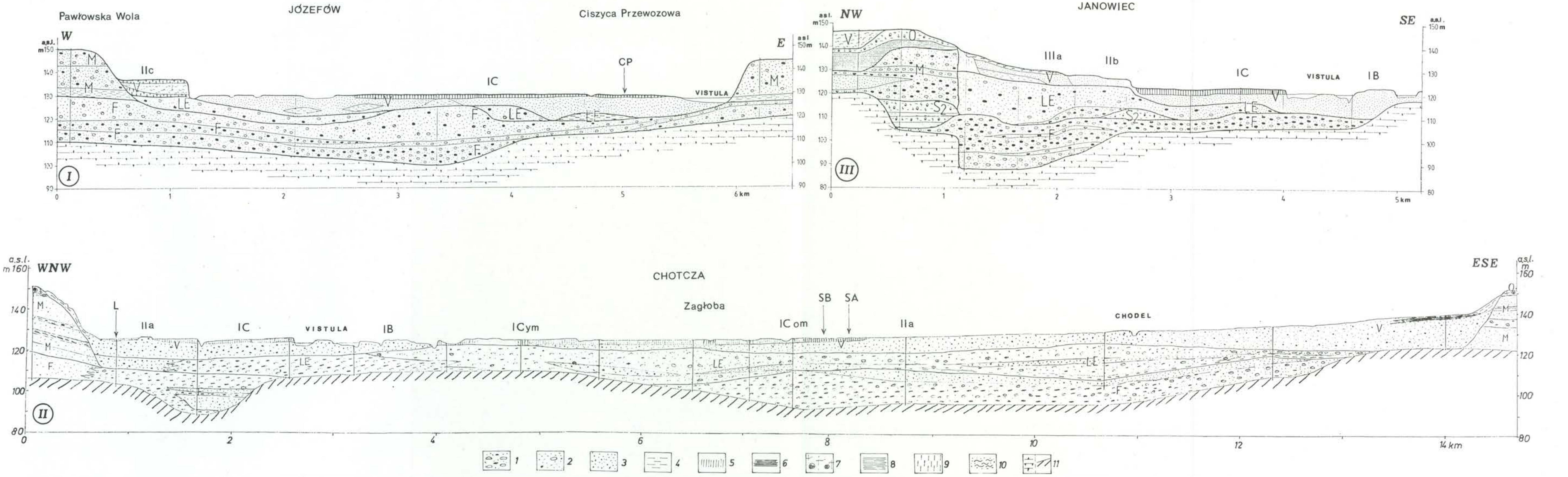

Fig. 2. Geological section across the Vistula valley: Józefów – I, Chotcza – II, Janowiec – III (see Fig. 1) (by W. Pożaryski)

1 – pebbles and gravels with sands, 2 – sands with gravels, 3 – sands, 4 – silts, 5 – silty and sandy overbank deposits, 6 – peats, 7 – tills, 8 – glaciolacustrine clays, 9 – loess, 10 – slope wash, 11 – bedrock; Age of sediment: F – Małopolski and Ferdynandów interglacial, S_2 – San 2 glaciation, M – Mazovian interglacial s. 1., O – Odranian glaciation, LE – from Lubawa to Eeemian interglacial, V – Vistulian an Holocene

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upper ones (50–55 and 40 m). In the southern part of the gorge J. Samsonowicz (1934) has distinguished two Holocene terraces: a rarely inundated one (4 m) and a meadow one (2–3 m).

In the papers by K. Pożaryska (1948), K. Pożaryska and W. Pożaryski (1951) and W. Pożaryski (1952) referring to the surroundings of Józefów and to the northern part of the gorge the sandy terrace, being several tens of meters high and originating from the turn of the Pleistocene, has been discerned. The sandy medium terrace (6–8 m) was supposed to have corresponded to the beginning of the Holocene. Black oaks and peats found in the valley floor had been related to the Littorina period. The papers of W. Pożaryski (1953, 1955) have extended knowledge in this respect. After the maximum Vistulian glaciation the river incision and terrace formation progressed gradually until the middle Holocene. The maximum incision reached several meters below the water level in the present-day channel. There have been distinguished: the Late Pleistocene high terraces IIIb (15.0–18.5 m) and IIIa (11.0–13.5 m), i.e. the terraces of "high accretion" built of loess and delluvia, the Late Glacial medium terraces IIc (7.5–9.0 m), IIb (5.5–7.5 m) and the Early Holocene one IIa (3.0–5.5 m) formed of sands with inserts of delluvia at the slopes as well as the Holocene low terraces: the flood terrace IC (2.5–3.5 m) and the floodplain terrace IB (1–2.5 m) which are covered with overbank deposits (*madas*). The latter one has additionally been subdivided into the old-*mada* terrace (OM), young-*mada* terrace (YM) and the youngest, *mada*-sandy terrace. The present-day Vistula forms a "large river channel" (IA) with numerous bars (Fig. 1C). The author has also distinguished two generations of small paleomeanders. In the case of the older ones peats are covered with the old *mada* and in the young ones with the young *mada*. The old clayey *mada* was deposited in the Subboreal because the artifacts of the Lusatian culture had been found at its top on the fossil soil. In the period of 2500–2000 BP the inter-*mada* sands were deposited while the accumulation of the young, sandy *mada* which was replaced by sands at ca. 1000 AD started at the beginning of our era.

In all the former studies the chronostratigraphy could not be determined by radiometric methods and the facial differentiation of alluvia (channel sands, *madas*) was assigned the age differentiation, sands – the Pleistocene, *madas* – the Holocene, respectively.

In the 1960s E. Falkowski (1967, 1982), when studying the southern part of the gap, applied a genetic approach to the analysis of the floodplain structure for the first time and distinguished fragments formed by the meandering and braided river. The Vistula river was deeply incised in Allerød and had changed its pattern from the brailed to meandering one. In the moist Atlantic *madas* started to accrete. The rate of sedimentation of flood deposits increased rapidly in the Young Holocene, simultaneously with an increasing human impact. An anthropogenic factor is responsible for the river turning wild since the 15th century and for the change of the river pattern into a braided one in the 19th century. However, the lack of detailed documentation in Falkowski's papers (excluding the profile in Basonia) makes these opinions to be considered as not fully evidenced, especially as the author has not applied any of the chronostratigraphic methods.

The purpose of this paper is to provide more details and to verify the former

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opinions on the stages of the Vistula valley evolution in the Late Glacial and Holocene, similarly to revision done for the gap in the whole Pleistocene (Pożaryski *et al.* 1993, 1994). An important role is played here by the ^{14}C-datings and the modern approach developed during the studies of the other Vistula valley sections (e. g. Starkel ed. 1987; Kalicki 1991). In the present study the materials collected by W. Pożaryski in the 1950s and the profiles and drillings made by T. Kalicki in 1993 have been utilized.

The authors wish to express their cordial gratitude to Prof. Leszek Starkel, the coordinator of the grant 6-0783-91-01 entitled "Paleohydrological changes in the valleys of the southern Poland during the last 20 000 years on the background of global changes" under which the present study was performed. Mr Paweł Prokop and Mr Stanisław Kędzia are acknowledged for their assistance in the fieldwork and Mrs Jolanta Sala is due many thanks for the laser analysis of grain size composition (Fritsch method) and for sieve analyses. The radiocarbon datings have been made in the ^{14}C Laboratory in Gliwice.

GEOLOGICAL STRUCTURE AND MORPHOLOGY

The Vistula, leaving the Sandomierz Basin lined with the Miocene clays, cuts through the area of the southern Poland Uplands built of the resistant Mesozoic rocks. Downstream, the river again enters the basin of the not resistant Paleogene and Neogene layers. The antecedent gap is located on the Upper Cretaceous rocks dipping to the north – gaizes, marls and chalks. The nature and width of the Vistula gap varies and depends on the substratum resistance (Fig. 1). The valley, 4 km wide on the average, narrows even to 1,2 km dissecting the hardest layers of the Uppermost Mastrycht near the town of Kazimierz Dolny. On the other hand, the valley widens to 10–12 km on the outcrops of soft chalk in the area of the Chodelka Basin.

Alluvia fill the 30 m deep valley which was formed in the Małopolski interglacial (Pożaryski 1953, 1955; Pożaryski *et al.* 1993, 1994). The coarse gravels lying at the bottom (Fig. 2) are related to this interglacial as well as to the next, Ferdynandów, one. Deposits of the Mazovian interglacial s. l. have not been preserved in the valley. They were washed away after the retreat of the last Oder ice sheet from the gorge area, i. e. in the period of the Lubawa to Eemian interglacials. In that period a new valley was incised which coincides with the old, pre-Odranian valley (Fig. 1B) but not in all sections. In the new Vistula valley sandy-gravel channel alluvia were deposited. At their top there are river sediments associated with the Vistulian, forming the high III (11.0–18.5 m) and medium II (3–9 m) sandy terraces. In the Holocene the sandy floodplain I, covered with *madas*, was formed (1–3.5 m).

The gap Vistula valley is divided into three sections differing with respect to the structure and morphology: Zawichost–Solec, the widening of the Chodelka Basin from Solec to Janów, and the narrowing between Janowiec and Puławy (Fig. 1).

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SECTION ZAWICHOST–SOLEC

In the southern section near Józefów, the post-Odranian valley is inserted in the older valley and it is cut in the alluvia of the Mazovian interglacial. The thickness of these alluvia reaches 30 m (Fig. 2I). The valley is filled with sandy-gravel alluvia of the Lubawa and Eemian interglacials as well as with the Vistulian-Holocene alluvia separated by an erosional level.

The present-day valley is ca. 3 km wide. The upper terraces are preserved in fragments, usually at the mouths of the Vistula tributaries, and are in the form of narrow ledges. The whole bottom of the valley is occupied by the floodplain. Its older parts were formed by the meandering river while the younger ones by the braided river (cf. Falkowski 1982). In the relief of the older parts the traces of few paleomeanders are visible. In the discussed section two study profiles with fossil soil, Ciszyca Przewozowa and Nieszawa, are located (Fig. 1).

The profile Ciszyca Przewozowa is located at the margin of the alluvial fan of the Kamienna river, on the young-*mada* terrace formed by the meandering river (Pożaryski 1955; Falkowski 1982) and rising to 3.5–4.0 m above the river level (Fig. 3). At the bottom of the profile, at the level of water table fairly well sorted medium sands being the top part of the channel deposits occur (Fig. 4). The first member of the flood deposits starts above. In the lower part of this member there are interbeddings of deposits containing more sands or silts. A fining-upward sequence occurs above. The member ends with the fossil soil formed on clayey silts (Mz = 7.5∅). The top of this soil has been dated at 5170±210 BP (Gd-9150). Above the first fossil soil the second member of the flood deposits with fining-upward sequence, i. e. clayey silts and silty-clayey muds (Mz = 6.1–6.7∅), begins. This member ends with the second fossil soil. The third member of the flood deposits is more homogenous and contains more clay size particles (Mz = 7.0∅) than the former one and ends with the third fossil soil. The latter is overlain with the fourth more sandy member of the *madas* (Mz = 5.4∅).

The studied profile is analogous with profile 23 knows from this area, including three fossil soils and which was described in the 1950s (Pożaryski 1955). In Pożaryski's paper (1955) one can find information about the storage pits with artifacts of the Lusatian culture which was found in the neighbouring outcrop. The pits dug in the silty-clayey *mada*, reaching the depth of 1.7 m from the terrace surface, were filled up and covered with 0.7 m thick sandy *mada* layer. When relating this information to the profile studied it seems that the Lusatian settling was most likely located on the first fossil soil.

In the vicinity, in Ciszyca Górna, there is another dated alluvia profile which was examined by D. Dowgiałło during the geological mapping of the Solec sheet (1:100 000) (Fig. 1). The medium sands with chalk gravels are overtopped here with 2 m thick organic deposits covered with 2 m thick layer of fine sands. The top of organic deposits is dated at 3670±110 BP. Unfortunately, the coordinates of this profile are not precise and therefore it is not clear whether the top sands are the deposits of the alluvial fan resting on the clayey *madas* or whether they are sandy *madas* of the abandoned channel.

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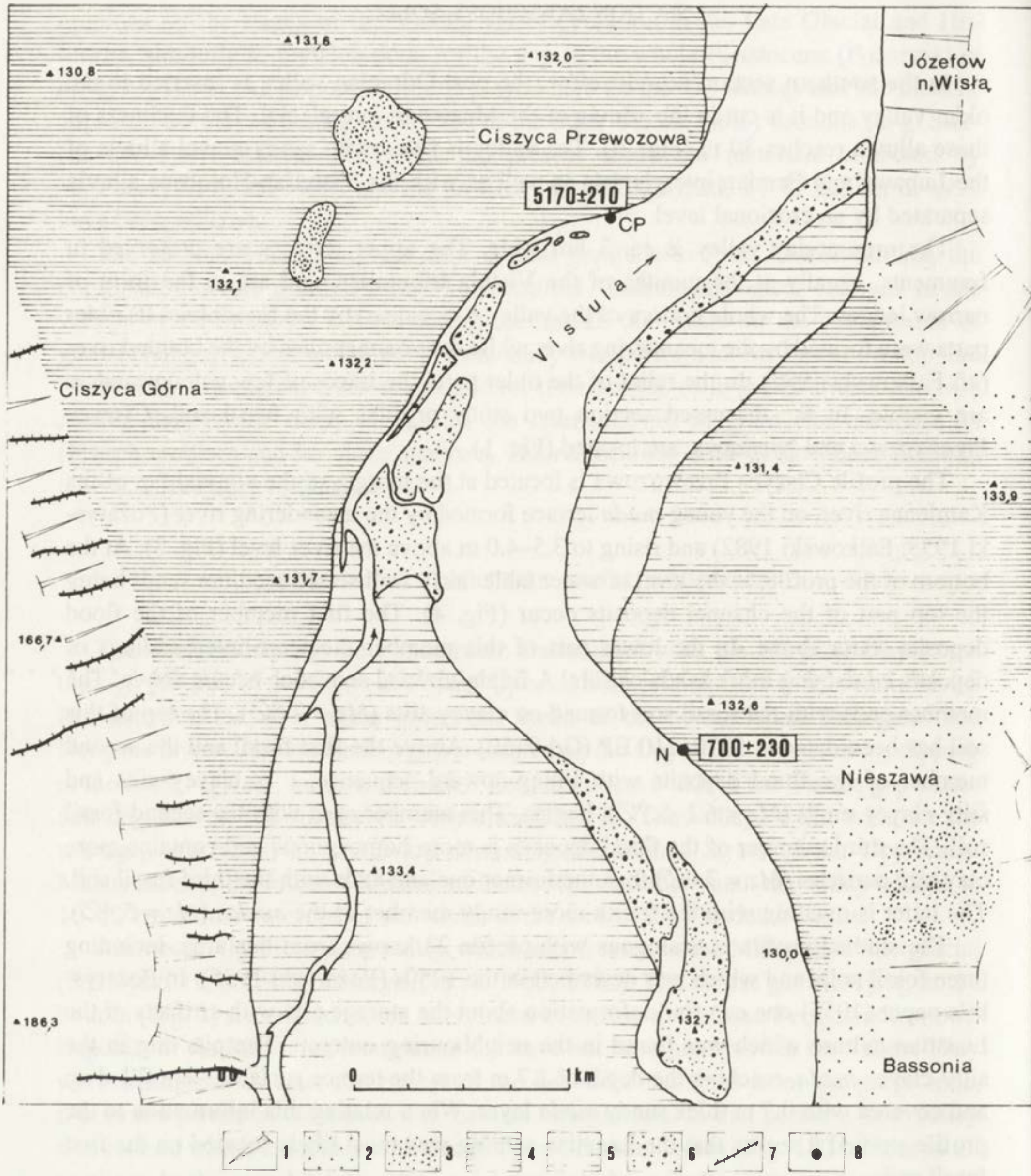

Fig. 3. Geomorphological map of Ciszyca Przewozowa (CP) and Nieszawa (N) sites (by Pożaryski 1955, modified)

1 – slope of Vistula valley, 2 – sandy middle terrace (IIc), 3 – eolian sands and dunes, 4 – "young mada" flood plain (IC), 5 – youngest flood plain (IB), 6 – present bars (IA), 7 – small erosional valleys, 8 – study profiles

The profiles in Nieszawa, as in the case of Ciszyca Przewozowa, are located in the area of the young-*mada* terrace (IC) formed by the meandering river (Pożaryski 1955, Falkowski 1982). This terrace is slightly lower and rises up to 2.5–3.0 m above the

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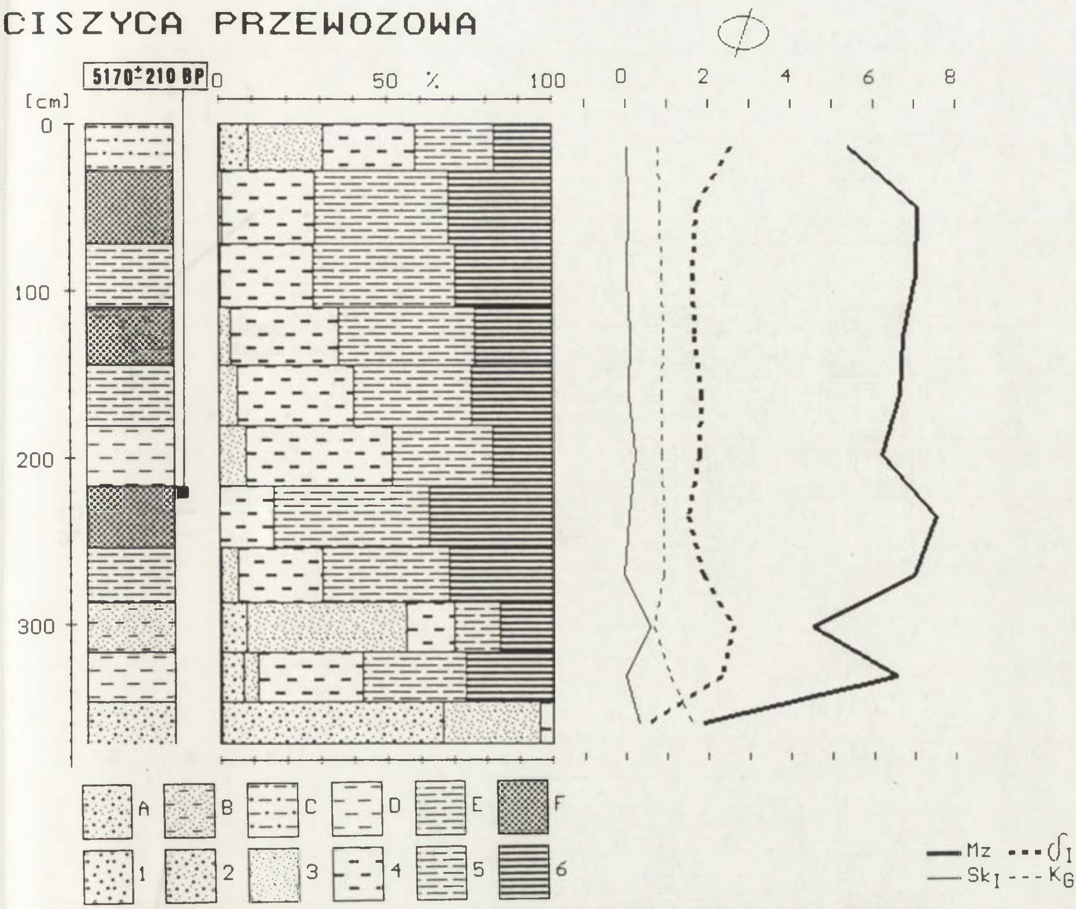

Fig. 4. Profile Ciszyca Przewozowa, grain size composition and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – sands, B – silty sands, C – sandy silts, D – silts, E – clayey silts, F – fossil soils; Fractions: 1 – coarse sand (–1 to 1∅), 2 – medium sand (1 to 2∅), 3 – fine sand (2 to 4∅), 4 – coarse and medium dust (4 to 6∅), 5 – fine dust (6 to 8∅), 6 – clay (above 8∅); *Mz* – mean grain size, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis

river level (Fig. 3). At the bottom of this terrace there are well sorted sands of various sizes (Fig. 5). On the channel facies rests the first member of clayey-silty *madas* (*Mz* = 5.9–7.0∅) with a normal sequence. This member ends with the fossil soil. The top of the soil discussed is dated at 700±230 BP (Gd-9160). The second member of silty *madas* (*Mz* = 5.9–6.5∅) rests above. The third member of *madas* – clayed sands (*Mz* = 3.8∅) – occurs on the two members mentioned above in the profile Nieszawa 1 located 50 m downstream.

Within the same, although slightly higher (3.5–4.0 m), patch of the floodplain ca. 1 km upstream there is located the profile in Basonia, described by Falkowski (1982) (Fig. 1). Basing on artifacts he distinguished a few *mada* members. The oldest member, whose bottom is most often below the water level, is formed by clayey-silty

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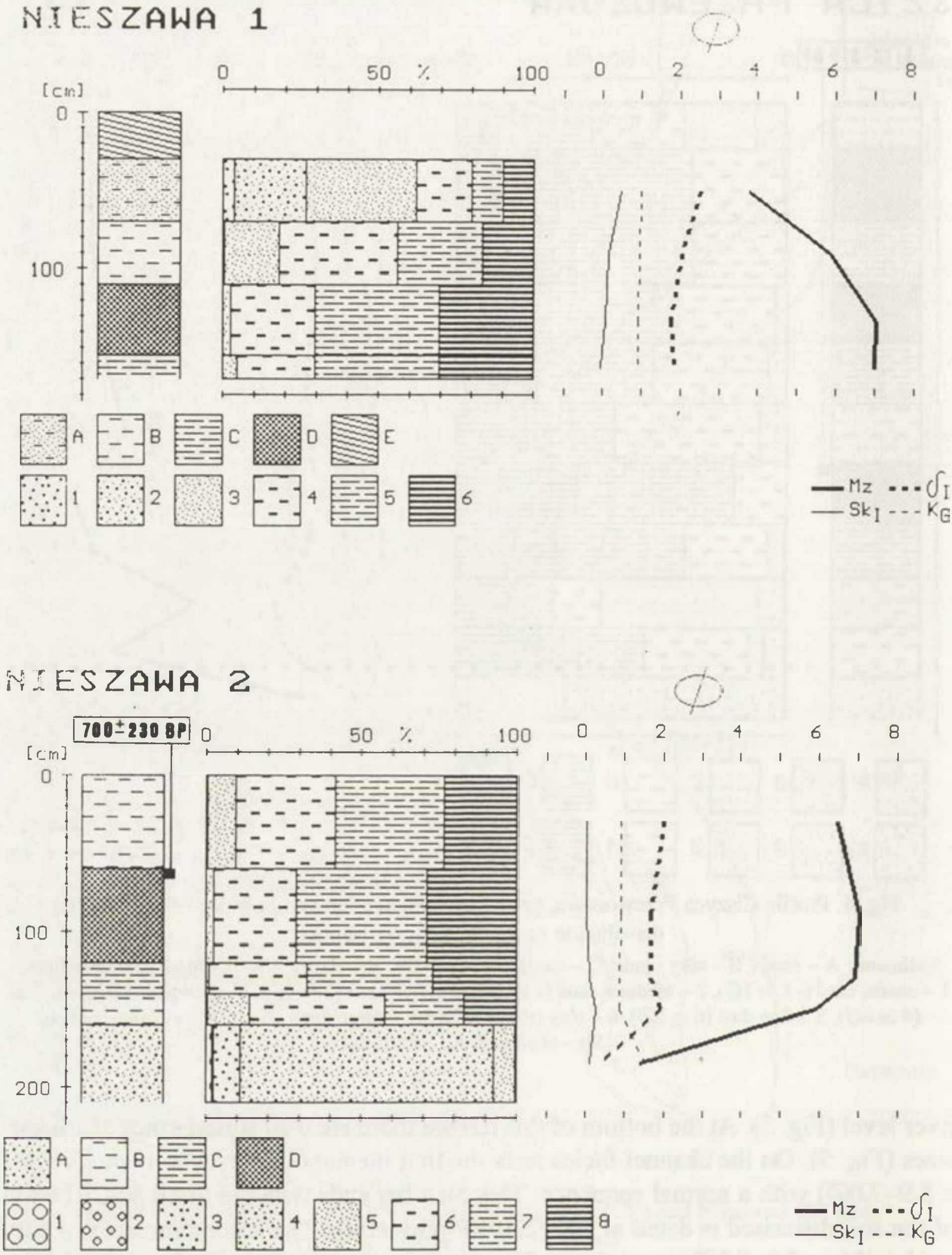

Fig. 5. Profiles Nieszawa 1 and 2, grain size composition and Folk-Ward's grain size distribution parameters (by T. Kalicki)

1. Sediments: A – silty sands, B – silts, C – clayey silts, D – fossil soil, E – soil; Fractions: 1 – coarse sand (–1 to 1∅), 2 – medium sand (1 to 2∅), 3 – fine sand (2 to 4∅), 4 – coarse and medium dust (4 to 6∅), 5 – fine dust (6 to 8∅), 6 – clay (above 8∅). 2. Sediments: A – sands, B – silts, C – clayey silts, D – fossil soil; Fractions: 1 – coarse gravel (below –4∅), 2 – medium and fine gravel (–4 to –1∅), 3 – coarse sand (–1 to 1∅), 4 – medium sand (1 to 2∅), 5 – fine sand (2 to 4∅), 6 – coarse and medium dust (4 to 6∅), 7 – fine dust (6 to 8∅), 8 – clay (above 8∅); *Mz*, δ_I, Sk_I, K_G see Fig. 4

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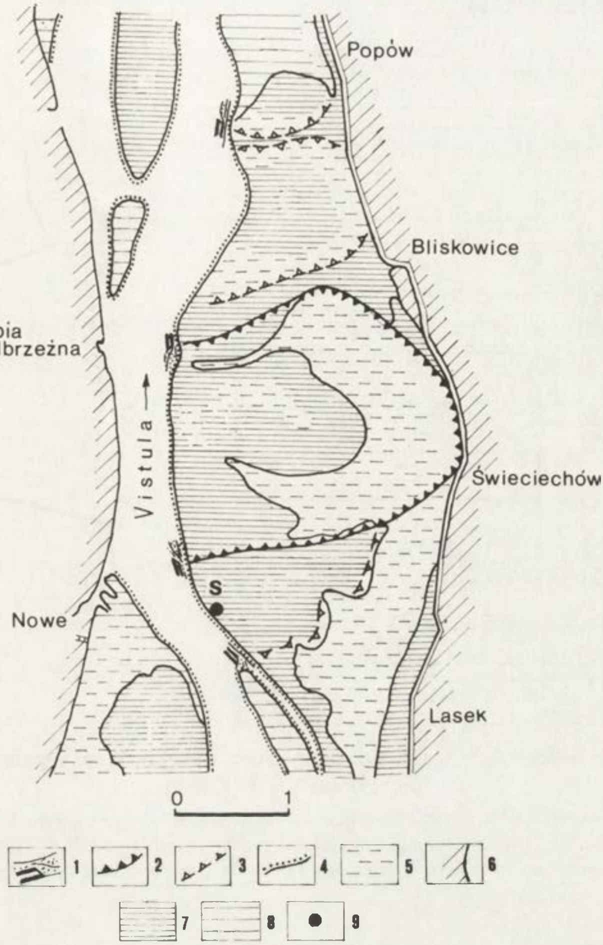

Fig. 6. Geomorphological map of Świeciechów site (by W. Pożaryski, modified)

1 – outcrops with fossil soil burried by sandy mada, 2 – edge of young palaeomeanders, 3 – edge of older palaeomeanders, 4 – bank of present river, 5 – swamps, 6 – slope of the Vistula valley, 7 – higher flood plain IC, 8 – lower flood plain IB, 9 – study profile Świeciechów

madas wiht the artifacts of the Globular Amphora and the Funnel Beaker Cultures. This member ends with the fossil soil rising ca. 2 m above the river level. In the soil the artifacts of the Trzciniec and Lusatian Cultures are found. Above there is the second member of sandy *madas* which also ends with the fossil soil with the artifacts of the 12th–15th centuries. The soil rises ca. 3 m above the river channel and is overtopped by the third member of sandy *madas* with the artifacts of the 17th–20th centuries.

About 10 km upstream, in Świeciechów, another fragment of young-*mada* terrace formed by the meandering river (Pożaryski 1955; Falkowski 1982) occurs. In the are of the above mentioned fragment W. Pożaryski (1955) has distinguished and described a fossil flood plain with clayey old *mada*. In the bottom of the mada, at the

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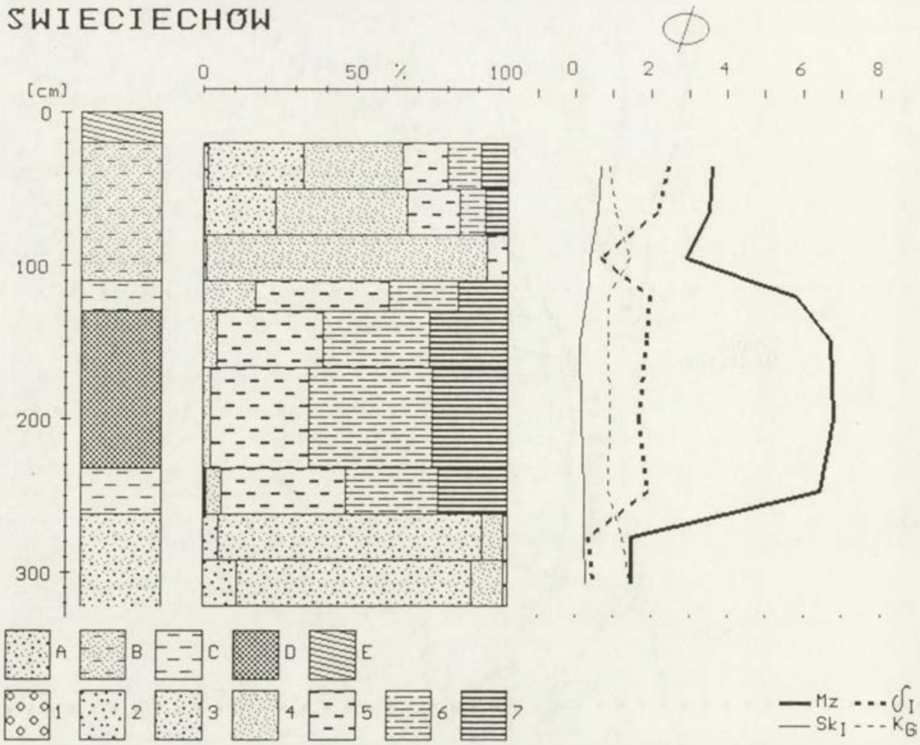

Fig. 7. Profile Świeciechów, grain size composition and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – sand, B – silty sands, C – silts, D – fossil soil, E – soil; Fractions: 1 – medium and fine gravel (–4 to –1∅), 2 – coarse sand (–1 to 1∅), 3 – medium sand (1 to 2∅), 4 – fine sand (2 to 4∅), 5 – coarse and medium dust (4 to 6∅), 6 – fine dust (6 to 8∅), 7 – clay (above 8∅); *Mz*, δ_I, Sk_I, K_G see Fig. 4

sand interface a trunk of a black oak was stuck. The fossil floodplain was dissected by a paleomender in Świeciechów and then covered with younger sandy *madas*. The profile in Świeciechów studied at present is located on the floodplain rising 2.5–3.0 m above the river level (Fig. 6). In the bottom of the profile occur well sorted medium sands which end the channel facies (Fig. 7). The sands are covered with the first member of silty-clayey *madas* (*Mz* = 6.5–6.8∅) which ends with the fossil soil. Above the latter there occurs the second member of silty *madas* (*Mz* = 5.8∅). The third member of *madas* is formed by loamy sands (*Mz* = 2.9–3.6∅) with the sequence fining-upward. By analogy to the profiles of Nieszawa the development of the profile in Świeciechów indicates that both patches of the floodplain as well as the fossil soils are assumed to be of similar age. Additionally, the meander undercutting the terrace in Świeciechów provides evidence that the Vistula was a meandering river ca. 700 years ago (Fig. 6). Very sandy *madas* covering the fossil soil in Świeciechów which have been deposited closely to the active Vistula channel and whose composition is very similar to that of the youngest *madas* of Nieszawa 1 can probably be related to functioning of the meander.

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CHODELKA BASIN

The structure of alluvia in the middle reach is analogous with the structure described above. The composition of gravels accumulated in the Chodelka valley in the period from the Lubawa to Eemian interglacials indicates that they were deposited there by the Vistula river (Fig. 2II).

Almost one half of the valley width is occupied by large pathes of sandy and medium terraces with dunes preserved in the marginal parts of the valley. Semicircular undercuttings are the evidence of destructive action of the meandering Vistula. The wide valley bottom with numerous paleomeanders is covered with *madas* which also enter the Chodelka valley. In the floodplain W. Pożaryski (1955) has distinguished the old-*mada* terrace covered with clayey overbank deposits and the young-*mada* terrace with more sandy *madas* which is located closer to the Vistula. In this reach on the medium with dunes terrace the peat-bog Lucimia is located while paleomeanders of Szczekarkow and Niedźwiada (Fig. 1) occur in the area of the old-*mada* terrace.

The peat-bog in Lucimia occupies a deflation depression on the eolian transformation terraces IIa and IIb (Pożaryski 1955). The peat-bog surfaces rise ca 1.5 m above the river and the surrounding dunes reach the heights of 126–128 m a. s. l., i. e. 4.5–6.5 m above the river level (Fig. 8A, B). Sands with gravels and sands of various sizes (Fig. 8C) underlain the peat-bog. Above there is the first layer of brown, weakly decayed peats with wood pieces. The bottom of these peats has been dated at 11 020±130 BP (Gd-6954). Upwards the peats discussed change gradually into gyttia and organic silts which evidence inundation of the peat-bog. Above there is the second layer of black-brownish peats which are covered with a several centimeter thick layer of clayey silts ($Mz = 7.3\varnothing$). The sequence of deposits in this peat-bog is analogous with that in the profile Całowanie in the Warsaw Basin, the latter being located in a similar morphological setting. The gyttias providing evidence of the inundation and separating of two peat layers were deposited here in the Younger Dryas (Borówko-Dłużakowa 1961; Sarnacka 1987).

The paleomeander of Szczekarków A of the radius of about 500 m and the width 250–300 m undercuts the medium terrace with dunes IIa and occurs in the area of the old-*mada* terrace (Pożaryski 1955). The zone of point bars is risen by ca. 3 m while the abandoned channel only by 1 m above the river level (Fig. 9). The sediments filling the abandoned channel, of maximum thickness up to 6 m, rest on the channel deposits – on sands with fairly well sorted gravels (Fig. 10). In the channel fill a few members can be discerned (Fig. 11). These members start with clayey silts ($Mz = 6.9–7.2\varnothing$) which reach the thickness of 1 m. These silts change gradually upward into peaty silts. The bottom of the peaty silts which are over 1.3 m thick has been dated at 4500±110 BP (Gd-6956). Farther upward they gently change into gyttia-like silty-clayey muds. Just above these deposits there is the peat layer of the thickness exceeding 2 m and of the organic matter content of 40–70%. The peats in the marginal, the shallower parts of the abandoned channel rest directly on the channel deposits (profile A1 – Fig. 12). The top of the peats in question has been dated at 200±100 BP (Gd-6957) which means 1680, 1760 or 1800 cal. AD. The peats are covered with

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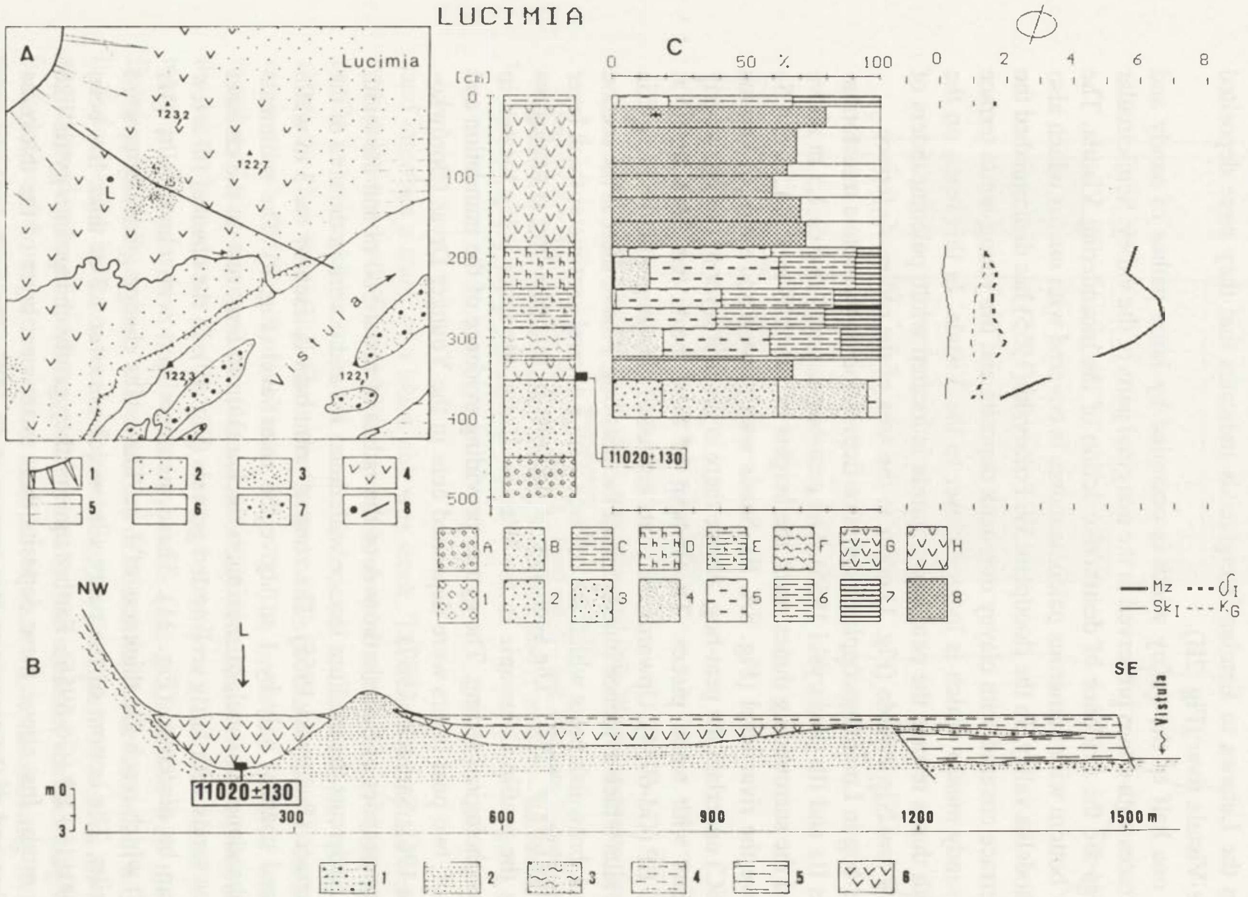

Fig. 8. Geomorphological map of Lucimia site (A), cross section (B) (Pożaryski 1955, modified) and grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters of profile (C) (by T. Kalicki)

A: 1 – slope of the valley, 2 – middle terraces (II), 3 – dunes, 4 – peat-bog, 5 – older flood plain (IC), 6 – younger flood plain (IB), 7 – recent bars, 8 – cross section and borring; B: 1 – gravels with sands, 2 – sands, 3 – deluvia, 4 – silts, 5 – clayey silts, 6 – peats; C: Sediments: A – gravel with sands, B – sands, C – clayey silts, D – organic silts, E – organic clayey silts, F – gyttia with clay, G – peaty silts, H – peats; Fractions: 1 – medium and fine gravel (–4 to –1∅), 2 – coarse sand (–1 to 1∅), 3 – medium sand (1 to 2∅), 4 – fine sand (2 to 4∅), 5 – coarse and medium dust (4 to 6∅), 6 – fine dust (6 to 8∅), 7 – clay (above 8∅), 8 – content of organic matter; Mz, δ_I, Sk_I, K_G see Fig. 4

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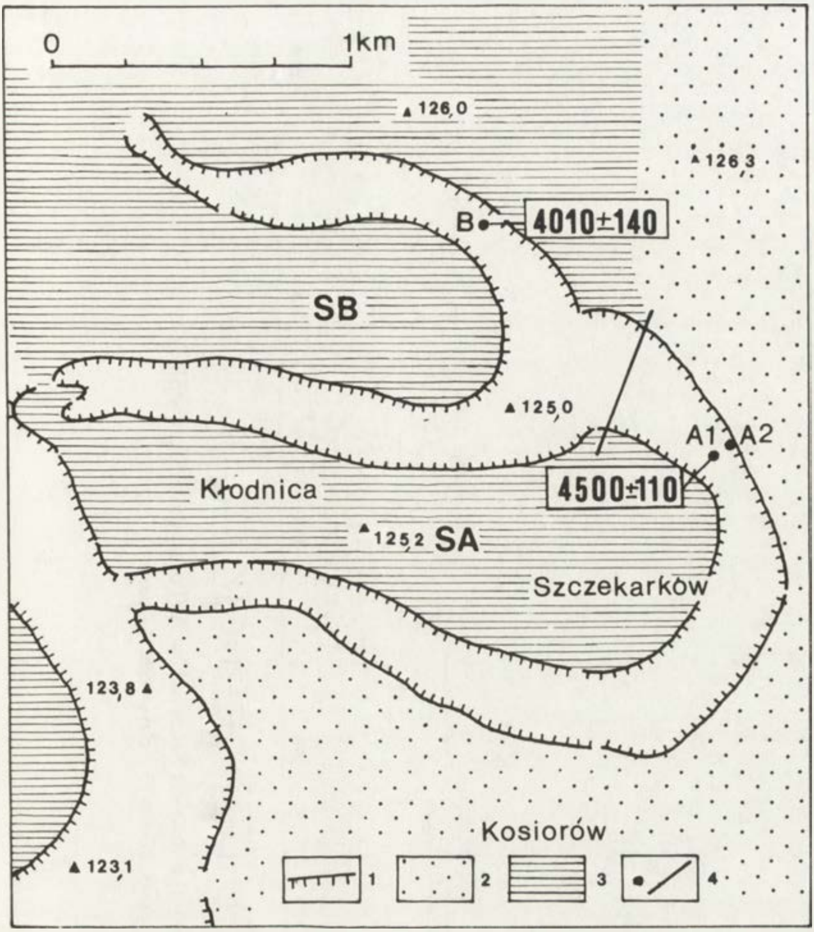

Fig. 9. Geomorphological maps of Szczekarków A and B sites (Pożaryski 1955, modified)
1 – edges, 2 – middle terrace (IIa), 3 – "old mada" flood plain (IC), 4 – borrings and cross-section

a normal sequence of a half a meter thick layer of clayey silts (Mz = 7.6–7.0∅) with a growing-upward sequence. The paleomeander was cut off at the turn of the Atlantic and Subboreal. The nature of the sediments is the evidence of calm sedimentation and the filling, and then overgrowing of the abandoned channel. In the last centuries the change of the sedimentation conditions occurred, when the peat was covered by clayey muds.

The paleomeander Szczekarków B, of the radius of about 400 m and the width of 250–300 m undercuts the paleomeander Szczekarków A from the west (Fig. 9). A characteristic feature of the fill of the paleomeander in Szczekarków B is large diversity of sediments which is the evidence of large variability of sedimentation conditions. There are three members here (Fig. 13). At the bottom (2 m) of the fill the silts are interbedded with loamy sands which is the evidence of connection of the cut off abandoned channel with an active channel. The layer of organic muds in the middle of this member has been dated at 4010±140 BP (Gd-9404). The top, over

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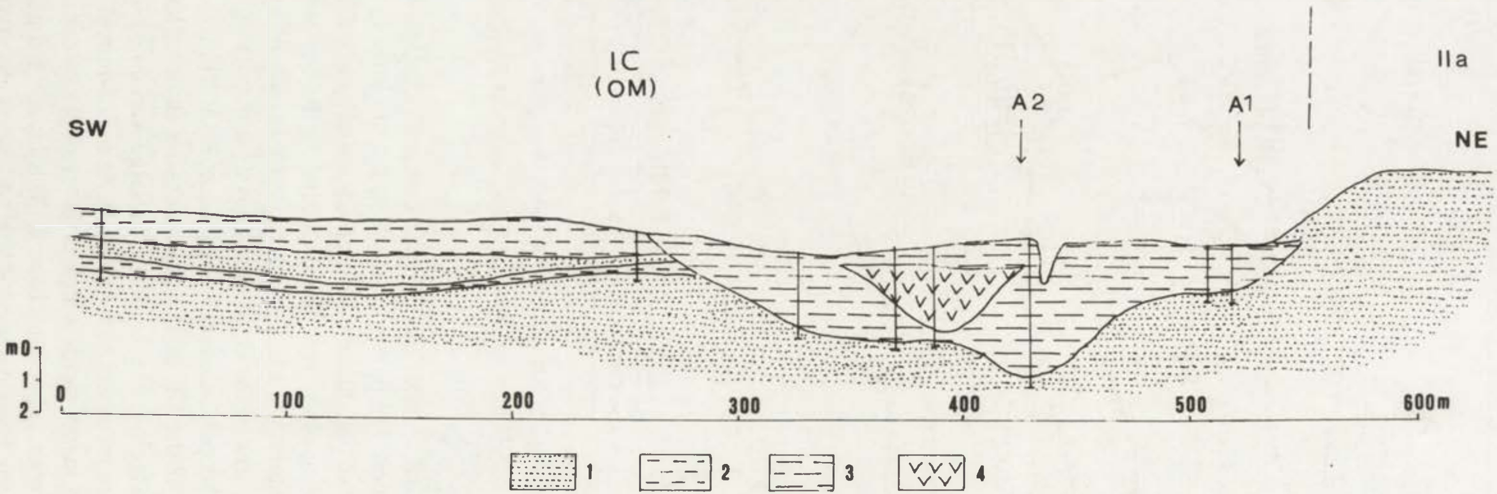

Fig. 10. Section across the palaeomeander Szczekarków A (Pożaryski 1955, modified)
1 – sands, 2 – silts, 3 – clayey silts, 4 – peats

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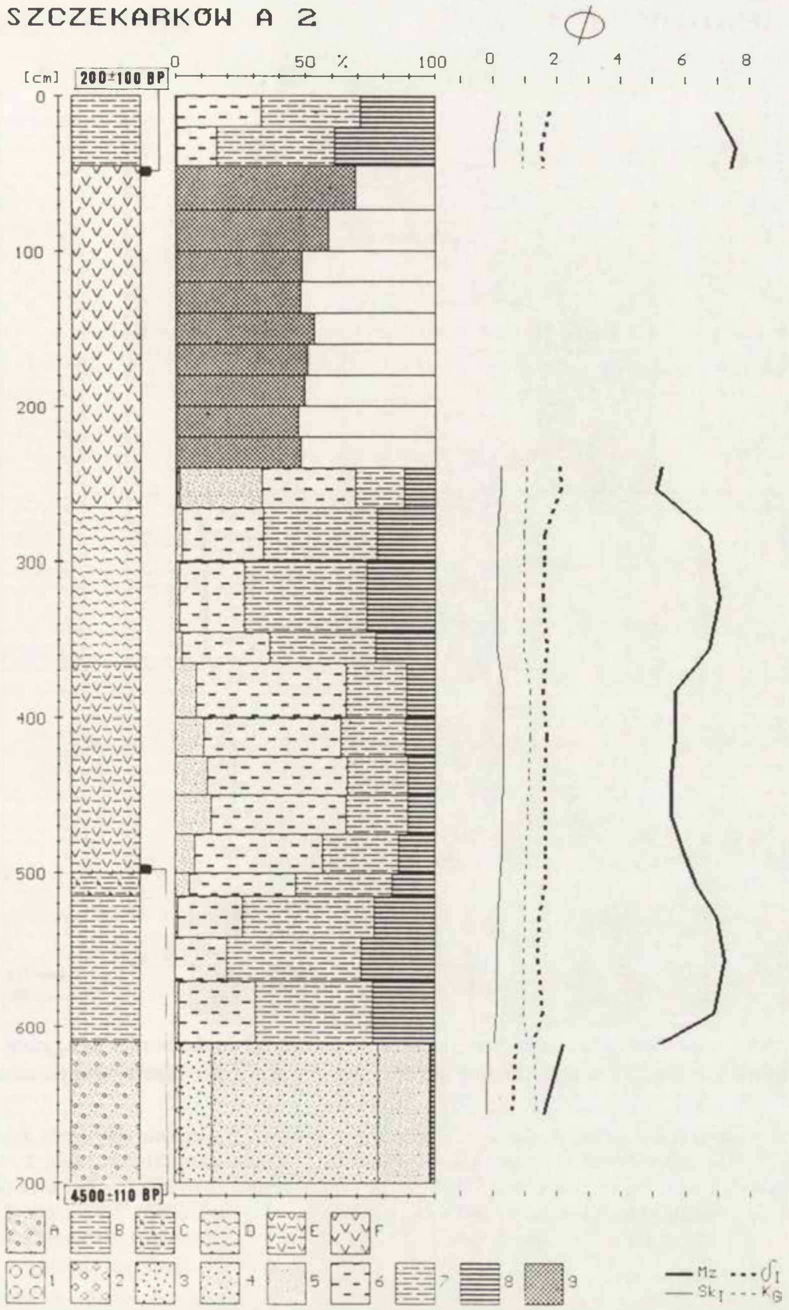

Fig. 11. Filling of palaeomeander Szczekarków A, profile A2 in the central part, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – gravel with sands, B – clayey silts, C – organic clayey silts, D – gyttia with silts, E – peaty silts, F – peats; Fractions: 1 – coarse gravel (below –4∅), 2 – medium and fine gravel (–4 to –1∅), 3 – coarse sand (–1 to 1∅), 4 – medium sand (1 to 2∅), 5 – fine sand (2 to 4∅), 6 – coarse and medium dust (4 to 6∅), 7 – fine dust (6 to 8∅), 8 – clay (above 8∅), 9 – content of organic matter; *Mz*, δ_I, Sk_I, K_G see Fig. 4

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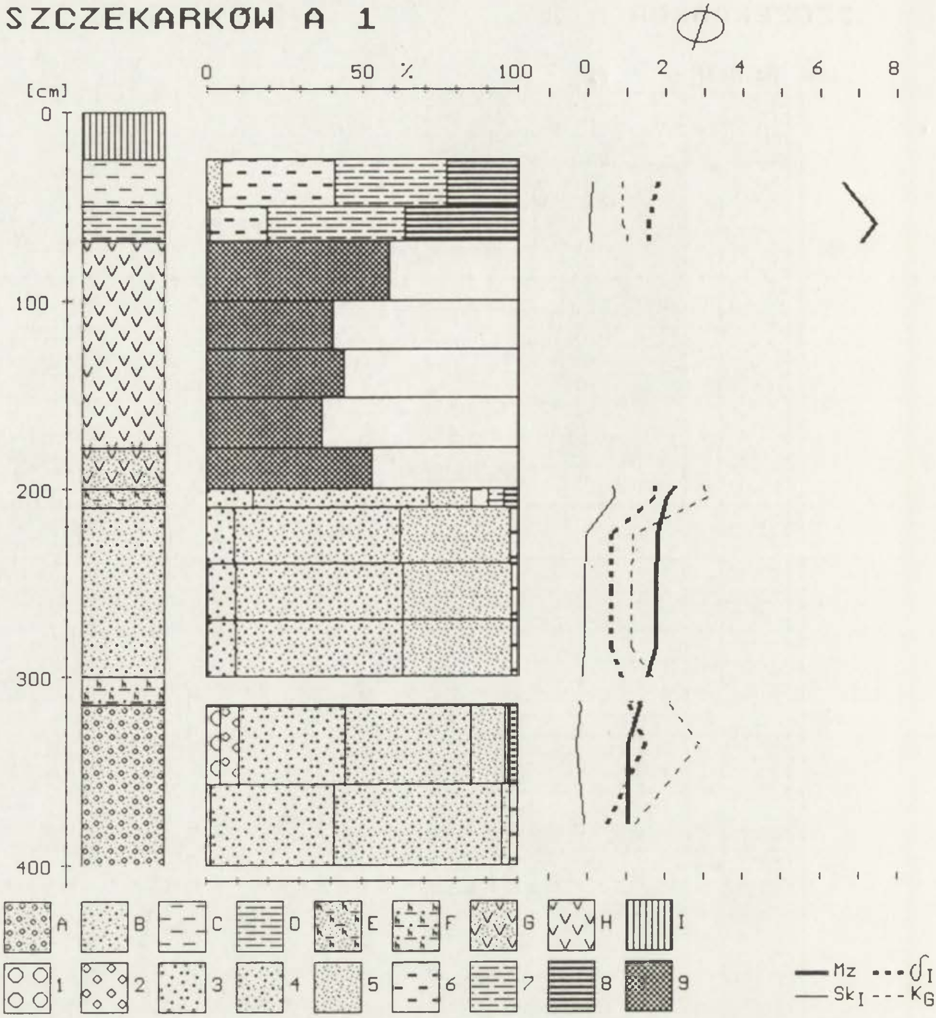

Fig. 12. Filling of palaeomeander Szczekarków A, profile A1 in the border part, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – gravel with sands, B – sands, C – silts, D – clayey silts, E – organic silty sands, F – organic sandy silts, G – peats with sands, H – peats, I – soil; Fractions: 1 – coarse gravel (below –4∅), 2 – medium and fine gravel (–4 to –1∅), 3 – coarse sand (–1 to 1∅), 4 – medium sand (1 to 2∅), 5 – fine sand (2 to 4∅), 6 – coarse and medium dust (4 to 6∅), 7 – fine dust (6 to 8∅), 8 – clay (above 8∅), 9 – content of organic matter; *Mz*, δ_I, Sk_I, K_G see Fig. 4

2 m thick fills, are similar to those of Szczekarków A. They are formed of peaty silts and of peats interlayered with sandy silts. Organic deposits are covered with 70 cm thick layer of the decantation clays (*Mz* = 7.9∅) changing into silty-clay muds (*Mz* = 6.6∅) towards the top. The tempestuous sedimentation in the abandoned channel could have been associated with a short distance from the active channel. It cannot be

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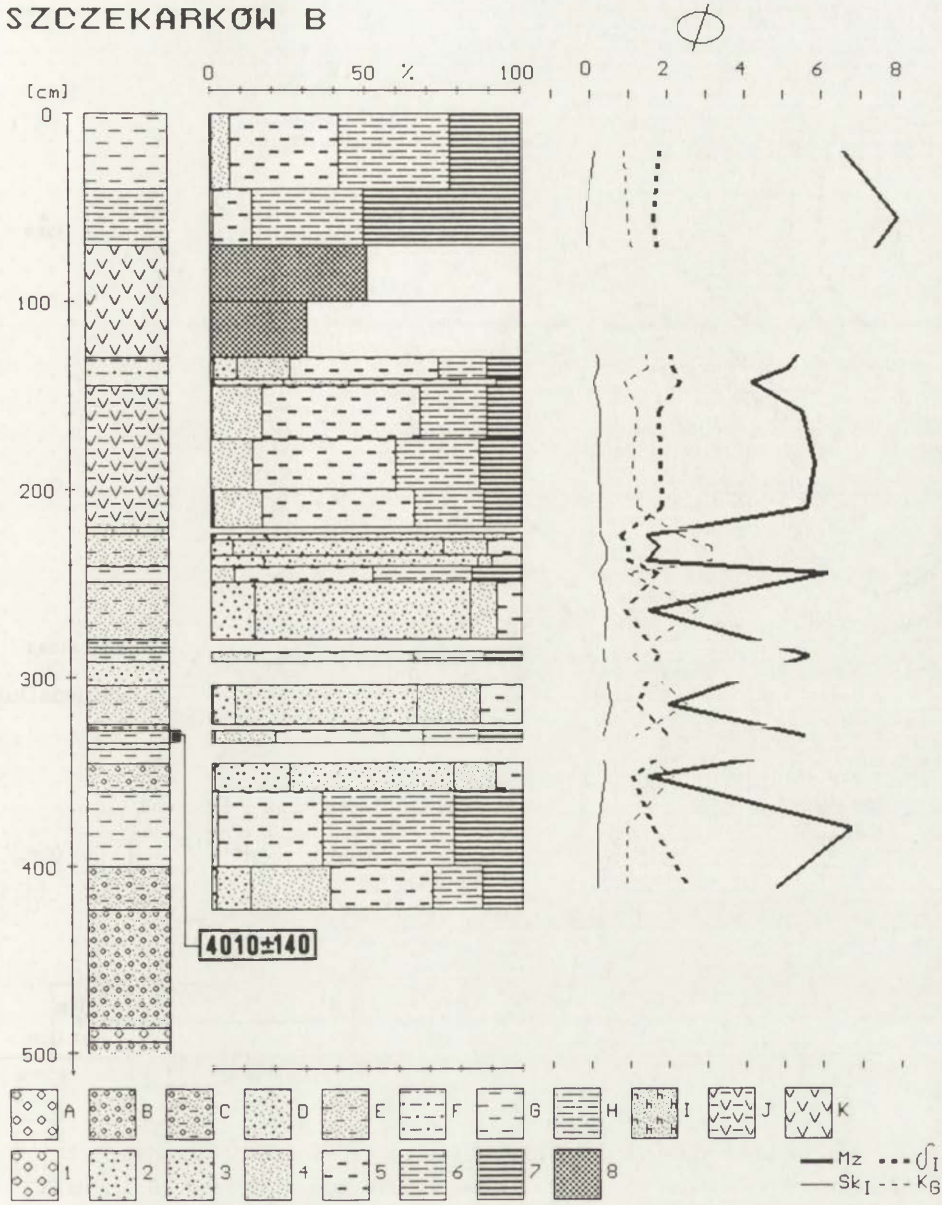

Fig. 13. Filling of palaeomeander Szczekarków B, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – gravel, B – gravel with sands, C – clayey gravel with sands, D – sands, E – silty sands, F – sandy silts, G – silts, H – clayey silts, I – organic sands, J – peaty silts, K – peats; Fractions: 1 – medium and fine gravel (–4 to –1∅), 2 – coarse sand (–1 to 1∅), 3 – medium sand (1 to 2∅), 4 – fine sand (2 to 4∅), 5 – coarse and medium dust (4 to 6∅), 6 – fine dust (6 to 8∅), 7 – clay (above 8∅), 8 – content of organic matter; *Mz*, δ_I, Sk_I, K_G see Fig. 4

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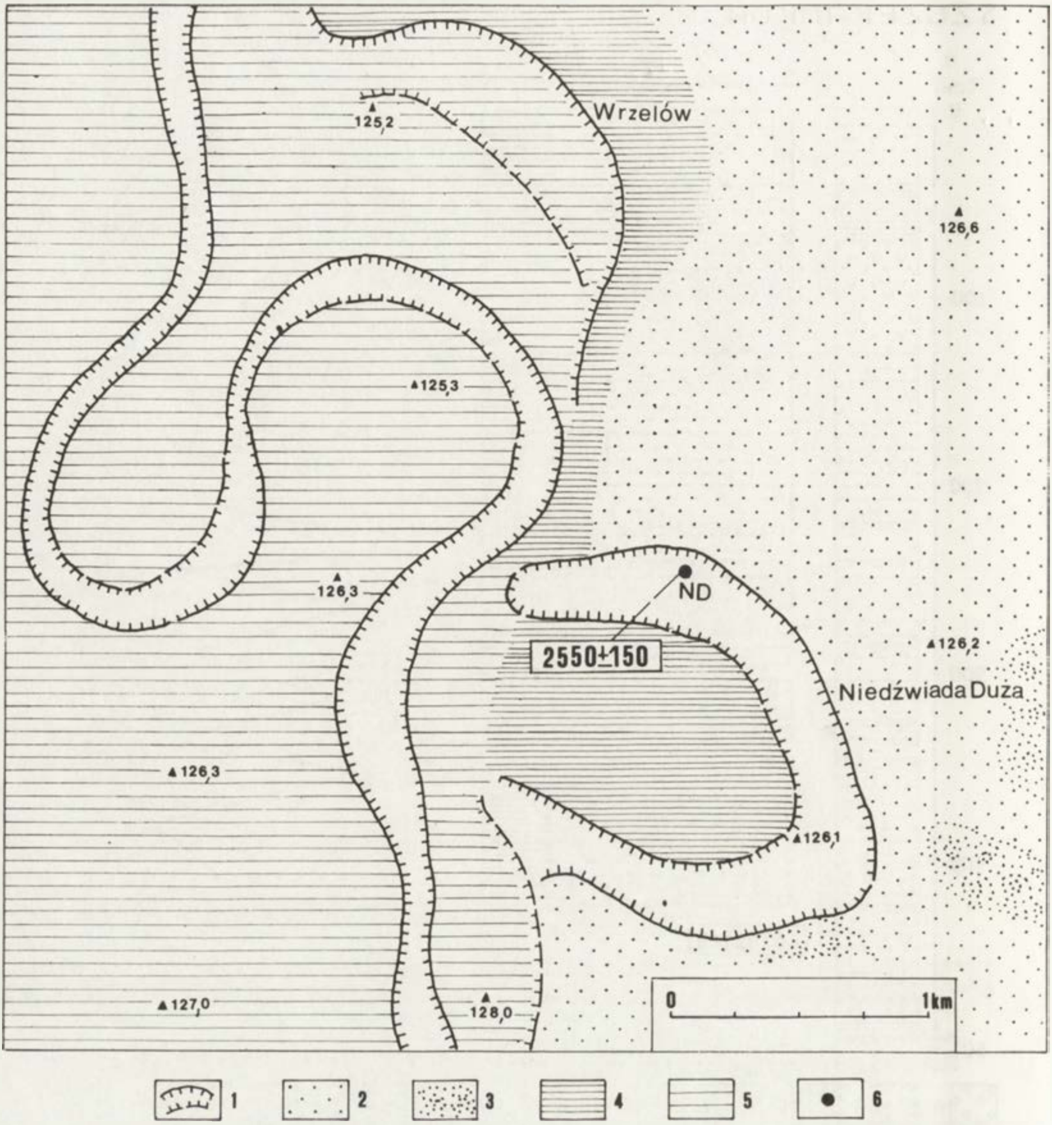

Fig. 14. Geomorphological map of Niedźwiada site (Pożaryski 1955, modified)
1 – palaeomeanders, 2 – middle terrace (IIa), 3 – eolian sands and dunes, 4 – "old mada" flood plain (IC), 5 – "young mada" flood plain (IC), 6 – study profile

excluded that the youngest *madas* slightly coarser than in Szczekarków A result from the above as well.

By analogy with the previous ones the paleomeander in Niedźwiad, of the radius of 500–600 m and the width of 300 m, occurs in the area of the old-*mada* terrace and it undercuts the medium terrace with dunes IIa (Pożaryski 1955). The zone of point bars is risen by ca. 2 m above and the abandoned channel is 0.5 m below the river

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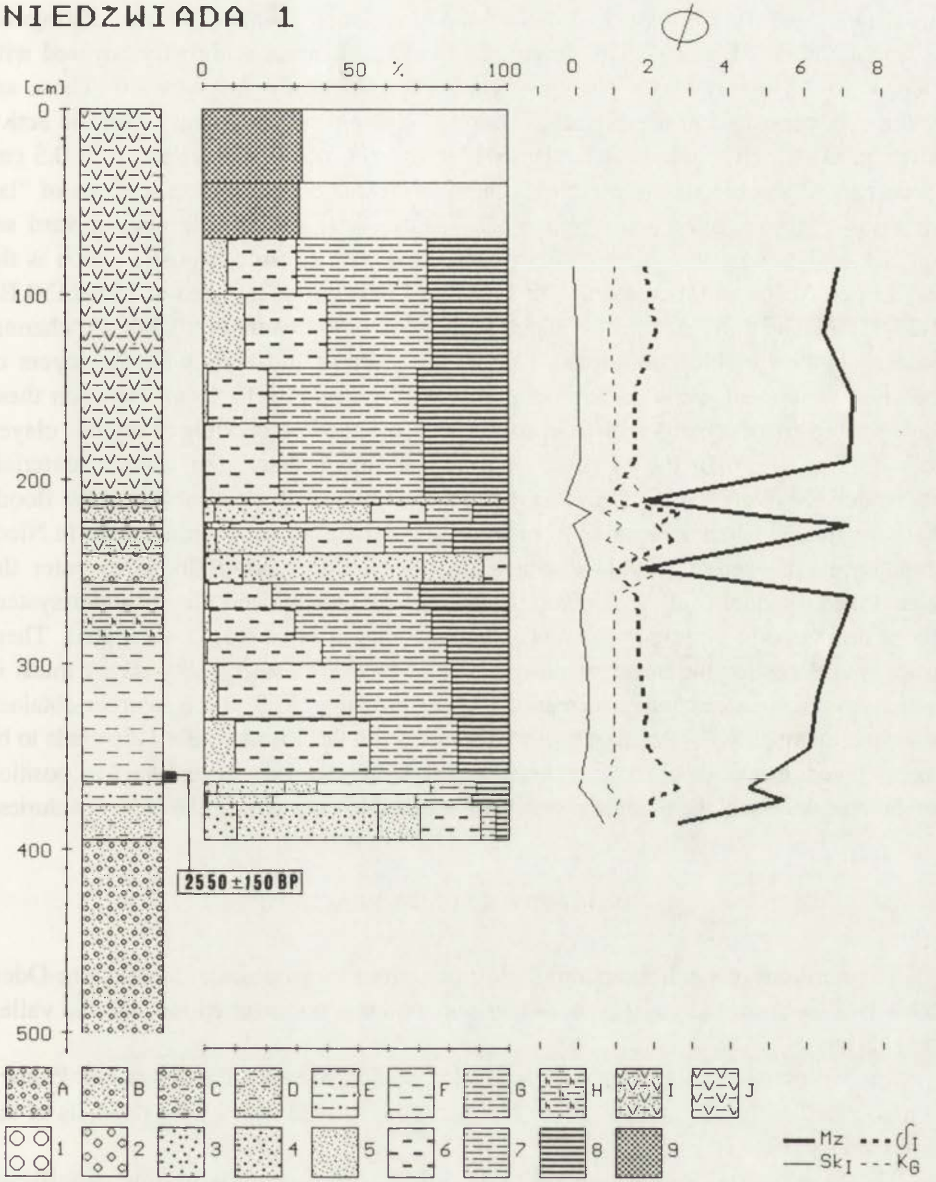

Fig. 15. Filling of palaeomeander Niedźwiada, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki)

Sediments: A – gravel with sands, B – sands with single gravel, C – clayey gravel with sands, D – silty sands, E – sandy silts, F – silts, G – clayey silts, H – organic clayey silts, I – peaty-silty sands, J – peaty silts; Fractions: 1 – coarse gravel (below –4∅), 2 – medium and fine gravel (–4 to –1∅), 3 – coarse sand (–1 to 1∅), 4 – medium sand (1 to 2∅), 5 – fine sand (2 to 4∅), 6 – coarse and medium dust (4 to 6∅), 7 – fine dust (6 to 8∅), 8 – clay (above 8∅), 9 – content of organic matter; *Mz*, δ_I, Sk_I, K_G see Fig. 4

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level (Fig. 14). In the 4 m thick fill of the abandoned channel one can distinguish a few members (Fig. 15). The gravel-sandy channel facies is directly covered with poorly sorted loamy sands changing gradually into sandy silts upward. These are sediments deposited in the cut off abandoned channel whose contact with the active channel is still alive which is confirmed by gravels, of the diameters up to 0.5 cm, occurring at the top of the member. These gravels produce a specific form of "lag deposits". Above, silty muds (*Mz* = 6.1–7.2∅) occur with the finning-upward sequence and change into clayey silts interbedded with organic deposits which is the evidence of calm sedimentation. The bottom of silts has been dated at 2550±150 BP (Gd-9159). The third member is related to the sedimentation in the abandoned channel under highly variable conditions. This member starts and ends with the layers of medium sands and sands of various grains with gravels up to 1 cm. Between these layers there are peaty silts with sand admixtures and the interbedding of organic clayey silts (*Mz* = 7.1∅). In the discussed period the floods delivering coarser materials inundated the overgrowing abandoned channel. It seems very probable that the floods had manifested when the system of meanders undercutting the paleomeander in Niedźwiad was the active Vistula channel and the setting caused floods to enter the abandoned channel (Fig. 14). When the Vistula had abandoned this meander system the sedimentation conditions in the paleomeander in Niedźwiada stabilized. Then, there was deposited the upper member which is formed of peaty, silty-clayey muds in which organic matter content increases upward, reaching 30% in the samples obtained from the member top. A relatively short distance from the Vistula caused the muds to be more clayed than peats of the abandoned channels in Szczekarków and the low position of the channel made the organic accumulation possible even during the recent centuries.

JANOWIEC–PUŁAWY REACH

The northern reach differs from the former ones in separation of the old, pre-Oder, buried valley from the young, post-Oder one which is not inserted into the old valley (Fig. 2III).

The valley is very narrow, and the local widening between Parchatka and Puławy is associated with dissection of the soft substratum formed here by the deposits of the older valley (Fig. 1).

The floodplain occurs in the valley bottom. As the valley is narrow, significant areas are occupied by the youngest fragments IB (Pożaryski 1955) of the floodplain. In one of the fragments, rising 3 m above the river level, the profile of Parchatka (Fig. 16) is found. The well sorted medium sands are overtopped with two members of *madas* which are of the channel levee facies in nature. The lower member of the older *mada* starts with silty muds with organic detritus. Above there is a complex of interlaminated loamy sands (*Mz* = 3.6–4.4∅), sandy silts (*Mz* = 5.0∅) and silty muds (*Mz* = 6.5∅). The thickness of particular laminae varies from a few millimeters to several centimeters. When considering the member as a whole there are sometimes slightly more homogenous layers of sands and sandy silts corresponding probably to larger

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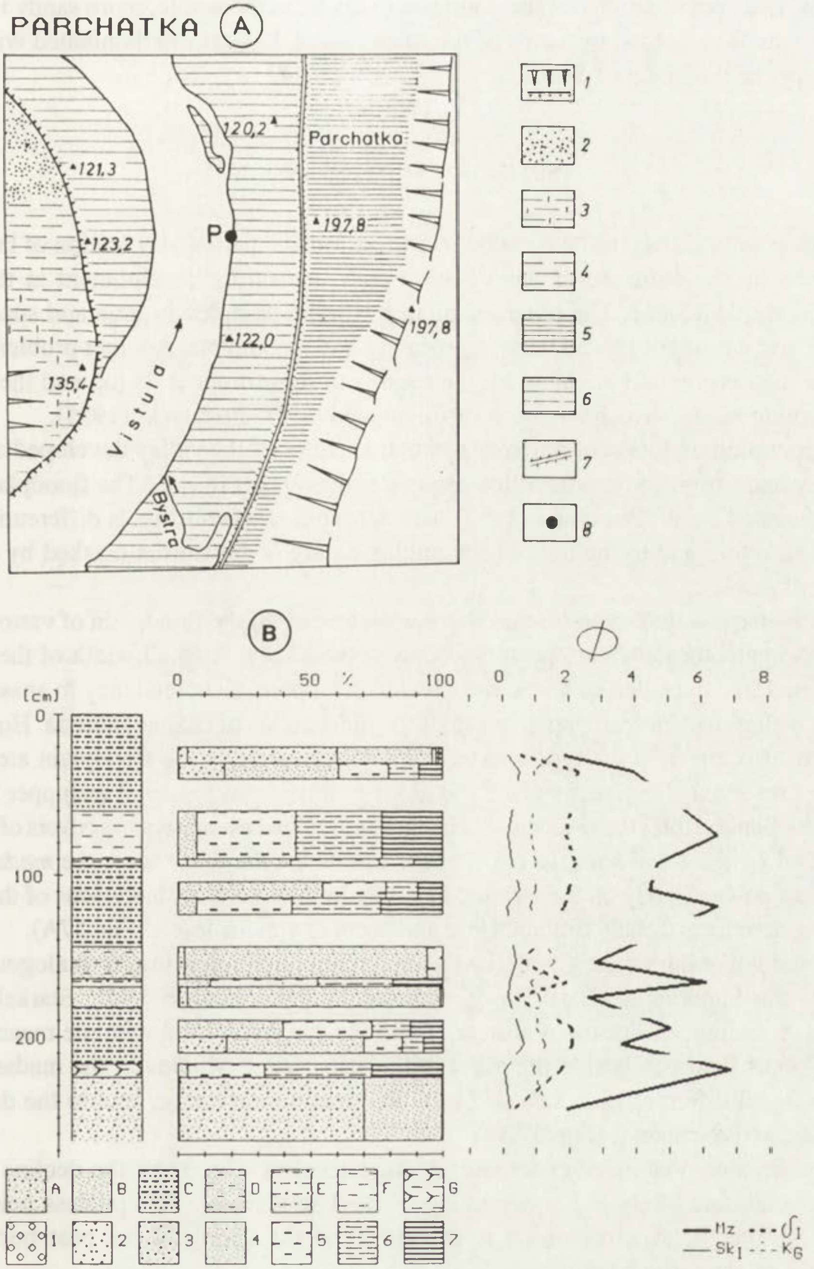

Fig. 16. Geomorphological map of Parchatka site (A) (Pożaryski 1955, modified) and grain size composition and Folk-Ward's grain size distribution parameters of study profile (by T. Kalicki)

A: 1 – edges, 2 – dunes, 3 – high terrace IIIb, 4 – high terrace IIIa, 5 – higherflood plain IC, 6 – lower flood plain IB, 7 – enbankment, 8 – study profile Parchatka; B: Sediments: A – coarse and medium sands, B – fine sands, C – sands with intercalations of muds, D – silty sands, E – sandy silts, F – silts, G – detritus with silts; Fractions: 1 – medium and fine gravel (–4 to –1∅), 2 – coarse sand (–1 to 1∅), 3 – medium sand (1 to 2∅), 4 – fine sand (2 to 4∅), 5 – coarse and medium dust (4 to 6∅), 6 – fine dust (6 to 8∅), 7 – clay (above 8∅); *Mz*, δ_I, Sk_I, K_G see Fig. 4

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floods. The upper member of the youngest mada is, as the whole, more sandy than the lower one. It is formed by sands of the thickness of 1–3 cm interlaminated with silty sands of the thickness of 5–10 cm.

SUMMARY AND DISCUSSION

The results allow a more detailed interpretation and partial verification of the older opinions on the structure of the Vistula valley and on its development in the Late Glacial and Holocene. The obtained picture is more complex in time and space than the former one although still very fragmentary and incomplete. Another problem is the age of the clayey "old *mada*" with the fossil soil most often at its top and the age of the "young *mada*" which has been distinguished by W. Pożaryski (1955).

Depending on local conditions particular sections of the valley developed autonomously and provided records of the sequence of events (Fig. 17). The floodplain (IC) distinguished by W. Pożaryski (1955), which seems to be uniform, is differentiated as to the structure and to the age. This complex nature is most often masked by a thick cover of *madas*.

In the narrow, gap-type reaches there are segments of the floodplain of various age. Here the paleomeanders are preserved only sporadically. A small width of the valley restrained free meandering so the river had likely a permanent tendency to anastomosing as well as to hindered preservation of the older series of channel alluvia. However, records of changes in the type and rate of sedimentation on the floodplain are found in few preserved older fragments. By analogy to the narrow valley of the upper Dniepr (Kalicki, Sanko 1992) the evidence of changes is provided by subsequent covers of *madas* separated by the fossil soils. In the younger inserts, on the other hand, the *madas* have been laid down directly on the channel deposits. In these sections the *madas* of the same age are, therefore, facially differentiated and occur at various levels (Fig. 17A).

In the widening of the Chodelka Basin the floodplain structure is analogous with that of the Sandomierz Basin (e. g. Szumański 1982; Kalicki 1991; Starkel *et al.* 1991). A number of inserts of alluvia of various age, associated with the meandering river, occur here one beside the other at the same level. Moreover, the madas show here a facial differentiation related to the floodplain morphology and to the distance from the active channel (Fig. 17B).

The braided Vistula river formed medium terraces (IIb, a) by the decline of the Pleniglacial, and likely at the beginning of the Late Glacial. This process was completed before the Allerød which is evidenced by the dating of the peat bottom in Lucimia on the terrace IIa.

Probably in the Allerød, as has already been suggested by E. Falkowski (1967, 1982) to whom datings were not available, the concentration of the channel took place and resulted in the river incision. Due to the lowering of the groundwater table related to the above incision the development of eolian processes on the upper sandy terraces was possible on the higher sandy terraces and the dunes night have developed. The dissection of the upper terrace by the decline of the Allerød has been stated in the

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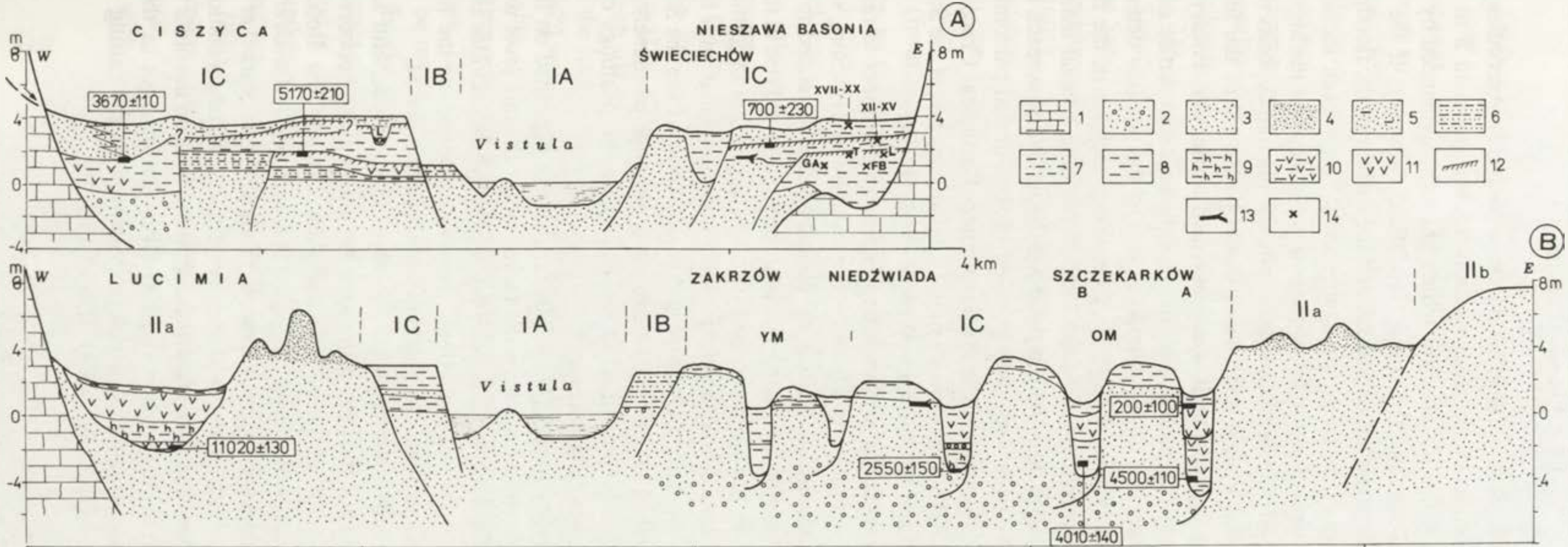

Fig. 17. Schematic sections across the Vistula river valley floor in the narrow section (A) and wide section (B) (by T. Kalicki)

1 – marls and chalk, 2 – gravel with sands, 3 – sands, 4 – eolian sands and dunes, 5 – silty sands, 6 – intercalation of sands and silts, 7 – sandy silts, 8 – silts, 9 – organic silts, 10 – peaty silts, 11 – peats, 12 – fossil soils, 13 – subfossil trees, 14 – archaeological artefacts; FB – Funnel Beaker Culture, GA – Globular Amphora Culture, T – Trzciniec Culture, L – Lusatian Culture

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profile Całowanie as well (Schild 1969, 1975; Sarnacka 1987). According to E. Falkowski (1982) the dissection in the study section reached down to 3 m below the present-day water level in the Vistula river which has to be evidenced by the madas found at this depth and forming the fossil floodplain. However, if the difference between the bottom of the meandering channel and the surface of the floodplain in the discussed section were ca. 7 m, then the channel should have been incised 9–10 m below the present-day Vistula level to allow for eolian processes at the higher terrace. If, we assumed the Allerød channels at such a depth, the organic deposits occuring in Zawichost 10 m below the Vistula water level would be the fill of the fossil paleomeander not the Eemian deposits, as it was pressumed earlier (W. Pożaryski 1955). The above interpretation is not excluded by the paleobotanical expertise of M. Gołąbowa who accepted the decline of the Allerød as one of the possible determinations of the age of the deposits (Pożaryski 1955). A very deep incision of the river in the studied reach is indirectly confirmed by the lack of the Late Glacial *madas* on the terrace IIa. Such *madas* were described in the downstream Warsaw reach (Biernacki 1971, 1975; Sarnacka 1987). A very deep position of the Allerød paleomeanders of the Vistula has been well documented in the Sandomierz Basin near Cracow (Kalicki 1991; Kalicki, Krąpiec 1991), and formerly in the foreland reaches of the San (Starkel 1960; Mamakowa 1962) and the Wisłoka (Wójcik 1987) rivers.

The deposition of peats in the deflation depression on the upper terraces by the decline of the Allerød (Lucimia) could have been caused by local factors, such as the damming of the Zwolenka stream outflow by dunes, or can be related to a general development – the beginning of the Young Dryas accumulation and rise in the groundwater level. The change in the sedimentation type and deposition of gyttia in Całowanie (Borówko-Dłużakowa 1961; Sarnacka 1987) was associated with this factor. The river aggradation in the Young Dryas period is also known from the Sandomierz Basin near Cracow (Kalicki 1991, 1992). Due to slow, although permanent, tendency to the uplifting of the channel level and of the floodplain the peatbogs or swamps could survive during the whole Holocene.

In the Atlantic the clayey madas (Mz = 7.0–7.5∅) were deposited on the Vistula flood-plain and their differentiation within the facies of the channel level was not too large (Mz = 4.5–6.6∅). The soils were developing as well which provides evidence of a small intensity of the flood accumulation. The above contradicts the findings of E. Falkowski (1982) who attributed the mada accretion to this period.

The first, more detailed information on the level of the floodplain and of the Vistula channel originates just from the turn of the Atlantic and the Subboreal. At that time the channel was ca. 5 m below (Szczekarków A) and the floodplain ca. 2 m above the present-day water level (Ciszyca Przewozowa). Moreover, in these periods, which are well documented near Cracow (Kalicki 1991; Starkel *et al.* 1991), during the intensified activity of the Vistula river the faster sedimentation of silty *madas* (Mz = 6.1–6.7∅) resulted in the fossilization of the soils on the older fragments of the floodplain (Ciszyca Przewozowa – 5170 BP). The changes in the channel pattern took place in wider fragments, which is evidenced by the cutting off of the paleomeander in Szczekarków before 4500 BP and 4010 BP.

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In the Subboreal the sites of the Lusatian culture descend in the valley bottom. However, they are found on the older and higher fragments of the floodplain accreted by the *madas* at the turn of the Atlantic and Subboreal (Ciszyca Przewozowa) or on the fragments adjacent to the slopes (Basonia). The intensive management in the loess areas (Kruk 1988) causes fans to form at the outlets of erosional incisions and of the upland tributaries which results in the change of the sedimentation type in the depressions adjacent to the slopes (Ciszyca Górna).

At the beginning of the Subatlantic (2550 BP) some changes of the Vistula channel in the Chodelka Basin took place and the meander in Niedźwiada was cut off.

The following phase of the intensified accumulation of the *madas* was the younger Medieval (700 BP) which resulted in the formation of the next fossil soil (Nieszawa, Basonia, Świeciechów). The silty *madas* (Mz = 5.8–6.5∅) rest directly on the fossil soil. In the Sandomierz Basin numerous black oaks are known of this period and they provide evidence of the intensified river activity not only in the gorge (Kalicki, Krąpiec 1991).

A common change in the sedimentation conditions is observed on the whole floodplain just in the recent centuries. That was probably caused by the increasing human impact in the Vistula drainage basin. At first, the river showed a tendency to turn wild (from the 15th century), and then, from the 19th Century, the river changed its pattern to the braided one (Falkowski 1982). In the channel vicinity there is a change in the grain size composition, so the *madas* are transformed into the sandy deposits (Mz = 2.9–3.8∅) which are often of the levee facies in nature (e. g. Parchatka). In the valley narrowings the *madas* of this type often cover the whole bottom, rest directly on the Medieval silty *madas* and are not separated from them by the fossil soil which has not developed yet. An increased frequency, and probably magnitude, of floods resulted in fossilization of the youngest soils developed on the silty *madas* (Ciszyca Przewozowa) in the uppermost located fragments of the floodplain. The soils have been covered with silty-sandy *mada* (Mz = 5.4∅). In the wider parts of the valley the youngest *madas* of the levee facies were deposited along the Vistula river while clayey-silty muds (Mz = 7.0∅) were laid down on the organic deposits in a far distance from the channel in the low-lying areas (to 1.5 m above the river level) such as paleomeanders of peatbogs. These clayey-silty muds are similar to the Atlantic *madas* with respect to the grain size composition. The results of the studies prove that the grain size composition of the *madas* must not be used as the age indicator as accepted by W. Pożaryski (1955) when distinguishing the clayey “old *mada*” and the sandy “young *mada*”.

The grain size composition is only the indicator of the facial differentiation of the *madas* and is mainly associated with the distance from the active channel. The silty *madas* predominated in the studied reach until the modern era. In the older Holocene the *madas* were mainly accumulated in the periods of the increased river activity (e. g. 5000, 700BP) while soils were formed during the periods of relative calmness on the floodplain. Just in the recent centuries a rapid increase in an accumulation rate, a change in the composition and character of the flood deposits occurred simultaneously with the tendency of the river to turning wild.

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REFERENCES

Biernacki Z., 1971, *Typy sedymentacyjne a inżyniersko-geologiczne jednostki przestrzenne aluwiów Wisły w rejonie Warszawa* (typescript), Warszawa.

– 1975, *Holocene and Late Pleistocene alluvial sediments of the Vistula river near Warsaw*, Biul. Geol. Uniw. Warsz. 19, 199–219.

Borówko-Dłużakowa Z., 1961, *Przyczynek do znajomości holoceńskich torfowisk na tarasach Wisły pod Warszawą* (typescript), Arch. PIG, Warszawa.

Falkowski E., 1967, *Ewolucja holoceńskiej Wisły na odcinku Zawichost–Solec i inżyniersko-geologiczna prognoza jej dalszego rozwoju (Holocene evolution of the Vistula river valley between Zawichost and Solec and engineering geological prognosis of its future development)*, Biul. PIG 198, 57–142.

– 1982, *The pattern of changes in the Middle Vistula valley floor*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Strud., Spec. Issue 1, 79–92.

Jankowski W., Stolarska A., 1978, *Ocena możliwości wystąpienia tysiącletniej fali powodziowej w rejonie Warszawy*, Mater. Bad. IMGW, Ser. Hydrol. Ocean. 1–48.

Kalicki T., 1991, *The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 11–37.

– 1992, *The structure and age the Drwień depression interrupting the Vistula floo-plain east of Cracow (South Poland)*, Studia Geomorph. Carpatho-Balcan. 25–26, 91–115.

Kalicki T., Krąpiec M., 1991, *Black oaks and Subatlantic alluvia of the Vistula in the Branice–Stryjów near Cracow*, [in:] L. Starkel (ed.) *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 39–61.

Kalicki T., Sanko A. F., 1992, *Genesis and age of the terraces of the Dnieper river between Orsha and Shklov, Belorussia*, Geogr. Pol. 60, 151–174.

Krishtofovich N., 1896, *Posletretichnye obrazovania v Novo-Aleksandrii*, Novo-Aleks. Inst. Zap. 9, Warszawa.

– 1904, *Geologicheskoye stroyenie i vozrost niekatorykh drevnikh posletrichnykh torfianikov Lublinskoy gubierni*, Vezegodnik po Geol. i Min. Rosii 7, 4, 95–103, Puławy.

Kruk J., 1988, *The history of colonisation of both the Vistula river valley and the loess-covered uplands*, Excursion Guide Book, Symposium Vistula Basin, 44–46, Kraków.

Mamakowa K., 1962, *Roślinność Kotliny Sandomierskiej w późnym glacjale i holocenie (The vegetation of the Basin of Sandomierz of in the Late Glacial and Holocene)*, Acta Palaeobot. 3, 2, 1–57.

Pożaryska K., 1948, *Stratygrafia plejstocenu w dolinie dolnej Kamiennej (Stratigraphy of Pleistocene of the Lower Kamienna valley)*, Biul. PIG 52.

Pożaryska K., Pożaryski W., 1951, *Przewodnik geologiczny po Kazimierzu i okolicy*, Wyd. Muzeum Ziemi, Warszawa.

Pożaryski W., 1952, *Z geologii czwartorzędu doliny Wisły pod Zawichostem (From Quaternary of the Vistula valley near Zawichost)*, Biul. PIG 65, 365–381.

– 1953, *Plejstocen w przełomie Wisły przez Wyżyny Południowe (The Pleistocene in the Vistula Gap acrossthe Southern Uplands)*, Prace Inst. Geol. 9.

– 1955, *Osady rzeczne w przełomie Wisły przez Wyżyny Południowe*, Prace Inst. Geol.

Pożaryski W., Maruszczak H., Lindner L., 1993, *Stratygrafia osadów środkowoplejstocenskich w przełomie Wisły przez wyżyny południowe w świetle analiz termoluminescencyjnych (komunikat wstępny)*, Przegl. Geol. 2, 103–106.

– 1994, *Rozwój plejstoceńskiej doliny Wisły środkowej ze szczególnym uwzględnieniem przełomu przez wyżyny południowopolskie*, Przegl. Geol. 42, 7, 523–531.

http://rcin.org.pl

S a r n a c k a Z., 1987, *Evolution of the Vistula valley between the outlets of Radomka and Świder rivers in the Late Glacial and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II,* Geogr. Stud., Spec. Issue 4, 131–150.

S a m s o n o w i c z J., 1934, *Objaśnienia arkusza Opatów. Ogólna mapa geologiczna Polski (Explication do la feuille de Opatów. Carte geologique generale de al Pologne)*, PIG 1.

S a w i c k i L., 1925, *Przełom Wisły przez Średniogórze Polski (Der Mittlepolnische Weichsel-durchbruch)*, Prace IG UJ 4.

– 1933, *Przyczynek do znajomości dyluwium oraz morfogenezy przełomu Wisły pdo Puławami (Contrybution a la connaissance du Quaternaire et de la morphogenese de la vallee de la Vistule pres de Puławy)*, Przegl. Geogr. 13, 158–169.

S c h i l d R., 1969, *Uwagi o stratygrafii archeologicznej wydm śródlądowych (On the archaeological stratigraphy of the inland dunes) [in:] R. Galon (ed.), Procesy i formy wydmowe w Polsce*, Prace Geogr. 75, 145–162.

– 1975, *Późny paleolit,* [in:] *Prahistoria Ziem Polskich*, 1, 159–338, Warszawa.

S o j a R., M r o z e k T., 1990, *Hydrological characteristic of the Vistula River*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5, 45–62.

S t a r k e l L., 1960, *Rozwój rzeźby Karpat fliszowych w holocenie (The development of the Flysh Carpathians relief during the Holocene)*, Prace Geogr. IG PAN 22.

– ed., 1987, *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4.

S t a r k e l L., G ę b i c a P., N i e d z i a ł k o w s k a E., P o d g ó r s k a - T k a c z A., 1991, *Evolution of both the Vistula floodplain and Late Glacial – early Holocene palaeochannel systems in the Grobla Fores (Sandomierz Basin)*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 87–99.

S z u m a ń s k i A., 1982, *The evolution of the Lower San river valley during the Late Glacial and the Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 57–78.

W ó j c i k A., 1987, *Late-Glacial lacustrine sediments from Roztoki and Tarnowiec near Jasło (Jasło–Sanok Depression)*, Acta Palaeobot. 27, 1, 27–41.

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GENESIS OF THE FLUVIAL SYSTEM OF THE LOWER VISTULA RIVER BASED ON THE SELECTED SIDE VALLEYS

INTRODUCTION

In the interwar period (1918–1939) in the work dealing with paleogeography of the lower Vistula valley R. Galon (1934) presented the main stages of this valley development during deglaciation. His studies inspired many researchers who undertook detailed geomorphological studies in this valley as well as in the valleys of some tributaries (Galon 1953, 1961, 1968; Niewiarowski 1968, 1987; Drozdowski 1974, 1982; Wiśniewski 1976, 1982, 1987, 1990; Mojski 1982, 1990; Tomczak 1982, 1987; Andrzejewski 1984, 1986, 1991, 1994; Florek E. *et al.* 1987; Baraniecka, Konecka-Betley 1987; Starkel, Wiśniewski 1990 and others).

As results from the studies on fluvial systems, which have been carried out up to now, the problems arise when the influence of independent and changing factors, resulting in certain threshold values and determining fluvial processes (Schumm 1977 and others) is to be determined.

Six lower and middle reaches of the valleys yielding to the Vistula valley between the Warsaw Basin in the south and the Grudziądz basin in the north were subjected to the geomorphological studies. These are the valleys of the Bzura, the Skrwa, the Mien, the Zgłowiączka, the Tążyna and the Wda which, according to the concept of A. S. Schumm (1977), form a fluvial system (Fig. 1). Considering this system the studied sections include the second zone (a transitional one or that of predominating transportation), and the third zone (in which deposition mainly takes place). The valleys have been selected as to differ with respect to morphogenesis, physiographic parameters and to the age at which particular sections were incorporated into the analysed system.

It has been assumed that the choice presented above will help to explain numerous problems associated with the mechanism of formation of this uniform system as well as with the character of fluvial processes during the last 15 000 years.

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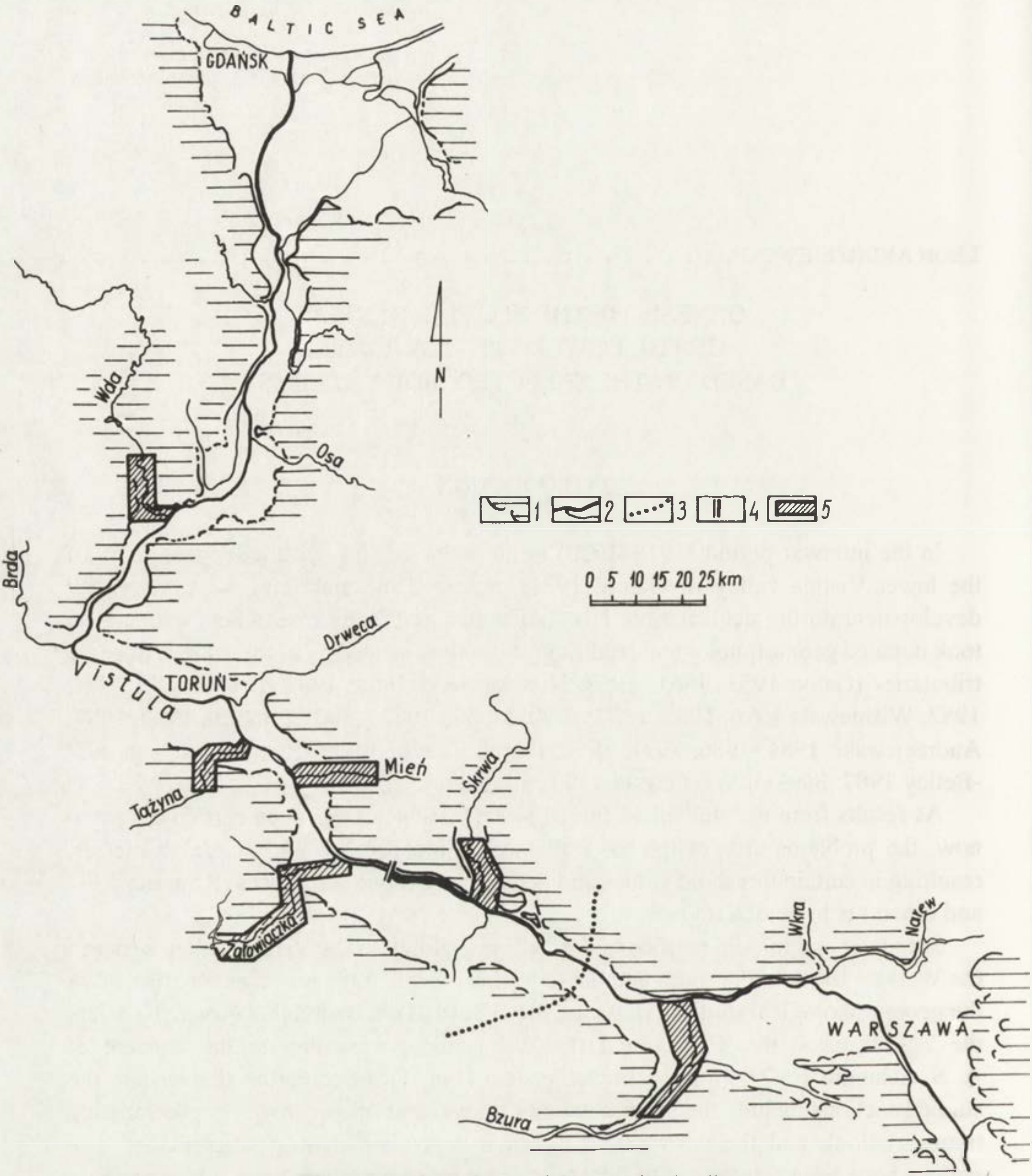

Fig. 1. Location scheme of the examined valleys
1 – moraine upland, 2 – river network, 3 – maximum extent of the last glaciation, 4 – dam, 5 – location of the examined valleys

Various study methods have been applied. The levels and terraces in each of the discussed valleys have been subjected to a detailed geomorphological mapping and are presented in longitudinal profiles (Fig. 2–4). Extensive structural-textural studies of the alluvia forming mainly the floodplains and the supraflood terraces of the examined valleys allowed to distinguish fundamental lithofacies and borders between them in several geological cross-sections which are transverse to the valleys axes.

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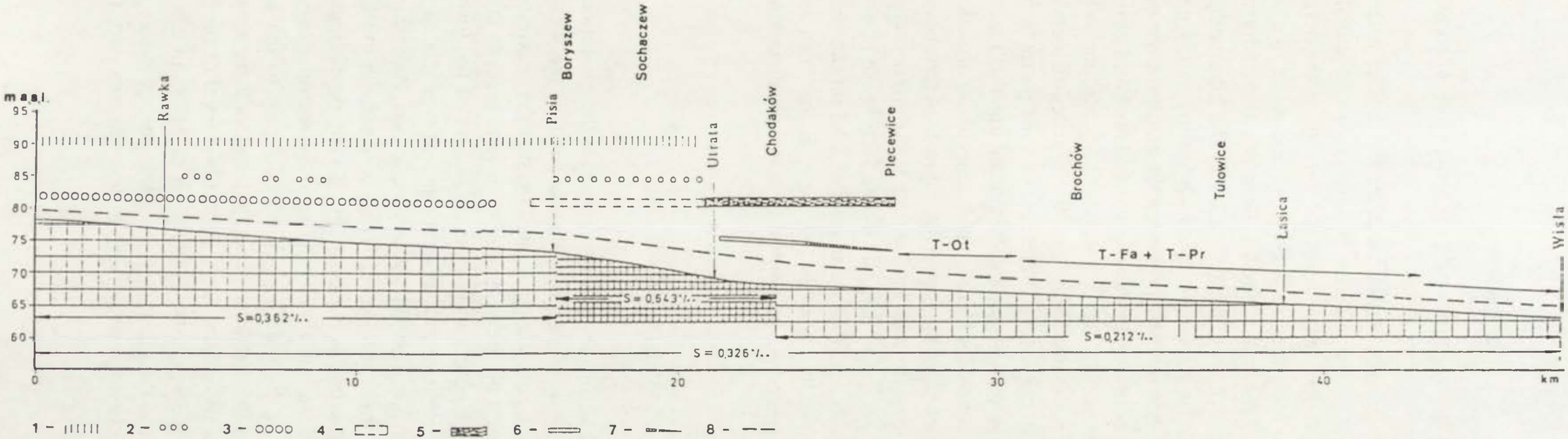

Fig. 2. Longitudinal profile of the lower section of the Bzura valley

1 – of the moraine upland, 2 – the upper level of meltwaters, 3 – the lower level of meltwaters, 4 – level of the dead valley, 5 – level of the Błonie ice-marginal lake, 6 – the Bzura terrace in the region of Chodaków, 7 – accumulation level of the Bzura river downstream of Chodaków, 8 – valley bottom

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MORPHOGENESIS OF THE VALLEYS OF THE ANALYSED FLUVIAL SYSTEM

The system of the lower Vistula valley includes the proper valley together with some tributaries, downstream of the Warsaw Basin, i. e. over the distance of ca. 400 km. In the first reach the Vistula river dissects the uplands of the period of the Warta glaciation, and then, starting from the Płock Basin, it passes the area which was in the range of the last glaciation. As it has already been mentioned by many scientists, a characteristic feature of the lower Vistula valley is the alternating occurrence of wider sections, called basins, and narrowings which are frequently gaplike in nature. E. Wiśniewski (1987, 1990) has recently presented the results of the ongoing geological and geomorphological studies. He has also presented his own opinion on the valley evolution since the transgression of the last ice sheet. According to his studies, particular sections of the lower Vistula valley rapidly adjusted to new erosional bases during the retreat of the last ice sheet. Therefore, various patterns of terraces have developed in these sections, which can be concluded on the basis of the terrace correlation in the longitudinal profile. Numerous datings of the organic deposits filling the paleochannels and dead ice depressions on the supraflood terraces indicate that the Vistula reached its present-day bottom very early. It occurred earliest between the Warsaw and Płock Basins, i. e. ca. 14 500 BP. These facts make one verify the views on the age of the upper terraces in the Vistula valley and on the moment when the Vistula formed a gap near Fordon towards the north. It has been assumed that the examination of some side valleys can be helpful in better understanding of the evolution of the main river valley.

THE BZURA VALLEY

The Bzura river, described in the previous issue on the evolution of the Vistula valley (Andrzejewski 1991) yields into the Vistula river in the western part of the Warsaw Basin (Fig. 1). The Bzura valley located outside the maximum extent of the last glaciation was the first among the examined valleys to react to the changes in the analysed fluvial system. A specific morphogenetic feature of the lower reach of this valley is the fact that, in a certain period, its development was related to the extensive Warsaw ice-dammed lake (Andrzejewski 1994; Wiśniewski, Andrzejewski 1994).

In this part of the valley three sections differing with respect to their development and the gradients of their present-day bottoms (Fig. 2) can be distinguished.

The first valley section, from the Rawka outlet to the surroundings of Boryszewo, being 1–2 km wide, dissects the moraine upland rising up to the height of 90–92 m a. s. l. Above the two-step floodplain with paleomeanders there are two levels lying at higher positions. The best developed is the supraflood level of the height of 80–82 m a. s. l. above which rise the fragments of the level of 84–85 m a. s. l. These levels (Andrzejewski 1994) register the phase of the high energy water outflow of the multi-channel system of the braided rivers which flew towards east, i. e. to the Warsaw ice-dammed lake.

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The additional information on the origin of these waters is provided by the studies of E. Wiśniewski (Wiśniewski, Andrzejewski 1994) in the proglacial valleys of the Przysowa–Słudwia and Ochnia which dissect the Kutno Plain located to the west. The meltwaters flow in the valleys from the icesheet towards the Warsaw–Berlin ice marginal channel (*pradolina*) during the Leszno phase and when it had reached the waters were directed towards east and deposited the sediments building the levels mentioned before of 84–85 m a. s. l. and 80–82 m a. s. l. in the Bzura valley upstream of Boryszewo. Thus the assumption that during the maximum extent of the Last Glaciation the water flew out from the proglacial lake in the Warsaw Basin towards the west in the Warsaw–Berlin marginal channel (Jewtuchowicz 1967), whose eastern section is formed by the Bzura valley, is hardly to be accepted.

The next, ca. 800 m wide, incised section between Boryszewo and Chodaków was formed later due to intensive river downcutting still in the decline period of the Upper Plenivistulian (Andrzejewski 1991, 1994). The best developed supraflood terrace, of the height of 76–77 m a. s. l. in the vicinity of Boryszewo and descending to the height of 72–73 m a. s. l. in Chodaków, resulted mainly from the braided river activity. The present-day Bzura in these sections shows a tendency to turning wild. Fluvial processes undergoing in this way in the discussed valley section should be related not only to the climatic factors but their reasons should be sought in a significant change in the gradient of the bottom of the Bzura valley (Fig. 2). Downstream of Chodaków, already in the area of the Vistula valley, the gradient of the bottom of the Bzura valley changes rapidly from 0.643 to 0.212‰.

In the development of the Bzura valley downstream of Chodaków one can distinguish three fundamental phases. In the decline period of the upper Plenivistulian there predominated the accumulation of alluvia in the area of the immense meander, called the “great Bzura meander”. Of the late Vistulian period there is a number of paleomeanders whose geometrical parameters are much larger than those of the present-day paleomeanders. In the youngest, Holocene phase of the Bzura valley development the wide, two-step present-day floodplain was being formed. In the form of the alluvia development of the floodplain and of the supraflood terrace of this section of the Bzura valley there have not been stated the traces of frequent changes in the vertical river position during the last 15 000 years. The conclusions of M. D. Baraniecka and K. Konecka-Betley (1987) referring to the vertical oscillations of the Vistula in this period, expressed as subsequent inserts of the series of the Vistula alluvia in the Bölling and the Allerød, are questionable because these processes were probably reflected in the lower section of the Bzura valley bottom.

THE SKRWA AND WDA VALLEYS

In the first phase of formation of the valleys of the Skrwa and Wda rivers the main factors were the meltwaters. In the case of the Skrwa valley these waters drained to the Płock Basin in two definite levels, which were formed during the Kujawy subphase (Kotarbiński 1972). Thus, it can be assumed that the meltwater outflow on the

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Skrwa sandur started ca. 17 200 BP (Kozarski 1986). According to Kotarbiński, the highest river terrace, 83–85 m a. s. l., in the lower section of the Skrwa valley, was formed during the Pomeranian stage. The studies of the author mentioned have indicated that in this valley section the well developed supraflood terrace, of the height of 60–61 m a. s. l., existed already at the beginning of the late Vistulian. One can presume that all the terraces and sandur levels in the lower section of the Skrwa valley (Fig. 3) were formed in the period from 17 200 to 14 500 BP (Andrzejewski 1994). In the late Vistulian and the Holocene history of the Skrwa valley development only the floodplain was formed, sometimes in two levels.

As indicated by the author's studies, in the lower section of the Wda valley two definite sandur levels of the heights of 82–85 m a. s. l. and 75–80 m a. s. l., respectively, can be stated. These levels were formed during the meltwater outflow in the Pomeranian phase and in the Kaszuby–Warmia subphase (Churska 1961; Drozdowski 1967; Sylwestrzak 1978; Szupryczyński 1988). Below the sandur levels numerous river terraces resulting from intensive downcutting and lateral erosion (Fig. 3) have been preserved in morphology of the lower Wda valley.

The fluvioglacial processes and then fluvial ones influenced especially the formation of the Skrwa and Wda valleys. The river network being developed included terrain depressions of various geneses into the valley patterns, transforming them to a various degree. In the case of the lower Skrwa valley these are extensive valley meanders following subglacial troughs and dead ice depression patterns. In the lower section of the Wda valley, downstream of Kozłów, in 4 geological cross-sections (Andrzejewski 1994) there have been stated gyttias and peats occurring under the Wda alluvia. This is, therefore, the example of the fossilization of lacustrine deposits filling the older depression capped by the river alluvia.

UPLAND SECTIONS OF THE MIEŃ AND ZGŁOWIĄCZKA VALLEYS

The Mień and Zgłowiączka rivers, in their upland reaches occupied and transformed to a various degree the depressions which were of the nature of the subglacial troughs and of the dead ice depressions. Due to the degradation of ice preserving the depression and to the supply of mineral deposits from the neighbouring uplands the crevasse forms were developed, namely kames, kame ridges and kame terrace (Andrzejewski 1984, 1994). The organic deposits, of differentiated thickness, filling the trough bottoms (peats, gyttias and lacustrine chalks) are the evidence of several lacustrine phases at least. Niewiarowski (1986) distinguishes 6 phases of transformation of the subglacial troughs in the process of their joining the valley systems. Among them there is a lacustrine-fluvial phase. In the case of the examined trough sections of the Zgłowiączka and Mień valleys three lacustrine phases can be discerned. During the oldest phase fine mineral sediments accumulated within the troughs which had been filled with winter ice to a large degree while the neighbouring uplands had been subjected to deglaciation. Kame terraces and kames were formed then. This phase falls into the decline of the upper Plenivistulian.

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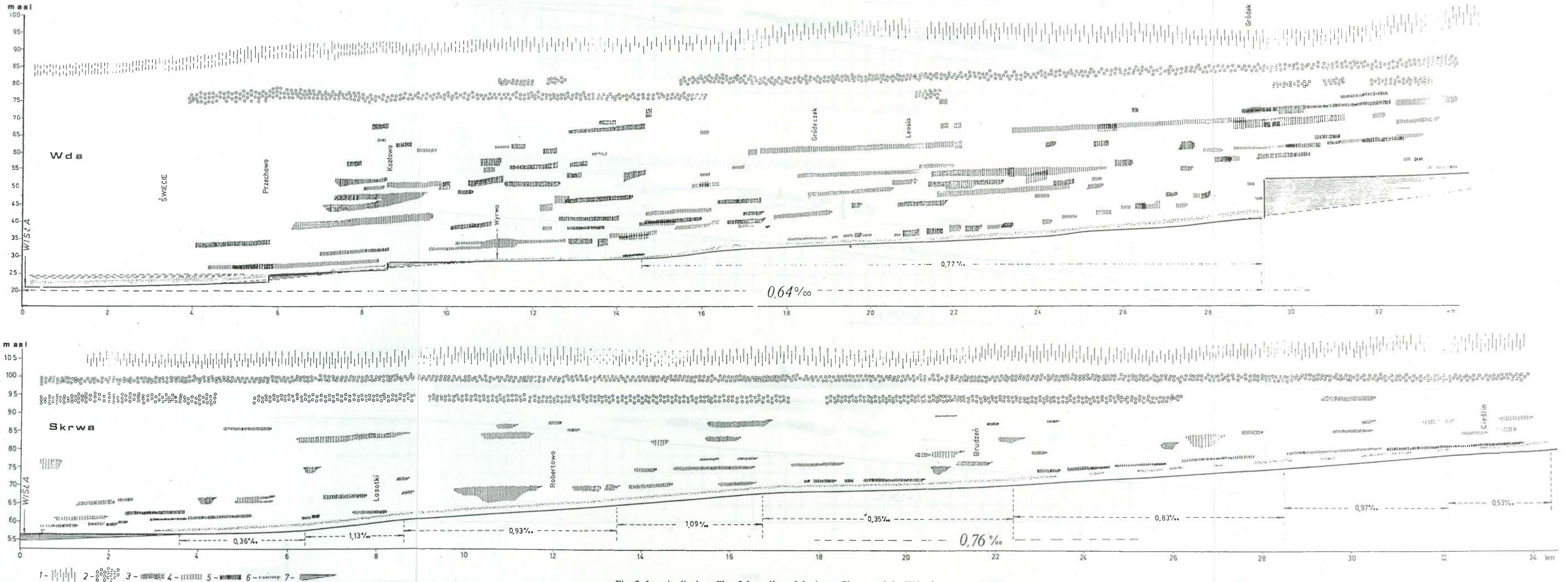

Fig. 3. Longitudinal profile of the valley of the lower Skrwa and the Wda rivers

1 – level of upland, 2 – sandur levels, 3 – left bank terraces, 4 – right bank terraces, 5 – both banks terraces, 6 – level of the floodplain, 7 – lake, ponds and other water bodies

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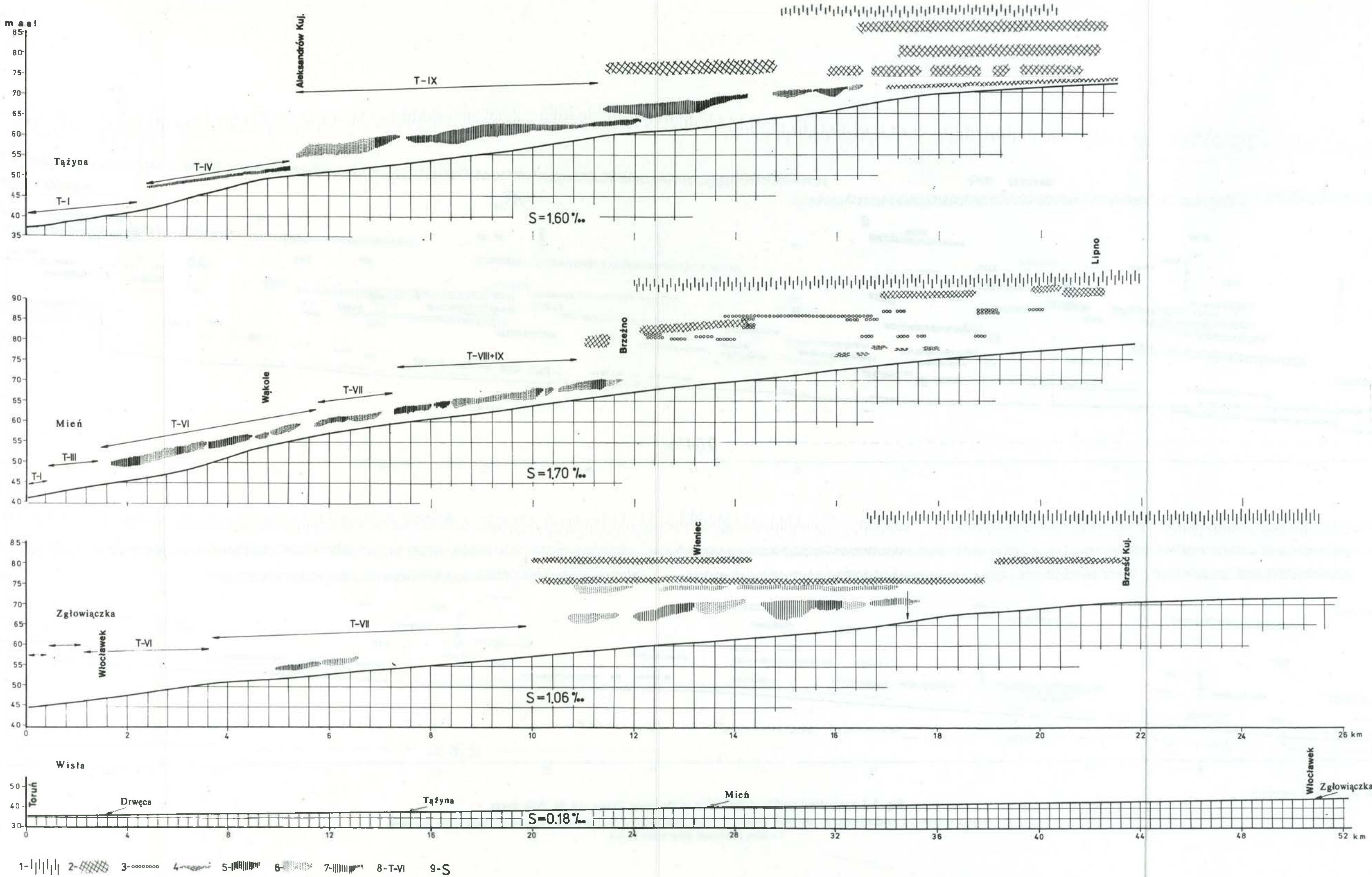

Fig. 4. Longitudinal profiles of the valleys of the Tążyna, Mień and Zgłowiączka rivers

1 – level of upland, 2 – lowered levels of upland, 3 – kame terraces and kames, 4 – the Late Vistulian lake terraces, 5 – left hand side river terraces, 6 – right-side river terraces, 7 – left-side river terraces, 8 – the Vistula terraces, 9 – gradients

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The next lacustrine phase is documented by the deposits which, in the trough section of the Mień valley, form the levels marked locally or small, 2–3 m high, mounds in the valley bottom. These mounds are most often built of very fine sands interlaminated with silts, silty muds and lacustrine chalks (Andrzejewski 1994). Inferring from the results of the studies on the lacustrine deposits occurring in the Mień valley, a few kilometres east of Lipno (Oszast 1957) this phase occurred in the pre-Allerød period. The youngest lacustrine phase in the bottoms of the Zgłowiączka and Mień valleys is registered in a several meter thick series of peats and gyttias. This series fills the bottom of the trough sections of the considered valleys. The third phase of the lacustrine sedimentation should be related to the Holocene which is evidenced, among others, by the date (9250±135 BP) obtained in the bottom part of the profile consisting of organic deposits filling the trough section of the Zgłowiączka valley in the vicinity of Lubraniec (Andrzejewski 1984).

The lakes occupying the trough sections of the analysed valleys were incorporated in a hydrographic system of the lower Vistula valley just at the decline of the late Vistulian which is confirmed by the results of the studies on sediments and fluvial forms in their outlet sections developed in the area of the Vistula terraces.

REACHES OF ZGŁOWIĄCZKA, MIEŃ AND TĄŻYNA IN THE AREA OF THE VISTULA VALLEY TERRACES

Three of the analysed valleys, i. e. the Zgłowiączka, Mień and Tążyna valleys, in their outlet reaches dissect terraces in the Vistula valley over significant distances. The analysis of their longitudinal profiles and their links with the dissected Vistula terraces allowed a more precise determination of the mechanism of these valleys development in relation to the changing erosion-accumulation base, the latter being the Vistula river. This analysis also allowed to define in which sequence these valleys have been incorporated in the discussed fluvial system (Fig. 4).

In the case of the Zgłowiączka and Tążyna valleys the pattern of terraces provides evidence that these valleys have been incorporated stage by stage. At the sites where the discussed valleys enter the lower and lower Vistula terraces, new steps appear. For example, in the longitudinal profile of the Tążyna valley one can distinguish three erosional terraces recording subsequent phases of the river incision.

A different pattern of terraces is observed in the Mień valley. Over the whole length of its lower section, incising in a few terraces of the Vistula valley, there is only one supraflood terrace sloping from the height of 66–67 m a. s. l. in the region of Brzeźno to 49–50 m a. s. l. at the outlet of the Mień river into the Vistula. Therefore, the stage by stage elongation of the Mień valley towards its outlet during the descent of the Vistula to the lower and lower terrace is not observed.

The reason behind these differences can be sought in the non-synchronous incorporation of the valleys into the analysed system. The Zgłowiączka river was probably the first to become the Vistula tributary. It results from the fact that in this valley there is a well developed erosional river terrace of the height of 65–70 m a. s. l. This terrace

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T a b l e 1. Classification of the valleys of the studied system (according to the degree of their fluvial transformation)

Valley type	Morphology	Geological structure	Present-day channel	Location of valleys or their sections
I. Valleys exclusively formed by erosional-accumulational river action	Developed system or river terraces. Well developed terraces of old paleochannels on the surface of supraflood terraces and floodplain	River terraces of erosional nature. Floodplains and sometimes supraflood terraces are characteized by lithofacial development typical of meandering channels	Predominating system of freely meandering river of fairly stable fluviodynamics	Outlet valley sections within the Vistula terraces
II. Valleys formed by erosional-accumulational river action on routes of meltwater outflow	The highest levels in the valley developed due to meltwater action; system of river terraces developed below	Erosional river terraces. Valleys filled with river alluvia. In the case of meandering rivers these are thick alluvia of the flood lithofacies	Depending on valley bottom width different channel patterns can occur. Sinuous channels predominate	Wda valley upstream of Kozłów; entire Skrwa valley; Bzura valley upstream Chodaków; Zgłowiączka valley between Wieniec and Nowy Młyn
III. Valleys following depressioins of glacial origin and with definite traces of fluvial transformation	Steep valley slopes; river terraces usually lacking. Valley form dependent on the pattern of glacial depressions. Kame terraces and kames often present in the valley	Kame terraces and kames usually built of fine sands, silts and lake deposits (clay, chalk). Valley bottom partially filled with organic deposits (peat, gyttia). Significant amount of river alluvia in sediments filling the bottom		Wda valley between Kozłów and Świecie; fragments of Zgłowiączka and Mień valleys within the upland
IV. Valleys following depressions of glacial origin but without traces of fluvial transformation	Steep valley slopes; river terraces lacking. Bottoms of varying widths. System of kames and kame terraces in the area of the bottom and at the interface with the upland	Kame terraces and kames built of fine sands, silts and lake deposits (clay, chalk). Bottom filled with organic deposits of varying thickness (peat, gyttia)	Channel network similar to straight or pattern	Zgłowiączka valley between Topólka and Brześć Kujawski; fragments of Mień valley between Lipno and Brzeźno

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records the beginning of the Zgłowiączka outflow to the Vistula river which was flowing at the level of terraces VIII and VII at that time. Taking under consideration the formerly presented new opinions on the age of Vistula terraces it can be expected that this moment took place already at the decline of the upper Plenivistulian.

Some time later the second river incorporated in the Vistula valley system was likely the Tążyna river which, at that time, flowed at the level of the erosional terrace of the height of 67–71 m a. s. l. corresponding also to the already mentioned Vistula terraces VIII and VII.

The Mień river has joined the analysed system as the third one. As its only terrace, the supraflood terrace, hypsometrically corresponds to the Vistula terrace III one can expect that this event took place already in the late Vistulian I the Older Dryas most probably.

DIVISION OF THE VALLEYS OF THE EXAMINED SYSTEM ACCORDING TO THE DEGREE OF THEIR FLUVIAL TRANSFORMATION

Complexities and polygeneses of the valleys of the Polish Lowland are recorded in their geomorphology and geology, which has been pointed out by many authors (Piasecki 1976; Wiśniewski 1976, 1990; Sylwestrzak 1978; Niewiarowski 1986; Koutaniemi, Rachocki 1987; Starkel 1991). Morphogenetic characteristics of the valleys of the discussed fluvial system, and then the detailed analysis of the geological structure of their bottoms indicated how complex the evolution of this system was (Andrzejewski 1994). Rivers in their numerous reaches flowed in diversified concave forms originating from the anaglacial and cataglacial phases of the last glaciation and incorporated them in the uniform valley system. Thus, the influence of the fluvial processes on the system development was differentiated. For the author these processes became the basis of the typology of the examined system valleys (Table 1). In the introduced typology the extreme positions are taken, on one hand by the valleys or valley sections whose genesis is exclusively associated with a river activity, and on the other – the depressions of various genesis in which the traces of the river activity are lacking. The depressions are filled with deposits which do not represent the fluvial environment but in which the present-day river channel has been incised.

Undoubtedly the relief of the valleys of the type I and II was conditioned by the climatic changes and the resulting hydrological consequences. In the valleys of the type III and IV the predominant role in the relief development has been played by the processes related to advances and retreats of glaciers in these areas during the last glaciation.

TENDENCIES IN FLUVIAL PROCESSES IN THE VALLEYS OF THE ANALYSED SYSTEM IN THE LATE VISTULIAN AND THE HOLOCENE

At the beginning of the late Vistulian, i. e. 13 000 BP, the majority of the Polish Lowland rivers reached at least the level of the supraflood terraces and sometimes of the floodplains (Tomczak 1982, 1987; Wiśniewski 1982, 1987, 1990; Manikowska

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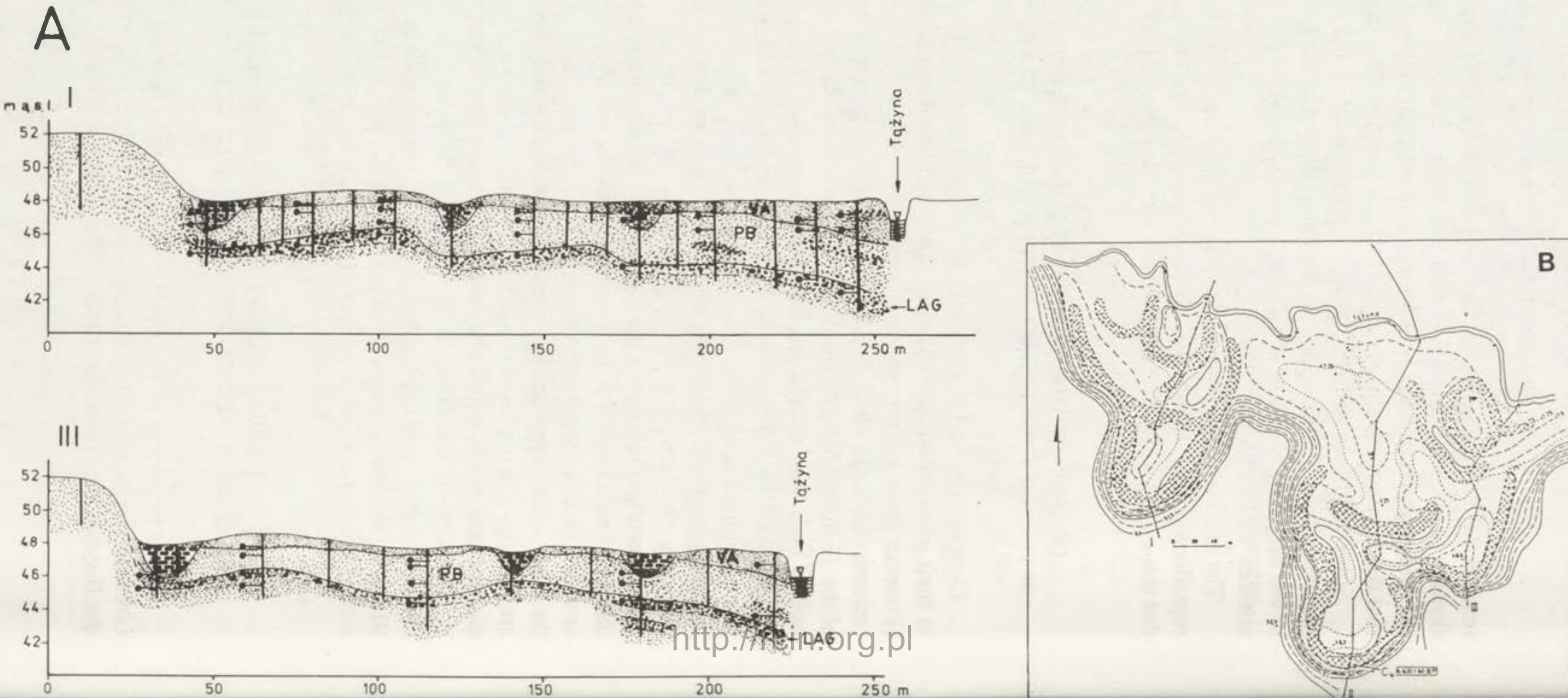

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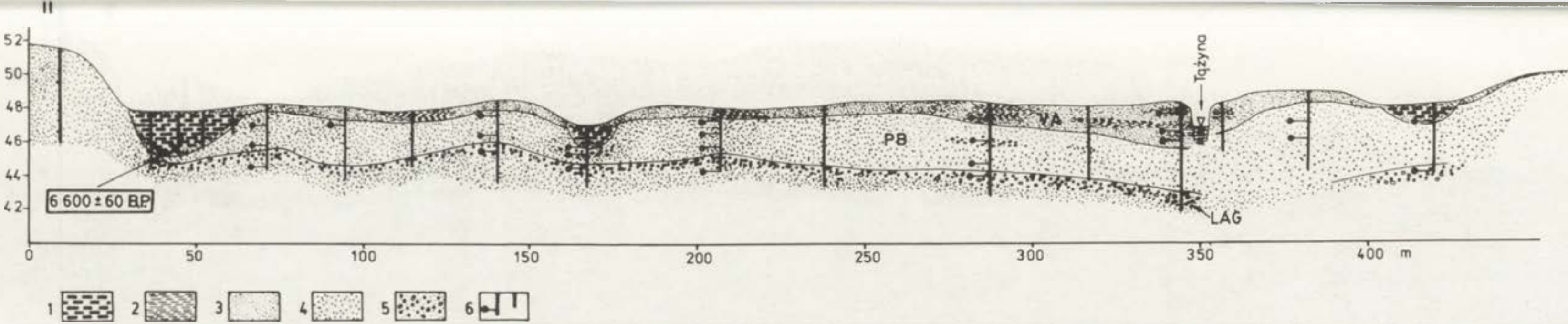

Fig. 5. (A) Geological profiles I, II, III in the bottom of the Tążyna valley

1 – peat, 2 – silts, 3 – fine sands, 4 – medium sands, 5 – coarse sands and gravels, 6 – location of drillings and sampling sites. (B) Location of geological sections (I, II, III) against the hypsometry of the Tążyna valley floor, reconstruction of the run of palaeochannels

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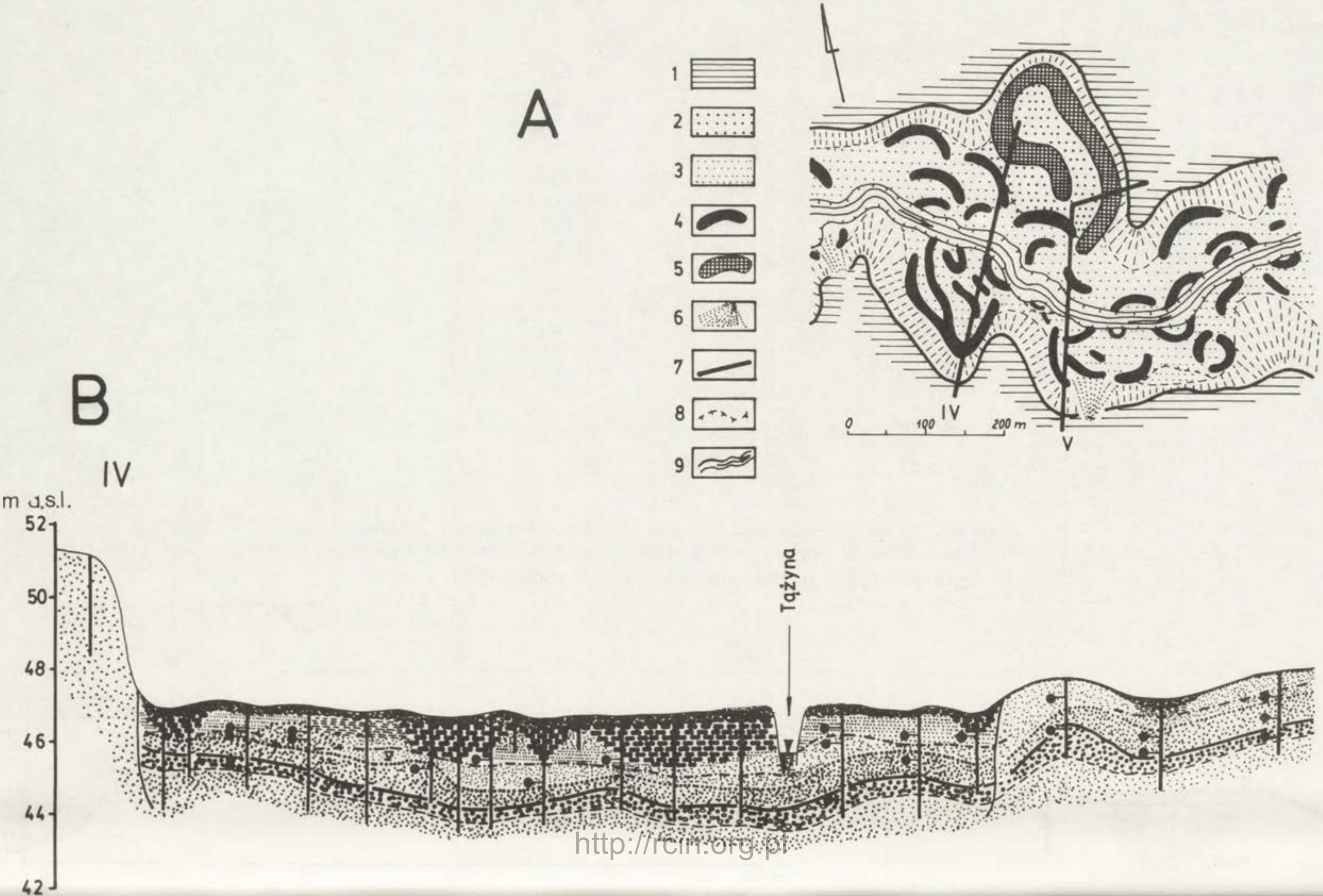

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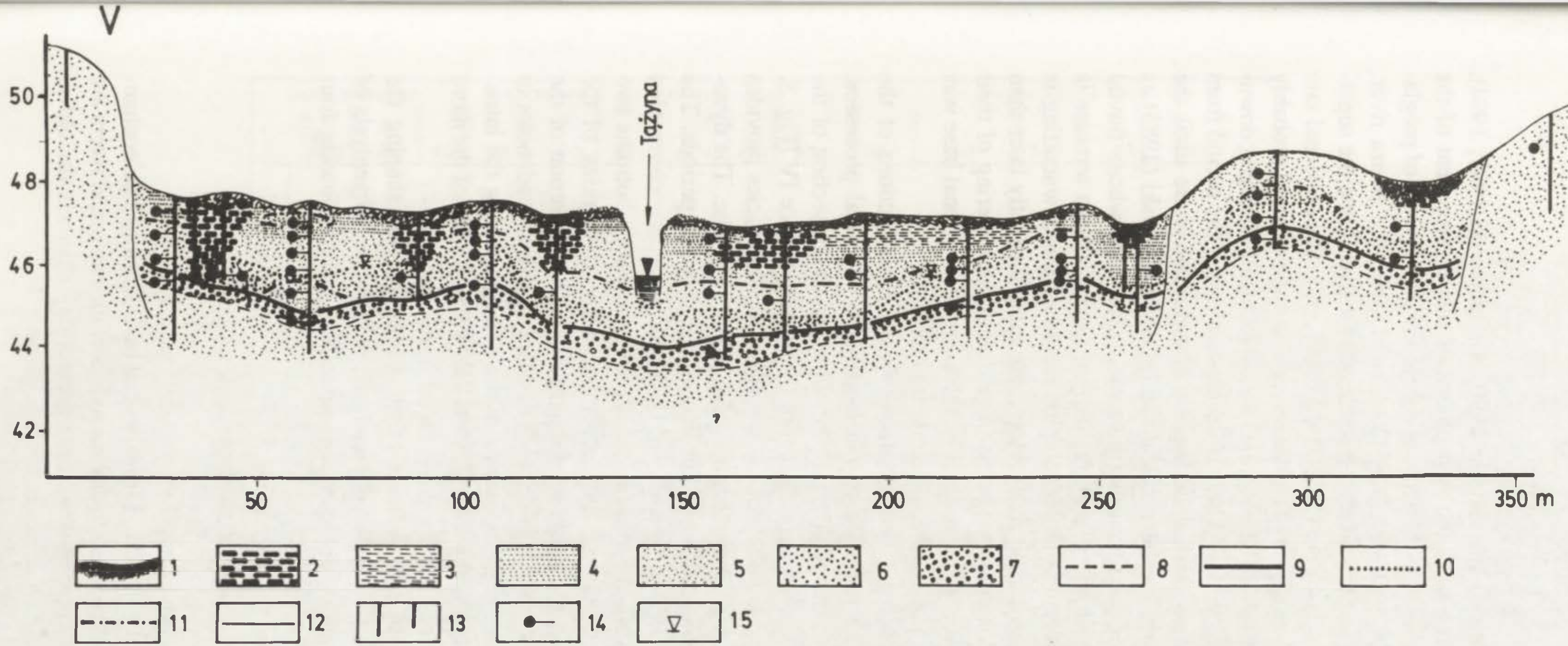

Fig. 6. A. Morphology of the Tążyna river valley with localisation of geological transects; B. cross sections

A: 1 – terrace of the Vistula, 2 – overflood terrace, 3 – floodplain, 4 – younger generation of paleomeanders, 5 – older generation of paleomeanders, 6 – alluvial fan, 7 – transect line, 8 – scarps and undercuttings, 9 – river channel. B: 1 – organic mud, 2 – peat, 3 – silt, 4 – fine sand, 5 – middle size sand, 6 – coarse sand, 7 – gravel, 8–12 – bases of litofacies (LAG, PB-B, PB-M, VA), 13 – borings, 14 – sites with samples, 15 – groundwater level

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1985; Florek E. *et al.* 1987; Starkel, Wiśniewski 1990; Andrzejewski 1991, 1994). The dynamics of erosional processes in the first phases of the development of the discussed valley system is best visible in the valleys developed on the roots of proglacial waters outflow. The Skrwa river which as the second, after the Bzura river, merged into the Vistula outflow formed all its terrace levels located above the supraflood terrace in a very short period of time (17 200–14 500 years). The erosional rate of this period is estimated at 14.8 mm/year. The Wda river was characterised probably by a faster incision rate. It was linked to the Vistula river dynamically incising downstream of the gap at Fordon at this period. The Vistula erosion rate in the period from the outflow of proglacial water southward during the Pomeranian phase until the formation of the supraflood terrace has been calculated by E. Drozdowski (1983) as 18 mm/year. The erosion rate of the remaining discussed tributaries whose fluvial activity has been recorded in their outlet sections incised in the Vistula terraces is similar to the above one. However, the morphological record of the downcutting is different here because these rivers started to develop their valleys slightly later than the Skrwa and Wda rivers by elongation stage by stage due to the lowering of their erosional base i. e. the Vistula river. Thus, the role of the lowering erosional base was the dominant factor in the development of the Vistula tributaries.

The boarders between the distinguished lithofacies in the cross-sections of the valley bottoms became the major indicator of the tendencies in fluvial processes. A good example of the above are the geological profiles of the outlet section of the bottom of the Tążyna valley. This section is incised in the Vistula terrace IV (Fig. 5, 6). The slight although permanent lowering of the top of the log lithofacies provides evidence of incision of the examined river channels also in the Holocene. The dynamics of this process, however, was much smaller than in the previous periods. The river downcutting, especially in the youngest part of the Holocene, was accompanied by accretion of alluvia of the overbank lithofacies. Thus, in the valley bottoms two opposite tendencies are observed, namely the deeper and deeper reworking of the channel alluvia, especially during the bankfull discharges, and the accretion of the floodplains with flood lithofacies. Thus it is difficult to determine river tendencies in this period. It can be only assumed that the heights of the channels during the intensified floods were nto changing during the recent 2500–3000 years despite of the more and more intensive influence of the anthropogenic factor in this period.

Paleochannels are the morphological effects of the fluvial process shaping the floodplains and some supraflood terraces of the analysed valleys. In the analysis of selected parameters of the hydraulic geometry the variability of the following four elements has been considered (Fig. 7):

- channel width at the bankful discharge (W_{bkf})
- channel depths at the bankful discharge (d_{bkf})
- width/depth ratio (w/d)
- radius of curvature of meanders (R_m).

The given values are the average obtained from several best developed paleochannels. The corresponding values of the present-day meanders of the examined rivers are given for the comparison. When compared with the present-day channels the oldest

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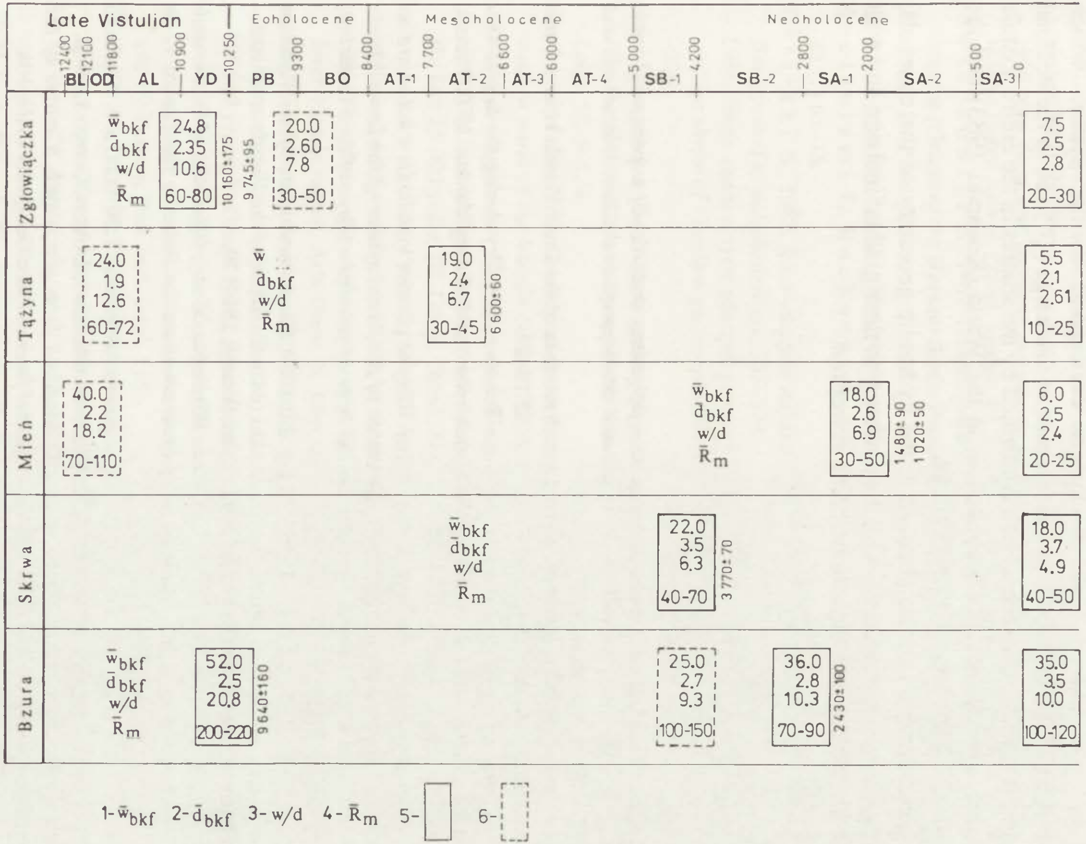

Fig. 7. Changes of selected elements of hydraulic geometry of studied paleochannels

1 – width of channel at bankfull stage, 2 – depth at bankfull stage, 3 – *w/d* relation, 4 – meander radius, 5 – age of paleochannel fill, 6 – probable age (based on geomorphic situation)

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paleochannels of the late Vistulian are several times wider and only slightly shallower which is also reflected by the decrease in the parameter of the channel shape. There is also observed an increase in the river sinuosity which corresponds to the gradual decrease in the radius of paleomeanders.

The analysis of changes of the selected parameters of hydraulic geometry of the paleochannels in the analysed Vistula tributaries in the period the late Vistulian – the Holocene has indicated that these changes correspond to the system which S. A. Schumm (1977) relates both to the decrease in discharge (Q^-) and in the bedload transportation (Q_s^-). The above has been confirmed by the studies in the entire Vistula valley (Starkel 1983, 1988, 1991) as well as in the Warta (Kozarski 1983) and the Prosna (Rotnicki, Młynarczyk 1989) valleys.

The general direction of the changes in the hydraulic geometry of the channels, presented above, was synchronous with the tendency to their gradual incision and with the increase in thickness of the alluvia being reworked.

REFERENCES

Andrzejewski L., 1984, *Dolina Zgłowiączki – jej geneza oraz rozwój w późnym glacjale i holocenie (The Zgłowiączka valley – its origin and development in the Late Glacial age and Holocene)*, Dokum. Geogr. 3.

– 1986, *Geomorphological evolution of selected mouth sections of the lower Vistula river tributaries in the Late Glacial and Holocene*, Geogr. Pol. 52 19–29.

– 1991, *The course of fluvial processes in the lower Brzura river valley during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, IV*, Geogr. Stud., Spec. Issue 6, 147–154.

– 1994, *Ewolucja systemu fluwialnego doliny dolnej Wisły w późnym vistulianie i holocenie na podstawie wybranych dolin jej dopływów (Evolution of the fluvial system of the lower Vistula valley in the Late Vistulian and Holocene on the base of selected valleys of its tributaries)*, Rozprawy UMK, Toruń, 1–113.

Baraniecka M. D., Konecka-Betley K., 1987, *Fluvial sediments of the Vistulian and Holocene in the Warsaw Basin*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 151–170.

Churska Z., 1961, *The so-called Porto Cassubica (Kashubian Gate), beginning of the outwash of the Pomeranian Stage*, [in:] *Guide-Book of excursion from the Baltic to the Tatras, VI th INQUA Congress Poland*, 70–72.

Drozdowski E., 1967, *Objaśnienia do mapy geomorfologicznej 1:50 000, ark. Chełmno (Explanation to geomorphological map, 1:50 000, sheet Chełmno)*, Dokum. Geogr. 1, 1–48.

– 1974, *Geneza Basenu Grudziądzkiego w świetle osadów i form glacjalnych (Genesis of the Grudziądz Basin in the light of its deposits and glacial forms)*, Prace Geogr. IG PAN, 104.

– 1982, *The evolution of the Lower Vistula river valley between the Chełmno Basin and the Grudziądz Basin*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 131–147.

– 1983, *Zur Chronologie der jungeren Erosion und Sedimentation im uneren Weichseltal*, Petermanns Geogr. Mitt. 282, 155–162.

Florek E., Florek W., Mycielska-Dowgiałło E., 1987, *Morphogenesis of the Vistula valley between Kępa Polska and Płock in the Late Glacial and Holocene*, [in:] L. Starkel

http://rcin.org.pl

(ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 189–205.

Galon R., 1934, *Dolina dolnej Wisły, jej kształt i rozwój na tle budowy dolnego Powiśla (Die Gestalt und Entwicklung des unteren Weichseltales in Beziehung zum geologischen Aufbau des unteren Weichselgebietes)*, Bad. Geogr. Pol. Półn.-Zach. 12–13.

– 1953, *Morfologia doliny i sandru Brdy (The morphology of the Brda valley and outwash sand plain)*, Studia Soc. Sci. Toruń, Ser. C 1, 6.

– 1961, *Morphology of the Noteć–Warta (or Toruń–Eberswalde) ice marginal streamway*, Prace Geogr. IG PAN 29.

– 1968 *New facts and problems pertaining to the origin of the Noteć–Warta Pradolina and the valleys linked with it*, Przegl. Geogr. 40, 2, 307–315.

Jewtuchowicz S., 1967, *Geneza pradoliny Warszawsko-Berlińskiej między Nerem a Moszczenicą (Origin of the Warsaw-Berlin Pradolina between the river Ner and Moszczenica)*, Prace Geogr. IG PAN 62.

Kotarbiński J., 1972, *Morfologia sandru i doliny Skrwy*, Maszynopis, arch. IG UMK Toruń.

Koutaniemi L., Rachocki A., 1987, *Origin of Pradolinas*, Z. Gletscherk. Glazialgeol. 23 (1) 65–76.

Kozarski S., 1983, *River channel adjustment to climate change in west central Poland*, [in:] *Background to paleohydrology*, 355–374.

– 1986, *Skale czasu a rytm zdarzeń geomorfologicznych vistulianu na Niżu Polskim (Timescales and the rhytm of Vistulian geomorphic events in the Polish Lowland)*, Czas. Geogr. 57, 2, 248–270.

Manikowska B., 1985, *O glebach kopalnych, stratygrafii i litologii wydm Polski Środkowej (On the fossil soils, stratigraphy and lithology of the dunes in central Poland)*, Acta Geogr. Lodz. 52, 9–124.

Mojski J. E., 1982, *Geological section across the Holocene sediments in the northern and eastern parts of the Vistula Deltaic Plain*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 149–169.

– 1990, *The Vistula River Delta*, [in:] L. Starkel, (ed.), *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Strud., Spec. Issue 5, 126–141.

Niewiarowski W., 1968, *Morfologia i rozwój pradoliny i doliny dolnej Drwęcy (Morphology and evolution of the pradolina and valley of the river Drwęca)*, Studia Soc. Sci. Torun, Ser. C 6, 6.

– 1986, *The phases of transformation of subglacial channels into river valleys: a case study of the lover Vistula region*, Acta Uniw. N. Cop. 21, 67, 61–72.

– 1987, *Evolution of the lower Vistula valley in the Unisław Basin and at the river gap to the north of Bydgoszcz-Fordon*, [in:] L. Starkel (ed.) *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 233–252.

Oszast J., 1957, *Historia klimatu i flory Ziemi Dobrzyńskiej w późnym glacjale i holocenie (History of the climate and flora of the Dobrzyń Region, Northern Poland, in the Late Glaciation and Holocene)*, Biul. Inst. Geol. 118.

Piasecki D., 1976, *Doliny złożone rzek Zachodniego Przymorza (Composite valleys of rivers of the western Baltic littoral)*, Czas. Geogr. 47, 1.

Rotnicki K., Młynarczyk Z., 1989, *Późnovistuliańskie i holoceńskie formy i osady korytowe w dolinie środkowej Prosny i ich paleohydrologiczna interpretacja (Late Vistulian and Holocene channel forms and deposits of the middle Prosna river and their paleohydrological interpretation)*, Ser. Geogr. 43, UAM, Poznań, 1–76.

Schumm S. A., 1977, *The fluvial system*, Wiley and Sons, New York, London, Sydney, Toronto.

Starkel L., 1983, *The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15 000 years*, [in:] *Background to palaeohydrology*, 213–234.

– 1988, *Historia dolin rzecznych w holocenie*, [in:] *Przemiany środowiska geograficznego Polski*, Wszechnica PAN, Ossolineum, 87–107.

http://rcin.org.pl

– 1991, *Long-distence correlation of fluvial events in the temperate zone*, [in:] *Temperate paleohydrology*, Wiley, 473–491.

S t a r k e l L., W i ś n i e w s k i E., 1990, *The evolution of the Vistula Valley*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue, 5, 141–146.

S y l w e s t r z a k J., 1978, *Zagadnienia morfologii i typizacji dolin północnego skłonu Pomorza (Chosen problems of the morphology and classification of the types of valleys on the northern slope of Pomerania)*, Biul. PIG 306.

S z u p r y c z y ń s k i J., 1988, *Morphology and ice melting in a Pomeranian outwash plain, Wda valley*, Geogr. Pol. 55, 173–179.

T o m c z a k A., 1982, *The evolution of the Vistula river valley between Toruń and Solec Kujawski during the Late Glacial and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 108–129.

– 1987, *Evolution of the Vistula valley in the Toruń Basin in the Late Glacial and Holocene*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 yeras, II*, Geogr. Stud., Spec. Issue 4, 207–231.

W i ś n i e w s k i E., 1976, *Rozwój geomorfologiczny doliny Wisły pomiędzy Kotliną Płocką a Kotliną Toruńską (Geomorphological development of the Vistula valley between the Płock Basin and Toruń Basin)*, Prace Geogr. IGiPZ PAN 119.

– 1982, *The geomorphological evolution of the Vistula river valley between Włocławek and Ciechocinek during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, I*, Geogr. Stud., Spec. Issue 1, 93–107.

– 1987, *Evolution of the Vistula valley between Warsaw and Płock Basin during the last 15 000 years*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, II*, Geogr. Stud., Spec. Issue 4, 171–187.

– 1990, *The lower Vistula valley*, [in:] L. Starkel (ed.), *Evolution of the Vistula river valley during the last 15 000 years, III*, Geogr. Stud., Spec. Issue 5, 146–153.

W i ś n i e w s k i E., A n d r z e j e w s k i L., 1994, *The problem of the Warsaw ice-dammed lake drainage through the Warsaw-Berlin Pradolina at the last ice-sheet maximum*, Z. Geomorph. N. F. 141–149.

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