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

PART VI

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НА ПРОТЯЖЕНИИ ПОСЛЕДНИХ 15 000 ЛЕТ

VI

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

PART VI

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1. INTRODUCTION

1. 1. METHODS AND TECHNIQUES IN PALEOHYDROLOGY
Leszek Starkel

In the studies on the evolution of fluvial systems the focus is mainly on the reconstruction of one element of the water budget – the runoff. The components of the water budgets may be reconstructed on the basis of various geological records (sediments, forms, fossil flora and fauna) or by using various models (cf. Starkel 1995b). All the reconstructions are based on the uniformitarian principle. Sediments as well as plants and other remains reflect the relations which exist between them at present. These relations are believed to be immutable in time. The second assumption is that a reconstructed fluvial system or a plant association remain in a full equilibrium with the heat and water balances at that time. The above results in fundamental errors in the undertaken reconstructions. It is well known that in the periods of accelerated changes, like those at the beginning of the Holocene (Starkel 1991a), or at the Atlantic-Subboreal transition, many components of the geosystems were not in the equilibrium with the climatic system, their transformation was delayed and in the circulation systems participated the elements inherited from the past e.g. soils, plant communities or river channels.

Knowing the requirements of a single plant species and of associations one may reconstruct with a high probability the rainfall and evaporation patterns using various statistical correlations (Webb, Bryson 1972; Grichuk *et al.* 1984; Klimanov 1990). The runoff may also be reconstructed indirectly (Georgiadi 1992). Unfortunately, in these models the water budget in the ecotonal zones is inadequately reconstructed and water supply from the active layer of permafrost is not taken into consideration. Therefore, precipitation totals are overestimated for the permafrost zone (cf. Frenzel *et al.* 1992). In the semiarid areas the dendrochronological method supports the reconstruction of a multi-annual variation in precipitation (Stockton *et al.* 1985). The long-term course of rainfall and water storage may be reconstructed very well from the records of water level fluctuations in closed basins or from the sediments, facies,

coastal forms, diagrams of diatoms or Cladocera (Digerfeldt 1986; Street-Perrot, Harrison 1985). When try to correlate events in large regions, the counting of the percentage of the lakes differing as to the tendencies in water level fluctuations in various time slices, may lead to erroneous conclusions. The above may be due to a low representativeness of the investigated lakes as well as due to the rapid climatic changes in the selected time slices (e.g. 12 or 9 ka BP). The recurrence layers in the peat sections are also good indicators of lowering of the ground water table, and, indirectly, of decline in precipitation and rise in evaporation (Casparie 1972; Aaby 1976; Ralska--Jasiewiczowa, Starkel 1988). However, all the reconstructions should be made very carefully because many registered changes could be of a local character.

The retrodiction of the runoff, especially of the bankfull discharge and of the mean annual discharge is based on various parameters of the river channel and sediments. Many equations used for the reconstructions lead to large errors (cf. Gregory, Maizels 1991). When reconstructing the discharge, the errors involved in the evaluation of particular parameters add up and the resultant error may exceed over 100% (Soja 1994a, see chapter 2.2 in this volume). Dozens of the developed equations of discharge in meandering channels are based on different assumptions (Dury 1977; Rotnicki 1991). The presence of a single channel (without bifurcation) and the acceptance of the first armoured horizon as the limit of reworking of channel deposits by a river as well as the top of the channel facies and the bottom of the paleochannel are vague assumptions in these recostructions. In fact, the channel after the cut-offs or avulsions might have been filled up with coarse material during several subsequent floods. The reconstructed discharge is related to the moment of avulsion dated by fine deposits with organic material (Rotnicki 1991). Again, it is not always correct because the developed paleomeander systems were formed during former, long and relatively stable periods (Starkel 1994).

In the reconstructions of discharges of braided channels the errors can reach several hundred percent (Maizels 1983). The grain size analyses may also provide very controversial information on river discharges (Church 1988). The cataclysmic or extreme discharges reconstructed on the base of the slack-water deposits (Baker 1987) give comparable results for stable channels cut in the bedrock. In the series of such flood the events which are larger than the previous ones are mainly recorded. The elevation of the bedrock in the channels is also flexible (Soja 1977; Froehlich, Starkel 1987).

In the forested catchments the buried tree trunks ("black oaks") are good indicators of frequencies of floods throughout centuries. In the valleys of Central Europe the tree trunks are mainly clustered in particular centuries (Becker 1982; Krąpiec 1992b).

The extreme rainfall events are reflected in various landslides. Deep landslides are mainly induced by continuous falls of rain and rainy seasons and, on the contrary, the debris flows or mudflows by heavy downpours (Starkel 1976, 1985; Kotarba 1989).

In the high mountains the fluctuations of glacier margins reflect the changes in thermal and precipitation regimes. However, individual glaciers react to these changes at a various rate and with a various delay (Patzelt 1985). The isotopic dating of the groundwater reservoirs supports to distinguish a relict character of several basins (mainly in the arid zone) and more humid phases (cf. Geyh 1972).

The reconstruction of the whole budget is usually based on the models that are correlated with geological records. The most comprehensive picture may be presented for the closed lake basins (Kutzbach 1980; Swain *et al.* 1983). Much more doubtful reconstructions are obtained if they are only based on the vegetation (Georgiadi 1992) or on the river paleodischarges (Rotnicki 1991).

Acceleration of the water cycle by human activity should also be considered. When examining the last millennia, the highest flood frequency has been stated in the case of the overlapping humid phases and increased deforestation (especially since the Roman period – Starkel 1983; Needham, Macklin eds. 1992).

A precise dating of events is of particular importance in all the paleohydrological reconstructions. The radiocarbon method is not sufficiently accurate in the case of ^{14}C plateaus or rapid climatic changes and, therefore, it is not adequate for correlation of the phases over large territories (e.g. the episodes about 10 ka, 8 ka or 5 ka BP).

A general conclusion may be drawn from this short review. The errors involved in various methods are related to metachronous transformation of various systems, precision of records acquisitions or to spatial differentiation of events. Therefore, a fundamental demand is to correlate the results obtained from the analyses of genetically different deposits, forms and organic remains. First of all, continuous and discontinuous paleohydrological records should be compared. The continuous records are undisturbed and preserved in stable systems such as laminated lake deposits. Calcareous precipitation in caves, tree rings and ice cores reflect long-term trends in the water budget. The extreme events, i. e. floods or droughts, are registered in flood deposits or a recurrence horizons in peatbogs in other environments.

When studying paleohydrology of the fluvial systems the obtained results should be correlated with other records from lakes, bogs, glaciers etc. Such approach helps one to differentiate long-term tendencies from single extreme events, local changes from regional ones and to find the rhythmicity in synchronous and diachronous, climatic and hydrologic changes in distant locations.

1. 2. CRITICAL REVIEW OF METHODS
FOR PALEODISCHARGE RECONSTRUCTIONS

Roman Soja

Paleohydrology, a branch of the paleogeographic sciences, uses the results of various disciplines as well as measuring techniques to support the conclusions also of a qualitative character. The parameterization of processes and mechanisms of water cycle in the past is very complicated or even impossible. The crux of the matter is indicated by problems encountered when identifying parameters of mathematical models of the present-day processes which, in fact, may be measured directly. The use of records from the past, reflected in the environment, is one of basic difficulties in reaching the final conclusions. In most cases the direct records do not exist. The flowing water leaves behind sediments and forms. The older the forms and deposits are or the greater the intensity of their reworking, the less possible the location of

events in time and their quantitative characteristics is. The plant or mollusc remains may indicate the environment of standing or flowing water, but do not provide information to evaluate a river discharge. The silty overbank deposits have been formed during floods but again the discharge is unknown. Those deposits found far from the river channel, even on the higher terraces, may help to reconstruct the extent of floods, but the channel parameters from that time have not preserved.

Meanwhile, a very ambitious aim of paleohydrology is to provide quantitative reconstructions as well. Therefore, there is a tendency to look for extreme events, which have left sediments and forms, helping to obtain parameters which may be introduced to equations.

Especially floods exceeding in magnitude those which have occurred hitherto, may leave clear records but at the same time they may cancel former records. Unfortunately, hydrologic events in their majority do not leave any traces which could be supportive in the present-day reconstruction. There are not and cannot be any accounts of characteristic flow parameters (averages) which are usually used in all descriptions of a fluvial regime. Therefore, we have to search for relationships between several preserved records and very distant hydrological parameters using indirect interrelations. In this way the errors are growing and multiplying.

In spite of various methodical and technical difficulties various approaches to paleodischarge reconstructions were undertaken in Poland, Great Britain and the USA. K. Rotnicki and his team in Poznań (1983, 1991) retrodict (a new term) the bankfull and mean annual discharges of the meandering Prosna river and try on this background to make unique reconstructions of the water budget during the Holocene. J. K. Maizels and her collaborators in Aberdeen (1983, 1991) concentrate their efforts on braided rivers in high latitudes, reconstructing discharges during historical times and in the Lateglacial. The V. R. Baker's team (1991) from Tucson carries extensive studies in various zones in stable channel cross-section cut in the bedrock, using the slackwater deposits as an indicator of the highest water level (Ely, Baker 1985).

Empiric formulae

The first paleodischarges were reconstructed on the basis of relations between channel parameters and discharge. The following parameters were introduced: channel width, width of meander belt, radius of meander curvature, length of meander wave etc., and mathematical formulae were drawn for rivers with well established hydrological parameters. Therefore, these formulae are of regional character and valid either for a given catchment or type of hydrological regime. The examples of adaptation of the formulae intrudiced by S. A. Schumm (1977), G. H. Dury (1964, 1985) and others are relatively rare. K. Klimek and L. Starkel (Starkel *et al.* 1982) tried to reconstruct the paleodischarges of the Wisłoka river, S. Kozarski *et al.* (1988) of the Warta river and W. Florek (1978) of the Bóbr river.

The comparative table of results based on various formulae was presented for the Prosna river valley by K. Rotnicki (1983, 1991). The obtained results are not encouraging. One of the causes of a failure in application of the formulae, besides their regional character, is a terminological inaccuracy. G. Williams (1988) discusses this

problem using the term "full-channel discharge", as example, which is not an exact equivalent of the terms "channel forming discharge" or "bankfull discharge".

The scarcity of comparative approaches and testing of fomulae is connected with the fact that most of the formulae were created long time ago, when the goals of paleohydrology were mainly restricted to the qualitative reconstructions. Possibilities of reconstructions of paleodischarges on the way of formulating empirical relationships were not sufficiently explored. This may be evidenced by successful attempts in searching relations between parameters of a channel cross-section and discharge by G. Wharton *et al.* (1989). Thus, a modern resolution of the discussed problem is to be expected in a short time.

The engineering formulae based on the relation: discharge = regional coefficient multiplied by the catchment area are oversimplified and useless in paleohydrology. Much more interesting results may be obtained using formulae in which the discharges (mean annual, maximal or of different probabilities) are based on relations between catchment size, annual rainfall totals, gradient, water infiltration rate, vegetation etc. But in all cases is needed a correct identification of all the parameters. In case of the Southern Poland the formula of J. Punzet (1978) elaborated for catchments below 500 km^2 should be tested. In this formula it is easy to determine coefficients describing a role of soils, slope gradients and the only problem is mean annual precipitation. If precipitation totals are determined from dendroclimatic data or by maens of other techniques, there will be no problems with obtaining reliable results. In such circumstances the variable parameters of paleochannels or sediments will be no more needed as driving factors in paleodischarge calculations.

Braided channels

The calculation of water discharge for a braided channel is especially difficult during the high water level even by use of modern techniques. The weakest point of the procedure is determination of the water level and a cross-section area. The principal feature of the braided river is the change of the channel during successive flood phases. The shape of the channel after the flood (used in the calculations of the discharge) may be different from the cross-section during the flood (cf. the Białka river in Podhale – Baumgart-Kotarba 1983). The overloading of the river causes the channel bottom in a rising phase of the flood to differ from that in a falling phase when deposition takes place. The water level and velocity have even greater variability depending on local and momentary conditions. Therefore, all reconstructions for braided rivers must consider these circumstances and do not pretend to great exactness. According to J. Maizels and J. Aitken's (1991) the error of estimation of the cross-section area is from +50% to –50%, but the error of the finally reconstructed discharge may vary from –50% to +350%. It is not meaningless whether the maximum discharge of any river, e. g. the Vistula in Cracow, is 2200 m^3/s or three times larger, reaching 7000 m^3/s. The latter value is known for the Vistula downstream of the mouth of the San river, where the Vistula catchment area is seven times larger than in Cracow. Errors of such magnitude should prevent the results from being used in farther considerations because they exceed a potential variability of river discharges in several climatic zones!

Meandering channels

The meandering channels are more stable then the braided ones, but the finding of numerical relations between channel parameters and river discharge is not a simple task as well. K. Rotnicki (1983, 1991) proposes to use the Chezy-Manning equation to calculate the bankfull discharges in the paleomeanders. The cross-section area and gradient are taken from the field measurements and the roughness coefficient is evaluated after the Cowan's method (1956). The age of paleochannel is dated on the base of bottom sediments filling up the abandoned form. The author calculates the bankfull discharge with the error 7–20%, then calculates mean annual discharge and reconstructs the water budget and its changes during the Holocene (Rotnicki 1991).

The Chezy-Manning formula may be used, if reliable input data are available. Techniques of collecting records of a strictly defined accuracy have been described and should be followed during data acquisition (Pasławski 1973). If the above pre-requisites are not satisfied, the obtained results will not be reliable.

As it was the case for the braided rivers, the first out of the fundamental difficulties is connected with calculations of an area of an active channel cross-section. The river discharge over the total length of a single meander does not vary in a measurable range and can be assumed constant. However, the cross-section area varies to ±50% so the other parameters have to change in a similar range. Visible indicators of changes in flow velocity, roughness coefficient and channel gradient over very short distances are deep kettles, slack water currents or shallows in the river channel. In sections of the greatest area backwater currents are observed or only a part of the cross-section is active during low and medium water levels. When taking a direct measurement in a river we select the best section, eliminating sections with slackwater or with sudden changes in the depth. Such a possibility does not apply to the paleo-meanders. The estimation of a channel cross-section is based upon the position of the pointbar which has been formed in the meander arc by the backward current. The channel gradient is estimated for 500 meter long segments of the valley floor and the proposed method does not satisfy the accuracy criterion. The gradients of meandering rivers are 0.0001–0.00001 and one is unable to read the gradient for sectors shorter than 2–3 km long from the topographic map. The method of L. W. Cowan (1956) may not be used to determine the roughness coefficient in the channels with deep rework-ing of the bedload. Also the methods of estimation the mean annual discharge from the bankfull one are doubtful. K. Rotnicki (1991) assumes this relation as 5:1, which is valid for the Prosna river, but it is different in other hydrological regimes.

Bedrock channels (canyons, gaps)

V. Baker (1991) suggests another approach to discharge reconstructions. He con-siders calculations of paleodischarges in the channels cut in the bedrock, whose cross-sections do not change over centuries and/or millennia, to be methodologically correct and sound. Provided a constant in time cross-section in rocky channels, ca-nyons and gorges, sediments and depositional structures formed by backwater cur-rents, by damming or slackwater deposits are used for reconstructions of flow velocity and water level during a flood. Decreasing gradient and flow velocity results in back-

water effects. Under natural conditions the above occurs during damming of the recipient water body, during icejams or in narrowed reaches of the channels during extremely high flows. In such circumstances very fine laminated sediments are deposited and hang above the valley floor. Such flood deposits, in order to be preserved, need to occur in niches, rock benches or caves. To determine the water level V. Baker introduces the term "paleostage indicators", usually meaning the top of sediments left behind by the running water. Most of Baker's group studies were carried out in the arid and semiarid zones, where such deposits are quite well preserved. In last years the traces of such cataclysmic floods have been discovered in Altai Mountains and the calculated discharges exceed 20 million m^3/s (Rudoy, Baker 1993).

It is known from praxis, however, that the traces the water level are uncertain. The level of sediments deposited by the running water is only loosely related to the water level, yet is always lower. One can not determine whether the thickness of the water layer above the top of sediments was 100 or 200 cm. Therefore, calculation of the active cross-sectional area is impossible. The gradient necessary for velocity calculation is determined from the differences in the sediment heights. Unfortunately, one cannot comment upon the above parameters as well as calculation techniques because the authors refer the reader to acronyms of computer programs used by HS Hydrological Survey (R. H. Webb et al. 1988).

The methodology of reconstruction of paleodischarges with help of slackwater deposits is continuously improving (Ely, Baker 1985; Enzel et al. 1993). But still the question of the cross-sectional area, even in the rocky channels, remains ambiguous. The channel cut in the bedrock may periodically be filled, in part, with debris. Depending on the river power and bedload the debris may be supplied or removed in various channel reaches during consecutive floods or in dry and wet periods.

Final comments

The main difficulty in all reviewed methods is the parameterization of the input data for the proposed formulae. In the light of recommendations for measurements, most of the parameters introduced to the equations do not fulfil basic criteria of hydrological calculations. The error limits acceptable in the palaeohydrological reconstructions are matter of discussion. The present-day measurements are the references. Mean errors of discharges of given probabilities reach 20–30%, and these values are acceptable. It should be remembered, however, that after passing some boundary values the error is so high that all hydrological calculations are useless.

The reconstruction of paleodischarges is one of more complicated paleogeographical problems. The described procedures are simplified. The new formulae do not find many followers besides their authors and collaborators. The progress is possible by implementing new measuring techniques and enlarging the number of contributing researchers. Most of suggested methods are rather expensive, require specific equipment and absolute datings. The scarcity of critical reviews and discussions of paleodischarges in the journal causes a lot of concern. In Poland the last meeting devoted to these problems took place in 1988 in Poznań and in 1994 the author published a critical note (Soja 1994a). In the current project, calculations of the channel cross-

section and paleodischarge on the basis of detail surveying of the Vistula paleomeander at Zabierzów Bocheński have been attempted (Kalicki *et al.* in this volume). The results of reconstructions are subject to extensive limitations in interpretation which are discussed in the consecutive chapters.

1. 3. HISTORY OF RESEARCH IN THE UPPER VISTULA BASIN
Leszek Starkel

The review of studies in the whole Vistula valley till 1988 was presented in the 3-rd volume of *Evolution of the Vistula valley during last 15 000 years* (Starkel ed. 1990). Therefore, I shall remind main stages in the evolution of opinions on the history of the upper Vistula course.

During the first geological surveying for the *Geological Atlas of Galicia*, M. Łomnicki (1895–1903) and W. Friedberg (1903) discovered that not only the lowest floodplain but also the 4–8 m high one (above the mean water level) is built of the Holocene alluvia with subfossil trunks. Later, the finding of the Dryas florae and Lateglacial lacustrine deposits in several profiles caused M. Klimaszewski (1948) to believe that the whole valley floors were filled with the Vistulian sediments with the Holocene loams on the top. Later the Holocene age has been proven again by findings of A. Środoń (1952) and in the middle course of the Vistula by W. Pożaryski (1955).

In 1960 at least 3 parallel fills were documented (Starkel 1960), connected with humid phase accepted at that time (Allerød, Atlantic, Subatlantic). The cooperation with palynologists as well as the radiocarbon datings helped to distinguish several phases of increased flood activity: during the Younger Dryas, at the Boreal–Atlantic transition, in the early Subboreal and during Subatlantic (Ralska-Jasiewiczowa, Starkel 1975; Starkel 1977). The wet phase ca 8.4–7.8 BP (Niedziałkowska *et al.* 1977; Mamakowa, Starkel 1977) marks off especially well. Climatically controlled change in channel parameters (Falkowski 1975; Szumański 1983) and antropogenically controlled aggradation and tendency to braiding in the last millennium (Klimek, Starkel 1974; Szumański 1977) have been stated.

Studies in the Wisłoka valley (Starkel in: Alexandrowicz *et al.* 1981) provided records for the theory on altering phases of different flood frequency (Starkel 1983). The wet phases are characterised by widening and straightening of channels with avulsions, indicating new alluvial fills. The tendency either to erosion or to aggradation depends on sediment load and deforestation. Therefore, rising of the channel floors is observed during the Younger Dryas and the last two millennia. In general these hydrological variations coincide in time with the fluctuations of alpine glaciers (Starkel 1983, 1985).

The studies in the upper Vistula valley, carried out under the framework of the IGBP-158 A project, have shown an agreement with the presented concept (Niedziałkowska *et al.* 1985; Rutkowski 1987; Kalicki, Starkel 1987; Gębica, Starkel 1987; Sokołowski 1987). Simultaneously a reflection of humid phases was found in the left tributaries (Rutkowski 1991; Alexandrowicz *et al.* 1988) with dominance of aggradation in the loess region (Śnieszko 1985).

The most intensive studies were carried out in the Cracow reach, where parallel to the radiocarbon dating the dendrochronological method was introduced in 1987. It facilitated more precise identification of individual floods and their clusterings (Kalicki 1991c; Krąpiec 1992a, b; Kalicki, Krąpiec 1991a, b and others). Also the timing of channel avulsions was determined (Kalicki 1991b; Starkel *et al.* 1991a). It seems to be clear now that practically all advances of the Alpine glaciers during the Holocene have their equivalents in the fluvial history and other phenomena (Starkel ed. 1990; Kalicki 1991c).

These encouraging results stimulated us to continue studies in the present project No. 6-0783-91-01 sponsored by the State Committee of Scientific Research (1991–1994).

1. 4. AIM, SCOPE AND METHODS OF INVESTIGATION

Leszek Starkel

The study area presented in this volume covers a part of the Vistula basin, especially the Sandomierz Basin, which forms a part of the Carpathian foredeep. In the wide valley floors were developed and preserved several generations of alluvial fills and paleochannels, reflecting the alternation of the fluvial systems due to climatic changes in the late Vistulian and Holocene and due to human impact increasing in the last two millennia.

The information acquired is not equally comprehensive. In most cases conclusions and hypotheses are based on records from the Vistula valley between Cracow Gate and the mouth of the Raba river, and from the Wisłoka valley at the immediate foreland of the Carpathian foothills (Fig. 1).

The present study aims at the reconstruction of hydrological changes in the fluvial system of the upper Vistula. A more thorough knowledge on these changes was gained thanks to the precise examination and systematic inquiry, carried out under IGCP-158 project in the 1980s, that included surveying of new sections, more detailed investigation repeated in several old sites and introduction of new study techniques (which are standard procedures in other research centres but which have been used by our team to a limited extent). These new techniques included detailed reconstructions of paleochannel cross-sections and paleodischarges (cf. Rotnicki 1983, 1991; Kozarski 1991) or a use of geophysical methods. Some of the undertaken tasks were completed only partly.

Moreover, the applied methods comprised field studies, laboratory analyses as well as a reconstruction and correlation of past events. The surveying and mapping of the valley reaches, description of samples taken from the previously studied outcrops and from new boring cores were performed by T. Kalicki, L. Starkel, P. Gębica in collaboration with Prof. W. Pożaryski. In the borings participated also I. Kasza, S. Kędzia and P. Prokop. The testing of a geophysical method for surveying of alluvial beds was made in one site by J. Mościcki and colleagues from the Institute of Geophysics, Academy of Mining and Metallurgy in Cracow (Kalicki and Mościcki – in press).

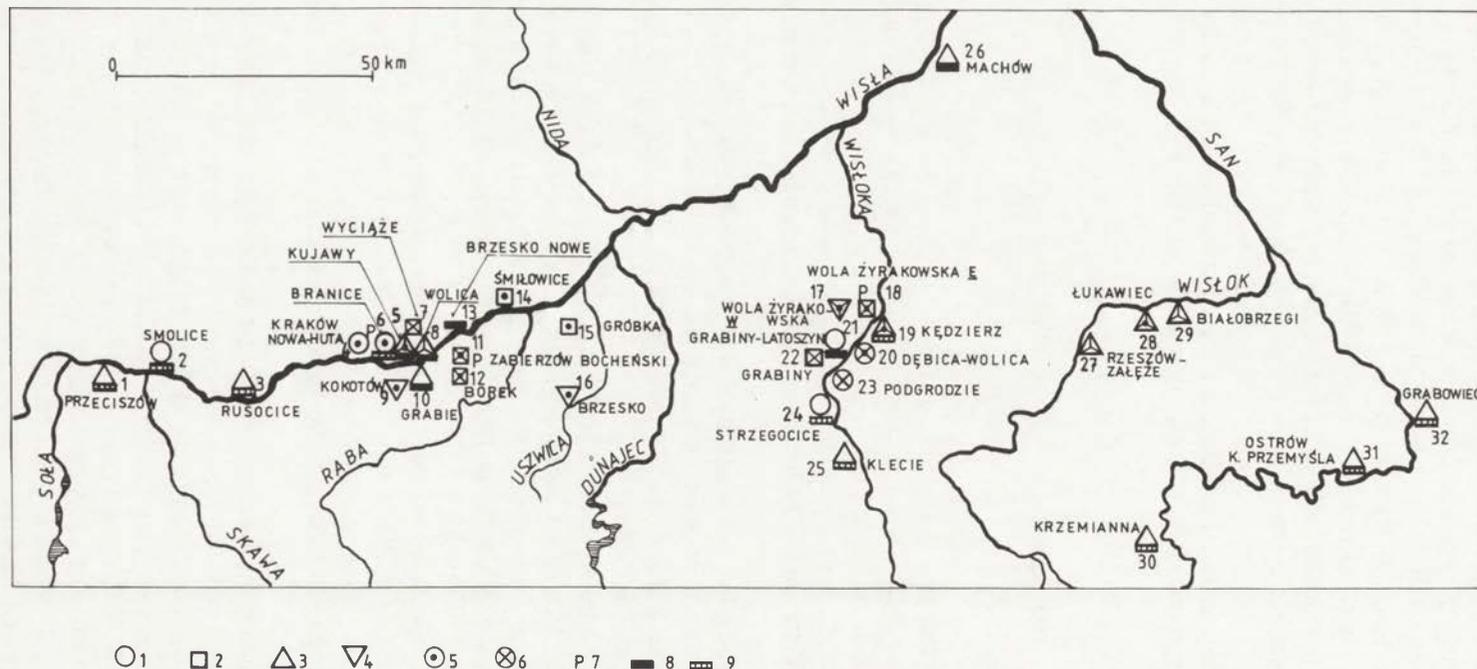Fig. 1. Sites studied in this project in the period 1991–1994 (by L. Starkel)

1 – earlier studies sites, resurveyed, 2 – newly studied paleochannels, 3 – new gravel and clay pits, 4 – new examined borings, 5 – radiocarbon datings, 6 – sedimentological analyses, 7 – palinological analyses, 8 – several dendrochronological datings (more then 5), 9 – other dendrochronological datings (less then 5)

Grain size was analysed using laser and sieving techniques, and carbon content was determined by Ms J. Sala in the laboratory of the Department of Geomorphology and Hydrology. Pollen diagrams for two sites in the Vistula valley were made by V. Zernickaya from the Institute of Geological Sciences, Byelorussian Academy of Sciences while for the sites in the Wisłoka valley by W. Granoszewski and K. Mamakowa from the Institute of Botany, Polish Academy of Sciences. Extensive dendrochronological studies were carried out by M. Krąpiec from the Institute of Geology and Mineral Resources, Academy of Minning and Metallurgy. Radiocarbon datings were performed in the Laboratory of the Institute of Physics, Silesian University under the guidance of A. Pazdur and M. F. Pazdur. Testing of formulae for paleodischarges was undertaken by R. Soja. V. Klimanov from the Institute of Geography, Russian Academy of Sciences collaborated in the reconstruction of annual precipitation and temperature (study in progress) on the basis of pollen diagrams delivered by K. Harmata and K. Szczepanek from the Botanical Institute of Jagiellonian University and D. Nalepka from Institute of Botany, Polish Academy of Sciences. Most figures were kindly redrawn by Mrs M. Klimek.

The results of the studies on several sites and river reaches have already been published (5th volume on the *Evolution of the Vistula Valley* – ed. Starkel 1995). However, the present summarizing volume discusses several problems encountered in the reconstruction of the upper Vistula fluvial system.

1. The registration of threshold changes in the fluvial system in relation to long-lasting phases and to extreme events.

The background to the reconstruction of the changes is, on the one hand, characteristics of precipitation (L. Starkel) exceeding the threshold values (downpours, continuous rain and rainy seasons), on the other, characteristics of the present runoff regime (R. Soja). Phases and episodes with channel avulsions or cut-offs, which are essential from hydrological viewpoint, were determined by detailed examination of age and parameters of the paleochannels and sediments in selected sites (L. Starkel, T. Kalicki and others). Particularly thorough analyses were performed in 8 cross-section of the Vistula paleomeander at Zabierzów Bocheński in order to reconstruct former forms and paleodischarges (separate paper in this volume by T. Kalicki, L. Starkel, J. Sala, R. Soja and V. Zernickaya).

2. The elaboration of ca 300 subfossil oaks from new sites and from several old ones in the Vistula, Wisłoka and San river valleys as well as from sites in the upper Odra and Nysa Kłodzka rivers (by M. Krąpiec).

Dendrochronological dating of these oaks (by M. Krąpiec) contributes to the identification of main flood phases in the Carpathian valleys (by M. Krąpiec, T. Kalicki).

3. The grain size composition of the overbank deposits as an indicator of flood phases (by T. Kalicki).

The review of all the studies on grain size, age, and fossil soils, which have been performed in the Vistula and Wisłoka valley, and which help to determine the role of climatic changes and human impact on variation in suspended load in the rivers during the Late Vistulian and Holocene.

4. All the collected records and evidences analysed in four time diapasons.

a) Late Vistulian and Eoholocene (20–8.5 ka BP), During that time the main transformation of the fluvial system, including runoff regime and sediment facies (by L. Starkel and P. Gębica) occurred.

b) First humid phases in the Holocene (8.5–7.8 ka BP). The detailed reworking of the flood sequences in Podgrodzie (presented in this volume by E. Czyżowska and L. Starkel – chapter 2.5).

3) Period of the stable, full Holocene with several flood phases (7–3 ka BP) and with human activity manifesting on a local scale (by L. Starkel).

d) Period of the last 3000 years during which climatic rhythmicity with various flood frequencies was substantially modified by the increasing human activity (by T. Kalicki).

5. The correlation of records has been found in the fluvial system with data obtained from studies on other environments (by L. Starkel).

The full agreement between the correlated data has been confirmed. The adopted approach included a reconstruction of precipitation totals (study by V. Klimanov – in progress), analysis of a landslide activity in the flysch Carpathians (cf. Starkel 1995c) and a comparison with studies on changes in lake level and groundwater levels with a special emphasis on Lake Gościąż (Starkel et al. 1996).

6. The closing chapter deals with the correlation between the events in the upper Vistula basin and the events reported in the studies on fluvial history and on other paleohydrological changes in Central Europe and the whole temperate zone; the close correlation of events in the mountain-upland belt of Central Europe is accentuated (by L. Starkel). The differences in runoff regime in various climatic zones are emphasized.

The following questions are still open:

– how to distinguish a single extreme flood from the phases when the series of extreme floods occur with various frequency;

– to what extent may the landnam phases modify the climatically controlled rhythm of fluvial activity.

2. THRESHOLD VALUES AND EXTREME EVENTS IN THE FLUVIAL SYSTEM OF THE UPPER VISTULA

2. 1. RAINFALLS AND THEIR THRESHOLD VALUES

Leszek Starkel

The basic parameter affecting changes in a hydrological regime is rainfall. However, frequency of rainfalls of a given total, intensity, duration and their distribution in time as well as long-term fluctuations, causing changes in evaporation and water storage, controls this regime indeed.

In sediments and forms of a fluvial system we may observe reflection of the extreme events conditioning erosion and deposition in river channels and at their banks, or a more continuous record of groundwater fluctuations and flood events in the distant flood basins (cf. Starkel, Thornes 1981; Ralska-Jasiewiczowa, Starkel 1988). To understand the registration of different extreme events better, various types of precipitation, which are characteristic for the upper Vistula river basin, are discussed below.

In the Carpathians and at their foreland the total annual precipitation fluctuates between 700–1800 mm and is concentrated in 140–190 days (Fig. 2). About 50% of rain fall in summer months (June – August). Before the last warm decade the seasonal winter storage of water in snow fluctuated between 50 and 500 mm. Precipitation and snowmelt causing a rapid rise in runoff and water storage, visible in sediment sequences and forms, may be categorized in four main types (Starkel 1976; Słupik 1981) given below.

The first type includes short-lasting downpours with totals reaching 50–100 mm per hour and with the intensity exceeding 1–2 mm/min. Daily falls of rain may reach up to 300 mm (Cebulak 1992). A typical feature is their small extent. They result in an intensive runoff, a slope wash (up to 6 $m^3s^{-1}km^{-2}$ – after Słupik 1973), earth flows and debris flows (Kotarba 1989).

These downpours create local floods in small catchments, where a specific runoff may reach 10 $m^3s^{-1}km^{-2}$ (Soja 1981). Such downpours are registered in the sequence of the Maga alluvial fan (tributary of the Wisłoka river), deposited during several centuries from 8400 a BP (Niedziałkowska *et al.* 1977) or in the layers from the Little Ice Age in the Tatra lakes (Kotarba 1989).

In the second category there are continuous rainfalls covering extensive areas, occurring every 10–20 years with the intensity of 5–20 mm per hour and 50–200 mm
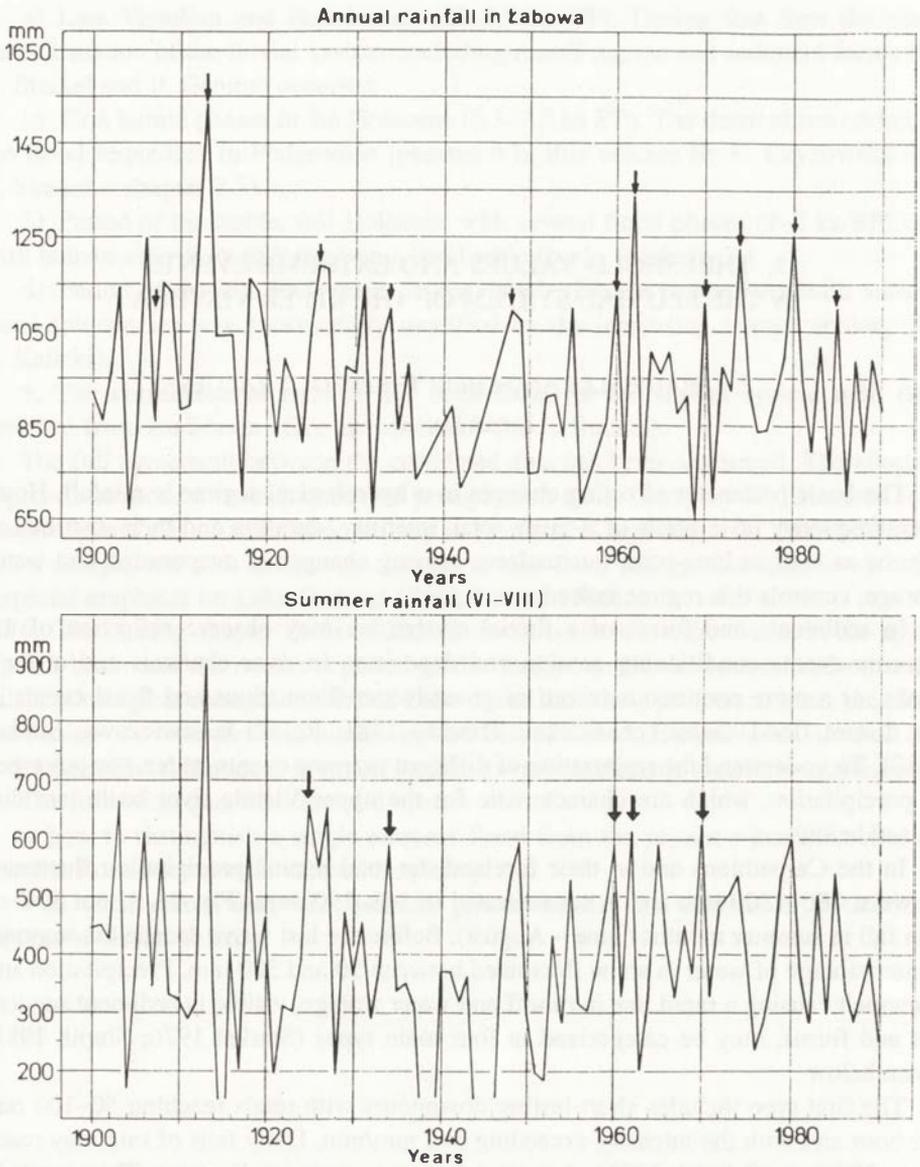
Fig. 2. Courses of annual and summer rainfalls in 20th century at Łabowa near Nowy Sącz
(after data collected by T. Niedźwiedź and E. Cebulak; compiled by L. Starkel)

Arrows over annual rainfalls indicate landslide episods
Arrows over summer rainfalls indicate large summer floods

per day. During consecutive 3–5 days their totals may reach 200–600 mm (Gil, Starkel 1979). Such rainfalls cause catastrophic floods in catchments located in the mountains and at the mountain foreland (Punzet 1981), and lead to reshaping of a channel form

and to overbank deposition. The rainfalls discussed here are related to threshold discharges. The threshold discharges were calculated for the braided channel of the Białka river in the Tatra foreland (Baumgart-Kotarba 1983) and for the channels of various order in the Beskidy Mts (Soja 1977; Froehlich, Starkel 1991). Then, on floodplains and on river banks (levee) deposition of madas (Klimek 1974b; Niedział-kowska 1992) takes place. During such continuous falls of rain the landslides often occur (Ziętara 1968; Starkel 1976).

A long rainy season or whole wet years present another type of extremes. During such years the rainfall totals exceed the mean value by at least 30–50%. Moreover, the groundwater level rises, many seasonal swamps develop and landslides reactivate on mountain slopes (Starkel 1995c). In the Carpathians the year 1974 was such. At the field station in Szymbark only in October ca 200 mm rainfall was recorded (Gil, Starkel 1979).

Snowy winters belong to the extreme seasons as well. Snow cover may store from 200 to 1200 mm of water in lower elevations and in the Tatras, respectively (Nie-dźwiedź, Obrębska-Starklowa 1991). The rapid snowmelt after such snowy winter combined with a rainfall may cause heavy floods, especially accompanied by ice jams. The floods of this kind often occurred in the Vistula basin in the previous centuries and led to various transformations of the river channel, including avulsion (Rojecki 1965). Before the Holocene a number and importance of the snowmelt floods were probably much greater (Starkel 1993).

Based on various types of rainfalls and floods registered in forms and sediment sequences in the valley floors of the upper Vistula basin many interesting conclusions may be drawn. During the Holocene several phases of a higher flood frequency and frequent continuous rainfalls were registered (Starkel 1983). However, these phases were simultaneously with the periods when wet years (with dated active landslides) and local heavy downpours of high intensity (Starkel 1985, 1995c; Kotarba 1992) occurred more often.

A classical, well recognised phase of this type was the Little Ice Age, when also glacier advances were registered in the Alps and Scandinavia (Grove 1979). This may be explained by reactivation of the western cyclonic circulation which favoured ex-treme precipitation (of various types), including heavy snowfalls. The parallel rise in the mean annual rainfall and decrease in evaporation (perhaps combined with a higher cloudiness) created the conditions for a groundwater level rise and gradual changes in plant communities (Ralska-Jasiewiczowa, Starkel 1988).

2. 2. HYDROLOGICAL REGIME OF THE UPPER VISTULA RIVER

Roman Soja

The Vistula belongs to the rivers of a classic allochtonous regime. Only its short section from the springs at the slope of Barania Góra Mt. to the city of Skoczów, has an autochtonous, typical mountain regime of a very diversified flow. Downstream of Skoczów, the Vistula river, flowing at the mountain foreland, merges tributaries from
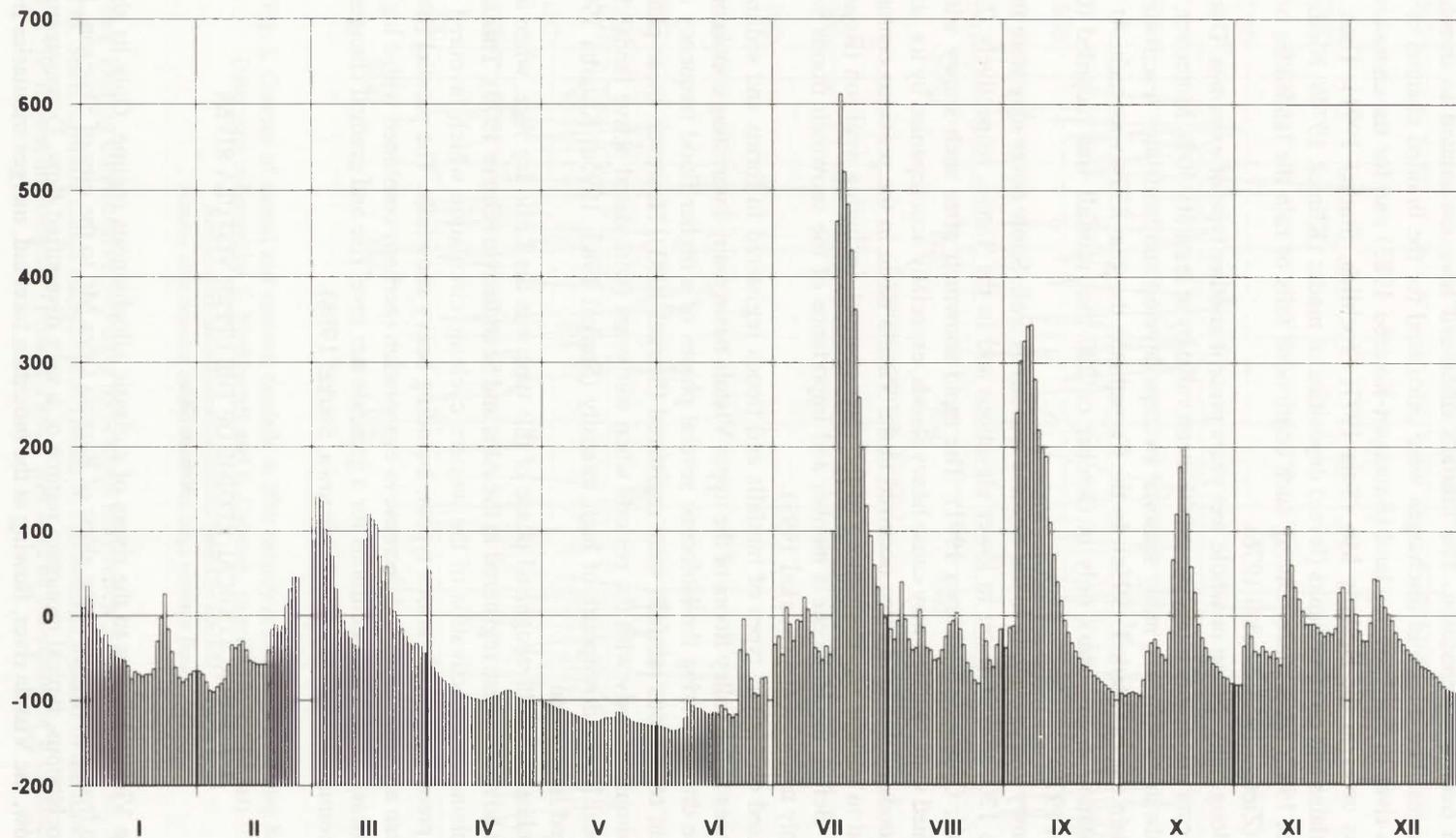
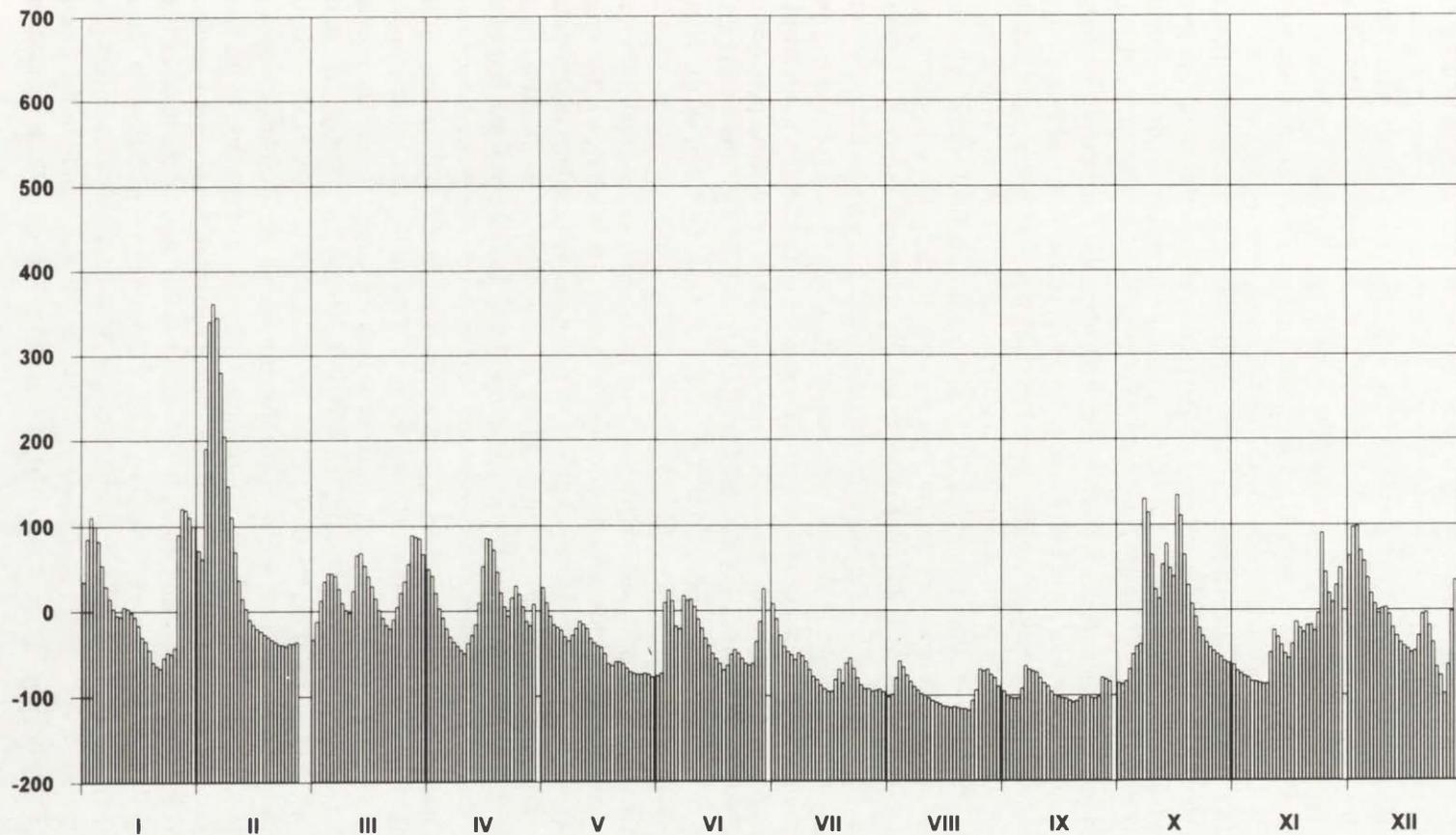Fig. 3. Water stages of the Vistula river at Szczucin in 1934 (compiled by R. Soja)

Fig. 4. Water stages of the Vistula river at Szczucin in 1923 (compiled by R. Soja)

the Carpathians and the Middle Poland Uplands as well as small streams from the belt of the Carpathian Foreland basins, nevertheless, preserves most properties typical of the Beskidian rivers. The left tributaries from the uplands and particularly small tributaries from the basins have almost no influence on the Vistula regime. The Vistula regime in the Sandomierz Basin is controlled by the large Carpathian tributaries: the Dunajec, Wisłoka and San rivers. The Carpathian type of regime is preserved to the mouth of the Narew river, downstream of Warsaw (Soja, Mrozek 1990).

The Vistula regime downstream of Cracow can be defined as nonuniform (in terms of high short-term variability), of pluvial-nival-groundwater alimentation, with spring and summer freshets (Dynowska 1971). From Cracow to the mouth of the Dunajec river the Vistula runoff in winter (November-April) and summer (May-October) hydrologic seasons is the same. In the annual cycle the highest mean monthly discharges of the Vistula river are in April and the lowest in September. A period of high flows starts in February and lasts to August. In the remaining part of a year mean monthly flows are lower than the annual mean. The feature which marks off the Vistula regime from typical continental or oceanic rivers is a twofold high flow period. The first, spring culmination of flow is caused by snow melting, the second by long-lasting rain. A good illustration of this pattern of flows in an annual cycle is Figure 3, presenting the year 1934 with one of the largest freshets which have occurred in the Vistula drainage basin. Meltwater high flows occur along the whole Vistula course every year yet their importance increases downstream. Prevalence of rainfalls is best marked in the spring part of the Vistula drainage basin (to Skoczów) and its importance decreases downstream. Downstream of the San mouth the secondary culmination caused by falls of rain is still noticeable yet it does not occur downstream of the Narew junction with the Vistula.

The maximum monthly discharges are associated with summer high flows and exceed almost twice the discharges associated with meltwater high flows. The origin of high flows in the Vistula drainage basin is very complex and medium hight freshets can appear in any month. In spring the melting of a snow cover starts earliest in the Carpathian Foreland and in the Basin, and expands successively over the belt of the uplands and the Beskidy Mts. The process of melting is often accelerated by falls of rain, causing a rapid disappearance of snow in lower parts of the mountains. At the same time there are falls of snow in the upper parts of the mountains, which diminish and simultaneously prolong the culminations of meltwater high flows. The summer freshets, induced by long-lasting rain, reach to 150–250 mm in 3–5 days and, in the first phase, are formed in the western part of the drainage basin. The flood wave the Soła outlet to the Raba outlet, i. e. over the distance longer than 100 km, changes its parameters to a slight extent. Lack of larger tributaries causes flattening of the wave culmination. Superimposing the waves of the Vistula, Raba and Dunajec rivers results in catastrophic freshets in the Sandomierz Basin. Such was the origin of the flood in 1934. In the Vistula drainage basin years without floods happen only sporadically (Fig. 4) and most often these are dry years when a low meltwater flood marks off. In the tables given below, the water level gauge at Tyniec represents the Vistula regime in the Cracow section. The water level gauge at Jagodniki is located downstream of the Raba mounth.

The Vistula channel is mainly modelled during high water level, yet 2-year flow is significant. An important role in transformation of the Vistula channel was played by floods induced by ice jams, which formed against artificial obstacles (bridges) or were caused by natural obstacles occurring numerously in a sinous channel. The ice-jam freshet of 1876 inundated a large part of Cracow. The freshets in 1888, 1893, reaching Cracow, resulted from ice-jams in the vicinity of Niepołomice. The ice-jams were most frequent in the Vistula reach between Cracow and the Dunajec mouths, but they do not occur at present.

In hydrological regime of the Vistula river features of an anthropogenic origin can be found easily. Here belong the lowering of culmination and a change in the lowest flows due to functioning of reservoirs in the western part of the Vistula drainage basin, a disappearance of continuous ice-cover and an increase in amplitudes of water stages. The water level in the channel during the highest flows is 2–3 m above the floodplain level. The river is confined by anti-flood embankments and lacks any contact with the floodplain. One can presume that under natural conditions the water level in the channel without the embankments could not have been higher than the floodplain level even by a metre, except for local damming. Nowadays, the whole suspended load is transported out of the drainage basin while earlier the suspended particles were deposited on the floodplain. A detail description of the Vistula channel transformation since 1800 (Trafas 1992) suggests that the term "canel-river" instead of "river" should be used when referring to the Vistula downstream of Sandomierz.

Significant changes in the environment of the Vistula drainage basin during the last 200 years and the observed climatic changes point to the alternation of the river regime, at least in the case of high flows. Hydrologic materials do not evidence the changes in runoff magnitude as well as in precipitation totals for the period after 1990 (Fal 1993). J. Punzet (1972) has suggested an increase in discharges in the Vistula drainage basin down to the Dunajec mouth and an increase in high flow frequency in 1870–1970. The paper of J. Stachy and H. Nowak (1977), referring to the same period, does not confirm the suggestions mentioned above. The author applying various techniques for detecting changes (Soja 1994b) has analyzed duration of high water levels for the gauging post at Szczucin for the period 1890–1993 and has not found statistically significant trends of changes in number of days with high discharges during a year, hydrological seasons and months. The negative tendency has been obtained for the days with high water levels, yet at the limit of significance. There are no premises to accept the hypothesis that the floods grew more rapidly when the time was passing and the concentration of flow was occurring faster. Thus, one can say that no significant changes in hydrological regime in the case of freshets took place in the last century, i. e. factors modelling the river channel did not change. An outstanding feature is lack of ice-jam floods due to disappearance of an ice cover on thermally and chemically contaminated rivers. One should take into consideration that the Vistula drainage basin was thoroughly changed indeed by urbanization, industrialization and alternation of land use layout etc. Nevertheless, a freshet runoff and its annual pattern did not change. On the other hand, the channels of large and small rivers were totally transformed in the last century due to a direct or indirect human impact.

2.3. WAYS OF TRANSFORMATION OF THE VALLEY FLOORS DUE TO CHANGES IN SEDIMENT DELIVERY AND FLOOD FREQUENCY

Leszek Starkel

The shift from a cold climate in the Pleistocene to the temperate one during the Holocene created the background for the concept of a change in a river channel pattern from the braided to meandering one (Schumm 1965). An important change in a river channel evolution occurred during the Late Vistulian. Large paleomeanders in this age were found in the middle reaches of the Vistula basin (Falkowski 1975; Szumański 1983) and of the Warta catchment (Kozarski, Rotnicki 1977). The next changes in the fluvial regime decided of a rapid diminishing of parameters of a river channel just at the turn of the Holocene. Various generations of the Holocene paleo-channels were generally small and similar in size to an exception of slightly larger ones which had developed after the wetter phase during the Boreal/Atlantic transition (Kalicki 1991c). A distinct increase started in the historical times (Starkel 1983; Gębica, Starkel 1987; Kalicki 1991c). Following Starkel's model each phase with a high flood frequency was expressed in cutting off or an avulsion of meanders and in widening and straightening of channels. Then, with the decline of fluvial activity a new generation of free meanders developed (Starkel 1983). Depending on the sediment delivery (overloaded or underloaded rivers) the development of the new channel generation was accompanied either by tendency to downcutting or to aggradation. The last trend was typical in the Younger Dryas and in the Medieval time.

However, to get such clear sequences of changes (to develop free meanders) a wide valley floor and sandy alluvia several meters thick are needed. From this point of view several types of valley reaches have been distinguished in the valleys of the Subcarpathian Basins and Carpathian Foothills (Starkel 1990; Gębica 1995). Three of them are characteristic of wide valley floors which favour free meandering (Fig. 5).

1. Alluvial fans at the mountain foreland with channel avulsions, built of strips of various age, and formed by braided or meandering rivers (fan of the upper Vistula – Niedziałkowska *et al.* 1985; fan or the Raba river – Gębica 1995; fan of the Wisłoka river – Starkel 1960).

2. Alluvial fans at the outlet from the foothills or from the gap with the main tendency to narrowing of an active zone during the Holocene, expressed by several cuts and fills; this type is represented by the Wisłoka reach near Dębica (Starkel 1960; Alexandrowicz *et al.* 1981) as well as by the Vistula downstream of Cracow Gate where some avulsions also occur (Kalicki 1991b, c).

3. In the river reaches of low gradients (below 0.3%) and with wide floors there are suitable conditions for frequent avulsions and development of new fills; the Vistula valley downstream of Niepołomice in this type (Gębica, Starkel 1987; Kalicki *et al.* in this volume) or wide mounths of tributaries such as the Raba and Dunajec rivers (Gębica 1995; Sokołowski 1995).

On the contrary there are also valley segments where the sequence of fills is limited. Among them four types may be distinguished.

4. Narrowings without free meanders where each subsequent flood removes the

older alluvia. Therefore, in Cracow Gate Rutkowski (1987) has mainly stated the sediments of the last millennia. In the case of the transverse valley of the Vistula between Sandomierz and Puławy the hydrological changes during the Holocene are recorded in sequences of overbank deposits separated by horizons of fossil soils (Pożaryski, Kalicki 1995). The sediments of the slack-water deposit type (Baker 1983) were found in the Dunajec gorge across the Pieniny Mts (of the late Subboreal age – Lożek 1991) and in the upper San valley in the Eastern Carpathians. Here they were in the form of sandy intercalations in the peat sequence (from the younger Dryas and late Boreal – Ralska-Jasiewiczowa, Starkel 1975).

5. In the mountain reaches with a steeper gradient and narrower valley bottom the rocky floor outcrops. Such conditions facilitate formation of several rocky-alluvial benches connected with tendency to incision, described from the Dunajec river gorge across the Beskid Sądecki Mts (Froehlich *et al.* 1972) and from the upper Wisłok valley (Zuchiewicz 1987).

6. In the left-hand side tributary upland valleys (the Nidzica valley, for example) the dominance of suspended load results in continual aggradation. In the thick sequence of alluvial loams the main changes in a type and concentration of sediment load, especially from the beginning of human activity are registered (Śnieszko 1987; Rutkowski 1984, 1991). Similar aggradation started in smaller basins draining the Carpathian Foothills, for example, the Wielopolka (Starkel 1960) or Uszwica valleys (unpublished).

7. Alluvial fans of small tributaries may provide evidence of a detail sequence of flood events, representing usually one phase with a higher flood frequency. In the case of the Maga fan in Podgrodzie it was possible to separate single events (Niedziałkowska *et al.* 1977; Czyżowska and Starkel – chapter 2.5 in this volume). In Besko the beginning of fan deposition was dated after 8 ka BP (Koperowa, Starkel 1972).

The registered phases and events are reflected in a different way (Starkel 1994) in each of the seven distinguished types of the valley reaches.

Among the forms terrace steps are very rare but paleochannels abandoned by cutting-offs (singular) or an avulsion (long systems) are found more frequently. Their parameters reflect changes in bankfull discharge and sediment load. The phases with the higher flood frequency are registered in different fluvial sediments:

a) in erosional forms, where coarse sediments of channel facies are mainly inbedded with log beds at the bottom,

b) sandy overbank sediments of levees frequently with registration of separate floods,

c) silts and clays of flood backswamps with registration of larger floods, expanding over the whole floodplain,

d) alluvial fans of tributary creeks, superimposed over the alluvial plain of the main river.

GENERAL MODELS

EXAMPLES

I.

1000±40g

XIXc

YD

AL

A₂

SB / SA

YD

1000 BP

II.

m 16

N

ŁG

AT

SB

SA

BO

ŁG

S

27745±300

13260±160

6450±130

6255±40

VISTULA

10630±190

8630±130

2200±140

7980±160

7740±90

9660±180

8

0

-8

10920±130

3035±55

9200±100

11920±170

11090±120

9660±110

9390±180

1480±60

2200±70

III.

37±4kaTL

SB-SA

VISTULA

10520±110

5460±110

5060±110

AL

4860±110

8010±140

YD

9840±140

6540±130

9780±150

5420±110

IV.

m 8

W

E

3670±110

5170±210

VISTULA

700±230

4

0

-4

http://rcin.org.pl

0   1 km

Fig. 5. General models and examples of various types of transformation of alluvial plains during Late Vistulian and Holocene (compiled by L. Starkel)

I. Sequence of fills with tendency to narrowing of floodplain (example of the Wisłoka alluvial fan – after L. Starkel 1982, changed in 1995); II. Sequence of fills dominance of lateral shifting (example of Vistula near Cracow with some avulsions after Kalicki 1991c); III. Sequence of fills with dominance of avulsions (example of the Vistula at Grobla Forest – after Gębica, Starkel 1987; Starkel *et al.* 1991); IV. Narrow valley with dominance of vertical accretion and sequence of burried soils (example of middle Vistula gap – after Pożaryski, Kalicki 1995); V. Mountain reach with tendency to downcutting (example of the Dunajec gorge across the Beskid Sądecki – after Froehlich *et al.* 1972); VI. Left-side tributaries draining loess plateaus with tendency to aggradation (example of Nidzica valley – after Śnieszko 1987). 1 – gravels and sands, 2 – sandy bars, 3 – alluvial loams (mada), 4 – peat, 5 – gyttja, 6 – paleochannel fill, 7 – loess, 8 – bedrock, 9 – soil horizons, 10 – archeological artefacts, 11 – tree trunks, 12 – dated horizon

2. 4. ANALYSIS OF PALEOCHANNELS IN THE VALLEYS OF THE UPPER VISTULA AND THE WISŁOKA

Leszek Starkel, Tomasz Kalicki, Roman Soja, Piotr Gębica

Among numerous paleochannels, which age of abandonment was determined by the radiocarbon dating of the bases of their fills, the generation of the large Late Vistulian paleomeanders, of the small Holocene ones, and again the generation of larger paleomeanders of the recent centuries were stated in agreement with the concept of E. Falkowski (1975) and A. Szumański (1983). Several systems of meander bends of the Holocene age corresponding to rhythmical fluctuations in the flood frequency (Starkel 1983, 1994; Kalicki 1991b, 1992b) were indicated. The parameters of the selected paleochannels in the Wisłoka and Vistula valleys were determined by measurements on maps and sometimes on aerial photographs. These parameters included: radii of curvature and widths (Trafas 1975; Klimek, Starkel in: Alexandrowicz 1981; Szumański 1986; Gębica, Starkel 1987; Kalicki 1991b, c, 1992b; Baumgart-Kotarba 1991).

Only in the case of a few meander bends in the Wisłoka valley (Starkel *et al.* 1982) determination of the channel forming discharges was attempted, large deviations in magnitudes of the parameters of the channels belonging to one system and simultaneously definite differences between the generations were stated.

During the studies on the abandoned system of the Late Vistulian channels in Grobla Forest (Starkel, Kalicki 1984) and then, in the abandoned channels downstream of Cracow (Kalicki 1991b, c), several profiles consisting of some borings were made. These borings enabled one to determine the paleochannels parameters, i. e. real depth and cross-section area, more precisely.

During the period of 1992–1994, besides the model studies in Zabierzów Bocheński, several other paleochannels of the Vistula, Raba, and Wisłoka rivers were investigated in several ways.

The overview of the results of these analyses is presented below. It should be borne in mind that each radiocarbon dating is usually by several tens or more years younger than the moment of the channel abandonment (especially if the organic deposits are underlain by a layer of silts or sands). It should also be assumed that the mature meandering channel ofter reflects a long period, undoubtedly lasting for a few hundred years of discharges which formed the discussed parameters (Kalicki 1991b, d; Starkel 1994). Moreover, the authors assume that the paleochannel or the system of paleochannels were abandoned in the phase of a large frequency of floods (Starkel ed. 1990), but that does not exclude the possibility of a meander cut off in effect of a singular flood.

The studies on the abandoned channel in Zabierzów Bocheński have indicated (Kalicki *et al.* in this volume) that the reconstructions of paleodischarges based on various formulae provide rough and diversified estimates, so a comparison between the parameters of channels of various age tells about relative changes in channel forming discharges. However, the changes in discharges are already visible from the comparison of the channel parameters such as an channel width, an radius of curvature, and an length of a meander wave.

©1 ◐2 ◯3 ◖4 ▣5 ⊟6 ⊙7 ◐8 ⊖9 ⊕10 ✳11 ⊗12 ◕13 ◑14 ◡15 ◠16 ●17 ◗18 ⊗19
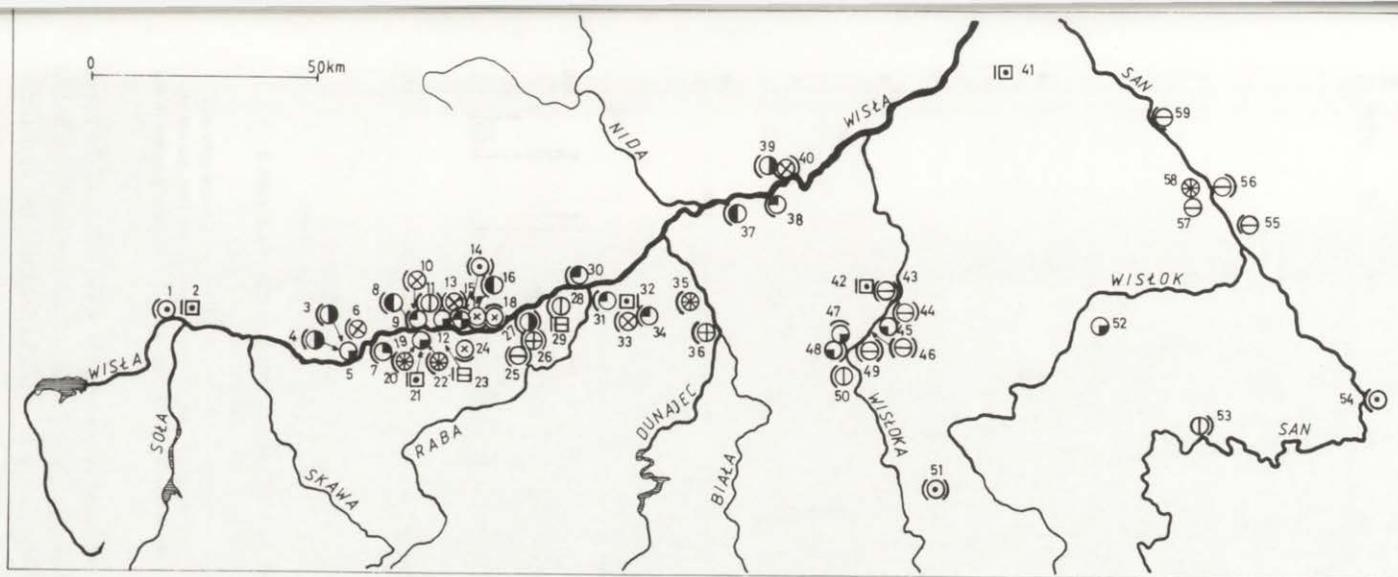
Fig. 6. Datings and age of the paleochannels in the Upper Vistula and tributary valley

Dating of the paleochannels using various methods: 1 – radiocarbon, 2 – palinological, 3 – dendrochronological, 4 – historical. Braided paleochannel of various age; 5 – older then Allerød, 6 – from the Younger Dryas. Paleomeanders of various age: 7 – older than Allerød, 8 – Allerød, 9 – Younger Dryas, 10 – Preboreal period, 11 – Boreal period (up to ca 7.8 ka BP), 12 – ca 7.0–6.0 ka BP, 13 – ca 5.5–5.0 ka BP, 14 – ca 4.5–4.0 ka BP, 15 – ca 3.5–2.8 ka BP, 16 – ca 2.2–1.8 ka BP, 17 – 7th–11th century, 18 – 14th–17th century, 19 – 17th–19th century. S i t e: 1 – Bieruń (Klimek 1992), 2 – Gorzów (Klimek 1992), 3 – Jeziorzany I (Rutkowski 1987), 4 – Jeziorzany II (Rutkowski 1987), 5 – Jeziorzany III (Rutkowski 1987), 6 – Bielany (Rutkowski 1987), 7 – Koło Tynieckie (Rutkowski 1987), 8 – Przy Rondzie (Kalicki 1991b), 9 – Łęg A (Kalicki 1991b), 10 – Czyżyny (Kalicki 1991b), 11 – Nowa Huta (Kalicki, Zernickaya 1995), 12 – Kujawy (Kalicki, Krąpiec 1992), 13 – Pleszów (Wasylikowa et al. 1985), 14 – Pleszów II (Kalicki 1992b), 15 – Branice–Stryjów I (Kalicki, Krąpiec 1991a), 16 – Branice–Stryjów II (Kalicki, Krąpiec 1991a), 17 – Branice III (Kalicki 1991b), 18 – Wolica (Kalicki, Krąpiec 1995a), 19 – Lasówka I (Kalicki 1991b), 20 – Rybitwy I (Kalicki 1991b), 21 – Rybitwy II (Kalicki 1991b), 22 – Lasówka II (Kalicki 1991b), 23 – Brzegi (Kalicki 1992a), 24 – Grabie (Kalicki, Krąpiec 1991b), 25 – Borek (Kalicki unpubl.), 26 – Drwinka I (Gębica, Starkel 1987), 27 – Zabierzów Bocheński (Kalicki et al. in this volume), 28 – Grobla Forest (Gębica, Starkel 1987), 29 – Drwinka II (Starkel et al. 1991), 30 – Śmiałowice (Kalicki unpubl.), 31 – Uście Solne (Gębica 1995), 32 – Gróbka (Gębica 1995), 33 – Strzelce Małe I (Gębica 1995), 34 – Strzelce Małe II (Gębica 1995), 35 – Zabawa (Sokołowski 1995), 36 – Niwka (Sokołowski 1995), 37 – Mędrzechów (Sokołowski 1995), 38 – Szczucin (Sokołowski 1987), 39 – North I – of Szczucin (Sokołowski 1987), 40 – North II – of Szczucin (Sokołowski 1987), 41 – Kobylarnia (Mycielska-Dowgiałło 1987), 42 – Wola Żyrakowska W (Starkel 1995d), 43 – Wola Żyrakowska E (Starkel, Granoszewski 1995), 44 – Brzeźnica (Mamakowa, Starkel 1977), 45 – Kędzierz (Starkel, Krąpiec 1995), 46 – Dębica Kolejowa (Alexandrowicz et al. 1981), 47 – Grabiny younger (Starkel 1995d), 48 – Grabiny older (Alexandrowicz et al. 1981), 49 – Podgrodzie (Niedziałkowska et al. 1977), 50 – Strzegocice (Klimek 1992), 51 – Roztoki (Wójcik 1987), 52 – Wisłok valley (Strzelecka 1958), 53 – Podbukowina (Mamakowa 1962), 54 – Stubno (Klimek 1992), 55 – Rzechów (Szumański 1986), 56 – Kulno (Szumański 1986), 57 – Jelna I (Szumański 1986), 58 – Jelna II (Szumański 1986), 59 – Ulanów (Szumański 1986)

31
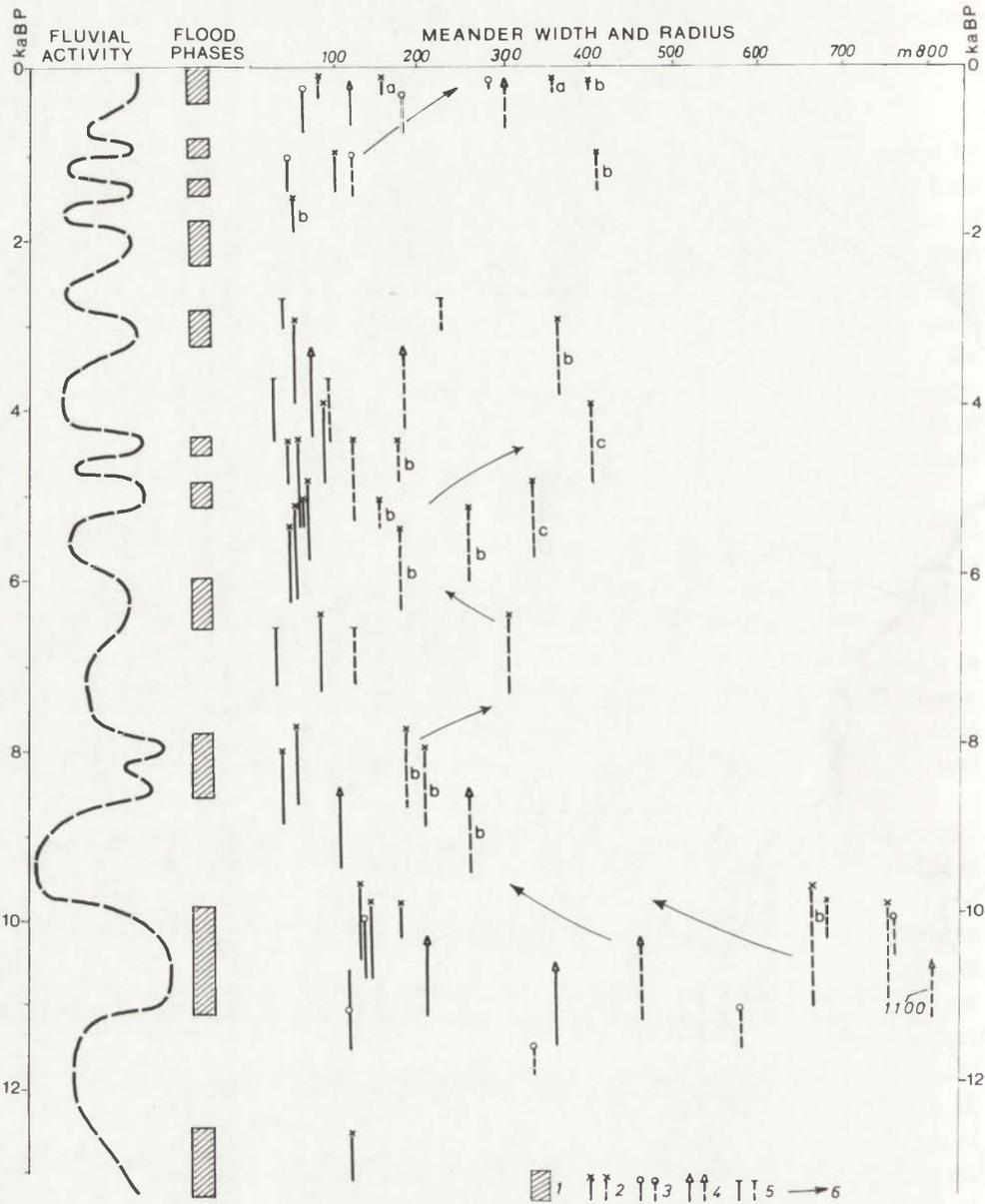
Fig. 8. Fluvial activity and parameters of the paleochannel presented on Figure 6
(compiled by L. Starkel 1995 with some additional localities)

1 – flood phases, 2 – width and radius of the paleomeanders in the Vistula valley (a – Cracow gate and upstream, b – between Cracow and junction with the Dunajec river, c – downstream of the Dunajec outlet), 3 – width and radius in the Wisłoka valley, 4 – width and radius in the San valley, 5 – width and radius in the Raba valley

Therefore, these parameters for ca 60 dated paleochannels in the valley of the upper Vistula and its tributaries are summarized (Fig. 6), including 14 paleochannels studied in details. Paleodischarges forming the paleochannels were calculated using the formulae:
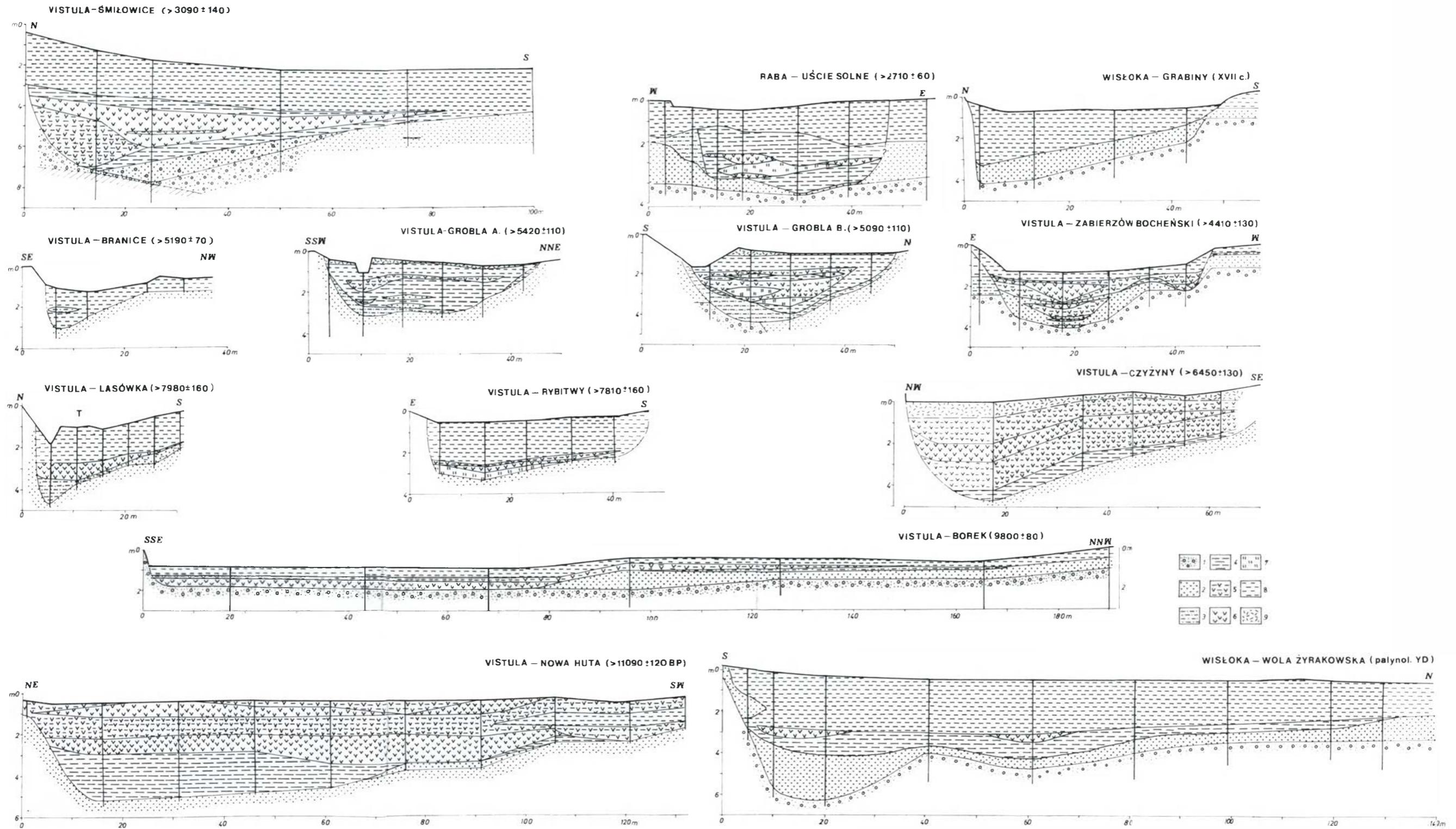
Fig. 7. Cross-sections of the paleomeanders dated by radiocarbon and palynological methods:
Nowa Huta (Kalicki 1987, 1992b), Borek (Kalicki unpubl.), Wola Żyrakowska (Starkel, Granoszewski 1995), Lasówka (Kalicki 1991b), Rybitwy (Kalicki 1991b), Czyżyny (Kalicki 1991b), Branice (Kalicki 1991b), Grobla A and B (Starkel, Kalicki 1984; Gębica, Starkel 1987), Zabierzów Bocheński (Kalicki et al. in this volume), Śmiłowice (Kalicki unpubl.), Uście Solne (Gębica 1995), Grabiny (Starkel 1995d).

1 – channel facies (gravel and sands), 2 – sands, 3 – silty sands or sandy silts, 4 – silty and clays of paleochannels fills, 5 – organic muds, 6 – peat, 7 – gyttja, 8 – overbank mada, 9 – artificial debris

$$Q_{\text{mean}} = 0.027\ W_b^{1.71},$$

where W_b – channel width (according to Inglis 1949, after G. Williams 1988)

$$Q_b = \left(\frac{4.7R^{0.98}}{36}\right)^2,$$

where R – radius of meander in feet, Q_b – bankfull discharge in cubic feet (according to Leopold, Wolman 1960, after G. Williams 1988).

Seven out of these 60 paleochannels are the braided river channels older than the Allerød or the Younger Dryas. 3 out of 14 detailed measured paleomeanders are large meanders of the Allerød and of the Younger Dryas (nos. 11, 25 and 43), 2 are of the Boreal/ Atlantic transition (nos. 20 and 22), 5 of the Atlantic (nos. 8, 10, 16, 28a, 28b), 2 of the Subboreal (no. 27 – Zabierzów Bocheński, and no. 34) and 2 of the recent centuries (nos. 12 and 47). Their cross-sections are presented in Figure 7.

Comparison between the paleochannels of various ages indicates distinct, almost abrupt changes at the Vistulian/ Holocene transition, especially in the sections where channel avulsions occur (Kalicki 1992a, b; Starkel 1994). Differences in channel parameters are not likely due to the effect of increased frequencies of floods during short wet phases which lead to straightening and widening of the channels (the wet phases channels, except for those of the 17th–19th century, have not been preserved – cf. Starkel in: Alexandrowicz *et al.* 1981), but due to the stable periods preceding the floods when the channel forming discharges differed one from another (Fig. 8).

The oldest trough of the undoubtedly large paleomeander of the Vistula near Oświęcim was abandoned before 12 500 BP (no. 1 – Klimek 1992). At that time many rivers had braided pattern, as indicated by wide plains with shallow troughs which had been filled with peat in the Allerød, large channels were cut off, among others, downstream of Cracow (no. 11 – Kalicki 1991b; Kalicki, Zernickaya 1995), on the Wisłoka river near Strzegocice (no. 50 – Klimek 1992) and in the San valley near Dubiecko (no. 53 – Mamakowa 1962). The systems of braided channels in the lowerings of the Drwień and Drwinka rivers are of the Younger Dryas (nos. 23, 29 – Kalicki 1992a; Gębica, Starkel 1987) as well as the large paleomeanders in the Wisłoka valley (nos. 43, 44, 46, 49 – Starkel 1995d) and in the San valley (nos. 55, 56, 57, 59 – Szumański 1986). At that time both systems probably coexisted. For example, in the section of the Vistula valley downstream of Niepołomice, at the margin of the valley floor, the large paleomeanders that had been abandoned at the end of the Younger Dryas were identified (nos. 25, 26 – cf. Gębica, Starkel 1987; Kalicki *et al.* in this volume). In the lower Dunajec valley the change to the meandering system occurred at the beginning of the Holocene. Here, the large meander occurred at the beginning of the Holocene. Here, the large meander bends originated from the Early Holocene (nos. 36, 35 – Sokołowski 1995).

The parameters of the Holocene paleomeanders were smaller by an order of magnitude (widths were 2–4 times smaller, radii of curvature 2–5 times smaller, Fig. 7, 8). Except for the Dunajec river the channels abandoned 9–8 ka BP were

especially narrow and sinuous, that points to large water discharges of the Early Atlantic rivers. The parameters of the river channels, which had been abandoned ca 5.0 ka BP, were again smaller then those which had been abandoned in the Subboreal – larger (Kalicki 1991b). The transition from the end of the Atlantic to the Early Boreal was the period of the most evident avulsions of the channels. The several metres long sections of the paleochannels in Grobla Forest (Gębica, Starkel 1987; Starkel *et al.* 1991) and in Zabierzów Bocheński (Kalicki *et al.* in this volume) show how much the parameters of particular meander bends can differ within the whole system.

In the recent millennium there was a successive increase in the paleochannel parameters, related to the registered deforestation phases which, in turn, led to the shift of the braided channel pattern in the 16th–18th centuries (Klimek, Starkel 1974; Szumański 1977). The parameters of some rivers reached sizes similar to those of the lateglacial rivers (Fig. 7).

Results of the calculations of paleodischarges for 14 selected paleochannels were very interesting (Table 1). The Late Vistulian channels pointed to the bankfull discharges far exceeding those known from the 19th century. In most cases the young Holocene discharges were, at average, 10–20% of the Late Vistulian ones.

The above review shows that the records of the data concerning the features of the paleochannels of the Late Vistulian and the Holocene are not uniform as well as the extent to which they were studied (the best – in the Vistula valley downstream of Cracow – Kalicki 1991b, c, 1992a, b). The parameters of the paleomeanders indicate very well the changes in the discharges and in the river load transportation, while the times of their cut off and their avulsions usually correlate well with the phases of an increased flood activity, related to the rhythmicity in the climatic oscillations (Starkel 1983, 1994; Kalicki 1991e). If one draws the curve of the oscillations in the relative discharges, obtained from the present analysis, then this curve is an exemplification of the model presented by L. Starkel in 1983. This curve differs significantly from the only one, more detailed reconstruction of the changes in discharges in the Holocene in Central Poland, based upon the parameters of the paleomeanders in the Prosna river valley (Rotnicki 1991), where the features characteristic for given time were attributed to the particular dated paleomeanders. One should, however, assume that paleomeanders reflect the regime of longer periods of time. Besides, an increase in mean annual discharges in the Younger Dryas (up to 24 m^3s^{-1}) and an abrupt decrease at the beginning of the Holocene (to the values typical of the Holocene – 6 m^3s^{-1}), for single meander bends K. Rotnicki calculates an increase (to 18 m^3s^{-1}) at about ca 9.3 ka BP, to 10 m^3s^{-1} at 6.5 ka BP, and to 9.1 m^3s^{-1} at ca 4.2 ka BP. One should assume that an increase in the Preboreal was apparent and related to transformation of the channels inherited from the Younger Dryas.

T a b l e 1. Parameters of selected paleomeanders and their reconstructed paleodischarges

Valley locality *river*	Age (after ^{14}C or palynology)	Channel width W (m)	Meander radius R (m)	Q_{mean} (m^3/s)	Q_b (m^3/s)	References
Vistula Zabierzów Bocheński	early 19-th c.		580		1214	*R* after Trafas 1975
Wisłoka Grabiny	16–17-th c.	(48–50)	170	19.5	110	Starkel 1995d
Raba Uście Solne	> 2710±60	32 (24–40)	150–300	10.1	86–334	Gębica 1995
Vistula Śmiłowice	> 3090±140	~90	~340	48	426	Kalicki unpublished
Vistula Zabierzów Bocheński	> 4410±130	42	190	16.1	136	Kalicki *et al.* in this volume
Vistula Branice	> 5190±70	(30–50)	220	14.8	182	Kalicki 1991b
Vistula Grobla Forest (younger system)	> 5090±110	58 (45–70)	125–165 or sinuous	28.0	60–103	} Starkel, Kalicki 1984, Gębica, Starkel 1987, Starkel *et al.* 1991
Vistula Grobla Forest (cut-off channel)	> 5420±110	50 (45–55)	125–235	21.7	60–207	
Vistula Czyżyny	> 6450±130	70	300	38.6	334	Kalicki 1991b
Vistula Rybitwy	> 7740±90	(40–60)	100–220	21.7	38.7–182	Kalicki 1991b
Vistula Lasówka	> 7980±160	(30–50)	130–240	14.8	65–215	Kalicki 1991b
Vistula Borek	> 9800±80	(160–180)	670	176	1611	Kalicki unpublished
Wisłoka Wola Żyrakowska	late Younger Dryas	128	750	108	2010	Starkel, Granoszewski 1995
Vistula Nowa Huta Plac Centralny	late Allerød > 11 090±120	(120–130)	650	104	1519	Kalicki 1987, 1992

$Q_{mean} = 0.027\ W_b^{1.71}$, where W_b – channel width (after Inglis 1949, from G. Williams 1988)

$Q_b = \left(\dfrac{(4 \cdot 7R^{0.98})}{36} \right)^2$ where R – radius meander in ft, Q_b – bankfull discharge in cu. ft. sec. (after Leopold, Wolman 1960, from Williams 1988)

2. 5. RHYTHMICITY OF FLOODS AT THE BOREAL–ATLANTIC TRANSITION IN THE ALLUVIAL FAN AT PODGRODZIE UPON THE WISŁOKA RIVER

Elżbieta Czyżowska, Leszek Starkel

History of research and methods

The site at Podgrodzie, found in the early 1970s by K. Czekierda, due to its thickness (15.75 m) and sediment diversity (paleochannel fill buried by an alluvial fan) has been investigated by various sedimentological (Niedziałkowska *et al.* 1977), palynological (Mamakowa, Starkel 1977), later by malacological methods (Alexandrowicz *et al.* 1981) as well as dated by radiocarbon method by M. A. Geyh from Hannover (15 samples). The grain size composition was analyzed by sewing and areometric method. Then the Folk-Ward indexes were calculated (Mz, δ, S_k, K) as well as the $CaCO_3$ content and roundness index was measured using Krygowski graniformametric method.

In the 1980s E. Niedziałkowska (1991) extended their investigations by surveying a transect exposed in the lateral rim of a landslide (Fig. 9). The NE inclination and thickening of beds were stated.

In 1993 E. Czyżowska in consultation with E. Niedziałkowska sampled a new step-like profile from the retreating niche (ca 15 m from the previous exposure). Altogether 183 samples were taken, among them 21 from clay horizons with high organic content (Fig. 9). Even 2–3 mm thick laminae were sampled. From the uniform layers 10–20 cm thick 2–3 samples were taken. These small samples of fine material were analyzed by Laser technique (Analyssette 22 produced by Fritsch) under J. Sala's supervision in the laboratory of the Department of Geomorphology and Hydrology. In clay and sandy samples with organic matter carbon content was determined by loss on ignition.

The lithology of the profile after previous investigations

The Podgrodzie site exposes the structure of the alluvial fan of a small creek Maga, 2.3 km long and 1.2 km^2 catchment. It dissects the escarpment of the Carpathian Foothills built of Inoceramus sandstones and shales overthrust on the Miocene claystones.

Lower members (A and B) of the Pleniglacial colluvia and alluvia are cut by an erosional surface covered with gravels and sands of the Younger Dryas (member C) forming a floor of a paleochannel. The fill of the channel is formed by deltaic sands and silts (member D), later buried by gyttja, wooden peat and other oxbow-lake sediments (member E). These sediments were deposited between 9950 and 8390 ±105 BP. The existence of thin clayey and sandy intercalation above the horizon dated at 9160±135 BP, dipping 10–15° towards NE-E, suggests the input from the tributary creek. The lack of the redeposited Miocene pollen (Mamakowa, Starkel 1977) may indicate the absence of erosion of the Miocene beds in the Maga channel and filling of the paleochannel only by largest floods of the Wisłoka river. The upper member F, 9.17 m thick, is the alluvial fan sediment, deposited by the Maga creek, dipping 10–15° to NE. It is built of alternating sandy, silty and clayey-sandy (with the organic admixture) beds, with a high content of rebedded Miocene pollen. These distinct

breaks in deposition are clear, especially in the upper part, where the fossil soil horizons are present. Several buried vertical tree stumps with root systems, well preserved pollen and radiocarbon dates show that this member, ca 6 m thick, was deposited during a relatively short time span between 8390±105 and 7785±145 BP (Fig. 10).

Excluding the top, 2.25 m, thick part with lamination destroyed by pedogenesis, E. Niedziałowska and L. Starkel counted 29 sandy layers of the total thickness of 3.96 m and mean Mz 1.7–4.0, 30 silty and silty-sandy beds of the total thickness of 1.94 m and 16 clay organic horizons of swampy character. Analyzing the sequence of the beds it has been stated that at least 24 floods were registered during 600 years (Niedziałkowska *et al.* 1977).

All fan deposits show weak sorting and weak roundness of sand grains, generally better in sandy layers ($Wo > 1000$) than in sandy-silty ones ($Wo – +800–900$) (cf. Niedziałowska 1991). Thus, it is concluded that the growth of the fan was synchro-nous with the flood phase registered in many localities in Southern Poland (Ralska--Jasiewiczowa, Starkel 1975; Starkel 1984).

The results of investigations of the section surveyed in 1993

The total thickness of a new profile reaches 8.70 m. The silty, clay or sandy horizons with the high organic content, representing longer breaks in deposition, form 17.3% (130 cm) of the total thickness. The top part of 120 cm, transformed by pedogenic processes, was not considered.

Based on all the grain size analyses and using the slightly modified Shepard's classification (1954) helped in distinguishing the following 5 groups: clayey silt, silt, sandy silt, silty sand and sand. The other 4 groups were not present. Among all the samples the most frequent are sands (43,7%), as well as silty sands (24.8%). The thickness of various grain size groups shows the similar pattern. The sandy layers, together 3.22 m thick, represent 42.9% of the total thickness (including peat). The total thicknesses of other groups are presented in Table 2.

T a b l e 2. Thickness of particular type of lithological sediments and percentage of sediment of the alluvial fan at Podgrodzie

	Grain classes									
	Clay	Silty clay	Sandy clay	Clayey silt	Silt	Sandy silt	Clayey sand	Silty sand	Sand	Peat
Thickness [cm]	–	–	–	21.5	7.0	122.5	–	148.0	322.0	130.0
[%]	–	–	–	2.9	0.9	16.3	–	19.7	42.9	17.3

Characteristic of sediments is based on the lithological indicators proposed by Folk and Ward (1957). The mean grain sizes (Mz) of the discussed fan fluctuate between –2.29 to 6.34 with distinct peaks between +2.0–3.0 (26.1%) and 4.0–5.0 (26.8%). Their standard deviation indicate weak sorting ($\delta = 1–2$, 26.1%) and very weak sorting ($\delta – 2–4$, 26.8%). Skewness varies from –0,3 to +1,0 with dominance between –0.11
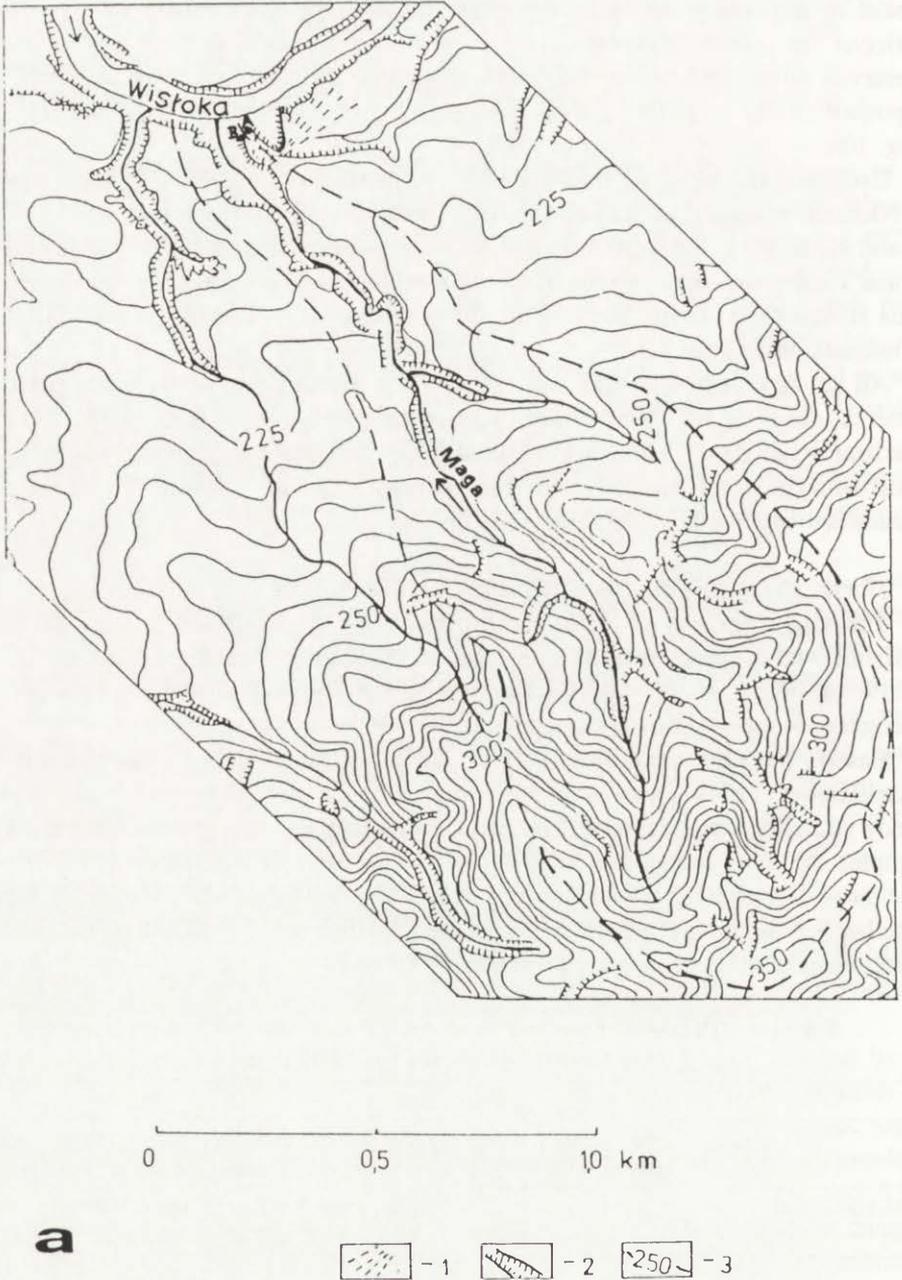
Fig. 9. Localization of elaborated profiles of the alluvial fan at Podgrodzie

a. Hipsometric of the Maga catchment: 1 – alluvial fan, 2 – undercuts, 3 – isohipses; b. Localization of
elaborated profiles of the alluvial fan (A, B): 4 – landslide edge, 5 – profiles, 6 – profile number;
c. Cross-section of the alluvial fan deposition at Podgrodzie, according to E. Niedziałkowska (1991):
7 – alluvial fan deposits, 8 – paleochannel filling deposits, 9 – redeposited Miocene clay, 10 – position of
studies profiles, 11 – other profiles, 12 – phase of deposition; PL – Younger Pleniglacial, PB – Preboreal,
BO – Boreal, AT – Atlantic, 13 – radiocarbon datings
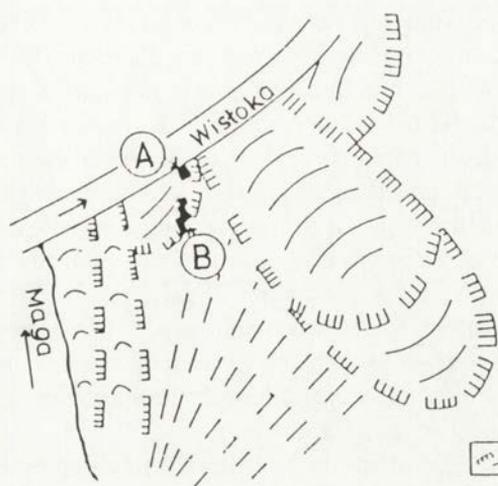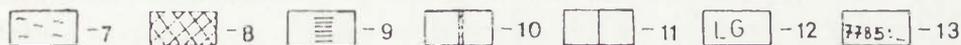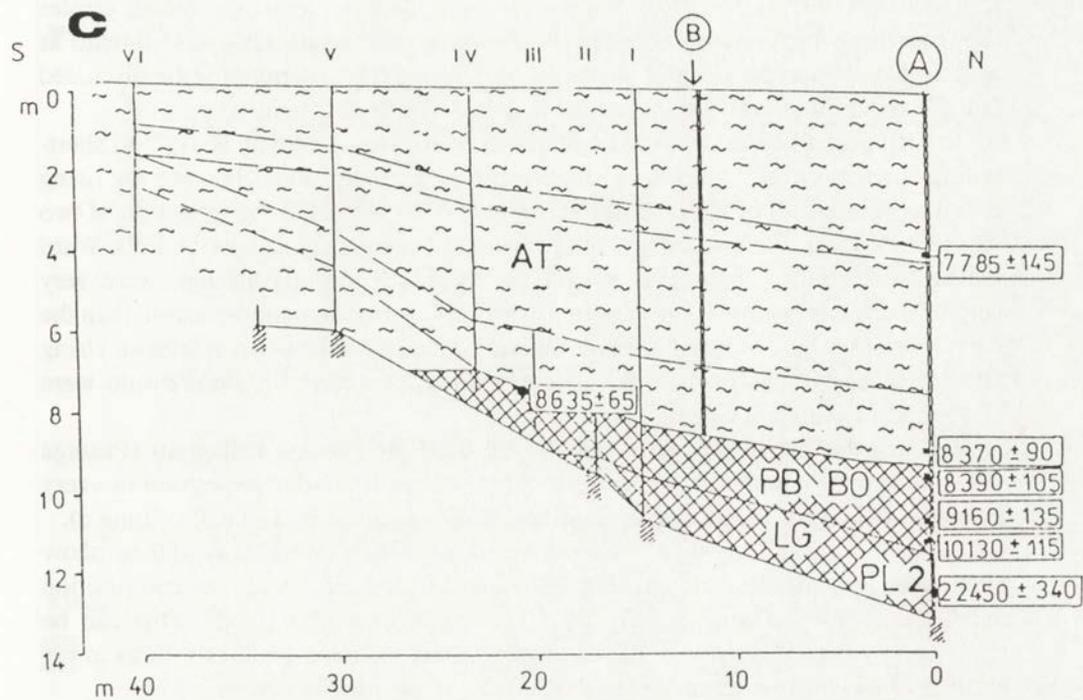
and +0.72 (28.1%). Kurtosis covers the diapazone from 0.53 to 2.60 with culmination between 1.11 and 1.50.

The detail recognition of lithological parameters of all layers visible in the profile, the position of particular samples on the C/M Passega's diagram (1969), as well as the examination of sedimentological structures varying in the vertical section, were the background for several approaches in distinguishing particular flood episodes and their groups, separated by distinct breaks visible in organic deposition. Several criteria have been used. The first, most general criterion allows for separating flood sequences based on the above mentioned fine grained layers with high organic content (7–23%). 14 swampy horizons like that helped to distinguish 14 phases of floods (Table 3).

A more detailed analysis, based on the other criteria, allows to discriminate in each complex single beds or sequences of beds which may respond to a particular flood event.

The recognition of a sequence of thin layers formed during one flood is very difficult, because it needs a detailed reconstruction of transportation and deposition in the very unstable environment of the alluvial fan.

Studies on the overbank deposits of the Wisłoka river carried by Klimek (1974b) and Niedziałkowska (1991) have shown that one flood in a larger catchment creates the sequence, which reflects both the rise in water level (coarsening of sediment) as well as its fall (finer sediment towards the top). Using this criterium for the discussed fan, 94 single flood events may be distinguished (Table 3, column a).

In such a small catchment the flood events were connected with heavy and short-lasting downpours (cf. Soja 1981). Therefore, two parts explained above by the rising or falling water level of the same flood, should be considered as the reflection of two different floods of various energy. In separation of coarser sequences the Folk-Ward indices, indicating a continuous rise of the dynamics towards the top, were very helpful. Such a sequence is interpreted as several floods that are more active than the previous ones or as disturbing the equilibrium of the channel system upstream. Using this criterium several sequences were identified and altogether 100 flood events were distinguished (Table 3, column b).

The distribution of particular samples on the C/M Passega's diagram (Passega 1964) allows for a more detailed analysis of the dynamics during deposition of every layer and finally for identification of up to 122 flood episodes (Table 3, column c).

94 flood events among them are represented by a single layer. Many of them show similarities, nevertheless the existing differences (thickness, grain size composition and indices) show a great variety of dynamics of particular floods. This can be explained by the differences in the discharge, in the sediment load, as well as in the shifting of the shallow channel over the surface of the alluvial fan.

The remaining 24 floods are represented by more complex sequences. The sequence consisting of 5 layers, being 23 cm thick, is especially interesting. It shows consecutive changes of Mz from 2.29ø at the base, the changes from the turbulent flow of suspended load to the uniform suspension without any differentiation of a density in a vertical profile (Passega 1964; Passega, Byramjee 1969).

There were also distinguished: 1 flood represented by 4 layers, 6 floods by 3 layers and 16 – represented by 2 layers.

T a b l e 3. Quantity of flood events selected on the base of the four criteria for fourteen periods of the flood sedimentation of the alluvial fan at Podgrodzie

Selected periods of flood sedimentation				Quantity of floods based on particular criterion		
^{14}C dating	Period	Depth of base [cm]	Thickness [cm]	a	b	c
7785±145 BP	I	312.0	192.0	14	26	27
	I/II	322.0	10.0			
	II	355.0	33.0	2	2	5
	II/III	360.0	5.0			
7820±100 BP	III	382.0	22.0	3	6	6
	III/IV	392.0	10.0			
	IV	408.0	16.00	4	5	6
	IV/V	409.0	1.0			
	V	462.0	53.0	3	13	16
	V/VI	465.0	3.0			
8015±135 BP	VI	567.0	102.0	8	18	19
	VI/VII	571.0	4.0			
	VII	572.0	1.0	1	1	1
	VII/VIII	575.0	2.0			
	VIII	585.0	10.0	1	2	2
	VIII/IX	608.0	23.0			
	IX	627.0	19.0	4	6	9
	IX/X	634.0	7.0			
	X	772.0	138.0	5	13	20
	X/XI	800.0	28.0			
	XI	807.0	7.0	1	1	1
	XI/XII	814.0	7.0			
	XII	824.0	11.0	1	2	3
	XII/XIII	830.0	5.0			
	XIII	841.0	11.0	1	3	4
	XIII/XIV	842.0	1.0			
	XIV	848.0	6.0	1	1	3
8390±130 BP	XIV/XV	871.0	23.0			

▨ – peaty layers (with sand admixture) containing higher quantity of organic matter.

Taking into consideration the time of deposition ca 600 years (between two radiocarbon dates) we stated, using the last discussed criterium, that during this period 95 flood events were registered (Table 3).

During this period 12 breaks were registered by horizons with organic sediments and distinct signs of pedogenesis. The distribution of floods, as well as the lenght and distribution of organic deposition, were very diversified.

Conclusions and discussion

Surveying the sequence of the fan deposits at Podgrodzie from the very beginning we assumed that at the margin of the fan we could not have obtained the registration of all the floods produced by the Maga creek.

The creek changed its water course in time, therefore many floods are not registered in the discussed profile. It may be documented by comparing two main profiles sections described in 1970s and 1993. These profiles are located in the same part of the alluvial fan and continuity of the main series and organic horizon, however they register several differences in number and character of floods.

The existence of deeply rooted stamps and swampy character of intercalations support the opinion about lack of erosional breaks and preservation of primary deposits. Only slight erosion could exist during floods, formed in the same year or consecutive years, when the surface could not be re-vegetated and easily eroded.

The fan sequence shows several regularities in deposition. There existed flood phases, which lasted several years up to several decades, but which differ in their length, number of floods and thickness of sediments. During the fan deposition precipitation and runoff regime, as well as the dynamics of sediment load, were very unstable. Between breaks with organic horizons the series from several cm up to 192 cm thick were deposited! Such breaks may indicate decline in heavy rain frequency, but also shift of a channel or cutting of a deeper channel. The main buried soil horizon, dated at 7785±145, BP suggested that this particular break was much longer than the others (several centuries?) and later aggradation continued again for some time.

The results of detailed analyses made by E. Czyżowska (in press) agree with the previous opinion (Niedziałowska *et al.* 1977; Starkel 1984) that the Podgrodzie site registered the phase with very frequent floods causing so rapid aggradation. This phase corresponds well to the time of floods registered in many other localities in the Carpathian valleys (Ralska-Jasiewiczowa, Starkel 1975; Starkel 1983, 1984; Kalicki 1991c).

The floods in the valley floors of larger basins in Southern Poland are mainly caused by continuous rainfalls or by rapid snowmelt (Starkel ed. 1989). Small creeks could react to downpours of high intensity and short duration. The studies at Szymbark experimental station have shown that at present the rainfall intensity may reach 50–100 mm during 30 to 120 minutes and be followed by an intensive runoff (Słupik 1973; Soja 1981). The simultaneous occurrence of such local floods, on a scale of centuries, with the high flood frequency in large river basins (Starkel 1984) may indicate a general increase in rainfalls and increase in frequency of various extreme events after the relatively stable early Holocene with drier, continental climate (Starkel 1984, 1991a). For the same period, also in the Tatra Mts. Kotarba (1993) indicated a phase of debris flows, which may be related only to heavy downpours.
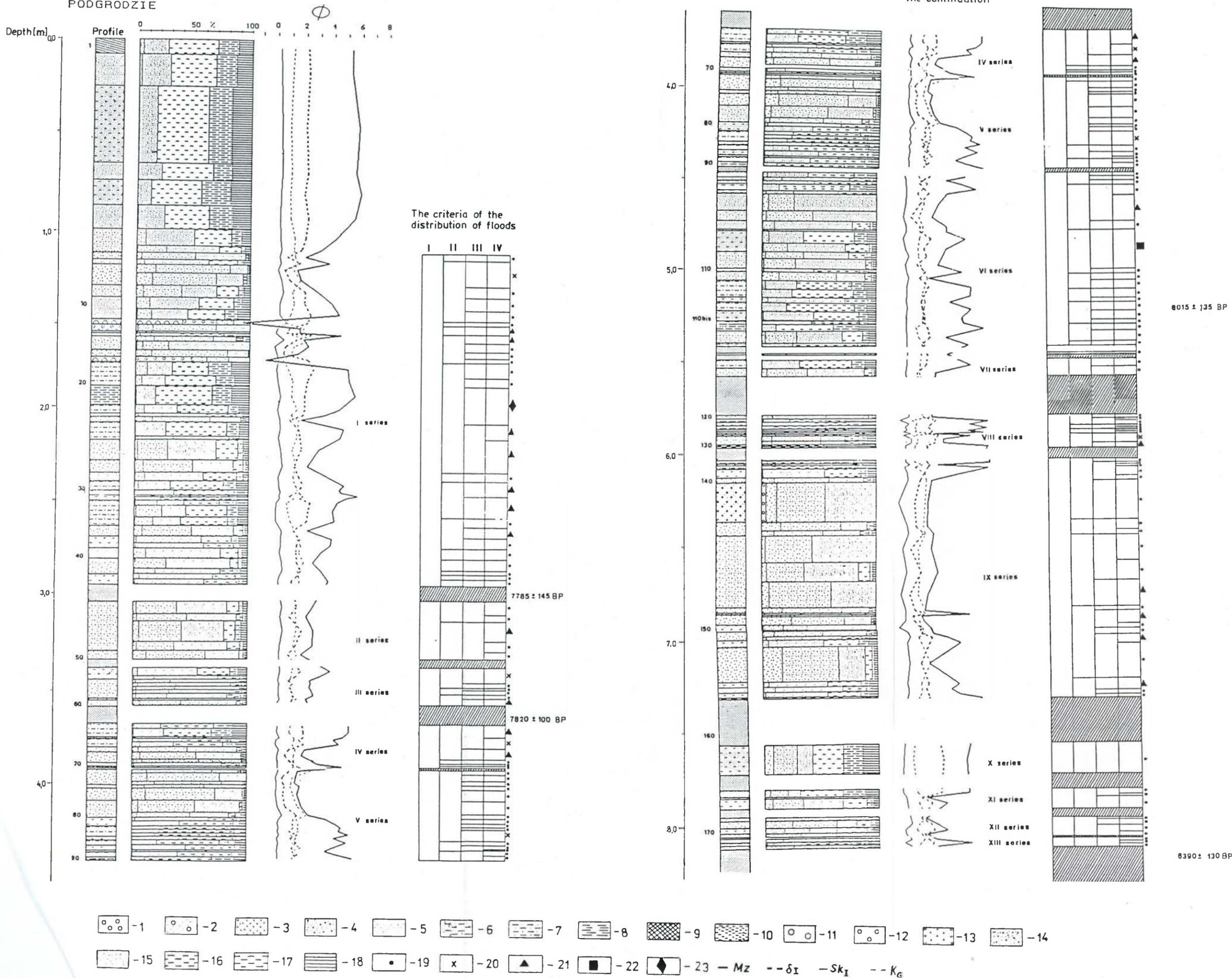
Fig. 10. Sequence and granulometry of newly elaborated profile B at Podgrodzie

Sediments: 1 – gravels, 2 – sands with gravels, 3 – coarse sands, 4 – medium sands, 5 – fine sands, 6 – silty sands, 7 – sandy silts, 8 – silts, 9 – peats, 10 – soil. Fractions: 11 – medium gravel, 12 – fine gravel, 13 – coarse sand, 14 – medium sand, 15 – fine sand, 16 – coarse and medium silt, 17 – fine silt, 18 – clay. The structure of particular floods on the ground of the fourth criteria: 19 – the flood sequence composed of one layer, 20 – the flood sequence composed of two layers, 21 – the flood sequence composed of three layers, 22 – the flood sequence composed of four layers, 23 – the flood sequence composed of five layers. Folk and Ward's grain size distribution parameters; Mz – mean grain size in phi scale, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis

3. OVERBANK DEPOSITS AS INDICATORS OF THE CHANGES IN DISCHARGES AND SUPPLY OF SEDIMENTS IN THE UPPER VISTULA VALLEY – THE ROLE OF CLIMATE AND HUMAN IMPACT

Tomasz Kalicki

State of the studies

The madas building the top of the floodplains were considered by numerous researchers to be the deposits associated with human activity (Klimaszewski 1948; Mensching 1951). However, the following studies documented that the madas had been deposited in various periods of the Late Glacial and Holocene (Pożaryski 1955; Starkel 1960; Rutkowski 1987; Kalicki 1991c, 1994). In some papers two types of madas were distinguished: the "old" one – clayey mada and the "young" one – sandy mada. The different grain size composition of the madas was to correspond to their different age (Pożaryski 1955; Kowalkowski, Starkel 1977). In the 1980s the number of the radiocarbon dated mada profiles increased quickly, but the quantitative data as to the grain size composition of the madas were available only in a few cases (Starkel ed. 1982, 1987, 1990). Exceptional in this respect there are the papers referring to the Vistula valley (Niedziałkowska *et al.* 1985; Niedziałkowska 1991; Kalicki 1991b, 1992a, b; Kalicki, Krąpiec 1991a, b; Starkel *et al.* 1991; Gębica 1995), to the Wisłoka valley (Kowałkowski, Starkel 1977; Starkel, Granoszewski 1995; Starkel, Krąpiec 1995) and to the Raba valley (Alexandrowicz, Wyżga 1992). J. Rutkowski (1987) pointed to the differences in the grain size composition of the madas on the floodplains and within the paleomeanders of various generations in the Cracow Gate. The first summary of the quantitative data on the overbank deposits in the Vistula valley near Cracow was attempted by T. Kalicki (1991c). The analysis of the grain size composition of the flood deposits and of the abandoned channel fills indicated the variability corresponding to climatic changes at the transition from the Late Glacial to the Holocene and to the anthropogenic deforestation and development of agriculture in the Neoholocene. The youngest madas showed variability in the grain size composition, which was associated with a distance from an active channel. The analogous variability was stated in the Vistula fan in the madas of the last millennium (Niedziałkowska 1991). However, it was shown later that the variability related to the distance from the channel occurred also in the older mada covers (Kalicki 1991b, 1992a, b).

Aim and method

Madas are the overbank deposits dropped by flood waters on the morphologically differentiated floodplain. These are most often badly and very badly sorted fine sedi-

Table 4. List of the madas (age and facies) in the Sandomierz Basin (Vistula valley and Raba fan)

Age	Type of mada (facies)				
	lv	fp	bs	ob-cf	cf
Pre-Allerød	> 11 920 BP R1 d = 2,70–3,40 m 5p Mz = 2,7–6,5ø δ_l = 1,7–2,9 > 11 860 BP Gr1 d = 2,50–2,80 m 3p Mz = 4,7–7,3ø δ_l = 2,4–3,4				
Allerød		> 11 630 BP R/87 d = 2,45–2,95 m 3p Mz = 5,3–7,3ø δ_l = 2,4–2,6			10 920 BP B15 2p Mz = 5,7–6,2ø δ_l = 2,0–2,4
Younger Dryas	~ > 10 520 BP G16 d = 1,6–2,2 m 4p Mz = 1,9–5,3ø δ_l = 0,8–1,5 > 9840 BP G27d = 1,72–2,20 m 2p Mz = 3,6–3,9ø δ_l = 3,6		10 820–10 020 BP Gr1 d = 1,82–1,89 m 1p Mz = 8,9ø δ_l = 2,0 < 10 640 BP US18 d = 3,40?–3,55 m 1p Mz = 7,9 δ_l = 2,5ø < 10 440 BP Sz1 d = 3,67?–3,97 m 1 p Mz = 8,3ø δ_l = 2,6	< 10 920 BP B15 2p Mz = 3,7–4,2ø δ_l = 2,0–2,3	> 9660 BP NH d = 2,48–4,70 m 22p Mz = 3,2–6,7ø δ_l = 1,9–2,6
PB		< 9660 BP R1 d = 1,80–2,40 m 4p Mz = 6,1–7,2ø δ_l = 2,2–2,4	< 9480 BP STM11 d = 2,0–2,2 m 1p Mz = 9,5 δ_l = 2,1		

BO	> 9280 BP Pr1 d = 2,05–2,65 m Pr6 d = 1,65–2,50 m 10p Mz = 0,9–5,6ø δ_l = 0,4 = 2,7	> 9280 BP Pr1 d = 1,1–2,05 m Pr6 d = 0,00–1,65 m 9p Mz = 4,2–6,0ø δ_l = 2,1–3,1	9840–8010 BP G27 d = 0,95–1,50 m 3p Mz = 6,9–8,4ø δ_l = 2,8–3,5 < 8890 BP R/87 d = 1,70–2,15 m 2p Mz = 6,5–6,9ø δ_l = 2,3–2,8	< 8540 BP G26 d = 2,6–2,9 m 2p Mz = 6,7–7,5ø δ_l = 2,4–2,7	> 8650 BP G26 d = 3,0–3,92 m 3p Mz = 1,0–3,2ø δ_l = 1,4–2,3 8650–8540 BP G26 d = 3,0–3,92 m 4p Mz = 5,5–6,2ø δ_l = 2,2–2,6
AT-1		< 8090 BP STM11 d = 0,85–1,85 m 5p Mz = 5,5–7,2ø δ_l = 2,1–2,7 < 8010 BP G28 d = 0,50–0,85 m 2p Mz = 7,2–8,7ø δ_l = 2,5–2,8 < ~8010 BP G27 d = 0,60–0,95 m 2p Mz = 7,7–9,4ø δ_l = 2,3–2,6		< 7980 BP Dr d = 0,35–1,05 m 3p Mz = 8,4–10,0ø δ_l = 1,9–2,4	> 7980 P LA1 d = 1,62–2,80 m 3p Mz = 4,4–6,3ø δ_l = 2,1–2,5 > 7210 BP STM4 d = 4,35–6,35 m 6p Mz = 4,4–8,8ø δ_l = 2,2–2,8
AT–2/AT–3	< 6670 BP STM4 d = 1,4?–3,25 m 8p Mz = 4,9–5,6ø δ_l = 1,9–2,3		R/87 d = 0,4–1,7 m 7p Mz = 7,4–9,7ø δ_l = 1,8–3,1 R1 d = 0,6–1,8 m 5p Mz = 7,7–9,7ø δ_l =1,9–2,4 G16 d = 0,0–1,5 m 8p Mz = 6,5–9,0ø δ_l = 2,3–2,7 G15d = 1,4–2,1 m 6p Mz = 6,8–9,4ø δ_l = 2,0–2,6ø Pr1 d = 0,00–1,10 3p Mz = 7,0–8,8ø δ_l = 2,2–3,1	< 6780 BP R3 d = 0,75–2,10 m R2 d = 0,85–1,80 m 8p Mz = 8,0–9,2ø δ_l = 2,0–2,7 < 6690 BP ŁBd =?1,80–3,10 m 5p Mz = 4,3–4,7ø δ_l = 1,5–2,2 > 6670 BP STM4 d = 3,6–3,8 m 1p Mz = 6,8ø δ_l = 2,1 < 6160 BP LA1 d = 0,00–0,80 m LA2 d = 0,00–1,60 m 10p Mz = 7,8–9,1ø δ_l = 2,3–2,8	

AT–4	< 8540 BP, ~5500 BP? G26 d = 1,27–2,6 m 7p Mz = 2,4–4,1ø δ_l = 1,8–3,0 5400–5000 BP G20 d = 1,0–2,6 m 8p Mz = 2,9–5,9ø δ_l = 1,0–2,4	< 8540 BP, ~5500 BP? G26 d = 0,5–1,27 m 2p Mz = 6,7ø δ_l = 3,3–3,6 <8170 BP, ~5500 BP? G18 d = 0,0–1,9 m 8p Mz = 3,2–6,4ø δ_l = 1,4–4,5 ~5500 BP? G25 d = 1,05–1,8 m 3p Mz = 3,0–4,3ø δ_l = 2,2–2,4 5400–5000 BP? G20 d = 0,0–1,0 m 2p Mz = 6,0–6,2ø δ_l = 2,2–2,4		< 5460 BP G19 d = 0,4–2,0 m 9p Mz = 3,6–6,7ø δ_l = 1,8–3,0 < ~5420 BP G24 d = 1,2–2,9 m 7p Mz = 7,2–8,4ø δ_l = 2,3–2,7 < 5230 BP PRI d = 2,9–3,85 m 2p Mz = 4,8–5,1ø δ_l = 2,3ø < 5190 BrA1 d = 1,15–1,40 m 2p Mz = 6,5–6,7ø δ_l = 2,9	> 5460 BP G1 d = 2,0–4,7 m 10p Mz = 2,0–7,1ø δ_l = 1,2–2,9 > 5230 BP PRI d = 4,5–5,6 m 2p Mz = 4,6ø δ_l = 2,0–2,2
SB–1				Dr d = 0,00=0,35 m 1p Mz = 5,7 δ_l = 3,3ø	5090–4060 BP G22d = 1,35–3,0 m 5p Mz = 1,5–8,1ø δ_l = 0,6–3,0
SB–2	G15 d = 0,45–1,4 m 4p Mz = 2,5–8,5ø δ_l = 0,9–2,7		STM11 d = 0,20–0,85 m 1p Mz = 9,8ø δ_l = 1,9	< 4060 BP G22 d = 0,0–1,35 m 5p Mz = 6,9–8,7ø δ_l = 2,2–3,3	
SB–3			G27 d = 0,0–0,6 m 2p Mz = 8,6–8,7ø δ_l = 2,8–3,0	< 3290 BP Bg4c d = 0,4–1,0 m 1p Mz = 6,2ø δ_l = 3,2 BrA1 d = 0,20–1,15 m 10p Mz = 5,8–8,1ø δ_l = 2,7–3,3	> 2710 BP US1 d = 2,35–3,40 m 4p Mz = 4,2–8,0ø δ_l = 2,0–2,5 > 2620 BP STM8 d = 2,0–3,6 m 6p Mz = 2,4–6,3ø δ_l = 1,8–2,5

SA-1		> 2370 BP API d = 1,60–1,85 m 2p Mz = 6,0–6,9ø δ_I = 2,6–2,7 < 2370 BP API d = 0,70–1,05 m 1p Mz = 4,4ø δ_I = 2,4		< 2710 BP US1 d = 0,0–2,15 m 3p Mz = 7,5–8,9ø δ_I = 2,4–2,7 < 2620 BP STM8 d = 0,0–1,80 m 4p Mz = 5,3–7,1ø δ_I = 2,0–2,3	2200 BP B3 3p Mz = 1,3–6,7ø δ_I = 0,4–2,7
SA-2	1850–1680 BP B2 d = 3,05–3,25 m 2p Mz = 2,6–5,5ø δ_I = 0,5–2,3	1850–1680 BP B2 d = 1,00–3,05 m 5p Mz = 5,2–7,3ø δ_I = 2,0–2,6 > 1680 BP B30 d = 2,1–3,5 m 6p Mz = 2,7–5,9ø δ_I = 2,0–3,3	R/87 d = 0,00–0,40 m 2p Mz = 7,6–8,5ø δ_I = 2,2–2,8 R1 d = 0,00–0,60 m 3p Mz = 7,8–8,5 δ_I = 2,6–3,0ø G15 d = 0,00–0,45 m 2p Mz = 7,4–8,6ø δ_I = 2,4–2,7		
SA-3	< 1660 BP XIV w.? B26 d = 1,2–2,2 m 4p Mz = 1,2–4,7ø δ_I = 0,5–2,1 XIV w.? B20 d = 1,0–1,25 m 2p Mz = 3,1–3,7ø δ_I = 1,2–1,4	< 1680 BP, XIV w.? B30 d = 0,80–2,10 m 4p Mz = 4,8–5,8ø δ_I = 2,0–2,4 < 1660 BP XIV w.? B26 d = 0,00–1,2 m 1p Mz = 6,5ø δ_I = 2,5 XIV w.? B2 d = 0,00–1,00 m 2p Mz = 5,2–6,0ø δ_I = 2,0–2,3 XIV w.? B20 d = 0,00–1,2 m 4p Mz = 5,7–6,5ø δ_I = 2,4–2,7 XIX w. G1 d = 0,00–0,35 2p Mz = 3,3–4,5ø δ_I = 2,2–2,8		< 3030 BP ŁA d = 0,00–0,50 m 1p Mz = 6,2ø δ_I = 3,1 BrA1 d = 0,0–0,2 m 2p Mz = 6,3–6,5ø δ_I = 3,0 G19 d = 0,00–0,40 m 1p Mz = 8,1ø δ_I = 2,5 R3 d = 0,00–0,75 m R2 d = 0,00–0,85 m 2p Mz = 5,3–7,5ø δ_I = 2,6–2,8	

d – deep in profile, p – number of samples.

ments – silts and clays, but also clayey sands and in the case of levee – sands. In the papers dealing with classification of the overbank deposits (Allen 1965; Starkel, Thornes 1981; Teisseyre 1985, 1988; Gradziński *et al.* 1986) some facies of the madas corresponding to the sedimentation conditions and morphology of the floodplain have been distinguished. In the present work, besides the commonly distinguished facies of levee (lv), floodplain (fp), backswamps (bs), and crevasses (cr), an additional facies of madas deposited in the abandoned channels (ob-cf) has been distinguished separately from the abandoned channel fills (cf). The madas of the latter facies (ob-cf) are accumulated on the organic deposits in the abandoned meander bends in the final stage of the abandoned channel filling, when the height difference between the paleochannel and the plain on the point bars becomes insignificant. Therefore, the mechanism of the mada sedimentation is analogous to the typical madas, but differs significantly from the oxbow-lake and bog sediments filling the channels in the first stages. In the present work, the profiles dated directly and indirectly, and for which quantitative data on the grain size composition of the madas are available are taken into account. Besides the author's results, the preliminary materials provided by L. Starkel, and P. Gębica were elaborated. However, when the above results were put together many problems as to the merits and methods have been encountered. Particular problems appeared in the case of the mada profiles. The post-sedimentation soil profiles and the later penetration of roots destroyed the original record of events if such have existed at all. The date from the base of the mada profiles cannot be assigned to the whole mada cover but only to its lower part directly overlaying the dated sediments. The age of the upper part of the profile can only be interpreted in relation to the general geomorphic situation. The changes in the sequences of the deposits have been accepted as the boundaries between the mada covers in such profiles. Furthermore, the datings of the intra-mada humus layers and buried soils allow for the dating of the directly overlaying series and, with a substantial approximation (older than...), the underlying series. Moreover, the date from the humus layer is also the averaged value of the period in which the floods were rare. Yet another problem is related to uneven representation of various sedimentation environments, because the majority of the studied profiles originated from the abandoned channels or backswamps, where the organic horizons allowing for the dating below and above occur.

The largest number of records originated from the section of the Vistula valley between Cracow and the Raba river mouth (Kalicki 1991b, 1992a, b; Starkel *et al.* 1991; Gębica 1995). Despite the fact that the studies were carried out by one research group using seemingly one approach, the density of sampling in the particular profiles was different. Recently additional methodologial problems emerged, because the profiles were previously examined by the aerometric method and currently by the Fritsch's laser method. Different is also the method for calculating Folk and Ward's indices, especially when interpolating the curve for the fine fractions, i. e., the fractions typical of the mada profiles. In the studies on the Vistula valley downstream of Cracow one methodology for extrapolation of the cumulative curve to 14ø (Folk-Ward 1957) has been accepted. Unfortunately, it was impossible to recalculate the data from the older papers as they were lacking complete quantitative preliminary data. All these
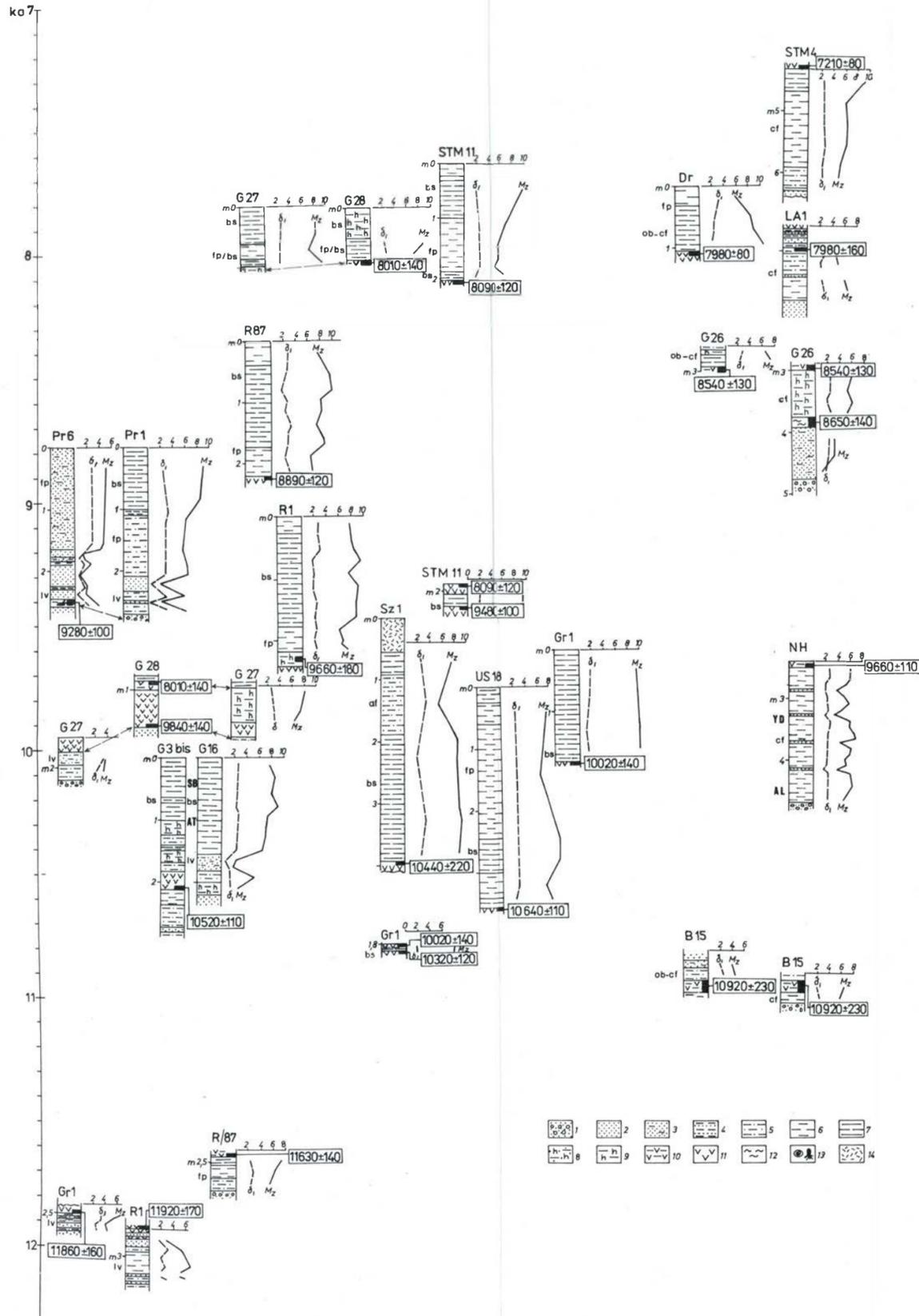
Fig. 11. Profiles of overbank deposits (mada) and abandoned channel from the Vistula and Raba valley, deposition of which started between 12 and 7 ka BP (see Fig. 1)

Fig. 12. Profiles of overbank deposits (mada) and abandoned channel from the Vistula and Raba valley, deposition of which started after 7 ka BP (see Fig. 1)

Explanation – see Fig. 11

1 – gravels with sand, 2 – sands, 3 – silty sands, 4 – sands with interbedding of silts, 5 – sandy silts, 6 – silts, 7 – clayey silts, 8 – organic sandy silts, 9 – organic silts, 10 – peaty silts, 11 – peat, 12 – gyttja, 13 – tree trunks and stamps, 14 – mounds. Facies: bs – backswamp, lv – levee, fp – flood plain, ob-cf – overbank channel fill, cf – channel fill, af – alluvial fan, cr – crevasse

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methodological inconsistences should be taken into account when interpreting the results, especially if referring to absolute values. The preliminary records from the Vistula valley (42 profiles: 23 from the Cracow region, 12 – from Grobla Forest, 7 – from the Raba fan), including age of the profiles and division into facies, have been presented in Figures 11, 12 and in Table 4. Despite the fact that there are many profiles, the information resulting from the gathered materials is only fragmentary. For the sake of comparison there have also been presented the mada profiles from the Upper Vistula valley (4 profiles – Niedziałkowska *et al.* 1985; Niedziałkowska 1991), from the Vistula gap in the uplands (7 profiles – Pożaryski, Kalicki 1995), from the Wisłoka valley (7 profiles – Kowalkowski, Starkel 1977; Starkel, Granoszewski 1995; Starkel, Krąpiec 1995), and from the Raba valley (1 profile – Alexandrowicz, Wyżga 1991).

Vistula valley downstream of Cracow and the Raba fan

Sedimentological analyses and radiocarbon datings enabled to distinguish several mada covers of various age in the Vistula valley and in its Carpathian tributaries in the western part of the Sandomierz Basin (Fig. 11, 12, Table 4).

I. The Late Vistulian madas

The Late Vistulian madas occurred directly on the channel deposits of a braided river within preserved alluvial planes. They are overlain by organic deposits, so that it is possible to date the end of the mada accumulation. The Younger Dryas madas cover the Allerød peat. These are:

a) The pre-Allerød madas (older than 11 900–11 800 BP) of levee facies. These madas are 0.3 m thick on the Raba fan and 0,7 m thick in the Vistula valley. They are formed by alternated layers of coarser and finer deposits which are poorly and very poorly sorted. The difference in the form of these madas consists in a larger thickness of particular layers of the Vistula deposits. Moreover, the Vistula madas are slightly better sorted and coarser in the sandy and silty layers ($Mz = 2.7$–6.5ø) than the Raba deposits ($Mz = 4.7$–7.3ø).

b) The Early Allerød madas (older than 11 600 BP) of the floodplain facies. In the Vistula valley these madas are 0.5 m thick and are formed by very poorly sorted silty deposits ($Mz = 5.3$–7.3ø) fining upward.

c) The Younger Dryas madas preserved in various facies. In the Vistula valley within the levees there were deposited sands interlayered with sandy silts ($Mz = 1.9$– -5.3ø) which are medium and poorly sorted. In many places they were more uniform ($Mz = 3.6$–3.7ø) and slightly fining upward; and very poorly sorted. These deposits reached thickness of 0.5–0.6 m. Within the backswamps on the fans of the Raba and the Uszwica rivers very poorly sorted, clayey madas ($Mz = 7.9$–8.9ø) accumulated. Their thickness did not exceed 0.1–0.3 m. In the Vistula paleomeanders abandoned by the end of the Allerød silty muds ($Mz = 5.7$–6.2ø) and organic ones were replaced by sandy muds ($Mz = 3.7$–4.2ø) or there were deposited up to 2.2 m thick very poorly sorted sediments, mainly silty muds periodically interlayered with clayey sands ($Mz = 3.2$–6.7ø).

II. The Eoholocene madas

a) The Preboreal madas are preserved in two facies. Within the Vistula floodplain these were very poorly sorted silty muds (Mz = 6.1–7.2ø), sometimes slightly organic ones, which thickness reached 0.6 m.

Within the backswamps on the Raba fan very poorly sorted, 0.2 m thick, clays (Mz = 9.5ø) deposited.

b) The Boreal madas are preserved in all the facies. Therefore, the character of deposits on the whole floodplain can be reconstructed with a large accuracy. In the immediate vicinity of the active Vistula channel, on the fragment of the floodplain which was forming at that time, the levee deposits reaching fairly large thickness (0.6–0.85 m) were accumulated. The levee deposits were formed as alternated layers of sands and sandy muds (Mz = 0.9–5.6ø) which were well and very poorly sorted respectively. The levee deposits changed upward into the deposits of the floodplain which was in the vicinity of the channel. The floodplain deposits consist of very poorly sorted clayey sands and sandy muds (Mz = 4.2–6.0ø), slightly fining upward and reaching large thickness of 0.95–1.65 m. On the older fragments of the floodplain within the area of the lateglacial alluvial plain with peat, very poorly sorted silty madas (Mz = 6.5–6.9ø) were deposited closer to the channel. As the distance from the channel increased, the silty madas became more organic and clayey (Mz = 6.9–8.4ø), changing finally into clayey peat. These madas are 0.45 m thick. In the Vistula abandoned channels, after the first stages of filling with sandy sediments (0.8 m), organic and peaty muds (0.9 m) were deposited and then, by the end of the Boreal, they were covered with 0.3 m thick, very poorly sorted clayey muds (Mz = 6.7–7.5ø).

III. The Mesoholocene madas

On the old, lateglacial alluvial plains, which were lower than the meander belts and which formed backswamps, very poorly sorted clayey madas (Mz = 6.5–9.7ø) were deposited during the whole Atlantic period. Precise determination of their age is impossible, because they form a continuous profile without buried soils and do not contain materials allowing for dating. These madas, depending on the profile, cover the Younger Dryas levee deposits or the Eoholocene silty and sandy madas deposited on the floodplain. Their division into three members, according to the age, is determined by the datings of the base of the profile (the beginning of accumulation), but the end of sedimentation cannot be determined.

a) The Old Atlantic madas (younger than 8100–8000 BP) are preserved in some facies. In the Vistula valley, thin (0.2 m), very poorly sorted clayey madas (Mz = 8.7ø) were deposited on the floodplain while peaty muds were deposited slightly farther from the channel. Later on, the thickness of accumulated madas decreased (0.25–0.1 m) and their clay content increased (Mz changed from 7.2 to 7.5ø) with the increasing distance from the channel. When the system of meanders in Grobla Forest had been abandoned (ca 5100 BP), clayey madas (Mz = 8.6–9.2ø) appeared in both profiles (Fig. 11).

Very poorly sorted silty madas (Mz = 5.5–7.2ø), which were deposited on the Raba fan, reached much larger thickness to 1 m. There could have been abundant crevasse

splay deposits. Very poorly sorted clays (Mz = 8.4–10.0ø), reaching a significant thickness (0.7 m), were deposited in the Eoholocene Vistula Paleomeanders.

Fairly thick, very poorly sorted muddy deposits (Mz = 4.4–8.8ø), rarely inter-layered with sands, were also deposited during the first stages of filling the Vistula and the Raba meander bends which had been abandoned at that period.

b) The Middle Atlantic madas (younger than 6780–6160 BP). The majority of the profiles originate from the paleomeanders. There the organic deposits were covered with 0.2 m thick, very poorly sorted silty madas (Mz = 6.8ø) in the Raba valley. In the Vistula valley the organic deposits were covered with 0.8–1.0 m thick clayey madas (Mz = 7.8–9.2ø) far from the channel, and with thick (1.3 m), better sorted sandy madas (Mz = 4.3–4.7ø) which could have had the character of levee in the vicinity of the active channel (Kalicki 1991b, 1992b; Kalicki, Zernickaya 1995).

On the Raba fan the madas of the levee were deposited along the active Raba channel. However, they differ significantly as they are lacking characteristic sandy intercalations and they are formed by the compact and thick (3 m) cover of very poorly and poorly sorted silty-sandy muds (Mz = 4.9–5.6ø), as it was the case of the Vistula valley.

c) The Late Atlantic madas (ca 5500–5000 BP) distinguished in Grobla Forest. Some facies can be identified here. The madas of the levee are formed by the alter-nated layers of poorly sorted clayey sands (Mz = 2.4–3.0ø) and very poorly sorted silty muds (Mz = 4.2–6.0ø). On the older point bars these madas change upward to the deposits of floodplain facies formed by very poorly sorted silty muds (Mz = 6.2–6.8ø). In some profiles of the floodplain the sandy intercalations, which are characteristic of the levee, are lacking at their base and the madas are fining upwards, starting from poorly sorted clayey sands (Mz = 3.2ø) and ending with very poorly sorted silty muds (Mz = 6.4ø). On the youngest segments of the point bars, which have formed just before the abandonment of the whole system, the sequence of the mada deposits ends abruptly on very poorly sorted clayey sands fining upwards (Mz = 3.2–4.4ø), because there was not enough time for the sands to be covered with silty madas. The above picture is confirmed by detailed studies on the Subboreal system in Zabierzów Bo-cheński, where the youngest series of the channel deposits (IV) is overlain with a much thinner mud cover than the older series III (Kalicki *et al.* in this volume).

The madas of this period occur in the fills of the paleomeanders besides the full sequence of the floodplain deposits. In Grobla Forest the accumulation of peaty muds was interrupted by the accumulation of silty muds and then by that clayey sands (Mz = 3.8ø). In other abandoned channels of the Vistula sandy muds (Mz = 4.5–5.6ø) and silty muds (Mz = 6.5–6.6ø) were deposited at that time.

IV. The Neoholocene madas

a) The Subboreal madas

In the Subboreal, within the backswamps encompassing the lateglacial alluvial plain, very poorly sorted clayey madas probably continued to accumulate – Mz = 8.4––8.5ø in the Vistula valley and up to 9.8ø in the depression of Gróbka on the Raba fan. Within these basins to the north of Grobla Forest the crevasse splay deposits

(1 m) were inserted probably in this period after the Vistula avulsion. The crevasse splay deposits consist of clayey sands ($Mz = 1.6$–$3.5\emptyset$) slightly fining upwards at the base (0.4 m). Above the pattern of fining is reversed, which can indicate that sediments were deposited not by one, but by several floods. The remaining profiles of that period group within the paleomeanders, but only few are dated. In the Older Subboreal very poorly sorted silty madas ($Mz = 5.7\emptyset$) of similar grain size composition to the madas on the floodplain in the system of Zabierzów Bocheński were deposited in almost filled, abadoned channel of the Drwinka stream, located closely to the active channel. Far from the Vistula river, in Grobla Forest, very poorly sorted clayey madas ($Mz = 7.0$–$8.7\emptyset$) were deposited.

b) The Subatlantic madas

In the Older Subatlantic very poorly sorted silty and clayey madas ($Mz = 5.3$–$8.9\emptyset$) were deposited in the Raba abandoned channels.

The Middle Subatlantic (1850–1680 BP) is the period for which the madas can be characterized rather accurately. The levee facies, 0.25 m thick, is represented by the alternated layers of moderately well sorted sands ($Mz = 2.6\emptyset$) and very poorly sorted silts ($Mz = 5.5\emptyset$). Towards the top of the profile these sediments change to floodplain sediments fining upwards and form very poorly sorted silty madas ($Mz = 5.2$–$7.3\emptyset$). Sometimes the levee facies are lacking at the base of the discussed madas and then flood deposits form a sequence with a very pronounced fining upwards from very poorly sorted clayey sands ($Mz = 2.7\emptyset$) to silty muds ($Mz = 5.9\emptyset$). In more or less the same period sandy muds ($Mz = 4.6\emptyset$) were deposited in the paleomeander at Rondo Mogilskie.

The next period of the mada deposition was the Medieval time. The levee facies reached then the thickness of 0.3–1.0 m. This facies consists of alternated layers of moderately well sorted sands ($Mz = 1.2$–$3.1\emptyset$) and very poorly sorted sandy muds ($Mz = 3.7$–$4.7\emptyset$). Towards the top these sediments change to floodplain deposits of the type of very poorly sorted silty madas ($Mz = 4.8$–$6.5\emptyset$). A characteristic feature here is the lack of upward fining of these deposits and even the reverse pattern has been found in some cases, e.g. in the profile from Branice where Mz diminishes to the top from 6.5 to $6.2\emptyset$ or from 5.8 to $4.8\emptyset$. This phenomenon was being observed here for the first time during the whole studied period.

In the 19th century very poorly sorted clayey sands ($Mz = 3.3$–$4.5\emptyset$) were deposited on the segments of the point bars forming at that time.

During the whole Subatlantic very poorly sorted clayey madas ($Mz = 7.4$–$8.6\emptyset$) were deposited in the backswamps. Similar sediments were deposited in the Vistula paleomeanders in Grobla Forest ($Mz = 8.1\emptyset$) distant from the channel. However, in the number of profiles, especially in the narrower section of the Vistula valley near Cracow, in which samples were also taken in the top parts, one observes a pronounced shift of the last samples towards coarser sediment fractions. The above refers to the profiles from the backswamps (R/87, R1) as well as to the profiles from the paleomeanders (R2, 3, BrA1) (Fig. 12). This distinct tendency causes the shift of Mz from 9.7 to 7.8–$7.6\emptyset$ in the backswamps and from 8.1–9.1 to 6.3–$5.3\emptyset$ in the paleomeanders. The lack of the phenomenon in the backswamps sediments of the Raba fan may be

caused by too large distance from the Vistula channel or, which is more likely, may result from the failure to sample the uppermost parts of the profiles.

Vistula fan near Drogomyśl

The alluvial fan of the Vistula occurs in the immediate foreland of the Beskid Śląski Mts, in the zone of tectonic subsidence. The published papers allow to characterize the madas in the region of Drogomyśl (Niedziałkowska *et al.* 1985; Niedziałkowska 1991). Within the 2 km wide valley floor three zones were distinguished, the 400 m wide zone of levee and two backswamps. In the recent millennium the 0.5–2.0 m thick madas were deposited in a reverse sequence (Mz = 7.7–4.6ø) within the levee. These madas consisted of sandy muds which upward gave way to silty sands interbedded with sands at the top of the profile. Both papers of E. Niedziałkowska presented different characteristics of the backswamps deposits. In the paper of 1985 there is an information about sedimentation of clayey and silty deposits with the reverse sequence (Mz from 7.8–7.1ø at the base to 5.2–6.0ø at the top); their thickness reaches to 7 m. E. Niedziałkowska *et al.* (1985) emphasizes that the upper 4 meters of sediments are coarser and relates that to human activity. On the other hand, in the paper published in 1991 she writes about upward fining of the sediments deposited in the backswamps. She also claims that the madas become finer and more homogeneous as the distance from the channel increases.

The analysis of the profiles described in these papers allows to determine a more precise sequence of layers. Two profiles are located within the levee. In the outcrop – Drogomyśl A, there were the first deposited clayey sands interbedded with sandy silts (Mz = 3.1–4.1ø). Upward the sands gave way to 3 m thick sandy madas (Mz = 5.1ø). In a profile 6F two members can be distinguished, which mark stages of the levee accretion: the lower one consisting of silts of the thickness of 2.5 m and with the reverse sequence (Mz = 7.8–6.5ø), and the upper one consisting of sands with a weak reverse sequence (Mz = 4.8–4.4ø).

In a profile 10 within the eastern backswamp, one can distinguish three members: the lower one, younger than 31 000 BP, consisting of 3.3 m thick clays (Mz = 7.2––7.9ø) and two members younger than 905±120 BP – the middle one, 1.7 m thick, fining upward (Mz = 2.9–6.0ø), and the upper member (Mz = 2.8–6.5ø), which is 1.4 m thick and at the top of which the sequence changes from the normal to the reverse pattern. In the western backswamp, in profile 4, located ca 300 m from the Vistula channel, in the 7 m thick layer of the overbank deposits the sediments become coarser upward from the depth of 4 m (Mz decreases from 8.7 to 8.1ø), however, a definite decrease in Mz values (to 6.0ø) occurs only at the depth of 2.5 m and then to 4.6ø at the last 0.3 m. Based on the legends to the profiles one may expect a similar arrangement in the profiles located farther from the channel, unfortunately the detailed data have not been published. The profiles presented above support the statement of E. Niedziałkowska's *et al.* (1985) about the upward coarsening of the sediments, but not about their upward fining as E. Niedziałkowska wrote in 1991.

The middle Vistula valley in the gap through the uplands

The madas in the Vistula gap through the uplands were descirbed by W. Pożaryski (1955), who distinguished "the old mada", clayey one (the content of the grains smaller than 0.01 mm is 48–62% and increases towards the top) and the "young mada", silty one (the content of the grains smaller than 0.01 mm is 30–33%). Based on the found archeological artifacts in the profile in Basonia, E. Falkowski (1975) distinguished some madas coarsening upwards which rest one over the other and are of various age. The recent detailed studies (Pożaryski, Kalicki 1995) allowed for indication and dating of some generations of the madas.

The oldest Atlantic madas (older than 5170 BP) are developed in two facies: levee facies and floodplain facies (Ciszyca Przewozowa). The levee (0.6 m) is formed of intercalations of very poorly sorted silty muds (Mz = 6.6ø) and clayey sands (Mz = 4.5ø). The madas of the floodplain consist of poorly sorted clayey muds (Mz = 7.0–7.5ø) fining upward.

The Subboreal madas with the artefact of the Lusatian culture at the top are preserved as two members (1.85 m thick) of the floodplain facies. These members are separated by a buried soil (Ciszyca Przewozowa) which has not been dated. The members consist of poorly sorted silty and clayey muds (Mz = 6.2–7.1ø) fining upward.

The Subatlantic madas (older than 700 BP) are formed of poorly sorted silty and clayey muds (Mz = 5.9–7.0ø) fining upward of the floodplain facies (Nieszawa and Świeciechów). The Medieval madas accumulated ca 700 BP were very poorly sorted silty muds (Mz = 5.8–6.5ø) of the floodplain facies (Nieszawa and Świeciechów).

The youngest madas of the levee facies were deposited on the levels to 2 m above the Vistula river consisted of alternated laminae of very poorly and poorly sorted sandy and silty muds (Mz = 4.7–6.5ø), as well as of sands and clayey sands (Mz = 2.6––4.4ø). The youngest, 0.6 m thick, topstratum is better sorted and more sandy, however, Mz values of intercalations are here 1.9–4.0ø, which indicates intensification of floods in the recent centuries (Parchatka). In the floodplain facies, close to the channel and on the slightly higher levels (to 3 m above river) very poorly sorted clayey sands (Mz = 2.9–3.8ø), sometimes with a weekly marked fining upward (Nieszawa and Świeciechów) were deposited and reached the thickness of 0.7–1.1 m. The deposits of the floodplain facies close to the channel, but on the levels above 3.5 m, were formed of 0.25 m thick, very poorly sorted sandy muds (Mz = 5.4ø) (Ciszyca Przewozowa). In the backswamp facies (Lucimia) there were deposited 0.15 m thick poorly sorted clayey muds (Mz = 7.3ø). In the recent centuries in the paleomeander located far from the Vistula river there were also deposited 0.5–0.7 m thick, poorly sorted, clayey muds (Mz = 7.9–6.5ø) with a reverse sequence (Szczekarków A nad B).

The Raba valley

In the outlet part of the Raba valley, which is here 1.0–2.5 km wide, there is the mada profile in Łężkowice which has been described by S. W. Alexandrowicz and B. Wyżga (1992). In the 5.5 m thick profile, the basal 2 m are formed of alternated muds and sandy muds laminae interbedded with sands. They are interpreted by

S. W. Alexandrowicz and B. Wyżga as the abandoned channel fill. However, inferring from the structure of the deposits, it seems more likely that it is the levee facies. Farther upwards, at the base, these deposits change into the floodplain deposits (1.5 m). The base is formed of homogeneous silty muds (Mz = 6.1–5.8ø) with a very poorly marked reverse sequence. Towards the topstratum the above deposits give way to clayey-silty muds (Mz = 6.9–7.5ø) fining upward and dated at 9850±210 BP. Sedimentation of all these layers may be related to the Late Glacial. The 0.25 m thick, clayey muds (Mz = 8.1–8.4ø) fining upward, rest above the dated deposits. Above these clayey muds the fining changes and in the 0.7 m thick overlaying muds the sequence is reverse (Mz = 8.0–7.2ø) and their age is assumed as the Atlantic. The next 0.5 m thick member has also the reverse sequence (Mz = 7.4–6.3ø). The next member overlaying the muds has a normal sequence (Mz = 6.3–7.1ø) which changes into the reverse one (Mz = 6.7ø) in the uppermost sample. All these members are associated with sedimentation in the backswamp in the Subboreal and the Subatlantic. The above indicate accretion interrupted by periods of relative stability, although not leading to formation of buried soils.

The Wisłoka valley

In the Wisłoka valley several sites have been described in the region of Dębica in the immediate foreland of the Carpathian Foothills. In the 9 m high terrace in Brzeźnica two madas have been distinguished (Kowalkowski, Starkel 1977). Both in the abandoned channel and in the floodplain, the 1.5–2.5 m thick, older mada (younger than 9535 BP) is clayey (up to 44–73% clay) with a well developed soil profile at the top. The lack of samples from the uppermost parts (from 0 to 0.5–1.0 m) does not allow for identification of sequences in sediments. This mada takes form of detached deposits within the Younger Holocene dissection. At the top of the younger insert there is the young mada which started to be deposited ca 1040 BP. This mada reaches the thickness of 4 m and in the 1.6 m thick analyzed deposits this mada is more silty than the older one (16–41% of clay).

Ca 9360–9040 BP, in the lateglacial paleomeander in Wola Żyrakowska (Starkel, Granoszewski 1995), the organic deposits were covered with poorly sorted, clayey madas (Mz = 6.9–7.8ø) changing into silty muds (Mz = 6.1ø) towards the top. Later, the deepest spots in the paleomeander were filled with two main members of madas fining upward, sandy muds (Mz = 5.3–5.8ø) giving way to silty muds (Mz = 6.3–6.6ø). All these sediments cover the 1.6–2.0 m thick madas of the floodplain facies, fining upward; from sandy muds (Mz = 5.3–5.5ø) at the base to clayey muds (Mz = 6.5–7.6ø) at the top.

In the outcrop in Kędzierz (Starkel, Krąpiec 1995) two members of the madas younger than 540 AD may be distinguished. The lower, 1.2 m thick member of the levee type is formed of sandy muds alternating from more to less sandy muds (Mz = 4.7–5.9ø). The upper member consists of 0.2 m thick sandy muds (Mz = 5.6ø) underlain with sands.

General regularities

The madas were deposited during the entire Holocene, yet with various intensity. Comparison of the dated mada profiles and the performed above analysis of the grain size of the madas of various age, including their facial development, allows to indicate some regularities.

An increase in the rate of the mada accumulation leads to the change in accumulation type of the floodplains, for example covering of the organic deposits, peat or soils, with madas. The dated mada profiles group in certain periods of time, which coincide with the periods of intensified river activity, described precisely for the Vistula valley near Cracow (Kalicki 1991c) and some of them have been learnt earlier in the valleys of the Carpathian rivers (Ralska-Jasiewiczowa, Starkel 1975, 1988). These periods comprised the Older and Younger Dryas, 9800–9300, 8500–8000, 6700–6000, 5500–5000, 4500–4000, 3500–3000, 2700–2600, 2200–1800 BP, 5–6th c., 10–11th c., 13–14th c. and the Little Ice Age.

The detailed analysis of situation in the Vistula valley downstream of Cracow in these periods allows for elaboration of the mada sedimentation pattern within one phase. In the initial stage there was a deposition of silty-sandy madas along the active channel and a simultaneous deposition of clays in peatbogs in the marginal parts of the valley, as well as accumulation of clayey madas in the depressions, for example in abandoned channels due to frequent floods inundating the whole valley floor. In the middle stage, because of triggering of the meander migration, new segments of the floodplain were formed: point bars covered with sandy madas. In the final stage, due to channel avulsion, there was accumulation of clayey madas in that zone of the valley to which avulsion of the channel had taken place.

From the middle Holocene anthropogenic changes of the environment and soil erosion were more intensive. At the beginning this changes were of local importance (e. g. delluvia in Pleszów – Wasylikowa *et al.* 1985). However, in 5000–4500 BP these changes manifested clearly as the shift from accumulation of organic madas to accumulation of silty madas or less organic ones (Kosmowska-Suffczyńska 1983; Rutkowski 1984, 1991; Śnieszko 1985; Alexandrowicz 1988) in smaller river valleys (the Prądnik, the Rudawa, the Nidzica, and the Racławka), draining the loess uplands, in the Vistula catchment. Expansion of man in the Bronze epoch to the Carpathians (Valde-Nowak 1988) was marked by intensified accumulation of the madas in the Vistula valley, especially in the Oświęcim Basin (Klimek 1988) from 3000 BP and by formation of silty levees on the Raba fan (Gębica 1995).

In the Roman period in the Vistula valley there was a pronounced aggradation and fossilization of fragments of the older floodplains by the younger silty-sandy madas (Kalicki, Krąpiec 1994). From ca 1500 BP the above was accompanied by intensified accumulation of the madas in valleys of the upland (Alexandrowicz 1988; Rutkowski 1991) and the Carpathian tributaries (Klimek, Starkel 1974; Alexandrowicz *et al.* 1981). The youngest phases of the mada deposition in the Vistula valley manifested in intercalations in peat and in cultural levels (Radwański 1972), while the swampy floors of the side valleys were covered with loess delluvia (Kosmowska-Suffczyńska 1983). In the 19th c. the development of madas was limited by channelization and

embankments of the Vistula. Since then sedimentation has been reduced to the inter-embankment zone (Dembowski 1984; Rutkowski 1986). The rivers of the Carpathian Foreland dissected the older floodplains and the sedimentation of the madas was reduced to the zone in the channel vicinity (Klimek 1974b).

On this general background the more specific picture, based on the changes in the grain size composition of the madas, is developed. In the Sandomierz Basin the madas are diversified, on one hand, in relation to climatic-vegetation changes at the turn of the Late Glacial and the Holocene and in relation to the human activity in the Neoholocene, on the other hand, to the distance from the active channel (Kalicki 1991c, 1992a, b). These differences depend on the facies.

The Younger Dryas levees are slightly coarser than in the pre-Allerød period. The levees of the Raba river on its fan, as well as the Vistula levees in the gap from the Atlantic period, were formed of relatively fine deposits. The differences between particular layers were relatively small – the smallest in the whole studied period (Mz = 4.9–5.6ø on the Raba fan and Mz = 4.5–6.6ø in the gap). The above provides the evidence of a large stability of discharges in the Atlantic. During the recent 500 years the discussed facies were the coarsest when considering the whole Holocene and the Late Glacial. The grain size composition and sorting of the deposits are more diversified in particular layers (Mz = 0.5–3.7ø in the Sandomierz Basin and Mz = 1.9–4.0ø in the gap) and indicate a definite increase in the oscillations of the Vistula discharges.

In the floodplain facies it is clear that the finest Vistula madas originated from the Boreal and Atlantic (Mz = 7.2–9.2ø). In the Late Glacial the Mz values of such madas are 5.3–7.3ø and from the end of the Atlantic to the Subatlantic Mz is 2.7–7.3ø. However, the absolute values of the Mz of the madas covering the point bars depend very strongly on the stage of the development of the mada cover. Such differentiation may occur within one meander during its development and may be fixed due to abandonment of the channel by avulsion (e.g. ca 5100 BP) or due to channelization and embankment of the Vistula valley in the mid-19th century. The above leads to formation of fractional sequences of the madas, ending with clayey sands, on these youngest segments. Therefore the sandy madas of the 19th century (Mz = 3.3–4.5ø) do not provide evidence of an abrupt change in sedimentation in this period, but their grain size composition fully corresponds to the Late Atlantic madas (Mz = 3.2–4.4ø) occurring in the analogous morphologic situation. A definite difference in the grain size composition of the Boreal–Atlantic clayey madas and the coarser madas of the last millennium have also been observed in the Wisłoka valley.

The variability of the grain size composition of the madas is also very clear in the madas of the backswamp facies of the Vistula and the Raba valleys, however, their precise dating is very difficult due to the lack of organic horizons. The absolute values of Mz of these sediments strongly depend on the distance from the channel. In the basins closer to the Vistula the values Mz = 8.4–8.5ø are typical, while in the more distant basins on the Raba fan these values are even 9.8ø. On the other hand, in the narrow Raba valley the Mz values do not exceed 8ø and oscillate about 7ø most often.

In the madas of the abandoned channel facies (ob-cf) the type of deposits depends strongly on the distance from the channel. Close to the Vistula the sandy and silty

madas (Mz = 4.3–5.7ø) were deposited and the clayey madas (Mz = 8.0–9.2ø) were deposited in the abandoned channels located far from the Vistula.

In the two last discussed facies there is a pronounced propensity to the change in the sequence of sediments, from the normal (fining upward) to a reverse one, towards the topstratum. This propensity does not occur only in the basins distant from the Vistula (depression of the Drwinka stream in the Vistula valley, depression of Gróbka on the Raba fan) and in the Wisłoka valley, where the sedimentation of the youngest madas did not occur due to the distance from the channel or due to the higher elevation of the older plain (Brzeźnica on the Wisłoka river). Due to the lack of the samples from the topstratum of the profiles this propensity may not have been stated in these both cases.

In order to provide a more extensive and complex explanation of tendencies in changes in the grain size composition and in the development of flood deposits on the Vistula floodplain there is the contrastive analysis of the valley cross-sections in the Boreal and in the period of the deposition of the youngest Subatlantic (historical?) madas presented. The deposits of the levee facies (BO: Mz = 0.9–5.6ø; SA: Mz = 1.2––4.7ø) occurred at the base of the madas covering the point bars. Towards the top these deposits gave way to silty madas in the Boreal (Mz = 4.2–6.0ø) fining upward and then to silty-sandy madas in the Subatlantic coarsening upward (Mz = 6.5–4.8ø). Simultaneously, on the older undercut fragments of the floodplain, the madas deposited in the vicinity of the channel in the Boreal contained slightly more clay particles (Mz = 6.5–6.9ø) then those deposited on the point bars. These madas contained more and more clay particles as the distance from the channel increased (Mz = 6.9–8.4ø). Within the area of the paleomeanders located far from the Vistula clayey muds fining upwards (Mz = 8.4–10.0ø) were deposited in the Boreal, and clayey and silty muds coarsening upwards (Mz = 9.1–5.3ø) were deposited in the Subatlantic. In the backswamps organic madas were accumulated in the Boreal, and in the Subatlantic accumulation of clayey madas coarsening upwards (Mz = 9,7–7,8ø). within the backswamp started. The latter madas became finer as the distance from the channel increased (Mz from 8.6 to 9.2ø).

The madas accumulated in a given period differ as to the thickness depending on the facies, for example the levee of the Younger Dryas reached 0.5–0.6 m and madas precipitating in backswamps 0.1–0.3 m.

The analysis of the mada profiles allowed for identification of the series of types of facial succession of the madas and for development of conceptual models of mada sedimentation (Fig. 13). Due to the large width of the Vistula valley in the Sandomierz Basin particular inserts of alluvia usually cover the madas of the same age as the age of the channel deposits. The deposits of the fossil floodplains, preserved underneath the younger mada cover, are exceptional cases. The old Holocene floodplains, noncovered with younger deposits, occurred in the Wisłoka valley. On the other hand, the facial succession of the madas is more diversified within the lateglacial alluvial plains. These plains during the Holocene functioned as the older floodplains outside the meander belts and later as backswamps. Vertical accretion of the madas was observed there in result of decantation. It is very likely that the accumulation of the madas

Sandomierz Basin

A
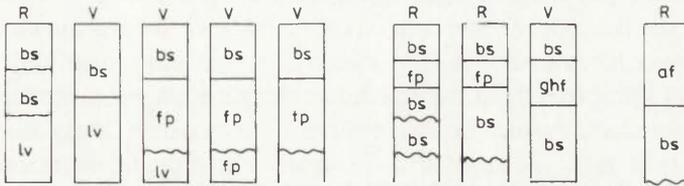
B
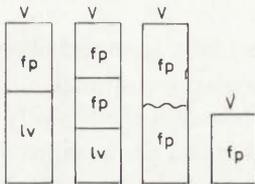
C
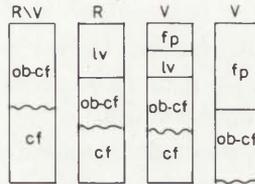
Vistula gap
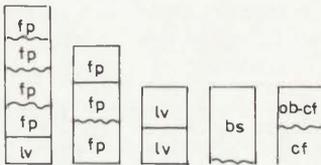
Fig. 13. Types of sequences of mud facies in the Vistula valley
A – backswamps over the late glacial braided alluvial plain, B – located at flood plain,
C – located in the abandoned channel. Explanation – see Fig. 11

ceases in the backswamp most distant from the Vistula channel, still before the Subatlantic (lack of change in tendency to coarsening upwards). The periodical change of sedimentation type in the backswamp, perturbing vertical accretion, was observed more rarely. Close to the Vistula channel the change in sedimentation type was due to deposition of crevasse splays and on the Raba fan, in the direct vicinity of the active channel, due to deposition of the floodplain sediments. Only in the outlet of the Uszwica river the backswamp disappeared in result of infilling by the fan of a tributary of the Vistula. In the majority of the abandoned channels there was one type of their infilling. However, under specific conditions, for example in the vicinity of the active meander belt, the full fossilization of the abandoned channel and its covering with the deposits of levees or a floodplain could have occurred. Therefore, the system of the Late Atlantic meanders in Grobla Forest does not exhibit nowadays any links

with the younger systems of the paleochannels for example. This type of the facial succession occurs also in the Wisłoka valley, and prospectively in the Raba valley.

In the gap of the middle Vistula, through the Uplands, various types of mada sedimentation are found, depending on the valley width. In the wider parts the mechanism is simpler and more similar to that observed in the Sandomierz Basin. The facial type of the mada is strongly dependent on the distance from the channel. On the other hand, in the more narrow parts one observes the vertical accretion of the madas of the same facies of the levees or of the floodplain. In the youngest, historical madas the differentiation resulting from the distance from the channel (clayey madas in backswamps and in distant paleomeanders) is supplemented by the differentiation of the grain size of the deposits, corresponding to the height of the segments of the floodplain above the river level. As the height increases, the finer and finer sediments are accumulated.

In the narrower, outlet sections of the Carpathian tributaries and likely during the subsidence, the sedimentation of the youngest madas depends strongly on the distance from the channel, e.g. on the Vistula fan in the foreland of the Beskidy Mts. Along the river there were deposited the madas of the levee and on the sides the madas of backswamps. Provided a tendency to river incision (the Wisłoka, the Raba rivers) the older madas could have remained non-covered with the younger madas, because the latter were deposited on the lower level at that time.

4. PHASES OF "BLACK OAKS" ACCUMULATION

4. 1. DENDROCHRONOLOGY OF "BLACK OAKS" FROM RIVER VALLEYS IN SOUTHERN POLAND

Marek Krąpiec

Introduction

Subfossil oak trunks are fundamental materials used (in Eurpe) to compile long dendrochronological standards. They are valuable sources of information about sediment age, paleoclimatic changes etc. (Becker 1992; Leuscher 1992; Kalicki, Krąpiec 1995). Systematic studies on "black oaks" were started in the Department of Stratigraphy and Regional Geology, Academy of Mining and Metallurgy in 1987. The studies were carried out under project CBPB 03.13 coordinated by Prof. L. Starkel. The aim of the studies was to work out a growth standard for oak wood of Southern Poland. On the background of over 340 samples of the subfossil oaks from 13 sites (indicated with symbols A and B in Figure 14) the scales covering ca 4000 years have been elaborated, including three absolutely dated – based on South German standards – regional chronologies: Vistula 1 (474 BC – 304 AD), Standard 1 (261 AD – 823 AD) and Vistula 2 (1100–1529 AD) (Krąpiec 1992b).

During three recent years (1992–1994), under the framework of grant no. 6-0783-91-01-P2, over 270 black oaks were sampled from 19 sites including 6 sites studied previously and 13 new sites – cf. Figure 14, symbols B and C. Due to a uniform distribution the new sites from the Odra, San and Wisłoka river valleys are valuable complement of the earlier materials. During the performed studies a standard methodology was employed (Krąpiec 1992b) and measurements were taken at a prototypical site linked with an IBM computer. Analysing obtained sequences one aimed at working out local chronologies and singular trunks were absolutely dated basing on the Southern Poland standard chronology. Results of datings of the samples for the given sites are presented below.

Results of dendrochronological datings

Lewin Brzeski (no. 2 in Fig. 14)

In the gravel-pit in Lewin Brzeski, located on the left-bank of the Nysa Kłodzka river, in the distance of ca 2 km from the city centre and ca 500 m from a sugar-mill, a gouged boat was found among sandy-gravel alluvia reaching the depth of several meters. The well preserved, pulled up boat was handed over to the museum in Bis-

kupin for conservation works while from the two trunks of "black oaks" occurring in the neighbourhood samples for dendrochronological analyses were taken (Table 5). It was discovered that the trunks were felled in ca 162 and 218 BC.

Lack of the alburnum and the traces of reworking on the trunk surfaces provide evidence of redeposition.

T a b l e 5. Compilation of dendrochronologically analyzed samples of "black oaks" from the gravel-pits in: Branice (B) – no. 1–12, Grabiny (GB) – no. 13–17, Grabowiec (GW) – no. 18–19, Kędzierz (KN) – no. 20–24, Klecie (KL) – no. 25–29, Lewin Brzeski (LB) – no. 30–31, Ostrów near Przemyśl (OS) – no. 32–37, Przeciszów (PR) – no. 38–40, Roszków (RO) – no. 41–45, Rusocice near Czernichów (RS) – no. 46–47, Smolice-Zakole "A" (SM) – no. 48–50 and Strzegocice (ST) – no. 51–54

No.	Labo-ratory code	Sample description	Num-ber of tree rings	Albur-num	Dating of dendro-chronological sequence	Date of oak felling
1.	B85	trunk	191	–	38–228AD	after 238AD
2.	B86	trunk	62	62	1174–1235AD	1238(–6/+10) AD
3.	B87	trunk	279	–	367–645AD	after 655AD
4.	B88	stump of oak hewed with an axe	163	–	59–221AD	after 231AD
5.	B89	top fragment of a trunk	149	142-9		
6.	B90	trunk	75	–		
7.	B91	trunk	216	–	107BC–108AD	after 118AD
8.	B92	trunk	216	–	1058–1273AD	after 1283AD
9.	B93	fragment of a trunk	138	–	1179–1316AD	after 1326AD
10.	B94	stump of oak hewed with an axe	102	–	1325–1426AD	after 1436AD
11.	B95	branch fragment	49	–		
12.	B96	trunk	191	–	32–222AD	after 232AD
13.	GB1	trunk	121	–	453–333BC	after 323BC
14.	GB2	fragment of a trunk	174	–	1380–1553AD	after 1563AD
15.	GB3	trunk with traces of hewing	225	217-25	1331–1555AD	1555AD
16.	GB4	trunk	202	–		
17.	GB5	top fragment of a trunk	155	–	449–295BC	after 285BC
18.	GW1	top fragment of a trunk	71	–		
19.	GW2	fragment of a trunk	179	–	388–210BC	after 200BC
20.	KN1	trunk	170	–	C^{14}:3920±50 BP	
21.	KN2	trunk	71	–		
22.	KN3	trunk	133	–	408–540AD	after 550AD
23.	KN4	trunk	155	–	C^{14}: 4870±60BP	
24.	KN5	trunk	94	–		
25.	KL1	trunk	117	–		
26.	KL2	trunk	173	–	53BC–119AD	after 129AD
27.	KL3	trunk	82	–	1175–1256AD	after 1263AD
28.	KL4	top fragment of a trunk	46	–	1340–1385AD	after 1392AD
29.	KL5	trunk	216	–	1172–1387AD	after 1397AD
30.	LB1	fragment of a trunk	203	–	374–172BC	after 162BC
31.	LB2	fragment of a trunk	223	–	450–228BC	after 218BC
32.	OS1	trunk	271	–		811 or 994AD

No.	Laboratory code	Sample description	Number of tree rings	Albur-num	Dating of dendro-chronological sequence	Date of oak felling
33.	OS2	top fragment of a trunk	118	–		
34.	OS3	trunk	111	–		
35.	OS4	trunk	60	–		
36.	OS5	trunk	128	–		
37.	OS6	trunk	59	–		
38.	PR1	trunk	114	–	577–690AD	after 700AD
39.	PR2	fragment of a trunk	83	–	624–706AD	after 716AD
40.	PR3	fragment of a trunk	285	–	372–88BC	after 78BC
41.	RO1	pile	46	–		
42.	RO2	trunk	115	–		
43.	RO3	trunk	112	–		
44.	RO4	trunk	161	–	882–1042AD	after 1052AD
45.	RO5	trunk	77	–		
46.	RS1	trunk	104	–	415–518AD	after 528AD
47.	RS2	trunk	77	–	415–491AD	after 501AD
48.	SM39	trunk	104	–	471–574AD	after 584AD
49.	SM40	plank	109	–	939–1047AD	after 1057AD
50.	SM41	trunk	115	–		
51.	ST20	trunk	147	–		
52.	ST21	trunk	95	–		
53.	ST22	top fragment of a trunk	161	–	361–521AD	after 531AD
54.	ST23	trunk	139	–	650–788AD	after 798AD

Krzyżanowice (no. 3 in Fig. 14)

In the gravel-pit in Krzyżanowice, located within the area of the floodplain on the left bank of the Odra river, ca 6 km north of the state border, 35 samples from the black oak trunks were taken for analyses. Huge trunks, over 1 m in diameter, were the basis for determination of chronology KRZAA3 (Fig. 15). This chronology represents the period 111 BC–227 AD. All the trunks of this chronology were redeposited, but primarily entered the river successively, every several years in the period 110 BC–230 AD. In Krzyżanowice the tree trunks felled in the period 470–560 AD, forming chronology KRZAA1 (Fig. 16) are represented most numerously. As it was the case of the oaks of this period from other sites (e.g. Kujawy, Wolica), the oaks in Krzyżanowice started their growth in ca 380–410 AD. The preserved form of the trunks, i.e. lack of the alburnum and traces of reworking by river material, provides the evidence of trunk redeposition.

During gravel excavation fragments of a gouged boat, i.e. the bottom and a part of the stern, were pulled up from under the water. This boat was made from a singular oak trunk in the mid-10th century which is evidenced by the last preserved heart-wood ring dated at 934 AD. Moreover, three trunks, whose stage of preservation indicated their resting "in situ", were also encountered in this gravel-pit. The above trunks from chronology KRZAA2 (Fig. 16) which, unfortunately, could have been dated neither on Southern Poland standard nor on the Bednarz's scale. Lack of correlation, as well
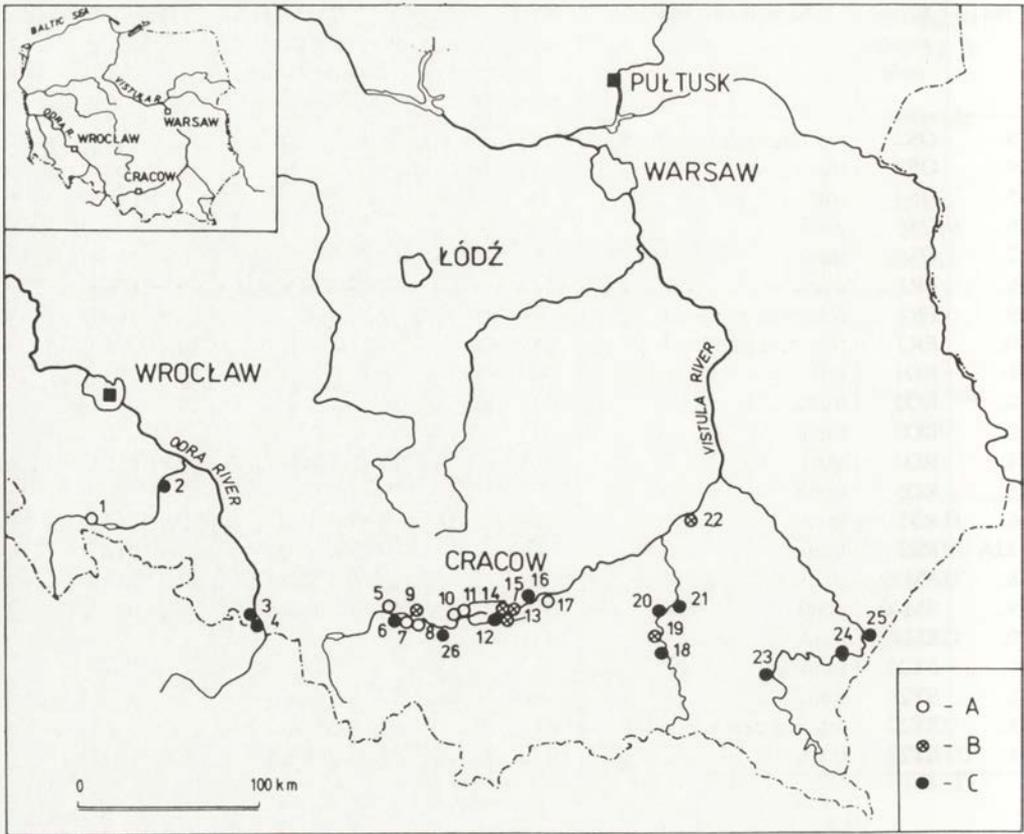
Fig. 14. Localization of the sites with subfossil "black oaks" studied dendrochronologically
in Southern Poland

1 – Paczków, 2 – Lewin Brzeski, 3 – Krzyżanowice, 4 – Roszków, 5 – Oświęcim Dwory, 6 – Przeciszów,
7 – Podolsze, 8 – Smolice – Zakole B, 9 – Smolice – Zakole A, 10 – Ściejowice, 11 – Stopień Wodny
"Kościuszko", 12 – Kraków – Kujawy, 13 – Grabie, 14 – Branice, 15 – Wolica, 16 – Nowe Brzesko,
17 – Niedary, 18 – Klecie, 19 – Strzegocice, 20 – Grabiny, 21 – Kędzierz, 22 – Machów, 23 – Krzemienna,
24 – Ostrów, 25 – Grabowiec, 26 – Nowe Brzesko; A – profiles elaborated in 1988–1990 in the project CPBP
03.13, B – profiles elaborated both is 1988–1990 and 1991–1993, C – new localities elaborated in 1991–1993

as a light, unchanged colour of wood indicate that these trunks might originate from
the recent 300–400 years.

Roszków (no. 4 in Fig. 14)

The grevel-pit in Roszków is located on the left-bank of the river within the area
of the Odra floodplain. A series of samples elaborated by T. Goslar in the mid-1980s
(1987) originates from this gravel-pit. At present excavation is going on in the north-
ern part of the gravel-pit. Five samples were taken for analyses out of which one trunk
was absolutely dated at ca 1050 AD (Table 5).

KRZYŻANOWICE (KRZAA3)
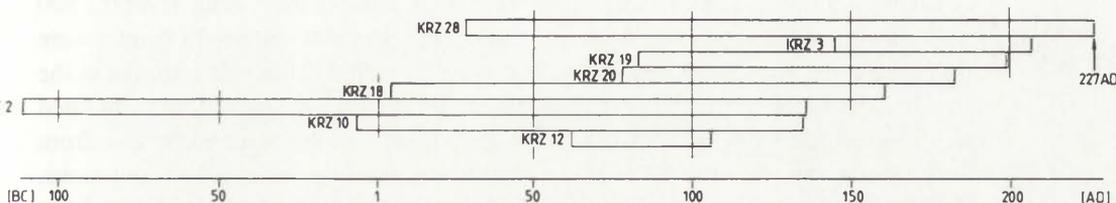
Fig. 15. Subfossil oaks dated dendrochronologically from Krzyżanowice – chronology KRZAA3

KRZYŻANOWICE (KRZAA1)
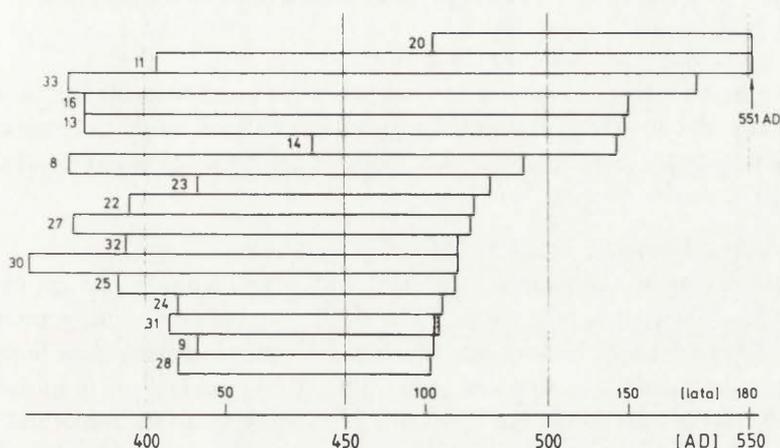
KRZYŻANOWICE (KRZAA2)
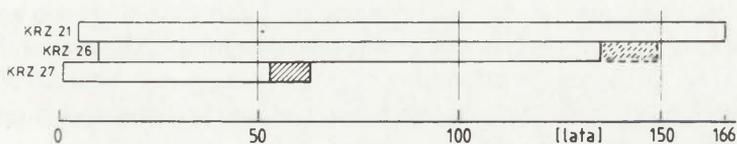
Fig. 16 – Correlation diagram of subfossil oaks from Krzyżanowice –
chronology KRZAA1 and KRZAA2

Przeciszów (no. 6 in Fig. 14)

During channelization of the Vistula river near the Podolsze stage of fall straight-ening of the Vistula channel was necessary in some locations. Such works were carried out on the left bank at the height of the village of Przeciszów. In 1989 fragments of the pulled up trunks were laid down there and rested in heap of gravel and sand during the next three years. Samples in a form of slices were taken in 1992. The oldest black oak was felled in ca 78 AD. The next two trunks were deposited in the Vistula alluvia at the beginning of the 8th century, i.e. in ca 700 and 716 AD (Table 5).

Smolice-Zakole A (no. 9 in Fig. 14)

Gravel-pit Smolice-Zakole A is located on the left bank of the Vistula river, ca 500 m downstream of the road Babice–Zator. During the previous studies 38 trunks were sampled from the gravel-pit in Smolice. The samples included the oldest trunks in the Vistula valley, dated at over 8000 BP (Krąpiec 1992a; Kuc, Krąpiec 1994), obtained from a well-pit. Under the framework of the grant three samples were taken: two from the trunks and one from the 19×27 cm board with mortises arranged in four rows. A functional purpose of this board is difficult to define as the board has been preserved only fragmentarily, nevertheless its absolute dating is possible. The board is made from the oak cut down in the vicinity of Cracow ca 1057 AD. One of the trunks was also dated at ca 584 AD (Table 5).

Rusocice near Czernichów (no. 26 in Fig. 14)

For dendrochronological studies two samples were taken from the trunks of black oaks which had been dredged from the gravel-pit located on the left-bank of the Vistula river near the road Rusocice–Łączany. These trunks were redeposited. They were felled in the 4th century AD (Table 5).

Kujawy (no. 12 in Fig. 14)

In 1971 extensive earthworks associated with constructing a sewage treatment plant for the Nowa Huta quarter were started in the Kujawy housing estate. The earthworks were done in the zone where the two Vistula paleomeanders functioning in the recent millennium (Kalicki, Krąpiec 1992, 1994) marked off in morphology. During the construction works lasting over 2 years more than 100 trunks and stumps of oaks hewed with axes were pulled up to the surface. For dendrochronological studies 96 samples were taken. These samples form three chronologies. The oldest chronology, marked KUAA2, represents the period of 386–560 AD (Fig. 17). It has been worked out basing on 24 trunks. The trunks are lacking the Sapwood and have traces of reworking by a river. Thus, these are redeposited trunks. Majority of the oaks of this generation started their growth during a 20 years long period, between 390–410 AD. These oaks, although 50–150 years old but still relatively young trees, were being felled in the period of 450–560 AD.

Chronology KUAA1, over 600 year long and representing the period of 536–1141 AD (Fig. 18) is best defined. It has been developed basing on 40 samples which are mainly characterized by large sizes (diameters up to 1.8 m) and by numerous annual tree rings (over 200). Among the trunks of this generation the stumps of oaks hewed with axes (between 900 and 1050 AD) are resting "in situ". In the location of a primary deposition the trunks of black oaks with the completely preserved Sapwood and sometimes with the bark have been found as well.

The youngest trunks, felled by the Vistula river ca 1310–1320 AD (chronology KUAA4, Fig. 17) occurred in the alluvia of the younger system of the abandoned channels.

Grabie (no. 13 in Fig. 14)

The gravel-pit in Grabie is located on the right bank of the Vistula river, close to

KRAKÓW – KUJAWY (KUAA 2)
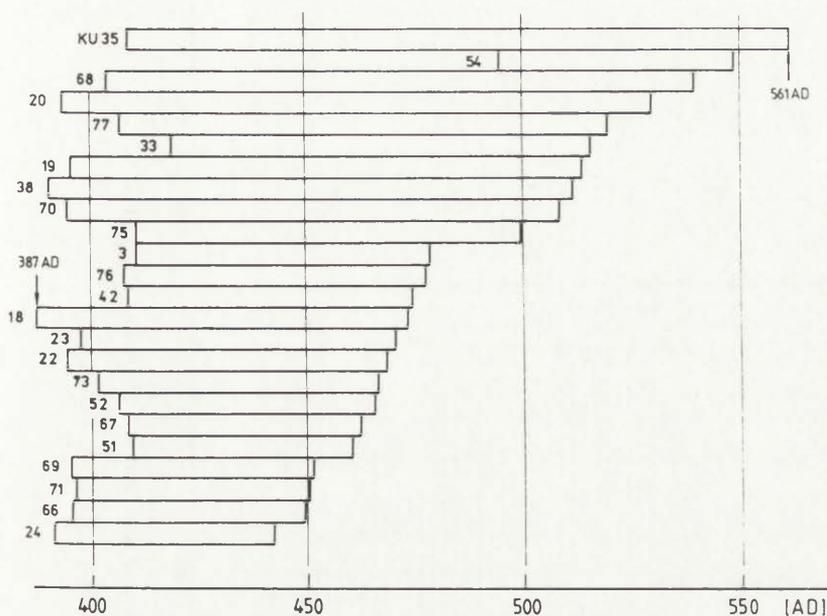
KRAKÓW – KUJAWY (KUAA 4)
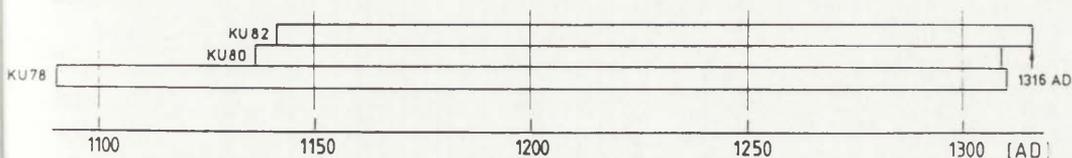
Fig. 17. Subfossil oaks dated dendrochronologically from Kujawy near Cracow –
chronology KUAA2 and KUAA4

the present-day river channel. The abandoned channel, which was artificially cut off
in the 19th century, marks off in morphology (Kalicki, Krąpiec 1991b). Based on 24
trunks sampled to 1991 chronology GA1-2 covering 534 years and dated at 1779–
–1244 cal. BC (Krąpiec 1992b) was determined.

During two recent years the next 6 samples were obtained from the black oaks
trunks possessing from 130 to 200 tree rings. These trunks were felled during the same
phase as those mentioned above, i.e. ca 1280–1200 cal. BC.

Branice (no. 14 in Fig. 14)

A gravel-pit in Branice–Stryjów belongs to the largest ones in the Vistula valley.
It is located ca 18 km east of the Cracow centre, on the floodplain near the present-day
Vistula channel. Two abandoned channels and deposits, which mark off in morpho-
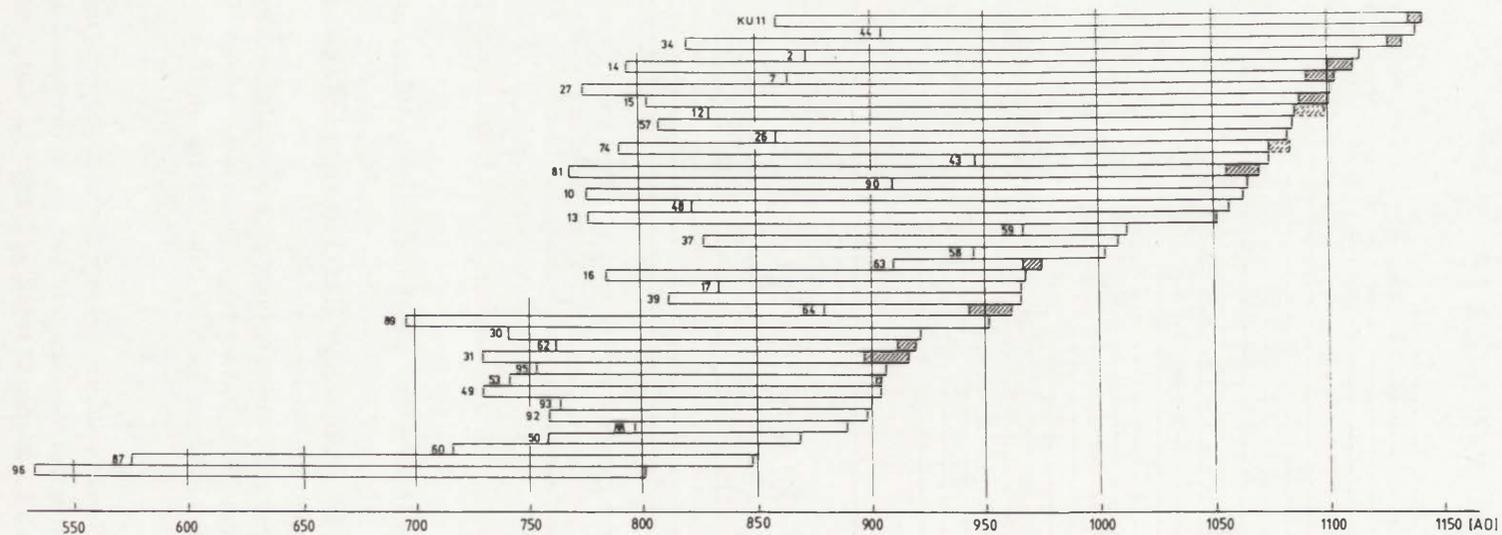
Fig. 18. Correlation diagram from subfossil oaks from Kujawy near Cracow – chronology KUAA1

logy, have been described by T. Kalicki and L. Starkel (1987) and the papers of T. Kalicki and M. Krąpiec (1991a, 1994) are about alluvia and black oaks. During three recent years a rate of excavation works in the gravel-pit decreased substantially. Because of this reason only 12 subfossil oaks were sampled in 1991–1994 (Table 5). The oldest samples originate from the Roman period. Among these samples there is an oak stump cut down by a man in the 3rd century. One sample originates from the oak felled after 655 AD while 4 consecutive samples from the oaks felled in the 13th and 14th centuries. Among them the stem of the oak hewed with an axe in ca 1440 AD was found. Age distribution of the black oak samples from Branice correlates well with previously determined oak chronologies from this gravel-pit (Krąpiec 1992a, b).

Wolica (no. 15 in Fig. 14)

The gravel-pit in Wolica is located on the left bank of the Vistula river, ca 20 km east of the centre of Cracow, within the zone of sand bars of the older abandoned channel cut off during channelization in the mid-19th century. Trunks of the "black oaks" were taken (Krąpiec 1992b) and the next 30 samples have recently been taken.

Stumps with traces of hewing by axes and trunks with alburnum and bark rested shallowest, i. e. at the depth of ca 2.5 m. Vertical position in sediments and presence of the lower order roots are indicative of resting "in situ". The stumps make up chronology WAA1 covering 93 (Fig. 19). This chronology shows similarity neither to the Southern Poland chronologies nor to the Bednarz's scale (1987) for the period of 1760–1980 AD. The chronology seems to originate from the period between the 16th century and the first half of the 18th century.

The trunks forming chronology WAA2 (Fig. 19) are represented most numerously. Trees compiles in this chronology started their growth almost simultaneously during less than 20 years (380–400 AD). The subsequent felling of the tree occurred between 450–560 AD while the majority reached sediments between 470–500 AD. All trunks of chronology WAA2 were redeposited, as well as two trunks included to chronology WAA5, dated at 102–250 AD (Fig. 20). Attention should be paid to sample W49 obtained from the board being probably a side of a gouged boat made from the oak cut in ca 212 AD.

The next seven trunks form chronology WAA4 covering 275 years (Fig. 20) and dated at 2875–2600 BP. The trees included to this chronology were successively being felled during almost 200 years. These trunks were redeposited as well. Trunks forming chronology WAA4 are very interesting, because they originate from the period in which the "black oaks" are sporadically found.

The oldest of the compiled chronologies WAA3 (Fig. 20) represents period 3125––3000 BP. It has been compiled basing on four redeposited trunks.

Basing on the Southern Poland chronology of black oaks the next three samples from the gravel-pit in Wolica were dated. These samples originated from the oaks felled in the Middle Ages, i.e. ca 831, 1121, 1226 AD.

Nowe Brzesko (no. 16 in Fig. 14)

In 1992 several oak trunks were pulled up from the Vistula channel close to the city of Nowe Brzesko. The oak wood was obtained for heating purposes. Majority of

WOLICA (WAA 2)

WOLICA (WAA1)
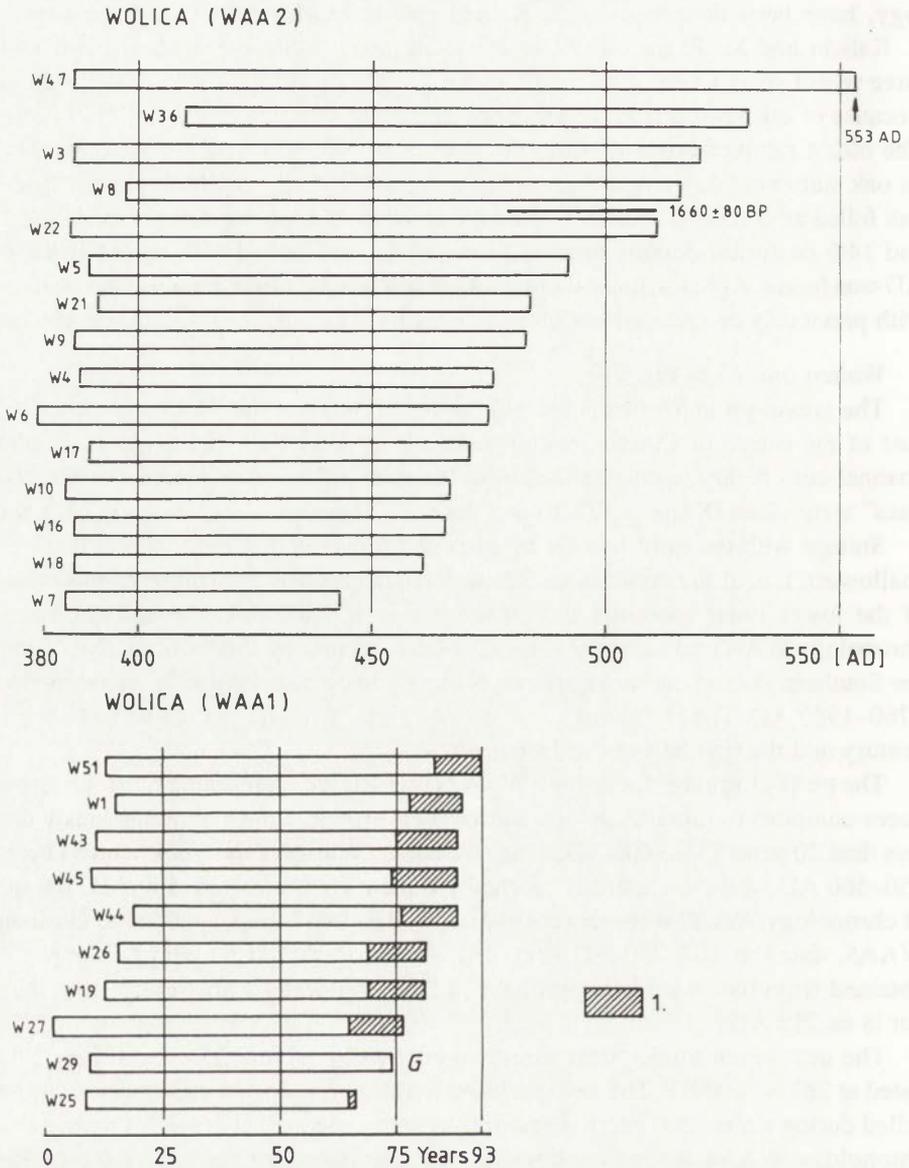
Fig. 19. Correlation diagram of subfossil oaks from Wolica near Cracow – chronology WAA1 and WAA2

1 – Sapwood

the samples turned out to be of the same age (Fig. 21). Chronology NBAA1 compiled on the basis of these samples was 364 years old. This chronology was absolutely dated at 191 BC–173 AD. The oak trunks were being felled from the end of the 1st century AD to the end of the 2nd century AD with maximum intensity in the first quarter of the 2nd century. A characteristic feature of the trunks assembled in the chronology is

WOLICA (WAA5)
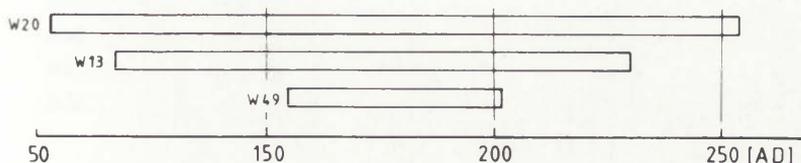
WOLICA (WAA4)
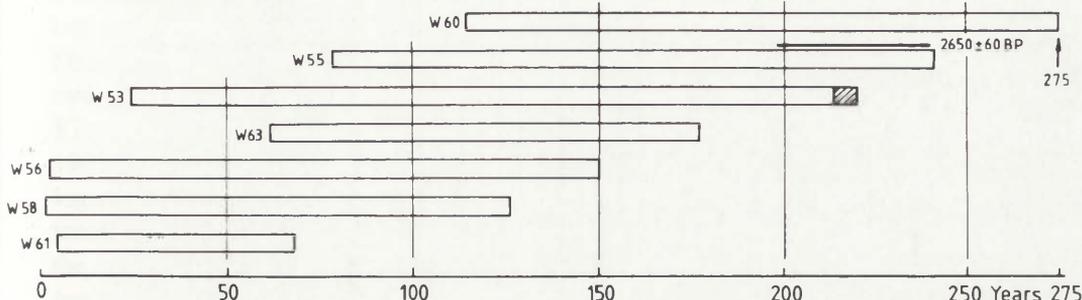
WOLICA (WAA3)
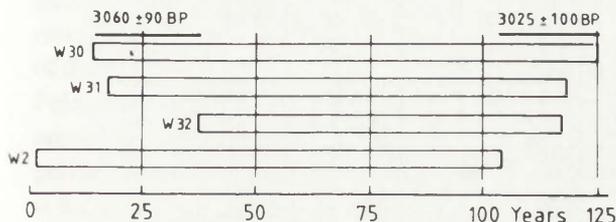
Fig. 20. Subfossil oaks dated dendrochronologically from Wolica – chronology WAA3,
WAA4 and WAA5

1 – Sapwood

lack of the alburnum and visible traces of reworking which confirms the earlier
hypothesis about significance of these features for differentiation between the oaks
occurring "in situ" and redeposited ones.

The remaining oaks originate from other time periods, i.a.: NB1, 202 tree rings
felled in ca 791 AD; NB 10, 114 tree rings felled in ca. 498 AD; NB 13, 82 tree rings
felled in ca 1324 AD.

Klecie (no. 18 in Fig. 14)

In the gravel-pit in Klecie which is located on the left bank of the Wisłoka river
within the area of the floodplain, five trunks of the black oaks were sampled (Table 5).
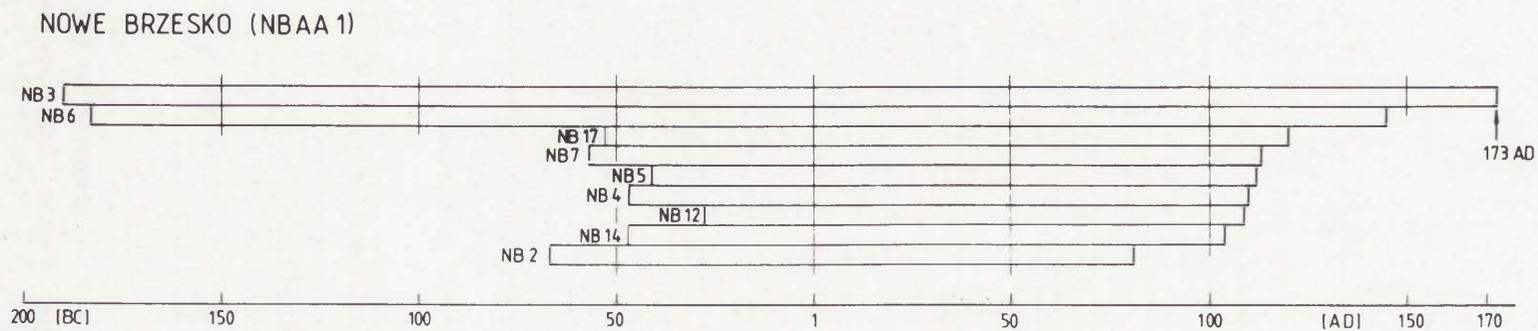
Fig. 21. Correlation diagram of subfossil oaks from Nowe Brzesko near Cracow – chronology NBAA1

The oldest of the dated trunks was felled in ca 130 AD. The next three trunks originate from the 13th and 14th centuries AD. Thanks to the oak trunk having 216 tree rings and which is marked KL5 (dated at ca 1397 AD), it was possible to date two trunks with much shorter sequences of the tree rings: KL3 at ca 1263 AD and KL4 ca 1392 AD.

Strzegocice (no. 19 in Fig. 14)

The gravel-pit in Strzegocice is located on the left-bank of the Wisłoka valley, ca 3.5 km south-east from the city of Pilzno. Under the framework of the studies carried out under the umbrella of CPBP programme, three chronologies were developed in Strzegocice: one dated dendrochronologically at 626–823 AD (STA3) and the other two (STA1 and STA2) dated by radiocarbon method (Krąpiec 1992b). Chronology STA1, covering 273 years, was developed basing on 7 samples (cf. Fig. 24, Krąpiec 1992b). This chronology did not show a clear similarity to the other available chronologies of black oaks. For the purpose of primary dating two samples were taken from trunk ST15 for radiocarbon analysis (one sample consisted of the tree rings close to the core, the second – of the outer tree rings). Due to insufficient funds one analysis has been carried out and the obtained result of dating – 725±80 BP (KR-125) – refers to the tree rings close to the core according to a report. As a similarity between chronologies STA1 and Vistula 2, the latter covering the period between 1100–1529 AD was not stated and as a light colour of an oak wood in the discussed trunks seemed to confirm their short-term resting in sediments, a presumption was made that these trunks were younger, probably of the 16th and 18th centuries (Krąpiec 1992b). The result of the recent studies have revised the above concept. Thanks to numerous trunks of the black oaks and to archaeological materials, a gap in chronologies from Southern Poland covering the early Middle Ages (800–1000 AD) has been filled up. It became apparent that chronology STA1 howed a definite similarity to all the scales of this period, i. e. to the chronology from Kujawy (t = 4.9), Machów (t = 4.2), Wrocław (t = 6.2), Branice (t – 3.8), and thus can be dated at 905–1177 AD. In order to verify the former radiocarbon dating the sample consisting of the near-core rings was analyzed for the second time. The obtained result 970±30 BP (Gd-3776) corresponds well to the recent dendrochronological dating. In the light of presented facts the radiocarbon date 725±80 BP should be matched with the outer rings of the trunk ST15 while the outcome is caused either by replacement of samples or their description in the radiocarbon, or dendrochronological laboratories.

In 1992–1993 the next four samples were taken (Table 5). Two samples were dendrochronologically dated: ST122 at ca 531 AD and ST23 at ca 798 AD.

Grabiny (no. 20 in Fig. 14)

In the gravel-pit in Grabiny, located on the left terrace of the Wisłoka river, dated at the last millennium (Awsiuk *et al.* 1980; Alexandrowicz *et al.* 1981), slices were sampled from the five dredged out trunks or from the trunk fragments (Table 5). The oldest samples are from the 4th and 3rd centuries BC (ca 285 BC and 323 BC). These samples bear traces of reworking by river transporting materials which provides evi-

dence of redeposition. The next two trunks are much younger. They are dated at the mid-16th century. A huge 225 years old oak, 1.8 m in diameter, marked GB3, was felled in 1555 AD. There are axe traces in the butt part of this oak tree at the height of 1 m from the root system. Traces of hewing, 20 cm deep and ca 50 cm wide, occur at both sides of the trunk which indicates that chopping of this tremendous oak was attempted before its felling into the river, when it grew on the Wisłoka bank before being undercut. That last sample originates from the oak felled after 1563 AD. These samples correlate well with the datings by radiocarbon method.

Kędzierz (no. 21 in Fig. 14)

In the precipitous, straight bank of the Wisłoka river the sediments building the rendzina terrace and containing the black oak trunks outcrops over the distance of ca 150 m. This outcrop has been described by Starkel (Alexandrowicz *et al.* 1981; Starkel, Krąpiec 1995). In 1992 slices were sampled from five oak trunks for dendrochronological analysis (Table 5). None of the sampled trunks had the Sapwood and the traces of reworking by river material, in a form of hollows, provide the evidence of the trunk redeposition. Comparison of the obtained dendrochronological sequences with the Southern Poland standard allowed for the absolute dating of one of the trunks KN3, felled after 550 AD. The remaining sequences show neither similarities to the black oak standard nor to the "floating" scales from the older Holocene phases. The two performed radiocarbon datings of trunks KN4 and KN1 (Table 5) confirmed their origin from the time periods which dendrochronologically have not been defined in Southern Poland.

Machów (no. 22 in Fig. 14)

Due to the closing of the open sulphur mine in Machów, engineering works are undergoing in the vicinity of the north-western scarp of an outcrop. In 1992 samples for dendrochronological analyses were taken from the trunks laying in sandy-gravel deposits at the depth of 5–6 m. The analyzed trunks had from 120 to 200 tree rings. The performed analysis allowed to conclude that the trunks had been felled in the first half of the 11th century (Fig. 22). In the case of two trees having the Sapwood and completely preserved bark it was possible to determine precisely the date of the growth end: M3 – 1025 AD and M5 – 1026 AD. The remaining trunks, lacking the Sapwood, can be dated only approximately. Trunks M2 and M4 were felled in the twenties of the 10th century. The last of the studied oaks ceased to grow in ca 1032 AD.

Recently, another series has been sampled from Machów. Two oaks from the north-western scarp have been elaborated. Their felling is dated at ca 1019 and 1027 AD, respectively.

Krzemianna (no. 23 in Fig. 14)

In the gravel-pit Krzemianna (between Dynów and Sanok), which is located on the left bank floodplain of the San river one slice was sampled from the 176 years old oak trunk. This trunk was lacking the Sapwood which evidences its redeposition. The oak

MACHÓW (MAA1)

M6
M4
M5
M2
M3
MAA1
1026 AD

850   900   950   1000   1020 [AD]

10   50   100   150   200 [lata]
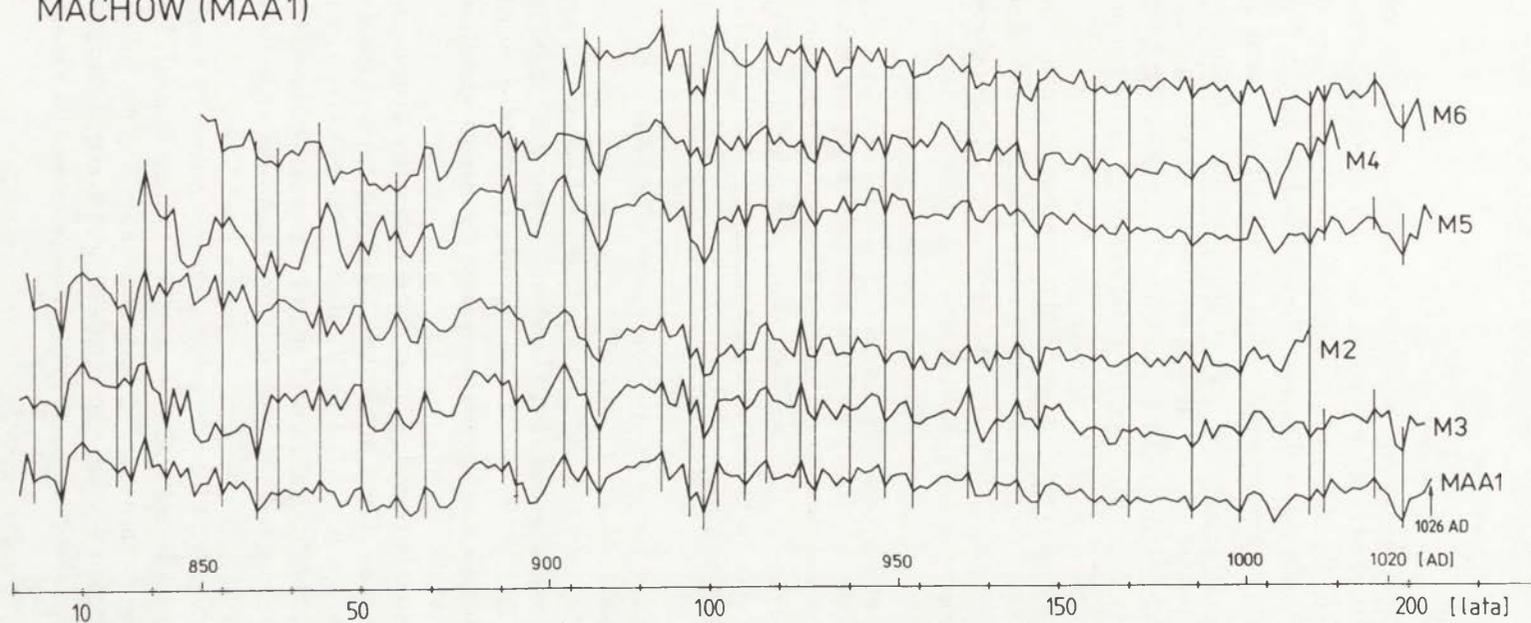
Fig. 22. Dendrochronological curves describing Machów chronology – MAA1

tree grew from 299 BC to ca 114 BC (the last preserved ring of heart-wood is dated at 124 BC).

Ostrów near Przemyśl (no. 24 in Fig. 14)

In the gravel-pit in Ostrów, located on the left-bank floodplain of the San river, 6 slices were taken from dredged oak trunks which were characterized by light coloured wood inside the trunks and by a few cm thick, dark coloured flaking wood belonging to the outer part of the heart-wood. By analogy with the Vistula valley the light colour could have been interpreted as an indicator of a young age of the oaks. However, comparison of the obtained dendrochronological sequences with the standard chronology did not allowed for absolute dating. Only in the case of the largest trunk (217 annual rigs) two segments, which are in a relatively good agreement, were found, i.e. ca 811 or 994 AD, being the possible dating of the last preserved annual ring.

The other sequences from Ostrów failed to correlate with older "floating" scales.

The next samples originating from Przemyśl Region, which allow for defining local chronologies, may be helpful in absolute dating. Dating of chronologies of this type is much easier than of singular samples.

Grabowiec (no. 25 in Fig. 14)

In the gravel-pit in Grabowiec located within the floodplain area on the left bank of the San river fragments of the two black oak trunks laying in sandy-gravel deposits were sampled (Table 5). The first trunk, GW1, had only 71 tree rings and was not dated by radiocarbon method. The second trunk, almost 181 years old redeposited black oak, was felled ca 200 BC.

Southern Poland dendrochronological standard of "black oaks" (474 BC–1529 AD)

After analysing over 600 subfossil oaks from river valleys of Southern Poland it was possible to compile a continuous standard covering 2029 years, from 474 BC to 1555 AD (Fig. 23). New materials in forms of local chronologies and singular dendrochronological sequences allowed to improve the existing regional chronologies and to fill the "early Medieval gap".

Despite numerously occurring trunks dated at the early Roman period (i. e. from Branice, Krzyżanowice, Nowe Brzesko) the "black oaks", which could unambiguously cross-match chronologies Vistula 1 and Standard 1 (260–300 AD), have not been found.

The adequate development of the standard in this period is confirmed by correlation with the two independent Southern German standards: of B. Becker (1981) and E. Hollstein (1980).

Among the developed local chronologies there are also the scales covering the early Middle Ages. The 600 years long chronology from Kujawy (536–1141 AD) is the most crucial for compilation of a continuous standard. Together with the chronologies from Branice, Machów and Strzegocice they allowed to extend chronology Standard 1 and to glue it thanks to the 80 years long period common with Vistula 2 (Fig. 23).
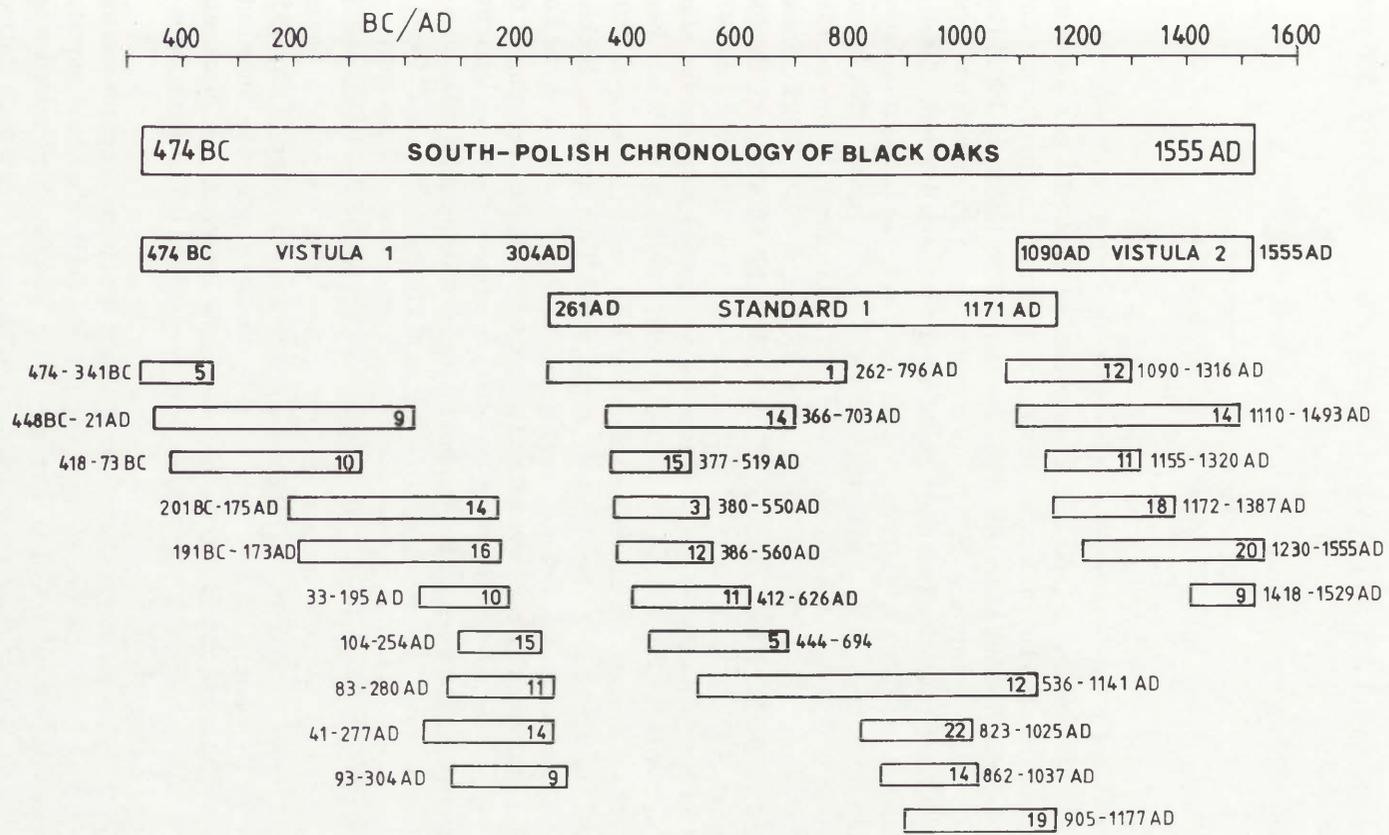
Fig. 23. Comparison of the local chronology dated in calendar years used for definition of the South-Polish dendrochronological standard. Explanation of signs as on Fig. 14

Some of the recently dated oaks originated from the 12th–16th centuries. Thanks to these oaks the compiled chronologies from Kujawy, Grabiny and Klecie allowed for a better defining of regional chronology Vistula 2 and its extension to 566 years (1090–1555 AD).

4. 2. RECONSTRUCTION OF PHASES
OF THE "BLACK OAKS" ACCUMULATION
AND OF FLOOD PHASES

Tomasz Kalicki, Marek Krąpiec

Since the 19th century remarks on the occurrence of the trunks of various tree species, of the "black oaks" most often, in alluvia of Central European rivers have been found in the literature (Bieniasz 1888; Zaręczny 1894; Friedberg 1903; Heck 1928). From the very beginning the age of the trunks was controversial and in the Polish papers it was assumed as the Older Holocene (Kmietowicz-Drathowa 1964) or the beginning of the Subatlantic (Środoń 1952; Starkel 1960). The radiocarbon datings of the trunks from alluvia in the Vistula basin (Mościcki 1953; Tauber 1968; Myciel-ska-Dowgiałło 1972; Ralska-Jasiewiczowa, Starkel 1975; Lindner 1977; Środoń 1980; Alexandrowicz *et al.* 1981; Goslar, Pazdur 1985; Szumański 1986; Kalicki, Starkel 1987; Turkowska 1988; Kalicki, Krąpiec 1991a, b, 1992, 1995a; Kowalski, Swałdek 1991; Krąpiec 1992a, b), in the Odra basin (Dumanowski *et al.* 1962; Wroński 1974; Florek 1978, 1982; Goslar 1987), as well as in the basins of Danube and the Rhine (Geyh *et al.* 1962; Becker, Frenzel 1977; Becker 1982, 1993), in the Weser basin (Schmidt 1973; Leuschner *et al.* 1987), and in the Elbe basin (Hiller *et al.* 1991) proved that "black oaks" originated from the whole period of the Holocene. Becker's works (1993) showed that pine trunks were accumulated in the alluvia in the Late Glacial. The pine trunks were replaced by the oak trunks at the beginning of the Holocene. The above was related to the expansion of oaks on the floodplains after a climatic warming. The evidence for the above is provided by plentiful collections of the trunks from Central Europe and by the oldest trunks of the "black oaks" found in alluvia and dated at the Preboreal (Turkowska 1988; Golsar 1990; Becker 1993).

The mechanism of accumulation of the trunks in alluvia was also questioned. At first, the commonly accepted opinion was that accumulation was due to singular catastrophic floods causing the trees to fall down on the floodplain (Tichy 1951; Becker 1972). The floods were most often related to the wet period of the Subatlantic (e.g. Środoń 1952) and had to lead to the formation of the horizons of the "black oaks" found in the alluvia. Somewhat later a bigger role was assigned to lateral migration of the channels (e.g. Florek 1978).

The trunks, except for several, have been resting in the channel deposits and they have been buried due to accretion in the zone point bars during the lateral migration of the channel (Florek 1978; Kalicki, Krąpiec 1991a). The oaks were undercut and after getting into the river channel were floating and transported for a small distance, and then probably anchored at the nearest of the point bars, where they formed
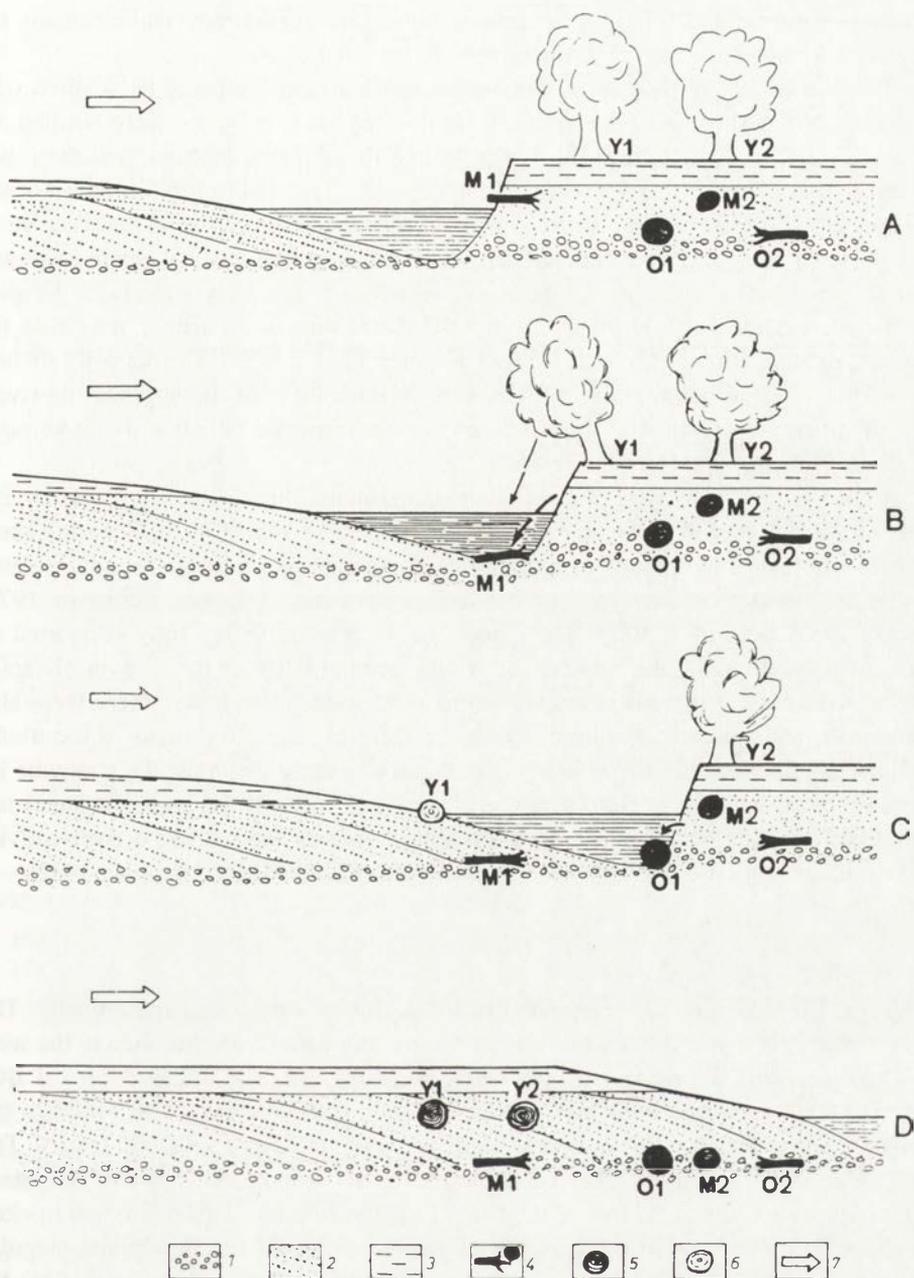
Fig. 24. Scheme of a tree accumulation in alluvia and formation the "simulate aggradation sequence" and "level of black oaks"

1 – lag deposit – gravels, 2 – point bar deposit – sands, 3 – overbank deposit – muds, 4 – "black oak" trunks of the older (O) and middle (M) generation, 5 – "black oak" trunk of the youngest (Y) generation, 6 – trunk of oak, 7 – direction of the lateral migration of channel

a natural obstacle, and finally were quickly buried with sediments. Falling down, the trees could have also happened during the channel avulsion.

The lateral channel migration caused the subfossil oak trunks to be washed with the older alluvia (Fig. 24). The subfossil trunks, heavier than water, were washed out from their original position in the upper part of the channel deposits, and then they were accumulated again in the channel lag deposits. That led to the formation of the "black oaks" horizons in the alluvia. If at that time the oaks growing on the river banks were fallen down, they would accumulate in the upper part of the channel deposits and would result in the "simulate aggradation" sequence in the alluvia (Kalicki, Krąpiec 1995a, b). Because of the process above described only some trunks may date the deposits in which they are found (Kalicki, Krąpiec 1994, 1995b). The deposits are best dated by the felled oak stumps, which occur in the alluvia of the aggradating rivers and are preserved *in situ* with the whole root system, and are buried with the younger deposits (Kalicki, Krąpiec 1992, 1994).

Although the "black oaks" have been accumulated during the whole Holocene, their number varied in particular phases of this period (Fig. 25). In Germany there were distinguished the phases of accumulation of the trunks (Haupthorizonte) related to the increased river activity and the terrace formation (Becker, Schirmer 1977; Becker 1982; Schirmer 1983). The studies in the Vistula valley fully supported an uneven distribution of the number of trunks accumulated in the alluvia (Krąpiec 1992a). Besides the periods when numerous oaks were fallen down, there were also the periods with sporadic falling of the oaks. Referring back to process of the trunks getting into the channel, the periods with numerous falling down the trees may be interpreted as the phases of the intensified lateral erosion and the lateral channel migration or avulsion of the channels, so as the periods of the increased river activity and of the formation of the new inserts of alluvia (Kalicki 1991c; Krąpiec 1992a).

The Preboreal – the Subboreal

In the Eo- and Mesoholocene the black oak trunks were found sporadically. The oldest trunks (of 4 trees) from the Vistula valley originated from Smolice to the west of Cracow. Their falling down was dated at 7900–7800 BP (6800–6450 cal BC) (Krąpiec 1992a). Numerous small trunks of ashes and oaks were also found in the Vistula paleomeander in Rybitwy near Cracow, dated at 7810 BP (Kalicki 1991b). The accumulation of the trunks occurred at the end of the pronounced phase of the intensified Vistula activity at the turn of the Boreal and the Atlantic. This phase was marked downstream of Cracow in the changes of sedimentation of the floodplain, singular meanders cut off and the avulsion of the channel in the final stage dated at ca 7980 BP (Mamakowa 1970; Gębica, Starkel 1987; Kalicki 1991b, c; Starkel *et al.* 1991; Kalicki, Zernickaya 1995).

Another group of the oak and ash trunks, dated by the radiocarbon method, originated from the Vistula valley from 6560–6340 BP (Sokołowski, Wasylikowa 1984) and from the Wisłoka valley (Grabiny) from 6000–5900 BP (Awsiuk *et al.* 1980). Falling down of these trunks coincided with the beginning and the end of the intensi-
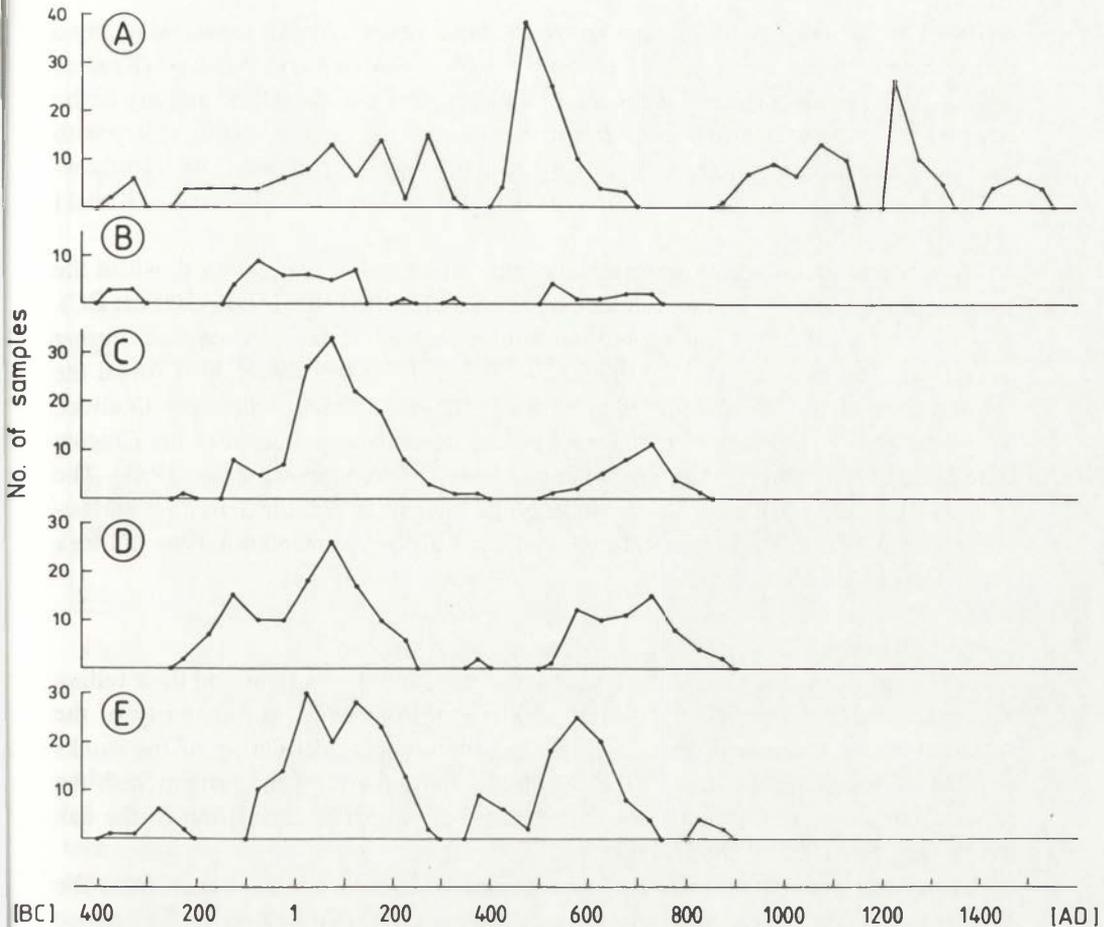
Fig. 25 – Distribution of the number of falling oak trees in the Vistula valley – A (Krąpiec 1992b), Fulda and Oker valley – B (Delorme, Leuschner 1983), Main valley – C (Delorme, Leuschner 1983), Main valley – D (Becker 1982) and Danube valley – E (Becker 1982)

fied river activity manifesting in the change of sedimentation type and the cut off the meanders (Alexandrowicz *et al.* 1981; Wasylikowa *et al.* 1985; Kalicki 1991b, c).

The next trunks of oaks and the other tree species which falling down was dated by radiocarbon method at 5500–5000 BP originated from the valleys of the Vistula, the Wisłoka, and the Bóbr rivers (Alexandrowicz *et al.* 1981; Florek 1982; Sokołowski 1987; Kalicki 1991b). It corresponded to the period of the intensified activity of the rivers dated at 5500–5000 BP and marked in the Vistula valley near Cracow by the cut off the meanders and the channel avulsion (Kalicki 1991b, c; Starkel *et al.* 1991).

The better pronounced period of the accumulation of the "black oaks" was in 4600–4400 BP (3300–3000 cal BC). The oaks of this period were found in the Wisłoka valley – 4540±65 BP (Alexandrowicz *et al.* 1981), in the Bóbr valley –

4610–4590 BP (Florek 1982) and in the Vistula valley near Cracow, where two dendrochronological generations had been found in Smolice and Niedary (Krąpiec 1992a). This period corresponded to the second phase of the intensified activity of the rivers at the Atlantic and Subboreal transition which started in the Vistula valley with the cut off the meanders in the Cracow Gate (Sokołowski, Wasylikowa 1984; Rutkowski 1987) and with the channel avulsion in the region of Zabierzów Bocheński (Kalicki *et al.* in this volume).

The first more numerous generation of the "black oaks" was fallen down in the Vistula valley (Grabie, Branice) in the period of 3200–3000 BP (1500–1300 cal BC). The traces of mechanical damages to the trunks, probably caused by ice floes during the ice-jam floods, were of ca 1400–1320 cal BC. Here there were also found the oldest traces of human activity in a form of the trunks felled with axes (Kalicki, Krąpiec 1991b). The singular dated oaks of this period also occurred in the Cracow Gate (Rutkowski 1987) and in the Wisłoka valley (Alexandrowicz *et al.* 1981). The felling of the oaks took place in the phase of the intensified Vistula activity manifesting in the cut off the meanders and in the changes of the sedimentation type (Klimek 1988; Kalicki 1991b, c, 1992a).

The Subatlantic

A precise reconstruction of the frequency of seeding of new trees and their felling was possible for the period of the last 2500 years from which the majority of the subfossil trunks originated (Fig. 26). The dendrochronological dating of the trunks enabled to determine the date of the beginning and the end of the growth with the accuracy of a few years. Some absolutely dated phases of accumulation of the oak trunks (Krąpiec 1995) were distinguished.

The oldest phase (375–300 BC) was represent by a dozen of trunks from the Vistula valley (the Oświęcim Basin and the Cracow Gate) (Rutkowski 1987; Krąpiec 1992a) and from the Odra valley (Dumanowski *et al.* 1962). This phase is better pronounced in the Danube valley (Becker 1982) than in Poland.

In the most sites, which had been dendrochronologically studied, in the valley of the Southern Poland, the trunks of the Roman period (225 BC–325 AD) occurred (Krąpiec 1992a; Kalicki, Krąpiec 1991a, 1995b). There were also numerous trunks, which had been dated by radiocarbon method, from the Vistula valley (Mycielska--Dowgiałło 1972; Środoń 1980; Rutkowski 1987), and from the Wisłoka valley (Alexandrowicz *et al.* 1981). During this long-lasting phase the seeding and felling the trees occurred simultaneously. In the Vistula valley near Cracow there had often been found the stumps felled by man at that time, rough-hewn fragments of trunks, canoes hollowed out of the tree trunks and poles (Kalicki, Starkel 1987; Kalicki, Krąpiec 1991a). The Roman phase of the trunk accumulation is known from all larger valleys of Central Europe (Becker 1982, 1993; Delorme, Leuschner 1983; Leuschner *et al.* 1987). The phase of the trunk felling corresponds to the period of the changes in sedimentation type on the floodplains of the Vistula and the Wisłoka rivers (Kalicki 1991b, c; Klimek 1992) and with the beginning of aggradation in the Vistula valley near Cracow (Kalicki 1991c).
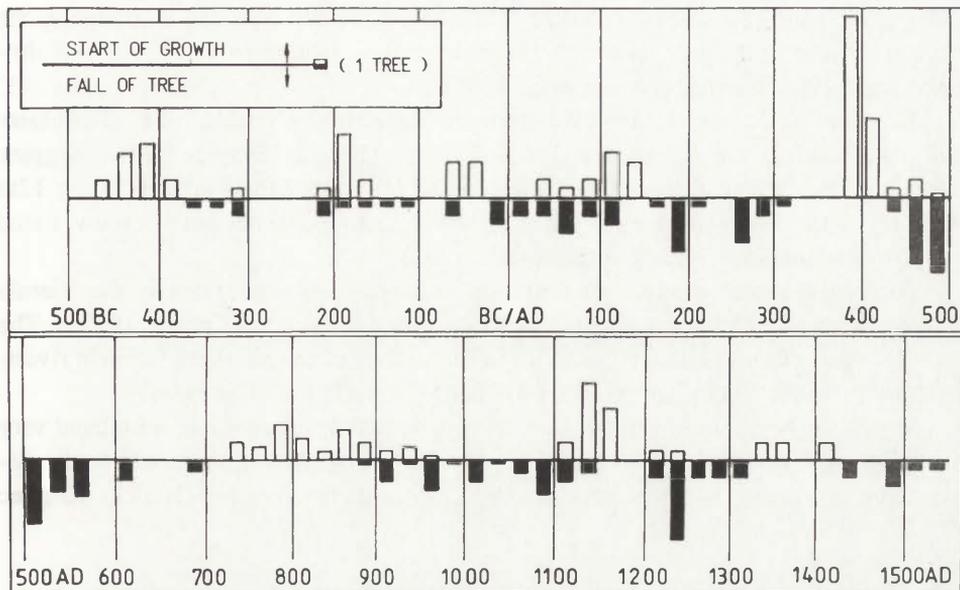
Fig. 26. Start of the growth and fall of trees in the Vistula valley near Cracow during the period
500 BC – 150 AD

The period of the next hundred years was characterized by the lack of the felled oaks in the Vistula deposits as well as in the majority of Central European rivers (cf. Becker 1982, 1993; Delorme, Leuschner 1983; Leuschner *et al.* 1986). At the turn of the 4th and 5th centuries a regrowth of the oak forests on the floodplains occurred.

In the mid 5th century 425–575 (625) AD felling the trees in a large scale was started in the valleys of the Vistula, the Wisłoka and the Odra rivers (Kalicki, Krąpiec 1992, 1994; Starkel, Krąpiec 1995; Krąpiec 1992a) and in the valleys of the small rivers in the Sudetes and in the Holy Cross Mts (Góry Świętokrzyskie) (Wroński 1974; Lindner 1977). At the beginning of this phase there were felled down young trees, aged 50–70, which started their growth at the turn of the 4th and 5th centuries, and then during the phase duration the older and older trees. This phase is best pronounced in the rivers in Central Europe (Becker 1982; Delorme, Leuschner 1983) and in Ireland (Baillie 1994).

The next 200 years (700–900 AD) is the period without felling the trees in the Vistula valley but with a well pronounced seeding of new trees on the floodplain.

These trees were accumulated during the phase lasting from 900 to 1150 AD and marked in the Vistula valley near Cracow (Kalicki, Krąpiec 1992; Krąpiec 1995) and near Machów, as well as in the Wisłoka valley (Alexandrowicz *et al.* 1981). This phase, similarly to the Roman one, lasted fairly long. Moreover, as in the Roman period, the trees growing on the floodplain had been cut down, which was confirmed by numerous stumps of the felled oaks preserved *in situ* in the Vistula valley (Branice, Kujawy) (Kalicki, Krąpiec 1992, 1994). In this period the aggradation in the valley

floors took place, as well as a change in the sedimentation type and a change in the channel course in the Vistula and the Wisłoka valleys (Radwański 1972; Alexandrowicz *et al.* 1981; Niedziałkowska *et al.* 1985).

The next, well marked, Medieval phase, indicated in the Vistula valley (Kościuszko lock, Branice) was assigned to 1200–1325 AD (Kalicki, Krąpiec 1991a; Krąpiec 1992a). Then there had been felled the oaks which started their growth in the 12th century. In the mid 14th century the shift of the Vistula channel near Cracow, dated by historical methods, occurred (Bąkowski 1902).

The last phase of the turn of the 15th–16th centuries was stated in the Vistula valley (Branice, Smolice) and in the Wisłoka valley (Grabiny) (Krąpiec 1992b). The two youngest phases had no equivalents in the valleys of the Southern German rivers, because there the floodplains had already been deforested in most cases.

Moreover, beginning from the 16th century the oak trunks were accumulated very rarely in the alluvia in the Vistula valley. In the young alluvia one could find redeposited trunks which had been deposited by the Vistula much earlier (Kalicki, Krąpiec 1994, 1995b).

Conclusions

The trunks of the "black oaks" of the older periods of the Holocene occur sporadically in the river valleys in Southern Poland and form separate chronologies or only singular datings of these trunks are known. Thus, one can infer that less trees were getting into the deposits, which was probably related to the laterally stable channels with meanders of complicated shapes. The lateral migration was blocked by compact vegetation in the valley floors and the trees fell down sporadically during the cut off the necks of the meanders or during the channel avulsion.

The oaks older than 1500 BC were characterized by the thin tree rings (the average annual tree ring – ca 2 mm thick). Then the trunks with much thicker, ca 2.9 mm, tree rings appeared (Krąpiec 1992a). This change in the ring thickness could be related to fertilization of the habitats on the floodplain due to soil erosion and aggradation of the madas (Becker, Frenzel 1977).

On the base of the first evidences of human activity in the Neoholocene, one has been finding the direct traces of felling the trees in the floodplains for 3000 years, which led to a gradual opening of the forests on the floodplain. The anthropogenic deforestation of the floodplain favoured the lateral channel migration. From that period there was an abrupt increase in the number of accumulated trunks. Therefore, a continuous reconstruction of the phases of the intensified channel migration in the Vistula valley near Cracow was possible. The picture of the Neoholocene phases might be slightly disturbed by felling the trees on the floodplains (less oaks on the plains, cutting down the trunks falling into the water, cutting down the protruding "black oaks" etc.). The youngest phases were not marked due to the almost entire lack of oaks on the plains.

Both in the Older and Younger Holocene there was a very good correlation between felling the oaks and the phases of the intensified activity, which had been distinguished on the basis of the other data. The good correlation of the felling

between various river valleys in Central Europe (cf. Delorme, Leuschner 1983; Becker 1982) indicated the predominance of the climate causing intensified river activity (Fig. 25). The climate, which was the dominating factor in the older phases of the Holocene, could have been stimulated by the human impact in the recent two millennia, and especially in the Roman and Medieval times.

5. SUMMARY OF PALEOHYDROLOGICAL CHANGES
IN THE UPPER VISTULA BASIN

5. 1. CHANGES IN FLUVIAL SYSTEMS AT THE END OF THE VISTULIAN
AND IN THE EOHOLOCENE

Leszek Starkel, Piotr Gębica

In the upper Vistula drainage basin there are ca 60 sites, each with two radiocarbon datings on average, which register fluvial deposits of 13–8 ka BP. Palynological documentation is available for the sections of the profiles from 18 sites. Under the grant 6 of these sites were studied and pollen diagrams were developed for 2 sites.

Due to the brakes caused by erosion and due to the mechanism of the floodplain evolution (lateral migration of the channels, subsequent incisions and infills), the continuous series representing periods longer than 3–4 thousand years are very rare. This chapter is a short overview of the state of the studies, which were discussed in a broader scale in the papers associated with IGCP Project no. 253 "Decline of the Pleistocene" (Starkel, Gębica 1995). Figure 27 presents the main changes in sedimentation registered in various valley sections in the period from 13 to 7.5 ka BP.

The timing of dissection of the Plenivistulian covers has been questioned until recently. As in the case of the Prosna valley (Rotnicki 1987) and of the Wieprz valley (Harasimiuk 1991) also in the valleys of the Carpathian foreland the dissection started before the maximum advance of the Vistulian ice-sheet (Starkel 1994). The fragments of the sandy terraces and fans without loess probably were formed till 20–15 ka BP (Jersak *et al.* 1992). The dissection before the Bölling reached at least the level of the present-day floors of the river channels, if accumulation of peat on the alluvia in Pleszów near Cracow started about 13 260±160 BP (Kalicki 1992b). In the San valley downstream of Przemyśl the abandoned channel fill is dated at 15 200±500 BP (Klimek 1992). The fossil plains of the braided rivers occurring lower than the present-day channels of the Vistula and Raba rivers started to overgrow with peat in the Bölling and the Allerød (Kalicki 1992a; Gębica 1995). Also in the zone of the Carpathian Foothills, the San (Mamakowa 1962) and the Jasiołka (Wójcik 1987) abandoned channels, descending below the level of the present-day channels, started to fill up at the beginning of the Allerød. In the Podhale the erosional terrace of the Czarny Dunajec river, where the peat started to accumulate, formed before the Bölling. The oldest paleomeanders, dated at the Bölling and the Allerød, indicate that the change in the paleochannel pattern took place over a large area in the Late Glacial (cf. Kozar-

ski 1983). Parameters of large paleomeanders were 3–4 times the size of the Holocene paleomeanders. The widths of the Vistula, the Wisłoka and the San channels exceeded 100–150 m and radii of the curvature reached 650–1100 m. The second generation of large meanders formed in the case of the Wisłoka and the San rivers in the Younger Dryas (Szumański 1986; Starkel 1995d). The rivers restored the braided pattern in many sections. The plains and deposits of the braided river of this period were registered in the Vistula valley downstream of Cracow (Kalicki 1992a; Starkel *et al.* 1991). There emerge also very large meanders, dated at the beginning of the Holocene (Kalicki, Starkel 1987; Nalepka 1991; Kalicki *et al.* in this volume), which either originate from the transitional period to the Holocene or can be the evidence of simultaneously occurring braided and meandering channels. Such parallel channels are known from Eastern Siberia with permafrost.

Cooling of climate in the Younger Dryas caused the river aggradation, which manifested not only in the higher level of the river bottoms, but in lateral migration with cutting the erosional benches even in the Miocene substratum (Starkel in: Alexandrowicz *et al.* 1981). A larger flood frequency is evidenced by covering the Allerød peat in the flood plains with the madas (Ralska-Jasiewiczowa, Starkel 1975).

The parameters of the younger, Eoholocene paleochannels are much smaller, 2–5 times, than the Late Vistulian ones (cf. Fig. 27). One of the small paleomeanders in the lower San valley, abandoned before 8560±100 BP, is inserted in the large, Late Vistulian paleomeander (Szumański 1986). Thus, there is the evidence of limited flood flows and reduced supply of a material due to development of a dense vegetation cover. Many sections of the alluvial plain were overgrown with peat again (Starkel *et al.* 1991) and the clayey madas ($Mz = 8$–$10\emptyset$) were deposited on the plains in opposite to the older madas which grains differ in sizes ($Mz = 4$–$9\emptyset$). The above was accompanied by the channel deepening.

In the valleys of the Vistula tributaries with higher gradients (e.g. the Soła, Raba, Dunajec rivers), the traces of the large paleomeander phase are lacking, which could indicate that the braided pattern were preserved till the beginning of the Holocene. Recently the larger paleomeanders have been stated in the lower Dunajec valley (Sokołowski 1995). The beginning of these paleomeanders filling up is dated at 9640±180 and 8200±140 BP. Their widths reach 100 m. These are likely the Eoholocene paleochannels with transitional parameters to small meanders. From the comparison of the changes registered in the 250-years long intervals (Fig. 27) it seems that the periods of the most frequent changes are: the beginning of the Allerød (12.0–11.75 ka BP) and the decline of the Allerød (11.25–11 ka BP), as well as the transition from the Younger Dryas to the Holocene (10.5–9.5 ka BP), when the final transformation of the fluvial system took place.

ka BP

UPPER VISTULA (Niedziałkowska et al. 1985)

OŚWIĘCIM REACH (Klimek 1992)

CRACOW GATE (Rutkowski 1987)

CRACOW – NIEPOŁOMICE (Kalicki 1991c)

PODŁĘŻÓWKA (Nalepka 1991)

DRWINKA + GROBLA (Starkel et al. 1991, Kalicki et al. in this vol.)

RABA FAN (Gębica 1995)

8-
9-
10-
11-
12-
13-
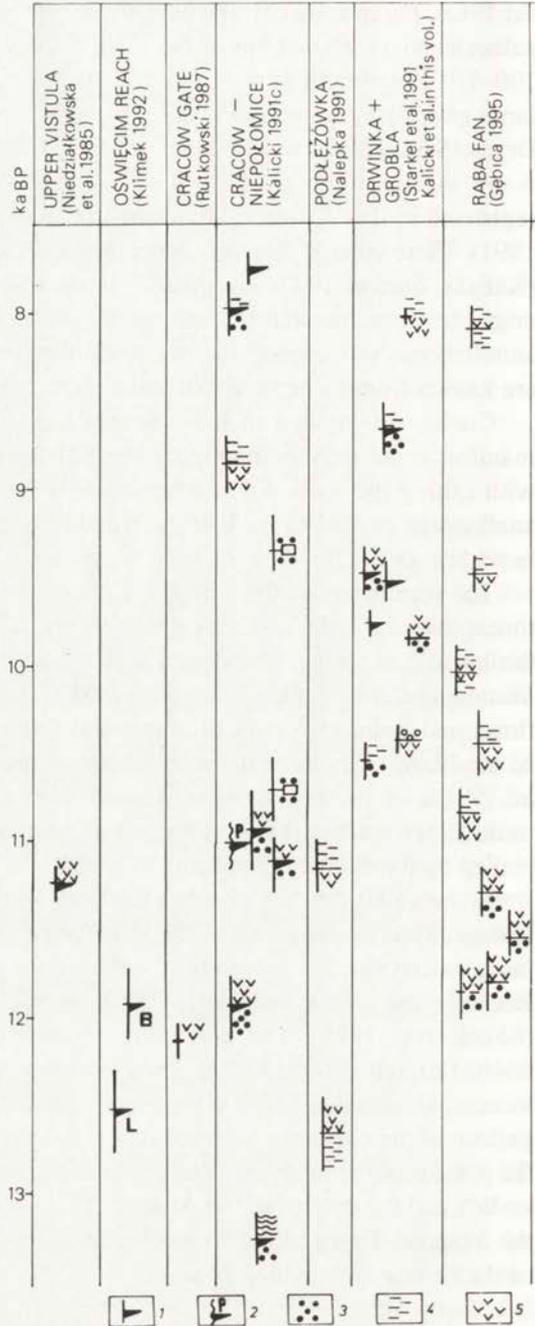
Fig. 27. Records on flood phases during the Late Vistulian and Eoholocene in upper Vistula basin
(after compilation made by L. Starkel and P. Gębica 1995)

1 – radiocarbon age of the bottom of paleochannel fill, 2 – age of the paleochannel calculated by palinological method, 3 – channel sediments, 4 – overbank facies, 5 – peat, 6 – gyttja, 7 – alluvial fan, 8 – age of "black oaks", 9 – fossil soil, 10 – type of paleochannel; B – braided, L – large paleomeander

RABA VALLEY (Alexandrowicz,Wyżga 92)

WISŁA TARNOBRZEG (Mycielska D. 1978)

LOVER DUNAJEC (Sokołowski 1995)

WISŁOKA VALLEY (Starkel 1982,1995d)

JASŁO-SANOK DEPR. (Wójcik 1987)

UPPER+MIDDLE SAN (Ralska-Jasiewiczowa, Starkel 1975)

LOWER SAN (Szumański 1986 Klimek 1992)

SANCYGNIÓWKA (Śnieszko1987)

NUMBER OF SITES INDICATING CHANGE

ka BP

15200±500

B.L 10

xxx 9

8

7

6
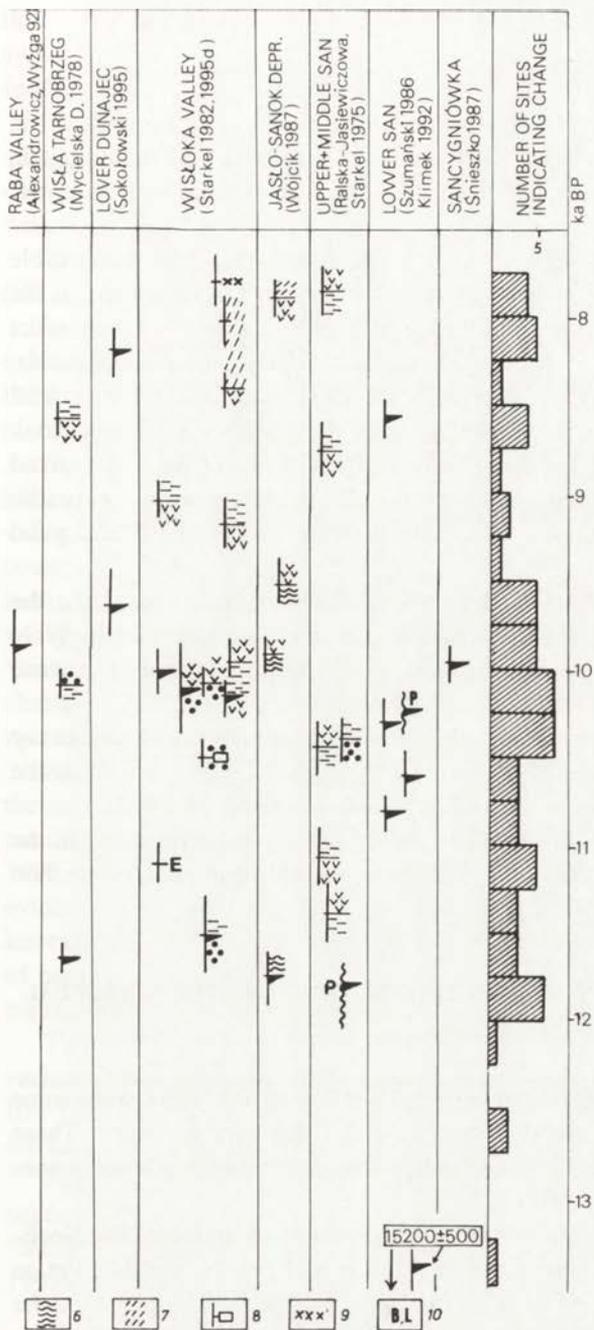
5. 2. HYDROLOGIC CHANGES AT THE BOREAL–ATLANTIC TRANSITION

Leszek Starkel

A period of the first moistening of climate under conditions of full forestation in the Holocene revealed very significant changes both in valleys and on mountain slopes. These changes were already indicated 20 years ago (Ralska-Jasiewiczowa, Starkel 1975; Starkel 1984).

The discussed period covers 8.7–7.7 ka BP. However, the most remarkable changes started ca 8.4–8.0 ka BP, when the series of floods was registered in the deposits of the alluvial fans at the margin of the Carpathian Foothills (Niedziałkowska *et al.* 1977; Czyżowska, Starkel – chapter 2.5 in this volume). The paleochannels, sometimes fossil ones (Kalicki 1991c; Starkel *et al.* 1991; Szumański 1986), with small parameters, which were then abandoned, indicate that spectacular changes took place after the period of stability. The most convincing evidence of the wide-spread floods is the covering of the organic deposits with madas or clayey sediments practically within the area of the contemporary flood plains of the Vistula, the Wisłoka and the San rivers (cf. Starkel 1994).

Even the large paleomeanders located in marginal zones, as for example the Vistula paleomeander in Nowa Huta (Kalicki 1987) or the paleomeander in Wola Żyrakowska on the Wisłoka river (Starkel, Granoszewski 1995), registered an increase in mineral substances in the meander fills starting from 8.9–8.8 ka BP.

There is a good correlation between this period, when continuous rains and heavy downpours occurred, and landslides (Gil *et al.* 1974; Starkel 1985), as well as the debris flows registered in the deposits of the Tatric lakes (Kotarba ed. 1993).

The opposite phenomenon, i.e. the break in accumulation, has been stated in the calcareous tuffa steps in the limestone valleys of the Cracow Upland which were then dissected by flood waters (Pazdur *et al.* 1988).

5. 3. CHANGES IN THE FLUVIAL SYSTEM IN THE ATLANTIC AND THE SUBBOREAL

Leszek Starkel

In the upper Vistula, in the period between 7.5 and 3.0 ka BP, there were some phases characterized by various flood frequencies and different moisture. These phases are reflected in the system of dissections, alluvial fills and mada sequences (Fig. 28).

The discussed period is also the time of expansion of an agriculture of the Neolithic and the Bronze epochs. The first traces of farming and grazing are dated at ca 4500 a BC (ca 6000 BP) (Kruk 1980; Wasylikowa *et al.* 1985). The phase of the Funnel Beaker Culture, dated at 3200–2500 a BC (4600–4100 BP), is very characteristic because the settling moved from the valley floors to slopes and watershed ridges both in the loess uplands on the left bank of the Vistula river and in the Carpathian Foothills, and thus the phase can be interpreted as moistening and cooling of climate (Kruk 1980; Machnik 1994). It is also the period of formation and inunda-

tion of peatbogs (Ralska-Jasiewiczowa 1980; Harmata 1987; Obidowicz 1988, Wa-sylikowa *et al.* 1985). In the same period spruce spread in the vertical zone of the foothill forests in the Beskid Niski Mts (Szczepanek in: Gil *et al.* 1974).

The next phase of the settling expansion took place in the Younger Subboreal simultaneously with the development of the late Bronze Lusatian Culture and is also correlated with the changes in vegetation cover (Ralska-Jasiewiczowa ed. 1989) and with the intensified floods.

In the period between 7.5 and 3.0 ka BP the following phases were distinguished (cf. Starkel 1995h):

In the period of 7.5–6.5 ka BP there were no significant changes in the fluvial system. The stable forest communities and the low ground water level indicate that the frequent large floods were lacking, but sporadic channel cut-offs are known (Szu-mański 1986).

Between 6.6 and 6.0 ka BP there was an activation of fluvial processes. The first indicators of this activation are the madas covering the organic deposits in the Vistula valley (Kalicki 1991c, Gębica 1995) and in the Uszwica valley (unpublished), and covering the calcareous tuffa in the Racławka valley (Rutkowski 1991). The next indicators are the abandoned channels and the tree trunks known from the Vistula valley (Wasylikowa *et al.* 1985; Kalicki 1991c; Sokołowski 1987) and from the Wisłoka valley (Starkel in: Alexandrowicz *et al.* 1981). The parameters of the cut off channels are larger than those of the younger channels (Fig. 28), which could indicate that they may have formed still during the floods in the Early Atlantic.

After the next dry phase, in which a rate of peat growth was generally decreasing, the activation of fluvial processes took place from 5.5 to 4.9 ka BP. This activation manifests in the change from organic or calcareous to mada sedimentation (Rutkowski 1991; Śnieszko 1987) and mainly in the changes in the river channels. The most evident example is the abandoned system of paleomeanders in Grobla Forest, ca 40 km east of Cracow (Gębica, Starkel 1987; Starkel *et al.* 1991). At first sinuous systems of narrow meanders (w = 45–50 m, r = 125–165 m) developed here. Many of these meanders were cut off with intensification of floods ca 5.5–5.4 ka BP.

The younger channel was only slightly sinuous with singular meanders. Its width varied from ca 45 to 75 m. It was abandoned by an avulsion between 5.1 and 5.0 ka BP. The swampy, abandoned channel in Pleszów filled with delluvia between 5.4 and 4.8 ka BP corresponds to this phase.

After the phase of the certain stabilization the next activation of fluvial processes occurred between 4.4 and 4.1 ka BP, during which channel avulsion, accumulation of "black oaks" (Rutkowski 1987; Sokołowski 1987; Krąpiec 1992b; Pożaryski, Kalicki 1995) and inundation of peatbogs (Ralska-Jasiewiczowa 1980) took place.

The Vistula paleomeander in Zabierzów Bocheński, in which particular bends were cut off before avulsion (Kalicki *et al.* in this volume), has been studied recently. The date from the base of the meander fill is 4410±100 BP.

After the subsequent phase of channel stability, which favoured spreading of beech and fir (Ralska-Jasiewiczowa ed. 1989), as well as the accumulation of calcareous tuffa (Jäger, Ložek 1983; Pazdur *et al.* 1988), the phase of floods started from ca 3.2

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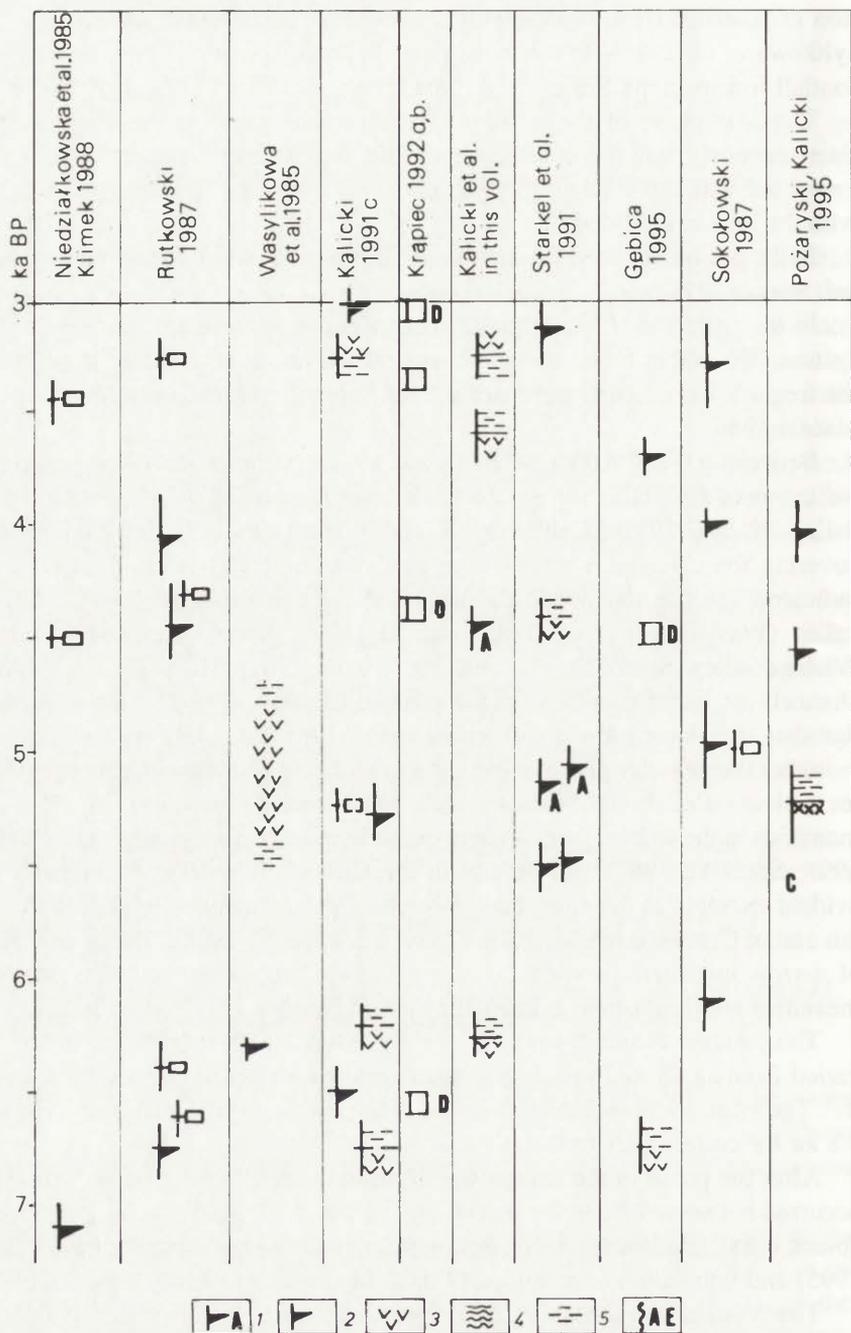
Fig. 28. Records on flood phases between 7 and 3 ka BP in the upper Vistula basin (after
L. Starkel 1995h, slightly changed)

1 – radiocarbon age of the bottom of the paleochannel fill with avulsion, 2 – the same – not clear avulsion,
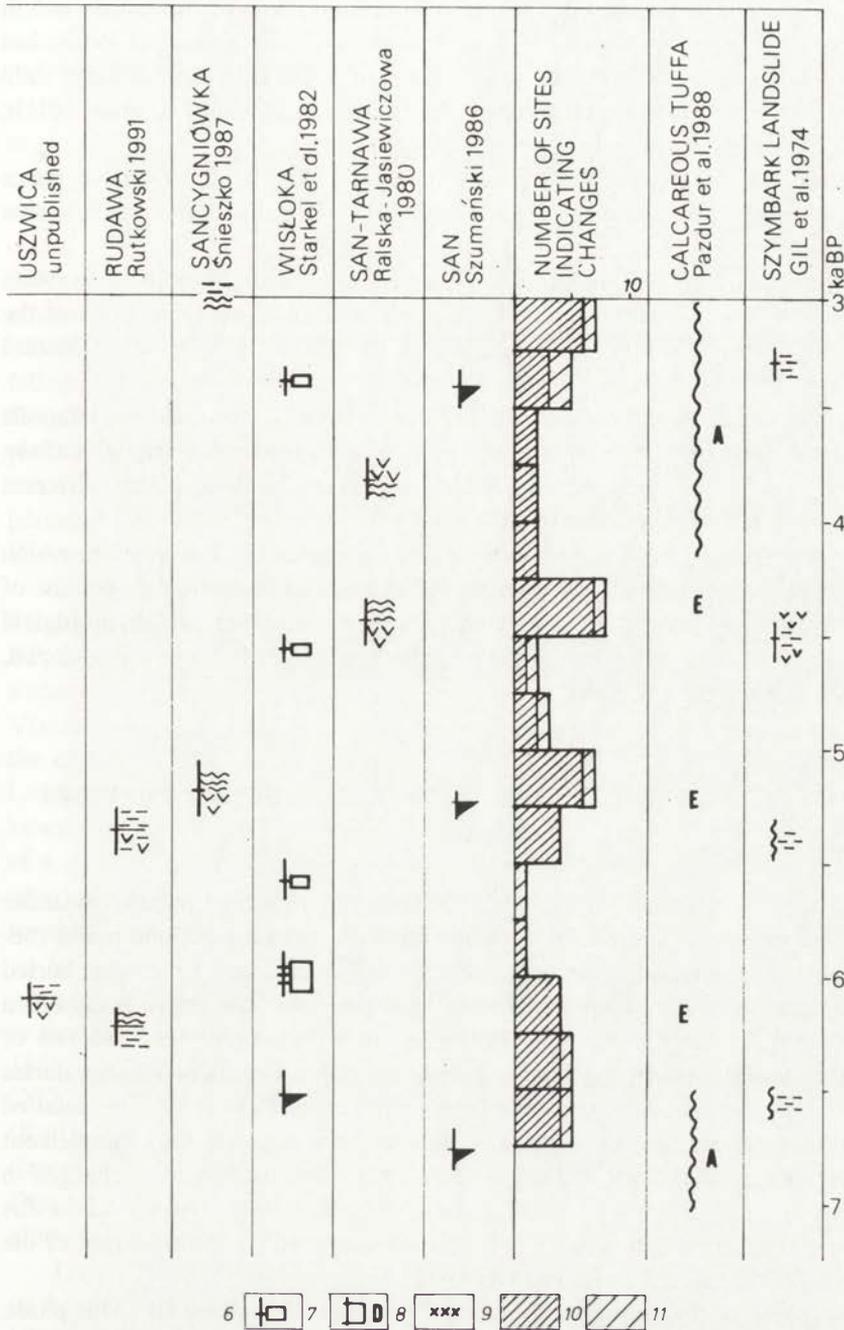
3 – peat, 4 – gyttja, 5 – overbank facies, 6 – calcereous tuffa deposition or their erosion, 7 – age of "black oaks", 8 – series of falling oaks dated by dendrochronological methods, 9 – fossil soil, 10 – number of sites indicating change in fluvial activity, 11 – other dated sites

(3.3) ka BP. This phase not only did manifest in accumulation of the madas and in abandonment of channels (Kalicki 1991b, c; Sokołowski 1987; Śnieszko 1987), but also in the presence of a tree-fall with traces of ice-jam floods between 3200 and 3000 BP and in the traces of a forest clearing on the floodplain (Kalicki, Krąpiec 1991b; Krąpiec 1992b – chapter 4.1 and 4.2 in this volume).

The cultural site of the Bronze epoch in the rock niche in the Dunajec gorge through the Pieniny Mts, which is covered with flood deposits, corresponds to this period (Ložek 1991).

In the Atlantic and the Subboreal there were very distinct oscillations in moisture and frequency of floods which, during the wet phases, led in many sections of the valleys to the threshold values and rebuilding of the entire fluvial system (Starkel 1995h).

Although these phases did not occur exactly rhythmically, in equal time intervals (duration of one cycle from 500–600 to 1800 years), they were regular enough to have been marked in different changes in the sedimentation on the flood plains, different inserts of alluvia and different channel systems.

In order to avoid any randomness in temporal distribution of information, which is related to the present uneven advancement of the studies in particular sections of the river valleys, these phases are correlated each time with other paleohydrological data in the upper Vistula valley and in the neighbouring areas (Ralska-Jasiewiczowa, Starkel 1988; Starkel 1985, 1995h).

5. 4. PHASES OF INCREASED RIVER ACTIVITY DURING THE LAST 3500 YEARS
Tomasz Kalicki

The increased river activity manifests in: changes in a channel pattern (meander cutting-off and avulsion), alternation of sedimentation conditions in flood plains (beginning of peat accumulation, covering of peat with alluvial loams, i.e. madas, buried soils), accumulation of numerous tree trunks in alluvia etc. The above phenomena might be related to changes in frequency and/or magnitude of floods. Analysis of records of the last 3500 years, from the valleys of the upper Vistula and its tributaries allows one to distinguish some periods of the increased river activity. The detailed dendrochronological studies are especially helpful here, because they supplement other geomorphological records and allow to obtain a continual record of changes in lateral migration of the Vistula channel (Kalicki, Krąpiec 1995b; chapter 4.2 in this volume). Also the buried archaeological levels may support the identification of the flood periods (Żaki et al. 1970; Radwański 1972).

The first period of the increased river activity was in 3500–3000 BP. This phase was studied most precisely in the Vistula valley (Fig. 29). In the initial stage (after 3590±140 and before 3260±110 BP) a sandy-gravel member Vb was inserted into the fill of the Subboreal system of paleomeanders in Zabierzów Bocheński (Kalicki et al. in this volume). The more frequent floods, inundating the whole floodplain, caused the peat in the marginal part of the valley in Pleszów II to be clayed from 3260±80

BP while the stagnant water in the backswamps and likely to rise in ground water level resulted in a local peat growth in the depression of the Drwień stream near Płaszów (3270±110 BP) (Kalicki 1992a, b). The first, rather numerous generation of black oak trunks, which provides evidence of triggering the lateral migration of the channel, originates from this period (3200–3000 BP, i.e. 1500–1300 cal BC). In ca 1400–1320 cal BC traces of a mechanical damage by ice floes during the ice-jam floods are marked on the trunks (Kalicki, Krąpiec 1991b). Singular dated trunks of this period occur also in the Vistula valley near Cracow (3250±100 BP, Rutkowski 1987; 2895±70 BP, Środoń 1980) and in the Wisłoka valley (3380±65 BP, Alexandrowicz et al. 1981). The lateral channel migration could have been promoted by a human activity directly on the floodplain. The traces of this activity, in the form of trunks felled with axes, were recorded for the first time in this period (Kalicki 1991c; Kalicki, Krąpiec 1991b). At the end of the discussed phase the development of paleomeanders yield to cut off the Vistula bend in Śmiłowice (3090±140 BP, Kalicki – chapter 2.4 in this volume) and in Łęg A (3030±100 BP, Kalicki 1991b). Moreover, the analysis of parameters of the Holocene paleomeanders indicated that their radii increased and the Vistula channel widened in this period (Kalicki 1991b).

Changes in the Vistula channel are also recorded in the other sections: in the Sandomierz Basin (3270±200 BP, Sokołowski 1987), in Oświęcim Basin (2940±70 BP, Klimek 1988) and in the San valley (3380±90 BP, Szumański 1986). There is a change in the type of the madas (overbank deposits) in the upland tributaries of the Vistula river (2930±150 BP, Rutkowski 1991) as well. An analogous alternation of the channels and changes in sedimentation took place in the valleys of the Polish Lowland in this period (Kozarski, Rotnicki 1977; Florek 1982; Tomczak 1987; Turkowska 1988; Alexandrowicz, Dolecki 1991; Kamiński 1993). The similar alternation of a sedimentation type, as well as accumulation of a large number of the trunks in alluvian are observed in the other valleys of Central Europe (Becker 1982; Aleksandrovskiy et al. 1987; Kalicki 1991a).

In the oldest Subatlantic a short period, 2700–2600 BP, with the traces of the increased river activity, can be identified. In the Oświęcim Basin this period manifests in the covering of the organic alluvial loams with silty loams (2710±90 BP, Klimek 1988) and in sandy layer in the paleomeanders in Zabierzów Bocheński near Cracow (2720±130 BP, Kalicki et al. in this volume). Several trunks, dated at 375–300 BC (Rutkowski 1987; Krąpiec 1992b), occur in the Vistula alluvia (Oświęcim Basin and Cracow Gate) and singular oak trunks are found in the Odra valley (2700±115, Dumanowski et al. 1962). This phase manifests in the accumulation of the trunks in alluvia more clearly in the Danube valley than in Poland (Becker 1982).

The following, very pronounced phase of the intensified river activity took place in the Roman period (2350–1800 BP). The Vistula paleomeanders of this period are known from the Cracow Gate (2100±80, Rutkowski 1987). The increase in frequency and probably in magnitude of floods resulted in deposition of sands and sands with gravels on peat in the vicinity of the channel. The base of the peat was dated at 2370±100 BP (Kalicki 1991b). On the other hand, in the Subboreal system of paleomeanders in Zabierzów Bocheński, which was located far from the Vistula, organic
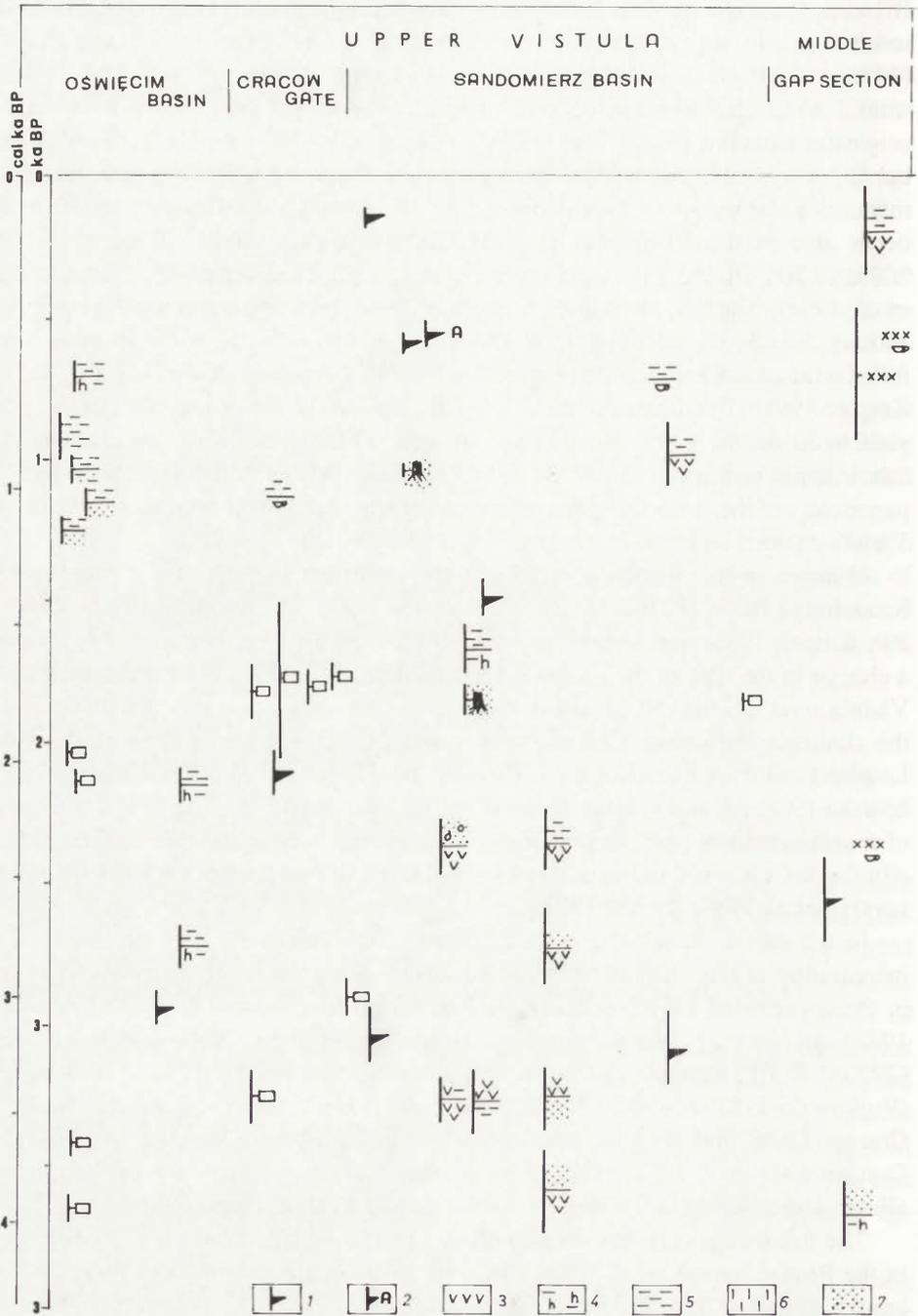
Fig. 29. Reflection of the Holocene climatic changes (flood phases) in both morphology and alluvia during the last 3500 BP – radiocarbon dating (by T. Kalicki)

Based on the publication: Upper Vistula in Oświęcim Basin (Niedziałkowska *et al.* 1985; Klimek 1988), Cracow Gate (Tauber 1968; Radwański 1972; Środoń 1980; Rutkowski 1987), Sandomierz Basin (Żaki *et al.* 1970; Mycielska-Dowgiałło 1972; Trafas 1975; Środoń 1980; Sokołowski 1987; Kalicki 1991b, 1992a, b,

unpubl.; Kalicki, Krąpiec 1991a, b; Kalicki *et al.* in this volume), Gap section (Falkowski 1967; Pożaryski, Kalicki 1995), tributaries – Raba (Alexandrowicz, Wyżga 1992), Wisłoka (Alexandrowicz *et al.* 1981; Klimek 1992), San (Szumański 1986, Klimek 1992), Rudawa (Rutkowski 1991), Prądnik (Alexandrowicz 1988), Nidzica (Śnieszko 1985), Nida (Lindner 1977), Czyżówka (Kosmowska-Suffczyńska 1983).

1 – cut off meander, 2 – channel avulsion, 3 – peat, 4 – organic silts, 5 – overbank deposits: silts, 6 – overbank deposits: loess madas, 7 – sands, 8 – sands with gravels, 9 – trunks of "black oaks" *in situ* covered by younger series, 10 – trees of "black oaks" in the alluvia, 11 – buried soils, 12 – archeological artefact, 13 – sites of "black oaks"

deposits were covered with clayey madas (2340±110, Kalicki *et al.* in this volume). This phase manifests in the accumulation of trunks in the alluvia (225 BC – 325 AD) commonly found in almost all the dendrochronologically studied sites in the valleys of Southern Poland (Krąpiec 1992b; Kalicki, Krąpiec 1991a, 1995a, b – chapter 4.2 in this volume). The radiocarbon dated trunks are numerous in the Vistula valley (1820±100, Tauber 1968; 1850±35 BP, Mycielska-Dowgiałło 1972; 1775±280 BP, Środoń 1980; 1800±70, 1765±55 BP, Rutkowski 1987) and in the Wisłoka valley (2260±120, Alexandrowicz *et al.* 1981). In the Vistula valley near Cracow one often finds stumps cut by man in this period, fragments of roughed down trunks, canoes hollowed out of tree trunks and poles (Kalicki, Starkel 1987; Kalicki, Krąpiec 1991a). These stumps, dated at ca 1950–1850 BP, found in the deposits *in situ* and covered with younger channel alluvia, provide the evidence of a change in the tendency from incision to aggradation in this period (Kalicki 1991c). The change in sedimentation pattern occurred in backswamps in the Oświęcim Basin, where organic madas had been covered with clayey madas (2150±60 BP, Klimek 1988) as well as in the lateglacial paleomeander of the Wisłoka river, where peat covered madas (1860±50 BP, Klimek 1992). The traces of this phase, in forms of abandoned channels or alternation of sedimentation type in floodplains, are identified in the valleys of Polish Lowland (Turkowska 1988; Alexandrowicz *et al.* 1989; Kozarski 1991). The Roman phase of the trunk accumulation is also known from all larger rivers of Central Europe (Becker 1982, 1993; Delorme, Leuschner 1983; Leuschner *et al.* 1987) while aggradation from the upland valleys in Central Germany (Richter 1965; Schirmer 1983).

After this phase the deep incision of the Vistula enabled the Late Roman colonization (Wyciąże) to enter the flood plain in the 4th century (Kalicki 1991c). The progressing aggradation and the subsequent phase of cutting-off the Vistula paleomeanders was dated in Branice–Stryjów at 1480±60 BP (Kalicki, Krąpiec 1991a). These paleomeanders were much smaller than those cut off in ca 3000 BP (Kalicki 1991b). There were also changes in the Raba channel (1480±90, Alexandrowicz, Wyżga 1992). In the valleys of the upland tributaries of the Vistula transition from organic madas to loess ones was common (Alexandrowicz 1988; Rutkowski 1991). In the mid-fifth century a mass of trees started felling in the valleys of the Vistula, Wisłoka, Odra rivers (425–625 AD) (Kalicki, Krąpiec 1992, 1994; Krąpiec 1992b, Starkel, Krąpiec 1995) and in the valleys of the small rivers of the Sudetes and Świętokrzyskie Mts (Wroński 1974; Lindner 1977). Tree trunks accumulated in alluvia in the discussed period occur also in the other valleys of Central Europe (Becker 1982; Delorme, Leuschner 1983) and in Ireland (Baillie 1994).

In the early Medieval period (7th–9th c.) settlements were located again in the valley floors (Radwański 1972). Due to aggradation and the resultant high location of the Vistula channel, however, floods reached much higher during the next phase of the increased river activity. That in turn forced the settlers in the 10th–12th c. to colonize higher located areas and to built anti-flood embankments in region of Okół in Cracow (Radwański 1972). The trees were accumulated in the Vistula alluvia near Cracow from 900 to 1150 AD (Kalicki, Krąpiec 1992; Krąpiec 1995) as well as near Machów and in the Wisłoka valley (Alexandrowicz *et al.* 1981). In the case of the

latter valley deforestation is pronounced in the pollen diagrams of the alluvia series with the "black oaks". As in the Roman period the well documented aggradation, which is confirmed by the *in situ* stumps (976 AD), covered with the younger channel alluvia with the tree trunks dated at 1078 AD (Kalicki, Krąpiec 1992, 1994), occurred in the Vistula valley in the discussed period. Moreover, in this period peat in the late Subboreal paleomeanders of the Vistula were covered with madas (990±110 BP; Kalicki – chapter 2.4 in this volume). The phase of aggradation of this period was described in the other sections of the Vistula valley in the Oświęcim Basin. E. Nie-działkowska *et al.* (1985) and K. Klimek (1988) reported the discussed phase in the direct foreland of mountains downstream the Vistula, T. Sokołowski (1987) – down-stream the mouth of the Dunajec river, S. W. Alexandrowicz *et al.* (1981) – in the Wisłoka valley, and J. Wroński (1974) and S. W. Alexandrowicz *et al.* (1989) in lowland valleys. In the discussed period similar changes in sedimentation, as well as aggradation, occurred in the Morava (Havlicek 1983), Berezina, Dnieper valleys and in the other rivers in the Russian Plain (Kalicki 1991a, 1993; Kalicki, Sańko 1992).

The next well marked Medieval phase was manifested in felling of tree trunks in the Vistula valley in the period of 1200–1325 AD (Kalicki, Krąpiec 1991a, Krąpiec 1992b). In the mid-fourteenth century avulsions of the Vistula channel near Cracow took place (Bąkowski 1902; Kalicki, Krąpiec 1992, 1994). The avulsions were dated by historical and dendrochronological methods. Parameters of the paleomeanders of this periods are very small, comparable with the Boreal ones (cf. Kalicki 1991b). Changes in the channel pattern were also stated in the lower San river, where paleo-meanders were dated at 760±60 and 665±50 BP (Szumański 1986). Yet in the Vistula gap through the uplands the fossilization of soils (700±230 BP, Pożaryski, Kalicki 1995) underwent due to intensified accumulation of the madas. Moreover, loess madas were accumulated more intensively in the upland valleys from the 14th–15th c. (Kos-mowska-Suffczyńska 1983).

The last phase of the tree felling at the turn of the 15th–16th c. was indicated in the valleys of the Vistula and Wisłoka rivers (Krąpiec 1992b). Identification of the younger phases using the dendrochronological method is impossible due to deforesta-tion of the floodplains (Kalicki, Krąpiec 1995b).

The youngest changes in the Vistula channel, which were determined basing on cartographic materials, occurred at the end of the 18th c., probably in the period of large floods in 1785–1788 (Trafas 1975). The paleomeanders of this age were large (Trafas 1975; Rutkowski 1987). The youngest "black oaks" found in the Vistula alluvia (Kalicki, Krąpiec 1995a) are likely to originate from the discussed period. In the recent centuries it has been observed that the channels tend to be braided, which is related to human activity (e.g. Falkowski 1967; Szumański 1986).

Conclusions

In the Neoholocene the phases of an intensified river activity are as follows: 3500–3000, 2700–2600, 2350–1800 BP and 5th–6th, 9th–11th, 14th–18th centuries. If researchers generally agree that in the older and mid-Holocene the phases of the increased river activity were associated with climatic fluctuations (cf. Starkel 1983;

Kalicki 1991c), the problem of the Neoholocene phases is still a subject of discussions. As indicated by archaeological sources, human impact on the environment was increasing as agriculture was developing. Therefore in opinions of many authors changes in river activity in the younger Holocene are attributed to human activity (e.g. Schirmer 1983; Brown 1987; Klimek 1988). Unfortunately, in many cases differentiation between climatic influences and human impact is very difficult because of their mutual overlapping. The above refers to Central and Western Europe, where anthropogenic changes began in the Neolith and intensified in the Neoholocene. In Poland such changes were slightly delayed, however, in the Bronze age man intensively managed loess and entered the Carpathians (Valde-Nowak 1988; Kruk 1988). In the Russian Plain human activity began later (Chotyński, Starkel 1982).

The first evidence that the phases were climatically conditioned also in the Neoholocene is their timing in various rivers of Central Europe. For example, a phase of 3500–3000 BP, which has been identified in the Vistula valley near Cracow for the first time (Kalicki 1991c), was later fully confirmed in other river valleys (Kalicki, Krąpiec 1991b). This phase is marked in the region extending from the Danube valley in the west (Buch 1990) to the valleys of the Berezina (Kalicki 1991a) or even the Oka rivers in the east (Glasko, Folomeev 1981). In the period between 3500–3000 BP, as in the older periods of the Holocene, there were phenomena pointing to humidification and cooling of climate, for instance the Löbben advance of alpine glaciers (Patzelt 1977; Bortenschlager 1982), a rise in lake levels (Ralska-Jasiewiczowa ed. 1989) or changes in vegetation in the Carpathians (Obidowicz 1988). The climatic changes might have been caused or favoured by Santorini and Hekla eruptions (3370 BP and 3100 BP, respectively) (Hammer *et al.* 1980; Baillie, Munro 1988; Kalicki, Krąpiec 1991b). Inferring from the development of the Lusathian culture in the discussed period, Klimek (1988) related the accretion of madas in the Oświęcim Basin in the last 3000 years only to human activity. A detailed analysis of the mada profiles, presented by Klimek, leads to identification of some stages in the mada accretion (after 2710, after 2150 and after 1220 BP), which also correspond to the phases of the increased activity known from the Central European rivers. The above does not deny the human influence on the accumulation of madas in the floodplains, especially in smaller valleys (e.g. Kosmowska-Suffczyńska 1983).

A more vigorous erosion of slopes resulted in fertilization of sites in the floodplain and, in turn, in a change in a wood structure of oaks from thin to thick rings (Becker, Frenzel 1977). However, the change in the wood structure occurred in Germany and Poland in a different period (Krąpiec 1992b).

A better argument for climatical conditioning of the phases seems to be the invigoration of the river activity which occurred in ca 1000 BP (Kalicki 1993). The phase of the invigoration is very well marked by the accumulation of madas, numerous black oaks trunk etc. in the Vistula valley near Cracow and in the other valleys of Central Europe. In the discused period there were changes in the type of sedimentation in the floodplains of the Russian Plain (Zolotokrylin *et al.* 1986, Klimanov, Serebryannaya 1986), as well as transformations of natural plant communities that indicated cooling of climate (Zernickaya, Kozharinov 1988). This phase was recognized in the natural

forested Berezina drainage basin with numerous peat and bogs (Kalicki 1991a), and also in the upper Dnieper drainage basin which had already been altered by human activity (Kalicki, Sańko 1992). In the wide Berezina valley the organic fill of the abandoned channel, which was cut off in 3120±40 BP, was covered with madas in ca 1000±50 BP and was probably caused by a change in a course of the river channel (Kalicki 1991a). In the narrow Dnieper valley the soil developing on silty madas was covered with sandy madas in ca 940±90 BP. The above confirms the increase in frequency and magnitude of floods (Kalicki 1993).

Dendrochronological studies support even more detailed correlation between valleys. Phases of the tree felling both in the older and younger Holocene are well correlated in various Central European rivers (cf. Delorme, Leuschner 1983; Becker 1982; Kalicki, Krąpiec 1995b – chapter 4.2. in this volume) and indicate the predominance of the climate triggering invigoration of the river activity. In the Neoholocene the influence of climate might have been stimulated to a large extent by the human activity. Probably due to the deforestation of the floodplain the Roman and early Medieval phases of the accumulation of numerous trunks in alluvia are marked with different intensity in various Central European rivers.

The examples presented above demonstrate that the phases of the increased river activity were associated with fluctuations of climate also in the Neoholocene. Anthropogenic changes in the environment intensified the effects of climatic fluctuations (Kalicki 1993). For example, cutting down of the trees in the floodplain facilitated lateral migration of the channels and the accumulation of numerous trunks in alluvia (Kalicki 1991c). Deforestation of the upper Dnieper basin was reflected not only in frequency of floods, but also in their magnitudes, and led to a change in composition of the madas and an inundation of the upper level of the floodplain. An analogous phenomenon of the mada thickening, associated with human activity, was observed in the upper Vistula basin although in different sections in different periods (Kalicki 1991c; Pożaryski, Kalicki 1995; Kalicki – chapter 3 in this volume).

Due to the deforestation and the farming which destabilized a fluvial system, it was possible to identify minute climatic fluctuations as well as singular events in the river valleys in the Neoholocene. "Concentration" of the Subatlantic phases, which was observed in several valleys (e.g. Schirmer 1983; Schellmann 1990), might result from the above and not only from the better analysis of the youngest period thanks to historical sources (Strasser 1992; Petts et al. ed. 1989).

6. THE UPPER VISTULA CATCHMENT ON THE BACKGROUND
OF CHANGES IN THE FLUVIAL SYSTEMS IN EUROPE
AND IN THE TEMPERATE ZONE

6.1. TEMPORAL COINCIDENCE OF INCREASED FLUVIAL ACTIVITY IN EUROPE

Leszek Starkel

The correlation of sequence and rhythmicity in the evolution of fluvial systems of a temperate zone (Starkel ed. 1990; Starkel 1990, 1991) is presented in the summary of studies on the evolution of the Vistula river. A synchronism of events was found to be typical in the evolution of the fluvial systems. Recently, a number of study sites has increased and several progress accounts have been published (Starkel 1994, 1995a, b, e, h).

In this chapter the emphasis is on general regularities and coincidences in the valley evolution in the upper Vistula valley when compared with the other parts of Europe (Fig. 30). This comparison leads to a conclusion that valleys in mountain and lowland areas are transformed differently.

The most common and typical are the rivers having their headwaters in the mountains. A location of the headwaters in highland terrains affects runoff regime of rivers which originate from the mountains and flow down across lowlands (Starkel 1985, 1990). The straight or sinuous mountain channels change into the braided ones at the margin of the mountains and into meandering ones downstream, and then as the anastomosing rivers they enter deltaic plains or estuaries of the tidal zones (Starkel 1995e). The above picture is usually more complex, because large rivers cross various structural units of different lithology and neotectonic tendency what results in various trends in the evolution of the particular sections of a longitudinal river profile (Starkel 1990). The longitudinal profiles of the lowland rivers are less complex.

The register of hydrological changes may either be very rich and includes generations of paleochannels with avulsions, cuts and fills, changes in facies and in rate of deposition (rivers draining mountain foreland) or this register is mainly restricted to sedimentological changes (lowland rivers), or to the slack-water deposits in the rocky gap sections (cf. Dunajec river).

In the whole former periglacial zone of Europe (at the ice-sheet foreland) a typical sequence of changes from the braided to meandering channels is observed in the middle river courses. Such changes are related to the decline in the flood frequency, especially from dominant snow-melt floods to rainfall floods, and to the decline in the
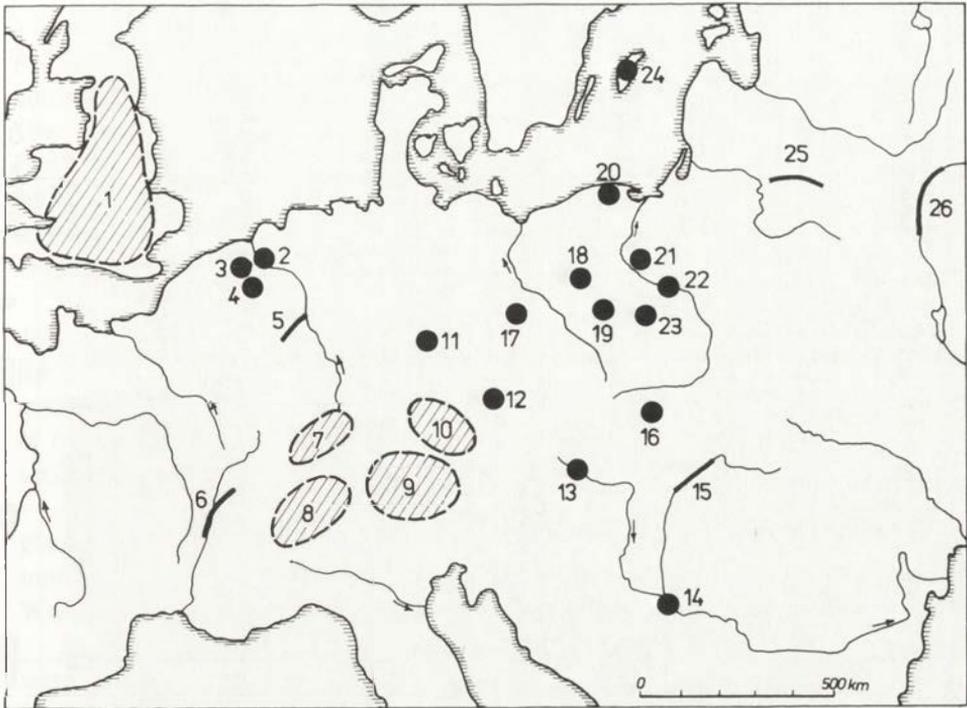
Fig. 30. Regions and sites in Europe mentioned in the text and presented on Figures 31 and 32

1 – English river valleys (Needham, Macklin 1992), 2 – Rhine delta (van der Woude 1981), 3 – small river valleys in S-Netherlands (Bohncke, Vandenberghe 1991), 4 – Maas (Paulissen 1973), 5 – Ahr valley (Heine 1982), 6 – Rhone valley (Bravard *et al.* 1991), 7 – Swiss plateau and Jura Mts (Magny 1993a; Wohlfarth, Ammann 1991), 8 – Swiss Alps (Joos 1982; Magny 1993a, b etc.), 9 – Austrian Alps (Patzelt 1977), 10 – Lech and Saalach (Brunnacker 1978; Schreiber 1985), 11 – Upper Main (Schirmer 1983), 12 – Upper Danube (Buch 1988), 13 – Slovak Danube (Kvitkovič 1993), 14 – Iron Gate (Brunnacker 1971), 15 – Tisa and Bodrog (Borsy and Felegyhazi 1983), 16 – Tatra Mts (Kotarba ed. 1993), 17 – Bóbr valley (Florek 1980), 18 – Warta valley (Kozarski 1991), 19 – Prosna valley (Rotnicki 1991), 20 – Słupia valley (Florek, Florek 1986), 21 – Strażym Lake (Różański *et al.* 1987), 22 – Gościąż Lake (Starkel *et al.* 1996), 23 – Łódź region (Turkowska 1988; Kamiński 1993), 24 – Gotland (Mörner, Wallin 1977), 25 – Neris valley (Gaigalas, Dvareckas 1987), 26 – Upper Dniepr valley (Kalicki, Sanko 1992)

sediment load (Fig. 31). The changes in the river channel pattern have been identified by A. S. Schumm (1965) and E. Falkowski (1967, 1975) and confirmed in the case of the valleys of the Vistula basin (Szumanski 1972, 1983; Starkel 1983), Warta basin (Kozarski, Rotnicki 1977), Maas basin and surroundings (Paulissen 1973; Bohncke, Vandenberghe 1991), upper Danube basin (Fink 1977; Buch 1988) and in the other ones.

These changes were probably metachronous in the S-N European transect and associated with the progressing retreat of a permafrost and an invasion of forest communities (Starkel 1991a). Large paleomeanders, dated in some river reaches of uplands and mountain forelands at Bölling or Allerød time, were replaced by the braided channels during the Younger Dryas, which has been suggested by Falkowski (1975) and later found in several valleys of the Ahr (Heine 1982), the upper Vistula (Kalicki 1991c, Starkel *et al.* 1991), the Nieman (Voznyachuk, Walczyk 1977) as well as in some valleys in Belgium (Munaut, Paulissen 1973) and England (Rose, Boardman 1983).
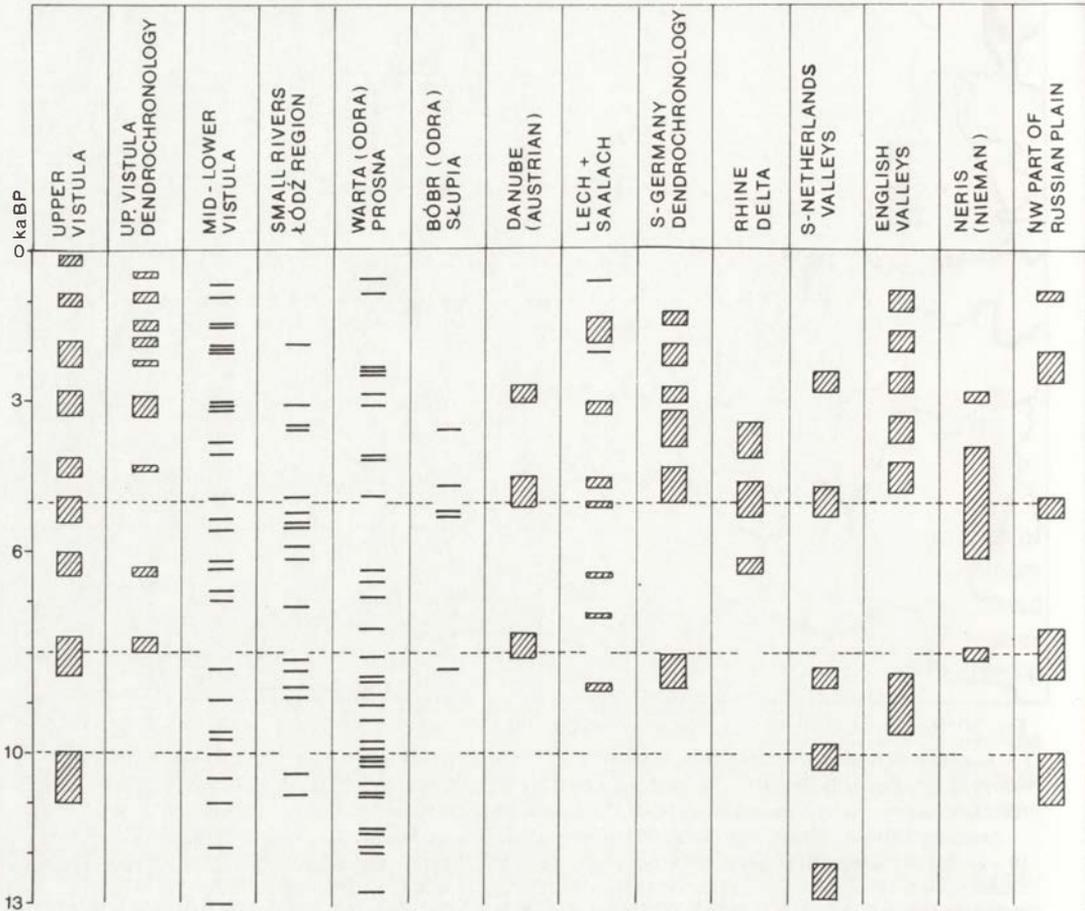
Fig. 31. Flood phases and radiocarbon datings of channel abundance in the selected European valleys during Late Vistulian and Holocene (compiled by L. Starkel)

Upper Vistula (Kalicki 1991c; Starkel 1984 and others), upper Vistula – dendrochronology (Krąpiec 1992b – chapter 4.1 in this volume), mid –lower Vistula (Florek *et al.* 1987; Tomczak 1987 and others), Łódź region (Turkowska 1988; Kamiński 1993), Warta and Prosna (Kozarski 1991; Rotnicki 1991), Bóbr and Słupia (Florek 1980, Florek, Florek 1986), Danube (Fink 1977), Lech and Saalach (Brunnacker 1978, Schreiber 1985), S – Germany dendrochronology (Becker 1982), Rhine delta (van der Woude 1981), S – Netherlands valleys (Bohncke, Vandenberghe 1991), English valleys (Macklin, Lewin 1993), Neris (Gaigalas, Dvareckas 1987), NW part of Russian plain (various sources)

In the areas of retreating mountain glaciers (the Alps) these changes were obviously delayed. At the beginning of the Holocene a general decline in all parameters of paleochannels is observed.

The Holocene, especially in the valleys of central Europe, is characterized by several alluvial fills of meandering rivers and in the last millennia by a general tendency to aggradation, combined sometimes with tendency to braid, related to increasing human impact (Starkel 1983; Schirmer 1983).

In 1983 and later, in 1991 and 1995 the author of the present study published

a comparison between phases of increased fluvial activity in the temperate zone. Floods and new alluvial fills, synchronous with glacial advances, are especially pronounced in the valleys of an Alpine region 8.5–8 ka and about 5 ka BP (Schirmer 1983; Becker 1982; Jorda 1993; Schreiber 1985). This second phase is even bipartite (Kalicki 1991c). In the recent years these phases have also been discovered in the Rhone valley (Bravard *et al.* 1991) and Elbe valley (Hiller *et al.* 1991). In the Danube river subsiding section downstream of Bratislava J. Kvitkovič (1993) described the alluvial sequence several meters thick, with buried oak trunks dated between 8.5 and 8.0 ka BP.

The channel avulsions, especially from the Atlantic/Subboreal transition, were documented in the Swiss Plateau (Wohlfarth, Ammann 1991) and in the NE part of the Hungarian Plain (Borsy, Felegyhazi 1983). Several phases of the increased fluvial activity were registered during the Subboreal and Subatlantic in the tributary valleys of the upper Danube (Brunnacker 1978; Schreiber 1985). K. Brunnacker (1971) described flood deposits of the late Subboreal from the Iron Gate section of the Danube.

A very interesting phenomenon is the correspondence between advances of Alpine glaciers and an increased aggradation in the Rhine delta. Such phases during the mid-Holocene were dated at before 6.0 ka BP, about 5.0 and 4.0 ka BP (van der Woude 1981).

In the lowland rivers of the oceanic climate the fluctuations in river discharges were relatively small. Nevertheless, K. Turkowska (1988) and later J. Kamiński (1993) discovered the channel avulsions and rises of the groundwater level in the second order catchments near Łódź (Central Poland) to occur about 8.5 ka, 5.5–4.5 and 3.5–3.0 ka BP. These phases are synchronous with flood phases in the upper Vistula valley as well as in the lower Vistula sections (cf. Florek *et al.* 1987; Tomczak 1987). In the Bóbr valley, at the Sudetes foreland, a pronounced aggradational phase was dated at the Atlantic–Subboreal transition and younger (Florek 1980). In the coastal catchment of the Słupia river a large paleomeander was dated also just at 8.3 ka BP (Florek, Florek 1986). Finally, in the middle part of the Warta valley the abandoned paleomeanders are related to several (wetter?) phases which are also of similar age: 8.6–8.1, 4.2–4.0 and 2.5–2.4 ka BP (Kozarski 1991). The age of single cut-off paleochannels of the Prosna river is more diversified (Rotnicki 1991).

Farther to the east the abandoned channels and overbank deposits separated by burial soils indicate occurrence of similar phases; these were observed in the Nieman basin (Gaigalas, Dvareckas 1987), western Dvina (Chebotarieva *et al.* 1965), the upper Dniepr (Kalicki 1995; Kalicki, Sanko 1992) and the Oka valleys (Glasko, Folomeyev 1981). For the last time the abandoned channels and new fills in the Sejm river valley, the tributary of the Dniepr, were dated at ca 4.0 ka and 2.0 ka BP (Wohl, Georgiadi 1994).

It should be emphasized that even in the distant areas the phases of a higher fluvial activity seem to be synchronous. The young Finish rivers with ungraded longitudinal profiles show the traces of the transformation of the channels in the older part of the Subboreal (ca 4.5–4.0 ka BP), in the early Subatlantic and up to 3 phases during the last two millennia (Koutaniemi 1991). The phases of the increased fluvial activity of British rivers dated at 4.8–4.2, 3.8–3.3, 2.8–2.4, 2.0–1.6 and 1.2–0.8 ka BP (Needham,

Macklin 1992) correspond rather to the advances of the Scandinavian glaciers than to the mid-European river valleys. A very good correspondence of these phases with an intensification of agriculture is explained as "climatically driven but culturally blurred".

A particular correspondence of the phases with frequent floods in the Carpathian and in the Alpine regions has finally been proved by the synchronism of the phases of deposition of the subfossil oaks in the river valleys from the Rhine and the Danube to the Vistula (Becker 1982; Krąpiec 1992b; Kalicki, Krąpiec – chapter 4.2 in this volume). The above may be explained by location of these areas in one belt with identical long-term fluctuations in the cyclonic circulation.

The rhythmicity of the long-term changes in runoff and fluvial activity outside this belt is either less pronounced or not fully synchronous in time. On the contrary, the general change at the transition from the periglacial to temperate climatic regime is well expressed everywhere from the Atlantic coast to the catchments of the Dniepr and Volga rivers.

6. 2. CORRELATION OF PALEOHYDROLOGICAL CHANGES IN CENTRAL EUROPE
Leszek Starkel

A retreat of an ice-sheet and wasting of mountain glaciers progressed in stages, what is documented by recessional moraines (Kozarski 1983; Patzelt 1977), under conditions of continental climate and precipitation deficit. Therefore the expansion of a permafrost and its subsequent wasting was favoured. The expansion of forest vegetation in the Bölling and Allerød (Ralska-Jasiewiczowa ed. 1989) conditioned changes in the outflow of meltwater and a smaller supply of material to rivers, registered in the shift from braided to meandering river pattern (Kozarski 1982; Starkel 1991a, b).

As the permafrost and dead-ice were melting, the formation of a groundwater reservoir was progressing and continued until the beginning of the Holocene (Starkel 1977).

These processes declined during the Younger Dryas cooling, when discontinuous permafrost (patches) were re-expanding (Pissart 1987), rivers tended to attain braided pattern (Heine 1982; Starkel 1990) and eolian processes were more active (Manikowska 1985). The decline of the Younger Dryas manifested in an abrupt change of climate, which had been lasting for several decades, and which registered in the change of $\delta^{18}O$ content in the lakes in the Alpine foreland (Lotter 1991) and in the Polish Lowland (Różański *et al.* 1992), as well as in a rapid expansion of forest vegetation (Ralska-Jasiewiczowa, val Geel 1993). Moreover, there was a decrease in river discharges, which was reflected in the alternation of the flood sedimentation from silty-sandy to organic one, and in the abrupt decrease in channel size (Szumański 1983; Starkel 1991a).

It has been stated that during the Holocene there were distinct, relatively cooler and moister phases which manifested in higher precipitation, higher storage and outflow, as well as in a higher frequency of extreme events (Starkel 1983; Magny 1993a; Nessje, Johannessen 1992). These phases, of different duration (200–700 years) and
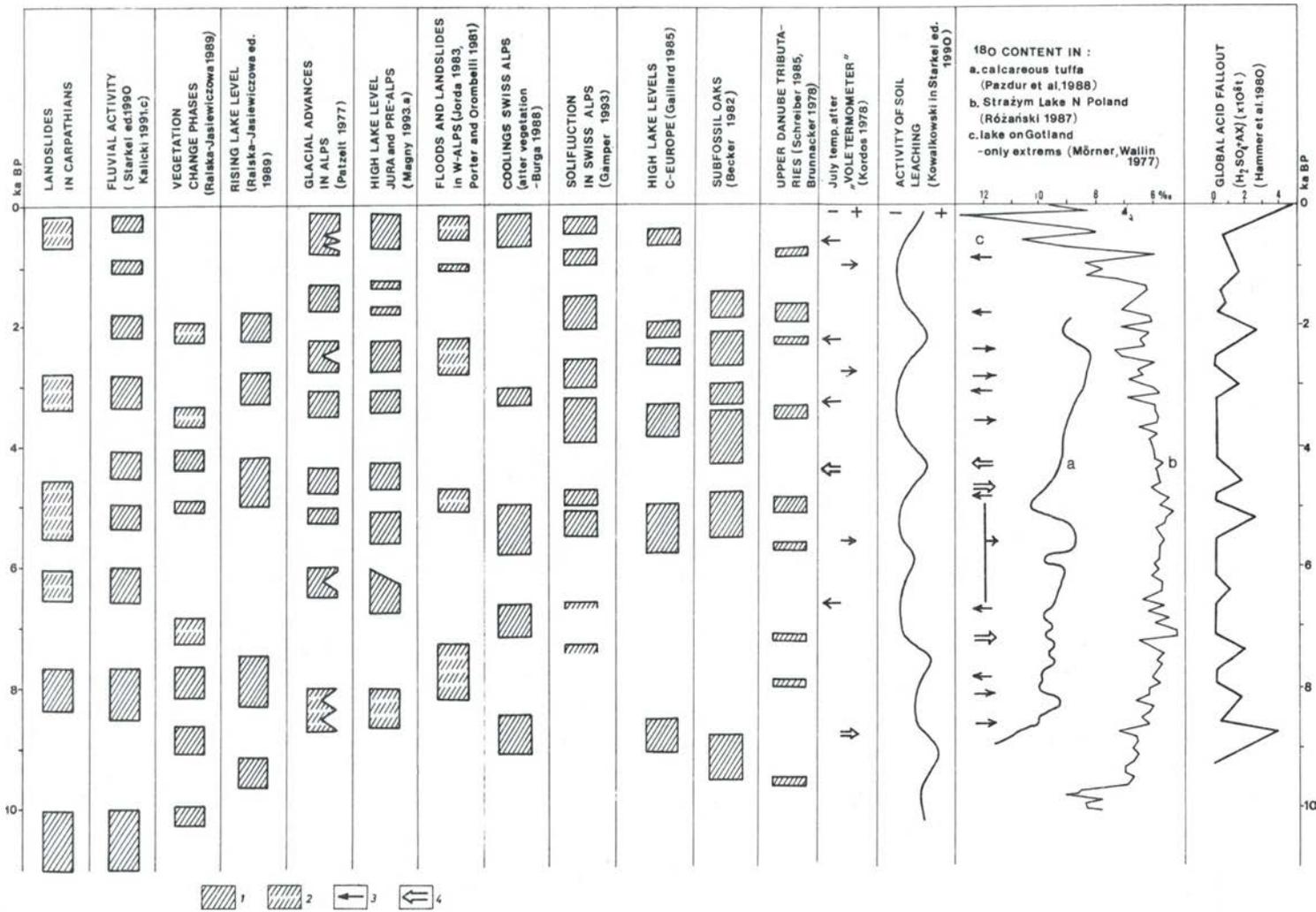
Fig. 32. Chronology or hydrological change during the Holocene in Central Europe (compiled after various authors by L. Starkel 1995i)

1 – phases of higher humidity, activity of expansion, 2 – less distinct phases (as above), 3 – tendency to cooling or warming, 4 – tendency – more distinct – double arrow
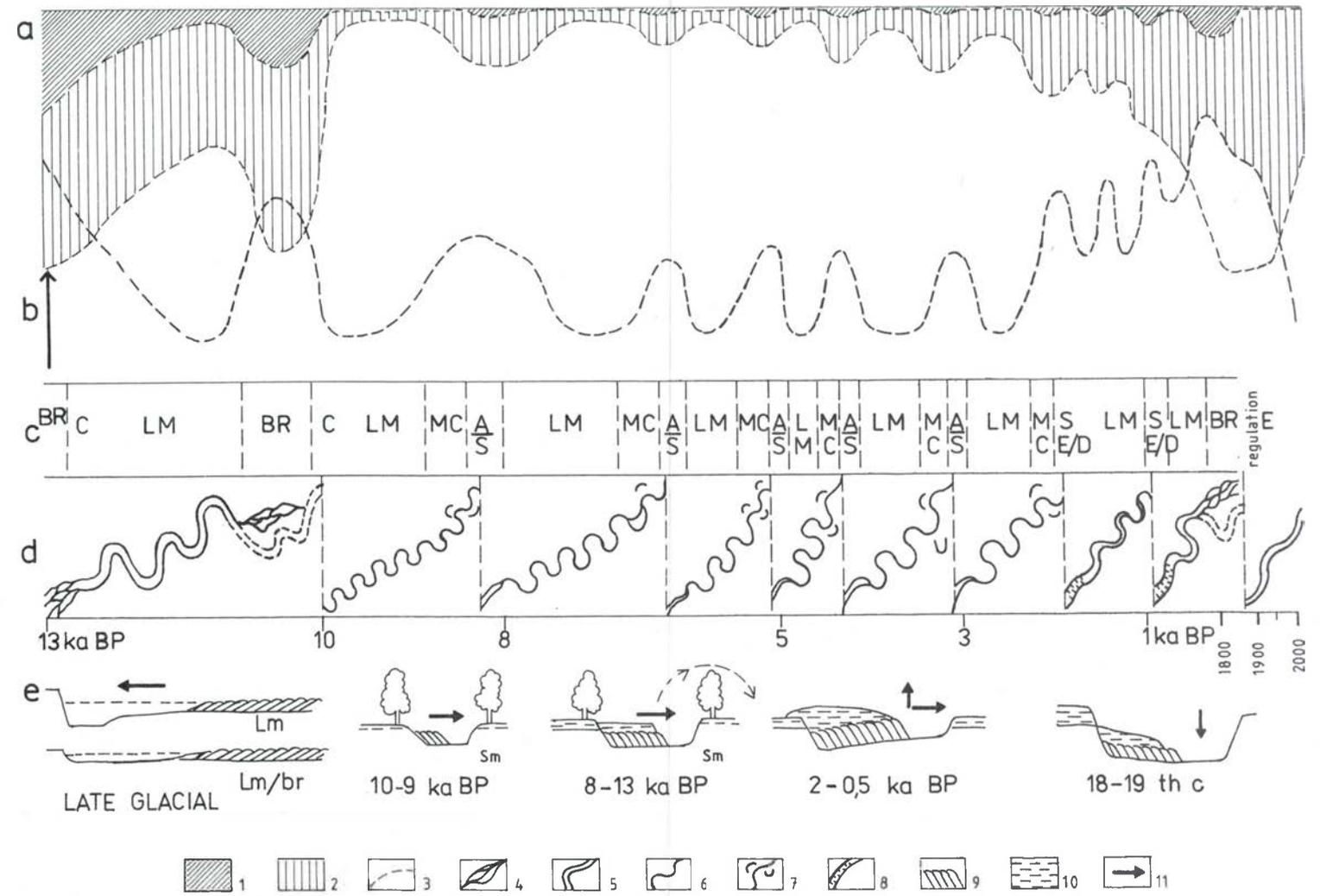
Fig. 33. Model of rhytmic changes and thresholds in the evolution of river and flood plains during last 13 000 years (elaborated by L. Starkel)

a – relative fluctuations of a transport and a delivery of bedload and suspended load, b – fluctuations in flood frequency (Kalicki 1991c, Starkel 1994), c – main directions of changes: BR – braided channels, C – concentration of channels, LM – lateral migration, MC – meander cut-off, A – avulsion, S – straightening, E – downcutting, D – aggradation; d – rhytmic changes of channel parameters, various cycles are separated by threshold changes in the fluvial system, e – schematic channel cross-sections and directions of their transformation during various phases of the Late Vistulian and Holocene. 1 – bedload, 2 – suspended load, 3 – curve of flood frequency, 4 – braided channel, 5 – large paleomeanders, 6 – small paleomeanders, 7 – cut-off meanders, 8 – incision of the straightened channel, 9 – channel bars, 10 – overback deposits, 11 – directions of channel changes

frequently with two culminations, were separated by longer, fairly stable, warmer and drier phases. The discussed alternation of phases is recorded in the following events and phenomena:

– various types of sediments, forms and organic remnants;

– in advances and retreats of glaciers and vertical zones in the mountains (oscillations of the upper timber line, permafrost limit and solifluction processes);

– in changes in malacofauna and in other animal species;

– in occurrence of landslides and debris flows;

– in types of river channels and alluvia facies;

– and finally in the change in relations between isotopes O and C (Berglund ed. 1986; Ralska-Jasiewiczowa, Starkel 1988; Starkel ed. 1990; Magny 1993a) (Fig. 32).

These phases differ in their development and in their spatial distribution, and are best manifested in high mountains and in correlative sediments at the mountain foreland (cf. Starkel 1985).

From the area of the Alps there are known the sites recording advances of glaciers and cooling periods in the Middle Preboreal (Patzelt 1977). However, the first substantial increase in moisture marked in the period 8.5–7.7 ka BP, i. e. when in a very slight delay to the Venediger phase in the Alps (from 8.7–8.0 ka BP – after Patzelt) there were observed: an increase in accumulation of calcareous dripstones in the caves of Slovenia (Franke, Geyh 1971), a rise of the water level of lakes (Gościąż Lake – Starkel *et al.* 1996), intensification of landslide processes in the flysch Carpathians (Starkel 1985) and of debris flows in the Tatras (Kotarba ed. 1993), and in Scandinavia (Sonstegaard, Mangerud 1977). These changes are synchronous with the above described changes in the valley floors and registering the first phase of the Holocene evolution of the river systems.

The next phase of the advances of the Alpine glaciers, ca 6.5–6.0 ka BP correlates with a high water level in the lakes of the Jura Mts (Magny 1993a) and with the intensification of the fluvial processes in the Southern Poland (Starkel 1990; Kalicki 1991c).

A definite moistening of climate in Central Europe was at the Atlantic – the Subboreal transition. This moistening is bipartite (5.4–5.0 ka and 4.7–4.3 ka BP) and has been identified in the positive oscillations of the glaciers, of solifluction and of the upper timber line in the Alps (Röthlisberger 1986; Burga 1988; Gamper 1993), in the rise of water table of lakes and in groundwater level (Gaillard 1985; Magny 1993a; Ralska-Jasiewiczowa, Starkel 1988); in the occurrence of landslides (Porter, Orombelli 1981), in the activation of screes (Ložek 1991); in the change in plant communities (Ralska-Jasiewiczowa 1989) and in small mammals (the so called "Vole Thermometer" – Kordos 1978). The subsequent channel avulsions in the Carpathian Foreland in the discussed period have been documented (Kalicki 1991c; Starkel *et al.* 1991; Kalicki *et al.* in this volume).

The next phase took place at ca 3.3–2.8 ka BP, when the river floods, recorded in the falling "black oaks" (Becker 1982; Krąpiec 1992b), corresponded to glacier advances and to high water level of the lakes (Magny 1993a). The propensity to the moistening is visible in the lakes and peat appeared at the beginning of Subatlantic

(Gaillard 1985; Niewiarowski 1990; Starkel *et al.* 1996) and was accompanied by the intensification of solifluction processes in the Alps (Gamper 1993). The deforestation, an registered by the "black oaks" examination (Becker 1982; Kalicki, Starkel 1987), begun indisputably influence the water circulation. The studies on the history of the settling and on the vegetation changes suggest that the beginning of the Medieval was rather dry, yet the phases of the tree falling in the 6th and 10th centuries were evident (Krąpiec – chapter 4.1 in this volume). A distinct phase of aggradation in the upper Vistula valley in the 10–11th centuries, initially attributed to human activity (Starkel 1983), appears to have a climatic reason as well because of the stated advances of the Alpine glaciers at that time (Magny 1993a). Moreover, rivers of the non-deforested Byelorussia indicate the intensification of floods (Kalicki 1991a, 1995). The last moistening of the Little Ice Age (16–19th c.) was registered by precise measurements of the glacier fronts, of floods, landslides and other extreme events (Starkel 1984). A very high coincidence between the black oaks dendrograms from the Alpine and Carpathian Forelands (Krąpiec 1992b) evidences that both the regions were in the zone of the same circulation of air masses. There are attempts to explain this coincidence by the solar activity cycles of various duration (from 2300 to 200 years). This coincidence can also be explained by the variation in ^{14}C production in the upper layers of the atmosphere. It is the above to which M. Magny (1993b) relates the rhythmicity in the oscillations of the lake levels in the Jura Mts – high water levels repeating every 100–300 years.

R. A. Bryson (1989), and A. Nessje and T. Johannessen (1992) after him, attribute a significant role in the increase in frequency of the extreme precipitation to the phases of intensified volcanic eruptions occurring at ca: 8700, 5200, 4600, 2100 as well as to the heavy rains, although of a small eruption frequency at ca 8150, 7400, 6450, 3150 and 1100 years BP. In younger Holocene these phases manifested in advances of glaciers in Scandinavia. The lack of such correlation was earlier explained by a very high insolation in the Early Holocene. The Scandinavian glaciers were constantly retreating in the Boreal and even more, while their advances in the Atlantic are not synchronous with the Alpine ones (ca 7300, 6300, 5700 ka BP – Karlen 1991). The water level in the lakes of Southern Sweden was high at 7.5–6.0 ka BP and low after 5.0 ka BP (Digerfeldt 1988; Harrison *et al.* 1993) which is reverse in the case of Polish lakes (Ralska-Jasiewiczowa 1989). In the meridional profile definite differences are observed in the circulation of moist air masses. The above could also be supported by the correlation of the tree rings of the subfossil oaks in the meridional profile from the Carpathians to the Baltic coast which are much worse than the correlation coefficient between the Alpine Foreland and the Carpathians (Krąpiec 1992b).

It seems that the flood phases or debris flows are better correlated one with the other, even in the European scale (cf. phases distinguished by Macklin, Lewin 1993 in Great Britain; Starkel 1985, 1995c, g) than oscillations of water level in lakes or of glaciers. The extreme precipitation is likely controlled by the content of aerosols. However, the long-period changes in precipitation, storage, and evaporation depend on rhythmicity of air circulation. The Russian researches (Klimanov 1990; Khotinsky 1984) also point to the differences in the meridional profile and differences in the

thermal and moisture rhythms. When reconstructing the climate in the southern part of the Russia, they found the concurrence of the warmer and moister phases for the first half of the Holocene, and the reverse tendency in the second half (the moister phases corresponded to the cooler periods).

6.3. EXTREME EVENTS AND RHYTHMICITY OF LONGTERM HYDROLOGIC CHANGES
Leszek Starkel

Extreme floods manifest in exceeding the bankfull discharges and inundation of the floodplain, and are registered by a deposition of sediments there, and by the change in channel parameters (width, depth, curvature) that can lead to cutting off the meanders and branches as well as to channel avulsions. Such events happen every 10–30 years on average (Klimek, Babiński in: Starkel ed. 1990; Froehlich, Starkel 1995), and occur in every century.

Based on the gained knowledge, presented in the monograph *Flood Geomorphology* (Backer *et al.* 1988) and in five volumes of *Evolution of the Vistula valley* (1982–1995) it is clear that the threshold values happen to be exceeded during the extreme floods, yet they are reflected in sediments by the series of events occurring one after another in short time spans. It has been stated that there were the phases of higher frequency of extreme events (Starkel 1983, 1984, 1993; Baker 1991 and others) at the decline of the Vistulian and in the Holocene. Substantial changes in the channel parameters took place particularly in the valleys in mountain and foremountain areas. The changes did not result from singular events, as evidenced by the whole sequences of events recorded in the overbank deposits and in the alluvial fans (cf. Niedziałkowska *et al.* 1977; Czyżowska, Starkel – chapter 2.5 in this volume).

The moment of the threshold change in a given section or a given profile often corresponds with a singular event, yet is preceded by a series of "preceding" events. Moreover, after the discussed threshold moment the subsequently occurring events preserve a new pattern.

R. Soja (1977) describing the Ropa river, provides examples of three floods, occurring in 1–3 year long time spans, which led to the shift from the channel of prevailing lateral migration to the channel fixed in the horizontal pattern, and over-deepened in a solid rock.

The Vistula reach between Cracow, Niepołomice and the Raba mouth provides some examples of channel avulsions preceded by a cut off of well developed meanders as well as of a channel straightening. In Grobla Forest (Gębica, Starkel 1987; Starkel *et al.* 1991) cutting off the meander, which started ca 5.5–5.4 ka BP, finally led to the channel avulsion at ca 5.1 ka BP. A similar sequence of changes is observed in the system of meanders in Zabierzów Bocheński which was abandoned at ca 4.4 ka BP (Kalicki *et al.* in this volume). The incised, braided Wisłoka channel of the 18–19th century undercut the sections of abandoned channels (of smaller parameters) which had been migrating from the 11th to 17th century (Alexandrowicz *et al.* 1981; Starkel 1995d, e).

The series of floods of the younger phases of the Holocene resulted in the change in tendency from the lateral erosion to aggradation. The above has been evidenced for the Wisłoka valley in Grabiny for the 10th–11th c. (Awsiuk *et al.* 1980) and for the Vistula valley in Branice for the Late Roman period (Kalicki, Krąpiec 1991a).

The maintaining of a new tendency in changes (or a new channel after the avulsion) is performed by the next extreme events, marked often in the channel deposits with "black oaks". In the case of a change in reverse direction – to the decrease in frequency of floods, the maintaining of the channel of smaller parameters was possible due to the lack of more frequent floods which could have disturbed the equilibrium.

The described rhythm of changes with repeating phases with exceeding of the threshold values are illustrated by the model in Figure 33. Each rhythm consists of a longer phase of lateral migration, after which the increased frequency of floods leads to the cutting off singular meanders, straightening of the channels and finally to the incision of a new trough (sometimes a braided one) or to the avulsion. However, such a cycle of changes needs not to be finished, the threshold value is not achieved either due to the lack of abrupt floods or due to the resistance of the channel bank. Therefore, the changes of the discussed type are very rare in the lowland rivers (Turkowska 1988).

In the model presented in 1983 the author emphasized the role of the driving factor: either the channel forming discharges can increase faster or the river load supply. Then the river erodes or aggrades (Starkel 1983). The tendency to the aggradation was pronounced in the Younger Dryas, the Roman period and in the Medieval (cf. Klimek, Starkel 1974; Kalicki 1991c).

Among the changes in the threshold values, there are two of a higher order and regulated by a general alteration of climate and of human impact; both the reasons cause changes in hydrologic regime and in supply of river load. At the beginning of Bölling the braided channels were changed into meandering ones – with the wasting of permafrost and expansion of vegetation (cf. Kozarski 1991). Yet frequent meltwater floods with ice-jams still occurred; in mountains the dense vegetation cover was lacking, thus re-establishing of the braided river pattern was possible in many sections in the Younger Dryas (Kalicki 1991c; Starkel *et al.* 1991; Kalicki, Zernickaya 1995).

An abrupt decrease in flood frequency and in river load transportation, expansion of forests onto the floodplains rapidly reduced the channel parameters. The described rhythmic changes with the exceeded threshold values in certain river sections in the Eoholocene and Mesoholocene became more intensive when the trees were cleared away in the valley floors and when the rate of the mada accumulation increased (product of soil erosion). Larger vertical oscillation of the channels and the accretion of the floodplains from the Roman period (Kalicki, Krąpiec 1991a) or the Medieval (Starkel 1995e) became possible. During the last centuries the aggradation took place within the wide channels – inherited from the period of floods in the Little Ice Age (Klimek, Starkel 1974; Fig. 33).

7. CONCLUSIONS AND PERSPECTIVES OF FURTHER STUDIES
Leszek Starkel

The studies carried out under this project and besides it make one draw several important conclusions.

1. There has been confirmed the concept of the evolution of a fluvial system due to the attaining the threshold values followed either by a relaxation period (and such changes are rhythmically repeating – Starkel 1983) or by a change which is completed and then the evolution of the system goes in a new direction (cf. Falkowski 1975; Schumm 1977; Kozarski 1983; Starkel 1990). However, the threshold values need not to be achieved during the phase of floods, as it is the case of numerous lowland rivers. These changes are also reflected in the sequencies of overbank deposits (cf. Kalicki – chapter 3 in this volume).

2. There are many limitation in the reconstruction and determination of the age of the phases which lead to the exceeding of the threshold values. The most important are given below.

2.1. The occurrence of various channel patterns (meandering, braided, anastomosing) both in the longitudinal profile of the valley and in its cross-section. This phenomenon is known from the areas of continuous and discontinuous permafrost and icing fields (Siberia and Mongolia). Therefore one should avoid, especially when reconstructing the lateglacial systems, a biased decision as to the exclusive presence of the meandering or braided system, based on the interpretation of a singular site.

2.2. In the given study section it might be difficult to separate the effects of the changes associated with particular extreme events from the effect of the phase with a higher flood frequency. Therefore the detailed studies on the sequences of events in the paleochannels, as well as the comparative investigation, are necessary. In the mature meandering system, exceeding of a small threshold during a singular flood, can cause the particular meander bends to be cut off (intrinsic threshold – Schumm 1977).

2.3. The length of the flood phases can be determined best by the detailed dendrochronological studies (Kalicki, Krąpiec 1991a, b, 1995b). Unfortunately, the accuracy of the radiocarbon methods often becomes insufficient, that is particularly the case of the radiocarbon plateau, for example at the Younger Dryas–Preboreal transition, when the inversion is commonly observed (Niedziałkowska *et al.* 1977; Starkel, Granoszewski 1995) or during the oscillations in the 16–19th centuries (Geyh 1972). The phase of the system transformation that last a few hundred years can be interpreted as an abrupt one.

3. The attempts to apply various study and laboratory techniques in this programme gave diversity of results.

3.1. The geophysical methods of the penetrometer-based resistivity lopping (PPO) and the multi-level electroresistivity logging, used when studying the paleomeander in Zabierzów Bocheński, evidenced that the main members of different lithology can be distinguished. Yet a reconnaissance boring is necessary for the identification of these members. One had to resign from an extensive application of both the methods because of their twice as large costs and because the simultaneous sampling of alluvia and more precise determination of the sequences of the paleochannel fills were necessary (cf. Kalicki, Mościcki – in press).

3.2. The methods of the reconstruction of paleochannels based on the meander parameters has been reviewed (Soja 1995; Soja – chapter 1.2 in this volume). Calculations showing the differences in discharges in the paleomeanders of various age were performed only in a small range. Therefore it seems more reliable to compare particular parameters of paleochannels (widths, depths, radius of curvature, cross-sectional area). Even in this case the calculations of the parameters are very difficult tasks, especially when there are not outcrops (cf. comments on Zabierzów Bocheński, Kalicki *et al.* in this volume).

4. The need of the correlation between events.

In order to determine the age of particular phases and events in a more precise way, as well as to understand their genesis and spatial extent it is necessary to correlate various records of paleohydrologic changes in river systems with those in lakes, vegetation, glaciers etc. Such an idea was behind the IGCP Programme no. 158 (Berglund 1983; Starkel 1983). The comparison between continuous and discontinuous records is especially needed and should refer to larger areas.

The continuous records are provided by the laminated lacustrine deposits (Digerfeldt 1986; Ralska-Jasiewiczowa ed. 1993), dendrochronology (Becker 1982), peat (Nilsson 1964), and calcareous dropstones etc. These records are possible due to a exceptional stability of sedimentation environment, where the exceeding of the threshold values is difficult and therefore very rare. Moreover, these records can be a good reference for the less stable environments.

The discontinuous records are known from the slope and river sediment profiles. There the phases and events, when the threshold values are exceeded, are registered. Thus, the regime of precipitation and extreme events can be reconstructed. This regime is responsible for the longterm trends and rhythms known from oscillations of glaciers or lake levels.

The spatial and temporal correlation, undertaken in the project, points to the occurrence of the almost identical rhythm of changes in a scale of Central Europe (Starkel 1983, 1990, 1994; Kalicki 1991c, 1995).

5. The perspectives.

The studies carried out under this project has pointed to the necessity of continuation and extension of the studies in the following directions:

a) development of the paleohydrological database for the area of Poland in relation to the existing international databases of glaciers, lakes, rivers, palynological and dendrochronological records and the others;

b) continuation of studies on the reconstruction of water circulation pattern in the Vistulian and Holocene based on the investigations of various sites including other than fluvial ones as well;

c) extension of the comparative studies in Europe in meridional and latitudinal profiles in order to find synchronism or metasynchronism of phases of various hydrological regimes and imposed phases of the intensified human impact. This direction was initiated by the studies undertaken in the IGCP Programme no. 158 (Starkel 1991b) and is continued in the studies which were started a few years ago in Byelorussia (Kalicki 1993, 1995).

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SUBBOREAL PALEOCHANNEL SYSTEM IN THE VISTULA VALLEY NEAR ZABIERZÓW BOCHEŃSKI (SANDOMIERZ BASIN)

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INTRODUCTION – ONGOING STUDIES

The Vistula river, after leaving the Cracow Gate, flows through the western part of the Sandomierz Basin. The bottom of the Vistula valley is occupied by a wide (3–7 km) floodplain which rises 4–5 m above the river level. Detailed studies carried out in the 1980s and 1990s allowed to recognise its structure. Within the floodplain there are several segments of various age (Kalicki 1991b). At marginal parts, especially in wide lowerings on the southern side and sometimes in the middle of the valley as erosional "remnants", there are preserved fragments of the lateglacial, braided alluvial plains (Gębica, Starkel 1987; Starkel *et al.* 1991; Kalicki 1992a). In the remaining area numerous paleomeanders occur - large, lateglacial ones (Kalicki 1987, 1992b) and several generations of small, Holocene ones (Kalicki 1991a, b). Fossil fillings of the Allerød and Boreal paleomeanders cut off by erosion and covered with younger deposits have also been stated (Kalicki, Krąpiec 1991a; Starkel *et al.* 1991).

MORPHOLOGY AND CHANNEL PARAMETERS

The site in Zabierzów Bocheński is ca 8 km to the NE of Niepołomice, between the Cracow section studied in details (Kalicki 1991b) and the section in the region of Grobla Forest (Starkel *et al.* 1991).

The investigated paleomeander is a part of 19 km long system of small radii meanders (25–60 m wide, index of sinuosity is 3.8), which stretches along 7 km from Wola Batorska to Chobot (Fig. 1). The system consists of 12 distincts, very well developed paleomeanders of an average radius of 151.6 m and of the sections of smaller sinuosity. The mean radius of curvature (out of 32 measurements) is 177.8 m and the radii of the half of them are between 130–190 m. The radii of a few meanders are very small, of 70–90 m. These are either the meanders which formed in the initial stage of development after meander necks had been cut off (e.g. Wola Zabierzowska, Ulesie) or the asymmetrical meanders with broken or narrow necks (e.g. Zabierzów Bocheński, Mikonowice).

In the system of paleomeanders one can distinguish several generations which
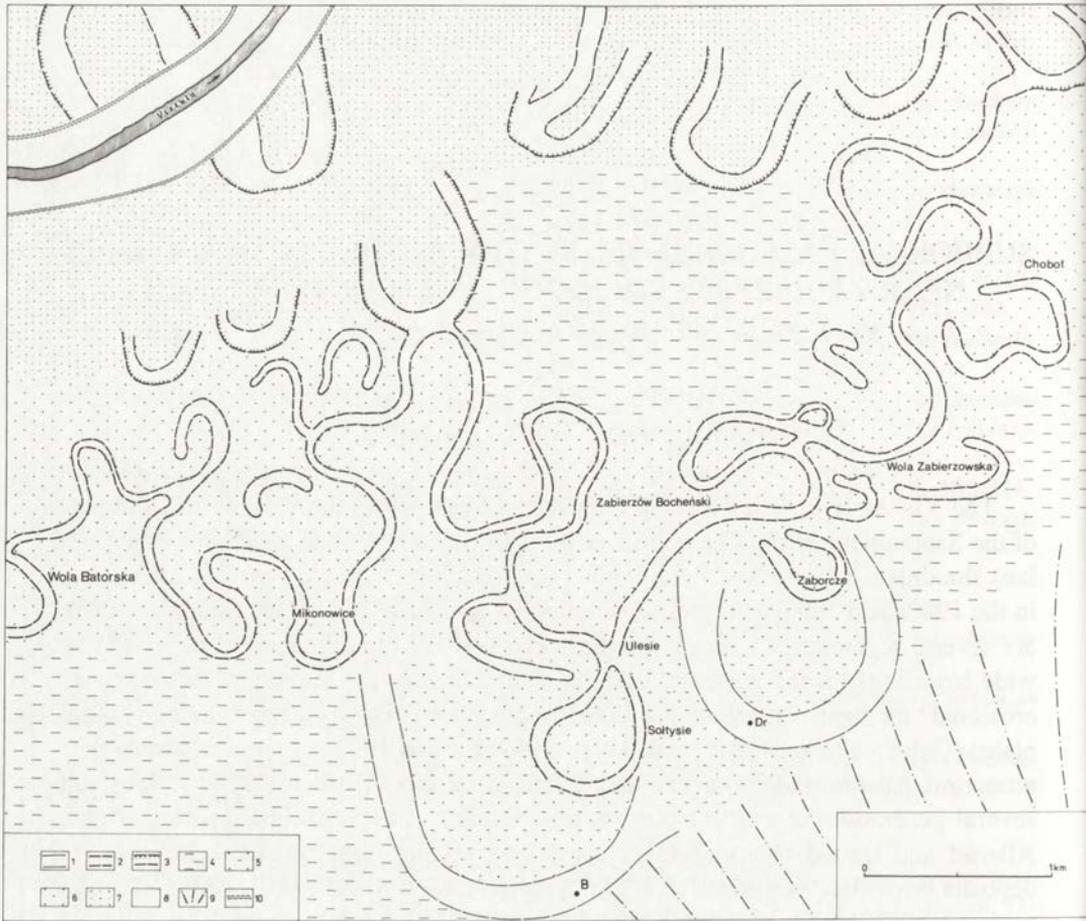
Fig. 1. Geomorphological map of the Vistula flood plain near Zabierzów Bocheński
(by T. Kalicki)

1 – Younger Dryas/Preboreal paleomeanders, 2 – Subboreal paleomeanders of Zabierzów Bocheński system,
3 – Subatlantic paleomeanders, 4 – Lateglacial alluvial braided plain, 5 – Younger Dryas/Preboreal flood
plain, 6 – Atlantic–Subboreal meander belt, 7 – Subatlantic flood plain, 8 – present flood plain
(interembankment zone), 9 – older Raba fan, 10 – embankment

have been cut off before avulsion. The youngest of the above have broken necks, but
they are still connected with the whole system of the meanders (e.g. Sołtysie, Zabie-
rzów Bocheński). The older are already separated from the system, their inlet parts are
illuviated, but they are still well marked in morphology (e.g. Wola Zabierzowska). In
the existing literature, due to the lack of datings, the Zabierzów system has been
considered either as of the 14th–16th centuries (Gębica 1986; Gębica, Starkel 1987)
or it has been included to the same generation as the Atlantic system of Grobla Forest
(Baumgart-Kotarba 1991). According to the latter author, the cut off meanders located
along this system and undoubtedly constituting one whole with this system, e.g. pa-
leomeander Zaborcze, were related to the earlier generation which had been deter-
mined as "likely the early Holocene" one.

In the south of this system there is the lateglacial lowering of the Drwinka stream which is dissected in the studied region by the large Younger Dryas paleomeanders. The fill of the younger paleomeander was dated at 9520±110 BP (Gębica, Starkel 1987; Nalepka 1991) while of the older one at 9800±80 BP (Kalicki – chapter 2.4 in this volume). In the north, closer to the Vistula river, the system in Zabierzów is undercut by the larger and younger paleochannels, out of which one has been directly connected with the system of the meanders. Slightly farther to the east, there is the wide lowering without traces of paleomeanders (Gębica 1995) likely to be a remnant of the late glacial, gravel-sandy alluvial plain covered with 0.5 m thick layer of silty madas (alluvial loams).

AIM AND METHODS

The aim of the detailed study on one of the very well developed paleomeanders in this system was not only the cognition of its age and facial differentiation of deposits, but especially systematic investigation of its parameters as well as an attempted to reconstruct discharges according to the method of K. Rotnicki (1991).

Therefore borings were made in 8 cross-sections of the channel as well as two transects, longitudinal and cross-sectional ones, across the zone of point bars. The borings in the channel were 6–10 m apart while those outside the channel 30–60 m apart. The total of 73 borings was made and all reached the Miocene substratum, thus they went through the whole series of alluvia. The borings were made with the mechanical drill GEOMERES (patent of Z. Młynarczyk, K. Rotnicki, S. Szczot of the Poznań University) which allows for undisturbed sampling. The material for palaeobotanical study was obtained with the help of K. Więckowski's corer. The profiles were levelled one with the others and the series were related to the spot height of 186.5 m at the map 1:10 000 scale.

All the profiles were sampled. The total of 1330 grain size analyses by the sieve method in the case of coarser sediments and by the laser method in the case of finer sediments (below 1 mm) was performed. The sieve analyses were carried out on the Fritsch sieves, calibrated from 0.063 mm to 1 mm every 0.5ø and from 1 mm to 16 mm every 1ø. The samples of material for the analyses were 100 g in the case of sands, ca 200–300 g in the case of gravels. Due to fairly small samples taken from sandy-gravel and gravel deposits, their analyses provided only approximate grain size composition (cf. Rutkowski 1992). The laser analyses were performed with the help of Fritsch "Analysette-22". The analysis consisted in multiple measurements of grain diameters in suspended sediment sample by a laser beam (Kasza 1992). The amount of the material sufficient for one measurement was ca 1–2 g, while 10 g were sufficient for a full analysis. Because of a new instrument used in these analyses and in order to avoid errors resulting from a new method applied, as well as due to the very small amounts of material taken for measurements, each sample was analysed 3 to 5 times depending on a sediment type (3 times in the case of homogenous deposits and of the very large or full repeatability of results, 5 times in the case of heterogenous

deposits and large divergence of cumulative curves). For further studies the middle result was accepted on the base of the mean diameter and the pattern of the cumulative curve.

In the case of organic deposits, 170 analyses of the content of organic matter were carried out by the loss of ignition in a temperature of 400°C.

All the analyses were performed in the laboratory of the Department of Geomorphology and Hydrology of Mountains and Uplands, Institute of Geography and Spatial Organization, Polish Academy of Sciences in Cracow by J. Sala. The computer programme developed by A. Walanus in collaboration with J. Sala was used for processing of laboratory data for particular profiles. Parameters characterizing grain size were calculated from cumulative curves according to the Folk-Ward formulae.

J. Mościcki participated in attempts to employ geophysical methods: the multilevel, the surface of the electro-resistance profiling and penetrometer-based resistivity logging (PPR). These methods turned out to be suitable for delimitation of the major types of deposits. However, due to informations being too general and due to the possibility of making errors in determination of lithology of the deposits, these methods were not accepted for a wider range of study (cf. Kalicki, Mościcki in print).

The age of the overbank and paleochannel facies were determined by 9 radiocarbon datings performed in the laboratory of the Institute of Physics of Silesian Technical University as well as by pollen analyses of 33 samples from the paleochannel fill in profile ZB near profile D4 carried out by V. P. Zernickaya of the Institute of Geological Sciences, Academy of Sciences of Belorus in Minsk. The samples were pretreated according to the method described by T. Kalicki and V. P. Zernickaya (1995). The pollen diagram, correlated with lithology, allowed for a determination of the age and a character of phases of the paleochannel filling.

The grain size analysis in all the profiles, especially in the point bar zone, allowed to distinguish 5 series of deposits of various age, which were separated one from the others either by the layers of lag deposits or differing in their sequence. In numerous cases, however, the determination of boundaries was very difficult because of the neighbourhood of the deposits which grain size compositon is alike. When analysing paleochannels fills the attention was paid to the relation between sandy point bars and the fossil channel, as the sand bars may fill the abandoned channel.

Attempting the reconstruction of the paleomeander parameters and aiming at the determination of paleodischarges the authors pay attention to difficulties in the defining of the basic parameters of paleochannels and to a possible diversity of interpretations of the results.

SUBQUATERNARY SUBSTRATUM

Based on the network of borings in the paleomeander in Zabierzów Bocheński and archive borings from the former gravel-pit, the very shallow Miocene clays were stated. Their top occurs from 178.1 to 182.1 m a. s. l. (Fig. 2). In the majority of borings it is at the height of 180–181 m and reaches its deepest point in the NE part of the paleomeander (cross-section E). Distinct lowerings, below 179 m, occur in the
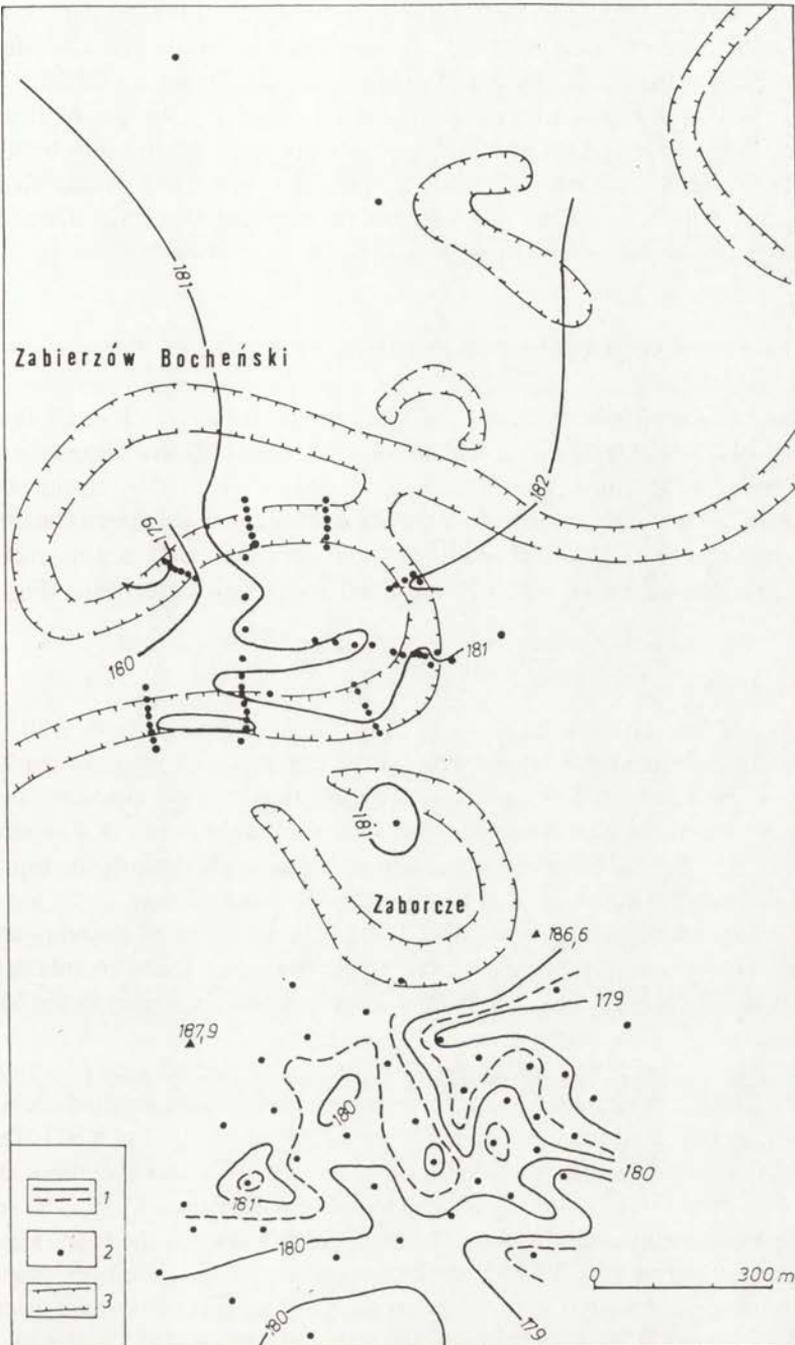
Fig. 2. Subquaternary relief in the study region (by T. Kalicki)

1 – isohypses of the top surface of Miocene clay, 2 – borings, 3 – cutoff edges

NW part of the paleomeander (cross-section H) and farther to the S, outside the area of the detailed studies in the region of the paleomeander Zaborcze. Despite a high density of borings, the main features of the subquaternary relief are difficult to identify. However, both the lowerings and the elevations seem to be the W–E oriented. Moreover, despite a small thickness of alluvia there is no relationship between the subquarternary relief and the present-day topography, which is best exemplified by the occurrence of both the maximum lowering and the elevation of the top of the Miocene clays within the paleochannel (cross-sections H and E, respectively).

CHARACTERISTICS OF ALLUVIAL SERIES

The thickness of alluvia resting on the Miocene clays does not exceed 7–8 m. Both in the zone of the point bars and in the abandoned channel fill five series of a various age have been distinguished. Two of them, fossil ones, are formed by channel deposits and by small remains of abandoned channel fills. Three younger series consist of the complete members of the channel and flood facies or of the abandoned channel facies. The series are most often separated by erosional levels with lag deposits (Fig. 3).

A. FOSSIL SERIES (PARTLY ERODED)

The top of the Miocene deposits is most often at the height of 180.5–181.1 m a. s. l. The oldest series I is preserved in the trough which is cut in the Tertiary deposits and descends to 179 m in cross-section H of the paleochannel, and tiny fragments of this series are probably visible in cross-section D and G. The series I is built of 2.0–2.5 m thick gravels with an admixture of sands towards the top. At the base rounded pebbles reach 4–5 cm in diameters. In some borings, at the top of this series there are thin (0.1–0.2 m) inserts of peaty mud and well decomposed dark brown peat. The radiocarbon dating of the sample from the base of organic deposites is 10 390±30 BP (Gd-10 203). The latter allows to relate this series to the Younger Dryas (Fig. 4, 5).

The series II, 1.5–2.5 m thick, extends over the entire studied area. It is limited by two levels of lag deposits: the base level usually rests on the unlevelled socle of the Miocene clays or sometimes cuts series I at the height of 182–183 m a. s. l. The base lag deposits consist of gravels of 4–5 cm and are poorly sorted. Within these deposits clay balls dragged from the substratum are found (cross-sections C, E). The series is mainly built of sandy deposits which become coarser towards the base ($Mz = 0.5$– $-1.7\emptyset$) and well sorted ($\delta_I = 0.4$–1.5). In cross-section G there have been stated mud and peat of the thickness of 0.5–1.0 m, being probably the remnants of the paleochannel fill. The base of peat has been dated at 9470±130 BP (Gd-7130) while the top at 9040±120 BP (Gd-6672). Thus the series II represents the Preboreal period, when in its younger phase the channel had been abandoned. The gravels at the base, of the character of the lag deposits, represent various phases of the accumulation and were reworked several times (Fig. 4, 6).
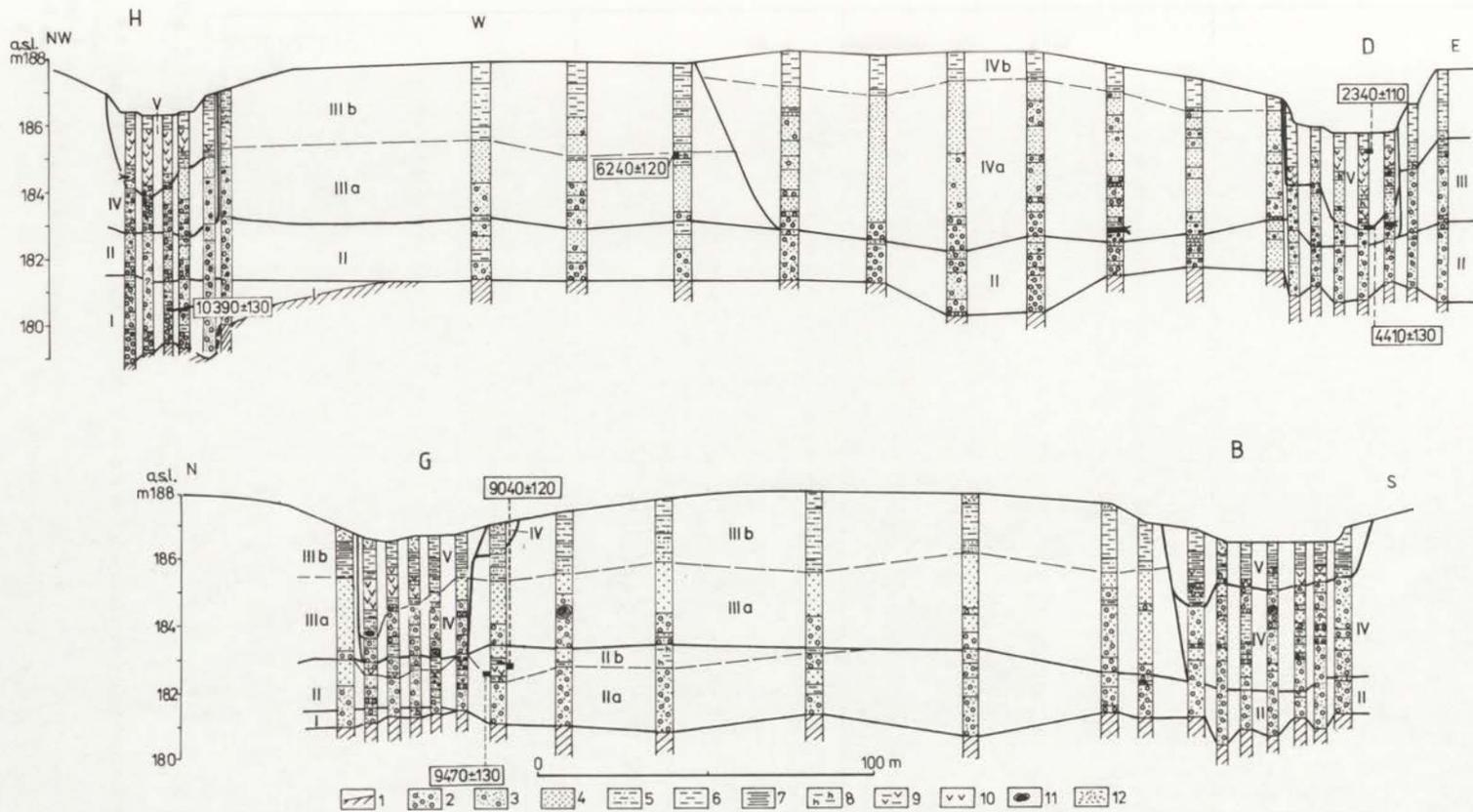
Fig. 3. General sections G–B and D–H across the paleomeander at Zabierzów Bocheński site (by T. Kalicki)

1 – Miocene clay, 2 – gravels and sands, 3 – sands with single gravels, 4 – sands, 5 – silty sands and sandy silts, 6 – silts, 7 – clayey silts, 8 – organic silts, 9 – peaty silts, 10 – peats, 11 – tree trunks, 12 – mounds
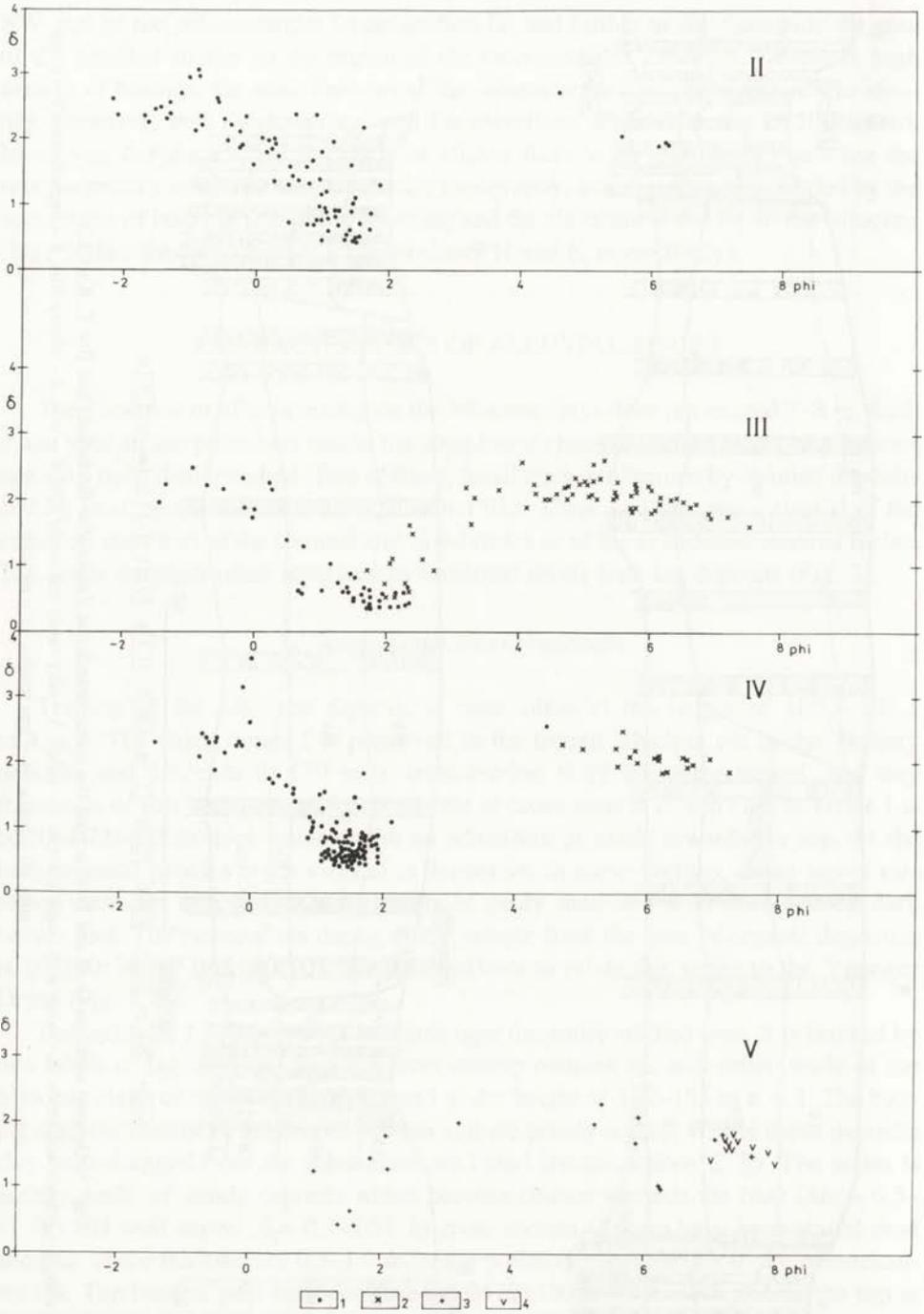
Fig. 4. Sedimentological characteristics of the II–V series at Zabierzów Bocheński site
(by L. Starkel)

1 – channel deposits, 2 – overbank deposits, 3 – abandoned channel deposits (Va–Ve),
4 – abandoned channel deposits (Vf)

ZABIERZÓW BOCHEŃSKI H3

[cm]

0   50 %   100   0   2   4   6   8

0

100

200

300
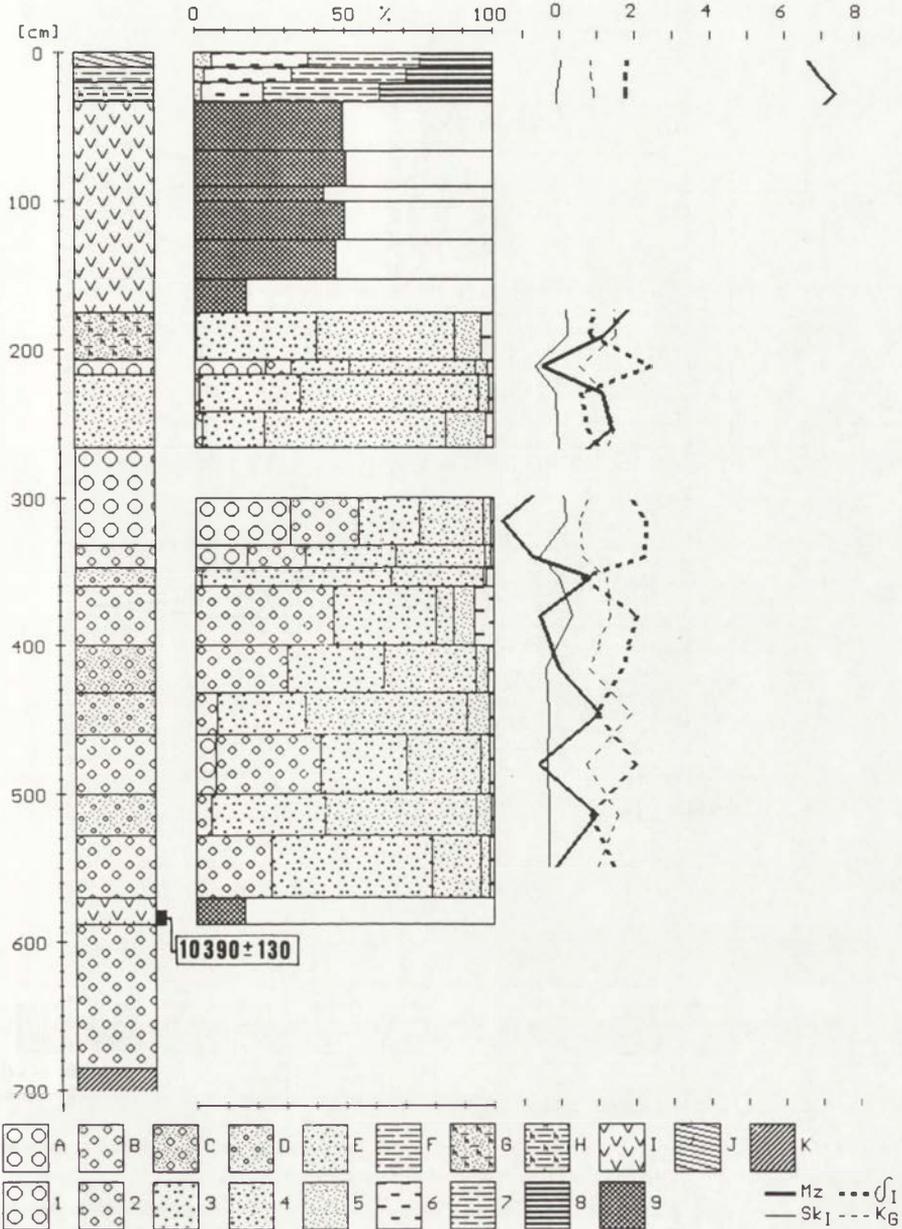
400

500

600

700

10390±130

Fig. 5. Profile H3, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki, J. Sala)

S e d i m e n t s: A – coarse gravels, B – gravels, C – gravel with sands, D – sands with single gravels, E – sands, F – clayey silts, G – organic silty sands, H – organic clayey silts, I – peats, J – soil, K – Miocene clay; F r a c t i o n s: 1 – coarse gravel (below –4ø), 2 – medium and fine gravel (–4 to –1ø), 3 – coarse sand (–1 to 1ø), 4 – medium sand (1 to 2ø), 5 – fine sand (2 to 4ø), 6 – coarse and medium dust (4 to 6ø), 7 – fine dust (6 to 8ø), 8 – clay (above 8ø), 9 – content of organic matter; Mz – mean grain size, δ_I – standard deviation, Sk_I – skewness, K_G – kurtosis
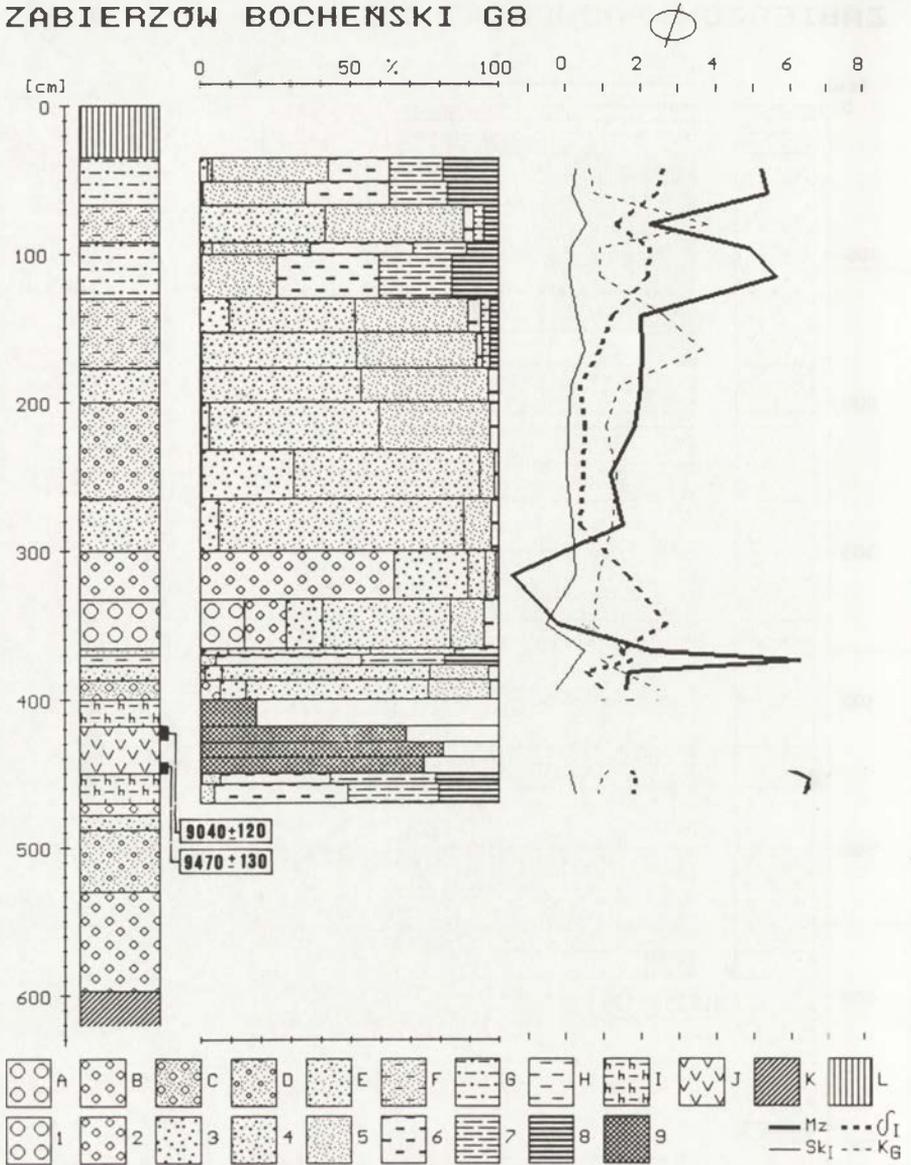
ZABIERZÓW BOCHEŃSKI G8

Fig. 6. Profile G8, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki, J. Sala)

S e d i m e n t s: A – coarse gravels, B – gravels, C – gravel with sands, D – sands with single gravels, E – sands, F – silty sands, G – sandy silts, H – silts, I – organic silts, J – peats, K – Miocene clay, L – mounds; F r a c t i o n s: 1 – coarse gravel (below –4ø), 2 – medium and fine gravel (–4 to –1ø), 3 – coarse sand (–1 to 1ø), 4 – medium sand (1 to 2ø), 5 – fine sand (2 to 4ø), 6 – coarse nad medium duts (4 to 6ø), 7 – fine dust (6 to 8ø), 8 – clay (above 8ø), 9 – content of organic matter: Mz, δ_I, Sk_I, K_G – see Fig. 5

ZABIERZÓW BOCHEŃSKI D15

Fig. 7. Profile D15, grain size composition and Folk-Ward's grain size distribution parameters
(by T. Kalicki, J. Sala)

S e d i m e n t s: A – gravels, B – gravel with sands, C – coarse sands, D – medium sands, E – fine sands,
F – silty sands, G – sandy silts, H – silts, I – organic sandy silts, J – organic silts, K – soil, L – Miocene clay;
F r a c t i o n s: 1 – coarse gravel (below –4ø), 2 – medium and fine gravel (–4 to –1ø), 3 – coarse sand (–1
to 1ø), 4 – medium sand (1 to 2ø), 5 – fine sand (2 to 4ø), 6 – coarse and medium dust (4 to 6ø), 7 – fine dust
(6 to 8ø), 8 – clay (above 8ø); Mz, δ_I, Sk_I, K_G – see Fig. 5
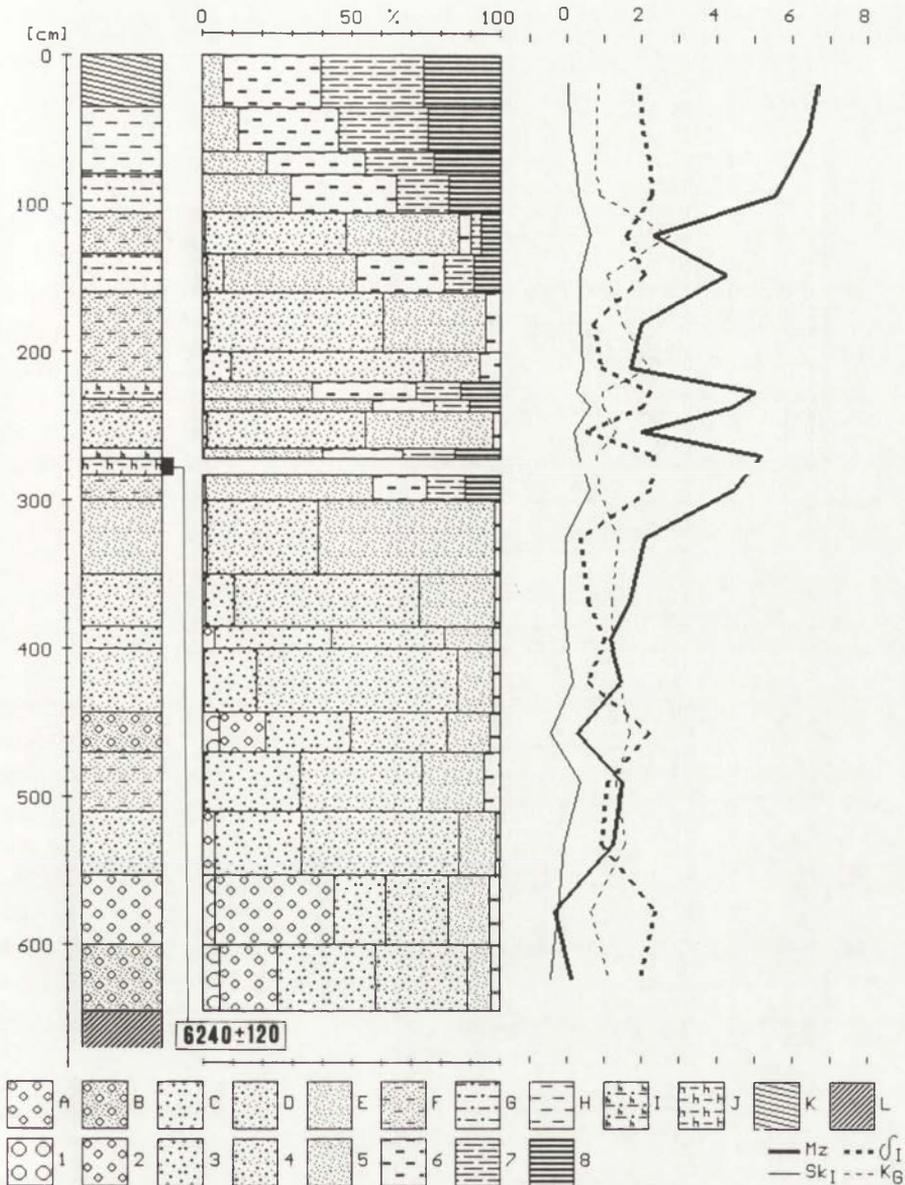
Fig. 8. Profile D13, grain size composition and Folk-Ward's grain size distribution parameters
(by T. Kalicki, J. Sala)

S e d i m e n t s: A – gravels, B – gravel with sands, C – sands with single gravels, D – sands, E – silty sands, F – silts, G – soil, H – Miocene clay; F r a c t i o n s: 1 – coarse gravel (below –4ø), 2 – medium and fine gravel (–4 to –1ø), 3 – coarse sand (–1 to 1ø), 4 – medium sand (1 to 2ø), 5 – fine sand (2 to 4ø), 6 – coarse and medium dust (4 to 6ø), 7 – fine dust (6 to 8ø), 8 – clay (above 8ø); Mz, δ_I, Sk_I, K_G – see Fig. 5

B. UPPER SERIES (WITH PRESERVED FULL SEQUENCE)

The series III rests on the series II and contains a full sequence of the channel and overbank deposits of the total thickness of 0.4–4.5 m. This series builds the plain of the height of 187.5–188.0 m a. s. l. The channel facies (IIIA) consists of coarser gravels of the maximum diameter of 5 cm which change upward to sands of the point bars (Mz = 0.7–2.3ø), which are well or medium sorted (δ_I = 0.35–0.85). On them there are madas (IIIB) of the thickness up to 2 m, which in the zone of the point bars (boring D15 and D16), change into interbedded sands and silts. The sands (Mz = 1.7– –2.7ø) are well, medium or poorly sorted (δ_I = 0.5–1.6) while silts (Mz = 4.5–6.7ø) are poorly and very poorly sorted (δ_I = 1.9–2.3). The total thickness of these deposits reaches 2.5–2.8 m. The character of the flood deposits of levee type points to the proximity of the active channel. The insert of organic mud at the base of these deposits has been dated at 6240±120 BP (Gd-10 202). Because of that the age of the series may be determined as the Boreal–the Older Atlantic and it simultaneously indicates a phase of an intensification of channel processes and an aggradation of madas on the plain (Fig. 4, 7).

The series IV builds the younger part of the point bars. They are higher than the older ones of the series III by 0.2–0.5 m (borings D14–D8 in cross-section D–H) and consist of three distinct members, which form a sequence typical for a menadering river: at the base there are lag deposits separating this series from the older series II, above – channel deposits – sands with gravels, sandy deposits of point bars and silty-sandy madas at the top. The basal gravels, which occur below the zone of the point bars and below the abandoned paleochannel, form a 1–2 m thick layer with one or two levels of lag deposits with fragments of wood. Rounded pebbles are 5 cm in diameter at maximum and are very poorly sorted (δ_I = 2.0–3.5). Sometimes below the fill of the main paleochannel there are two or three gravel layers which reflect the reworking of the alluvia during different floods. The member of the sandy point bars (occasionally with singular gravels of diameters to 2 cm) is usually well sorted with gradually finer grains towards the top. The average diameter (Mz) varies from 0.9 to 2.0ø while δ_I = 0.4–1.0. This member reaches the level of 186.5±187.2 m, i.e. higher than the series II which provides the evidence of the river aggradation. The thickness of the top layer of silty-sandy madas never exceeds 1 m, which would indicate a rela- tively rapid abandonment of the paleomeander by the Vistula and a decline in the mada aggradation. Based on the relation to the dated series III and V, the age of the series IV may be accepted as late Atlantic – early Subboreal (Fig. 4, 8).

C. ABANDONED CHANNEL FILL

The youngest series V is built of the abandoned channel fill and reaches the thickness of 3.25 m. Within this series one can distinguish some members differing in the content of the organic matter. In the initial phase of filling up of the abandoned channel mineral sediments were deposited in forms of bars narrowing the channel cross-section (Va–Vb), later, in period of intensified floods – in forms of inserts in organic deposits (Vd). The organic deposits accreted in the period of relative stability

(Vc and Ve). In the final stage in all the cross-sections the organic deposits became covered with clayey mud (Vf). The analysis of the pollen diagram provides the detailed information on sedimentation and age of events (Fig. 9).

Member Va

Two first members differ as to their character and thickness depending on the channel section (maximum to 1.75 m in cross-sections B and C). In the segments of the straight channel (cross-sections A, B, H) sandy-gravel deposits uniformly fill the whole bottom of the channel and cause its shallowing while at the bend (cross-sections C–G) the deposits take form of a sand bar (with a normal sequence) accreting outward the point bars and narrowing the channel cross-section. Two phases of filling with mineral sediments can be distinguished, because in cross-sections B and H the sands are covered with sands with gravels changing upward into sands again. This two phased development is even better confirmed at the meander bend (cross-sections C and D), where mud with thin sandy laminae (profile ZB), evidencing the flood flows is deposited in the deepest parts of the channel (member Va). These may be correlated with sands in the straight fragments of the channel (Fig. 9–11).

In the pollen diagram the deposits of this member (Va) belong to the pollen zone ZB-1 (samples 33–28) dated as the early Subboreal (SB-1). The age of this zone has been determined on the basis of the percentage of the pollen of *Carpinus* (2% on average), *Fagus* (1% on average), appearance of *Abies* (0.1% on average) and small amounts of *Ulmus* (1% on average) in the spectrum. Among the other trees there have been stated: *Pinus* (13% avg.), *Picea* (9% avg.) and out of the deciduous trees *Quercus* (9% avg.), *Tilia* (10% avg.), *Alnus* (9% avg.), *Corylus* (32% avg.). Such composition and percentage of trees correspond well with isopole maps elaborated by M. Ralska-Jasiewiczowa (1983). The large percentage of hazel in this zone is probably associated with local conditions. After the avulsion of the Vistula, the pioneer species entered the already inactive point bars with a thin cover of madas. The pollen of *Juniperus* and *Ephedra* provide the evidence of sandy habitat conditions. High percentage of hazel at the beginning of the Subboreal can also be caused by regional factors, because it has been stated not only in the eastern part of the Sandomierz Basin (Mamakowa 1962), but also in Pleszów nearby (Wasylikowa 1989).

In the composition of herbaceous plants (NAP) the representatives of riverine meadows predominate. Among aquatic plants *Salvinia natans*, *Myriophyllum spicatum*, *Potamogeton natans* are the most common. High percentage of *Salvinia natans* (3% avg.) is the evidence of a significant isolation of the abandoned channel from cooler waters of the Vistula and of the formation of a local body of stagnant and warmer water. Vegetation of peaty and shallow fragments of the abandoned channel includes *Alisma* cf. *plantago-aquitica*, *Sparganium*, *Typha latifolia*. The base and the top of this layer of mud with organic substances have been dated at 4410±130 BP (Gd-9303) and 3590±140 BP (Gd-10 098) (Fig. 12).

Member Vb

In the second state of the abandoned channel filling with mineral sediments the deepest sites, in which mud had been deposited hitherto, became buried with sands
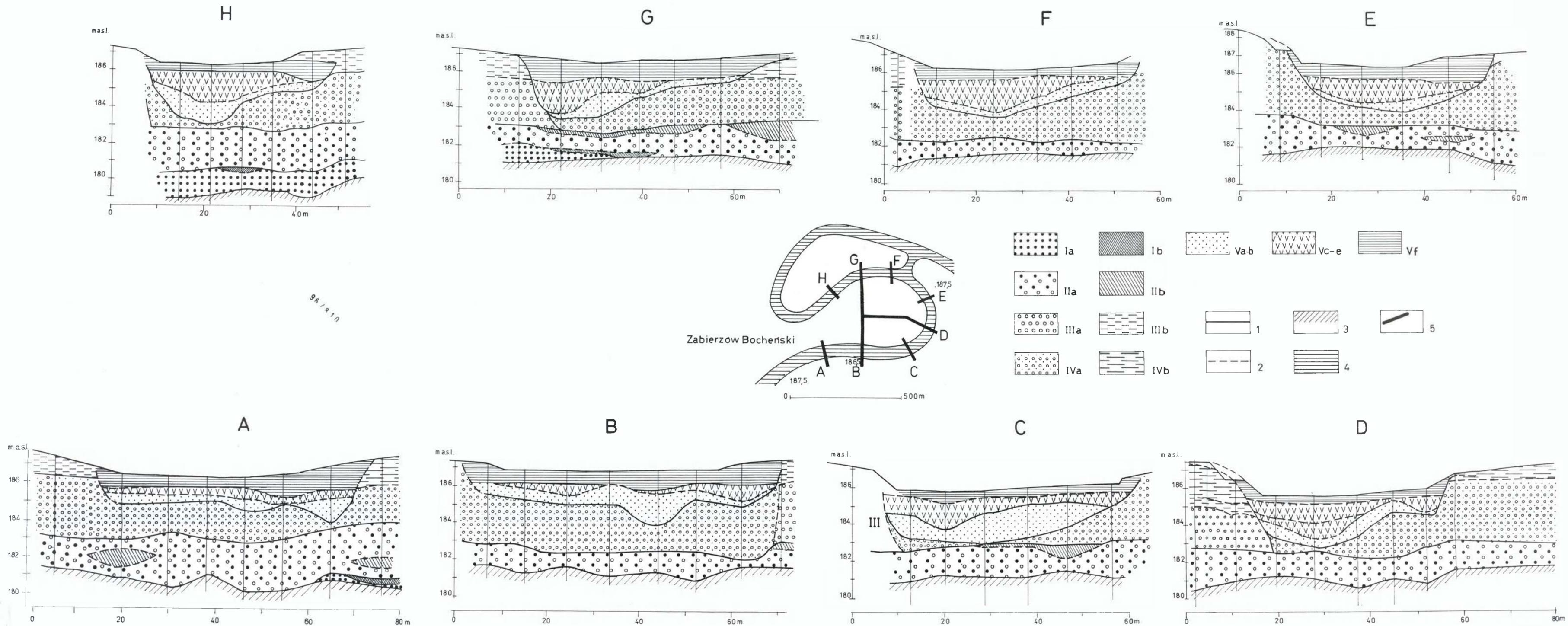
Fig. 9. Generalised section A–G across the paleomeander at Zabierzów Bocheński (by T. Kalicki, L. Starkel)

I–V number of series, Ia–IVa – channel deposits, Ib–IVb – abandoned channel and overbank deposits, Va–b – abandoned channel fill: mostly sands, Vc–e – abandoned channel fill: mostly organic sediments, Vf – abandoned channel fill: muds (madas) 1 – certain limits, 2 – uncertain limits, 3 – Miocene clays, 4 – paleomeander, 5 – cross-section

Fig. 10. Detailed section D across the palaeomeander (by T. Kalicki)

1 – Miocene clay, 2 – gravels and sands, 3 – sands with single gravels, 4 – sands, 5 – silty sands, 6 – sand with organic matter, 7 – sandy silts, 8 – silts, 9 – clayey silts, 10 – organic silts, 11 – peaty silts, 12 – peats with clay, 13 – peats, 14 – tree trunks

Fig. 11. Profile D4 in the palaeomeander fill, grain size composition, content of organic matter and Folk-Ward's grain size distribution parameters (by T. Kalicki, J. Sala)

S e d i m e n t s: A – coarse gravels, B – gravels, C – silty sands with single gravels, D – sands, E – silty sands, F – silts, G – clayey silt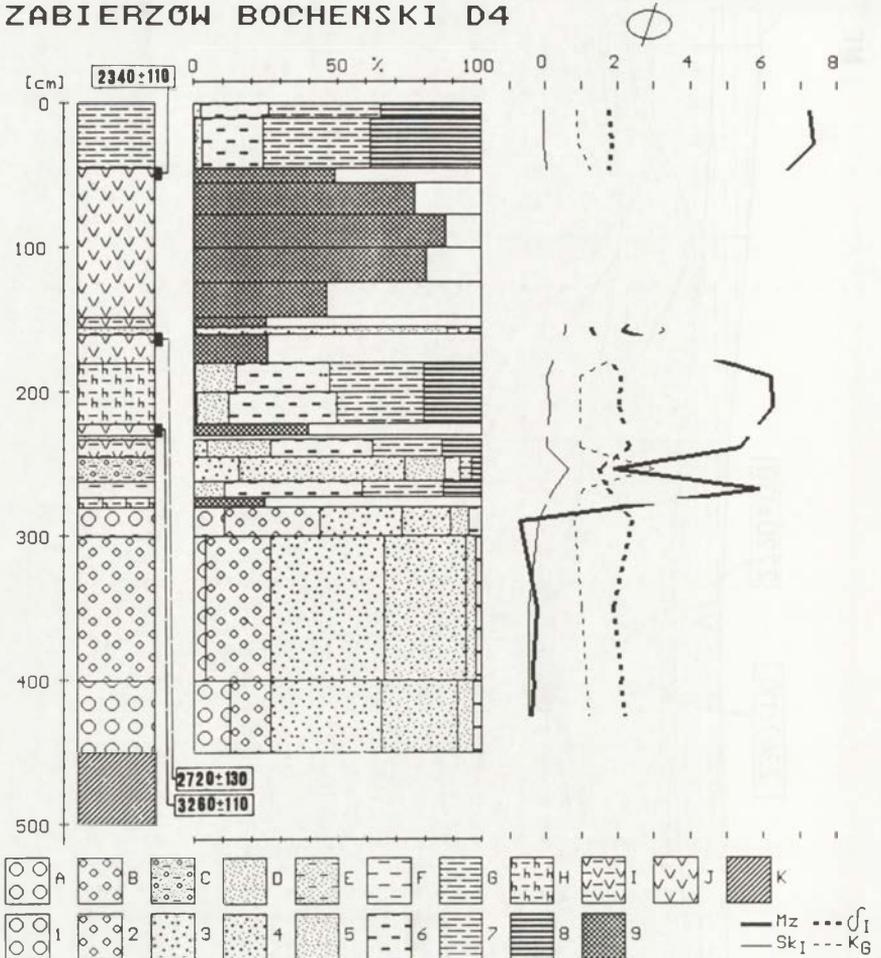s, H – organic silts, I – peaty silts, J – peats, K – Miocene clay; F r a c t i o n s: 1 – coarse gravel (below –4ø), 2 – medium and fine gravel (–4 to –1ø), 3 – coarse sand (–1 to 1ø), 4 – medium sand (1 to 2ø), 5 – fine sand (2 to 4ø), 6 – coarse and medium dust (4 to 6ø), 7 – fine dust (6 to 8ø), 8 – clay (above 8ø), 9 – content of organic matter; Mz, δ_I, Sk_I, K_G – see Fig. 5

with sandy and gravel bars (member Vb). The accumulation was accompanied by the washing out of the top of the underlying mud, which is marked in the palynological diagram by an increase in the amount of the corroded pollen. This sandy accumulation was interrupted by the accretion of peaty, sandy mud, which provides the evidence of a temporal stability and a subsequent flood (profile D4) (Fig. 9–11).

This sandy member Vb belongs to the pollen zone ZB-2 (samples 25–27) corresponding to the beginning of the middle Subboreal. There is a marked increase in a role of the hygrophilous trees: *Abies* (1.4% avg.), *Picea* (14% avg.), *Tilia* (12% avg.)
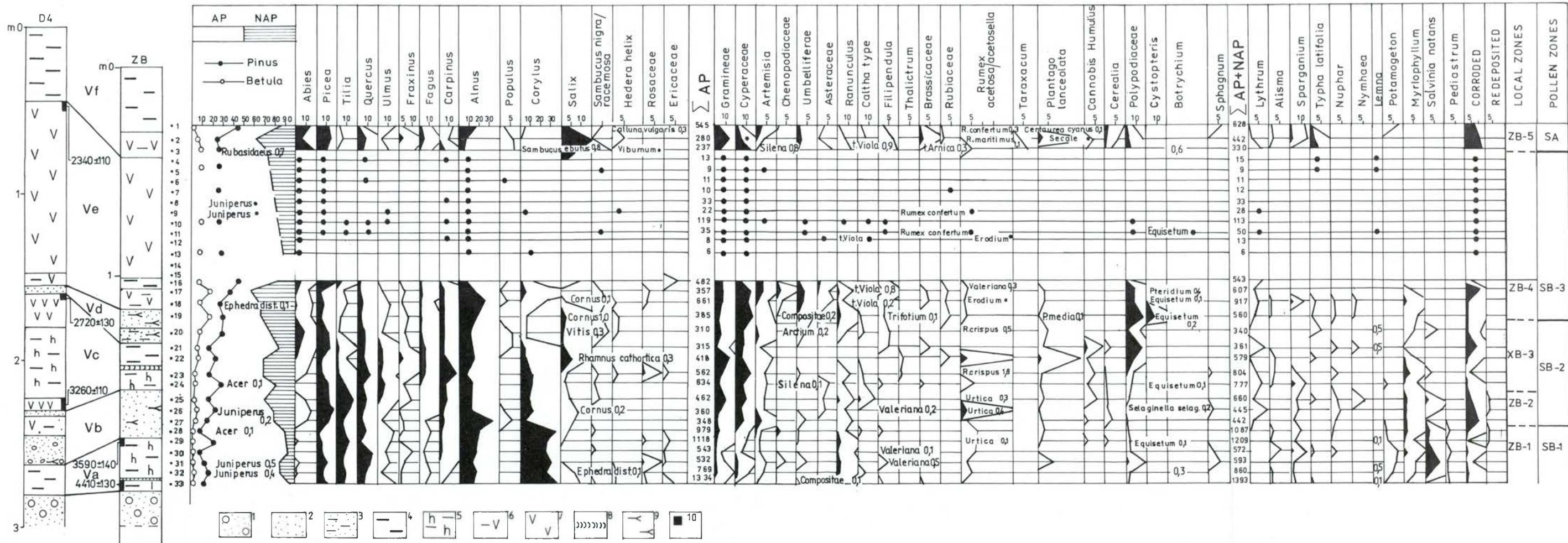
Fig. 12. Pollen diagram of the abandoned channel fill at Zabierzów Bocheński (by V. P. Zernickaya) correlated with D4 profile – see Fig. 11 (by T. Kalicki)

1 – gravels, 2 – sands, 3 – silty sands, 4 – silts, 5 – organic silts, 6 – peaty silts, 7 – peats, 8 – woods, 9 – detritus, 10 – radiocarbon datings

and an increased percentage of elm, beech and hornbeam. The evidence of moistening of climate and higher frequency of floods in also an increase in corroded and redeposited pollen. The increase in soil moisture caused diminishing of hazel and development of alder-willow thickets.

In the spectra of herbaceous plants, as in the previous case, the pollen of plants of flooded meadows and marshes predominate. Cooling of water in the oxbow lake caused gradual cessation of *Salvinia natans. Myriophyllum spicatum, Nuphar* and *Nymhaea* become more important.

In the diagram there are weak traces of a man. Among *Cerealia* occurs the pollen of *Triticum*, as well as that of *Plantago lanceolata, Rumex acetosella, Urtica dioica, Cananbis/Humulus.*

Based on correlation between profile D4 and the palynologically analysed profile ZB the period of the intensified flood may be dated at the time interval between 3590±140 BP and 3260±110 BP (Fig. 12).

Member Vc

In the subsequent stage flood processes became less intensive. Only in the deepest sites (below 184.0–184.5 m a.s.l.), within the paleomeander, there had been preserved backswamps which were filled up with silty organic mud ($Mz = 6.0\varnothing$), at the top and at the base – with peaty ones (25–40% of organic substance) – cross-sections C, D, G. On the other hand, in the upper located, onshore fragments of the abandoned channel, peat started to grow (member Vc) (Fig. 9–11).

In the diagram the pollen zone ZB-3 (samples 20–24) corresponds to this stage. The composition of tree plants indicates the optimum of the Subboreal. Among the coniferous trees *Abies* (max. 10%), *Picea* (max. 13%) and among the deciduous ones *Quercus* (max. 12%), *Carpinus* (max. 18%), *Fagus* (max. 7%), *Ulmus* (max. 5%) and *Fraxinus* (max. 4%) occur.

Among the herbaceous plants the role of *Gramineae* increases. In the three top samples (from sample 22) the importance of pollen of plants from moist sites as well as of those of open water reservoirs diminishes. A larger percentage of *Polypodiaceae* and *Equisetum* and *Alisma* indicates that the peat overgrows the water reservoir. It may provide the evidence of the shortlasting phase of drier climate and of the lowering of the groundwater table.

Peaty mud lying at the base of this member in the profile D4 has been dated at 3260±110 BP (Gd-10 101) while peaty mud lying at the top has been dated at 2720±130 BP (Gd-10 194) (Fig. 12).

Member Vd

In the subsequent stage the flood processes became intensified, what led to the infilling of the abandoned channel with the medium and fine, slightly clayey sands (member Vd). These sands are marked in almost all the cross sections at the bend of the peleomeander (C–F). In the marginal parts of the abandoned channel the same sands were deposited as a subsequent sand bar. In the axis of the abandoned channel the sands are present locally (cross-section D and profile ZB), however, silty mud

occurs more often there. As indicated in the palynological diagram this change there. As indicated in the palynological diagram this change in sedimentation type has been reflected in the pollen diagram as an increase in number of the corroded pollen. Correlation with profile D4 allows this phase of the intensified floods to be dated after 2720±130 BP (Fig. 9–11).

Member Ve

In the following stage of the abandoned channel filling the connection with the Vistula was broken and the entire abandoned channel became overgrown with peat (member Ve). The flood water, reaching here periodically, could be evidenced by the high content of clay in peat (10–50%), which was the highest at the base and at the top. The above deposits belong to the pollen zone ZB-4. The zone limit was laid out in the region of the descending curves of oak, elm, beech, hornbeam, and ash-tree. Among the coniferous trees the role of *Abies* decreased. Amount of alder and shrubs (*Corylus* and *Sambucus*) increased, as well as the amount of pine and birch in the composition of forests, which could indicate renovation of forest after tree clearance (Fig. 9–11).

The spectrum of herbaceous plants became more differentiated. Again, the role of the pollen of flooded meadows (*Ranunculus, Umbelliferrae, Filipendula ulmaria, Galium pallustre*) increases. The same applies to the role of the representatives of swamps of the families of *Polypodiaceae* and *Cyperaceae*. The percentage of the xerophytes (*Artemisia, Chenopodiaceae, Asteraceae, T. viola*) growing over the sandy soils gradually increases. The palynological dating of the deposits of the discussed zone in profile ZB from the depth of 1 m to 0.4 m was impossible, due to the complete lack of pollen in samples 14–15 and very tiny amounts of pollen in samples 13–14. Destruction of pollen in samples 14–15 can be associated with distinct lowering of the groundwater table and periodical drying of the peat-bog. The corroded and broken pollen as well as charcoal permanently occurs in peat (samples 4–13). The above provides the evidence of distinct changes: flooding and drying of the peatland and fires which could have been the traces of a land burning by a man as well. The evidences of a human activity are found in the overlying member (Fig. 12).

Member Vf

In the last stage of the channel filling the change in the sedimentation type is observed. In the majority of cases peat gradually changed into peaty mud, organic mud and then into clayey mud *Mz* = 7.2–7.5ø (member Vf). In some cross-sections (A–B and E–F) this change is even more abrupt, and at the base of clayey mud there are inserts of sands and sandy mud indicating the flood flow (Fig. 9–11).

These deposits belong to the pollen zone ZB-5 (samples 1–3). This complex has been assigned to the Subatlantic on the basis of the increase in the coniferous pollen: *Pinus* (34% avg.), *Abies* (12% avg.), *Picea* (12% avg.) and small percentage of *Tilia* (0.4% avg.), *Ulmus* (0.6% avg.), *Fagus* (2.2% avg.), *Carpinus* (3% avg.), which is in an agreement with the isopole maps of Poland (Ralska-Jasiewiczowa 1983). The complex of plants associated with human activity (*Secale, Triticum, Plantago lanceolata, Fagopyrum, Centaurea cyanus*) appears already in this zone (Fig. 12).

In the neighbour hood profile D4 peaty mud closing the organic accumulation of madas in the abandoned channel was dated at 2340±110 BP (Gd-6669).

PALEOMEANDER PARAMETERS
AND PALEOHYDROLOGICAL RECONSTRUCTIONS

In order to reconstruct discharges it was necessary to obtain numerical data on a series of parameters of the paleochannel.

Drafting of 8 cross-sections of the paleomeander was made on the base of borings. Despite the large density of the boring network (5–6 borings in one cross-section) some difficulties were encountered when connecting particular layers and especially when delimiting laterally the deposits filling up the channel. The above is related to the fact that the visible morphological boundaries of the abandoned channel do not correspond to the primary ones. These boundaries became changed and smoothed by ploughing; the upper edge of the scarp retreated and the lower one entered into the bottom of the abandoned channel as a result of overlaying the colluvial and deluvial covers. The above leads to errors in measurements of the channel widht both on the topographic maps and air photos as well as in the field. The measured widths are smaller that the real ones. These differences, regardless the interpretation, vary from 7–8 m (cross-sections C, D, F, H) to 17–20 m (cross-sections A, B, E, G) in the pa- leomeander in Zabierzów. One can speak about the real width of the filling (cf. Ka- licki, Krąpiec 1992) only when having a continuous outcrop. The cross-sections of the abandoned channel manifest all the features characteristic for a meandering channel. In the first straight section (cross-section AB) the channel is wider (60–70 m) and shallower (mean depth 1.5–1.75 m, max. 2.5–3.0 m). Simultaneously one observes the shift of the streamline from the left, northern bank, first to the centre (cross-section B), and then to the right, southern bank (cross-section C). The channel becomes asymmetrical at the bend (cross-sections C–G) which is best marked in the axis of the meander. Here the channel is narrower (45–55 m) and slightly deeper (mean thickness of the fill 1.5–2.0 m, max. – to 3.25 m). In the subsequent straight segment (cross-sec- tion H) the channel is the narrowest (33 m) and the deepest (to 3.25 m) in the whole studied reach (Fig. 13).

The next difficulty, which, providing the occurrence of some lag deposits horizons, can only be solved arbitrarily, is an identification of the base of the fill and of the boundary between the deposits of the still active channel and the bars infilling the channel after the abandonment. Therefore, depending on the accepted criteria of the interpretation of layers, the thickness, as well as the character of the channel fill, may vary in a very wide range. It was assumed that the bottom of the channel is indicated by the first lag deposits occurring in a boring. Thus the cross-section of the channel and its parameters have been calculated for two variants – maximum and minimum ones. The maximum thicknesses of the fill reach 2.5–3.25 m in various cross-sections. The mean thickness for the majority of the cross-sections is 1.5–1.75 m.

Another unsolved problem was the determination of the water level in the channel
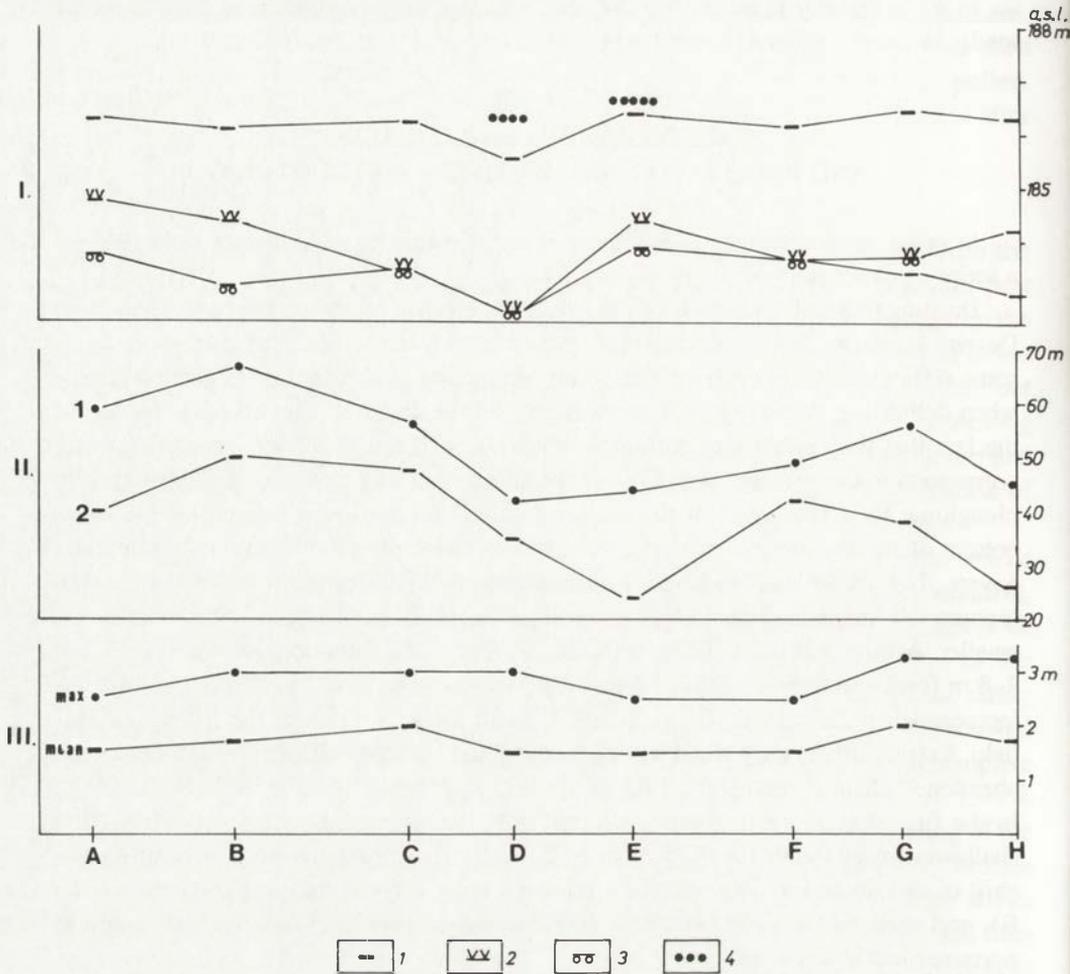
Fig. 13. Parameters of paleomeander various cross-sections (by T. Kalicki)

I – paleochannel fill: 1 – surface of paleochannel floor, 2 – base of organic fill, 3 – base of unorganic fill,
4 – top of point bar; II – width of paleomeander: 1 – interpreted after borings, 2 – measured on the surface;
III – mean and maximal thickness of paleochannel fill

– the bankfull stage. The madas at the undercut river bank do provide information on the bankfull stage. These overbank deposits could have been accumulated in the period of the system functioning (mainly) as well as after its cutting off. Accepting after K. Rotnicki (1983, 1991) the surface of the first point bar as an indicator one can determine such level only in two cross-sections D and E at the meander bend. In the remaining sections it was impossible to identify such level. Cross-sections D and E are on the paleomeander bend, i.e. where the back current occurs, and the area of the cross-section is the largest. At the present day the discharges are not recorded in such channel reaches because of very large measurement errors. Moreover, in these

sites the sandy bars narrowing the cross section were poured after the avulsion. Distinction of these bars from the deposits of the active channel is practically impossible in the borings.

The gradient of the water table accepted for calculations of paleodischarges, according to the method of K. Rotnicki, is equal to the gradient of the floodplain reduced by the sinuosity of the channel. This approach was a subject of criticism (Williams 1988; Soja 1994). Because of the significant length of the Zabierzów system another approach was possible. On the topographic map 1:10 000 the elevation of the water table is given for the drainage ditch extending along the whole system of the abandoned channels. The gradient equal to the gradient of this ditch has been accepted. This gradient in the almost 10 km long segment is equal to 0.0001702.

The magnitude of the roughness coefficient n was estimated in the range 0.035 to 0.040 based upon the grain size composition of the bedload in the present-day channel and in the cut-off meanders of the Vistula. The composition should not have been changed for the recent few millennia. One should rather expect the grain size in the channel to be finer and finer than the coarser. Therefore the lowest value, i. e. 0.035, has been accepted for calculations. In the material building the banks the coarser fractions and the tree remnants are lacking, what could indicate the large channel resistance to flow and thus, the higher roughness coefficient. Inferring from the cross-sections one comes to conclusion that the channels were compact with definitely marked, although not steep banks. The channel sinuosity could support an acceptance of the coefficient value of 0.040, but the mean depths of the bankfull discharges are very large, of the order of 2 m. Taking into account the recommendations given in the hydrometry handbooks (Pasławski 1973), the roughness coefficient for the studied cross-sections has been accepted as 0.035.

Discharges have been calculated according to the commonly used formula of Chezy-Manning:

$$Q = \frac{1}{n} \cdot R^{\frac{1}{6}} \cdot A \cdot \sqrt{R \cdot S},$$

where:

Q – discharge in m^3s^{-1},

n – roughness coefficient after Manning,

R – hydraulic radius,

A – area of the cross-section in m^2,

S – gradient.

In the both examined cross-sections the same gradient and roughness coefficient have been applied, thus the discharge depends mainly on the area of the cross-section and, to a lesser extent, on a hydraulic radius. The following values of the bankfull discharges have been obtained for the nearby located cross-sections: cross–section D – 71 m^3s^{-1}, cross-section E – max. 47.6 m^3s^{-1}. In the case of cross section E it is possible to accept the discharge of 37.3 m^3s^{-1} as well, which results from alternative identification of the base of the paleochannel fill. According to the calculations mean velocities of flow in the channel were: 0.65 $m \cdot s^{-1}$, 0.57 $m \cdot s^{-1}$ and 0.53 $m \cdot s^{-1}$, respectively.

The interpretation of the obtained values of discharges is very difficult. In the case of the same meander, in which the discharge does not change, three very different values have been obtained, which resulted only from the acceptance of a different cross-section for calculations. If the error resulting from accepting different cross-sectional areas is so large that the attempts to calculate the discharges more precisely have to fail. When accepting the gradient of the flood plain, for example of 0.002 instead of 0.0001702 for the studied channel reach, the values of the calculated discharges increase twice.

The very result of calculations, i. e. very small bankfull discharges, and so mean annual ones, gives a reason to another doubt. The discharges must have been much smaller than the present-day ones if the mean annual discharge of the Vistula in Cracow is 93.5 m^3s^{-1} (Soja, Mrozek 1990). In the region of Zabierzów Bocheński, after collecting a few tiny tributaries, the mean annual discharge slightly exceeds 100 m^3s^{-1}. The mean annual discharge of the Vistula fits entirely into the present-day channel, which is of classical river-canal form in this section. Numerous channelization practices, constructing of the riverbank passages in Cracow, deepening of shoals which hindered navigation, resulted in forming of the channel which does not, by any means, resemble a natural one in spite of preserving fairly large channel sinuosity. For over a hundred years the flood embankments have been enforcing accumulation and erosion in a very narrow belt along the river channel.

The term "bankfull stage" is difficult to define. The situation when the water completely fills up the rectangular channel and starts to inundate the flat area between the embankments, can be accepted as the bankfull stage. The discharge corresponding to such situation can be estimated as ca 200–400 or even 500 m^3s^{-1}. It is much larger than the discharge obtained from calculations and by no means comparable with natural conditions, because it refers to the river-canal. The reconstruction of the parameters of the Vistula channel is a fairly complicated problem for a few recent centuries (cf. Trafas 1975). The process of a transformation started before the first quite precise plans of the channel had been made and singular profiles and descriptions of the river channel, which had been made when building the bridges, refer to the sections and cross-sections of particularly favourable conditions from the hydrotechnical point of view.

OTHER METHODS OF CALCULATIONS OF PALEODISCHARGES

In the literature the formulae relating the meander parameters to characteristic discharges are often found. K. Rotnicki (1991) analyzes several of these formulae and states their small usefulness for determination of the characteristic discharges of the Prosna river. A similar analysis has been carried out by G. Williams (1988) criticising also the method proposed by K. Rotnicki (1983). In the literature there are no good examples of applications of the formulae.

The empirical formulae relating the parameters of the meanders with discharges are only the statistical generalization of the relationships between the parameters

describing the channel in a given river reach and hydrologic river parameters. These formulae are not fully of the character of the regional formulae. These are rather local formulae of very simplified structures. The simplicity of the formulae, i.e. a usage of one or two parameters in their design, makes them cannot reflect the entire variability of the environment. Working out of a regional or local formula requires a large number of input data which most often are not very abundant. If one cannot derive the own formula, one tries to apply the formulae known from the literature. Such approach is most often unsuccessful. There is no reliable reference and the result obtained from another formula cannot be accepted as such a reference. Additional problems arise, because some formulae are designed in non-metric systems and source materials are presented in difficult accessible publications.

For the Vistula in the region of Zabierzów Bocheński the calculations of the mean discharges, discharges of given probabilities and of the bankfull discharge (Tab. 1) have been attempted using the formulae discussed by G. Williams (1988) and using the method applied by K. Trafas (1975). The calculations have been carried out for the two, nearby located cross-sections, marked D and E. Unfortunately, the results are not satisfactory. The present-day mean annual discharge of the Vistula in the discussed region is 100 m³s⁻¹ while the discharges for the system of the Zabierzów paleomeanders are several times smaller. The bankfull discharge has been estimated, according to various formulae, at 70–600 m³s⁻¹. At present the bankfull discharge is much closer to the value being the upper limit of the range given above.

Some clarification is necessary to explain the Inglis' formula which had been used incorrectly by K. Trafas (1975). The discussed formula, which describes the relation-

T a b l e 1. Reconstructions of the discharges of Vistula paleomeander
(empirical formulas after Williams 1988)

Formula	Author	Estimation Q in $m^3 \cdot sec^{-1}$
$Q_m = 0.27 \, W_b^{1.71}$	Osterkamp, Hedman 1982	D – 19.2 E – 18.7
$Q_m = 0.929 \, W_b^{1.28} \, D_{max}^{1.10}$	Schumm 1972, Wiliams 1984	D – 16.0 E – 10.8
$Q_m = 0.000017 \, L_m^{2.15}$	Carlston 1965	29.6
$Q_{1.5} = 0.011 \, L_m^{1.54}$	Carlston 1965	325
$Q_{1.58} = 2.42 \, A_{1.58}^{0.72}$	Knox 1985	D – 71.0 E – 58.5
$Q_2 = 1.9 \, W_b^{1.22}$	Osterkamp, Hedman 1982	D – 206 E – 373
$Q_5 = 5.8 \, W_b^{1.10}$	Osterkamp, Hedman 1982	D – 397 E – 373
$Q_b = 4.0 \, A_b^{1.21} S^{0.28}$	Williams 1978	D – 584 E – 422
$Q_b = 1/nAR \sqrt{RS}$	Chezy, Manning	D – 71 E – 47.6
$Q_b = (L/36.0)^2$ where $L = 4.7 \, R^{0.98}$	Inglis 1949, L after Leopold, Wolman, R after Trafas 1975	217
$Q_b = (L/36.0)^2$ where $L = 4.7 \, R^{0.98}$	Inglis 1949, L after Leopold, Wolman, R after Trafas 1975	Vistula 1817 yr 1214

D and E – cross-section of paleomeander in Zabierzów Bocheński (see Fig. 9). Q_m – mean annual discharge, W_b – width of water surface at bankfull discharge, D_{max} – maximum depth in the profile, L_m – length of the meander wave, $Q_{1.5}$, Q_n – discharge n-year frequency, Q_b = bankfull discharge, $A_{1.58}$ – cross-section area at $A_{1.58}$ discharge, S – slope, n – roughness coefficient, R – hydraulic radius. In formulas Inglis as well as Leopold and Wolam L and R are presented in feet.

ship between the mean annual discharge and the wave length of a meander, was erroneously used. The formula describing the relationship between the bankfull discharge and the wave length of the meander should have been used instead. This formula has also been used to calculate the bankfull discharge of the Vistula of the beginning of the 19th century, when the Vistula parameters were close to the natural ones. In the other cases, when the wave length had been unknown, the relationship between the radius of the curvature of a meander and the wave length developed by L. B. Leopold *et al.* (1964) was used (Alexandrowicz *et. al.* 1981).

EVOLUTION OF THE SYSTEM IN ZABIERZÓW

The oldest series I is fragmentarily preserved in the N–NW oriented trough which is cut down in the top of the Miocene clays. These are remnants of the channel deposits and the paleochannel fills of the Younger Dryas. It is still a unsolved problem whether these are remnants of braided or meandering channels. A significant depth of the occurrence of these deposits, as well as a large erosional power allowing for scouring of the Miocene clays, points to a concentrated channel which could support T. Kalicki's (1991b) thesis that in the Younger Dryas the Vistula downstream of Cracow was of anastomosic nature with braided (Kalicki 1992b; Starkel *et. al.* 1991) and meandering reaches (Kalicki, Zernickaya 1995). Wide paleomeanders of this period are preserved in the relief south of the Zabierzów system.

The series II is formed by the channel deposits and remnants of the fill of the deeply incised channel of the beginning of the Preboreal. The position of the sediments and their spatial distribution indicate that the paleomeander fill is present here. The top part of this paleomeander was cut off by the preserved in morphology Zabierzów system migrating in the upper level. One cannont exclude that these are the remnants of the fill of the paleochannel which is the continuation of the large meander slightly visible in the morphology SE of Zabierzów. The fill of the latter meander has been dated in the site at the Drwinka stream as of the similar age (Gębica, Starkel 1987). The above confirms the thesis on a renewed concentration of the Vistula channel after the Younger Dryas, when the Vistula was a braided river and flew in the lowering of the Drwień river in Cracow region and in the lowering of the Drwinka stream in Grobla Forest (Kalicki 1991b; Starkel *et. al.* 1991).

In the Boreal the Vistula flew in the vicinity of the Drwinka lowering, which indicates filling up of the paleochannel dated at 8650 ± 140 BP (Starkel *et. al.* 1991). During the intensified activity at the beginning of the Atlantic (8010–7980 BP) clayey madas covered the peat in the paleomeander at Drwinka site and in the depression near Grobla Forest (Gębica, Starkel 1987; Starkel *et. al.* 1991).

The aggradation and the lateral migration of the channels took place in the Atlantic. The intensification is observed during the phase dated at 6500–6000 BP, which is reflected in the studied paleomeander. The organic madas overlying the series III became overtopped (6240 BP) by the levee deposits. The stage of a slow migration of

the meander and the formation of the series IV started. At the decline of the Atlantic, in the region of Grobla Forest, after the phase of the meander cutting off (5460–5420 BP) the avulsion to the north of the Vistula channel took place (before 5010 BP). It is very likely that singular meanders (e.g. Wola Zabierzowska, Zaborcze) were also cut off in the Zabierzów reach in this period and the meander in Zabierzów developed slowly.

Inferring from the dating of the base of the paleomeander fill, the Zabierzów system, after avulsion of the Vistula in the region of Grobla Forest, still remained a part of the active Vistula channel. This can be confirmed by the SW–NE orientation of the fragment of the system. This fragment undercuts at a certain angle the system preserved in Grobla Forest.

The next acceleration of the lateral migration, recorded in the generation of "black oaks" (Gębica, Krąpiec 1993) took place ca 4500 BP. It resulted in narrowing and cutting off of some meander necks, and then in the avulsion of the Vistula to the north in the Zabierzów section ca 4400 BP, and in abandoning of the system. The paleo-meanders of the discussed period are also known of the Cracow Gate (Rutkowski 1987; Kalicki 1991a, b).

After the system had been abandoned, the connection with the Vistula existed periodically. The evidence of the latter are sandy-gravel deposits and slightly loamy sands filling the abandoned channel and causing the shallowing in the straight reaches and the formation of point bars at the bends (member Va). After the phase of the intensified activity, floods were relatively rare the which is confirmed by the slow accretion of sediments and by the composition of plants in the abandoned channel.

In the period of 3590–3260 BP, next phase of floods initially led to significant shallowing of the Zabierzów system due to the building of a thick sandy-gravel member (member Vb) and then to the total separation of the system from the Vistula, probably due to blocking of the inlet section of the system in the region of Wola Batorska. As the final outcome, organic deposits (member Vc) started to accumulate in the paleomeanders. Changes in vegetation provide evidence of larger moisture in this period. For the first time this phase has been described for the Vistula in the Cracow reach (Kalicki 1991b; Kalicki, Krąpiec 1991b).

At the decline of the Subboreal, ca 2750 BP, the next flood, being rather an event than a phase, inserted a lamina of loamy sands into organic deposits (member Vd). A generation of "black oaks" found in alluvia (Kalicki, Krąpiec – chapter 4.2 in this volume) is the evidence of a certain activation of the lateral migration of the channels in this period.

In the next stage the abandoned channel is gradually filled up with peat and separate, small backswamps disappear (member Ve). The periodical excessive drying of the peat-land and the destruction of pollen could have been related to the progressing downcutting of the Vistula channel and to the lowering of the groundwater table (Kalicki 1991b).

At the beginning of the Roman period (2340 BP) the organic deposits became overtopped with clayey madas (member Vf). In about the same time (2370 BP) changes in the sedimentation type and the beginning of the next phase of the tree trunk accumulation in the alluvia of the Cracow reach are observed (Kalicki 1991a, b; Kalicki, Krąpiec 1991b).

CONCLUSIONS

The detailed study of the Vistula paleomeander in Zabierzów Bocheński leads to several conclusions of a methodological, stratigraphic and paleogeographic nature.

Based on more than 1300 grain size analyses from 73 boring profiles one can distinguish and characterize the main facies of the deposits, starting from channel deposits (lag and point bar deposits), through overbank ones (levee and madas) to lithologically differentiated fills of the abandoned channel. However, the assigning of the deposits to the series of various age is not a simple task not only due to limited possibilities of dating the channel deposits but also due to lag deposits occurring in several layers within one series. The latter is associated with the variable hydrological regime of the Vistula differing from the lowland river regime, for example of the Prosna river (Rotnicki 1983). Basing on the initial analysis of the material (the complete study on grain size composition will be the subject of a separate work) one can conclude that in the case of the channel deposits there are no distinct differences between the series of various age which has earlier been stated by E. Niedziałkowska (1991). On the other hand, the overbank deposits and fills of the abandoned channel better register the differences in a transportation of a suspended load depending on supply, type and magnitude of a flood as well as on a distance from a channel. The above confirms the former conclusions (Kalicki 1991b; Kalicki, Zernickaya 1995).

The sediments facies are also difficult to distinguish, especially within the abandoned channel fill, because the grain size composition of the channel deposits and of the deposits inserted in the initial stage of the channel filling is very much alike, thus a distinction between these deposits is very difficult and very subjective. However, the distinction between the facies is very important when reconstructing paleodischarges. As it results from the analysis of the cross-sections, the reconstructed parameters of the paleochannel may significantly differ one from another and thus one does not know which moment of evolution is reconstructed; whether it is a period when the channel has dynamically been modelled and has developed the observed curvature, or whether it is a period of a diminishing activity and forming bars which cause shallowing and narrowing of the channel. The reconstructions of the parameters of the paleochannels and paleodischarges have indicated that the bankfull cross-sections may differ by 25–35% depending on the adopted width and depth, and within a given cross-section this difference may reach up to 15%. Therefore the difference in the reconstructed paleodischarges is of the order of 33–48%.

The attempts to reconstruct discharges, which are described by numerical values, are complex tasks and the results obtained in this way are very uncertain and virtually impossible to interpret. They can be of a supportive value when describing temporal sequences of changes in the channel and in the transformation of the valley. They may also be used as indicators when describing channels of various age and channel parameters. This is the case of Zabierzów Bocheński, where the only unquestionable value of the attempted reconstruction of the discharges is the statement that the bankfull discharges had to have been much smaller (by 3, 4-times?) than at the present-day. One has to be satisfied even with the development of the methods of the

reconstruction of the paleodischarges, the latter cannot be used for the climatic and budget reconstruction as it is suggested by K. Rotnicki (1991).

The obtained values of the paleodischarge, even the largest ones, are relatively small (40–70% of the present-day mean annual discharge of the Vistula in that reach). It is not certain if the Vistula was not the anastomosing river and if the second channel did not function simultaneously. Moreover, the above can suggest that the discharges, when the drainage basin was completely overgrown with vegetation – i.e. under conditions of a large storage capacity and evapotranspiration, were fairly uniform and that the mean discharges did not significantly differ from the bankfull ones. The Vistula channel due to its low gradient was filled up during each rise in discharge and during the meltwater and summer floods the river inundated over the floodplain. The floods could have been favoured by very twisting channel which was easily subjected to freezing or damming, for example by tree trunks. The inundating river used old depressions which could lead to avulsion. The uniform discharges, the forestation of the valley floors and the strengthening of the channel banks caused a slow lateral migration of the meanders. In the case of the studied paleomeander this migration can be estimated for ca 150 m per 1800 years. At present there are no analogues to the channels of this type, because the floodplains have been deforested almost completely and the rivers have been deepened artificially due to exploitation of gravels, as well as they have been embanked, channelized and fitted to high and frequent amplitudes of discharges after the deforestation of drainage basins.

The series of borings reaching down the Miocene clays allowed to learn a very complicated structure of the floodplain being similar to that in the Cracow reach (Kalicki 1991b). Basing on the dating, it was possible to find out in one site almost all the phases of the intensified Vistula activity, which had been distinguished earlier in the Cracow reach (Kalicki 1991b). The younger deposits associated with the system of meanders visible on the surface (series III, IV, V) are lain on the deposits of at least two older alluvial series with the remnants of the paleochannel deposits (I, II) of the Younger Dryas and Preboreal. The above is the evidence of the lateral migration and confirms the tendency to the aggradation from the Younger Dryas to the beginning of the Subboreal, which has been described for the Cracow reach (Kalicki 1991b). The younger alluvia building the floodplain exhibit dichotomy (III, IV). The younger series IV is deeper reworked and its deposits are better sorted. This series was formed during the development of a very twisting, mature channel preserved at the surface. The avulsion of the channel was preceded by cutting off the necks of some meanders. The dated moment of the channel avulsion (4410±130 BP) correlates well with the records of floods and the abandonment of the paleochannels in the neighbouring sections of the Vistula valley (Rutkowski 1987; Kalicki 1991a), as well as in the other valleys of the Southern Poland (Florek 1982; Pożaryski, Kalicki 1995) and with partial flooding of peatland and with moister climate registered in a larger expansion of spurce in the mountains (Ralska-Jasiewiczowa ed. 1989; Starkel 1995).

The deposits filling the abandoned channel (series V) register periods and episodes of floods. The older of the periods was between 3590 and 3260 BP, when the abandoned channel had been still associated with the Vistula quite strongly. This period is

also marked in the other valleys of the southern Poland (Kalicki 1991b) and was related to the eruption of Santorini (Kalicki, Krąpiec 1991b). The traces of the younger period, ca 2700 BP, manifest in changes in sedimentation type or in a generation of the "black oaks" in the other sections of the Vistula valley (Klimek 1988; Kalicki, Krąpiec – chapter 4.2 in this volume). At ca 2300 BP the accretion of the organic deposist in the abandoned channel was interrupted by accumulation of the clayey madas. This subsequent phase of the moister climate has already been registered in the alluvia and in the lakes (Ralska-Jasiewiczowa, Starkel 1988; Kalicki 1991b; Krąpiec 1992; Kalicki – chapter 3 in this volume).

The studies in the region of Zabierzów Bocheński have confirmed regularities of the development and large complexity of the floodplains: inserting of the subsequent series due to the lateral migration, and the avulsion of the channel as well as the tendency to the aggradation known of the other sections of the Vistula valley and its tributaries (Starkel 1977, 1990; Kalicki 1991b, and others).

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ERRATA

Page	Verse	Is	Should be
25	20	"canel-river"	"canal-river"
30	31	ofter	often
34	5	Boreal	Subboreal
35	33	$Q_b = \left(\dfrac{(4 \cdot 7R^{0.98})}{36}\right)^2$	$Q_b = \left(\dfrac{4 \cdot 7R^{0.98}}{36}\right)^2$
40	20	94	50
40	40	at the base,	at the base to 4.35ø at the top,
108	25	small	less intensive
109	14	Backer	Baker
130	4	3 – Subatlantic	3 – Late Subboreal and Subatlantic
146	23	13–14.	13–4.

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