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A R T Y K U Ł Y

(ARTICLES)

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FREQUENCY OF FLOODS DURING THE HOLOCENE IN THE UPPER VISTULA BASIN

During the last two decades, in various climatic zones there were carried out studies on the size and frequency of floods in the past as well as on their absolute age (Baker *et al.* 1988). There were elaborated special methods of the recognition of extreme floods in the rocky canyons by examining slack-water deposits (Baker 1983). There exists also the records of more frequent floods, especially in the levee zone mainly from the initial phase of the upbuilding of abandoned channel bars. During longer time units, in the sediment or in the forms there may be revealed a tendency either towards an increase or a decline in the frequency of floods transforming the channel and overflooding the floodplain. In the case of larger rivers there occur floods with a recurrence interval of 10–30 years (Soja and Mrozek, in: Starkel 1990), in the case of a braided mountain stream with the frequency of 5–10 years (Baumgart-Kotarba 1983).

SEDIMENTOLOGICAL METHODS

Floods are registered in various facies of alluvium (Gregory and Maizels 1991). In the channel facies, besides the log horizons, there may be found coarse layers deposited during the particular floods. In the arid zone, as well as in the case of catastrophic floods, they may even build forms preserved till now (Baker 1983, Costa 1978). In the Carpathian river channels the deposition of side or central gravel bars and filling of channel branches by the gravels follows during every 5–10 year flood well visible just after flood (Froehlich *et al.* 1972, Baumgart-Kotarba

1989). The best sequence of floods may be reconstructed in the sections situated in the river channel either in the slack-water deposits (Baker 1983) or in the levee zone (Knox 1983, Fig. 1), where more frequent, even annual floods are registered. Such a single flood layer consists of 3 members described by Klimek (1974): the basal fine, loam, coarser laminated sand or silt and on the meadow soil, the middle coarser one with a distinct bedding and the top one again fine, deposited during the dropping of the flood wave. Such sequences of 1–2 meters have registered floods during no more than 100–200 years. The register rapidly stops in case of lateral migration of the channel or starts to be discontinued in case of so high a building up, that it cannot be flooded very frequently. Similar remains of bigger floods were registered as sandy layers in the oxbow lake sequences during their abandance (Gębica and Starkel 1987).

In more distant parts of the floodplain as well as in the alluvial fans the registration of floods is not complete, only catastrophic floods may be represented by separate layers (Niedziałkowska *et al.* 1977). The change in the flood frequency is reflected in the change of granulometry. The change to coarser sediments or superposition of organic deposits by alluvial loams is explained by the rise in flood frequency (Starkel 1983, Ralska-Jasiewiczowa and Starkel 1988).

The thicker coarser deposits and sequence of layers of alternating granulometry indicate that it cannot be event, but several floods. The lack of pedogenesis again indicates, that deposition took place at every 10–20 years.

On the contrary the flood phase ends with a rapid change to finer floodplain deposits and this is reflected in the formation of a fossil soil horizon or even peat layer. As supplementary indicators of frequent flood periods there serve the horizons of black oaks correlated by means of the dendrochronological method, found at the top of bar deposits or in paleochannel fills (Becker 1982). In small streams with the precipitation of the calcareous tuffa there are hiatus and lag layers explained as the breaks caused by great or more frequent (?) floods (Szulc 1986).

GEOMORPHOLOGICAL METHODS

In the temperate zone, among the best indicators of great single floods or a sequence of floods there are the cut-off paleochannels, channel avulsions and erosional benches formed by lateral erosion and preserved in a fossil form (Starkel 1983, 1990). With these changes there are combined new alluvial fills, separated from the older ones by erosional scarps. The decline in flood frequency may lead to inbedding of a new, more sinuous channel in the older, larger one (Szumański 1986). In the case of a braided channel the whole system of bars, pools and floodplain islands undergoes changes after every greater flood-therefore the surveying should be after every event

(Baumgart-Kotarba 1989). The repeated nivelation showed rapid turns in the vertical position of the channel bottom after great floods (Soja 1977, Froehlich 1982, Probst 1989). Sometimes it is connected with large bars moving downstream during floods.

DATING METHODS

The most exact datings of the floods exceeding the bankfull discharge during the last 200 years come from the near-channel deposits with layers recording the particular floods. These where deposited on the stuctures of channel embankments or in the places of the former position of the river channel, registered on old maps (Klimek 1974, Starkel in: Alexandrowicz *et al.* 1981). The overbank deposits may also be supperimposed on the layers well dated archeologically (Radwański 1972).

In the case of floodplain deposits with organic intercalations, the radiocarbon datings help to recognize the beginning or the end of the clustering of floods or of single flood with the accuracy up to 100 years. But usually they do not inform about the time intervals between separate flood events.

The clustering of black oaks during one or several decades suggest a much higher frequency of floods. The dendrochronological method is the most exact one, it helps to reconstruct the time of the death and first deposition of the black oak (Becker 1982). However we cannot tell anything about the size of the flood. But due to the preservation of cambium we are able to correlate some trees burried during 1–2 years which indicates the catastrophic flood. On the contrary, the finding of many trees deposited in a sequence of 100–200 years (and absent during previous centuries) indicates the series of floods, which caused an accelerated shift of the channel. Subsequently, a similar time of the tree growth on the floodplain shows the absence of catastrophic floods during that period. In such case a similar beginning of the tree growth of a whole group of trees indicates a preceeding phase of the floodplain transformation by floods (see: Becker 1982, Krąpiec 1992). The recognition of the tree scars also helps in the reconstruction of ice-jam floods, their higher frequency in an exact period of time may be interpreted as the higher frequency of snow-melt floods (Kalicki and Krąpiec 1991b).

FLOOD PHASES IN THE VISTULA CATCHMENT AREA

The geomorphological and geological data together with the radiocarbon datings collected in the 70-th and 80-th, especially in the IGCP–158 in the upper Vistula river basin, helped to evaluate our knowledge and ac-

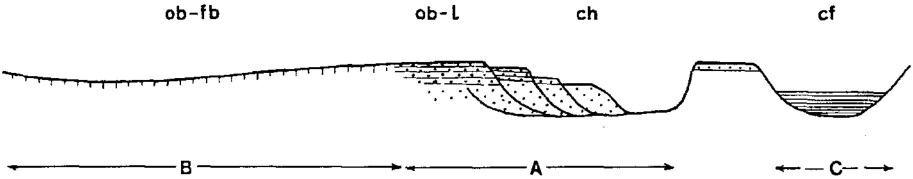

Fig. 1. Floods registered in various sediment facies: ch — channel facies, ob-l — levee, ob-fb — overbank (flood backswamps), cf — paleochannel fills, A — zone of registration of frequent flood, B — zone of registration of long-term flood phases, C — abandoned channels

Ryc. 1. Powodzie zarejestrowane w różnych facjach osadów: ch — korytowych, ob-l — przykorytowych wałów brzegowych, ob-fb — obniżeń równi zalewowych, cf — wypełnień paleokoryt, A — strefa rejestracji częstych wezbrań, B — strefa długotrwałych faz wezbraniowych, C — opuszczone koryta

complish the concept on the sequence of the cuts and fills connected with the alternate phases of higher and lower frequency of floods (Starkel 1983, 1984, 1990, Ralska-Jasiewiczowa and Starkel 1988). Many new data were provided by detail investigations in the Vistula valley downstream of Cracow (Kalicki 1991, Kalicki and Krąpiec 1991a, b, Krąpiec 1992, Starkel *et al.* 1991, Fig. 2).

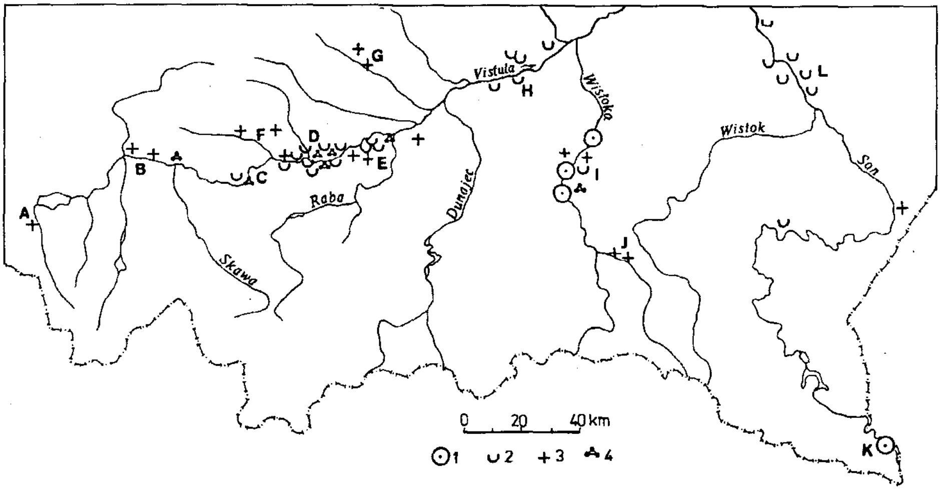

Fig. 2. Main localities in the Upper Vistula basin where great floods or phases with high flood frequency were registered: 1 — sequences of particular floods registered in the deposits, 2 — abandoned channels, 3 — rapid change in the granulometry in the profile, 4 — clusterings of black oaks dated by dendrochronological method. Letters indicate regions presented on Fig. 3

Ryc. 2. Ważniejsze stanowiska rejestrujące duże powodzie lub okresy o większej częstotliwości powodzi: 1 — serie pojedynczych wezbrań zarejestrowanych w osadach, 2 — opuszczone paleokoryta, 3 — nagłe zmiany składu mechanicznego osadu, 4 — fazy powału drzew zarejestrowanych metodą dendrochronologiczną. Literowe oznaczenia regionów jak na Ryc. 3.

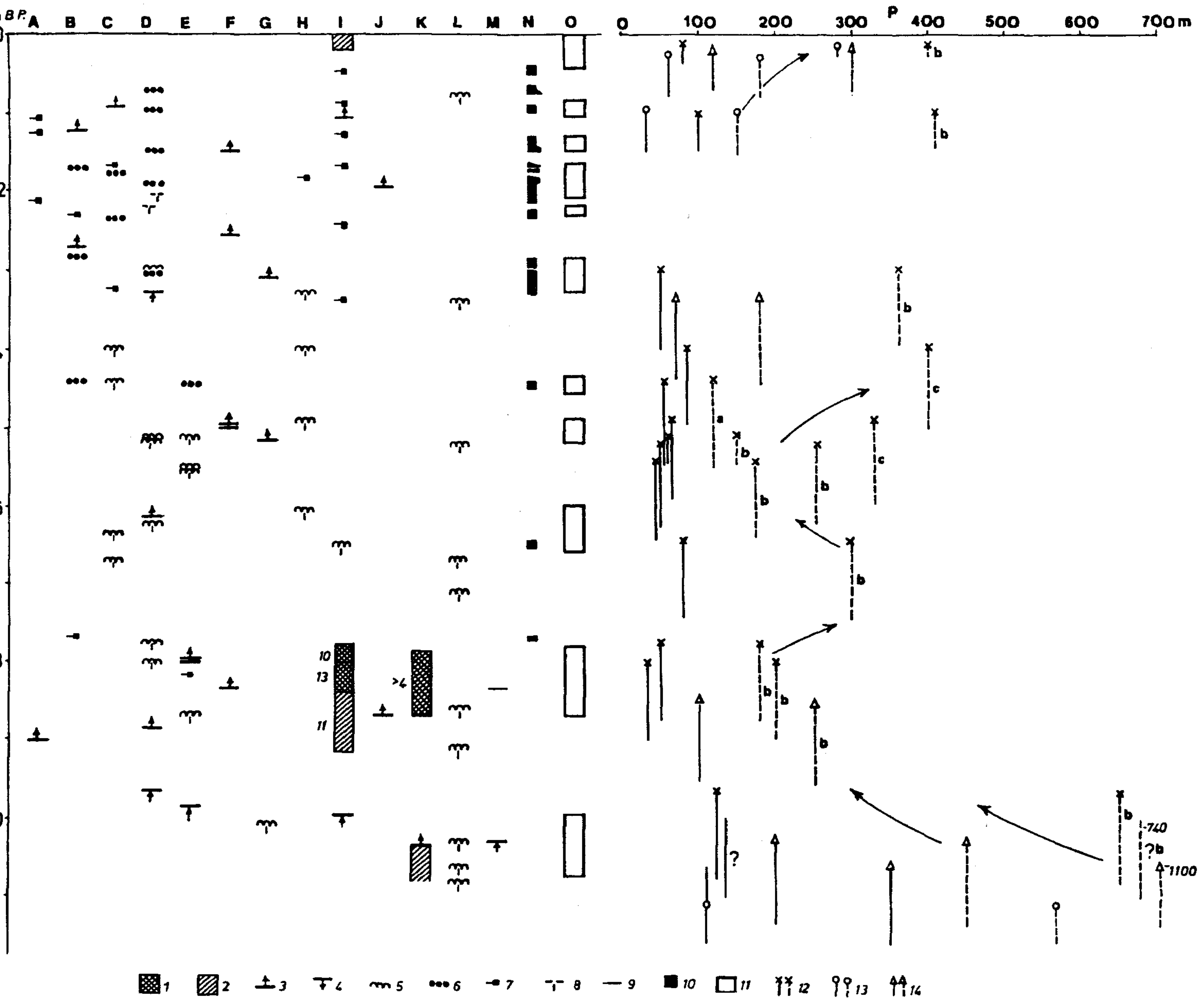

Fig. 3. Various records on the flood frequency and flood phases during the Holocene in the upper Vistula basin. Columns: A — Upper Vistula valley near Drogomyśl (Niedziałkowska *et al.* 1985), B — Upper Vistula near Oświęcim and Zator (Klimek 1987, 1988, Krąpiec 1992), C — Vistula in the Cracow Gate (Rutkowski 1987, Krąpiec 1992), D — Vistula downstream of Cracow (Kalicki 1991, Krąpiec 1992), E — Vistula near Grobla Forest (Gębica and Starkel 1987, Starkel *et al.* 1991), F — Rudawa and Prądnik river valleys (Alexandrowicz 1988, Rutkowski 1991), G —Nidzica valley (Śnieszko 1985), H — Vistula near Szczucin (Sokołowski 1987), I — Wisłoka valley near Dębica (Niedziałkowska *et al.* 1977, Klimek 1974, Starkel (ed.) 1981, Krąpiec 1992), J — Jasiołka valley (Wójcik 1987), K — Upper San valley (Ralska-Jasiewiczowa 1989), L — Lower San valley (Szumański 1986), M — other separate localities, N — clusterings of fossil oaks (after Krąpiec 1992), O — main phases of the higher flood frequency, P — width and meander radius of paleochannels (the line of about 1 ka length below the radiocarbon date indicate the probable duration of formation of river channel with preserved parameters). Signs: 1 — periods with well registered frequent floods (with number of identified particular floods), 2 — other periods with registered floods, 3 — beginning of flood phase reflected in change of lithology, 4 — end of the flood phase, 5 — time of the channel avulsion, 6 — clustering of black oaks, 7 — single oak trunks probably dating extensive floods, 8 — phases of afforestation of the flood plain by a new oak generation, 9 — other registered particular floods, 10 — main phases of deposition of the black oaks (column N — after Krąpiec 1992), 11 — phases of high flood frequency (summary in column D), 12–14 — width and meander radius of paleochannels (in column P): 12 — Vistula valley (a — upstream of Cracow, b — between Cracow and junction with with the Dunajec river, c — downstream of Dunajec outlet), 13 — Wisłoka valley, 14 — San valley

Ryc. 3. Informacje o częstotliwości powodzi i datowanych fazach powodziowych w holocenie w dorzeczu górnej Wisły. Kolumny: A — górna Wisła koło Drogomyśla (wg Niedziałkowskiej i in. 1985), B — górna Wisła koło Oświęcimia i Zatora (Klimek 1987, 1988, Krąpiec 1992), C — Wisła w Bramie Krakowskiej (Rutkowski 1987, Krąpiec 1992), D — Wisła poniżej Krakowa (Kalicki 1991, Krąpiec 1992), E — Wisła koło Grobli (Gębica, Starkel 1987, Starkel i in. 1991), F — doliny Rudawy i Prądnika (Alexandrowicz 1988, Rutkowski 1991), G — dolina Nidzicy (Śnieszko 1985), H — Wisła koło Szczucina (Sokołowski 1987), I — dolina Wisłoki koło Dębicy (Niedziałkowska i in. 1977, Klimek 1974, Starkel (red.) 1981, Krąpiec 1992), J — dolina Jasiołki (Wójcik 1987), K — dolina górnego Sanu (Ralska-Jasiewiczowa 1989), L — dolina dolnego Sanu (Szumański 1986), M — inne pojedyncze stanowiska, N — główne fazy powału dębów (wg Krąpca 1992), O — główne fazy o większej częstotliwości powodzi, P — parametry opuszczonych paleokoryt: szerokości i promienie krzywizny — poniżej poziomu datowanego odcinek rzędu 1000 lat oznacza prawdopodobny czas tworzenia koryta o zachowanych parametrach. Znaki: 1 — okresy zarejestrowanych bardzo częstych wezbrań (cyfra podaje ilość zidentyfikowanych wezbrań), 2 — inne okresy zarejestrowanych wezbrań, 3 — początek okresu wezbrań (zmiana litologii osadu), 4 — koniec okresu wezbrań, 5 — daty opuszczenia (przerzutu) koryta, 6 — okres powału pni, 7 — pojedyncze pnie datujące wezbrania, 8 — fazy wkraczania drzew na równinę zalewową, 9 — pojedyncze wezbrania, 10 — fazy powału drzew, 11 — okresy dużej częstotliwości wezbrań, 12–14 — parametry paleokoryt: 12 — Wisły (a — powyżej Krakowa, b — między Krakowem a ujściem Dunajca, c — poniżej ujścia Dunajca), 13 — Wisłoki, 14 — Sanu

However the existing data are not so detailed as the records collected in the rocky canyons of the arid zone with preserved slack-water deposits (Baker 1983). But in several localities the sequence of floods was reconstructed (Niedziałkowska et al. 1977, Starkel 1984, Klimek 1974). More frequently, the beginning or the end of the flood phases were correlated with the recognition of the facial changes in the vertical section by avulsions and changes in the channel parameters and by the horizons of black oaks.

The enclosed Fig. 3 presents the state of the information on the time and frequency of floods during the last 11 ka BP.

The filling of large paleomeanders during the Younger Dryas and early Preboreal as well as the simultaneous change from overbank sandy deposits to organic muds indicate a decline in the size and frequency of floods between 10300 and 9900 a BP (Starkel 1991).

The next reactivation of floods is noted since 8700–8400 a BP. In the particular case of Podgrodzie alluvial fan in the Wisłoka valley I counted in one profile 23 flood layers during ca 600 years, separated by some breaks with the formation of weakly developed swampy soils (Fig. 4). In Tarnawa on the upper river San in the sandy-silty member separating the sequence of the raised bog we distinguished 4–5 floods (Ralska-Jasiewiczowa and Starkel 1975). Of a similar age, ca 8360 ± 75 a BP, is the minerogenic lense in the peat deposits in the middle course of river Vistula (Schild 1982). This phase is also characterized by its changes to coarser deposits, channel avulsions and first black oaks. Kalicki (1991) proved that the width and radius of curvature of Atlantic paleochannels are greater than those abandoned about 8000 a BP.

The next phase of channel avulsions followed between 6500 and 6000 a BP. But more important floods started probably from 5200–5000 a BP, registered in frequent avulsions. Before the avulsion in the Grobla forest took place, 300–400 years earlier there started the cutting of single meanders and straightening of channel (Gębica and Starkel 1987, Starkel *et al.* 1991). The new generation of channels has again larger parameters.

Kalicki (1991) distinguished a separate phase of higher flood frequency ca 4500–4400 a BP. Of similar age are the abandoned channels and clusterings of black oaks known from other localities along the Vistula (Krąpiec 1991), the foreland of the Sudeten Mts. (Florek 1982), and Alps (Brunnacker *et al.* 1976). The next phase dated 3300–2850 a BP is reflected in further abandoned channels, block oak horizons (Kalicki, Krąpiec 1991a, b) and the fossilisation of alluvial soils (Klimek 1987).

The climatic interpretation of the records from the last 2400 years begins to be complicated due to human interference and especially to the forest clearance on the flood plains registered in I–II century A.D. (Kalicki, Starkel 1987). The layers with the tree trunks cut by man may be interpreted as the increase of flood frequency. The overloading of river is seen in upbuilding of the floodplain as well as of the channel bed (Klimek, Starkel 1974). But

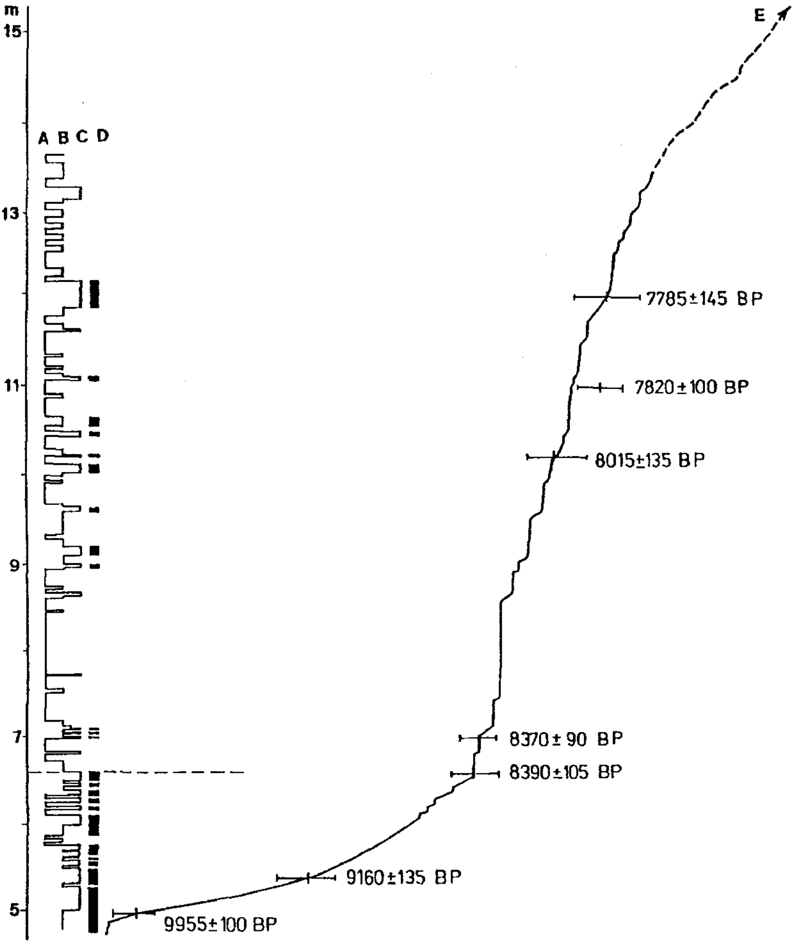

Fig. 4. Sequence of the alluvial fan in Podgrodzie in the Wisłoka valley with number of well defined particular floods (*after* Niedziałkowska *et al.* 1977, Starkel 1984): A — sandy layers, B — sandy-silty layers, C — silty clays, D — clays rich in organic detritus, E — cumulative curve of deposition in time

Ryc. 4. Stanowisko osadów stożka napływowego w Podgrodziu rejestrującego serię wezbrań (wg Niedziałowskiej i in. 1977, Starkel 1984): A — poziomy piaszczyste, B — poziomy pylaste, C — poziomy pylasto-ilaste, D — poziomy silnie organiczne, E — krzywa kumulacyjna sedymentacji w czasie

at the same time this indicates a higher flood frequency in the deforested areas (Soja 1977, Probst 1989). Taking into consideration all facial changes, the shift of channels, tendencies to aggradation or erosion and black oaks — in the Vistula valley and its tributaries we may distinguish flood phases during the late Roman period (2100–1700 a BP), early Mediaeval period (from 1500 a BP) and the well documented floods of the 11-th century A.D. (see: Starkel 1977, Rutkowski and Starkel 1989, Kalicki 1991, Krąpiec 1992). During the last one, aggradation caused the deposition of coarse gravels over the fine overbank deposits (Awsiuk *et al.* 1980). In the Wisłoka valley in Brzeźnica there were also found laminated flood deposits on the slope of early Holocene terrace (Starkel (ed.) 1981).

The 16-th to 18-th century channel scouring and the tendency to braiding caused by many great floods is documented by old maps (Szumański 1977) and historical sources (Mikulski 1963, Rojecki 1965). The over bank deposits since 18-th century registered frequent floods (Klimek 1974), similar to the present-day records (Soja and Mrozek in: Starkel 1990).

FINAL REMARKS

The flood frequency above described is characteristic in the upper Vistula basin; it is based on very dispersed records relating to the particular floods. Long-term variations in flood frequency are based on facial changes, the size and shifting of paleochannels, as well as on the clustering of black oaks. The much poorer records in the 70-th and early 80-th offered the background to present a hypothesis on the alteration of the phases of the changing frequency of floods during the Holocene (Starkel 1983), controlling the sequence of cuts and fills in the upper Vistula basin. This concept was proved later by new localities in the Vistula valley (see: Starkel 1990, Kalicki 1991, Krąpiec 1992 and many others) as well as in many other valleys of Central Europe (Becker 1982, Schirmer 1983, Schreiber 1985 etc.).

The phases defined above seem to correlate very well with the advances of glaciers and mass movements in the European mountains (Patzelt 1977, Starkel 1985), with the precipitation and dissection of the calcareous tuffa in the limestone uplands (Pazdur *et al.* 1988), as well as with the changes in the vegetation cover and lake levels (Ralska-Jasiewiczowa and Starkel 1988, Ralska-Jasiewiczowa 1989). It is not easy to separate the climatic factor from human intervention, both causing the rise in flood frequency, and finally transforming the fluvial system.

In the conditions of a vertically stable river channel the registration of flood frequency may not be full. In the case of slack-water deposits and levees, every following flood, to be registered in vertical sequence, should be greater (than the previous one) to cover the upbuilding plain, or it may be reflected in much finer deposits. Such is the mechanism of the formation of rhytmic members between the bar deposits below and the overbank loams above (Klimek 1974, Kalicki and Starkel 1987). Moreover the deposits of the alluvial fans do not register the full sequence of floods (cf. Fig. 4), because the flood waters usually cover only selected zones of the fan surface, which is indicated by the existence of fossil soils (Niedziałkowska *et al.* 1977). The avulsions of the river channel at longer reaches cause an end of the continuous registration of floods in the paleochannels — only the extreme ones may be reflected.

To avoid errors it seems to be important in the studies of the particular as well as of flood series in the valley floors of the temperate zone to watch synchronous changes in the channel zone as well as in the overbank deposits of the floodplain.

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STRESZCZENIE

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CZĘSTOTLIWOŚĆ POWODZI W HOLOCENIE W DORZECZU GÓRNEJ WISŁY

Badanie osadów, form i ich datowanie pozwala rzadziej na wydzielenie osadów i form z poszczególnych powodzi, a częściej na stwierdzenie długofalowych tendencji w zmianach częstotliwości wezbrań. Najlepiej sekwencję dużych powodzi można prześledzić w strefie przykorytowej tzw. „slack-water deposits" lub wałów brzegowych. Zapis długofalowych zmian wyrazistszy jest w zmianie facji na równinie zalewowej i tworzeniu nowych rozcięć i włożeń stowarzyszonych z przerzutami i zmianami parametrów koryt. Metoda radiowęgla pozwala określić czas zdarzeń z dokładnością do stulecia. Pnie czarnych dębów skorelowane z metodą dendrologiczną mogą być odnoszone nawet do poszczególnych zdarzeń powodziowych.

W dorzeczu górnej Wisły szczegółowszy zapis z identyfikacją poszczególnych wezbrań istnieje jedynie dla 2 ostatnich stuleci oraz dla przełomu okresów borealnego i atlantyckiego. Zmiany facji osadów, w składzie mechanicznym, tempie sedymentacji, wielkości i przerzutach koryt oraz częstotliwości depozycji czarnych dębów pozwalają zidentyfikować okresy o większej częstotliwości powodzi. Nowsze (od 1988 roku) zespołowe badania szczegółowe w dolinie Wisły poniżej Krakowa i dendrologiczne uszczegółowiły obraz rytmicznych zmian hydrologicznych w ciągu holocenu. Większa częstotliwość wezbrań została stwierdzona u schyłku młodszego dryasu, 8700–7700, 6600–6000, 5200–4900, 4500–4350, 3300–2850, 2350–1650 lat BP, V–VI w. A.D., X–XI w. i od XVI wieku. Fazy te korelują ze zmianami poza dnami dolin. Brak dotąd zapisu w osadach pewnych sekwencji powodzi dla dłuższych okresów. Niezmiernie złożone jest określenie roli czynnika klimatycznego i antropogenicznego w kształtowaniu częstotliwości wezbrań w ostatnich 2–3 tysiącach lat.