GEOCHRONOMETRIA Vol. 19, pp 53-58, 2000 – *Journal on Methods and Applications of Absolute Chronology*

CHRONOLOGY OF PHASES OF VARIOUS FLUVIAL ACTIVITY, OF EROSION AND DEPOSITION IN THE VISTULA CATCHMENT DURING LATE QUATERNARY

LESZEK STARKEL

Department of Geomorphology and Hydrology, Institute of Geography, Polish Academy of Sciences, Św. Jana 22, 31-1018 Cracow, Poland (e-mail: starkel@zg.pan.krakow.pl

Abstract. The former extensive studies in the Vistula catchment with dozens of profiles well dated by ^{14}C, helped to recognise great diversity of phases with dominance of erosion or aggradation changing in the longitudinal profile. Among them are very distinct synchronous phases with clusterings of extreme events during the Interpleni-glacial and during the Holocene.

1. FEATURES OF FLUVIAL ENVIRONMENT

The fluvial environment is characterised by a great diversity of processes and sediment both in the transversal section across the floodplain and channel as well as in the longitudinal profile. This diversity undergoes continuous changes in time (Starkel, 1990, 1994a). The hiatuses in sediment sequences, the parallel cuts and fills and various preciseness of dating of particular alluvial facies create different difficulties and traps in the interpretation of chronostratigraphy of fluvial forms and deposits.

During the longer time units in scale of stage the long-term variations of climate and environment decide on the transformation of the runoff and sediment load regime. On the last ones depend the general trends towards downcutting or aggradation in the valley floors (Schumm, 1965; Starkel, 1983). This glacial-interglacial cycle has been recognised long time ago, although the simple schemes on the glacial aggradation and interglacial erosion (Penck and Brückner, 1909) or on concentration of downcutting at the beginnings and ends of cold stages (Trevisan, 1949; Jahn, 1956) undergo reinterpretation.

The existence of parallel fills in the Holocene alluvial series (Starkel, 1960, 1983; Schirmer, 1983; Kalicki, 1991), later recognised also in sequences from the last cold stage (Starkel, 1995a) and discovery of units related to the single flood events (Niedziałkowska *et al.*, 1977; Baker, 1988) indicate together that both the fluvial erosion and deposition reflect the phases of different frequency of extreme events and these phases are realised mainly by the clusterings of extreme floods in short time intervals (Starkel, 1994b, 1999). The dating of these events and clusterings is complicated not only due to the errors in measuring, frequent redeposition of organic matter but also due to simultaneous vertical and lateral accretion of deposits. The vertical accretion, typical for lake or peatbog sequences take place over the extend floodplains as well as in paleochannels. The lateral shifting of river channels, avulsions and cut-offs of meander create erosional plains both horizontal and vertical, which separate members representing relatively short time intervals, deposited by lateral or vertical accretion. The dating of such units is very inaccurate because the neighbouring member (or fill) may differ only by years or by millenia.

2. STATE OF RESEARCH IN VISTULA BASIN

After the first recognition of stratigraphical diversity of alluvial members in the Vistula basin (Starkel, 1960; Klimek and Starkel, 1974; Ralska-Jasiewiczowa and Starkel, 1975) and Warta basin (Kozarski and Rotnicki, 1977) it followed the period of systematic collective investigation on the valley evolution during last 15000 years in the framework of the IGCP-158 project and national programme. Their products were the monograph of the fragment of the Wisłoka valley (Alexandrowicz *et al.*, 1981), six volumes on the evolution of Vistula valley (Starkel, *ed.*, 1982-1996) as well as of fragments of the Warta (Kozarski, 1991) and Prosna river valleys (Rotnicki, 1991). The evolution of fluvial systems during the late Vistulian and early Holocene was presented in a separate summary (Starkel and Gębica, 1995; Turkowska, 1995).

On the contrary the diversity of alluvial fills from the Vistulian stage and their various relation to climatic changes has been documented much later and supported by relatively low number of datings both ^{14}C and TL (Rotnicki 1987; Jersak *et al.*, 1992; Starkel, 1995a, b; Superson, 1996).

In the research project (KBN No. 6 P04E 02610) – "Geochronology of the upper Quaternary in Poland in the light of radiocarbon and luminescence dating" the previous results were summarised in separate chapter, supplemented by detail examination of about 15 sites in the upper Vistula river catchment and supported by several dozens of new radiocarbon dating (Starkel *et al.*, 1999). There were included several localities of interpleniglacial deposits (with various fills burried in the one terrace level), sites with dated transition from the interpleniglacial alluvia to the upper pleniglacial loess deposits, sequences in the valley floors of smaller creeks, in alluvial fans, in the overbank deposits of extensive floodplains and in the paleochannel fills. That chapter ended with general comments on the synchronism of phases of different fluvial activity in the upper Quaternary, on various trends in separate valley reaches and difficulties with interpretation of the ^{14}C and TL dating for the reconstruction of changes in the fluvial activity in the past.

This paper presents some regularities of evolution of fluvial systems, based on the data collected in the above mentioned projects.

3. THE SYNCHRONOUS PHASES OF HIGHER FREQUENCY OF EXTREME EVENTS AND HIGHER RATE OF CHANGES

The two cold phases of Vistulian with the icesheet advances over the Central-Eastern European Lowland and active criogenic and eolian processes in the wide periglacial belt (Behre, 1989; Kozarski, 1991), separated by a long interpleniglacial with distinct warming of Denekamp or Hengelo are well reflected also in the alluvial sequences. But the phases of the lower order are not sufficiently documented. The ^{18}O and CO_2 curves from the Greenland ice cores are showing especially between 40 and 30 ka BP, several rhytmic 1-2.5 ka long fluctuations of temperature reaching the amplitudes of the mean annual temperature up to 5°C (Dansgaard *et al.*, 1984).

Each of these phases starts with gradual cooling and ends with rapid warming similar to Younger Dryas-Preboreal transition. This rhytmicity per analogy should be reflected in varying frequency of extreme events. In the alluvial sequences the interpleniglacial periods is represented by the high deposition rate in the lowland Prosna valley (Rotnicki, 1987), in the valleys of the loessic Lublin Plateau (Harasimiuk, 1991; Superson, 1996) and in valleys of the Subcarpathian Basins, where 2-3 separate parallel fills and high deposition rate were recognised (Mamakowa and Starkel, 1974; Niedziałkowska and Szczepanek, 1993, 1994, Gębica *et al.*, 1999; Starkel, 1995a; **Fig. 1**). It seems that such distinct thermic fluctuations should cause distinct fluctuations in the frequency and efficiency of snow-melt floods, which were especially high during rapid warnings.

During the maximum cooling these oscillations are not so distinct. Generally synchronous (28-24 ka BP) transition from aggradation to downcutting in the Southern Poland seems to be connected with increasing continentality documented by a turn to the loess deposition (Maruszczak, 1986; Alexandrowicz, 1989; Łanczont, 1995; Gębica *et al.*, 1999).

The weak points of all datings from the interpleniglacial phases is a very disputable time separation of TL datings (cf. Superson, 1996) and extraction of ^{14}C datings mainly from fossil soils, which being exposed on the surface up to several millenia give generalised results. Very frequent are the inversions of dating, eg. mainly the bottom part of organic members, underlain by a coarse water-logged sediment, is rejuvenated (Starkel *et al.*, 1999). An additional complication in getting more precise chronostratigraphy is connected with the radiocarbon plateau (Goslar, 1996), which make impossible to put precise boundaries in the alluvial sequences. An especially well documented example give a transition Younger Dryas-Preboreal (**Fig. 2**).

Much better recognition of several phases with high frequency of floods is related to the Holocene fluvial forms and sediments (Starkel, 1983; Starkel *et al.*, 1996; Kalicki, 1991). These phases, each several centuries long, were distinguished through a very detail surveying

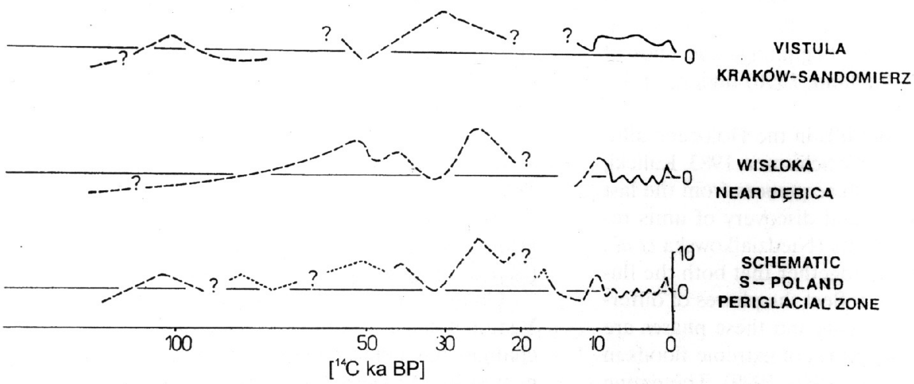

Fig. 1. *Channel level fluctuations in selected valley reaches and in the whole S-Poland during the Vistulian and Holocene (based on Starkel, 1994).*

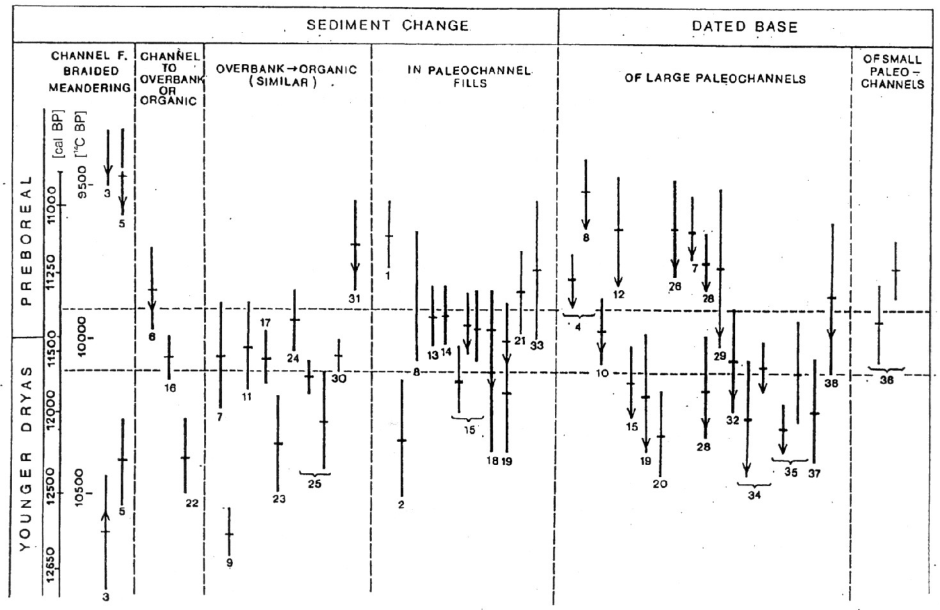

Fig. 2. Radiocarbon datings from the Younger Dryas-Preboreal transition indicating the changes in fluvial activity (sedimentation and abandance of river channels in Southern Poland. Beside the radiocarbon plateau is clearly visible the clusterings of response of rapid warming at the transition (10,100-9900 BP).

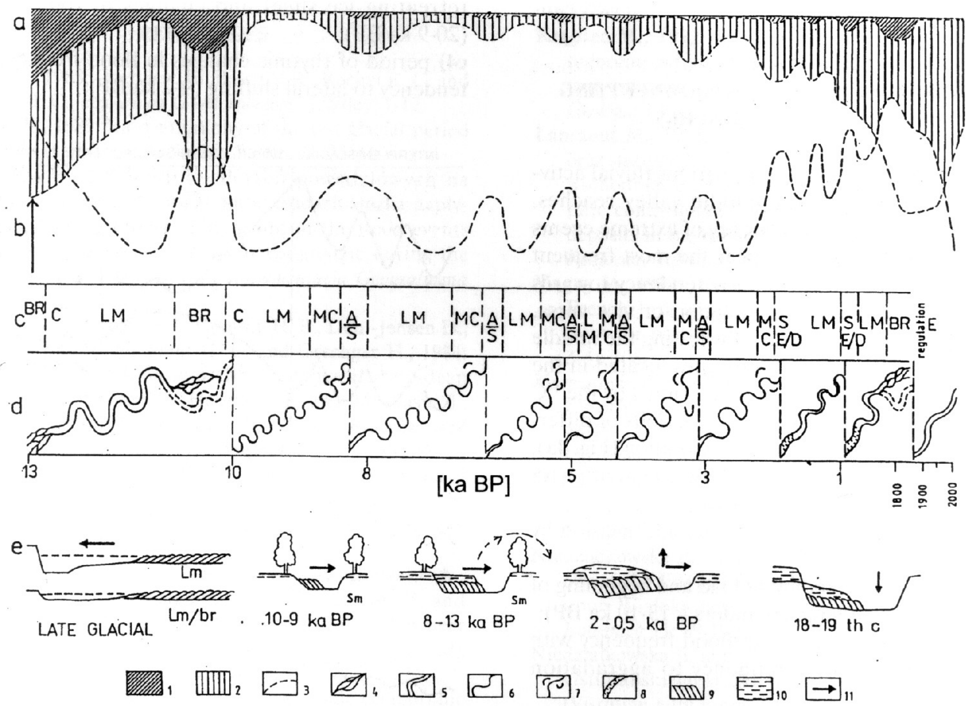

Fig. 3. Model of rhytmic changes in thresholds in the evolution of river and flood plains during last 13000 years (after Starkel et al., 1996): a – relative fluctuations of a transport and a delivery of bedload and suspended load, b – fluctuations in flood frequency (Kalicki, 1991; Starkel, 1994), c – main directions of changes; BR – braided channels, C – concentration of channels, LM – lateral migration, MC – meander cut-off, A – avulsions, 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 – overbank deposits, 11 – directions of channel changes.

of changes in granulometry of various facies, sedimentation rate, changes of channel morphometry and channel avulsions (**Fig. 3**) as well as by identification of sediments related to single floods and their clusterings (Czyżowska, 1997) and by clusterings of dated buried oaks (Krąpiec, 1992). In the upper Vistula basin the following phases of increased fluvial activity were recognised: 8.5-7.7, 6.6-6.0, 5.5-4.9, 4.4-4.1, 3.5-3.0, 2.7-2.6, 2.3-1.8 ka BP as well 425-625 AD, 900-1150 AD and after XIV century (**Fig. 3**).

In the tributary valleys the organic intercalations and fossil soils separating the members of overbank deposition also represent similar time intervals (Kalicki, Ludwikowska, In: Starkel *et al.,* 1999).

All these phases correlate with the rises of lake water level, higher frequency of landslides and debris flows in the Carpathians, advances of the alpine glaciers etc. (Starkel, 1985, 1994 b). These phases coincide with declines of the solar activity and relative coolings and at least some of them (like 8.5-8.0 ka BP) with simultaneous superposition of increased volcanic activity (Magny, 1993; Starkel, 1998)

Correlation of these phases and sometime also of single events must be made very carefully, because especially in the fluvial environment the hiatus is very common and organic remains are mainly redeposited, so even the AMS dating results must be taken very cautiously.

4. PHASES OF AGGRADATION AND DOWNCUTTING IN VARIOUS VALLEY REACHES

The above described phases of various fluvial activity are related mainly to the middle valley reaches, in which depending on the frequency of extreme events and sediment delivery there appear the most frequent crossing of threshold values and the tendency towards downcutting is replaced by aggradation or vice versa. The presented diagrams are just illustrating the middle courses (**Figs. 2** and **3**). In such reaches located in the Subcarpathian Basins in the period occupied by the ^{14}C dating were observed the following 6 periods of different rhytmicity and different trend of evolution (**Fig. 4a**):

a1) period of rhytmic changes in flood frequency with tendency to aggradation (40-25 ka BP);

a2) period of increasing continentality and incision by braided rivers (25-13 ka BP);

a3) period of increased sediment load and beginning of rhytmic changes (with large meanders – 13-10 ka BP);

a4) period of rhytmic changes in flood frequency with cuts and fills and starting tendency to aggradation (10-2 ka BP);

a5) period of rhytmic changes with tendency to aggradation due to deforestation (the last 2 ka), interrupted by river regulation.

In the upper river courses (in the Carpathians) with higher gradients the sequence of changes was different, conditioned by the higher sediment input under the periglacial climate (with diachronous snowmelt floods and summer solifluction) and by tendency to downcutting during periods with dense forest cover (Starkel, 1968, 1995). The following 5 periods may be distinguished (**Fig. 4b**):

b1) period of rhytmic changes with alternate phases of erosion and aggradation (40-25 ka BP);

b2) period of synchronous increased lateral and longitudinal transport with tendency to aggradation (25-15 ka BP);

b3) period of following downcutting combined with amelioration of climate (15-10 ka BP);

b4) period of rhytmic changes in flood frequency and alternate downcutting and aggradation (10-0,5 ka BP)

b5) period of increase transport (due to deforestation) and tendency to lateral erosion and aggradation (last 500 years).

Downstream, north of the belt of plateau the Vistula and other rivers were gradually blocked and later unblocked by the Scandinavian ice sheet. This gradual change of the base level altitude and length of the river valley were the main factor controlling the phases of evolution of the mid- lower course of the Vistula valley (Wiśniewski, 1987; Starkel, 1990):

c1) period of rhytmic aggradation (40-25 ka BP);

c2) period of continuous aggradation during the phase of advancing ice sheet (25-20 ka BP);

c3) period of rapid step-like downcutting during the retreating ice sheet and changes of river drainage (20-9 ka BP);

c4) period of rhytmic changes in flood frequency with tendency to lateral shifting (9-2 ka BP);

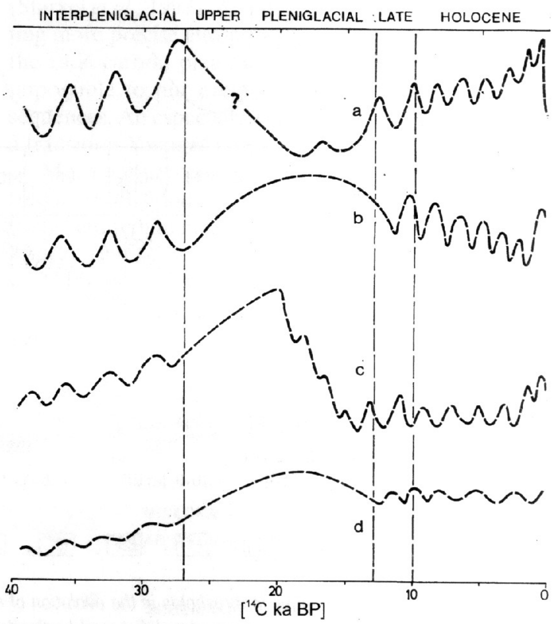

Fig. 4. *General models of fluctuations of the channel level reflecting various trends to aggradation or erosion during last 40 ka BP: a – middle river courses in Subcarpathian Basins, b – upper river courses in the Carpathian valleys, c – mid-lower coarse of Vistula, blocked by ice sheet, 4 – smaller river valleys of the lowland periglacial zone (Masovian plain).*

c5) period of rhythmic changes with tendency to aggradation (last 2 ka).

In the smaller lowland valleys of the former periglacial zone the sequence of changes differs from the river valleys with the mountain headwaters (**Fig. 4**, see Turkowska, 1995). The following 5 periods may be distinguished:

d1) period of rhythmic changes with progressing aggradation (40-25 ka BP);

d2) period of progressing aggradation under the extreme cold climate (25-21 ka BP);

d3) period of limited aggradation under cold continental climate (21-13 ka BP);

d4) period of rhythmic changes in the flood frequency with cuts and fills and slight tendency to downcutting (13-2 ka BP);

d5) period of slight tendency to aggradation (after deforestation).

The spatial differentiation of sequences in evolution of river valleys is explained by various factors playing leading role. But on the background of the glacial-interglacial cycle in the evolution are visible the distinct alternate phases of various river activity and among them the phases of higher frequency of extreme events. These phases seem to play a leading role in the formation of valley floors.

REFERENCES

Baker V. R., 1988: Overview. In: Baker V. R., Kochel R. C. and Patton P. C., eds, *Flood Geomorphology*. J.Wiley: 1-12.

Behre K. E., 1989: Biostratigraphy of the last glacial period in Europe. *Quaternary Science Reviews* 8: 25-44.

Czyżowska E., 1997: Zapis zdarzeń powodziowych na pograniczu borealu i atlantyku w osadach stożka napływowego w Podgrodziu (The record of the flood events in the alluvial fan sediments at Podgrodzie during the Boreal-Atlantic transition). *Dokumentacja Geograficzna IGiPZ PAN* 5: 74 pp.

Dansgaard W., Johansen S. J., Clausen H. B., Dahl-Jensen D., Gundestrup N., Hammer C. U. and Oeschger H., 1984: North Atlantic climatic oscillations revealed by deep Greenland ice cores. In: Hansen J. E. and Takahashi T., eds., *Geophysical Monograph 29; Climate Processes and Climate Sensitivity*. A.G.U., Washington D.C.: 288-298.

Alexandrowicz S. W., 1989: Stratigraphy and malacofauna of the Upper Vistulian and Holocene deposits of the Szklarka stream valley, Cracow Upland. *Bulletine of Polish Academy of Sciences, Earth Sciences* 37: 247-260.

Alexandrowicz S. W., Klimek K., Kowalkowski A., Mamakowa K., Niedziałkowska E., Pazdur M. F., and Starkel L., 1981: The evolution of the Wisłoka valley near Dębica during Lateglacial and Holocene, Starkel L., ed., *Folia Quaternaria* 53, Cracow: 1-91.

Gębica P. and Sokołowski T., 1999: Catastrophic geomorphic processes and sedimentation in the Vistula valley between the Dunajec and Wisłoka mouths during the 1997 flood, Southern Poland. *Quaternary Studies in Poland, Spec. Issue:* 253-261.

Goslar T., 1996: Naturalne zmiany atmosferycznej koncentracji radiowęgla w okresie szybkich zmian klimatu na przełomie vistulianu i holocenu (Natural variations of atmospheric radiocarbon levels in the period of rapid climatic changes at the Late Glacial-Holocene boundary). *Zeszyty Naukowe Politechniki Śląskiej, Seria Matematyka-Fizyka, Z. 81, Geochronometria* 15: 196 pp.

Goździk J., 1994: Etudes des fentes de gel en Pologne Centrale. *Biuletyn Peryglacjalny* 33: 49-78.

Harasimiuk M., 1991: Vistulian glacial cycle of the fluvial processes development in the valley of the Middle Wieprz river (SE Poland). *Annales UMCS, Sec. B* 46(5) Lublin: 81-109.

Jahn A., 1956: The action of rivers during the Glacial Epoch and the stratigraphic significance of fossil erosion surfaces in Quaternary deposits. *Przegląd Geograficzny* 28(supplement): 101-104.

Jersak J., Sendobry K. and Śnieszko Z., 1992: Postwarciańska ewolucja wyżyn lessowych w Polsce (Evolution of loesses plateau in Poland during the past-Warta period). *Prace Naukowe Uniwersytetu Śląskiego* 1227: 195 pp.

Kalicki T., 1991: The evolution of the Vistula river valley between Cracow and Niepołomice in Late Vistulian and Holocene times. *Geographical Studies, Spec. Issue* 6, Warszawa: 11-37.

Klimek K. and Starkel L., 1974: History and actual tendency of floodplain development at the border of the Polish Carpathians. *Abhandl. Akad. Wiss.* Göttingen 3: 29.

Kozarski S., 1991: Warta – a case study of a lowland river. In: Starkel L., Gregory K. J., Thornes J. B., eds, *Temperate Paleohydrology*. J. Wiley: 189-215.

Kozarski S. and Rotnicki K., 1977: Valley floors and changes of river channel pattern in the North Polish Plain during Late Würm and Holocene. *Questiones Geographicae* 4: 51-93.

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

Łanczont M., 1995: Warunki paleogeograficzne akumulacji oraz stratygraficzne zróżnicowanie utworów lessowych we wschodniej części Pogórza Karpackiego (Palaeogeographic conditions of depositin and stratigraphy of loess deposits in the eastern part of the Carpathian Foothills). *Rozprawy habilitacyjne UMCS* 50: 126 pp.

Magny M., 1993: Holocene fluctuations of lake levels in the French Jura and Sub-Alpine ranges and their implications for past general circulation pattern. *The Holocene* 3(4): 306-313.

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

Maruszczak H., 1987: Loesses in Poland, their stratigraphy and paleogeographical interpretation. *Annales UMCS Lublin* 41(2) sec.B: 15-54.

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

Niedziałkowska E. and Szczepanek K., 1994: Utwory pyłowe vistuliańskiego stożka Wisły w Kotlinie Oświęcimskiej (Vistulian silty sediments of the Vistula river fan in the Oświęcim Basin). *Studia Geomorphologica Carpatho-Balcanica*: 27-28, 29-44.

Penck A. and Brückner E., 1909: *Die Alpen im Eiszeitalter* 3, Leipzing: 1189 pp.

Ralska-Jasiewiczowa M. and Starkel L., 1975: The basic problems of palaeogeography of the Holocene in the Polish Carpathians. *Biuletyn Geologiczny Uniwersytetu Warszawskiego* 19: 27-44.

Rotnicki K., 1987: Main phases erosion and accumulation in the middle and lower Prosna valley in the last glacial-interglacial cycle. *Geographia Polonica* 53: 53-65.

Rotnicki K., 1991: Retrodiction of palaeodischarges of meandering and sinuous alluvial rivers and its palaeohydroclimatic implications. In: Starkel L., Gregory K. J. and Thornes J. B., eds, *Temperate Palaeohydrology*. J. Wiley 431-471.

Schrimer W., 1983: Criteria for the differentiation of late Quaternary river terraces. *Quaternary Studies in Poland* 4: 199-205.

Schumm S. A., 1965: Quaternary paleohydrology. *The Quaternary of the United States, vol. for VII Congress INQUA*: 793-949.

Starkel L., 1960b: Rozwój rzeźby Polskich Karpat fliszowych w holocenie (The development of the Flysh Carpathians relief during the Holocene). *Prace Geograficzne IG PAN* 22: 1-239.

Starkel L., 1968: Remarques sur l'etagement des processes morphogenetiques dans Carpates au cours de la derniere glaciation. *Biuletyn Peryglacjalny* 17: 205-220.

Starkel L., ed., 1982-1996: Evolution of the Vistula river valley during the last 15,000 years, part.I-VI. *Prace Geograficzne IG i PZ PAN, Special Issues*, Warsaw.

Starkel L., 1983: The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15,000 years. In: Gregory K. J., ed., *Background to Palaeohydrology*. J. Wiley: 213-234.

Starkel L., 1990: Fluvial environmental as an expression of geological changes. *Zeitschrift für Geomorphologie, Suppl. – Bd.*79: 133-152.

Starkel L., 1994a: Reflection of glacial-interglacial cycle in the evolution of the Vistula river basin, Poland. *Terra Nova* 6: 1-9.

Starkel L., 1994b: Frequency of floods during the Holocene in the upper Vistula Basin. *Studia Geomorphologica Carpatho-Balcanica* 27-28: 3-13.

Starkel L., 1995a: New data on the Late Vistulian and Holocene evolution of the Wisłoka valley near Dębica. *Geographical Studies, Special Issue* 8: 73-90.

Starkel L., 1995b: Evolution of the Carpathian valleys and the Forecarpathian Basins in the Vistulian and Holocene. *Studia Geomorphologica Carpatho-Balcanica* 29: 5-40.

Starkel L., 1998: Frequency of extreme hydroclimatically-induced events as a key to understanding environmental changes in the Holocene. In: *Water, environment and society in times of climatic changes*. Issar A. S. and Brown N., eds, *Background to Palaeohydrology*. Kluver Ac. Publ.: 273-288.

Starkel L., 1999: Space and time scales in geomorphology. *Zeitschrift für Geomorphologie, Suppl. Bd.* 115: 19-33.

Starkel L. 8500-8000 BP humid phase-global or regional. In: *Transaction of Japanese Geomorphological Union*, in print.

Starkel L. and Gębica P., 1995: Evolution of river valleys in Southern Poland during the Pleistocene-Holocene transition. *Biuletyn Peryglacjalny* 34: 177-190.

Starkel L. Gębica P., Kalicki T., Ludwikowska M. and Niedziałkowska E., 1999: Chronostratygrafia aluwiów i form fluwialnych w południowej Polsce (Chronostratigraphy of alluvial and fluvial forms in Southern Poland). In: Pazdur A., Bluszcz A., Stankowski W. and Starkel L., eds, *Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescsncyjnego*. WIND-J. Wojewoda, Wrocław: 133-156.

Starkel L., Kalicki T., Krąpiec M., Soja R., Gębica P. and Czyżowska E., 1996: Hydrological changes of valley floors in the upper Vistula Basin during Late Vistulian and Holocene. *Geographical Studies, Special Issue* 9, Continuo, Wrocław: 7-128.

Superson J., 1996: Funkcjonowanie systemu fluwialnego wyżynnej części dorzecza Wieprza w zlodowaceniu Wisły (Functioning of fluvial system of the upland part of the Wieprz river catchment in the Vistulian stage). *Wydział Biologii i Nauk o Ziemi UMCS Lublin, Rozprawy habililitacyjne* 53: 1-280.

Trevisan L., 1949: Genese des terrasses fluviales en relation avec lec cycles climatiques. *C.C. Congr. Internat. Geogr.*, vol.2, *Lisbone.*

Turkowska K., 1995: Recognition of valley evolution during the Pleistocene-Holocene transition in non-glaciated regions of the Polish Lowland. *Biuletyn Peryglacjalny* 34: 209-227.

Wiśniewski E., 1987: The evolution of the Vistula river valley between Warsaw and Płock Basins during the last 15,000 years. *Geographical Studies, Spec. Issue* 4, Warsaw: 171-187.