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CHRONOSTRATIGRAPHY OF ALLUVIA AND AGE OF FLUVIAL LANDFORMS IN THE CARPATHIAN FORELAND DURING THE VISTULIAN

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Abstract

A development of opinions on stratigraphy of alluvia and age of the Vistulian terraces in the valleys of the Carpathian foreland is presented, based mainly on publications of Professor Leszek Starkel. Studies of age of fluvial landforms and sediments of the Last Cold Stage in the Carpathian foreland have been started more than 100 years ago. Before the modern sedimentological methods and radiocarbon dating were introduced, pioneer studies of Pleistocene river terraces and sediments in the Carpathians were performed by Mieczysław Klimaszewski, and subsequently, by his student Leszek Starkel who mapped in 1950s a margin of the Carpathian Foothills as well as alluvial fans of Wisłoka, Wisłok and San rivers in the Carpathian foreland. In that time a stratigraphy of alluvial infillings in the marginal mountain zone was elaborated for the Late Vistulian and the Holocene. Starting from 1970s and basing on studies in key sites in the Wisłoka valley near Dębica, focused on palynological analyses and radiocarbon dating, general stratigraphical schemes of alluvial fills within the Vistulian terrace 15 m high and within the Holocene terrace 8–10 m high have been constructed. A comparison with the valleys in a periglacial area prowed that the Vistulian terrace 15 m high was incised before the maximum extension of the last Scandinavian ice sheet (i.e. before 20 ka BP) and the terrace 11–12 m high (with relics of braided river channels) was formed at the decline of the Plenivistulian. A final incision below the present river bed and aggradation occurred during the Late Vistulian (13–10 ka BP). The rivers changed their regime and their channel pattern from braided to large meanders-type as an effect of forest development and lower sediment load. The Younger Dryas cooling resulted in increased bedload and braiding.

Key words: chronostratigraphy, alluvia, river terraces, Carpathian foreland, Vistulian.

INTRODUCTION

The first studies of terraces and alluvia of the Last Glaciation in the Carpathian foreland reach back to the beginning of the 20th century (Friedberg 1903). In that time the Pleistocene sediments younger than glacial ones were distinguished, among which were 'Mammoth loam' (loess) and young diluvial sand terrace (Friedberg 1903; Łomnicki 1903). Klimaszewski (1948), partially following the German stratigraphical schemes, postulated that the terrace alluvia covered by loess were older than the last glacial period. Therefore, he connected the terrace 15–20 m high with the Middle-Polish Glaciation (Saalian). Klimaszewski disagreed with Jahn (1957) who connected the 15–17 m high terrace, covered by loess in the Wisłok River valley in Rzeszów, with the Vistulian Glaciation (Table 1, Fig. 1). At the same time, in the fifties of 20th century, the first sites of interstadial sediments were found and named after the names of sub-Alpine sites of interstadial paleosols Göttweig and Paudorf (Szafer 1952; Woldstedt 1956). In that time the length of the Vistulian Glaciation was estimated at about 60,000 years BP (Starkel 2008). Simultaneously, owing to identification of fossil flora from the Paudorf Interstadial, the duality of a terrace cover was proved (Środoń 1952; Stupnicka, Szumański 1957). Partial revision of the age of alluvia overlain by loess was due to interfingering of alluvia and solifluction covers at Dobra village in the Beskid Wyspowy Mts. (Klimaszewski 1958), where interstadial peat was dated at 32,550±450 yrs BP (Środoń 1968). Consequently the thesis that sub-loess alluvia originated from the Middle-Polish Glaciation, resulted in connection of the sand-gravel alluvia of the 6–10 m high terrace, covered by the Holocene overbank sediments, with the Vistulian Glaciation (Fig. 2A). Such judgement could have been confirmed by the Dryas flora found within the Holocene terrace of the San River (Kulczyński 1932, Klimaszewski 1948), although as early as during the geological surveying for the Geological Atlas of Galicia, Friedberg (1903) but also Łomnicki (1903) had described the Holocene sediments with subfossil trunks and malacofauna shells (Starkel 2011). Finally, the Dryas flora findings in the San deposits were ascribed to the early phases of the Late Glacial, preceding the Alleröd Interstadial (Środoń 1965).

AGE OF ALLUVIA, EROSION AND ACCUMULATION PHASES IN ALLUVIAL FANS AT THE CARPATHIAN MARGIN

In 1950s the opinion prevailed on prepotency of periglacial processes and common occurrence of Pleistocene

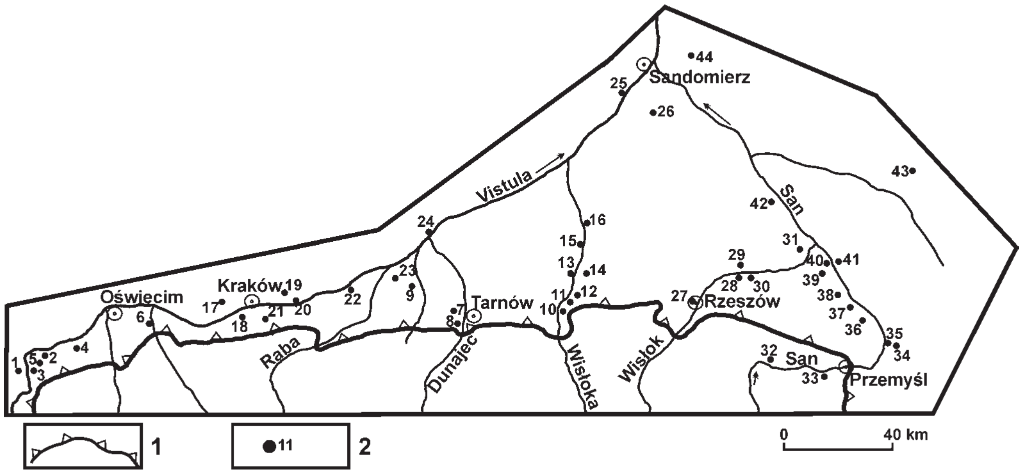

Fig. 1. Distribution of selected localities with Vistulian sediments in the Sub-Carpathian Basins presented in Table 1. *1* – Edge of the Carpathians, *2* – selected sites dated by radiocarbon and other methods.

sediments. A role of fluvial processes during the Holocene could have been restricted to the formation of overbank sediments as a result of soil erosion after deforestation. At the beginning of 1950s the Carpathian Foothills margin was mapped by Leszek Starkel, formerly for his master of sciences dissertation (Starkel 1957), and subsequently, selected areas in the Flysch Carpathians and in their foreland for his PhD thesis (Starkel 1960). In the mountain foreland he studied alluvial fans of Wisłoka, Wielopolka, Wisłok and San rivers, which brought evidence for the Holocene age of terrace alluvia, not only overbank sediments, but gravel-sand channel alluvia bearing subfossil tree trunks. Among them, he distinguished several cuts and alluvial fills with intercalations of peat dated by palynological method (Starkel 1960) (Fig. 2B). This analysis showed the occurrence of bottom gravel cover from the anaglacial phase of the Vistulian Glaciation and at least three alluvial fills representing the Late Vistulian (Alleröd), the climatic optimum of the Holocene (Atlantic Phase) and the Subatlantic Phase. The phases of erosion were attributed to dryer periods in the Late Vistulian (Younger Dryas) and the Holocene (Preboreal, Boreal and Subboreal Phases). A lack of sediments and landforms representing the Vistulian Glaciation in the Wisłoka valley was explained by Starkel (1957) by the Holocene cover. It was confirmed by ferruginous gravels (composed of flysch sandstone pebbles), 1–3 m above the Wisłoka riverbed, which were found in outcrops at Dębica and Latoszyn, under "recent" sand-gravel alluvia, often with wood remnants. Occurrence of the apparent gravel socle under the Holocene sediments proved presence of paleoterraces of the Vistulian Glaciation. Gravels from the Vistulian Glaciation could have filled the channel incised in fluvial and ice-dammed lake sediments of the Middle-Polish Glaciation (Starkel 1957) (Fig. 2B).

REVISION OF STRATIGRAPHY OF ALLUVIA AND AGE OF TERRACES IN THE WISŁOKA VALLEY

The valley of Wisłoka comprises two distinct terraces which were mapped in detail for the first time by Leszek Starkel at the beginning of the fifties. The upper level (the middle terrace) is 15 m high; the lower level is 8–10 m. The terrace surface is diversified in the vicinity of Brzeźnica village with dunes 1–5 m high (Starkel 1957). The middle terrace is associated with alluvial fans deposited in the outlets of Zawadka stream and Ostra stream valleys in the Carpathian edge. The fans, formed of sands and gravels, range the height 7–15 m above the valley bottoms and they are covered by loess. The 15 m deep undercut of the terrace at Kozłów, south of Brzeźnica, indicated gravel series upon Miocene clays and upper silt series overlain by sands. According to Starkel (1957) the beds with a Dryas flora occurring there, were connected with the Middle-Polish Glaciation, whereas Środoń (1965) attributed them to the Paudorf Interstadial of the Vistulian Glaciation. Sequence of the Paudorf Interstadial sediments were described on the left river bank at Nagoszyn (Środoń 1965; Laskowska-Wysoczańska 1971) where under sands and silts, gyttja underlain sands occurred at depth 14.3–14.9 m. In the eastern part of valley (right river bank), near Pustków, under the surface of the middle terrace, there was a paleochannel cut in Miocene clays, buried by gravel-sand and silt series, 32 m thick (Starkel 1957, 1972). The filling of this paleochannel Starkel (1957, 1972) attributed to the Middle-Polish Glaciation, when alluvial fans (deltas) were formed by the Carpathian rivers in the periphery of a large ice-dammed lake in the northern part of the Sandomierz Basin (Starkel 1984). However, according to Laskowska-Wysoczańska (1971) gravels filling the paleochannel were deposited at the Eemian Interglacial – Early Vistulian transition.

In connection with the Symposium of the Holocene Commission of INQUA in Poland at the beginning of 1970s, Leszek Starkel performed studies of sediments of the three terraces: 15 m high middle terrace and 8–10 m and 6–8 m lower (Holocene) terraces, undercut 700 m long at Brzeźnica. Paleobotanical analysis of organic sediments outcropped in four sequences comprised the basis for age interpretation of the examined alluvial fills (Mamakowa, Starkel 1972).

The 15 m high middle terrace is formed of gravels, overlain by 8 m thick series of clayey silts, sandy in the upper parts, rhythmically laminated. These sediments are covered by 3–4 m high unit of fluvial sands, duned in the uppermost

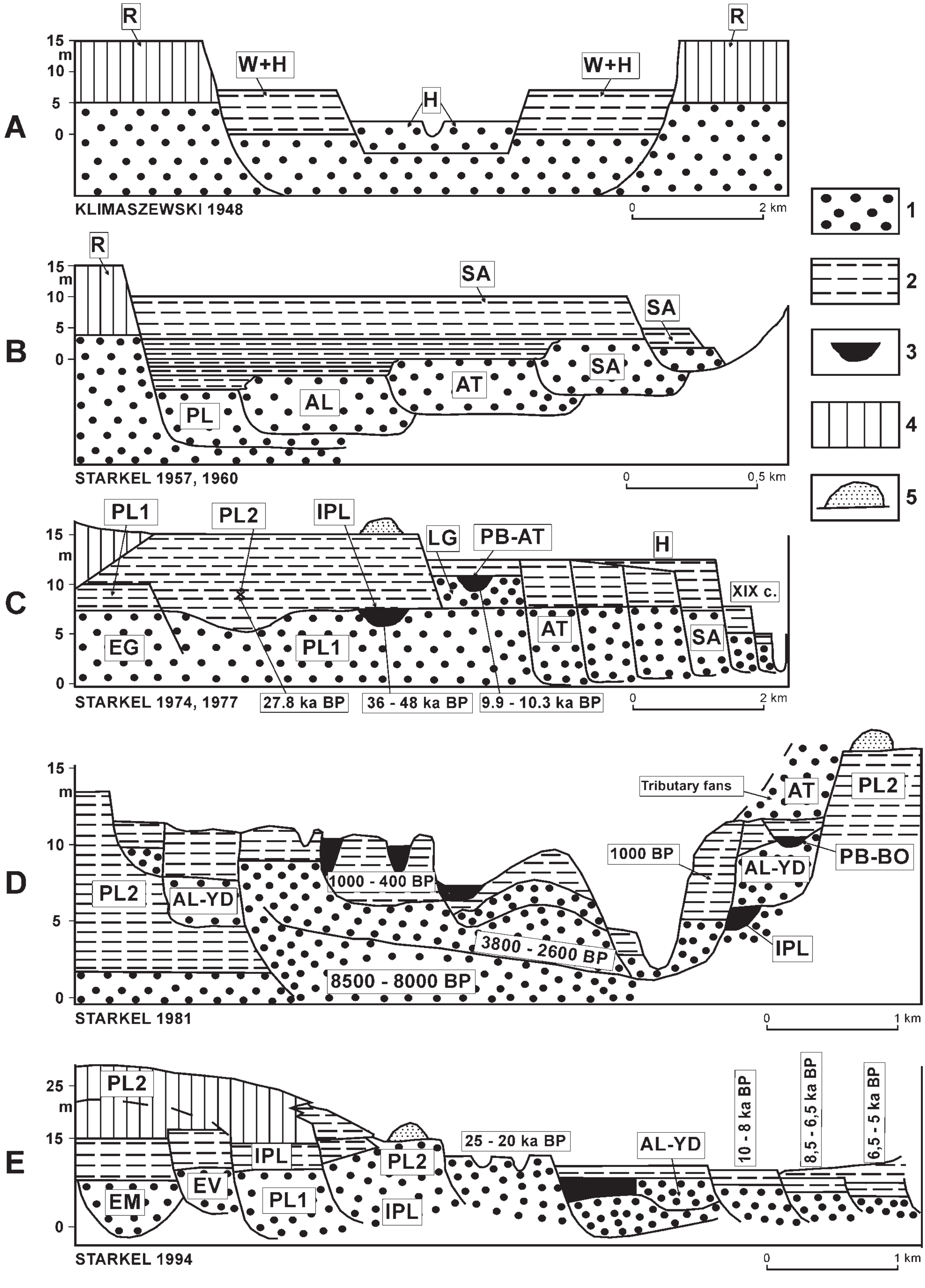

Fig. 2. Synthetic models of evolution and alluvial fills in the Wisłoka valley and other valleys in the foreland of the Carpathians during Vistulian and Holocene. *1* – channel facies, *2* – overbank facies, *3* – paleochannel fills, *4* – loess, *5* – dunes; R – Riss, W – Würm, EM – Eemian, EV – Early Vistulian, PL – Pleniglacial (1, 2), IPL – Interpleniglacial, LG – Late Glacial, AL – Alleröd, YD – Younger Dryas, H – Holocene, PB – Preboreal, BO – Boreal, AT – Atlantic, SA – Subatlantic.

Table1

List of main localities with investigated Vistulian alluvial sediments in the Fore-Carpathian Basins after Starkel (1995) and Gębica (2004), modified and supplemented

No	Locality	References	Eem	EV	PL1	IPL	PL2	LV
1.	Drogomyśl	Niedziałkowska et. al. 1985				=▼	=	○U▼⬇
2.	Chybie	Niedziałkowska et. al. 1985	○	▼⬇		=▼⬇	III	
3.	Pierściec	Niedziałkowska Szczepanek 1993-94			○	=▼⬇	III	
4.	Kaniów	Gilot et al. 1982				○=▼⬇	V▼III⬇	
5.	Bronów	Wójcik 2010					○	U-▼
6.	Zator	Koperowa, Środoń 1965			III	=▼⬇	III	
7.	Szujec	Sokołowski 1981				○▼	○	
8.	Dębina Zakrzowska	Gębica 2004			○	U▼⬇		
9.	Włoszyn	Gębica 1995				=▼⬇	○	
10.	Podgrodzie	Mamakowa Starkel 1977				○~▼	○=▼	○▼
11.	Latoszyn	Alexandrowicz, Klimek 1985						○=▼∂
12.	Dębica potok Wolicki	Starkel 1960, Starkel 1995a						○▼⬇
13.	Wola Żyrakowska	Starkel, Granoszewski 1995 Mamakowa et al. 1997					○=▼⬇	U▼⬇
14.	Brzeźnica	Mamakowa, Starkel 1974			○	U▼⬇	○=▼⬇	○
15.	Rzochów	Laskowska-Wysoczańska Niklewski 1969		U⬇M	○			
16.	Mielec Wojsław	Gębica 2004					○▼⬇	
17.	Kryspinów	Mamakowa, Rutkowski 1989				○▼⬇	○	
18.	Ludwinów	Sokołowski, Wasylikowa 1984			○	○=▼	○	
19.	Nowa Huta	Mamakowa, Środoń 1977			○	=▼⬇	III	
20.	Pleszów	Kalicki 1991						U▼⬇
21.	Stożek Podłężanki	Kalicki 1997						U▼⬇
22.	Trawniki	Gębica 1995			○▽	=▽	III▽∂	
23.	Gróbka	Gębica 1995						○=-▼⬇
24.	Opatowiec	Jersak 1991				○=▼	III∂	
25.	Piaseczno	Mycielska-Dowgiałło 1987				=▼⬇	○	○
26.	Kobylarnia	Mycielska-Dowgiałło 1987						U-▼
27.	Rzeszów	Jahn 1957 Starkel 1960			○	=	III	U⬇
28.	Łukawiec	Gębica 2004			○▽	=▽▼⬇	○□	○□
29.	Czarna Podbór	Gębica 2004				U▼⬇	○▽	
30.	Wola Mała	Gębica et al. 2004					○□	=□○▼⬇
31.	Grodzisko Nowe	Gębica et al. 2008					○U▼	U▼⬇
32.	Podbukowina	Mamakowa 1962						U-⬇
33.	Potok Krzeczkowski	Łanczont 2001		○~▽∂	~∂	III		
34.	Stubno	Klimek 1992					○U▼	U-▼
35.	Barycz	Kulczyński 1932					=⬇	
36.	Radymno	Alexandrowicz et al. 1989		○=▽	III	III	III∂	
37.	Jarosław	Jersak et al. 1992			○	=▼		
38.	Jarosław-Kruchel	Kołaczek 2011						U▼⬇
39.	Wólka Pełkińska	Wójcik et al. 1999					○=▼	=
40.	Kostków	Gębica et al. 2009b					○=▼⬇	=▼
41.	Manasterz	Gębica et al. 2009b					○=▼⬇	○
42.	Jelna	Szumański 1986						U▼
43.	Korytków	Buraczyński, Butrym 1989				○▽	○▽	
44.	Łążek	Mamakowa 1968				=▼⬇	○	

Signs: ○ - channel facies, = - overbank facies, U - paleochannel fills, V - alluvial fan facies, III - loess ~ - slope deposits, - - peatbogs, ▼- radiocarbon dating, ▽- TL dating, □ - OSL dating, ⬇- paleobotanical investigations, ∂ - malacological analysis, M - bones; EV - Early Vistulian, PL1 - Older Plenivistulian, IPL - Interplenivistulian, PL2 - Younger Plenivistulian, LV - Late Vistulian part (Fig. 2C). Within the silts the peat horizon occurs with pollen of dwarf birch (*Betula nana*), juniper and willow, indicating an open tundra environment. Peat from the depth of 8.3 m was radiocarbon dated in 1972 by M. Geyh from Hannover to 27,805±330 yrs BP (Hv-4898). This age confirmed the thesis of Środoń (1965) and Laskowska-Wysoczańska (1971) that the series of sediments of the terrace 15 m represented the Vistulian Glaciation and strictly "moved" the age of the silt unit from the Pleniglacial A (according to Środoń 1965) to the Pleniglacial B, i.e. to the Upper Plenivistulian (Mamakowa, Starkel 1974).

The Holocene terrace, 8–10 m high, has a complex structure. In the channel alluvia 5–6 m above the riverbed at Brzeźnica (Fig. 2C), a paleochannel was incised and filled with oxbow-lake sediments. Above it, upon the erosive surface, younger gravel and sand paleochannel sediments occur with younger oxbow-lake clay and peat sediments. This paleochannel is visible in plain relief as a meander cut in the terrace surface. Pollen analysis indicated that the sediments of the older oxbow-lake represented termination of the Alleröd Interstadial and the Younger Dryas (Mamakowa, Starkel 1972). The younger oxbow-lake sediments, which occur in the upper part of the sequence as well as in other sites in the Wisłoka banks represent Preboreal and Atlantic Phases. It was turned out later, that the sediments accounted to the Late Vistulian are older than the sediments of the terrace 15 m high. The date 35,965±1,000 yrs BP (Hv-4899) attributed the top of the older oxbow-lake sediments to a decline of the Hengelo Interstadial (Mamakowa, Starkel 1974) (Fig. 2C). Consequently, the bottom gravel of the terrace 8–10 m high represented an interval before the Hengelo Interstadial. Subsequently, synchronically to the organic accumulation in the oxbow-lakes, the gravels were eroded. The paleochannel cut in the gravels of the terrace 15 m high, was filled with alluvia of the Upper Plenivistulian (Pleniglacial B according to Środoń 1965). Radiocarbon ages of samples from the bottom part of the older oxbow-lake fills in the sequence of the terrace 8–10 m high at Brzeźnica, yielding 46,000–48,000 yrs BP (Starkel 1977, Starkel 1980, Starkel in: Alexandrowicz et al., 1981), indicated that the lower gravel represented not only the Interplenivistulian, but the lower part of the Pleniglacial A (Lower Plenivistulian) too (Fig. 2C). Therefore, cutting of the terrace deposits occurred after ca 35,000–36,000 yrs BP (Hengelo Interstadial?) and before the Upper Plenivistulian phase when a silty-sandy series of the terrace 15 m high was formed.

The erosive surface of sediments of the Hengelo Interstadial was much younger. The upper gravel-sandy unit with the younger paleochannel radiocarbon dated at 9,535±100 yrs BP (Hv-4900) originated probably at the end of the Late Glacial and was inserted in alluvia of the terrace 15 m high (Mamakowa, Starkel 1974). Therefore, a wide, erosive plain, truncating older gravel alluvia and the Miocene sediments 4–6 m above the Wisłoka riverbed was shaped by a braided river of the Late Vistulian age (Alleröd–Younger Dryas?) (Ralska-Jasiewiczowa, Starkel 1975; Starkel 1977, Starkel 1980). The earlier concept of Starkel (1960) concerning the occurrence of deep Late Vistulian paleochannels descending to below the present riverbeds at Brzeźnica was not confirmed.

At Podgrodzie (Mamakowa, Starkel 1977; Starkel in: Alexandrowicz et al. 1981) upon 3.5 m high socle of colluvia radiocarbon dated at 33,350±750 yrs BP, a silty layer, 0.65 m thick and dated at 22,450±310 BP occurred. It proved low position of the Wisłoka paleochannel before the maximum of the Vistulian Glaciation (LGM). At the erosive surface of the paleochannel stone pavement layers with wood were dated at 10,130±115 yrs BP. It was overlain by paleochannel fills dated at 9,955±100 yrs BP at the bottom part and at 8,390±100 yrs BP at the top. The uppermost part of the sequence is represented by fan sand 9 m thick of the tributary, formed at the beginning of the Atlantic Phase (Fig. 2D).

RESULTS OF RESEARCH IN 1990S AND AT THE BEGINNING OF THE 21ST CENTURY

The studies of valley evolution developed particularly intensively in the second half of 1980s and in 1990s in connection with the IGCP-158 project 'Paleohydrology of river valleys in the temperate climate zone' and the state project CPBP-03.13. made possible the application of wide spectrum of sedimentological, malacological, dating (^{14}C, TL), dendrochronological and other methods (Niedziałkowska et al. 1985; Starkel ed. 1987, 1990, 1991, 1995, 1996; Kalicki 1991, 1997, Starkel 1998, 2001, 2002; Klimek 1992, Alexandrowicz 1995; Gębica 1995, 2004; Łanczont 1995, 2001; Starkel, Gębica 1995; Mamakowa et al. 1997; Starkel et al. 1999; Wójcik et al. 1999, Wójcik 2010). Many new sites in valleys of the Carpathian foreland were dated in that time (Table 1, Fig. 1). After publication of the monograph of the Wisłoka river valley near Dębica, edited by Leszek Starkel in 1981 (Alexandrowicz et al. 1981; Starkel et al. 1982), a problem of the alluvia chronostratigraphy and of the terrace ages seemed not to be further developed. However, Professor Starkel desired to solve two other problems. The first one was the age of the alluvial plain with remnants of braided channels on the left bank of the Wisłoka valley in the vicinity of Żyraków and Wola Żyrakowska, lower than the terrace 15 m high and higher than the plains with large paleomeanders of the Late Glacial. The second dealt with depth of incision of the Wisłoka during the Late Vistulian.

The terrace 11–12 m high, 1–2 km wide in the vicinity of Żyraków is 3–4 m lower than the Pleniglacial right-side terrace, 15 m high at Brzeźnica (Mamakowa, Starkel 1974). On alluvial plain remnants of shallow (0.2–0.5 m deep) and discrete paleochannels remain, cut into a sand cover typical for a braided river. From the Wisłoka side the plain is cut (to the depth 1–1.5 m) by meandering, in places large-radial and wide, cut-off channels (Starkel 1995a). A lack of overbank sediments at the surface, which are typical of the Holocene floodplain and instead of them occurrence of sand-gravel channel series indicated relatively fast and deep cutting of the alluvial plain, which caused that floods could not reached the central part of the terrace during the Holocene. The boreholes along the axis of paleochannels of a braided river indicated that under 2 m thick sand-gravel channel deposits there were oxbow-lake sediments, represented by clayey silt with thin peat intercalations in the top. They overlie the lower sands and gravels of channel deposits at the depth of 4 m. Palynological analyses of peat by K. Mamakowa, indicated a tundra vegetation with tree clumps. Dating of peat from the depth of 2.2 m was radiocarbon dated to older than 33,500 yrs BP (Gd-49011), while the age 21,300±1,200 yrs BP (Gd-9007) from the depth of 2.45 m was certainly too young. At this stage of studies it could be possible to find undoubtedly that the terrace 11–12 m high is older than the Late Vistulian paleochannel and younger than the terrace 15 m high at Brzeźnica (Starkel 1995a).

Subsequently, in cooperation with the geologists S. Brud and J. Boratyn from the Geological Company in Cracow who supplied with results of recent drillings as well as TL and radiocarbon ages, a more precise model of alluvial fills from the Vistulian Glaciation in the Wisłoka valley could be constructed (Mamakowa et al. 1997) (Fig. 2E). It turned out, that within the terrace 15 m high in the Wisłoka valley the erosive surface with thin gravel-sand cover and remnants of braided river channels was attributed probably to the maximum of the Vistulian Glaciation. In this time the pre-Wisłoka river flowed north-eastwards to the Vistula valley, what is confirmed by oxbow-lake sediments dated at 18,000–17,000 yrs BP (Gębica 2004). According to Starkel (1988, 1994), Starkel ed. 1990 the period 18,000–13,000 yrs BP was the phase of deepening of river valleys, synchronic with lowering of the Vistula channel during a retreat of the Scandinavian ice-sheet of the Vistulian Glaciation. It could be indicated by a low position of the oldest Late Vistulian paleochannel fills of the Vistula valley near Cracow (Kalicki 1991) and of the San River in the Dynów Foothills (Mamakowa 1962) and the Carpathian foreland (Klimek 1992). The subsequent detailed recapitulation and confrontation of research results in various valleys of the periglacial zone in form of channel-level fluctuations (Starkel 1996, Starkel et al. 2007), proved a change in the tendency toward erosion after the Interplenivistulian accumulation, which was earlier observed in the lower section of the Prosna valley by Rotnicki (1987) and in the Wieprz valley by Harasimiuk (1991). Therefore, it was not a lowering of erosive base level related to the Scandinavian ice-sheet retreat (Jersak et al. 1992), but a change from oceanic to continental climate (Harasimiuk 1991) stimulated incision in the highest Vistulian terrace. The accelerated loess accumulation in that time confirms climate aridness (continentalism) progressing since ca. 30,000 until 20,000 yrs BP (Maruszczak 1987). The Younger Upper Loess deposited upon the Vistulian terrace since ca. 24,000–25,000 yrs BP (Alexandrowicz 1995, Gębica et al. 1998, Gębica 2004) indicates that river channels were incised deep in that time, thus the erosive phase preceded the maximum extension of the Scandinavian ice-sheet (LGM).

EVOLUTION OF VIEWS ON LATE VISTULIAN PHASES OF RIVER EROSION AND ACCUMULATION

The problem of erosion and depositional activity of rivers during the Late Vistulian was a subject of numerous publications based principally on studies of the Wisłoka valley and other valleys in the Upper Vistula drainage basin (Starkel 1957, 1960, Mamakowa, Starkel 1974, 1977, Starkel 1983, 1994, 1995a, 1995b, 2001, 2002; Starkel in: Alexandrowicz et al. 1981; Szumański 1983, 1986; Kalicki 1991, 1997; Klimek 1992; Starkel, Gębica 1995; Starkel et al. 2007; Gębica et al. 2009, Gębica 2011).

During mapping of the Wisłoka valley in 1953 in Dębica, Starkel (1957) found a paleochannel incised to depth 10–14 m into Miocene clays, under the surface of the Holocene terrace. The paleochannel was filled by the following sequence of sediments: lowermost gravels and sands, 3.5 m thick, bearing pine, larch and birch tree trunks, an intermediate unit of oxbow-lake sediments – sands and clays 0.1–0.5 m thick, with peat inserts, and a topmost unit of overbank sediments, 7.5 m thick, deposition of which was connected in the upper part with the alluvial fan of the Wolicki Stream. Palynological analysis of an oxbow peat indicated the Late Vistulian–Holocene transition (Starkel 1957). On the basis of these data Starkel (1957, 1960) ascribed the paleochannel fills bearing tree trunks to the Alleröd Phase. He connected the clays intercalated with peat with the period of weaker river depositional activity during the Younger Dryas (Starkel 1960).

In 1970s new data from Brzeźnica and Podgrodzie (Mamakowa, Starkel 1974, 1977, Starkel in: Alexandrowicz et al. 1981) led Starkel to the hypothesis that incision of the Late Vistulian channels could not be deeper than of the current channels. Such conception was still maintained at the beginning of 1980s (Starkel 1984), whereas research performed within IGCP 158 project (Starkel ed. 1990) resulted in findings of deeper, pre-Alleröd paleomeanders in the Vistula (Kalicki 1991) and San valleys (Mamakowa 1962), and even older than 15,000 yrs BP in the San valley downstream of Przemyśl (Klimek 1992). Similar age of 14,400 yrs BP was recently received for a bottom party of peat within the paleochannel of the Vistulian alluvial fan of the Vistula river between Skoczów and Goczałkowice (Wójcik 2010).

Finally, in 1992 a borehole situated in Dębica near the site studied in 1950s, drilled a peat yielding a radiocarbon age 10,060±90 yrs BP (Gd-7304) at the depth of 8 m under the sediments of the Wolicki Stream alluvial fan (Starkel 1995a). This peat was underlain by silts and sands, in which two horizontally oriented pine trunks were drilled. One of the trunks, found at the depth of 9.83–9.94 m showed the radiocarbon date 10,480±80 yrs BP (Gd-7311), thus the paleochannel incised in Miocene clays and descending ca. 1–2 m below the current riverbed level, was older than the Younger Dryas. These results were concordant with data recorded at the other sites in the Wisłoka, Wisłok and San valleys (Gębica 2011). In such way the hypothesis of L. Starkel formulated in 1950s century was confirmed.

The Late Vistulian was not exactly the period of erosive deepening of the large river valleys, but rather widening of valleys and inserting of alluvia, associated with transformation of braided into the meandering channels (Falkowski 1975, Starkel 1977, 1983, Kozarski 1983), characterised by the curvature radius 3–5 times larger than of the younger, Holocene channels. The paleochannel undercut the terrace 11–12 m high on the left bank of the Wisłoka at Wola Żyrakowska is an example of such large-radial paleo-me ander. A sequence of its sediments, 5.2 m thick, is represented by oxbow-lake fills: overbank clays at the bottom, overlain by biogenic sediments (indicating overgrowing of the lake), which are covered by silt-sand overbank sediments. The bottom part of the sequence, sampled at the depth of 5.2 m was radiocarbon dated at 10,000±130 yrs BP (Gd-68731), while the upper section of the sequence, sampled at the depth of 4 m, yielded 10,170±190 yrs BP (Gd-9008). Despite the age inversion both samples indicated that the beginning of the paleochannel filling took place during the Younger Dryas – Preboreal Phase (Starkel, Granoszewski 1995). This large paleomeander was abandoned at the end of the Younger Dryas, thus, similarly to the most of large paleomeanders dated in the lower section of the San (Szumański 1983). The oldest large paleomaeanders developed before the Alleröd. Development of pine-birch vegetation during the Alleröd caused peat formation in numerous sections of valley bottoms, therefore the oxbow-lakes were filled up more frequently (Gębica 1995, Starkel 1995b). In some valley sections the tendency toward aggradation and braided channels development took place during the Younger Dryas (Starkel, Gębica 1995). Truncation of wide erosive plains by rivers and deposition of 2–4 m thick series of diagonally bedded sands and gravels ended almost exactly during the Younger Dryas – Holocene (Preboreal) transition (Mamakowa, Starkel 1974, Starkel in: Alexandrowicz et al. 1981, Starkel 1983, 2002). The age from the topmost section of sands at Przemyśl-Przekopana, yielding 10,375±125 yrs BP, almost exactly indicates a decline of the Younger Dryas with significant activity of rivers (Starkel 1977). Similar series of channel alluvia of the braided river from the Younger Dryas and inserted fills of the meandering river from the Early Holocene were recorded in the Vistula (Kalicki 1991) and Wisłok valleys (Gębica et al. 2009). The Late Vistulian phase of increased fluvial activity is also observed under the alluvial fans deposited in the outlets of small valleys in the margin of the Carpathians (Kalicki 1997).

CONCLUSIONS

Presented progress of research on stratigraphy of alluvia and fluvial landforms indicates, that it reaches back to the beginning of the 20th century. Application of wide spectrum of paleogeographical and chronological methods, among others the radiocarbon dating, made possible "rejuvenation" of the age of terraces and attribution of the terrace 15 m high in the Wisłoka valley to the Middle and Upper Plenivistulian. Many dated sites were the basis for reconstruction of the scheme of terrace alluvia stratigraphy and particularly, the conception of 2–3 alluvial inserts in the Middle Plenivistulian, manifested at the Carpathian margins and separated insert dated at the maximum phase of the Vistulian Glaciation (LGM) (Fig. 2). The cutting of the high Vistulian terrace commenced before the maximum of the Vistulian (before 20 ka BP) and was connected with reduction of denudation in the arid, periglacial climate. The oldest large paleomeanders developed before the Alleröd. During the Younger Dryas large and wide paleomeanders were formed, currently well recognised in the Wisłoka and San valleys. In some sections of river valleys the tendency toward braided channels formation took place during the Younger Dryas. In spite of research progress our knowledge about river action in the Pleistocene–Holocene transition is still insufficient.

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