S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

PIOTR GĘBICA[1] (RZESZÓW), KAZIMIERZ SZCZEPANEK[2] (KRAKÓW),
DARIUSZ WIECZOREK[3] (KIELCE)

LATE VISTULIAN ALLUVIAL FILLING IN THE SAN RIVER VALLEY IN THE CARPATHIAN FORELAND (NORTH OF JAROSŁAW TOWN)

Abstract. The valley of the lower San river downstream from town of Jarosław is filled with the alluvial sediments of the thickness 15–19 m which form the Vistulian terrace (8–12 m above the river level) as well as system of the terraces of the Late Vistulian and the Holocene (5–8 m, 3–5 m and 1–3 m above the river level). Radiocarbon datings supplemented with palynological and sedimentological analyses made possible to distinguish the alluvial fill of the decline of the Upper Plenivistulian (15,600–14,000 BP) occurring within the Vistulian terrace as well as system of the paleochannels and the alluvial fills of the Late Vistulian, Preboreal, Boreal and the Subatlantic phases occurring within the Holocene terraces. Some of the Late Vistulian large paleomeanders of the San river could have been subsequently used by flood waters and finally filled up with peat sediments during the Subboreal phase. Under the Late Vistulian and the Holocene paleochannel fills, at the depth 3.5–5.0 m member of the sand alluvia of the decline of the Upper Plenivistulian (15,100–14,200 BP) were recorded, similarly to the Vistulian terrace. It can indicate the shallow incision of the Plenivistulian and/or the Late Vistulian sediments and reworking of the channel alluvia within the Holocene terraces of the San river. The aggradation of the thick overbank sediments upon the channel alluvia dated at 15,000 BP (within the left-side part of the valley) is probably connected with the alluvial fan of the Wisłok river.

Key words: lower San river valley, Plenivistulian and Late Vistulian alluvia, radiocarbon (^{14}C) datings, palynological datings

AREA, FRAME AND METHODS OF STUDY

In the Carpathian foreland the San river valley is 7–15 km wide and uses the eastern section of the Fore-Carpathian Through (Rynna Podkarpacka). The valley is distinctly asymmetric. The San riverbed is pushed by its right-side tributaries: Wiar, Wisznia and Szkło rivers, thus flows next to the slope of the loess plateau. The Holocene terraces is 5–6 km wide nearby the Wiar river mouth, while it is about 10 km wide in the vicinity the mouths of the Wisznia and Szkło rivers. The San riverbed incises this Holocene terrace as deep as 8–10 m. Between Medyka and Stubno villages the natural levee several kilometers wide occurs on the terrace 8–10 m high. It dips to the east, toward zone of the flood basins, about 3 m lower than the terrace level, within which the paleochannel studied by K. Klimek et al. (1997) occurs. According to the former (archival) borehole data, the natural levee of the thickness 2–4 m is formed of the alluvial loams interbedded with sands. They are underlain by the paleochannel fills or sands of channel facies, which occasionally contain tree trunks at the depth 9.0–9.5 m. It indicates that the channel incision reached the top of gravel series at the depth 9–10 m during the Late Vistulian and the Holocene.

To the north of Jarosław town the valley becomes wider. It is occupied by the extensive Vistulian terrace (8–12 m above the river level; t-III) duned at the uppermost part, covering the area between the San and Wisłok rivers (Fig. 1). The remnants of the erosional channels accompanied by the elongated natural levees (duned in some places) occur on the surface of this terrace-fan. The channels are most probably the remains of the Wisłok riverbed near its mouth into the San river (Gębica 2004). The Holocene terrace (5–8 m high) of the width 4–5 km is composed of system of the large paleomeanders of the curvature radius r = 550–600 m and the channel width w = 100–300 m, which form the separate Late Vistulian terrace level (t-IVa). Further toward the valley axis (predominantly in its left-side part), smaller and narrower Holocene paleochannels occur, which are situated within the Holocene terrace, 5–8 m high (t-IVb). The floodplain level is represented by the narrow terrace ledges, of the height 3–5 m and 1–3 m (t-IVc) and the width 100–400 m, lying on the both sides of the San riverbed. According A. Szumański (1977), the floodplain (3–5 m high) is formed of poorly sorted, bedded channel sands, covered by laminated alluvial loams, silts and sands deposited during floods. The sediments of the floodplain were deposited mainly in the 18th and 19th centuries as a result of change in the hydrological regime of the river and were inserted into the alluvia of the Holocene terrace as deep as 10 m (Szumański 1986). On the right-side part of the valley floor near Manasterz village the Vistulian terrace (t-III) is well developed (duned at the top part), in which the Manasterz sand pit is situated. It is cut by the large paleomeander, described by A. Szumański (1986) as the Late Vistulian form. The current San riverbed, 70–120 m wide, is characterized by slightly curvilinear course due to the artificial regulation and hydrotechnical reconstruction in the 20th century.

In September 2007 within the San river valley, 8–10 km north of town of Jarosław, the boreholes were drilled along the transect between Wólka Pełkińska and Manasterz villages. The study objective was to describe the lithology of the alluvia and, consequently, to determine the detailed stratigraphy of the Vistulian and the Holocene alluvial series. Totally 12 boreholes were drilled and the Manasterz sand pit was described. An analysis of granulometric composition of 106 samples (taken from 6 borehole logs) in the laser granulometer Analysette 22 (Fritsch) was carried out using sieve technique. Palynological analysis of 16 samples taken from 7 selected logs was carried out in the Botanical Institute of

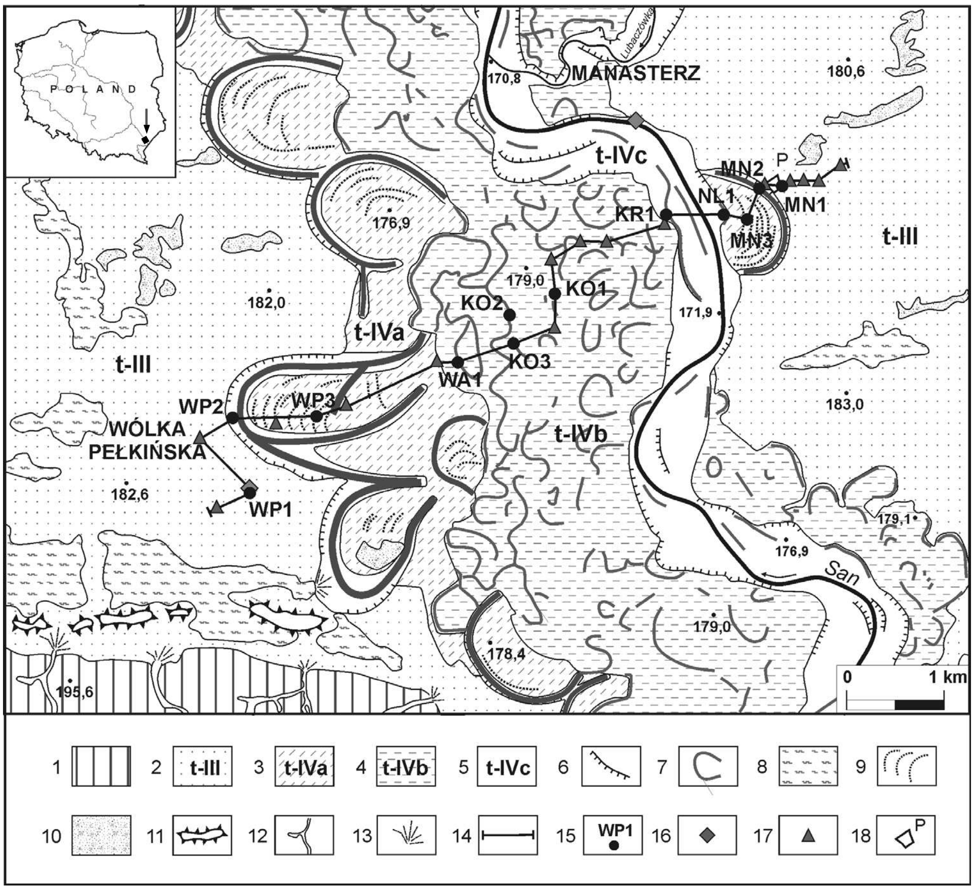

Fig. 1. Geomorphological map of the San valley floor to the north of Jarosław (after W ó j c i k and M a l a t a 2004 — modified) with location of studied boreholes and cross-section line. 1 — loess plateau, 2 — Vistulian terrace (8–12 m above river level) (t-III), 3 — Late Vistulian terrace with large paleomeanders (5–8 m above river level) (t-IVa), 4 — Holocene terrace (5–8 m above river level) with small paleomeanders (t-IVb), 5 — Holocene terrace (3–5 m above river level.) (t-IVc), 6 — erosional undercuts, 7 — selected paleochannels, 8 — depressions in the Vistulian terrace, 9 — natural levee and pointbars, 10 — aeolian sand fields and dunes, 11 — outliers, 12 — gullies, 13 — alluvial fans, 14 — line of geological cross-section, 15 — boreholes drilled in a framework of the granted project (WP1 — Wólka Pełkińska 1, WP2 — Wólka Pełkińska 2, WP3 — Wólka Pełkińska 3, WA1 — Wawry 1, KO1 — Kostków 1, KO2 — Kostków 2, KO3 — Kostków 3, KR1 — Kruby 1, NL1 — Nielepkowice 1, MN1 — Manasterz 1, MN2 — Manasterz 2, MN3 — Manasterz 3), 16 — boreholes and former (archival) boreholes with radiocarbon dates, 17 — other former (archival) boreholes, 18 — Manasterz sand pit

the Jagiellonian University in Cracow. The age interpretation of sediments was based on isopollen maps (R a l s k a - J a s i e w i c z o w a et al. eds. 2004). Palynological analysis of one sample taken from the Manasterz sand pit was conducted in the Division of Botany of the Ivan Franko Lviv National University, while malacofauna analysis of one sample taken from the Wawry-1 site was performed in the Faculty of Geology, Geophysics and Environment Protection of the AGH University of Science and Technology in Cracow. 15 samples were dated by radiocarbon method in the Radiocarbon Laboratory in Kiev, whereas one sample was dated by ^{14}C method in the Radiocarbon Laboratory in Gliwice (Tab. 1). The field data obtained from boreholes and outcrop were supplemented by 16 archival boreholes drilled within the alluvial series 15–19 m thick filling the San river valley.

Table 1

Samples dated by radiocarbon method. Calibration to calendar age was made using OxCal 3.10 program (Bronk Ramsey 2005) for probability level 95% (2φ)

Name and number of profile	Depth [m]	Type of material	Laboratory No.	Radiocarbon age [BP]	Calibrated age [BP]
Wólka Pełkińska (Malata, Wójcik, 2004)	7.27–7.38	Organic mud	Gd-11415	15,000 ± 300	18,950 ÷ 17,150
Wólka Pełkińska 2 WP-2/2.5	0.95	Peat	Ki-15369	8,670 ± 120	10,200 ÷ 9,450
Wólka Pełkińska 2 WP-2/5.5	1.85–1.90	Mud with organic detritus	Ki-15329	14,600 ± 220	18,550 ÷ 16,850
Wólka Pełkińska 2 WP-2/12	4.20–4.26	Silty sand with organic material	Ki-15241	7,250 ± 90	8,220 ÷ 7,920
Wawry 1 WA-1/2	0.71–0.75	Organic mud	Ki-15370	4,370 ± 90	5,350 ÷ 4,700
Wawry 1 WA-1/5	2.05–2.07	Organic mud	Ki-15371	7,270 ± 120	8,360 ÷ 7,920
Wawry 1 WA-1/5.5	2.47–2.50	Organic mud	Ki-15232	9,190 ± 100	10,600 ÷ 10,190
Kostków 3 Ko-3/5.5	1.27–1.30	Organic mud	Ki-15231	8,100 ± 90	9,300 ÷ 8,650
Kostków 3 Ko-3/14	2.52–2.55	Organic mud	Ki-15367	10,100 ± 120	12,100 ÷ 11,250
Kostków 3 Ko-3/21	4.85–4.95	Silty sand with organic detritus	Ki-15368	15,100 ± 190	18,850 ÷ 17,850
Kostków 2 Ko-2/10	3.50–3.56	Mud with organic material	Ki-15240	14,240 ± 100	17,550 ÷ 16,500
Kostków 1 Ko-1/8	3.09–3.14	Mud with organic material	Ki-15233	12,870 ± 120	15,700 ÷ 14,800
Kruby 1/9	3.58–3.64	Organic mud	Ki-15244	2,420 ± 70	2,720 ÷ 2,340
Kruby 1/12	4.08–4.10	Mud with fragments of wood	Ki-15247	2,150 ± 70	2,340 ÷ 1,980
Manasterz sandpit (2006)	2.40–2.50	Organic silt	Gd-15973	15,660 ± 290	19,550 ÷ 18,450

Table 1 cont.

Name and number of profile	Depth [m]	Type of material	Laboratory No.	Radiocarbon age	Calibrated age
				[BP]	
Manasterz Mn-1/1 sandpit (rok 2007)	2.23–2.25	Organic silt	Ki-15238	14,100 ± 130	17,350 ÷ 16,250
Manasterz Mn-1/2 sandpit (rok 2007)	2.38–2.40	Organic silt	Ki-15255	14,200 ± 100	17,450 ÷ 16,450

FORMER RESEARCHES

The occurrence of the Vistulian and the Holocene alluvia within the San river valley was suggested in the first Geological Map of the Galicia region (Łomnicki 1900). In Walawa and Barycz villages S. Kulczyński (1932) described clays and sands bearing Dryas flora, under the Holocene alluvial loams 5 m thick. Based on these profiles, M. Klimaszewski (1948) postulated that the lower alluvial series of the San river terrace represent the Middle Polish Glaciation (Saalian), while only the thin cover of the overbank sediments represented the Holocene period. Similar alluvial sands and silts with organic detritus, deformed by involutions, were described near the mouth of the Wisznia river into the San (Pękala 1964). Some sites in the Carpathian foreland were described by L. Starkel (1960), who postulated that the Dryas clays at the Barycz and Walawa sites were deposited during the Vistulian Glaciation. Based on palynological analysis carried out by M. Sobolewska, he distinguished the alluvial fill representing the decline of the Late Glacial (Late Vistulian) at the depth of 8 m in Hurko and Torki villages. The sand-gravel alluvia containing tree trunks and attributed to the Atlantic phase are inserted within the Late Vistulian series. Uppermost part of the Holocene terrace formed of the alluvial loams of the thickness up to 5 m, bearing sand lenses, were deposited during the Subatlantic phase. The channel alluvia at the Przemyśl-Przekopana site, dated by L. Starkel (1977) at the top part of the sequence at 10,375 ± 125 BP, indicates the decline of the fluvial deposition during the Younger Dryas.

The geomorphological mapping of the terraces in the lower section of the San river valley was conducted by J. Wojtanowicz (1978), who distinguished the accumulation level (9–11 m high above the river level) of the Vistulian age (duned at the top) and the lower Late Vistulian erosional level (5–7 m high), as well as the Holocene terrace (5–8 m high) and two floodplain levels: 3–5 m high and 1–3 m high. J. Wojtanowicz (1978) considered the alluvia filling the

San river valley to be deposited mainly during the Middle-Polish Glaciations (Saalian), whereas only the several meters thick sands forming the top of the terrace 9–11 m high were deposited during the Vistulian.

The researches of A. Szumański (1983, 1986) in the lower section of the San river valley confirmed the occurrence of the erosional level characterized by system of the shallow braided channels (terrace no. 1), whose age has not been yet determined, nested within the Plenivistulian terrace. This terrace is cut by the large meanders of the San river (terrace no. 2), whose fills were attributed to the Younger Dryas. The younger channel alluvia bearing tree trunks are covered by two-partite unit of the alluvial loams (terrace no. 3). A few radiocarbon datings obtained from the wood fragments found under the overbank sediments at the depth between 3–5 m represent the Atlantic, Boreal and Subboreal phases as well as the Middle Ages.

The study of K. Klimek et al. (1997) carried out in the San river valley close to the Carpathian margin, in the vicinity of Stubno village, proved the existence of trough up to 6 m deep, which was considered to be the paleomeander, whose filling began about 15,200 BP and lasted during the Late Vistulian and the Holocene. The older paleochannel was found near Wietlin and Bobrówka villages. It resembles the extensive paleomeander (r = 1.75 km), described by D. Wieczorek (1999). It is filled with sediments of the Pleniglacial age, dated by radiocarbon method at 36,400 ± 3,530 BP (KR-157) at the depth of 10.5 m as well as sand sediments of the Late Vistulian age dated by TL method at 13,000 ± 2,600 BP (Lub-3380) at the depth of 3.0–3.4 m. Maybe the formation of such a large paleomeander was connected with the influx of the proto-San river into the thermokarst depression (Gębica 2004), developed on the Middle-Polish Glaciation (Saalian) terrace (Wieczorek 1999). Organic horizon occurring at the depth of 12.85–12.95 m within gravels in Koniaczów village was dated (by radiocarbon method) at more than 36,500 BP (Wójcik and Malata 2004). The radiocarbon date (15,000 ± 300 BP) obtained from sand sediments (at the depth of 7 m) forming the extensive terrace-fan between the San and Wisłok rivers in Wólka Pełkińska village, indicates the decline of the Upper Plenivistulian as the time of sand deposition (Wójcik et al. 1999).

In the area where the Wisłok river meets the San river (near Grodzisko Nowe village) the paleochannel filled with the sediments of the Preboreal (radiocarbon date 9,530 ± 240 BP) or the Late Glacial age (palynological analysis of K. Szczepanek) cuts the Vistulian terrace (Wójcik et al. 1999; Wójcik, Malata 2004). The fills of another Late Vistulian paleomeander of the Wisłok river, located near its mouth, was recently dated at 11,670 ± 325 BP (Gębica et al. 2008). The peat horizon situated directly upon the Late Vistulian sediments represents the decline of the Atlantic phase and the Subboreal phase (radiocarbon dates: 5,400 and 3,000 BP). This peat is overlain with overbank (flood) alluvia of the Subatlantic phase (date 1,780 ± 75 BP). The events of the paleochannel filling were connected with the colonization phases of the archeological site located in the Vistulian terrace in the Bronze Age (Lusatian Culture), Roman period and the early Middle Ages (Czopek 2007; Gębica et al. 2008).

The filling of the large-radii paleochannel of the San river cutting the Vistulian terrace near Kopki village (ca 28 km downstream from the Wisłok river mouth), was dated by radiocarbon method at 3,220–1,100 BP (Bałaga et al. 1997; Bałaga and Taras 2001). The peat filling this paleochannel contains pollen grains of cereals and other anthropogenic plants proving the apparent colonization phases during the Bronze Age (Lusatian Culture), Roman Period and the Middle Ages.

BOREHOLE LOGS IN THE AREA OF WÓLKA PEŁKIŃSKA–KRUBY VILLAGES

The structure of the Vistulian terrace (8–12 m high; t-III) near Wólka Pełkińska village was described due to the Wólka Pełkińska 1 borehole as well as re-interpretation of the former (archival) borehole log of Wólka Pełkińska (Wójcik, Malata 2004) (Figs. 1, 2). The uppermost section of the Wólka Pełkińska 1 depositional sequence is represented by overbank sandy silts series as deep as 5 m (Fig. 3). It overlies fine- and medium-grained sands with malacofauna reaching the bottom of the borehole (depth of 9 m). These sediments (of the channel facies) contain silt and organic interbeddings dated at 15,000 ± 300 BP (Gd-11415) in the former (archival) Wólka Pełkińska borehole log (sampled at the depth of 7.27–7.38 m) (Wójcik et al. 1999; Wójcik and Malata 2004).

To the east of Wólka Pełkińska 1 borehole the large paleomeander of the San river (curvature radius r = 550 m, channel width w = 200–300 m) cuts the Vistulian terrace.

The depositional sequence of the Wólka Pełkińska 2 borehole log (Fig. 2) is as follow: peat horizon up to the depth of 1.0 m; in the interval 1.0–3.5 m sandy silts interbedded with sand layer (at the depth of 2.4–3.0 m), in the interval 3.5–4.6 m silty sands with organic material (Fig. 4). Results of palynological analysis indicate that the peat horizon (at the depth of 0.9 m) are abundant in well preserved pollen grains of pine, birch and willow as well as few grains of larch. Therefore they represent boreal plant association of the Late Vistulian-Holocene transition (Young Dryas-Preboreal) (Tab. 2). Within the silt unit at the depth of 2.4 m and in the silty sands at the depth 4,1 m less amount of pollen grains of pine, birch and alder occur. The radiocarbon date of the peat sampled at the depth of 0.95 m values 8,670 ± 120 BP (Ki-15369), suggesting the Boreal. This radiocarbon date is too young in relation to the palynological analysis indicating the Young Dryas-Preboreal. The radiocarbon age of organic detritus occurring within the sandy silt unit sampled at the depth of 1.85–1.90 m is 14,600 ± 220 BP (Ki-15329), suggesting the decline of the Upper Plenivistulian. The third sample taken from silty sands containing organic material at the depth of 4.20–4.26 m

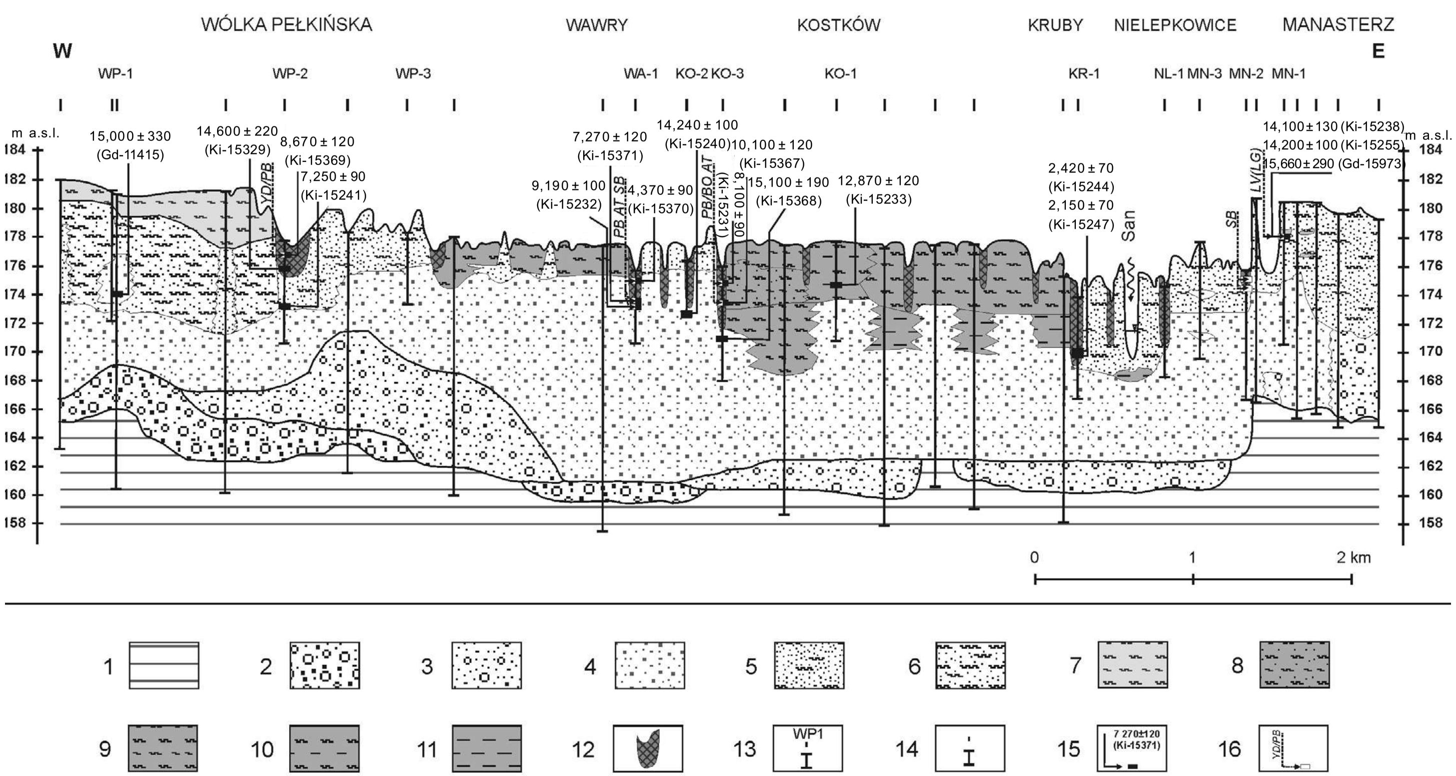

Fig. 2. Geological cross-section of the San river valley between Wólka Pełkińska and Manasterz villages, showing the lithology, radiocarbon datings and palynological age of alluvial sediments. 1 — pre- Quaternary substratum — Krakowiec Clays, 2 — gravel with sand, 3 — sand with gravel, 4 — sand, 5 — sand with silt 6 — silty sand, 7 — silts, 8 — sandy silt, 9 — alluvial loams, 10 — clayey silt, 11 — clay, 12 — paleochannel fill, 13 — boreholes drilled in a framework of the granted project, 14 — former (archival) boreholes, 15 — radiocarbon datings (radiocarbon age, laboratory number of samples), 16 — palynological analysis performed in a framework of the granted project. Age of alluvial deposits: LV — Late Vistulian, YD — Younger Dryas, PB — Preboreal, BO — Boreal, AT — Atlantic, SB — Subboreal

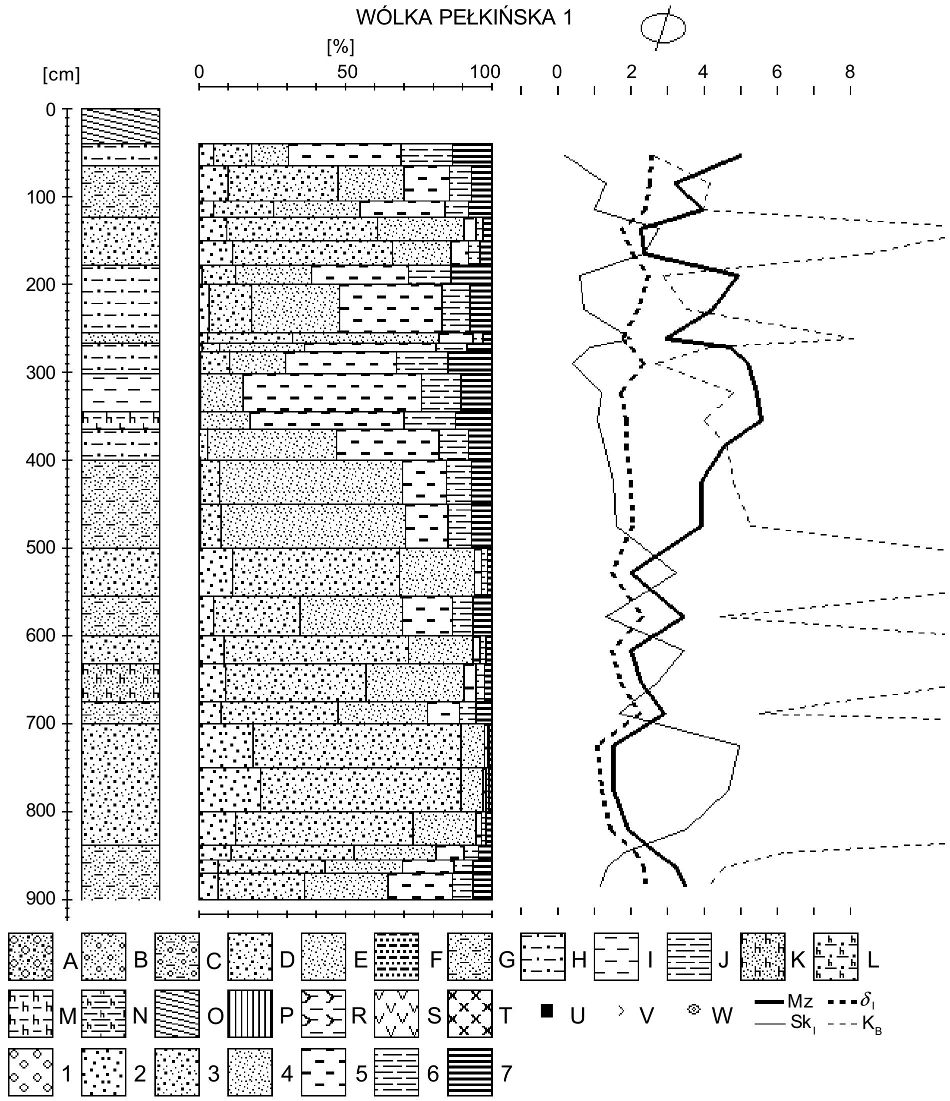

Fig. 3. Lithostratigraphical sequence and grain size indices of the Vistulian terrace (t-III) in the Wólka Pełkińska 1 borehole log. Explanation of symbols: A — sand with gravels, B — sand with rare pebbles, C — clayey sand with gravel, D — sand, E — fine-grained sand, F — silt interbedded with sand, G — silty sand, H — sandy silt, I — silt (mud), J — clayey silt, K — sand with organic matter, L — sandy silt with organic matter, M — silt with organic matter, N — clayey silt with organic matter, O — Holocene soil, P — earthwork, R — silt with organic detritus, S — clayey peat, T — peat, U — radiocarbon dates, V — organic detritus, W — wood fragments. Grain size indices after L. R. Folk and W. C. Ward (1957): Mz — mean grain size in phi scale, δ_I — standard deviation, Sk_I — skewness, K_G — kurtosis. 1 — medium- and fine-grained gravel 2–16 mm (–1– –4 φ), 2 — coarse-grained sand 0.5–2 mm (1–-1 φ), 3 — medium-grained sand 0.25–0.5 mm (2–1 φ), 4 — fine-grained sand 0.063–0.25 mm (4–2 φ), 5 — coarse- and medium-grained silt 0.02–0.063 mm (6–4 φ), 6 — fine-grained silt 0.004–0.02 mm (8–6 φ), 7 — clays <0.004 mm (>8 φ)

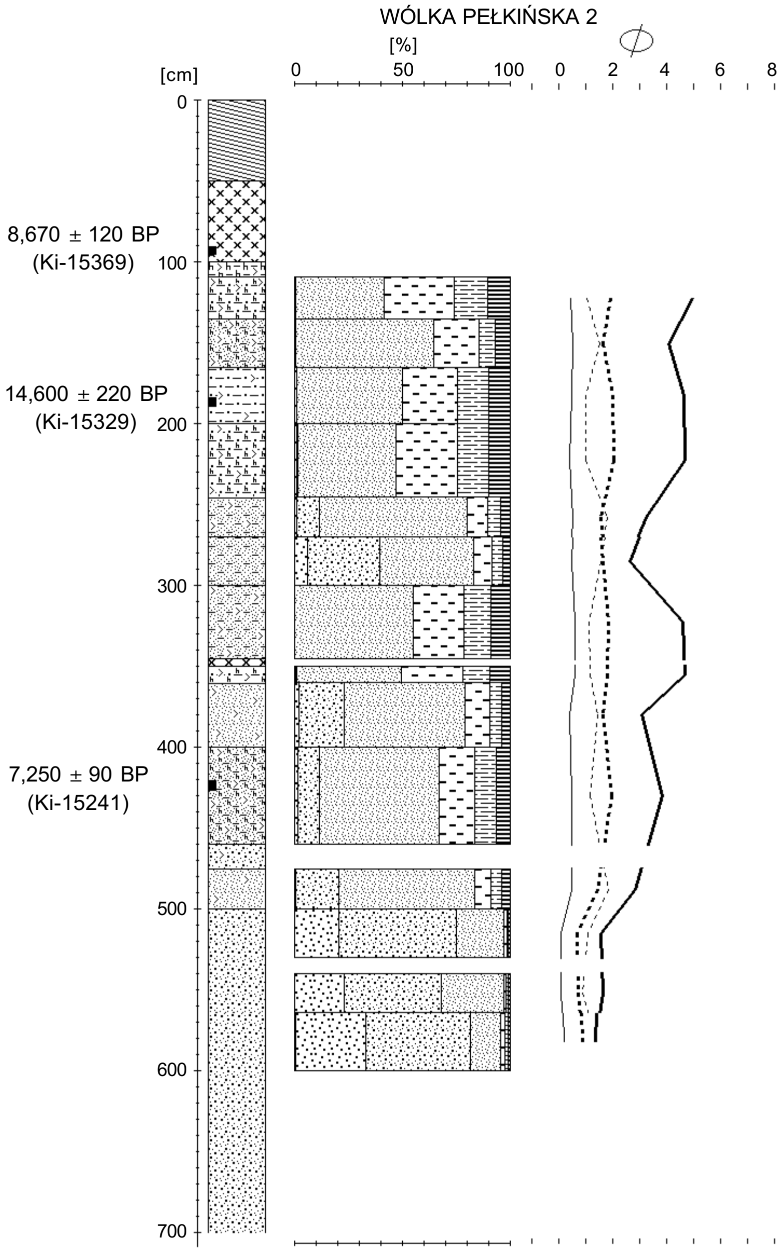

Fig. 4. Lithostratigraphical sequence and grain size indices of the Younger Dryas/Preboreal paleochannel in the Wólka Pełkińska 2 borehole log. Explanations see Fig. 3

(below the bottom of the paleomeander fill) was dated at 7,250± 90 BP (Ki-15241), suggesting the Atlantic phase. It seems that the date 14,600 BP is too old, whereas the date 7250 BP is most probably too young. The palynological analysis can not be used for the age determination due to insufficient state of the pollen grains preservation (Tab. 2).

The Wólka Pełkińska 3 borehole was drilled within the large-radii paleomeander of the San river, where the ground surface is situated 1–2 m above the plain with the Holocene paleochannels. It drilled silty-sandy overbank alluvia and channel sands forming the natural levees and meander pointbars, duned at the top part.

Further to the east, the extensive segment of the Holocene terrace 5–8 m high (175–178 m a.s.l.) lies. The terrace surface is situated around 1–2 m lower than the Late Vistulian paleochannel system (Fig. 2). The terrace is formed of the Holocene paleochannel system and the alluvial fills. The Wawry 1 borehole was located in the boundary zone between the terraces t-IVa and t-IVb. It was drilled within the paleochannel (r = 100 m, w = 50–65 m) cutting the Late Vistulian paleomeander. In the samples taken at the depth of 0.75 and 2.03 m (samples no 87 and 94, Tab. 2) pollen grains of thermophilous trees were identified: elm, hazel, oak, lime and alder. In these samples numerous shells of gastropods were also found. According to S. W. Alexandrowicz (personal com.) the gastropods represent the thermophilous taxa, living in the relatively shallow lake, which existed during the Atlantic and Subboreal. In turn, in the sample taken at the depth of 2.55 m (sample no 99) numerous pollen grains of pine, birch and elm as well as fewer pollen grains of willow, oak, alder and hazel were identified. This pollen assemblage indicates the deposition of this sediment during the Early Holocene (Preboreal/Boreal). Silt-organic horizon occurring at the top of the paleochannel fill, under clayey silts, sampled at the depth of 0.71–0.75, was dated at 4,370 ± 90 BP (Ki-15370), which suggests the Subboreal (Fig. 5). Silt-organic horizon situated at the bottom part of the paleochannel fill, sampled at the depths of 2.05–2.07 m and 2.47–2.50 m, was dated respectively at 7,270 ± 120 BP (Ki-15371) and 9,190 ± 100 BP (Ki-15232). The first date (sample no 94) suggests the Atlantic phase, while the second one (sample no 99) — the Boreal phase of the sediments deposition. Similar radiocarbon date, 9,090 ± 100 BP, was obtained from the organic detritus overlying sands at the depth of 3.5 m on the right-side part of the San river valley in Manasterz village (S z u m a ń s k i 1986).

In the Kostków 3 borehole log, drilled also within the paleochannel (r = 150 m, w = 35–50 m), in organic sediments sampled at the depths of 1.3 and 1.7 m numerous pollen grains of oak, hazel, elm and alder and few grains of hornbeam represent the association typical for forests of the Atlantic. Silt-organic sediment bearing wood fragments sampled at the depth of 1.27–1.30 m was dated at 8,100 ± 90 BP (Ki-15231) (Fig. 6), which indicates the beginning of the Atlantic. Alluvial silts with organic material sampled at the depth of 2.52–2.55 m

Table 2

Results of palynological analysis in the San river valley and their correlation with the radiocarbon datings (K. Szczepanek)

Site	Location	Sample number palinologically examined	Depth [m]	Sediments	^{14}C years BP	Age estimation based on pollen analysis	Pollen indicators
Wólka Pełkińska 2	N 50°05,221' E 22°36,418'	48	0.90	peat	8,670 ± 120	Younger Dryas/Preboreal chronozone	domination of pollen *Pinus* i *Betula*; vestigial amount of *Salix*, *Ulmus*, *Alnus*, *Picea*; abundant: Poaceae
		64	1.80	silt with plant remains	14,600 ± 220	no basis	very low pollen frequency
		80	4.10	sand with organic substances	7,250 ± 90	no basis	very low pollen frequency
Wawry 1	N 50°05,513' E 22°38'	87	0.75	organic silt	4,370 ± 90	Subboreal chronozone	abundant: *Quercus*, *Corylus*, *Tilia*, *Alnus*, *Ulmus*, *Picea*
		94	2.03	organic silt	7,270 ± 120	Atlantic chronozone	abundant: *Ulmus*, *Corylus*, *Quercus*, *Fraxinus*, *Alnus*
		99	2.55	organic silt	9,190 ± 100	Preboreal/Boreal chronozone	abundant: *Pinus*, *Betula*, *Ulmus*; less abundant: *Salix*, *Quercus*, *Alnus*, *Corylus*, *Fraxinus*
Kostków 3	N 50°05,637' E 22°38,843'	105	1.30	organic silt	8,100 ± 90	Atlantic chronozone	domination of pollen: *Corylus, Quercus, Ulmus, Alnus, Fraxinus*; scarce: *Salix, Tilia, Picea, Carpinus, Lemna*
		110	1.68	silt with plant remains	no datings	Atlantic chronozone	abundant: *Quercus, Corylus, Ulmus, Salix*; scarce: *Fraxinus, Alnus*; ocasionally: *Tilia, Picea, Carpinus*

Table 2 cont.

Site	Location	Sample number palinologically examined	Depth [m]	Sediments	^{14}C years BP	Age estimation based on pollen analysis	Pollen indicators
Kostków 3	N 50°05,637' E 22°38,843'	121	2.54	organic silt	10100 ± 120	Preboreal chronozone	domination of pollen: *Pinus, Salix*; plenty of: *Ulmus, Quercus, Betula*; ocasionally: *Corylus*, *Alnus, Fraxinus, Picea*
		139	4.90	dusty sand with organic substances	15,100 ± 190	no basis	very low pollen frequency
Kostków 2	N 50°05,781' E 22°38,814'	101	3.52–3.56	sandy silt with organic substances	14,240 ± 100	no basis	very low pollen frequency
Kostków 1	N 50°05,920' E 22°39,187'	100	3.90	silt with organic substances	12,870 ± 120	no basis	very low pollen frequency
Manasterz 2	N 50°06,476' E 22°40,959'	23	0.65	peat	no datings	Subboreal chronozone (younger)	abundant: *Carpinus*; less abundant: *Fagus*; some of: *Abies*; singular pollen grains: *Secale*, *Plantago lan.*, *Rumex* t. *acetosella*
		31	1.37	peat	no datings	Subboreal chronozone (younger)	abundant: *Carpinus*; less abundant: *Fagus*; some of: *Abies*; singular pollen grains: *Secale, Plantago lan.*, *Rumex* t. *acetosella*
Manasterz 1 sand pit, eastern part	N 50°06,495' E 22°40,145'	7	2.20	dust with organic substances	14,100 ± 130	no basis	very low pollen frequency
		18	2.30	dust with organic substances	14,200 ± 100	no basis	very low pollen frequency

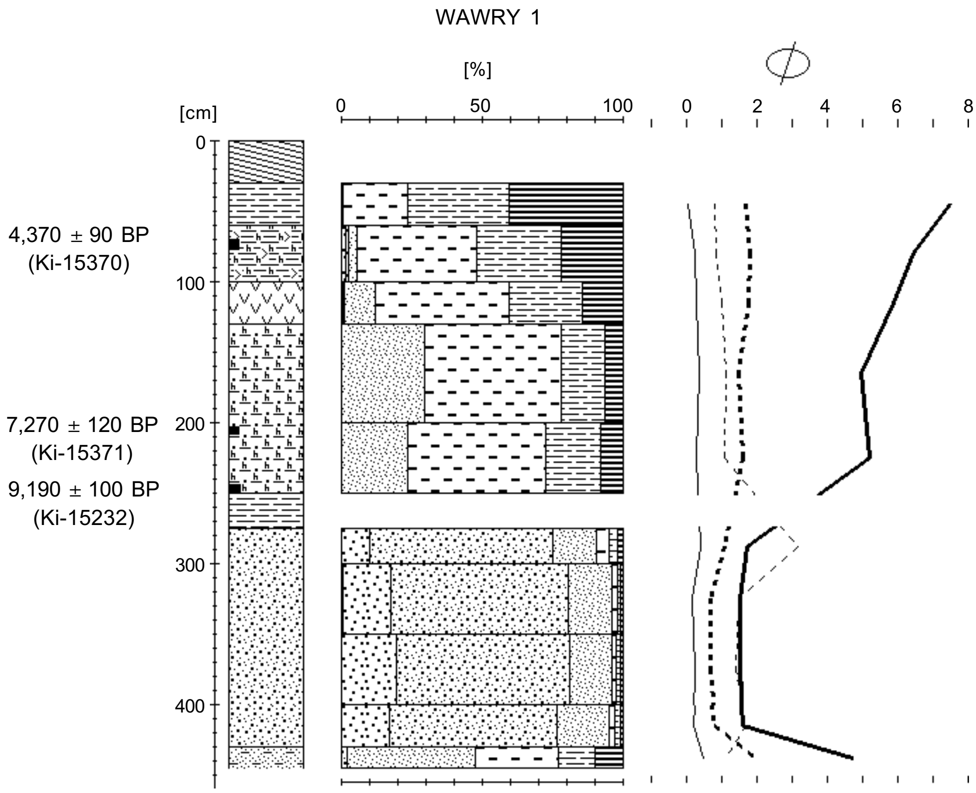

Fig. 5. Lithostratigraphical sequence and grain size indices of the Preboreal paleochannel in the Wawry 1 borehole log. Explanations see Fig. 3

were dated at 10,100 ± 120 BP (Ki-15367), which can prove the deposition at the beginning of the Preboreal phase. This age is confirmed also by palynological analysis showing, apart from the high number of pine and willow pollen grains, relatively high percentage of elm. Also the occurrence of pollen grains of other thermophilous trees, as oak, hazel, alder and ash does not exclude the Preboreal age of the sediment. The early appearance of the thermophilous trees, especially elm, oak, hazel, alder and ash could have been connected with the specific (warmer) local environmental conditions within the San river valley. The higher percentage of pollen grains of the thermophilous trees in the pollen profiles analyzed up till now (e.g. Mamakowa and Wójcik 1999; Starkel and Granoszewski 1995; Klimek et al. 1997) were attributed to the end of the Boreal and Atlantic.

Within the Kostków 3 depositional sequence silts are inerbedded with sand at the depth of 3.00–3.35 m. The sand layer was deposited by flood probably during the Younger Dryas. Silty sands containing organic material situated below

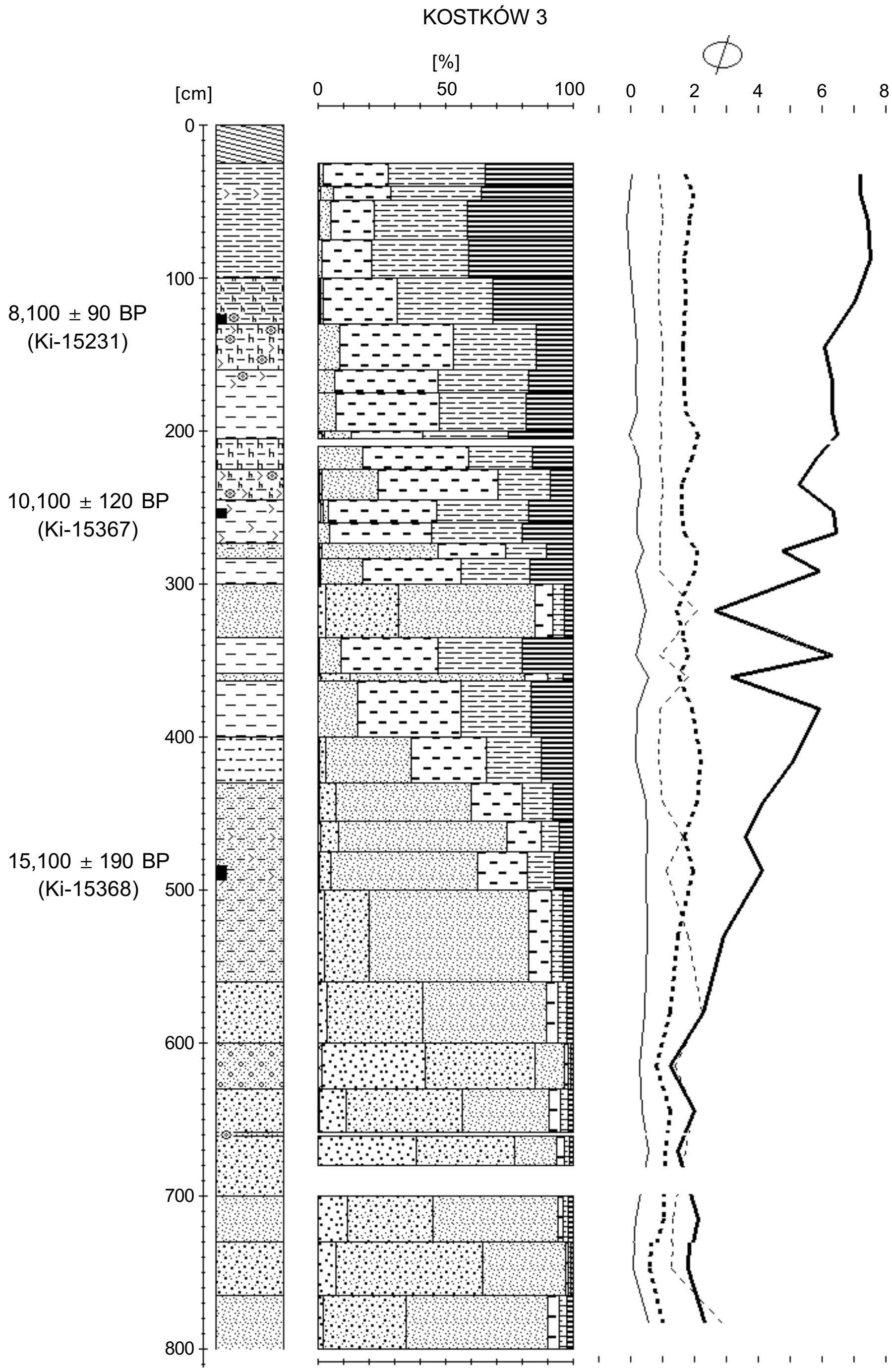

Fig. 6. Lithological sequence, grain size indices and radiocarbon datings of the Boreal paleochannel in the Kostków 3 borehole log. Explanation see Fig. 3

the paleochannel fills and sampled at the depth of 4.85–4.95 m were dated at 15,100 ± 190 (Ki-15368). So, they represent the overbank unit deposited during the decline of the Upper Plenivistulian, which can be confirmed by low frequency of pollen grains (Tab. 2).

The Kostków 2 borehole was drilled within the narrow natural overflow paleochannel situated between the paleochannels in which the Wawry 1 and Kostków 3 boreholes were drilled. It drilled medium- and fine-grained sands with interbedding of silty sand bearing organic material. Sediments sampled at the depth of 3.50–3.56 m were dated at 14,240 ± 100 BP (Ki-15240), which proves their deposition during the decline of the Upper Plenivistulian (Fig. 2).

The next, Kostków 1 borehole, situated 1.6 km far from the current San riverbed, drilled series of the overbank silts 3 m thick. Below this series unit of the natural levee sediments 1 m thick occur. The lowermost section of the sequence is represented by channel sands drilled to the depth of 7 m. Silts bearing organic material situated below alluvial loams, sampled at the depth 3.09–3.14 m were dated at 12,870 ± 120 BP (Ki-15233), which could indicate their deposition during the Late Vistulian.

Within the floodplain, 3-5 m high, which forms the ledge 200–400 m wide, lying along the current San riverbed, narrow paleochannels (6–10 m wide) are situated. The Kruby 1 borehole was drilled in one of these paleochannels. This paleochannel is filled with sand-silt unit 4.5 m thick bearing organic material and wood fragments. The samples taken at the depths of 3.58–3.64 m and 4.08–4.10 m were dated respectively at 2,420 ± 70 BP (Ki-15244) and 2,150 ± 70 BP (Ki-15247) (Fig. 2). It proves that the paleochannel was abandoned by river at the beginning of the Subatlantic.

Recapitulating, within the left side of the San river valley the following structural elements can be distinguished: alluvial fills representing the decline of the Upper Plenivistulian, outliers of the Late Vistulian sediments as well as the system of several fills with paleochannels from the Late Vistulian, Preboreal, Boreal (?) and the Subatlantic. It is not excluded, that the paleomeanders recorded in the Wawry 1 and Kostków 3 boreholes represent anastomosic channel systems developing during the Preboreal.

STRUCTURE AND AGE OF THE VISTULIAN TERRACE AND THE LARGE PALEOMEANDER OF THE SAN RIVER IN MANASTERZ SITE

In the right-side part of the San river valley near Manasterz village, the upper part of the Vistulian terrace (t-III) 8–12 m high above the river water table, is formed of silty fine-grained sands interbedded with silts containing organic material. Below the depth of 8–9 m, up to the depth of 14–15 m sands interbedded with fine-grained gravels occur. They overlie the Krakowiec Clays of the Miocene age (Fig. 2).

In July 2006, in the northern face of the sand pit of Manasterz at the depth of 2.30–2.55 m unit of silts abundant in organic material (paleochannel fill?) overlain and underlain by channel sands was found. According to N. Kalinovyč (personal com.) these silts at the depth of 2.40–2.50 m contain pollen grains of pine, birch, stone pine, willow, dwarf birch and herbaceous plants representing the Late Vistulian plant associations. Silts containing organic material sampled at the depth of 2.40–2.50 m were dated at 15,660 ± 290 BP (Gd-15973) in the laboratory at Gliwice (Fig. 2). This radiocarbon age is very similar to that obtained from the former (archival) borehole log of Wólka Pełkińska (15,000 ± 300 BP) (Wójcik and Malata 2004) situated in the left-side part of the Vistulian terrace. In 2007, in the eastern face of the Manasterz sand pit layer of silt-organic sediment was found at the similar depth (Fig. 7). Palynological analysis of sample taken at the depth 2.3 m displays very few pollen grains of pine, birch, spruce and larch, generally indicating cold-stenothermic plant associations. In 2008 these silts were dated by radiocarbon method in the laboratory in Kiev: sample taken from the depth of 2.23–2.25 m was dated at 14,100 ± 130 BP (Ki-15238), while

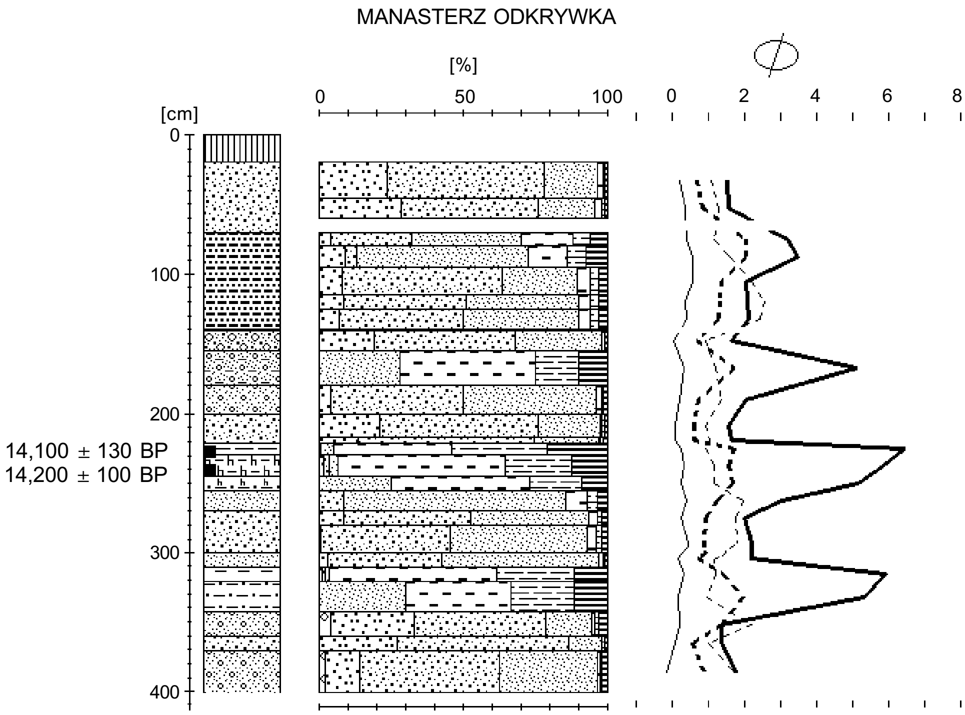

Fig. 7. Lithological sequence, grain size indices and radiocarbon datings of the Plenivistulian alluvial fill in the Monasterz sand pit. Explanation see Fig. 3

sample from the depth of 2.38–2.40 m was dated at 14,200 ± 100 BP (Ki-15255). Both dates indicate the decline of the Upper Plenivistulian and are very similar to the date obtained from the Kostków 2 borehole log (14,240 ± 100 BP), situated in the left side of the San river valley.

The Vistulian terrace (t-III) in Manasterz village is cut, similarly to the Wólka Pełkińska site, by large paleomeander of the San river of the curvature radius = 580 m and the channel width w = 80–100 m. Including the zone of the meander pointbars, it covers the lower fragment of the floodplain 5–6 m high. Owing to the Manasterz 2 borehole the following sequence of its fills was recorded: peat unit (0.00–0.70 m) and silts with organic material (0.70–1.37 m) overlying channel sands. Organic sediments sampled at the depths of 0.65 m and 1.37 m contain pollen grains of alder, oak, hazel, hornbeam, relatively numerous pollen grains of beach and fir as well as few pollen grains of cereals (e.g. rye) and ribwort plantain which are indicators of colonization. The occurrence of aquatic plant pollen grains proves the deposition within the shallow oxbow lake. The palynological dating and lower elevation of this paleochannel in relation to the surfaces of the Late Vistulian paleochannels can indicate the Young Holocene age of its fills, likely the Subboreal phase. The hypothesis of A. Szumański (1986), postulating the Late Vistulian age of this paleochannel can be confirmed by the structure of the meander pointbars composed of the arc-curved levees, marking the lateral shifting of the meander. They are formed of bedded sands and silts (levee sediments) passing downward into sands interbedded with fine-grained gravels (channel sediments) (Manasterz 3 borehole). These sediments are covered by thin blanket of overbank silt sediments. Probably it is the Late Vistulian channel (Szumański 1986), subsequently used as overflow channel during floods.

Within the neck of the above described paleomeander, but on the lower level of the floodplain 3–5 m high, representing the younger alluvial sediments the Nielepkowice 2 borehole was drilled within the paleochannel fills. The top part of the depositional sequence of its log is formed of sandy silts (0.0–0.8 m) overlying clayey silts interbedded with silts and silty sands (0.8–4.0 m). Regarding the location of this paleochannel, in the distance of 200 m from the current San riverbed, it can be considered that they are the overbank sediments deposited in the oxbow lake during floods for last several centuries.

Recapitulating, within the right-side part of the San river valley the following structural elements should be determined: alluvial fill attributed to the decline of the Upper Plenivistulian, large paleochannel, most probably developed during the Late Vistulian, which was ultimately filled up by peat sediments during the Subboreal phase.

DISCUSSION AND CONCLUSIONS

The results of radiocarbon datings, palynological analysis as well as sedimentological analysis confirm development and activeness of the large paleomeanders within the San river valley downstream from Jarosław town during the decline of the Late Vistulian, which were formerly described by A. Szumański (1983, 1986). These Late Vistulian paleochannels are undercut by system of smaller paleochannels, attributed to the Preboreal phase on the basis of palynological analysis (radiocarbon date 9,190 ± 100 BP) as well as the younger paleochannel and alluvial fill of the Boreal (with too old radiocarbon date 10,100 ± 120 BP obtained from the bottom of fills) (Figs. 2 and 8). Palynological analysis can indicate that the large paleochannels of the San river at the Manasterz site, described by A. Szumański (1986) as the Late Vistulian forms, could have been subsequently used by flood waters and ultimately filled up by peat sediments during the Subboreal phase. Probably similar situation took place at the Kopki site, where palynological analysis and radiocarbon datings of the paleochannel fills indicate peat accumulation also during the Subboreal phase (Bałaga and Taras 2001).

The radiocarbon datings partially do not confirm the results of palynological analysis, which indicate either younger age of sediments (Kostków 3), or much older age of sediments (Wólka Pełkińska 2).

Under the Late Vistulian and the Early Holocene paleochannel fills, at the depth ca 3.5–5.0 m the sand unit attributed to the decline of the Plenivistulian and dated at 15,100–14,200 BP was recorded. Similar age is assigned to the channel sediments of the left-side Vistulian terrace at the Wólka Pełkińska site (15,000 BP) (Wójcik and Malata 2004) as well as right-side Vistulian terrace at the Manasterz site (15,600–14,100 BP). Therefore, the left-side and right-side terraces represent the same alluvial series developed during the decline of the Upper Plenivistulian which may correlated the warmer climatic period called the Epe Interstadial (Kozarski 1991). This upper series of the Vistulian terrace discovered earlier in the Wisłoka valley (Starkel 1995) and Wisłok valley (Gębica 2004) has been dated first time so exactly in the Sandomierz Basin in the above described localities. The dissection of the terrace started probably during the pre-Late Vistulian warming of the Epe Interstadial (Starkel et al. 2007), e.g. much earlier than the formation of Late Vistulian fill forming lower terrace with large paleomeanders dated between 13,000–10,000 BP.

Closer to the Carpathian margin, the alluvial cover was cut during the decline of the Upper Plenivistulian. The paleochannel (?) at the Stubno site, reaching the depth of 3 m below the current San riverbed, was being filled since 15,200 BP (Klimek et al. 1997). Contrary to that, the overbank aggradation of the alluvia, situated several meters above the current riverbed (dated at the Wólka Pełkińska site at 15,000 BP; Wójcik, Malata 2004), was probably connected with the flood deposition on the alluvial fan of the Wisłok river.

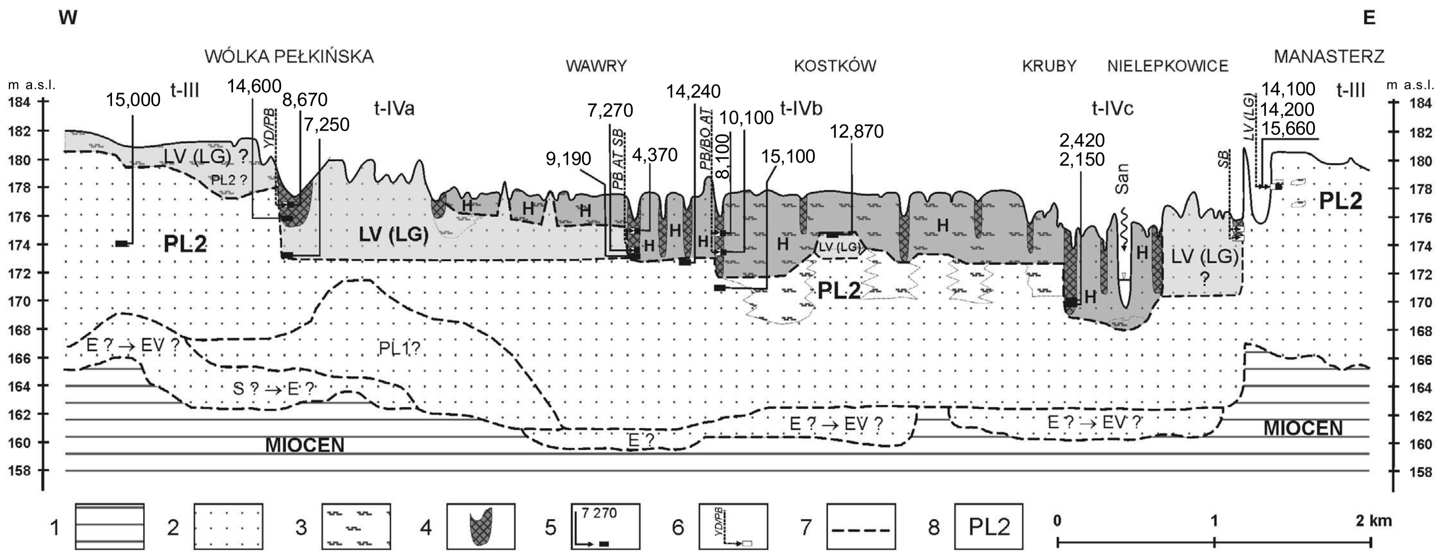

Fig. 8. Generalized stratigraphical and lithofacies scheme of the alluvial fills in the San river valley (north of Jarosław town). 1 — pre-Quaternary substratum — Krakowiec Clays, 2 — channel facies, 3 — overbank facies, 4 — paleochannel fills, 5 – radiocarbon datings (yrs BP), 6 – palinological age (chronozone), 7 — boundary of the lithostratigraphical alluvial units, 8 — age of alluvial deposits: S — Saalian (Middle-Polish Glaciation), E — Eemian, EV — Early Vistulian, PL1 — Lower Plenivistulian, PL2 — Upper Plenivistulian, LV — Late Vistulian, YD — Younger Dryas, PB — Preboreal, Bo — Boreal, SA — Subatlantic, H — Holocene (in general)

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[1] *Department of Geography*
University of Information Technology and Management in Rzeszów
ul. Sucharskiego 2, 35-225 Rzeszów, Poland
piotrgebica@wp.pl

[2] *Institute of Botany, Jagiellonian University*
ul. Kopernika 27, 31-501 Kraków, Poland

[3] *Geoconsult Sp.z o.o.*
ul. Mielczarskiego 139/143, 25-611 Kielce, Poland
wieczorek@geoconsult. kie.pl

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