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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

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ORIGIN, LITHOLOGY AND AGE OF THE HOLOCENE TERRACE OF THE WISŁOK RIVER IN THE SANDOMIERZ BASIN

Abstract. The paper presents lithological description as well as palynological analysis and radiocarbon datings of borehole logs and profiles outcropped within the Holocene terrace (6–7 m high) of the lower section of the Wisłok river valley. The occurrence of the Younger Dryas segment of the alluvial plain bearing tree trunks as well as overbank depositional members of the Boreal and Atlantic phases have been recorded. Within this last unit the paleosol dated by radiocarbon at 8,700 BP should be mentioned. The central part of the plain is occupied by the system of paleochannels filled with the oxbow-lake sediments of the Late Vistulian–Preboreal and Boreal phase as well as an unit of channel sand with wood fragments dated at the beginning of the Atlantic phase. The channel alluvia and sediments of the natural levee of the paleomeander system of Stary Wisłok (Old Wisłok), deposited by floods during the Subatlantic phase are the youngest fills nested within the structure of the studied plain. The aggradation of the levee sediments is also connected with human impact during the Roman Period (2nd– 4th centuries AD). Preservation of the alluvial and paleochannel fills of the Late Vistulian and the Early Holocene has been possible thanks to the avulsion of the Wisłok riverbed from the Stary Wisłok paleomeander system to the northern part of the valley in the 18th century AD.

Key words: Wisłok valley, Holocene terraces, alluvial fills, lithology, radiocarbon datings, palynology

GEOMORPHOLOGICAL SETTINGS

Downstream from town of Rzeszów the Wisłok river flows northeast and then east across 4–6 km wide, flat valley bottom using part of latitudinal depression of the Fore-Carpathian Trough (Fig. 1). From the south and the north the trough is bordered with plateau slopes. The floor of the trough, eroded in Miocene clays, is covered with the alluvia of the Vistulian terrace 8–10 (12) m high (above the riverbed) and the Holocene terrace. The Holocene terrace rise now ca. 6–7 m above the mean water level at the Wisłok river and is developed mainly in the right-side part of the river valley. The 4–6 m thick gravel unit, lying upon the uneven surface of the Miocene rocks at the depth of 11–13 m, is the characteristic element of the terrace structure. The gravel unit is overlain with a series of sands with gravels of the channel facies 4–5 m thick, while the uppermost unit

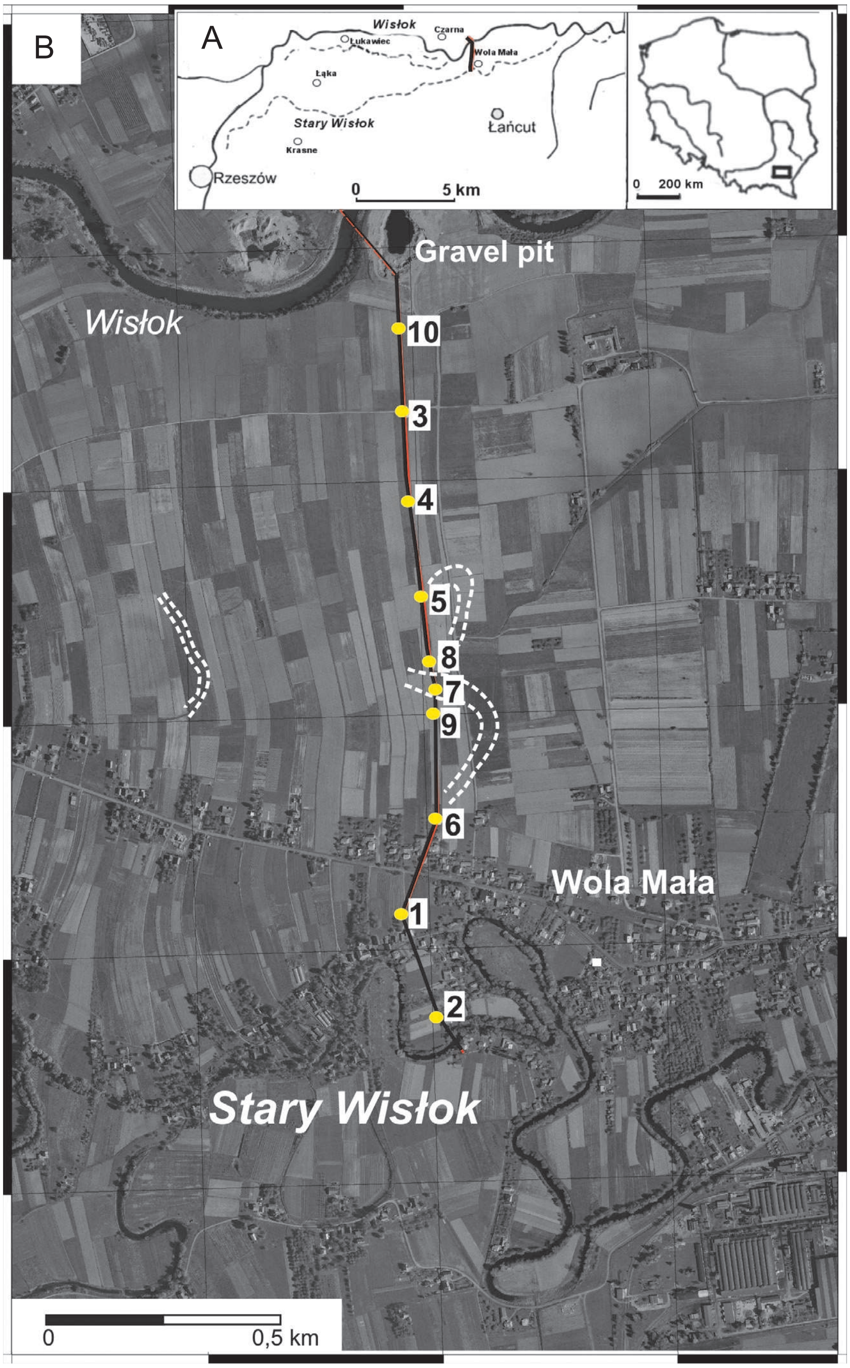

Fig. 1. A. Location of studied section of the Wisłok river valley. B. Location of transect line with boreholes in Wola Mała village near Łańcut

of the sequence is formed of oxbow-lake sediments and overbank sediments 3–4 m thick. The plain surface is uneven, covered with flat-bottomed basins (flood basins) without oxbow lakes, flat fragments of plain with remnants of paleomeanders as well as elevations rising 1–2 m above the plain (natural levees), associated with the system of the Stary Wisłok paleomeanders in the southern part of the valley (Fig. 1). The Stary Wisłok (Old Wisłok) riverbed of 20 m in width and the depth of 2–3 m, characterized by steep slopes and very winding shape, was ultimately abandoned after the flood in mid-18th century (Strzelecka 1958) and recently it has only occasionally been filled with water. After the avulsion of the Wisłok river to the north, the northern riverbed filled with sand-silt alluvia formed. Subsequently, the plain has been eroded and, simultaneously, aggraded by overbank sand-loam sediments during floods. During floods the overflowing water probably used also the abandoned Stary Wisłok riverbed, thus preserving it from filling up. Subsequent floods have also produced a natural levee along the current riverbed, which has hindered the access of flood water to the Stary Wisłok paleomeander system. For this reason, during the flood in July 1934 the waters did not reach this system, flooding only the lower parts of the terrace 6–7 m high near Łąka village (Lewakowski 1935; Starkel 1960). The alluvia forming the floodplain 5 m high (covered by water during overflows) fill the cuttings within the terrace 6–7 m high. The floodplain 5–6 m high forms narrow near-channel ledges on both sides of the current Wisłok riverbed.

FORMER RESEARCH, ORGANIZATION AND METHODS OF STUDY

Geological investigations of the lower section of the Wisłok river valley were started by W. Friedberg (1903). In several outcrops on the Wisłok riverbank he described bluish-gray “Young Diluvial” clays overlain with sand and loam alluvia of the Holocene. A. Jahn (1957) described the structure and the age of the Wisłok valley terraces in Rzeszów town. He found out that the depositional sequence of the terrace (6–8 m high) comprises the alluvial loams with inserts of peat layers. It reaches the depth of 8 m and overlies Vistulian gravel unit. It was attributed to the Holocene and fills the cutting within the alluvia of the middle (loess) terrace. Organic inserts within the bottom part of the Holocene terrace depositional sequence (at the depth of 6.5–7.5 m) were studied by L. Starkel (1960) in the southeastern part of Rzeszów town. According to K. Mamakowa (Starkel 1960) the pollen spectra of these organic sediments represent the Late Glacial (Late Vistulian) and the Early Holocene. Ceramic artifacts found by Janowski (Starkel 1960) in the left bank of the Wisłok river in Staromieście section, the northern part of Rzeszów town, were to be as old as about 2,000 BP (artifacts at the depth of 5 m) and about 4,000 BP (at the depth of 7 m). Based on these ages, the overbank alluvia of the terrace were attributed by L. Starkel (1960) to the Subatlantic phase.

The research conducted up till now, although based on a few radiocarbon dates, enabled to distinguish (within the northern valley trough, at the transect Łukawiec–Łąka–Krasne) the erosional socle of the Holocene terrace 6–7 m high formed of the Plenivistulian alluvia with remnants of Dryas flora (G ę b i c a 2004; S z c z e p a n e k et al. 2007) as well as several alluvial fills attributed to the Alleröd Interstadial, Younger Dryas and the Atlantic. Within the southern valley trough (south of the erosional remnant of the Vistulian terrace in Łąka village) a plain abundant in peat-bogs with the Late Vistulian paleochannel system of the Wisłok dated (by radiocarbon method) at 11,070 BP and Preboreal paleochannel dated at 9,700 BP (G ę b i c a et al. 2002; G ę b i c a and S u p e r s o n 2003; G ę b i c a 2004) is situated. Recent archeological excavations preceding the construction of A-4 highway enabled OSL datings of the "old" cover of the overbank flood sediments in Terliczka village (west of Łąka village), in which flint artifacts attributed to the Paleolithe or/and the Mesolithe were found. The cover of overbank sediments was dated at 6,470 BP (a sample from the depth of 0.75 m) and 9,400 BP (a sample from the depth of 1.25 m) (G ę b i c a and M i t u r a 2005).

In Wola Mała village, near the boundary with Czarna village, in the vicinity of town of Łańcut, in the 7 m high terrace undercutting of the large bend of the Wisłok riverbed the depositional sequence was described (G ę b i c a et al. 2002; G ę b i c a 2004). It consisted of the overbank silts with two inserts of dark clays (paleosols?) at the depths of 2.0 m and 3.0 m, which are underlain with gray silts dated by OSL method at 14,000 BP (at the depth of 3.7 m). The lowermost unit of the sequence is represented by channel sands dated at 22,200 BP. Therefore, the lower member of the terrace 7 m high sequence represents the Late Plenivistulian, while its upper member is of the Holocene age.

In turn, the extensive terrace-alluvial fan, situated between the San and Wisłok rivers, near the mouth of the latter, is formed of sand unit dated (by the single sample taken at the depth of 7 m) at 15,000 ± 300 BP, which indicates the Late Plenivistulian age of this unit (W ó j c i k et al. 1999). The Vistulian terrace near Grodzisko Nowe village was undercut by paleochannel of the Wisłok river, filled with sediments dated (in the bottom part) by radiocarbon method at 9,530 ± 240 BP, whereas the pollen analysis carried out by K. Szczepanek indicated the Late Vistulian (W ó j c i k et al. 1999; W ó j c i k and M a l a t a 2004). Within the other Late Vistulian paleochannel sequence situated in the vicinity of the multicultural archaeological site of Grodzisko Dolne (C z o p e k 2007), above the organic sediments dated at 10,450 and 11,670 BP, an unit of sands 2 m thick was deposited probably during the Younger Dryas. Directly upon the Late Vistulian series, at the depth of 1.3–2.0 m, a peat unit with wood fragments dated at 5,200 and 3,000 BP lies. The peat unit is overlain with sands abounding with organic material dated by radiocarbon method at 1,780 ± 75 BP. This date indicates the deposition of the sands during the Roman Period (2^{nd} and 3^{rd} century AD), in the time when the Przeworsk Culture existed at the Grodzisko Dolne site. It is confirmed by rye pollen grains identified by K. Szczepanek within this unit of sands (G ę b i c a et al. 2008).

Table 1

List of studied profiles and radiocarbon datings of the Holocene terrace 6–7 m high in the Wisłok river at Wola Mała village

Name and Profile Number	Type of material	Depth [m]	Laboratory No.	Radiocarbon Age B.P.	Calibrated Age 1σ 95%
Wola Mała (gravel pit)					
Wola Mała 1/2003	organic mud ball	5.0	Gd-12530	12,200 ± 150	12900–11800 BC
Wola Mała 2/2003	trunk	6.0	Gd-15525	11,475 ± 150	11750–11100 BC
Wola Mała WMI-1/2006	organic clay	2.10–2.15	Ki-13359	8,750 ± 60	7950–7659 BC
Wola Mała WM-IB-4	peat	3.00	Gd-12899	9,610 ± 90	9260–8750 BC
Wola Mała WM-2/4, 3	organic detritus	4.30	Ki-13360	9,810 ± 150	9650–9100 BC
Wola Mała WMI-3/4, 7	organic detritus	4.70	Ki-13361	10,970 ± 170	11220–10900 BC
Wola Mała 1-3 bis	organic detritus	4.30	Ki-133401	11,010 ± 150	11190–10985 BC
Wola Mała Pr.4	trunk	5.0	Ki-14838	11,050 ± 60	11200–11020 BC
Wola Mała Pr.6	trunk	5.50	Ki-14843	10,840 ± 70	11100–10970 BC
Wola Mała Pr.3	trunk	5.70	Ki-14842	10,980 ± 70	11050–10870 BC
Wola Mała n. Wisłokiem 1-4	trunk	5.5–6.0	Ki-13392	11,370 ± 80	11490–11230 BC
Wola Mała (boreholes log)					
Wola Mała WM 5/1	clayey peat	3.10–3.15	Ki-14852	9,480 ± 80	8840–8680 BC
Wola Mała 5/2, Pr.10	mud with organic material	3.45–3.50	Ki-14839	10,110 ± 70	10000–9400 BC
Wola Mała 2/1	mud with fragments of wood	4.60–4.72	Gds-574	1,780 ± 40	130–350 AD
Wola Mała 3/1	organic sand	1.70–1.72	Gd-19112	8,790 ± 100	8213–7606 BC
Wola Mała 3/2	sand with organic detritus	5.63–5.70	Gd-18487	12,450 ± 380	13756–11666 BC
Wola Mała 6/2	sand with fragments of wood	4.35–4.42	GdS-575	8,010 ± 50	7068–6751 BC
Wola Mała 6/4	mud with organic material	5.85–5.95	Gd-17483	11,620 ± 340	12433–10916 BC
Wola Mała 7/3	organic silt	3.45–3.50	Gd-19113	9,030 ± 110	8493–7961 BC
Wola Mała 7/2	organic silt	3.85–3.88	Gd-19115	9,200 ± 160	8844–10434 BC
Wola Mała 7/4	mud with organic material	5.20–5.24	Gd-17487	10,950 ± 230	11388–10434 BC

In the last several years the outcrops in the active gravel pit of Wola Mała near Łańcut were studied and 10 boreholes were drilled along the transect situated between this gravel pit and Stary Wisłok. Three selected logs were sampled for granulometric analysis which was performed by sieve and laser techniques (68 samples) in the laboratory of the Department of Geomorphology and Hydrology of Mountains & Uplands, Institute of Geography and Spatial Organization, Polish Academy of Sciences (PAS) in Cracow. The results are presented on the granulometric diagrams and as the granulometric indices after R.L. Folk and W.C. Ward (1957). Totally 21 samples from the gravel pit and boreholes were dated using the radiocarbon method in the Radiocarbon Laboratory of the Silesian University of Technology in Gliwice as well as in the Radiocarbon Laboratory of the Ukrainian Academy of Sciences in Kiev (Tab. 1). The palynological analysis of 5 selected borehole logs were performed in the Division of Botany of the Ivan Franko National University in Lviv, while the analysis of macrofossils were conducted in the Institute of Botany of the Jagiellonian University in Cracow.

ALLUVIAL SEDIMENTS OUTCROPPED IN THE GRAVEL PIT AT WOLA MAŁA

The gravel pit in Wola Mała village is situated on the right bank of the Wisłok river, 200 m to the south of the current riverbed and 5 km to the north of Łańcut town (Fig. 1). In 2002–2003 in the northwestern face of the gravel pit, 5 m high depositional sequence of fluvial sediments of the floodplain was described. It consists of bedded sands and loams of the natural levee, which overlie sands and gravels of the channel facies. Within the channel series the silt-organic pebble was found and dated at 12,200 ± 150 BP (Gd-12530). Therefore, the young, Holocene alluvia contain older clastic and redeposited material of the Late Vistulian oxbow-lake fills.

The new outcrop in the southern part of the pit enabled observation of the structure and the depositional sequence of the terrace 6–7 m high. Within the top part of the sequence, under grayish-yellow clays, at the depth ranging 1.75–1.85 m black clay-organic sediment occurs. It overlies weathered, gray bedded silts and sands abundant in organic detritus and wood fragments situated at the depth of 4.0–4.7 m. Upon the series of channel sands and gravels at the current water table (depth ca. 6.5 m) gray silts with organic detritus being the oxbow-lake fills were outcropped. They are overlain with gravels abundant in thin tree trunks and branches, among which a pine trunk was dated at 11,475 ± 150 BP (Gd-15525).

Depositional sequences outcropped within the extensive eastern face of the sand pit were described in 2006 and 2007. The top part of the sequence is composed of silty clay with gley horizon (0.50–0.75 m) and deeper unit of gray silty clay (depth of 1.5–2.4 m) with black clay-organic layer of the paleosol type (Fig. 2). At the depth 2.10–2.15 m it contained pollen grains of pine, stone pine, spruce and birch as well as rare pollen grains of elm, hazel and ash, which are trees representing plant communities characteristic for the Boreal phase. The organic-clay sediment sampled at the depth of 2.10–2.15 m was dated at 8,750 ± 60 BP (Ki-13359) — the decline of the Boreal phase.

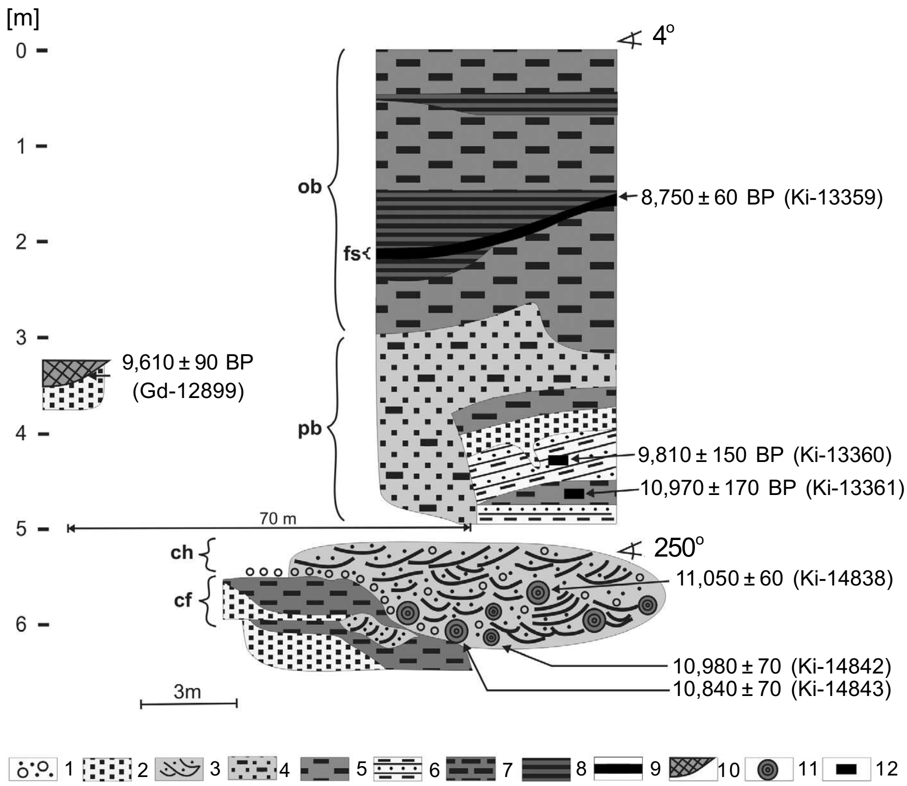

Fig. 2. Outcrop of the 6–7 m high terrace depositional sequence in the gravel pit in Wola Mała on the Wisłok riverbank. Explanation of symbols: 1 — sand with gravel, 2 — sand, 3 — cross-bedded sand and gravel, 4 — silty sand, 5 — alluvial silt (loam), 6 — cross- and horizontal bedded sand and silt, 7 — silty clay, 8 — clay, 9 — paleosol, 10 — paleochannel fill, 11 — subfossil tree trunk, 12 — organic detritus; ch – channel deposits, cf – paleochannel filling, pb – point bar deposits, ob – overbank deposits, fs–paleosol

At the distance of 20 m to the south of the above described profile, an outcropped layer of black organic-clay sediment lies at the depth of 1.50–1.55 m. Under this unit gray silts occurs. It passes into silty sands at the depth of 3.2–4.1 m. At the depth between 4.1–4.9 m cross-bedded clayey sands interbedded with gray silts (point bars) and abundant in organic detritus occur. Macrofossil analysis of sediment sampled at 4.3 m, performed by K. Szczepanek showed the occurrence of leaf fragments, two birch (*Betula pubescens*) seed elements, 2 seeds of birch sec. "albae", sedge "nuts" and fragments of willow branches (?). The sediment is also abundant in pollen grains of pine, birch, grass and sedge. This indicates the existence of swampy plain overgrown with sedges and often overflown during the Late Vistulian–Early Holocene. The organic detritus at the depth of 4.3 m was dated at 9,810 ± 150 BP (Ki-13360), whereas the sample from the depth of 4.7 m contained probably redeposited organic material dated at

10,970 ± 170 BP (Ki-13361). Therefore, the channel sandy bars were formed during the Late Vistulian–Early Holocene. The pine trunk buried at the depth of about 5.5–6.0 m and extracted during the gravel exploitation was dated at 11,370 ± 80 BP (Ki-13392).

At the distance of about 70 m to the north of the above described site, at the depth of 3.5 m an unit of peat-clayey sediments (oxbow-lake fills) were outcropped. They contain macrofossils of birch sec. "albae" and wood pieces of willow (*Salix* sp.), dated at 9,610 ± 90 BP (Gd-12899), so attributed to the Preboreal phase. In October 2007, due to the gravel exploitation, in the southern part of the pit, a sequence of sand-gravel channel sediments became accessible for study. Within this unit more than 10 thin tree trunks were buried (Fig. 2). The pine trunk buried at the depth of 5 m was dated at 11,050 ± 60 BP (Ki-14838), the trunk situated 0.5 m deeper was dated at 10,840 ± 70 BP (Ki-14843), while the third one lying at the depth 5.7 m was dated at 10,980 ± 70 BP (Ki-14842).

Recapitulating, the whole series of the channel sediments with tree trunks represents the phase of flood accumulation developed during the Younger Dryas, while the sandy bars were deposited within the Late Vistulian decline and at the beginning of the Holocene. The start of the oxbow-lake filling is attributed to the Preboreal phase (9,600 BP), whereas the deposition of overbank silts took place in the Boreal phase. At the end of the Boreal phase the paleosol developed. This paleosol dated about 8,700 BP evidences the stabilization period of the plain, after which the clay sediments were deposited in the flood basin.

DESCRIPTION OF THE BOREHOLE LOGS IN THE TRANSECT

In May 2007 and 2008 ten boreholes were drilled in the 7 m high terrace. The transect line of the length 1,500 m, was laid between the active gravel pit in Wola Mała village and paleomeander system of the Stary Wisłok (Figs. 1 and 3).

In the borehole log Wola Mała 10, situated 100 m to the south of the gravel pit, the depositional sequence is the same as in this gravel pit. Under clayey silts (Fig. 2), at the depth between 1.55–1.75 m dark brown clay-organic horizon (paleosol) occurs. It overlies gray clayey silts passing into sandy silts at the depth of 3.3 m (overbank sediment). Within the depth interval 4.3–5.3 m silty sands with inserts of silts and admixture of organic detritus occur. Downward, they grade into a series of sands with gravels of the channel facies. At the depth of 5.75–6.00 m this series is inserted with gray-black sand containing black organic detritus and coniferous wood fragments. Within this sand K. Szczepanek identified rare pollen grains of pine, spruce and birch, which indicate the Late Vistulian.

The logs of Wola Mała (WM) 3 and WM 4 boreholes, situated about 280 m and 480 m to the south of the gravel pit represent continuation of the sequence recorded in the gravel pit and WM 10 borehole log. Under the top unit of silty

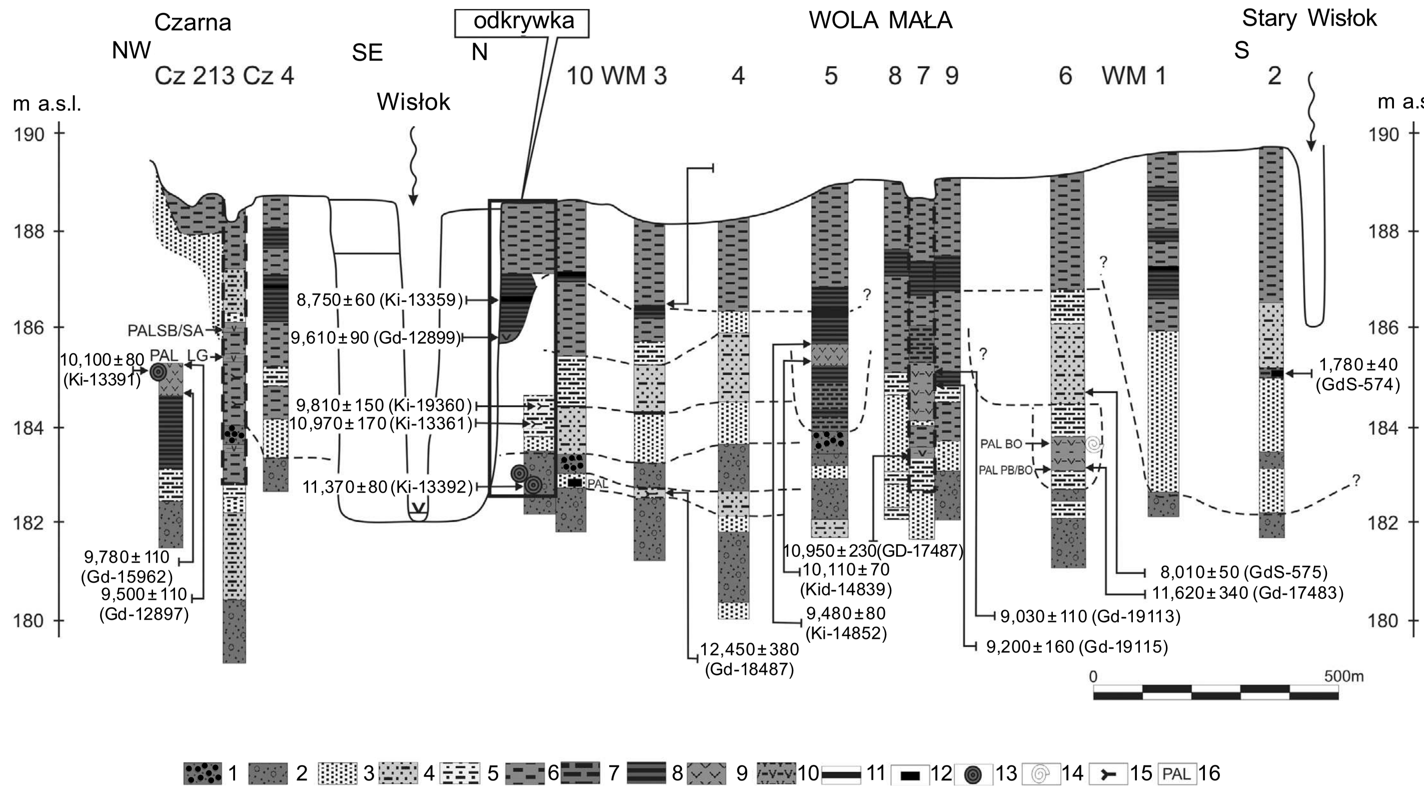

Fig. 3. Structure of the Holocene terrace (6–7 m high) and radiocarbon age of the alluvial fills in the borehole logs (on the transect in Wola Mała village near Łańcut) (P. Gębica). Explanation of symbols: 1 — gravel with sand, 2 — sand with gravel, 3 — sand, 4 — sand with silt, 5 — sandy silt, 6 — alluvial silt (loam), 7 — clayey silt, 8 — clay, 9 — peat, 10 — silt-organic sediment, 11 — paleosol, 12 — fragment of wood, 13 — subfossil trunk, 14 — shells, 15 — organic detritus, 16 — organic detritus with palynological analysis (suggested age: Late Glacial — LG, Preboreal/Boreal — PB/BO, Boreal — BO, Subboreal/Subatlantic — SB/SA)

clays, a layer (0.85 m thick) of clayey silts (Mz = 6.5–7.5 φ) with black clay-organic horizon of paleosol type occurs (depth of 1.65–1.85 m). Within this last unit N. Kalinovyč observed frequent pollen grains of pine, spruce and birch with the admixture of herbaceous plants (up to 20%), which suggest the Preboreal phase. A sample of this clay from the depth of 1.70–1.72 m of the Wola Mała 3 borehole log was dated at 8,790 ± 110 BP (Gd-19112) (Fig. 4), so the clay-organic unit (paleosol) deposited during the late Boreal phase, similarly to the black "organic clay" outcropped in the gravel pit. Below the clay-organic unit, at the depth of 3–4 m, overbank sandy silts (Mz = 5 φ) and silty sands lie. This silt-sand unit passes into medium- and coarse-grained sands at the depth of 4–5 m and deeper — into sands with gravels of the channel facies reaching the depth of 7 m. They are abundant in organic detritus and wood fragments (Fig. 3). In both logs at the depth of 5.5–5.7 m (6.0 m) dark gray and black silty sands with common organic detritus occur. The organic material sampled at the depth of 5.63–5.70 m in the WM 3 log was dated at 12,450 ± 380 BP (Gd-18487), so it is attributed to the Late Vistulian.

The borehole Wola Mała 5, situated 680 m south from the gravel pit drilled the paleochannel fills (Fig. 3). Within the sequence of this log, under the clays (Mz = 8 φ) and clayey silts (Mz = 6.8 φ), at the depth of 3.1–3.5 m, dark brown clayey peat occurs. The lower unit of paleochannel fill (interval 3.5–4.0 m) is represented by silts and silty clays (Mz = 5.9–6.3 φ) with organic material and plant fragments. The lowermost unit of the paleochannel fill is formed of clayey silts, which overlie poorly sorted sands and gravels of the channel facies at the depth of 5 m. Within the paleochannel silt-clay fill, at the depth 3.55–3.75 m (Fig. 5 — PAZ Pin-Pin cembra), pollen grains of pine, stone pine, larch, birch and willow were found, which suggests the deposition at the beginning of the Holocene (Preboreal phase). The palynological analysis of samples from the depth of 3.25–3.50 m evidenced the occurrence of pine, spruce, birch and willow pollen grains as well as increasing percentage of elm pollen grains. It proves the deposition of this sediment during the Boreal phase. The sample from the depth of 3.45–3.50 m was dated at 10,110 ± 70 BP (Ki-14839), which means its deposition during the Preboreal phase. In two samples taken from the peat unit at the depth of 3.15 and 3.25 m (PAZ Ul-Co-Ti-Qu), apart from pollen grains of pine, spruce, birch and willow, also pollen grains of warmer climate trees, such as elm, hazel, lime and oak were identified, indicating the decline of the Boreal phase. Radiocarbon dating of the peat sampled at the depth of 3.10–3.15 m proves the age 9,480 ± 80 BP (Ki-14852). Therefore, the sequence of the Wola Mała 5 borehole log records the changes in the facies from the channel sands to the paleochannel fills, which took place during the Younger Dryas–Preboreal transition as well as organic accumulation in the paleochannel lasting to the decline of the Boreal phase. Burial of the paleochannel sediments by clays can be probably attributed to the flood phase at the Boreal-Atlantic transition.

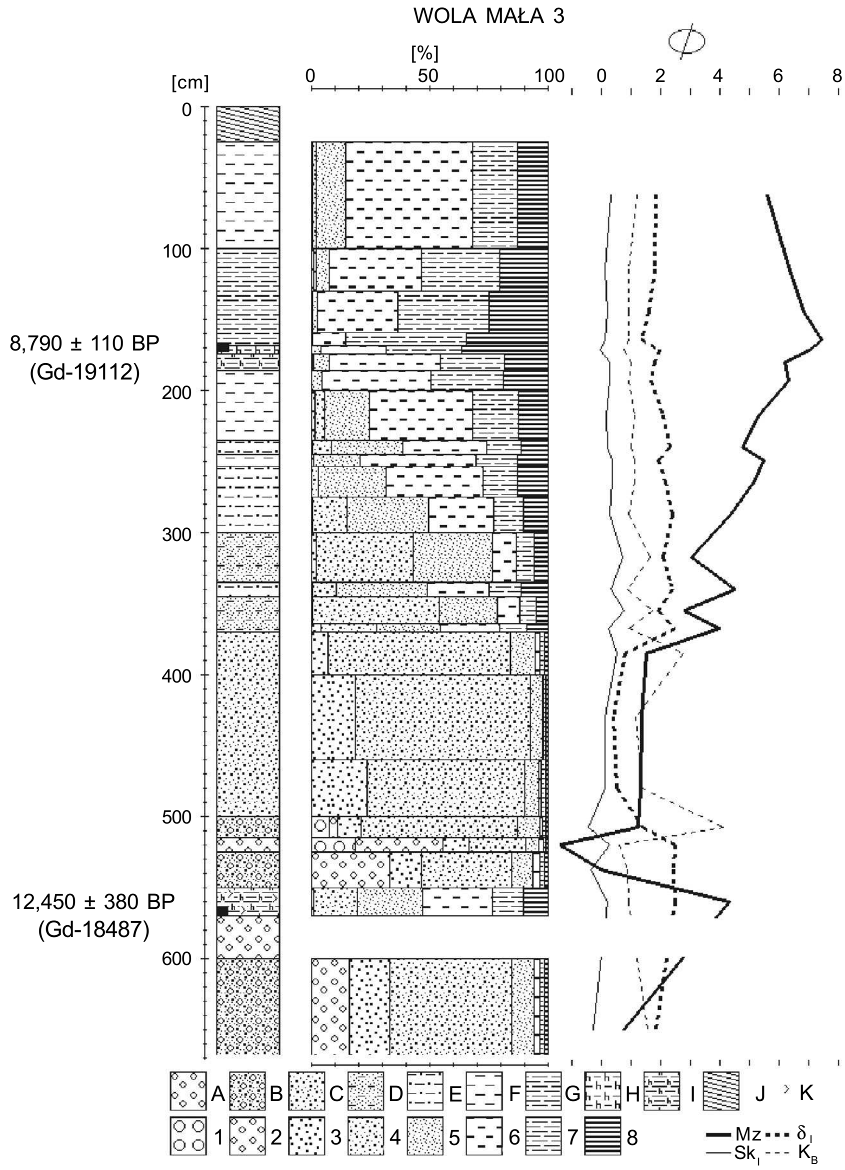

Fig. 4. Lithology, grain size indices and the age of the Late Vistulian–Eoholocene terrace in the Wola Mała 3 borehole log. Explanation of symbols: A — gravel with sand, B — sand with gravel, C — sand, D — silty sand, E — sandy silt, F — silt, G — clayey silt, H — silt-organic sediment, I — clayey silt-organic sediment, J — Holocene soil, K — organic detritus. 1 — coarse-grained gravel >16 mm (<–4 φ), 2 — medium and fine-grained gravel 2–16 mm (–1– –4 φ), 3 — coarse-grained sand 0.5–2 mm (1– –1 φ), 4 — medium-grained sand 0.25–0.5 mm (2–1 φ), 5 — fine-grained sand 0.063–0.25 mm (4–2 φ), 6 — coarse and medium-grained silts 0.02–0.063 mm (6–4 φ), 7 — fine-grained silts 0.004–0.02 mm (8–6 φ), 8 — clays <0.004 mm (>8 φ). 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

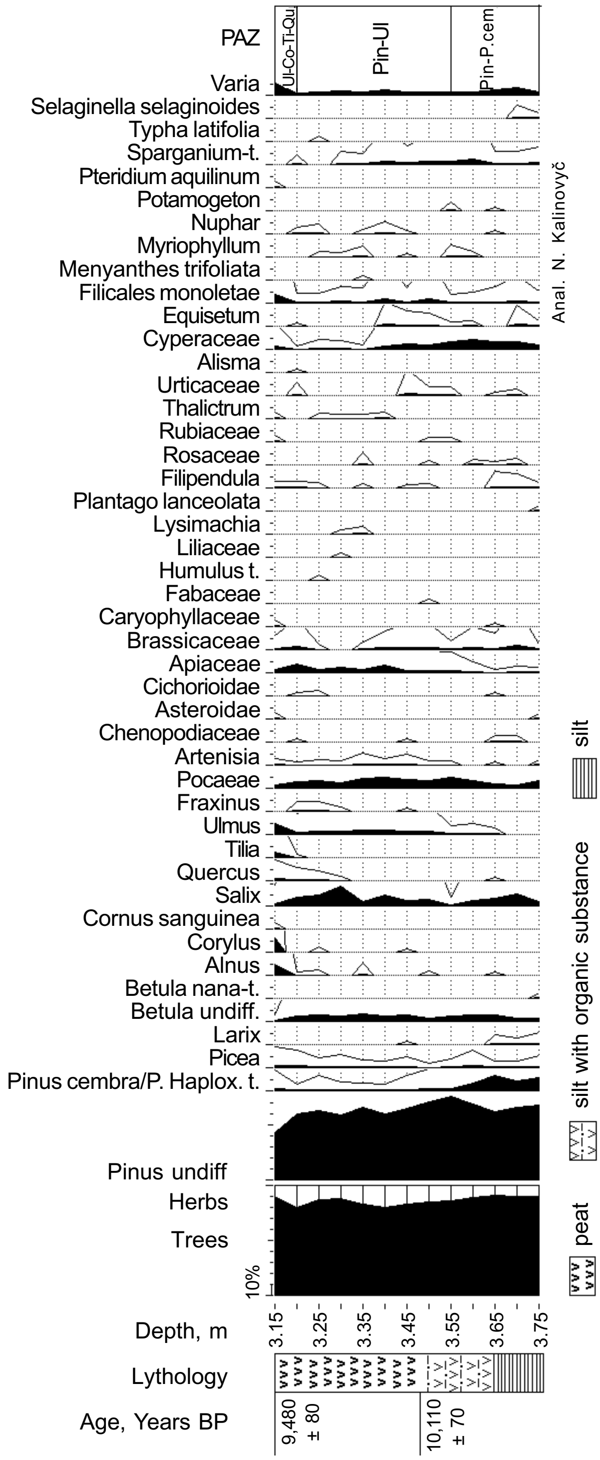

Fig. 5. Palynological diagram of samples from the borehole log Wola Mała 5 (anal. N. Kalinovyč)

The Wola Mała 7 borehole is situated within the oxbow-lake depression of the Wisłok river, 870 m to the south of the gravel pit (Fig. 3, Fig. 6). In the depositional sequence of its log, under 0.5 m thick layer of soil, yellow silts occur. They grade into grayish-brown silty clays (Mz = 6.2–6.4 φ) at the depth of 1.3–1.8 m. These silty clays pass downward into clays (Mz = 7.5 φ) at the depth of 1.8–2.0 m. At the depth 2.00–3.35 m overbank silts and clayey silts (Mz = 5.5–5.8 φ) occur, while the deeper interval, 3.35–4.63 m, is formed of grayish-black silts with organic material and gastropod shells (paleochannel fill). This unit overlies the layer of silts with sand 0.3 m thick. The lower unit (depth of 5.00–5.25 m) is formed of silts abundant in organic material and containing rare shells. The lowermost section of the log sequence (drilled up to the bottom of the borehole at 7 m) is represented by sandy silts as well as medium- and fine-grained sands.

The silt-organic sediment lying at the bottom of the paleochannel fills, at the depth of 5.20–5.24 m, were dated at 10,950 ± 230 BP (Gd-17487), which indicates the deposition during the Younger Dryas. A sample taken from the depth of 3.85–3.88 m was dated at 9,200 ± 160 BP (Gd-19115). Similar age was attributed to the silts abundant in organic material sampled at the depth 3.45–3.50 m and

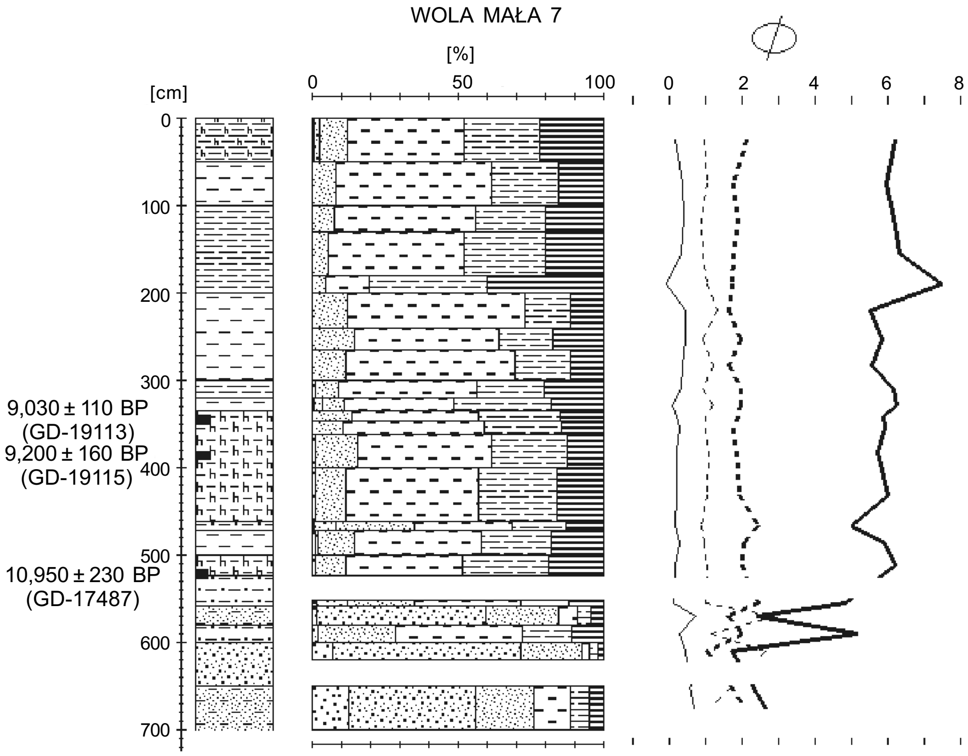

Fig. 6. Lithostratigraphy and grain size indices of the Younger Dryas paleochannel fill in the borehole log Wola Mała 7. Explanation of symbols see Fig. 4

dated at 9,030 ± 110 BP (Gd-19113). It means that in the depositional sequence WM-7 log the paleochannel cut off took place during the Younger Dryas, while the filling up of the paleochannel continued till the Boreal phase. The burial of the paleochannel fills by overbank silts should be attributed to the period of frequent floods at the Late Boreal and beginning of the Atlantic phases.

In the log sequence of the Wola Mała 6 borehole, situated 1,170 m far from the gravel pit, under the cover of clayey silts 2.3 m thick, series of levee sediments represented by sandy silts interbedded with sands occur (Fig. 3). At the depth between 3.0–5.2 m sands with organic detritus and wood fragments occur. They were sampled at the depth of 4.35–4.42 m and dated at 8,010 ± 50 BP (GdS-575) — the beginning of the Atlantic phase. The sands overlie the following units representing the paleochannel fill: a) brown silts abundant in organic material and malacofauna, at the depth of 5.20–5.45 m, b) dark gray silts with organic material and malacofauna, at the depth of 5.45–6.00 m, and c) silts with sand admixture, to the depth of 6.4 m. The silts sampled at the depth of 5.86–5.94 m contain pollen grains of birch, pine and rare pollen grains of stone pine and sea-buckthorn, which indicates that the filling of the paleochannel took place during the Vistulian decline and the beginning of the Holocene, similarly to the sequence of the WM 7 log. Therefore, the radiocarbon date of the sample taken from the bottom of these paleochannel fills at the depth of 5.85–5.94 m, valuing 11,620 ± 340 BP (Gd-17483), seems to be slightly too old. The sample taken from the silts with organic material, at the depth of 5.45–5.50 m, contains pollen grains of pine, birch, spruce, elm and ash, corresponding to the Boreal phase.

Recapitulating, in the sequence of the Wola Mała 6 borehole log the early Holocene accumulation of the oxbow-lake sediments was broken by the deposition of the channel facies sediments at the beginning of the Atlantic phase (date 8,100 BP). It is accurately correlated with the period of frequent floods (8,500–8,000 BP) distinguished by L. Starkel (Starkel 1977; Starkel et al. 1996), which was connected with the climate moistening at the beginning of the Atlantic phase, recognized in the depositional sequence of the tributary stream fan at the Podgrodzie site in the Wisłoka river valley.

About 100 m to the east of the Wola Mała 6 borehole the archaeological site (excavated for the project of the A-4 highway) is situated. In this site M. Hozer and A. Bajda-Wesołowska (unpublished data) observed the horizon containing the charcoal fragments and artifacts of the Łużyce Culture at the depth 0.8 m. It suggests the overbank sediments deposition during the Subboreal–Subatlantic transition (ca. 3,300–2,400 BP).

The boreholes Wola Mała 1 and Wola Mała 2 are situated within a wide natural levee, at the distance of 300 m (WM 1) and 100 m (WM 2) from the Stary Wisłok paleomeander system (Figs. 1 and 3). In the Wola Mała 1 borehole yellow-gray clayey silts were drilled to the depth of 1.8 m. The lower unit of the log sequence, situated at the depth of 1.80–3.65 m is formed of gray-brown silts

(Mz = 5.5–6 φ) with clay horizon (Mz = 7.5 φ) at the depth of 2.65–3.00 m. Under the depth of 3.65 m, up to the borehole bottom at 7.4 m, an unit of poorly sorted sands with gravels (pebbles up to 4 cm in diameter) occurs (Fig. 7). It represents the channel facies.

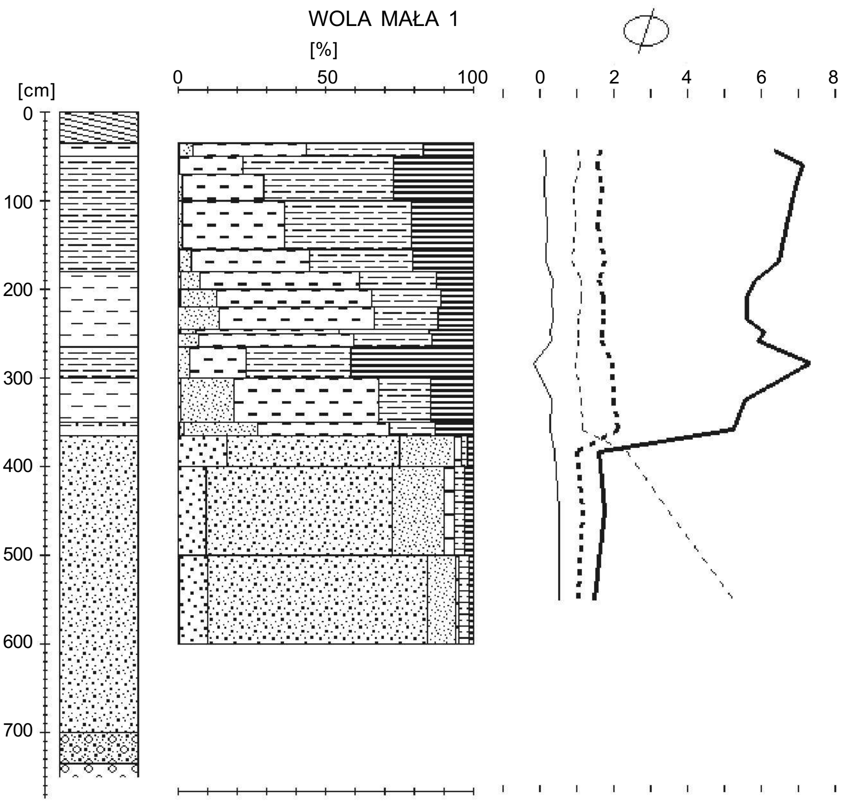

Fig. 7. Lithology, grain size indices of the natural levee deposits of the Stary Wisłok paleomeander system in the borehole log Wola Mała 1. Explanation of symbols see Fig. 4

In the depositional sequence of the Wola Mała 2 borehole log under silts, at the depth between 3.2–4.0 m bedded fine-grained sands and sandy silts occur (levee sediments). They overlie the unit of fine grained sands with organic detritus and wood fragments situated at the depth of 4.0–4.6 m. The gray silt with wood fragments, occurring at the depth of 4.60–4.72 m, at the boundary between sand-silt overbank sediments and fine-medium-grained sand channel series, was dated at 1,780 ± 40 BP (GdS-574). The deeper unit (depth of 4.72–6.30 m.) is represented by poorly sorted sandy pointbars containing fine organic detritus and wood fragments. It is underlain by sands with gravels (pebbles up to 2.5 cm in diameters) of the channel facies drilled up to the depth of 8 m.

The Wola Mała 1 and 2 borehole logs represent the youngest series of the channel and overbank alluvia deposited within the zone of natural levee of the Stary Wisłok paleomeander system during frequent floods of the Subatlantic phase (more humid climatic period about 2,200–1,700 BP — K a l i c k i 1991). The reinforced deposition of alluvial loams 4 m thick, which formed the levee after 1780 BP within the sequence of the WM 2 borehole log, is apparently connected with human impact increased during the Roman Period. It is confirmed by identically dated sands deposited upon organic fills of the Wisłok paleochannel at the Grodzisko Dolne site, in the vicinity of this archaeological site of the Przeworsk Culture (C z o p e k 2007; G ę b i c a et al. 2008).

DISCUSSION AND CONCLUSIONS

Within the cross-section of the Holocene terrace of the Wisłok river in the Sandomierz Basin, several paleochannel systems and alluvial fills of different age can be distinguished (Fig. 8). The oldest sand unit bearing organic detritus and pine-wood fragments, which is inserted into gravels at the depth of 5.5–6.0 m, is attributed to the Late Vistulian (Bølling–Alleröd Interstadials). The younger unit is represented by the channel alluvia with tree trunks deposited by floods during the Younger Dryas and overlain by pointbar sediments of meandering river of the Preboreal age as well as overbank silt-clay sediments deposited during the Boreal–Atlantic transition.

The central part of the plain is occupied by paleochannel system of the Wisłok river filled up with the organic-mineral sediments during the Younger Dryas–Preboreal transition, Preboreal and Boreal phases. It is accurately correlated with the changes in the sequence of the alluvial fan of the Wolicki stream

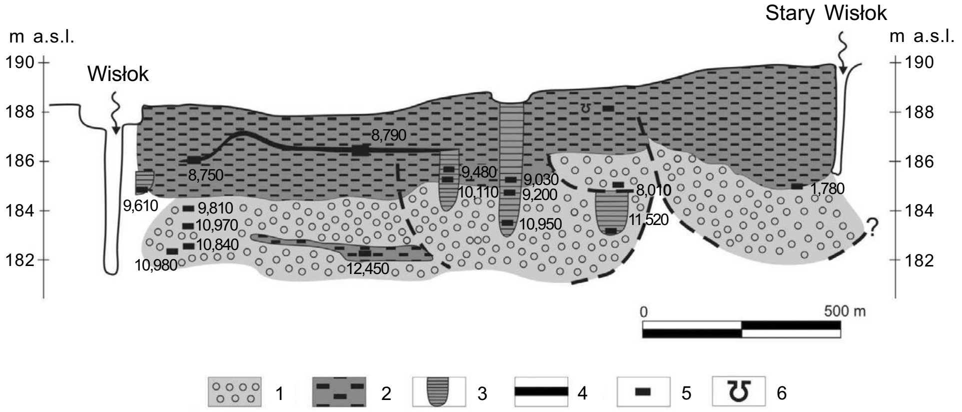

Fig. 8. General scheme of the alluvial fills and their radiocarbon age at the Wisłok Holocene terrace 6–7 m high near Łańcut town. Explanation of symbols: 1 — channel facies, 2 — overbank sediments, 3 — paleochannel fill, 4 — paleosol, 5 — radiocarbon datings (yrs BP), 6 — Łużyce Culture site

in the Wisłoka river valley and other profiles studied in Poland, which are attributed to the Younger Dryas–Holocene transition (S t a r k e l 1995, 2002). At the end of the Boreal phase (ca. 8,700 BP) the clay-organic horizon of the paleosol type developed due to the stable environmental conditions, upon which the clay unit was deposited within the flood basin. The formation of clay sediments was probably synchronic with the deposition of the channel series, during the early Atlantic phase (ca. 8,000 BP).

Within the described cross-section, sediments of the younger part of the Atlantic phase and the older part of the Subboreal phase are missing.

The youngest litho-stratigraphic member in the structure of the plain is represented by channel alluvia and silt-sand sediments of the natural levee of the Stary Wisłok paleomeander system, deposited by frequent floods during the Subatlantic phase (since ca. 1,800 BP) and connected with the increasing human impact during the Roman Period (2^{nd}–3^{rd} centuries AD), which was well recognized in the Vistula river valley in the vicinity of Cracow (K a l i c k i 1991).

Preservation of the alluvial fills and paleochannels of the Late Vistulian and the Early Holocene nested within the central part of the terrace was possible due to the avulsion of the river from the Stary Wisłok riverbed to the northern side of the valley in the 18^{th} century.

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