Il Quaternario
Italian Journal of Quaternary Sciences
***17**(2/1), 2004, 165-180*

RIVER RESPONSE TO THE HOLOCENE CLIMATIC FLUCTUATIONS: A CASE STUDY FROM ZELVIANKA RIVER VALLEY (BELORUSSIA)

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ABSTRACT: Kalicki T. *(et.al.), River response to the Holocene climatic fluctuations: a case study from Zelvianka river valley (Belorussia).* (IT ISSN 0394-3356, 2004).
A multidisciplinary research aimed at depicting the evolution of Zelvianka river valley (NW Belorussia) during the Holocene has been carried out. The valley incision started at the local ice-sheet *terminus* in the Young Pleniglacial following the Pomerian stage of the last glaciation (some 16÷15 ka BP) and, as marked by important changes of the river regime, was virtually over at c. 13.8 ka BP (Middle Lithuanian stage of deglaciation). Detailed geomorphologic survey coupled with stratigraphic analysis, ^{14}C dating and pollen spectra provided sound evidence that the complex structure of the valley bottom resulted from the lateral migration of the river which in turn depended upon large-scale climatic changes. Besides of critically reviewing the literature data new, ^{14}C dated pollen chronostratigraphies, fairly consistent with the up to date regional palynologic framework were obtained. Actually it has been found that the most important channel and sedimentation changes cluster at the AL/YD transition, c. 9300 BP, BO/AT transition, middle Atlantic, c. 4200 BP, c. 3250-3000 BP, Roman time (2100 BP) and 1000-900 BP, thus matching the timing of humid and cool climatic phases recorded by the enhanced activity of Belorussian and central European rivers. Though the first prehistoric settlements over the study area date back to Late Neolithic, Zelvianka valley was virtually unaffected by the human impact, except from some low intensity, local aeolian processes which developed in the Subboreal and Subatlantic on the deforested spots

RIASSUNTO: Kalicki T. (et.al.), Effetti delle fluttuazioni climatiche oloceniche sull'evoluzione della valle del fiume Zelvianka (N-W Bielorussia). *(IT ISSN 0394-3356, 2004).*
E' stata effettuata una ricerca multidisciplinare finalizzata alla ricostruzione dei tratti evolutivi più salienti della valle del fiume Zalvianka (Bielorussia nord occidentale) durante l'Olocene. L'incisione di questa valle, iniziatasi nel Pleniglaciale al termine dello stadio Pomeriano dell'ultima glaciazione (ca. 16÷15 ka BP) e conclusasi a ca. 13,8 ka BP (media deglaciazione Lituana), ha registrato importanti cambiamenti del regime fluviale. I dati geomorfologici, stratigrafici, palinologici unitamente a quelli della cronologia radiocarbonio concordano nell'indicare che la complessa struttura del fondo della valle deriva dalle migrazioni laterali del fiume che, a loro volta riflettono variaizioni climatiche di portata almeno regionale.
Lo studio ha evidenziato che le maggiori variazioni tanto nel regime di sedimentazione che nella direzione del corso fluviale si sono verificate alla transizione Alleröd/Dryas III, a ca, 9300 BP, alla transizione Boreale/Atlantico inferiore, nel medio Atlantico, a ca. 4200 BP, a ca. 3250÷3000 BP, in epoca Romana (2100 BP) ed infine dal 1000 al 900 BP. La datazione di tali eventi ne rivela la contemporaneità con fasi climatiche umide e fredde di portata almeno regionale in quanto precedentemente riportate per molte valli fluviali della Bielorussia e dell'Europa centrale.
Nonostante la presenza di insediamenti umani nell'area di studio a partire dall'ultimo Neolitico, la valle del fiume Zelvianka non mostra significative evidenze di impatto antropico, eccezion fatta per modesti processi eolici attivi nel Pre-boreale e nell'Atlantico inferiore nelle modeste aree soggette a deforestazione da parte dell'uomo.

Keywords: Holocene, Belorussia, climate fluctuations, river valley, radiocarbon dating, pollen analysis.

Parole chiave: Bielorussia, Olocene, fluttuazioni climatiche, cronologia radiocarbonio, analisi pollinica.

INTRODUCTION

The Pleistocene development of Zelvianka valley (Fig.1) resulted from the degradation of Neman stream Sozhian (Moscovian) ice sheet, damming of Neman river by Valday ice sheet and level changes of the Late Valday (Vistulian) ice-dam Skidel lake (Vozniachuk and Valchik, 1978). Zelvianka valley cuts the Belorussian Upland accordingly to the glacial valley of the kataglacial period of Sozhian glaciation (Gorecki, 1980). The valley, only 100-200 m wide at a narrow gap section nearby Piaski village (Piaski Gate), where it crosses the northernmost morainic ridge with glaciotectonic features (Levkov, 1980), broadens suddenly up to 2.5-3.0 km in the downstream flat upper Neman plain (Fedenya *et al*., 1985).

The valley evolution during the last glaciation was controlled by the recurrent fluctuations of the ice sheet *terminus*. Following river damming by the ice sheet, fine sands with silt intercalations (Usviacha series) accumulated in Neman as well as in Zelvianka river valleys. Then, the whole upper Neman plain was overflooded (maximum level: 128-138 m a.s.l.) by the ice-dam Skidel lake (Vozniachuk and Valchik, 1978) and a limnoglacial suite, resembling varve sediments (thin fine sands and sandy silts layers) was deposited (Kovbasyuk and Ivanov, 1998). The sequence, with ice wedges at the top (Levkov *et al*., 1988), records the progressive shallowing of Skidel lake during the recession of the last ice sheet, when terraces were originated

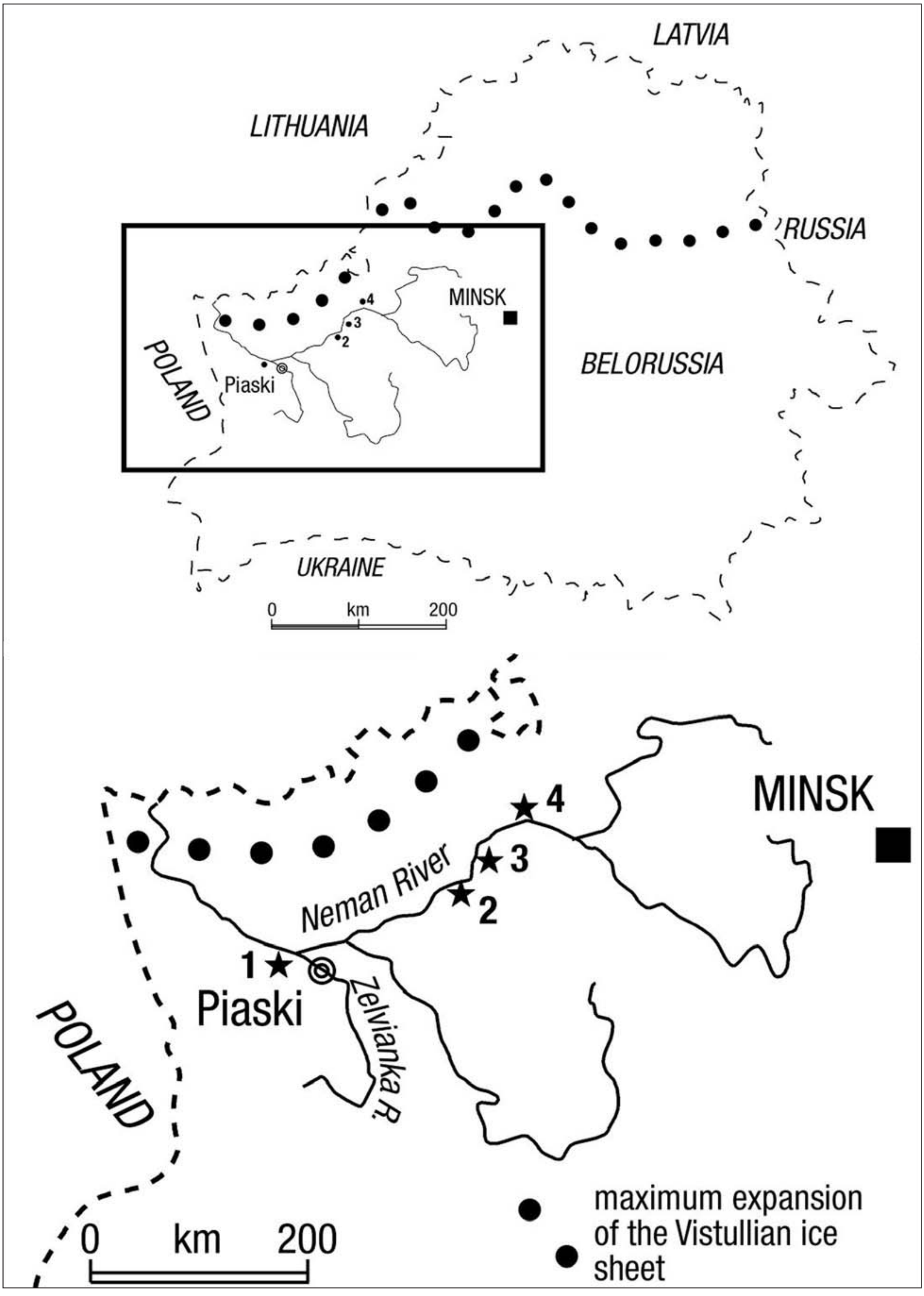

Fig. 1 - Sketch map of the study area. The location of the reference pollen spectra mentioned in the text is as follows:1 – Podbarany, 2 – Ogorodniki, 3 – Kremushovka, 4 - Morino.

by the Zelvianka river erosion of the limnological suite. The incision, 4-5 m deep near Piaski, deepens gradually downstream up to 10-11 m at the river mouth. At present the lacustrine sediments blanket a very flat plain (116-117 m a.s.l.) and only small relics of the former terraces, barren of organic matter are preserved.

Despite the numerous companion papers focusing on the Zelvianka river valley near Piaski village (Fedenya *et al*., 1985, 1992; Levkov *et al*., 1988; Ivanov, 1993, 2001; Ivanov and Yelovicheva, 1997), the overall framework for the Lateglacial-Holocene development of the valley is still unsatisfactory for relying on palaeobotanical and palaeozoological chronosequences lacking isotope dating and accurate location.

This work attempts a detailed reconstruction of the Lateglacial-Holocene evolution of Zelvianka river valley near Piaski by considering new data and, following a critical evaluation of the literature. The new established pollen chronostratigraphies are, for the first time in the area, also supported by ^{14}C readings. Our results are of regional scale concern, as valleys developed at the ice sheet *termini* on limnoglacial sediments accumulated in ice-dammed lakes are common features in northern Russian (Kvasov, 1976, 1987) and Masovian plains.

METHODS

A preliminary literature survey strongly suggested that further field work was needed for locating, checking stratigraphy and possibly re-sampling the reported profiles as well as selecting and sampling new key outcrops.

Samples for palynological analyses, collected at 5-8 cm intervals, were submitted to the standard chemical pretreatment (Erdtman, 1936; Pokrovskaya, 1950). The AP (Arboreal Pollen) + NAP (Non-Arboreal Pollen) sum, shrub species included, were considered. The percentages of other microfossils (pollen of aquatic taxa and spores) were calculated from AP+NAP pollen sum. TILIA and TILIA-GRAPH programs (Grimm, 1992) were used for calculation and plotting, respectively. The chronozonal distinction, matching the criteria after Mangerud *et al*. (1974), relied on both ^{14}C dating and correlation with the ^{14}C dated AP spectra from the sites of Ogorodniki, Morino, Kremushovka and Podbarany (Vozniachuk and Valchik, 1978; Kalicki *et al*., 2000) located along the Neman river valley near Piaski site (Fig. 1).

Radiocarbon dating was run with the liquid scintillation counting (LSC) technique on selected fractions of the organic matter in the sediment samples following decarbonation and removal of the mobile organics (Calderoni and Turi, 1998). Details on the chemical and counting protocols, equipments, ^{14}C decay rate measurement and age calculation were given elsewhere (Calderoni and Petrone, 1992).

PRESENT-DAY ENVIRONMENT

The c. 170 km long Zelvianka river begins between Lidziany and Kulyavichy villages and drains a 1940 km^2 catchment with a 0.41 km/km^2 river network density. River slope and annual discharge at the mouth average 0.41‰ and 11 m^3/s, respectively. The natural high sinuosity meandering channel, 15-20 m wide, is confined between steep, sandy banks. Upstream of the study area two river sections (44.2 km long) have been channeled to supply water to the Zelva and Papiernia reservoirs. The valley broadens from 0.5 to 3-4 km in the lower reach and the flat flood plain, only recently reclaimed, is up to 2.5 km wide except for the middle and lower reaches, where it narrows to 0.4-0.6 km (Blakitnaya kniga Belorusi, 1994). The study area is 14 km upstream of the Zelvianka river mouth to the Neman river. At Piaski gauge station the drainage basin accounts for 1800 km^2 (mean altitude: 166 m a.s.l.), most being currently cultivated, 17% forested and 14% consisting of marshes, swamps and peat bogs. Major forests, with pine communities (*Pinetum callunosum, Pinetum vacciniosum*) far predominant over fir, hornbeam and oak, spread along the right bank of Zelvianka river to the north of Piaski village. *Alnus glutinosa, Betula pubescens, Corylus avellana, Salix lopponum* and *Salix aurita* grow in the lowermost swampy areas with peaty soil. *Dryopteris thelypteris, Thelypteris palustris, Filipendula ulmaria, Comarum palustre, Galium palustre* and *Carex* are the dominant herbs.

Fig. 2 shows the mean monthly, maximum and minimum discharge of Zelvianka river since 1955 through 1975: the meltwater peak discharge in April points out the nival regime of the river. The mean annual discharge ranged from 18.9 to 6.59 m^3/s (mean: 9.42 m3/s) and peaked at 289 m^3/s in April 17, 1958. The water level during the spring floods is up to more than 2 m higher (mean: 676 cm) than the mean water stage (mean: 469 cm). The Zelvianka river is yearly frozen during some 75 days, as an average from December 25 up to March 11-23 (Gosudarstviennyy vodnyy kadastv, 1978).

VALLEY BOTTOM STRUCTURE

Along the 3 km long bifurcated reach of Zelvianka river beginning 2 km upstream of Piaski village the valley consists of two subparallel branches separated by an erosional remnant of the limnoglacial deposits on which the village lies at 116 m a.s.l. (Fig. 3). The southern branch, narrower and straighter than the northern one, shows, in the left bank of the ending part, one confined paleomeander cutting the limnoglacial series. Most of the studies were addressed to the northern valley branch for its well developed, up to 1 km wide flood plains. Here Fedenya *et al*. (1992) and Kovbasyuk and Ivanov (1998) recognized two and three steps, respectively, at 3.5 (4.0)-4.5, 2.0-3.0 and 1.0-1.5 m above river level (a.r.l.).

UPPER FLOOD PLAIN

Remnants of this level, less than 200 m wide, are recorded on both valley sides by a fining-upward alluvia sequence (Fedenya *et al*., 1992). The new field data, however, pointed out that the step height is morphology-dependent, thus implying that, for instance at Piaski-2, the paleochannels are significantly lower (2.5-3.0 m a.r.l) relative to the point bars (4.5-5.0 m a.r.l.). Further, the lag deposits were actually found at c. 1 m a.r.l., not below the river water level as previously reported by Kovbasyuk and Ivanov (1998).Only one among the profiles herein shown originated from the southern branch of the valley.

SOUTHERN VALLEY BRANCH

Piaski-Mill

This section (profile 11 after Fedenya *et al*., 1985, 1992) is near the scarp of the valley, where the river cuts the Piaski glaciodislocation and thus alluvia, only 3.6 m thick, overlies the chalk (Fig. 3 and 4). Mammal, amphibia and fish bones were found in the sands at 3.25 m deep. Because the mammalian assemblage mirrors mixed and deciduous forests, meadow and aquatic biotopes and the frog bones steppe environment, it has been inferred that the sediment deposited at the southern limit of the forest zone. Upward (2-3 m deep), a humified sandy layer contains entomofauna, similar to that of present times, that for including taxa of fast flowing water and stagnant or slowly flowing water (like in oxbow lakes with clay bottom) pinpoints the biotope varieties in the river valley. The occurrence of *Melolontha* sp. suggested that sediments accumulated in the Late Atlantic, thus under warmer and drier climate than at present. Based on the paleozoological data the alluvia was referred to the Middle Holocene.

NORTHERN VALLEY BRANCH

Piaski-2

This new profile, *c*. 3 m a.r.l. and very close to the right scarp of the valley bottom, shows at the base a paleochannel fill overlain by sandy-silty overbank deposits (Fig. 3 and 4). The former feature is made up by two units, the lower one (3.00-2.65 m deep), referred to the beginning of the infilling, consists of clastic sediments (clayey sands with gravels up to 0.5 cm), scattered organic matter and vegetal debris. The overlying organic sediments unit (2.65-1.10 m deep) displays, bottom to top, gyttja and peat. Just upward a yellow-gray-green colored, rich in vegetal debris gyttja level is shown. The occurrence of thin layers and lenses of coarse sands and small gravels (up to 0.5 cm) in its lower part points to intermittent river/oxbow lake communication. The pollen spectrum for Piaski-2 (Fig. 5) shows that the gyttja bottom (2.65-2.45 m deep), dated at 10,670±100 yr BP (Rome-1339), belongs to LPAZ *Betula nana–Pinus– NAP*. The high NAP (17.5-25.5%), together with *Betula nana* type, *Alnaster* (*Alnus viridis*), *Juniperus* and scant *Selaginella selaginoides*, reflects cold climate and open-forest landscape. *Lemna* and *Polygonum amphibium* grew in the oxbow lake and *Phragmites, Epilobium palustris* and *Equisetum* in the marshes. In the upward 30 cm of gyttja (2.45-2.15 m deep) LPAZ changes into *Betula–Pinus–Salix-NAP*. Here *Betula*, *Pinus* and *Salix* increase and NAP, attaining 28.5%, is dominated by *Artemisia*. Both *Polygonum amphibium* and *Myriophyllum* peaks reflect the ongoing overgrowing of the shallow (less than 3-4 m deep) lake. Pollen data are consistent with a YD cooler and drier at the late stage (10,500-10,200 yr BP) than at its beginning.

The lowermost 15 cm of the overlying gyttja silts (2.15-2.00 m deep), LPAZ *Pinus*, displays *Pinus* predominance, *Ulmus* first appearance and NAP decline to a mere 5%. The disappearance of hydrophilous plants, paralleled by a rise of *Polypodiaceae*, *Dryopteris thelypteris* and *Thelypteris*, marks the transition from shallow lake to peat bog. At first glance the comparison between the pollen spectra from Piaski-2 and Morino in the Neman valley (Vozniachuk and Valchik, 1978) reveals an almost synchronous blooming of pine. In particular, at Morino pine predominated prior to 9920±90

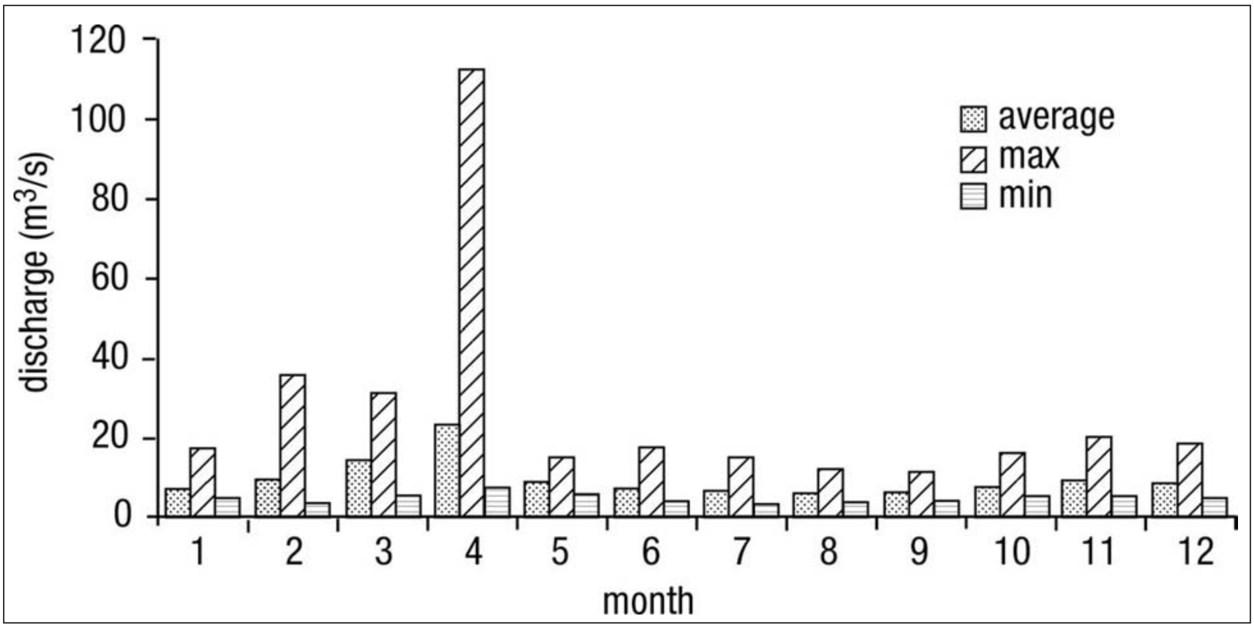

Fig. 2 - Monthly maximum, average and minimum discharge of Zelvianka river at Piaski gauge station during the period 1955-1975 (by T. Kalicki)

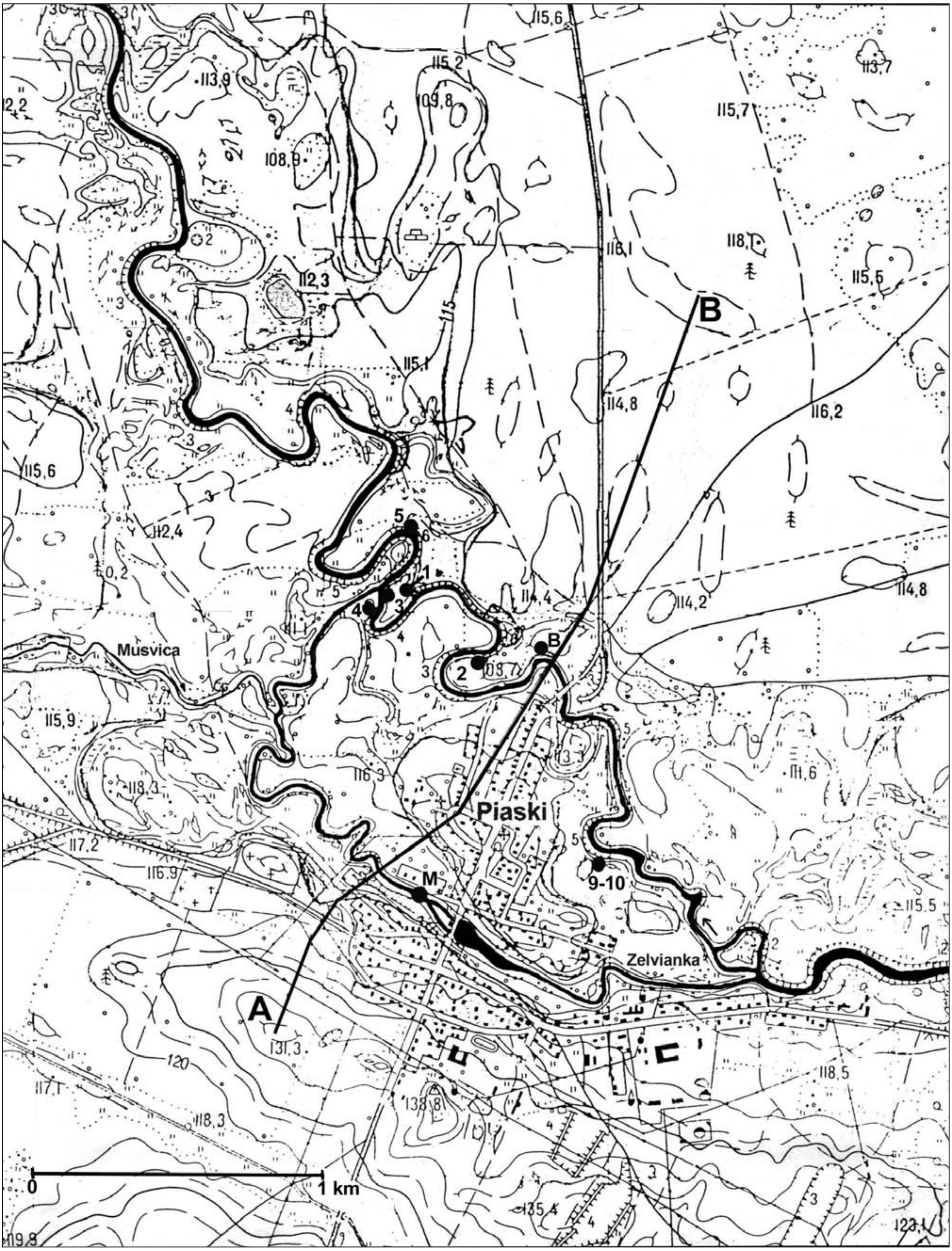

Fig. 3 - Zelvianka river valley near Piaski with study profile and geological section A-B (see Fig. 8) (by T. Kalicki)

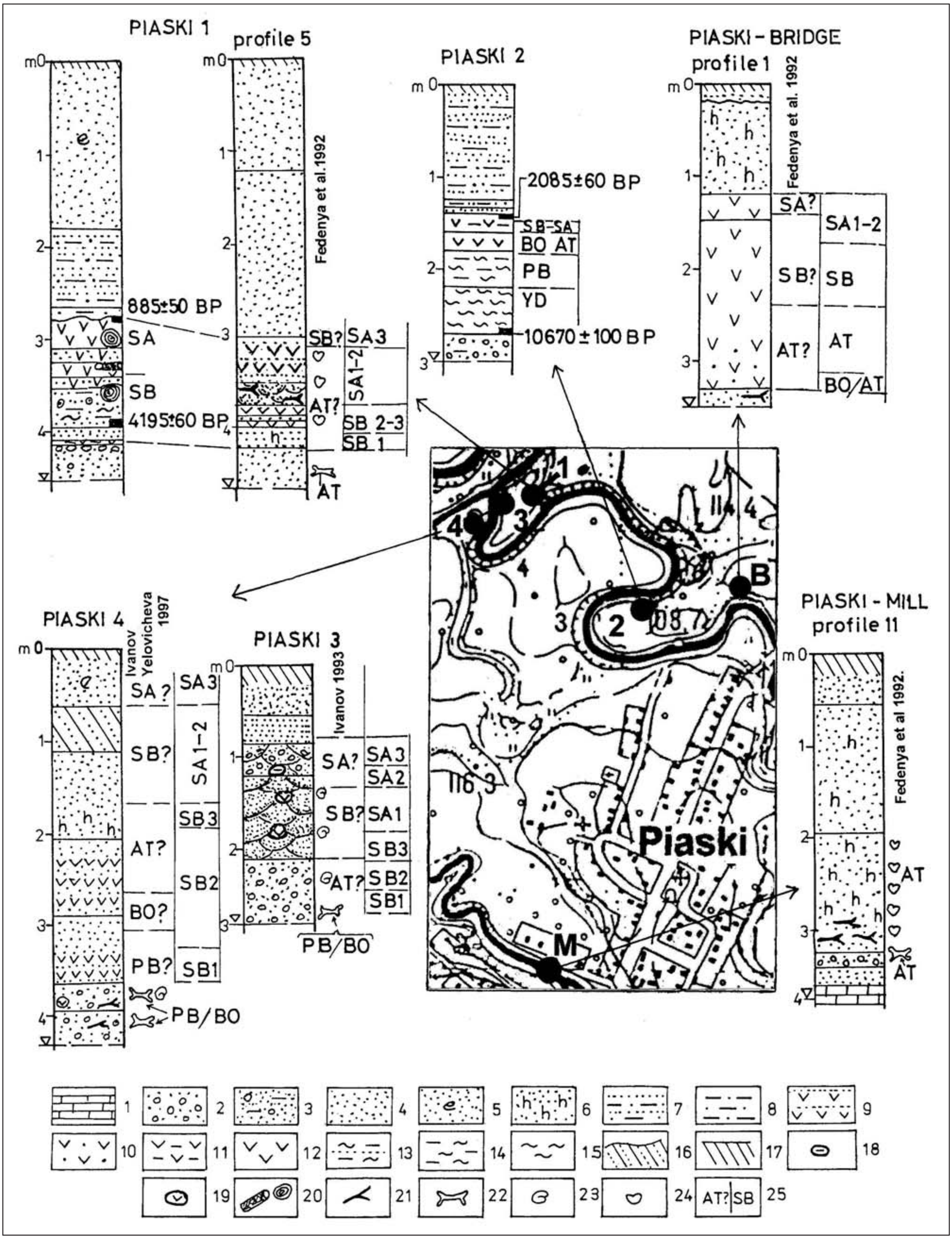

Fig. 4 - Study profiles in the Zelvianka river valley (by T. Kalicki)
1 – chalk, 2 – gravel with sand, 3 – sandy gravel with clay, 4 – sand, 5 – eolian sand, 6 – organic sand, 7 – intercalation of sand and sandy silt,, 8 – sandy silt, 9 – intercalation of peat and sand, 10 – sandy peat, 11 – peaty silt, 12 – peat, 13 – intercalation of gyttja silt and sand, 14 – gyttja silt, 15 – gyttja, 16 – buried soil, 17 – soil, 18 – clayey ball, 19 – peaty ball, 20 – subfossil tree, 21 – detritus, 22 – bones, 23 – shells, 24 – remnant of insects, 25 – older pollen datings (references) reinterpreted by V. P. Zernitskaya

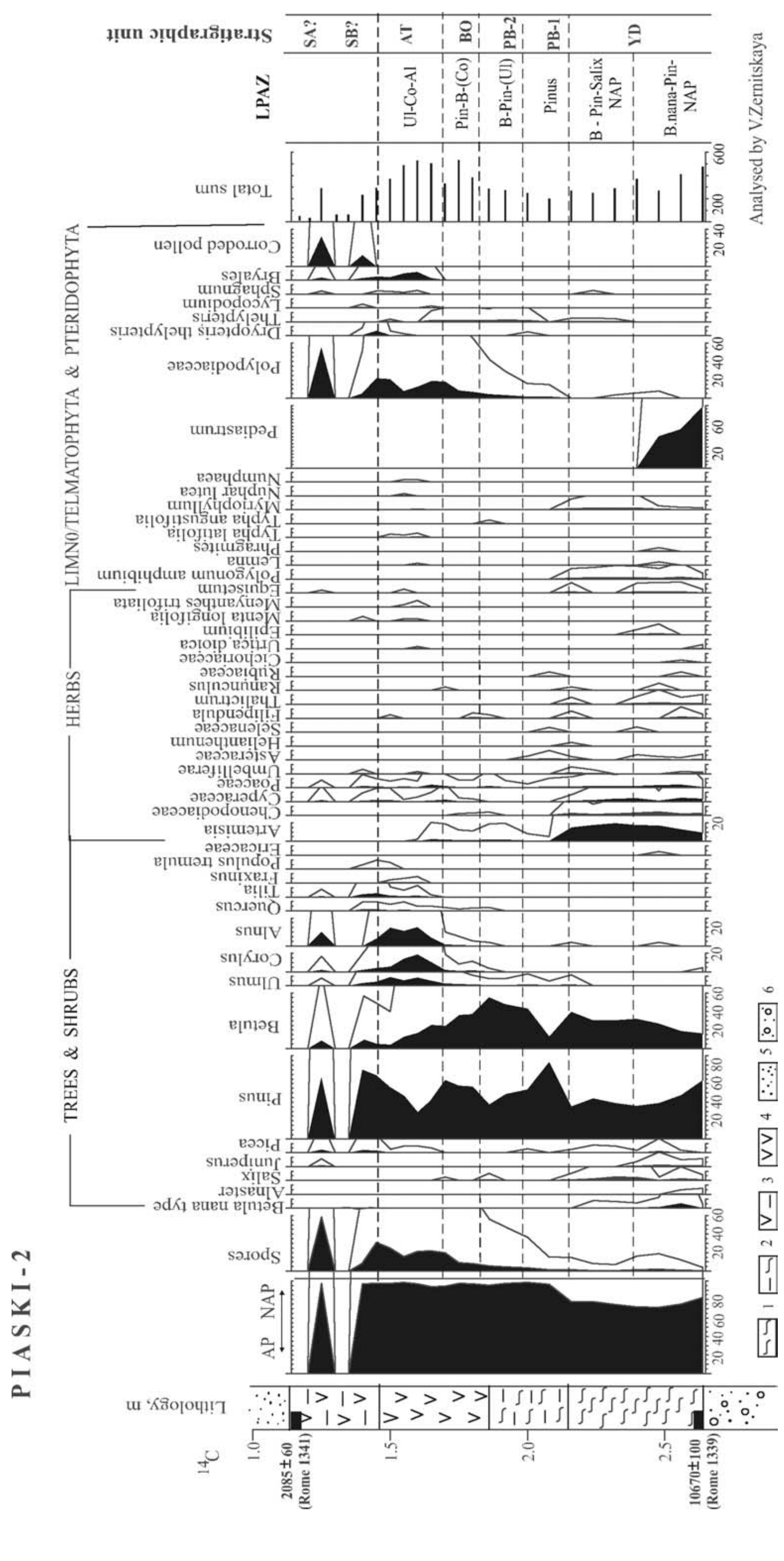

Fig. 5 - Pollen diagram of the Piaski 2 profile (by V. Zernitskaya) - 1 – gyttja, 2 – gyttja silt, 3 – peaty silt, 4 – peat, 5 – sand, 6 – sand with gravel

and 9970±110 yr BP (MIG-27 and Tln-136, respectively), thus in agreement with the PB-1 (~10,200 – 9800 yr BP) established in Zelvianka river valley.

The topmost gyttja silts (2.00-1.84 m deep), LPAZ *Betula-Pinus-*(*Ulmus*), show increase of *Betula* up to 55.3%, further rise of *Polypodiaceae*, *Thelypteris* and stable *Ulmus*. These sediments were assigned to the PB-2 (9800-~9200 yr BP) by analogy with the reference pollen spectra from Kremushovka and Morino sites (Vozniachuk and Valchik, 1978), both recording the birch peak between 9920±90 and 9320±100 yr BP (MIG-27 and MIG-41, respectively).

The lower part (1.84-1.70 m deep) of an overlying horizontal-bedded, compact peat layer, LPAZ *Pinus-Betula-*(*Corylus*), features *Betula* drop, *Pinus* and *Ulmus* rise and appearance of *Corylus, Quercus* and *Alnus* along with *Polypodiaceae* predominance among the NAP. This implies that the oxbow lake changed into a fern-covered swamp. The timing of a comparable AP spectrum (Morino site, Vozniachuk and Valchik, 1978) spans from 8940±80 to 8590±90 yr BP (MIG-28 and MIG-29, respectively) and therefore the LPAZ has been referred to __ (~9200-8000 yr BP). The upward (1.70-1.45 m deep) peat, LPAZ *Ulmus-Corylus-Alnus*, exhibits the peaks of *Ulmus* (9.1%), *Corylus* (18.6%) and *Alnus* (20.%), expansion of *Quercus* and *Tilia* and subordinate *Fraxinus* occurrence. The pollen spectrum, typical for AT, fairly matches that for Podbarany site (Zernitskaya, 1999; Kalicki *et al*., 2000). In the middle of the Atlantic (1.60-1.55 m deep) the most humid climatic phase is marked by the hydrophiles *Lemna, Thypha latifolia, Nuphar lutea, Numphaeae* and *Myriophyllum* as well as the hygrophiles *Menta longifolia* and *Menyanthes trifoliata*.

The organic paleochannel fill ends with severely decomposed clayey peat (1.45-1.10 m deep). The abundant corroded pollen content and the frequent fluctuation of many taxa points to floods and unsteady humidity in the peat bog, now populated by ferns and subjected to pedogenesis. Pollen data, though revealing a drop of *Ulmus* and *Corylus* and a rise of *Pinus*, *Picea*, *Quercus* and *Tilia*, were too meagre for any sound chronological assignment. However, the ^{14}C reading (Rome-1341: 2085±60 yr BP) at the top of these sediments provides an *ante quem terminus* for their deposition.

The bottom of the overbank deposits (1.10 m - upward) capping the paleochannel fill displays, bottom to top, two sandy, 2 cm-thick layers overlain by a 12 cm-thick silty-sands layer, that is a suite likely mirroring an abrupt sedimentation change due to a flooding event. Pedogenesis overshadowed the primitive structure of the topmost 80 cm of the upward intercalations of horizontally bedded sands and humified silty-sands.

Data suggest that the paleochannel was cut off at the Alleröd/Younger Dryas transition and then, following fast gyttja accumulation during the Younger Dryas, the oxbow lake disappeared at the onset of the Holocene. The organic paleomeander fill records the humid Middle Atlantic climatic phase. Probably, at the Subboreal/Subatlantic transition the lowering of the ground water table triggered the weathering of the topmost peat. Lastly, in response to the important sedimentation changes caused by floodings in Roman times, the peat bog was buried by overbank deposits.

Piaski-10

This new exposure (Fig. 3) shows the sandy level at c. 5 m a.r.l. and the paleochannels Piaski-10 and -9 on the upper and middle flood plains, respectively (Fig. 6). The former meander cut the higher sandy level and in turn was cut by the latter one. The height of the upper flood plain, less than 3 m in the paleomeander, rises to 4.5-5.0 m a.r.l. at the point bar. The bottom of the paleochannel fill is c. 1.5 m a.r.l. and channel medium sands occur at the base of the profile (Fig. 6). The organic silty

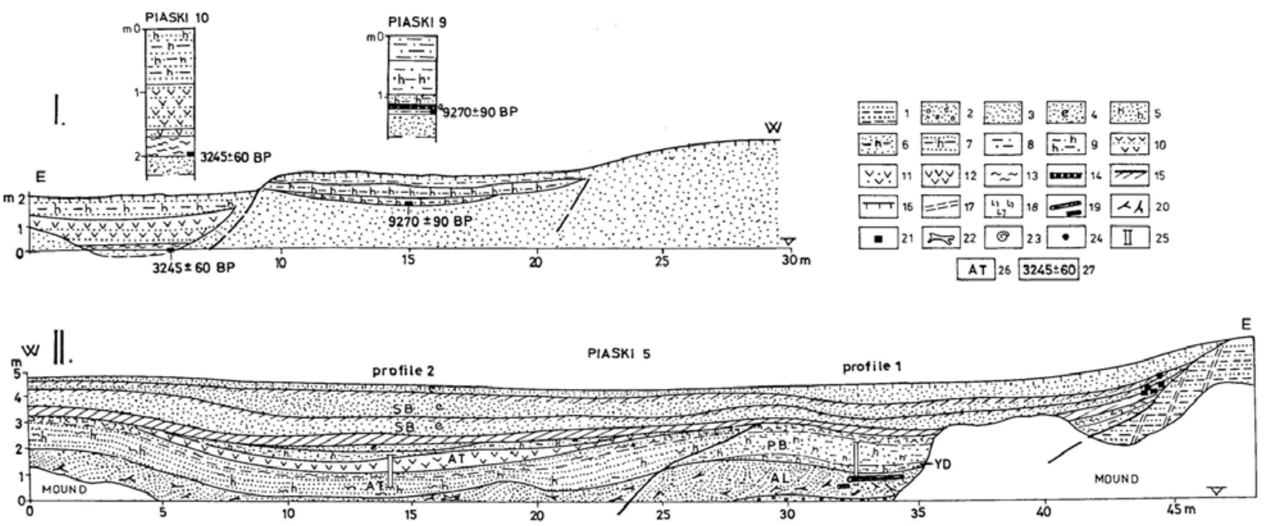

Fig. 6 - Section across the Piaski 9-10 sites (by T. Kalicki) and Piaski 5 (Levkov *et al*. 1988, modified by T. Kalicki)
1 – limnoglacial sediments (intercalations of sand and silt), 2 - gravel with sand, 3 – sand, 4 –eolian sand, 5– organic sand, 6 – organic silty sand, 7 – intercalation of sand and organic sandy silt,, 8 – sandy silt, 9 – organic sandy silt, 10 - intercalation of peat and sand, 11 – sandy peat, 12 – peat, 13 – gyttja, 14 – lacustrine chalk, 15 – buried soil, 16 – soil, 17 – slump, 18 – iron concretion, 19 – subfossil tree, 20 – detritus, 21 – charcoal, 22 – bones, 23 – shells, 24 – flint artifact, 25 – samples for palaeobotanical macroremnant study, 26 – palaeobotanical dating, 27 – radiocarbon dating; AL – Alleröd, YD – Younger Dryas, PB – Preboreal, AT – Atlantic, SB – Subboreal

sands (meadow ore) at the bottom of paleomeander fill were dated at 9270±90 yr BP (Rome-1337). Upward, following a level of lacustrine chalk with *Bithynia tentaculata* pointing to an ephemeral oxbow lake, meadow ore accumulated again. The topmost 0.5 m of the profile consists of overbank silty sands. The Early Holocene abandoned channel was close enough to the Zelvianka river to prevent any subsequent organic accumulation in the paleomeander.

Piaski-5

This exposure (Fig. 3) has been reported (Levkov *et al*., 1988) as a thermokarstic depression infilled by two age-distinct series of alluvia capped by aeolian sands (Fig. 6). Subfossil pine trees, up to 3 m long, were found in the cross bedding sands and gravels at the bottom of the fill (Fig. 6, profile 1). Based on the vegetal macroremnants both channel deposits and overlying sandy overbank sediments were dated to the Late Glacial/Preboreal transition. In turn, the depression fill (Fig. 6, profile 2) made up by gravel with sands and peats was subsequent, as pointed out by Preboreal/Boreal mammal bones (Ivanov, 2001) at the bottom of the lag deposits and vegetal macro-debris of the Middle and Late Atlantic mixed forest in the overlying sediments (Levkov *et al.*, 1988). Both alluvial members are topped by aeolian sands that, for containing at least three paleosols, did deposit intermittently. The sands contain flint tools, likely used for quarrying the chert in the glaciodislocated basement close to Piaski some 3400-3200 yr BP (Gurina, 1976).

However, the previously claimed thermokarstic origin of the depression has to be rejected for two sound reasons. First, the limnoglacial deposits could not accumulate during the maximum expansion of the Valday ice sheet (thus, while Zelvianka river was frozen) and further, a re-examination of the outcrop revealed two age-distinct paleomeanders cut in the limnoglacial series (Fig. 6). Thus, the channel deposit underlying the paleomeander fill consists of two diachronous alluvial bodies instead of only the one previously claimed. In addition the top of the Late Glacial channel facies is 2 m a.r.l. and the older paleomeander cut the limnoglacial series. Thus, the slumps on the scarp of the river valley do actually record bank erosion, in analogy with that reported from Vistula valley (Wasylikowa *et al.*, 1985), rather than thermokarstic processes. The pine trees fallen during the Late Glacial lateral migration of Zelvianka river accumulated in the sandy-gravels deposits. The older paleochannel cut off at the Late Glacial/Holocene transition and in the Preboreal was quickly infilled by sandy sediments containing a rather homogeneous assemblage of vegetal macroremnants (Fig. 6, profile 1). During the Early Holocene the younger meander undercut and partly destroyed the fill of the older, abandoned channel, then it was cut off in the Middle Atlantic. In the Late Atlantic, following its fast infilling by sands (Fig. 6, profile 2), the younger oxbow lake changed into a peat bog. During the Subboreal and Subatlantic both paleomeanders were covered with aeolian sands in a few phases. The flint artifacts in the buried soils could suggest that human impact played some role in the recurrent aeolian activity.

Piaski-4

The profile (Ivanov and Yelovicheva, 1997; Ivanov, 2001) is located on a narrow, 10 to 50 m wide, remnant of the upper flood plain, 3.5-4.5 m a.r.l. (Fig. 3). Basal channel sands with gravels contained well preserved, likely *in situ*, bones of amphibia, fish and mammals (typical of taiga coenoses) with some tundra species probably of the Preboreal/Boreal transition (Fig. 4). The upward sandy paleochannel fill (3.6-2.9 m deep) is overlain by sandy overbank deposits 1.8 m thick. Pollen data point to a continuous sedimentation from the second half of the Preboreal through the first half of the Subboreal. An overlying silty-sandy buried soil (1.1-0.6 m deep) was assigned to the second half of the Subboreal and the aeolian fine sands capping the sequence to the Subatlantic by the pollen data.

In our opinion, however, the above conclusions are puzzling. Actually, the claimed continuous sedimentation from the Preboreal through the present is ruled out by paleosol occurrences. Further, it is also well known that alluvia is deposited by meandering rivers mostly according to an horizontal rather then a vertical pattern. In addition, no firm conclusions can be drawn from the reported pollen spectrum that for having been determined on sands (also including a paleosol) and for lacking the pollen/corroded pollen ratio, prevents any *hiatus* recognition. By comparing the Piaski-2 and -4 palynostratigraphies it results that the latter lacks the LPAZ's *Betula-Pinus-(Ulmus)*, *Pinus-Betula-(Corylus)* and *Ulmus-Corylus-Alnus*, despite all of them all of them are quite evident since PB-2 to the end of AT in the Piaski-2 pollen spectrum. The LPAZ's *Pinus-Quercus*, *Betula-Quercus* with *Tilia*, *Carpinus* and *Fagus* displayed in the Piaski-4 pollen spectrum are typical for the Subboreal in Belorussia (Zernickaja, 1998, Zernitskaya, 1999), eastern Poland (Ralska-Jasiewiczowa and Latalowa, 1996) and southerneast Lithuania (Kabailiene, 2002). Both literature and new data (*e.g.*, Piaski-1 profile) constrain the deposition of the Piaski-4 sediment suite (Fig. 4) within the SB (4.1-1.7 m deep) and SA (1.7 m-upward).

Piaski-3

This profile (Ivanov, 1993), c. 3.0 m a.r.l. shows basal loams overlain by sandy alluvia (Fig. 3, 4). The lower portion (2.5-2.8 m deep) of subhorizontal bedding sandy-gravel channel alluvia contains well preserved, likely *in situ*, mammal bones pointing to widespread humid mixed forest. Palaeozoological and palynological data were judged consistent with a continuous sedimentation during the last 8000 yrs (from AT-1 to SA-3).

However, the previous criticisms for Piaski-4 also apply here, as the reported pollen spectrum, besides depicting only the AP trend, does not show the pollen amounts. Akin to Piaski-4, as the pollen diagram lacks the AT (*Ulmus-Corylus-Alnus*) while showing both SB and SA chronozones, it is reasonable that Piaski-3 sequence deposited since the Subboreal. This is also supported by new malacological data (predominance of channel species over those of different biotopes) from the 0.75-3.1 m deep sandy deposits, consistent with alluvia accumulation from the Atlantic to the Subatlantic (A. F. Sanko, *pers. comm*., 2002).

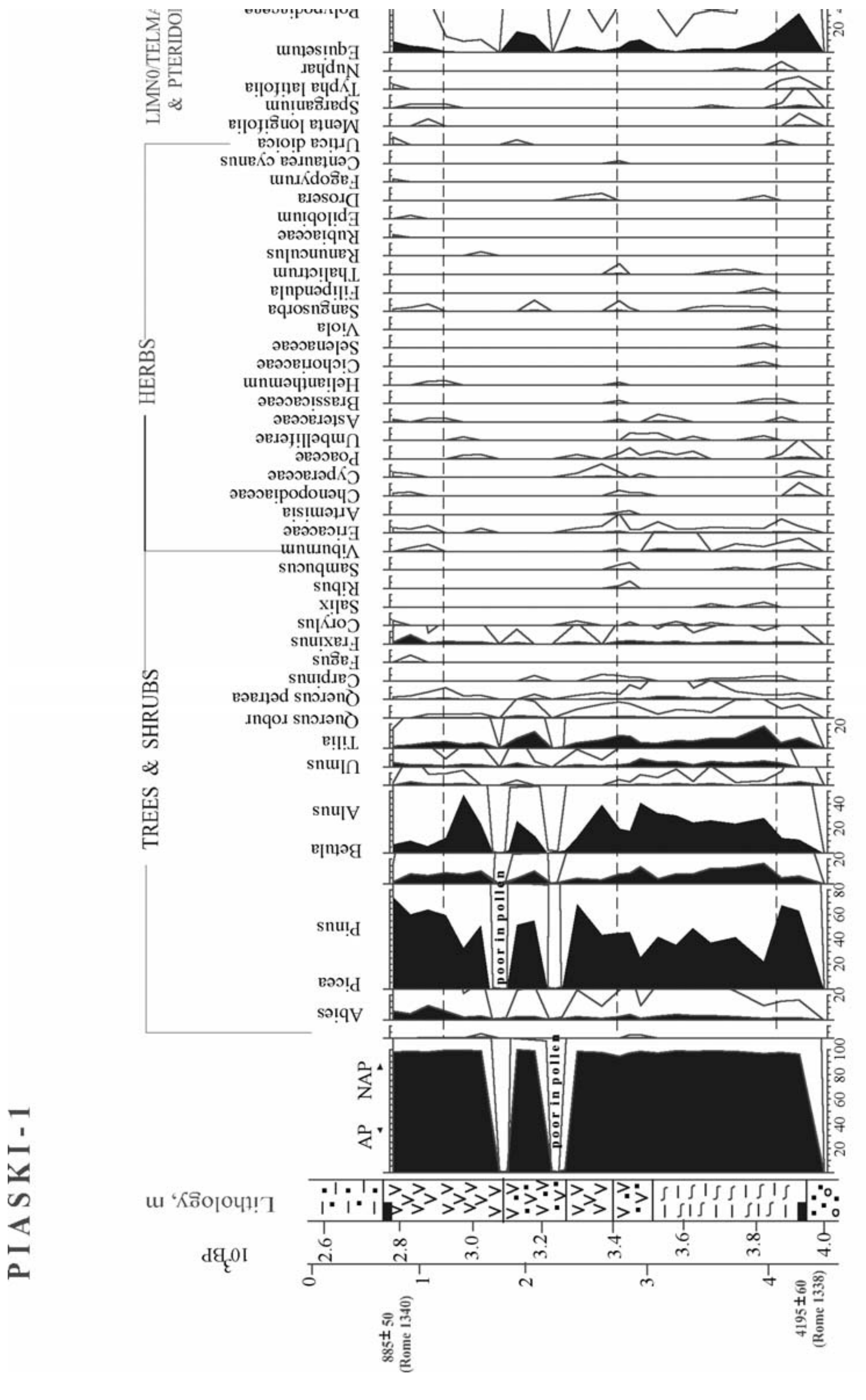

Fig. 7 - Pollen diagram of the Piaski 1 profile (by V. Zernitskaya) - 1 – gyttja silt, 2 – peat, 3 – sandy peat, 4 – sandy silt, 5 – sand, 6 – sand with gravel

MIDDLE FLOOD PLAIN

According to Kovbasyuk and Ivanov (1998) the middle flood plain is built of sandy overbank deposits rich in vegetal remnants and detritus and devoid of subfossil tree trunks. The overbank/channel sediments boundary lies below the mean river water level. Oxbow lakes were filled with humic sands 0.5-1.5 m thick and, sometimes, with peat intercalations up to 1.5-1.8 m thick.

Contrasting with the previously stated absence of slope and aeolian deposits, new field work at Piaski-1 identified thick aeolian sands covers. All the studied profiles herein reported are from the northern branch of the valley.

Piaski-1

This exposure (Fig. 4, profile 5) was referred to the upper flood plain for lying above the river level (Fedenya *et al*., 1985, 1992). By contrast, the new survey established that the topmost 2 m of the sequence are aeolian sands and thus the shown features do belong to the middle flood plain (Fig. 3 and 4). At the base of the channel deposits (4.22-4.67 m deep) an assemblage of likely *in situ* bones of mammals (mostly of mixed and deciduous forests, 25 and 17% of lake banks and meadows, respectively), amphibia of mixed and deciduous forests of Middle Holocene age and fish were found. The entomological assemblage from the organic paleochannel fill includes species of fast flowing waters together with those of stagnant or slowly flowing waters (as in oxbow lakes with clay bottom) and mirrors the variety of biotopes in the river valley during the Middle Holocene.

At Piaski-1 a new, ^{14}C dated pollen diagram has been determined as that previously available placed at the Atlantic-Early Subboreal the peat in the paleochannel, thus in open contrast with the up to date regional palynologic framework (Zernitskaya *et al*., 2003), The sampled exposure shows, bottom to top, four main members including channel deposits, organic paleochannel fill, sandy-silty overbank deposits and aeolian sands (Fig. 3 and 4). The basal member, c. 0.5 m thick, consists of medium and coarse sands and correlates with the layer with fossil bones after Fedenia *et al*. (1992). The transition to the overlying paleochannel fill is marked by a *lamina* of lag deposits (gravels 0.2-0.3 cm in diameter) covered with a 0.5 cm-thick *lamina* of peaty silts and a 15 cm-thick layer of medium and coarse sands. The upward organic paleochannel fill, submitted to pollen and ^{14}C analyses, shows a 0.5 m-thick gyttja silts (LPAZ *Pinus-Quercus* at 3.95-3.85 m deep), overlain by 0.7 m-thick peats (Fig. 7). The lowermost 5 cm of the gyttja silts, sandy and densely laminated, suggest some river input into the oxbow lake. The lack of sandy intercalations through the upward c. 10 cm points to low sedimentation energy and rules out flood events. The AP *Pinus* and *Quercus* predominate over *Picea, Tilia* and *Carpinus*. *Nuphar*, *Sparganium* and *Typha latifolia* grew in the oxbow lake and *Polypodiaceae*, *Sphagnum* in the marshes. The bottom of this Early Subboreal (SB-1) pollen chronozone was dated at 4105±60 yr BP (Rome-1338). It is noted that a comparable pollen spectrum was reported from Podbarany site (Kalicki *et al*., 2000) for sediments younger than 4645±50 yr BP (IGSB-709).

The lacustrine episode of the paleochannel with gyttja silts accumulation lasted up to the end of the Subboreal (LPAZ *Betula-Quercus-Carpinus*, 3.85-3.35 m deep). A few sandy *laminae* in the middle of the gyttja silts record episodic oxbow lake/river contacts. *Pinus* drop parallels the rise of *Betula*, *Alnus*, *Tilia* (6.6%), *Quercus* (20%) and *Carpinus* (2.6%) whereas *Fagus* is far subordinate. The rare hydrophyte *Typha latifolia* indicates a water depth less than 0.5 m. A comparison with the Ogorodniki pollen diagram, showing that *Tilia*, *Quercus* and *Carpinus* maximize between 3820±100 and 3530±100 yr BP (Tln-163 and MIG-44, respectively) and decline between 3530±100 and 2720±90 yr BP (MIG-44 and MIG-43, respectively), dates these sediments to the SB-2 and SB-3 (~4000-2700 BP). At c. 3000 BP the oxbow lake changed into a marsh where the intermittent grow of trees is recorded by subfossil trunks in the peats. The peat layer includes two sandy peat intercalations. The lower one spans through the uppermost part of LPAZ *Betula-Quercus-Carpinus*, characterized by decrease of Pinus, expansion of pioneer vegetation (*Betula* and *Alnus* in deforested areas) and *Viburnum*, *Sambucus* and *Calluna* occurrence. NAP in SB-3 sediments (3.50-3.35 m deep) reaches 10% and includes *Scleranthus*, *Helianthemum* and *Brassicaceae*. The rise of xerophytes and heliophytes, *e.g.*, *Artemisia*, *Chenopodiaceae*, *Cichoriaceae*, *Umbelliferea* and *Asteraceae* is matched by *Poaceae*, *Fagopyrum* and *Urtica dioica* appearance. Despite the lack of cultural species, the apparent deforestation could be accounted for, at least to some extent, by human impact, in that archaeologic sites of the Neman and Trzciniec cultures (Late Neolithic and Bronze Age, respectively) are known nearby Piaski village (Charnyavski, 1979; Arkhialogiya Belarusi, 1997). It is reasonable that following the local pine forests clearance for wood exploitation and flint quarrying in the glaciodislocated chalk, the wind blown sands originated from the deforested areas mixed up with the peat growing in the paleomeander. The concomitant humid climate, recorded by rise of *Polypodiaceae* and *Picea* (up to 5%) and *Abies* occurrence, resulted in trees fallen on the peat bog, where subfossil trunks were found at the silty gyttja/peat limit. Probably also the sandy intercalation reported by Fedenya et al. (1992) in the paleochannel fill were laid down from the same flood phase (Fig. 4).

The upward sediments of LPAZ *Pinus-Quercus-Alnus* (3.35-2.90 m deep), dated to 2700-1200 BP, show *Pinus* rise, high *Quercus* (8.4%) and *Alnus* (47%), *Tilia* decline and *Carpinus* disappearance. NAP are dominated by *Polypodiaceae*. Some sediment samples from 3.25-3.10 m deep were very low in pollen for the alternating peat and sandy *laminae* were severely affected by erosion and undulation. At 3.20-3.15 m depth *Polypodiaceae* increases and the hygrophytes *Sphagnum*, *Mentha longifolia* and *Rubiaceae* are weakly, though significantly, represented. The subfossil trunks, 15 to 20 cm in diameter, at the boundary between the laminated layer and the overlying peats (Fig. 4) mark a further phase of trees fallen on the peat bog caused by increased humidity. All the above features, along with the lack of human activity pollen markers, point out an enhanced flood frequency during the humid climatic phase in Roman time (*c*. 2000 BP). Tentatively, also the second sandy intercalation reported from the paleochannel fill by Fedenya *et al*. (1992) could be correlated with this flood phase (Fig. 4).

The uppermost peats (LPAZ *Pinus-Picea-Corylus*, 2.90-2.75 m deep) display scant *Ulmus* and *Carpinus*, expansion of *Pinus*, *Picea* and *Corylus*, decline of *Quercus robur* and desappearance of *Q. petraea*. The *Picea* peak (11.4% at c. 1000 yr BP) records a cooler and more humid climate. The higher humidity in the peat bog is also supported by the occurrence of *Sparganium*, *Typha latifolia*, *Nuphar* and the algae *Pediastrum*. The re-appearance of *Artemisia*, *Brassicaceae*, *Cichoriaceae*, *Poaceae*, *Calluna* and *Centaurea cyanus* along with the peak of *Corylus* indirectly reflect the human presence. Probably the exploitation of the deciduous wood contributed to spread the hazel. Frequent floods, triggered by climate fluctuations, significantly changed the sedimentation pattern in the paleochannel and the peat growth, definitely over at 885±50 yr BP (Rome-1340), was substituted for by accumulation of horizontal bedding, sandy-silty overbank deposits. These latter, up to 1 m in thickness, were blanketed during the last centuries by *c*. 1.8 m of aeolian sands and podsol developed at their top (Fig. 4).

The new findings contrast with some conclusion after Fedenya *et al*. (1985, 1992). Based on the mammalian assemblage the channel, active during the Late Atlantic/Subboreal transition, was cut off at *c*. 4200 BP. Despite of that the sandy intercalations in the organic sediments point out that episodic oxbow lake/river channel interactions did last over further hundred years. The signature of two humid climatic phases in the paleochannel organic fill (*c*. 3000 and *c*. 2000 BP) is provided by re-appearance of hydrophile taxa, trees fallen and sedimentation change in the peat bog. Then, a further flood phase (*c*. 885 yr BP) caused the peat bog burial by overbank deposits. The forest clearing recorded by pollen data at *c*. 3000 BP likely reflects the impact of the Neman culture settlements. However, it is reasonable that the origin of the thick cover of aeolian sands on the middle flood plain near the valley scarps only depended upon the extensive forest exploitation during the last centuries.

Piaski-Bridge

The section (Fedenya *et al*., 1992) displays middle-coarse sands with detritus overlain by peats and sands (Fig. 3 and 4). Previous palaeobotanical and palaeoentomological data bracket the origin of the paleochannel peats between the second half of the Atlantic and the beginning of the Subatlantic.

The new pollen spectrum for Piaski-2 (Fig. 5) conflicts with the previously stated timing of *Betula* decline and *Corylus* appearance and set the cut off at the Boreal/Atlantic boundary. Further, the important sedimentation change marked by the sudden appearance of fine, humified sands in the upper part of the sequence (Fig. 4, profile 1), previously placed at the Subboreal/ Subatlantic limit by the *Picea* peak, is more reliably

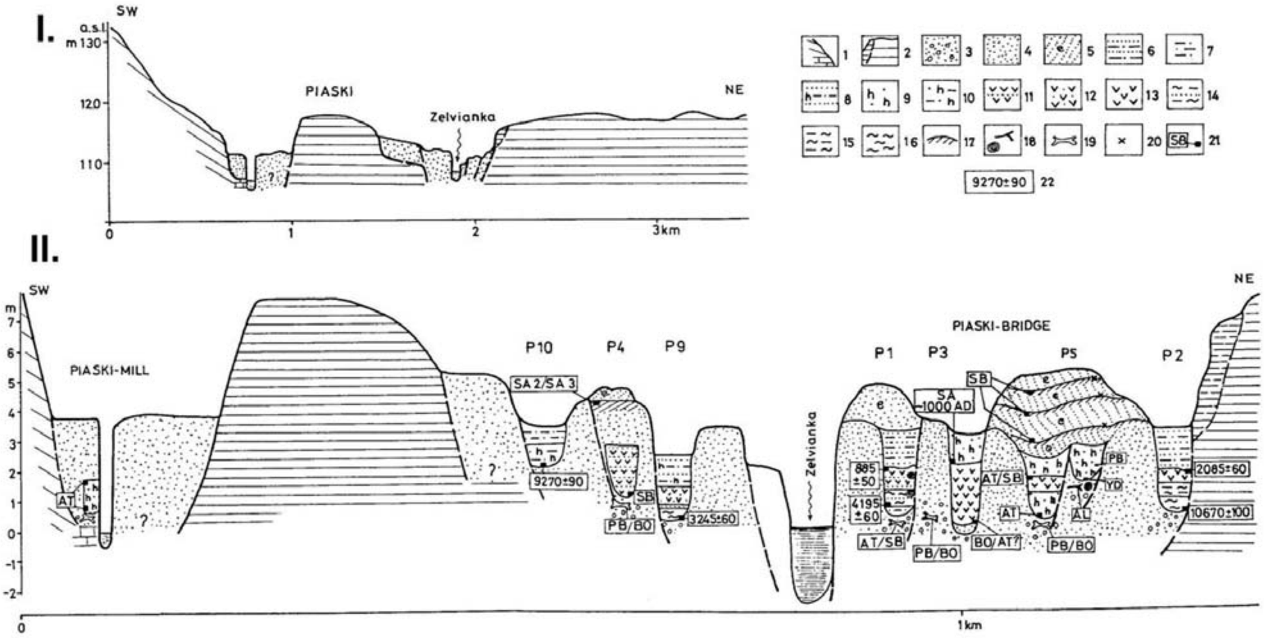

Fig. 8 - Geological section A-B (see Fig. 3) of the study area (I) and schematic profile (II) across the Zelvianka river valley near Piaski (by T. Kalicki)
1 – bedrock (tilt with glaciodislocated chalk), 2 – limnoglacial serie with slump, 3 – gravel with sand, 4 – sand, 5 – eolian sand, 6 – intercalation of sand and sandy silt, 7 – sandy silt, 8 – intercalation of sand and organic sandy silt, 9 – organic sand, 10 – organic sandy silt, 11 – intercalation of peat and sand, 12 – sandy peat, 13 – peat, 14 - intercalation of sand and gyttja silt, 15 – gyttja silt, 16 – gyttja, 17 – buried soil, 18 – subfossil trees and detritus, 19 – bones, 20 - flint artifacts, 21 – palaeobotanical, palaeozoological and archaeological datings, 22 – radiocarbon datings; AL – Alleröd, YD – Younger Dryas, PB – Preboreal, BO – Boreal, AT – Atlantic, SB – Subboreal, SA - Subatlantic.

dated at c. 1000 BP by the spruce maximum shown in both the previous pollen diagrams for this profile and in the new one from Piaski-1 (Fig. 7).

Piaski-9

The overall features of this new section (2.2.-2.5 m a.r.l.) are as for Piaski-10 (Fig. 3 and 6). The fine sands at the bottom of the paleochannel fill change upward into organic sediments, with a gyttja layer, dated at 3245±60 yr BP (Rome-1342), at the base. Through the upward 80 cm a regular alternation of a few mm thick, brown and whitish *laminae* is shown. The former ones, rich in organic matter, deposited during the vegetational seasons whereas the latter ones, made up by fine sands, during the spring floods. In our knowledge such an evidence of seasonal sedimentation change in paleomeanders was never reported. As the frequency of the laminae pairs is from 5 to 7 cm^{-1}, it can be estimated that the whole member deposited in some 500 yrs. Such peculiar lamination is overlain by sands with silty-sands intercalations.

PALEOGEOGRAPHY

The origin of Zelvianka river valley dates back to the disappearance of the dammed Skidel lake in the Young Pleniglacial, just after the Pomeranian stage of the last glaciation dated to 16.2 (Kozarski, 1995) and 15.5-15.0 ka BP (Valchik, 1992). The incision of Neman river and its tributaries on the Upper Neman Plain was over in Middle Lithuanian stage of deglaciation (13.8-13.7 ka BP, Valchik, 1992), when Zelvianka river bifurcated near Piaski and meanders, still well preserved downstream of the study site, were confined. The Young Pleniglacial incision of the limnoglacial sediments was so fast that the bottom level of the Late Glacial paleomeanders (*e.g.*, Piaski-2, -5 and -10) approach those of their Holocene analogues (Fig. 8). The vegetal macrofossils from the channel deposits (Piaski-5) date the upper flood plain at the Alleröd. A fast incision, followed by a relative stabilization, was also reported from the main Neman river valley, where the terrace T-1 and the upper flood plain formed during the Late Glacial and the Early Holocene, respectively (Vozniachuk and Valchik, 1978).

During the Younger Dryas the highlands were covered by pine-birch-juniper open forests, the humid lows by spruce and dwarf birch (*Betula nana*) and the open lands by xerophyte grass communities. The climate cooling forced changes of Zelvianka river course and the cut off occurred at the Alleröd/Younger Dryas transition (*e.g.*, Piaski-2, 10,670 BP). Evidence of river braiding, lateral migration and valley widening are the relatively shallow paleochannels (with subfossil trunks in their fills) that while undercutting caused slumps on the slope of the northern branch of the valley (Piaski-2 and -5). Probably some river aggradation took place, as the bottom of the river bed rose from *c*. 0.5-1.0 to *c*. 1.5 m a.r.l. from the Younger Dryas to the end of the Preboreal (Fig. 8). Willows as pioneer taxa grew on the new bars of the alluvial plain and also around the oxbow lakes. These latter experienced a highly variable rate and pattern of sedimentation (*e.g.*, fast gyttja accumulation at Piaski-2 or slow deposition of sands with detritus at Piaski-5).

The overall climate warming at the onset of the Preboreal is marked by vegetation changes, *e.g.*, spreading of pine forests on the highlands and elms on Zelvianka flood plain. Some paleochannels (Piaski-5) were filled up quickly with sandy sediments containing detritus. At the end of the Preboreal (PB-2) the region was covered with birch, pine-birch and elm forests. The shallow paleochannel Piaski-10 was cut off at *c*. 9270 BP. The evolution of Zelvianka river bed, as well as the lack of incision likely depended upon the relatively dry climate.

Elm rise, oak and hazel first appearance, increased the heterogeneity of the mixed forests and development of alder and fern patches on the humid flood plain took place in the Boreal. An incision phase of the river at the beginning of the Boreal is suggested by the mammal bone assemblages from the channel deposits of the middle flood plain, dated at the Preboreal/Boreal transition (Piaski-4 and -5) and at the onset of the Atlantic (Piaski-3). Likely, the event was caused by a wave of headward erosion originated in the Neman valley on the middle Neman plain, about 100 km downstream of the study area, prior to the Older Dryas (Kalicki, 2002; Kalicki *et al*., 2002). However, the Middle Holocene age of the bones from the channel deposits of the 1.5 m high Borodnichanka valley bottom in the Volkovysk upland (Fedenya and Kalinovskiy, 1981) points out that the regressive incision reached the upper section of the Zelvianka tributaries just in the Neoholocene. The cutting, coupled with the improved drainage of Zelvianka upper flood plain, changed the former oxbow lakes into peat bogs at *c*. 9000 BP (Piaski-2). In turn, the ephemeral lakes with gyttja accumulation in the Preboreal abandoned channels were substituted for by marshes with meadow ore formation (Piaski-10) just after 9270 BP. The oldest paleomeanders of the middle flood plain cut off at the Boreal/Atlantic transition (Piaski-Bridge) and the bottom height of their fillings equalled the present river water level (Fig. 8). Reasonably the channel changes were triggered by the humid and cooler climatic phase at the Boreal/Atlantic transition previously reported from central European river valleys and other environments (Starkel *et al*., 1996; Starkel, 2000).

In the Atlantic pine forests with birch there were confined in the poorest sandy soils, deciduous forests with hazel, elm and subordinate oak, lime and ash spread on the fertile flood plain. and alder and fern occurred in humid sites. The lateral river migration destroyed, completely or partly, some older paleochannel fills (Piaski-5). Then, in the Middle Atlantic the younger Piaski-5 paleomeander was cut off and fast infilled with sands. Both channel changes and a fast sedimentation rate point to frequent floods during the humid climate phase revealed by Piaski-2 pollen diagram. This climate trend is consistent with the *c*. 6420 BP humid phase in the Neman valley (Kalicki *et al*., 2000) and the c. 6500-6000 BP climate cooling and increased river activity in the Vistula river valley (Kalicki,1991b, 1996a; Starkel *et al*., 1996). The bones of Middle Holocene age from the channel deposits of the southern branch of Zelvianka valley (Piaski-Mill) suggest that since the end of the Atlantic only the northern branch was active. The

Late Atlantic drier climate, argued from the palaeozoological data from Piaski-Mill, accounts for the abandonment of the southern valley branch in response to the decreased river discharge. Accordingly, the Late Atlantic/Subboreal bones in the channel river facies of the paleomeander undercutting the valley slope at Piaski-1 support a widening of the active northern branch of the river valley. In some paleochannels (*e.g.*, Piaski-5) the Late Atlantic increased fluvial activity changed the sedimentation pattern from organic into clastic.

Climate cooling at the beginning of the Subboreal deteriorated the elm forests which were progressively substituted for by oak-pine forests. Despite that at *c*. 4195 BP the meander was cut off at Piaski-1, the sandy layers intercalated in the organic fill of the paleomeander reveal that some river/oxbow lake communication did still last over some hundred years. The modern vegetation subzone (*Carpineto-Querceto-Pinetum* forest) began to develop during the 4000-2700 BP timespan. Hornbeam, spruce, beech, birch and alder expanded whereas pine declined. Contemporary is the first evidence of settlements, referred to Late Neolithic (Neman culture) and Bronze Age (Trzciniec culture). Likely, the local anthropogenic impact resulted in spreading of bush (*Sambucus*, *Viburnum*, *Rubus*), rural and grasslands taxa (Piaski-1) and aeolian processes development. In the Subboreal and the Subatlantic the deposition of wind blown sands, interrupted by pedogenetic phases, covered both flood plain steps near the edge of the valley bottom (Piaski-5, -4 and -1). Flint artifacts and charcoal from the paleosols (Piaski-5) support that the aeolian activity was triggered by the human impact. A humid climatic phase at *c*. 3000 BP, implying re-appearance of hydrophilous taxa, fallen trees and sedimentation change in the peat bog, was recognized at Piaski-1 in the paleochannel organic fill. Despite of some anthropogenic overshadowing, this climatic phase is reliably marked by a rise of spruce, appearance of fir in the forests and also by channel changes at 3245 BP (Piaski-9). As this phase of enhanced river activity matches those reported from other river valleys in Belorussia (Kalicki, 1991a; Kalicki *et al*., 1997a, 2000) and central Europe (Kalicki, 1991b, 1996b) it is better accounted for by significant, large-scale climatic changes (Kalicki, 1995, 1996a) rather than the local forest clearing at c. 3000 BP.

In the Subatlantic (2700-1200 BP) *Quercus petraea* and *Carpinus* disappeared and declined, respectively, in the *Carpineto-Querceto-Pinetum* forests, whereas alder spread on the flood plain. The Subatlantic incision which formed the lower flood plain also deepened the ground water table and thus pedogenesis developed atop the peat bogs on the upper flood plain (Piaski-2). The neighborhood of the river, with steady regime and spring floods since the onset of the Subatlantic, is witnessed by a series of laminated sediments in the Late Subboreal abandoned channel (Piaski-9). In the Roman time (*c*. 2000 BP) a distinct humid phase is marked by re-appearance of hydrophyte taxa and occurrence of subfossil trees (Piaski 1) in the paleochannel organic fill, while both the flood plain higher steps were inundated. The floods are marked by sandy intercalations in the paleochannel fill on the middle flood plain (Piaski-1) and sedimentation changes in the abandoned channel on the upper flood plain. Here the peat bog was covered with overbank deposits at *c*. 2085 BP (Piaski-2). A further cool and humid climatic phase at 1200-800 BP is suggested by spruce and hazel rise and oak decline. The hydrophilous taxa in the peats from Piaski-1 paleomeander point to some input of flooded pollen: then, at *c*. 885 BP, the peat bog was buried by overbank deposits. Almost contemporary (c. 1000 BP) is the burial of the peats by clastic deposits in the abandoned Piaski-Bridge channel. These two flood phases, likely triggered by climatic changes (Kalicki 1996a), are also known from other Belorussian (Kalicki 1991a, 1995, Kalicki *et al*., 1997b, 2000, Kalicki and Sanko, 1998) and central European river valleys (Kalicki, 1996b, Starkel *et al*., 1996). Their identification relied on channel changes (meander cut-offs and avulsions), sedimentation pattern changes on the flood plains (beginning of peat aggradation, peats and soils burial by overbank deposits, abundant tree trunks in alluvia, etc.). Based on the above it is inferred that the local forest clearing can only account for the Subatlantic aeolian activity which originated the paleosol at Piaski-4.

CONCLUSIONS

The new ^{14}C dated pollen diagrams from Zelvianka river valley and the up to date palynostratigraphic framework for Belorussia (Zernickaja, 1998, Zernitskaya, 1999) pointed out the need to revise the previous pollen chronostratigraphies (Fedenya *et al*.,1992; Ivanov, 1993; Ivanov and Yelovicheva, 1997). Most important, it has been pointed out that the Atlantic is hardly recognized only by the deciduous taxa peak, hornbeam and beech included.

The rejuvenation of the drainage network on the upper Neman plain and the lowering of the level of the Skidel dammed lake, caused by the Vistulian ice-sheet retreat, were almost coeval . The fast Young Pleniglacial incision also propagated in other river valleys developed at the ice sheet front (Kalicki *et al.*, 1997b). Thus, the Zelvianka river level was almost steady from the Late Glacial through the Holocene.

Akin to western Dvina river valley on the Surash Plain (Kalicki *et al*., 1997b), the study area is too far from the sea coast to correlate the Young Pleniglacial, Boreal/Atlantic and the Subatlantic phases of Zelvianka river incision with the Baltic sea level changes as previously claimed (Kovbasyuk and Ivanov, 1998). The first two headward erosion phases caused by deglaciation were delayed and smoothed relative to the main Neman river valley, thus resulting in small height differences among the three Zelvianka river flood plains.

The extremely complex structure of the valley bottom depended mostly on the lateral migration of Zelvianka river during the Holocene. Impressively, almost each morphological level with paleomeanders includes numerous, age-distinct alluvial bodies.

Both channel and sedimentation changes in Zelvianka river valley cluster at AL/YD transition, *c*. 9300 BP, BO/AT transition, middle Atlantic, *c*. 4200 BP, *c*. 3250-3000 BP, Roman time (2100 BP) and 1000-900 BP. Most of these events, likely triggered by the Lateglacial and Holocene humid and cool climatic phases, fairly match episodes of enhanced river activity in Belorussia and central Europe. The only noticeable effect of the human impact on the evolution of the Zelvianka river valley is the activation of aeolian processes in deforested areas during the Subboreal and Subatlantic.

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Ms. ricevuto il 22 giugno 20024
Testo definitivo ricevuto il 2 novembre 2004

Ms. received: June 22, 2004
Final text received: November 2, 2004