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ORIGIN AND EVOLUTION OF BASINS IN THE EASTERN PART OF JASŁO-SANOK DEPRESSION (POLISH CARPATHIANS) IN THE LATE VISTULIAN AND HOLOCENE

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Abstract:

Results of a geomorphologic study as well as radiocarbon and pollen analyses of sediments in small basins of the Jasło-Sanok Depression (Western Carpathians) are summarised. Floors of these basins, carved in soft shale-sandstone Krosno Beds, are covered with channel fluvial deposits and oxbow-lake sediments with lake chalk and peat accumulated in the Late Vistulian and Holocene. Since the early Atlantic Phase (ca 8,400–7,900 BP) the apparent acceleration of overbank (flood) deposition intermitting the peat accumulation is observed. The plant succession includes the Late Glacial (pre-Allerød, Allerød and Younger Dryas) with coniferous park forests, through mixed deciduous forests of the Holocene with elm, hazel, oak and lime as well as spruce-elm forests with alder in wetlands, up to present-day hornbeam forests (Tilio-Carpinetum of various types) and extra-zonal Carpathian beech forests (Dentario-Glandulosae-Fagetum). *Abies alba* (fir) is frequent in both these association types. First evidences of synanthropic plants that prove presence of prehistoric man appeared in the Subboreal Phase. The oldest radiocarbon date 13,550±100 BP (Gd-7355) [16,710–16,085 b2k], from a bottom part of the Humniska section is probably overestimated. This is indicated by palynological data, which suggest attribution of this section to the older Allerød. Small thickness of gravel blanket from the Plenivistulian termination and the beginning of the Late Vistulian, as well as large areas devoid of weathering and solifluction covers indicate that during the Plenivistulian weathering processes and removal of silt-clay material predominated in the basins. In that time the deflation was among important processes, which is proved by deflation troughs, faceted cobbles and thick covers of the Carpathian type of loess. The Besko Basin has pre-Vistulian tectonic foundation, while landforms of its floor are of erosion-degradation origin and formed during the last Scandinavian glaciation. In the Holocene the basin floors were overbuilt with fluvial deposits up to 8 m thick.

Key words: deflation basins, radiocarbon dating, pollen analysis, Jasło-Sanok Depression, Carpathians

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INTRODUCTION

Carpathians and surrounding basins, located during Last Glacial Maximum (MIS 2) in the periglacial zone, were exposed for an active wind action. In particular, wind erosion and deflation played important role in landscape modelling of basins and foothills in the areas built of rocks less resistant to weathering and denudation. Among the areas in Central Europe that were intensively shaped by NW winds (blowing between Carpathians and Alps) during the Pleistocene was the Pannonian Basin in Hungary, where yardangs, ventifacts, deflation depressions and wind-blown sands, developed in periglacial conditions (Sebe *et al.*, 2011). Similar deflation landforms of small depressions and closed basins occur in the intra-mountainous Jasło-Sanok Depression (Doły Jasielsko-

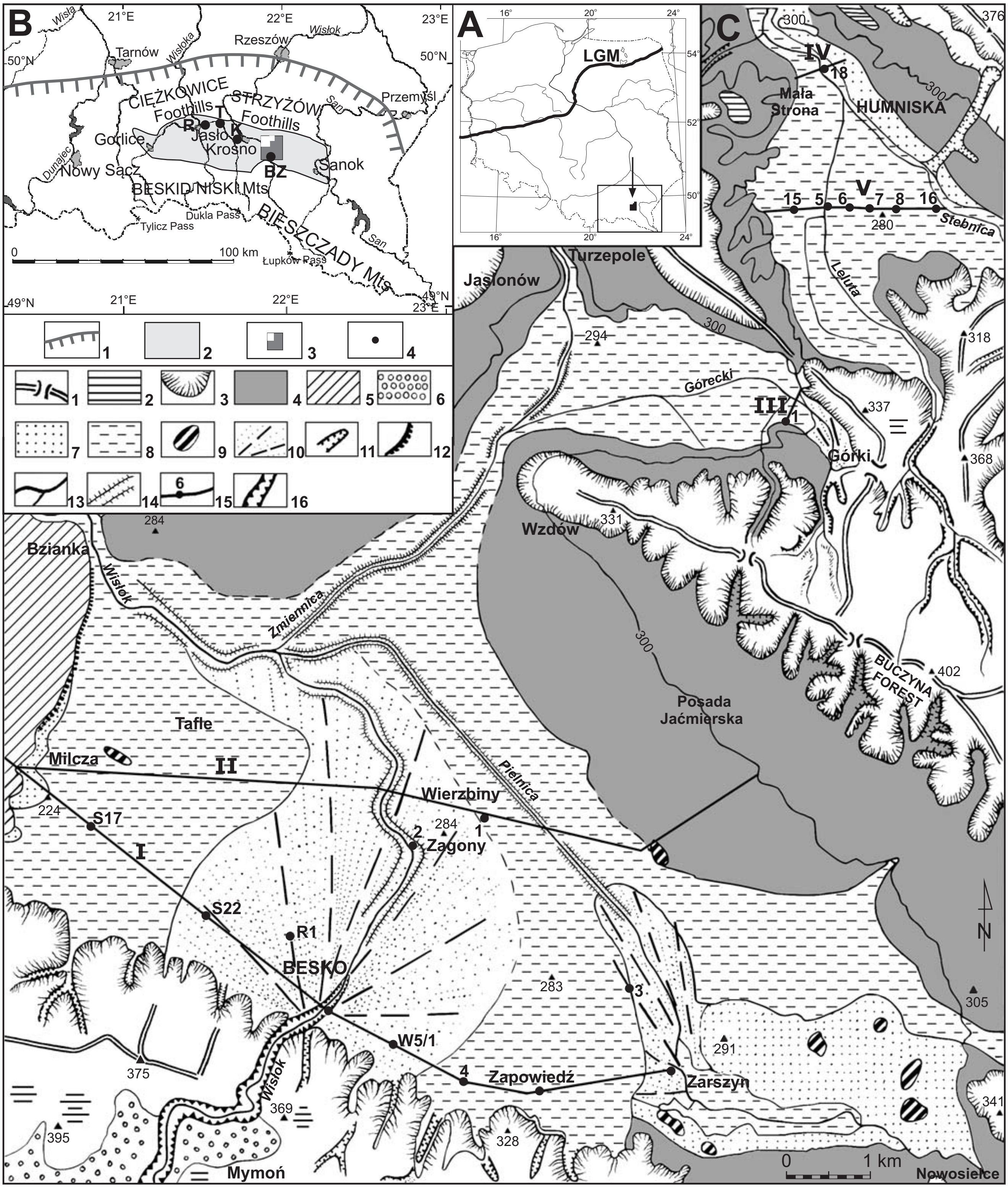

Fig. 1. A. Location of the study area and last ice-sheet maximum limit (LGM – Last Glacial Maximum). B. Location of the studied basins on the map of the Jasło-Sanok Depression and the key sites: R – Roztoki, T – Tarnowiec, K – Kępa, BZ – Besko-Zapowiedź; explanation of symbols; 1 – northern extent of the Carpathians, 2 – boundary of the Jasło-Sanok Depression, 3 – study area, 4 – sites quoted in the text. C. Geomorphologic map of the Besko Basin, Jasionów and Humniska Basin (prepared based on a manuscript map of Tadeusz Gerlach, 1:50 000). Explanation of symbols: 1 – hill ridges and passes, 2 – flattenings within the hill ridges, 3 – slopes, 4 – foothills, 5 – terrace with loess cover deposited in the Warthanian (Saalian) Glaciation (Haczów terrace level), 6 – gravel terrace deposited in the Warthanian (Saalian) Glaciation, 7 – Vistulian terrace, 8 – floodplain (Holocene), 9 – denudational hummocks, 10 – alluvial fans, 11 – erosional V-shaped valleys, 12 – erosional edges, 13 – Wisłok River gap near Besko, 14 – river, creak and stream channels, 15 – artificial embankments, 16 – geological cross-sections (transects).

Sanockie) in the Polish Flysh Carpathians (Gerlach *et al.*, 1972; Gerlach, 1990).

The Jasło-Sanok Depression is composed of flat basins at 250–360 m a.s.l. It is 20 km wide and 100 km long, and separates the mountain range of the Beskid Low Mts. (Beskid Niski) from the Strzyżów and Dynów Foothills (Fig. 1A, B). This zone is characterised by a relief with low foothills and vast Pleistocene terraces 30–80 m high. Its substratum is built of steeply dipping and relatively soft (easily eroded) strata of the Krosno Beds of the tectonic depressions named the Central Carpathian Synclinorium (Świdziński, 1953). The Jasło-Sanok Depression represents an erosional-denudational basin, but distinctly lower elevation of denudational levels in the depression when compared with the Foothills and Beskid Low Mts., suggests tectonic lowering of this area during the Quaternary (Fleszar, 1914; Starkel, 1972; Zuchiewicz, 1987). The Beskid Low Mts., which is ca 100 km long and 500–900 m a.s.l. high, represent the narrowest and lowest segment (Dukla Pass at 500 m a.s.l.) of the whole Carpathian range. It is a wide morphologic gate, which favours occurrence of strong funneled south winds that erode soil on the windward southern slopes during winter and deposit snow and clay-silt-sand material on the leeward (northern) slopes (Gerlach, 1977; Gerlach *et al.*, 1986). In turn, in the area of the Jasło-Sanok Depression the greatest number in the Carpathians (several dozen) of oval, closed basins and troughs occur, which are palaeo-lakes filled up with the Late Vistulian and Holocene organic sediments (Klimaszewski, 1948; Gerlach *et al.*, 1972; Gerlach, 1990; Wójcik, 1987, 2003). In the central part of the Jasło-Sanok Depression Gerlach (1990) documented occurrence of more than 10 palaeo-lake basins with predominantly N-S elongation, fusiform hills (ridges) of the same orientation and occurrence of ventifacts between the basins, which prove formation of these basins as deflation (wind-carved) hollows and troughs, eroded by strong southern winds before the Late Vistulian. Silt and clay have been removed by wind from the depressions. In turn, on leeward slopes and behind barriers of the structural obstacle-type hills of the Dynów Foothills, thick aeolian silty-clay (loess) was deposited (Gerlach *et al.*, 1991, 1993). Therefore, during loess deposition large areas must have been devoid of tight vegetation cover and rare rains occurred (Starkel, 1988). In the eastern part of the Jasło-Sanok Depression there are three basins: Besko Basin (Kotlina Beska), Jasionów Basin (Kotlinka Jasionowa) and Humniska Basin (Kotlinka Humnisk) (Fig. 1B, C).

The origin of these basins and their evolution in the Late Vistulian and Holocene has not been comprehensively explained yet. Detailed morphological characteristics of these basins as well as thickness and stratigraphy of sediments filling these basins are missing. Such an attempt of determination of a thickness, description of lithology, stratigraphy and age of the depositional sequences of this sediments and their relation to the geological structures of a substratum was made by a late Professor Tadeusz Gerlach in the eighties and nineties of the 20th century in a frame of the scientific project (KBN Nr 6 P20100704). His principal objective was to recognize source area of thick silt covers that occur in the southern part of the Dynów Foothills and in the Jasło-Sanok Depression. Unfortunately, he could not complete the materials due to his health condition. Consequently, the co-authors compiled his materials and supplemented them particularly with the paleobotanic analyses and absolute datings.

OVERVIEW OF RESEARCH

Different hypotheses on origin and age of sediments filling the listed above basins were postulated. According to Klimaszewski (1948, 1967) the basin floors are formed of sediments of the Vistulian age (terrace level III), overbuilt by the Holocene fluvial deposits. Klimaszewski's hypothesis was questioned by Koperowa (1970), who – based on a palynological analysis of 9 m long depositional sequence at Besko-Zapowiedź – proved that the upper two third of the sequence in the southern part of the Besko Basin is of the Holocene age, while only the lower part represents the Late Vistulian. Publications of Koperowa and Starkel (1972) as well as of Ralska-Jasiewiczowa and Starkel (1975), supplemented the study of the sequence from the Besko-Zapowiedź site with radiocarbon datings of peat at depth of 5.75–6.50 m. The age of the bottom sample ranged 9,530±150 BP (Bln-1148) [11,250–10,450 b2k], whereas the age of the top one was 7,900±100 BP (Bln-1147) [9,040–8,540 b2k]. Fluvial and lacustrine sediments, 3 m thick, in the bottom part of the sequence represents the Late Vistulian, while overbank fluvial deposits, 6 m thick, belong to various phases of the Holocene. Pollen grains of synanthropic plants, found in the middle part of the section at depth of ca 5.5 m, confirm presence of prehistoric man in the Subboreal Phase, 5,000–4,500 BP in the vicinity of the site. The pollen diagram of the sequence (witout peat horizons) as well as radiocarbon datings of peat are the important reference in chronology and deposition rate as well as relief development of the basin floor. These data enabled classification of landforms and sediments of the listed above basins to the Holocene on the Geomorphologic Map of Poland 1:500 000 (Starkel, 1980). Starkel (1972) postulated that the Besko Basin, filled with young fluvial deposits, is morphologically typical for currently subsiding areas, in which outliers built of the Carpathian flysch rocks sunk in the Holocene sediments (Starkel, 1972).

Publications of Wdowiarz and Zubrzycki (1985, 1987, 1991), as well as Wdowiarz *et al.* (1991), combined with completion of the Detailed Geological Map of Poland 1:50 000 (Rymanów map sheet), provided new data. According to these authors, the present-day relief of the Besko Basin has been shaped by neotectonic movements at the end of the Middle Polish Glaciation (Saalian) and during the Eemian Interglacial. The authors relate formation of flat basin floor to lateral erosion of the Pielnica and Zmiennica creeks and some smaller streams that flow from hills framing the basin from the southwest and northeast sides. The capture of the Wisłok river to the Besko Basin by small stream that cut the steep slope framing the basin from the southwest, caused formation of the vast alluvial fan of the Wisłok River. Wdowiarz and Zubrzycki (1991) referred formation of this fan to the Atlantic Phase, while Klimaszewski (1948) postulated that the Wisłok River capture took place in the Eemian Interglacial and the alluvial fan developed during the Vistulian. Zuchiewicz (1987) supported the hypothesis of Wdowiarz and Zubrzycki (1991) on the origin of the Besko Basin and the age of sediments covering its floor; however, he attributed the Wisłok River capture to the Late Vistulian or the Holocene. In the case of Quaternary sediments of the Jasionów Basin and Humniska Basin, apart from Klimaszewski (1948, 1967) synthesis, the data can be found in the publications of Krajewski (1933) and Depowski (1956). Both these authors mentioned occurrence of silt that cover slopes of the Stobnica River valley near the town of Brzozów. Depowski (1956) assumed that, apart from covers formed owing to deep weathering of the Krosno Beds, aeolian material represents a considerable part of a thick slope clay. He also described the Holocene bottom terrace built of clay and peat. Starkel (1960) postulated that in the catchment basin of the upper Stobnica River, upper sections of stream valleys were incised 5–10 m in the Holocene, and removed material was deposited in the main river valleys.

Gerlach (1990) connected development of the closed basins in the central part of the Jasło-Sanok Depression (south of the town of Krosno), filled with peat and lacustrine chalk, with deflation at the termination of the last Scandinavian glaciation. In the same paper he described also faceted cobbles (ventifacts) from the lowermost, relict Vistulian gravel blanket which separates two basins filled with the Late Vistulian and Holocene sediments. Their occurrence provides evidence of intensive wind erosion and aeolian reshaping of the older relief in this area.

Based on detailed analyses of grain size and petrography, heavy minerals, palaeobotanic analyses as well as the radiocarbon and TL datings of the more than 10 m thick clay-silt cover outcropped in the clay-pit at the Humniska-Mała Strona site, Gerlach *et al.* (1991, 1993) formulated the thesis that these sediments originated due to aeolian deposition during the Vistulian. According to this hypothesis, differences of grain size and petrography between loess from the Lublin Upland and silt at Humniska as well as apparent petrographic similarity between these latter sediments and the Krosno Beds indicate local origin of deposited material and allowed to distinguish the Carpathian-type of loess (Gerlach *et al.*, 1991, 1993).

Wójcik (2003) assumed that floors of the Besko Basin and other undrained basins developed with contribution of ground ice (degradation of ice wedges) and thermokarst during the last periglacial period. He compared development of the basin to the origin of the current alases in Siberia. Such an undrained basin of thermokarst origin occurs on the Vistulian terrace surface near Milcza in the western part of the Besko Basin (Wójcik, 2003). The south-eastern fragment of the Besko Basin and the Jasionów Basin were mapped (Malata and Zimnal, 2003, 2013). These authors reported results of three radiocarbon datings from the Besko and Jasionów Basin, but lack of detailed stratigrapical and lithological sections as well as of a palynological diagram of analysed deposits made it difficult to correlate with dated sections presented by the authors of this study. The above listed authors did not specify thickness of sediments in the Jasionów and Humniska Basins and did not describe diversity of their stratigraphy owing to lack of natural and artificial outcrops.

OBJECTIVE, MATERIALS AND METHODS OF STUDY

Tadeusz Gerlach conducted geomorphological mapping and geological cross-sections to supplement the data on thickness and stratigraphy of sediments within the studied basins. Thickness and structure of sediments that cover floors of the Jasionów and Humniska Basins were determined in 11 geological cross-sections with several dozen sounding boreholes and 33 boreholes drilled with the mechanic „Geomeres" derrick. Kazimierz Szczepanek collected 54 samples for a palynological analysis and radiocarbon dating from 3 borehole logs. Consequently, three pollen diagrams and 8 radiocarbon ages were conducted. In the Besko Basin Gerlach made two geological cross-sections. The first one (I; Fig. 1C) was based on outcrops in the Wisłok alluvial fan, examined during construction of a bridge of the Krosno-Sanok route. Descriptions of four borehole logs and several sounding boreholes were done during mapping of the Quaternary for the geological map 1:50 000, Rymanów sheet (Wdowiarz *et al.*, 1991) and supplemented with descriptions of the Besko-Zapowiedź and Besko-Zapowiedź II borehole logs (Koperowa, 1970; Koperowa and Starkel, 1972), as well as with descriptions of the borehole logs drilled in 1990s by Tadeusz Gerlach using the „Geomeres" derrick. The second geological cross-section (II) was based on data from 45 sounding boreholes drilled by Tadeusz Gerlach and on description of the outcrop in a distal part of the Wisłok River alluvial fan at the Zagonki site (Fig. 1C). Tadeusz Gerlach focused on observations of depth of the pre-Quaternary flysh rock substratum in floors of the basins as well as on thickness and stratigraphy of sediments that filled the basins.

Pollen analyses were performed by Kazimierz Szczepanek for two logs from the Humniska Basin (Humniska 6 and Humniska 18) and one log from the the Jasionów Basin (Górki 1). Results of palynological analyses from the trench and borehole log at the Besko-Zapowiedź site (Koperowa, 1970; Koperowa and Starkel, 1972) were also used for consideration. Location of the studied sites is presented (Fig. 1C) and radiocarbon datings are listed (Table 1).

Samples for the palynological analysis were subjected to maceration in concentrated HF acid and then – to the acetolysis using a method of Erdtman (1960). Pollen grains of vascular plants and spores of cryptogams were counted in each sample, usually on surface of microscopic specimen of 150–300 mm² up to ca 200 grains AP (pollen grains of trees and shrubs). In samples with very small amount

Table 1. Radiocarbon dates obtained from profiles at the eastern part of Jasło-Sanok Depression (Polish Carpathians).

Locality	Depth [cm]	Lab. No.	^{14}C BP	b2k	AD/BC; 95% confidence
Besko-Wierzbiny 1	462–475	Gd-6516	10790 ± 150	13070–12300	-11070, -10300
Besko-Zagony 1	570–590	Gd-1892	6800 ± 80	7865–7560	-5865, -5560
Besko-Zagony 2	540–550	Gd-3149	8570 ± 80	9815–9495	-7815, -7495
Besko-Zapowiedź	570–575	Bln-1147	7900 ± 100	9040–8540	-7050, -6540
Besko-Zapowiedź	625–630	Bln-1148	9530 ± 150	11250–10450	-9250, -8460
Górki 1	240–245	Gd-3786	8360 ± 60	9530–9205	-7530, -7205
Górki 1	280–285	Gd-11162	9900 ± 80	11735–11250	-9735, -9250
Górki 1	325–330	Gd-3785	11020 ± 40	13065–12815	-11065, -10815
Humniska 18	430–430	Gd-9020	7110 ± 100	8200–7765	-6200, -5765
Humniska 18	590–595	Gd-6892	10920 ± 130	13110–12670	-11110, -10670
Humniska 18	665–670	Gd-7355	13550 ± 100	16710–16085	-14710, -14085
Humniska 6	260–265	Gd-9023	8310 ± 130	9565–9040	-7565, -7040
Humniska 6	360–365	Gd-9019	8470 ± 270	10210–8785	-8210, -6785
Humniska 6	480–485	Gd-6890	10260 ± 130	12535–11470	-10535, -9470
Zapowiedź 6/1	650–675	Gd-7357	7519 ± 70	8475–8245	-6475, -6245
Zapowiedź 6/2	675–690	Gd- 6643	8660 ± 140	10190–9480	-8190, -7480
Zarszyn 0	125–135	Gd-6513	880 ± 80	980–730	-1020, -1270
Zarszyn 1	355–365	Gd 6514	10990 ± 150	13180–12715	-11180, -10715
Zarszyn 2	370–385	Gd-9021	12700 ± 200	15745–14275	-13745, -12275

of sporomorfs (pollen grains and spores), counting was made on specimen surfaces larger than 300 mm². The same method was used for palynological samples from the Besko sequence at the Besko-Zapowiedź site (Koperowa, 1970). Total number of tree, shrub and terrestrial vascular plant pollen grains was used for the calculation of percentage of particular taxa. Percentages of aquatic and wetland plants were calculated in relation to the basic sum plus number of grains (spores) of particular taxa in a sample. Results of palynological analyses are presented in a simplified pollen diagrams made using the POLPAL program (Nalepka and Walanus, 2003) that include curves of the most important sporomorphs (Figs. 4, 6, 8, 10).

Samples for radiocarbon datings were selected based on lithological changes in the sequences and dated in the Radiocarbon Laboratory of the Silesian University of Technology in Gliwice (Poland). Based on the calibration curve IntCal13 (Reimer *et al.*, 2013), the conventional datings were calibrated using the program POLPAL (Nalepka and Walanus, 2003; Walanus and Nalepka, 1999, 2016). The calendar age of each pollen spectrum, obtained using the program Depth/Age (Walanus and Nalepka, 2016) and recorded in the format b2k (before 2000), is placed (after rounding-off) next to depth descriptions in the pollen diagrams.

Pollen diagrams from Górki 1, Humniska 18, Humniska 6 (analysed by K. Szczepanek) and Besko-Zapowiedź (analysed by Koperowa in 1970) built the base for analysis of plant cover as well as ecological and climatic conditions in the discussed area in the past. All diagrams were divided into local pollen assemblage zones (L PAZ – according to Janczyk-Kopikowa, 1987). Apart from radiocarbon dating (Table 1), age of sediments was estimated with a use of of pollen analysis and the chronozones (Mangerud *et al.*, 1974; Walanus and Nalepka, 2010).

SHAPE AND GEOLOGICAL STRUCTURE OF THE BESKO, JASIONÓW AND HUMNISKA BASINS

Besko Basin

The shape of the Besko Basin is similar to the rectangle elongated in SE-NW direction and slightly widened in the NW part. The longer basin axis is ca 16 km long, whereas the shorter axes range 4 km in Zarszyn and 6 km in the Besko-Wzdów transect (Fig. 1C). The basin floor, ranging ca 50 km^2, dips from 310 m a.s.l. at Nowosielce to ca 275 m a.s.l. in the Bzianka village. The Besko Basin is crossed by the following rivers and creeks: Wisłok, Pielnica, Zmysłówka, Zmiennica, Granicznik, Siedliska and their tributary streams. Owing to anthropogenic regulations, most creeks have straight embanked channels (with embankments up to 2 m high). More than 90% of the flat basin floor is located below 295 m a.s.l. The basin elongation (SE-NW) refers to tectonic structures and resistivity of the bedrock. A steep slope of a ridge between Zmysłówka village in the west and Nadolany village in the south-east frames the basin from the southwest. The ridge formed along the axis of the Besko Anticline, built of thick-bedded sandstone of the Lower Krosno Beds (Oligocene), relatively resistant to weathering and denudation. The northern slope of this ridge is cut by v-shaped valleys. The ridge occurs at 388–410 m a.s.l. in the western segment to 540 m a.s.l. in the eastern part. The eastern part of this hill range is cut by the Pielnica creek, whereas the middle part is crossed by the Wisłok valley which forms a narrow and steep-slope gorge, ca 40 m deep. Downstream of this river gap (gorge), the Wisłok forms a vast alluvial fan. The Pielnica Stream, after change of its course from meridional (S-N) to the northwest, flows onto the basin floor and forms an elongated alluvial fan (Fig. 1C).

A vast, slightly sloped foothill of the Kostarowiec-Wola Górecka-Bukowskie Góry ridge (475–425 m a.s.l.) frames the basin from the north-west. This ridge developed along the axis of the Trześniów-Haczów Anticline built of the Menilite Shales (Wdowiarz *et al.*, 1991) that bear hornstone strata which are very resistant to weathering and erosion. The ridge is cut by the stream valleys of Zmiennica, Siedliska and Granicznik to 295–285 m a.s.l. The apparent straight edge frames the basin from the west, is 18 m high and slightly sloped to the north (towards the Wisłok valley). The low (235 m a.s.l.) watershed of Wisłok and San catchments at Pisarowce, frames the basin from the east. The bedrock between the ridge developed in the Besko Anticline and the anticlinal Kostarowiec-Wola Górecka-Bukowskie Góry ridge is built of very soft rocks of the Upper Krosno Beds and the Besko Basin has been eroded just in these rocks.

Jasionów Basin

The Besko Basin floor passes into the flat-bottomed Jasionów Basin northeastwards, behind a narrow section of the Zmiennica creek valley (Fig. 1C). The basin relief is closely dependent on geological structure. The basin is framed by two ridges formed in axial parts of two anticlines built of the Upper Cretaceous Istebna Beds and – at both sides – of the Menilite Shales with layers of strong hornstones (Malata and Zimnal, 2003, 2013). The southern basin margin is demarcated by the Trześniów-Haczów ridge, 400–420 m a.s.l. high, while the northern margin is delimited by the Zmiennica-Turze Pole-Górki hill range, 370–420 m a.s.l. high. The Upper Krosno Beds built of very soft fine-grained sandstones interbedded with shales (Upper Oligocene and Lower Miocene) form the pre-Quaternary rock substratum of the basin between these hill ranges. The Jasionów Basin developed just in this soft rock at confluence of the Zmiennica and Potok Górecki creeks.

Humniska Basin

The Humniska Basin is located to the northeast of the Jasionów Basin, behind the low Zmiennica-Turze Pole ridge at ca 320 m a.s.l. (Fig. 1C). Its flat floor occurs at ca 280 m a.s.l. and occupies ca 4 km^2. The basin is located in the southern part of the Strzyżów Foothills and is drained by the upper Stobnica River and its tributary, the Leluta Stream. The frames of this basin are formed of two parallel anticlinal ridges, elongated SE-NW and higher than 350 m a.s.l. The north-eastern margin is formed of the Grabówka ridge at 375 m a.s.l., whereas the south-western and south-eastern margins are framed by ridge from 383 m a.s.l. to 425 m a.s.l. high, lower at Górki-Turze Pole site (<320 m a.s.l.). Both these ridges are separated by the Humniska basin, 6 km wide, relief of which is strictly controlled by very soft rocks of the Brzozów Syncline (Koszarski, 1961). A lowering of the ridge at the Górki-Turze Pole site, 1.5 km long, is a type of wide “gate” between the Jasionów Basin formed within the northern marginal zone of the Jasło-Sanok Depression and the Humniska Basin in the southern segment of the Strzyżów Foothills.

MORPHOLOGY OF FLOORS OF THE BESKO, JASIONÓW AND HUMNISKA BASINS

Besko Basin

The Besko Basin floor principally declines northwestwards at ca 2‰. It occurs at 294 m a.s.l. at the Wisłok inflow to the basin, while 7.5 km downstream at 279 m a.s.l. at Bzianka (Fig. 1C). The following landforms can be distinguished in the Besko Basin floor:

1) Slightly convex alluvial fan of the Wisłok, cut by the river channel to 7 m depth in the central part. In the Besko transect the fan is 3.5–4 km wide, 4–4.5 km long and occurs at 294 m a.s.l. in its proximal part. In its central part, 3.5 km far from the river gap outlet, the fan surface declines to 280 m a.s.l., thus the dip angle reaches 4‰. In the western part, 2.5 km far from the river channel, the fan surface drops to 278 m a.s.l., which gives 6.4‰ dip. Similar sloping (5.5‰) is observed in the eastern part of the fan where it occurs at 283 m a.s.l. near Zarszyn. Therefore, elevation difference between central part of the fan and its peripheries is 11–16 m. Vast swampy and reed overgrown area is located an the marginal northwestern segment of the fan.

2) Alluvial fan of the Pielnica Creek (tributary of the Wisłok River) in the eastern segment of the basin at Zarszyn resembles slightly convex and elongated levee, 2 km long and 0.75 km wide, which is cut to 4 m depth by a regulated channel of the Pielnica Creek. The fan surface at Zarszyn occurs at 287 m a.s.l. However, east of the Pielnica channel at distance of ca 300 m, the fan surface drops to 284 m a.s.l. and passes into a floodplain of its tributaries.

3) Flat lowered plain at 284 m a.s.l. between the Wisłok fan at Besko and the Pielnica Creek fan at Zarszyn is drained by several drainage ditches. One of them, situated in the central part of the plain and called Zawisłocze, refers to the large flood in 1402, during which the Wisłok channel moved to the east closely to Zarszyn, and then changed its course toward the north (Będkowski, 1963). Remnants of the Wisłok riverbed from that time, including fragments of palaeomeanders are still visible. In the 18th century the Wisłok got back its current channel. In a southern segment of the plain, buildings of the Zapowiedź hamlet are located, where the Besko-Zapowiedź depositional sequence of the Late Glacial and Holocene sediments was described (Koperowa, 1970; Koperowa and Starkel, 1972).

4) Two vast shallow basinal plains: the first between the Wisłok fan at Besko and the edge of the Middle Polish Glaciation terrace at Milcza village, and the second one between the Pielnica fan at Zarszyn and gently sloping, wide foothill of the Kostarowce hill. Toward the north and northwest, near Bzianka Górna village both basins merge and

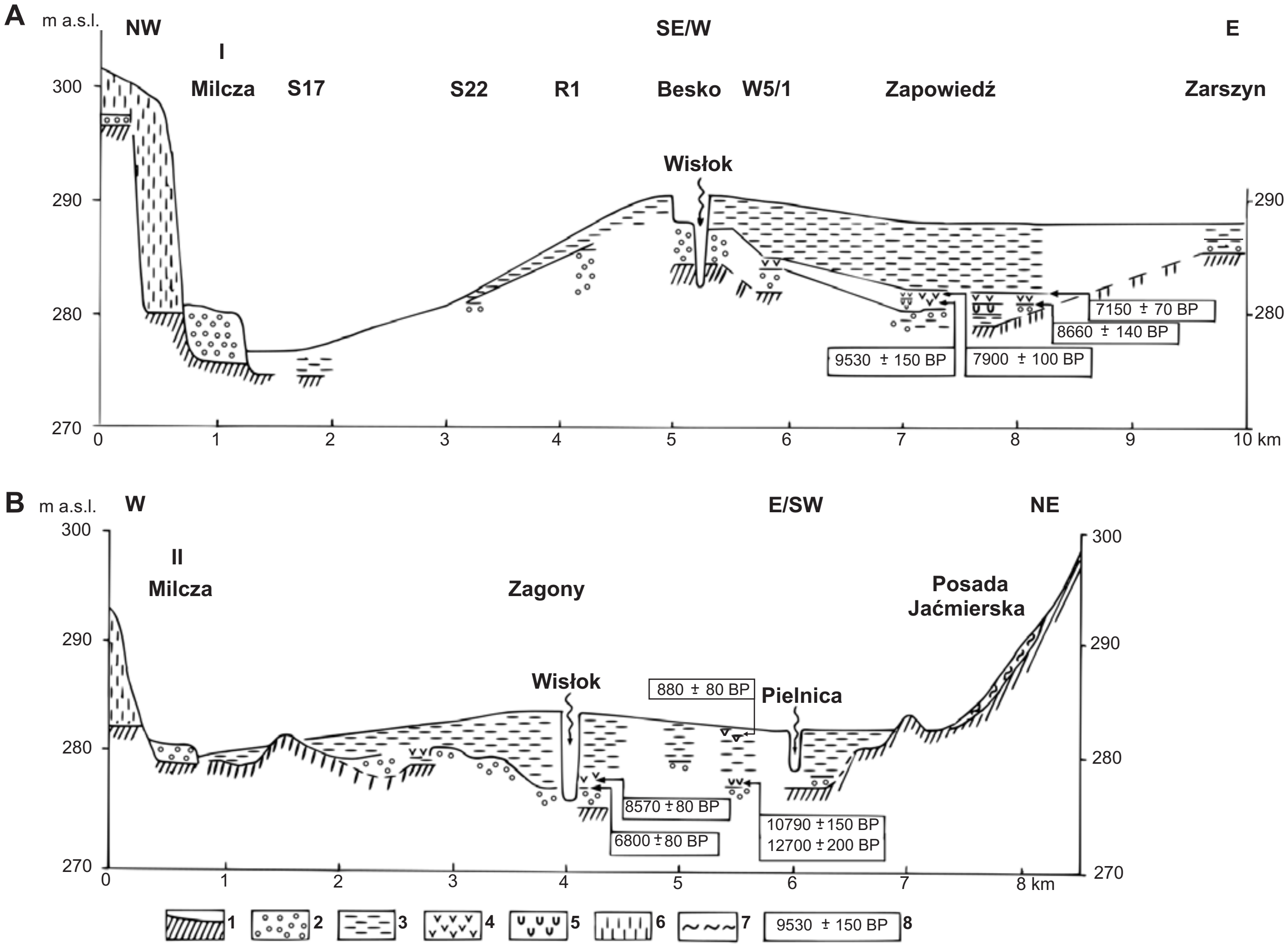

Fig. 2. A. Geological cross-section of the southern part of the Besko Basin: Milcza-Besko-Zapowiedź-Zarszyn transect (I); for location of a transect see Fig. 1C (prepared by P. Gębica based on borehole logs described by T. Gerlach). B. Geological cross-section of the central part of the Besko Basin: Milcza-Tafle-Zagony-Posada Jaćmierska transect (II). Location of transect – see Fig. 1C (prepared by P. Gębica based on borehole logs described by T. Gerlach). Explanation of symbols: 1 – Quaternary bedrock (Krosno Beds), 2 – channel gravel, 3 – overbank silt, 4 – peat, 5 – lacustrine chalk, 6 – loess, 7 – slope (solifluction) sediments, 8 – radiocarbon datings (not calibrated).

form a floodplain of the Pielnica Creek and Wisłok River, 6 m high. The first basin, situated in the western part of the Besko Basin is drained by the regulated Zmysłówka streambed. Within this basin the alluvial fan with small peaty undrained depression spreads at Milcza village. Apparent outlier ca 1 km long, 1 m high and oriented SE-NW, built of sandstone of the Krosno Beds is set to the north of this fan. In the second basin, in the marginal zone of the Pielnica fan toward Zarszyn and Długie villages, a ground surface slightly raises and passes into the Pielnica fluvial terrace, 5 m high. In these plain several denudational hummocks (outliers), 2–15 m high and latitudinal (S-N) elongations as well as circular domed hills are located to the north of the Zarszyn-Sanok road. A similar denudational hummock (outlier), 1.5 m high and elongated SE-NW, is located to the north of the Pielnica fan near Posada Jaćmierska village. It is built of hard sandstone of the Krosno Beds that is covered with a thin weathering blanket. Very similar small outliers are noted also in the NW part of the Besko Basin, near Poręby (Tafle) hamlet.

Jasionów Basin

Toward the north, the Besko Basin is connected with the Jasionów Basin (Fig. 1C) along the narrow valley (river gap) cutting and crossing the Góry Bukowskie-Las Buczyna ridge, drained by the Zmienniczka Stream. A floor of this basin, 3 km long and 1.5 km wide, is located at 290 m a.s.l. and has longitudinal elongation. The basin floor is cut by regulated channel of the Zmiennica Creek, 5 m deep, and its tributaries.

Humniska Basin

The Humniska basin widens towards the south. A narrowing of the Stobnica River valley at Humniska-Mała Strona demarcates a northern boundary of the basin. A width of the basin floor in the transect I, located upstream the narrow valley section, ranges 300 m, whereas it is 1050 m wide in the transect III. A width of the basin floor reaches 2200 m in the widest place (transect IV; Fig. 1C). The largest area in the basin is occupied by the flat Holocene floodplain at 300–276 m a.s.l., cut by the Stobnica River channel in the eastern part, the Leluta streambed, 3.0–3.5 m deep and channels of its tributaries. The Leluta streambed and channels of its tributaries have been channelised. The Stobnica River and its tributaries have suffered frequent floods e.g. in the June 1992 and July 2001 the floodplain was overflowed with water 0.5 m deep. The bench of the Stobnica valley terrace, 5–6 m high, occurs in some places along the eastern basin margin. A terrace at the western slope of the basin at Humniska-Mała Strona is covered with the Vistulian loess at 290–298 m a.s.l. (17–25 m above the Stobnica riverbed) (Gerlach *et al.*, 1991, 1993).

SEDIMENTS FILLING THE BESKO, JASIONÓW AND HUMNISKA BASINS – RESULTS OF ANALYSES AND DATINGS

Besko Basin

Thickness and structure of sediments of the Besko Basin is described in two geological cross-sections:

1 – transect connecting the Wisłok fan next to the river gap outlet at Besko and the Pielnica fan in Zarszyn (I),

2 – transect Milcza-Zagony-Posada Jaśmierska in the central part of the basin (II) (Figs. 1C, 2A, B).

Stratigraphic interpretation of sediments is based on four depositional sequences radiocarbon dated (Table 1), among which the one from the Besko-Zapowiedź site provides also with palynological data.

The Besko-Wierzbiny site (1) is located in a marginal (distal) part of the Wisłok alluvial fan at 282 m a.s.l. (Fig. 1C). A sequence at this site comprises peat, 15 cm thick that overlies gravel and is overlain with overbank clay and silt, 4.62 m thick. Radiocarbon dating of peat from depth of 4.62–4.75 m yields 10,790±150 BP (Gd-6516) [13,070–12,300 b2k] and indicates the Late Vistulian (Younger Dryas). The Besko-Zagony site (2) is situated in the central part of the basin, in the right undercut of the Wisłok riverbed that just turn north (Fig. 1C). In the sequence of the Wisłok alluvial fan, 7 m thick at this site, peat at depth of 5.7–5.9 m overlies clay and gravel, and was dated at 6,800±80 BP (Gd-1892) [7865–7560 b2k] (Fig. 2B). The upper peat bed at depth of 5.4–5.5 m, overlain by overbank silt, was dated at 8,570±80 BP (Gd-3149) [9,815–9,495 b2k]. Pollen analysis of this upper peat refers it to the Preboreal Phase, therefore the age of the lower peat is underestimated (Wdowiarz *et al.*, 1991). In the southern segment of the basin, at the Zarszyn 1 site (3), a marginal part of the Pielnica alluvial fan is built of overbank silt with peat filling a palaeochannel at depth of 3.55–3.85 m (Fig. 2B). A bottom part of peat was radiocarbon dated at 12,700±200 BP (Gd-9021) [15,745–14,275 b2k] and the peat top at 10,990±150 BP (Gd-6514) [13,180–12,715 b2k], and it indicated the Late Vistulian age. The upper peat in this

Table 2. The lithological description of the Besko-Zapowiedź I borehole. The depositional sequence according to Koperowa (1970).

Depth [cm]	Description of sediment
0–240	loam
240–300	loam with charred pieces of wood
300–550	clay with charred pieces of wood
550–575	clay with a layer of vivianite and wood pieces
575–635	peat
635–750	lacustrine chalk with snail shells
750–870	lacustrine chalk with sand and snail shells
870–890	clay
890–910	gravel with sand

Table 3. The lithological description of the Besko-Zapowiedź II borehole. The depositional sequence according to Koperowa, Starkel (1972).

Depth [cm]	Description of sediment
0–155	sandy silt
155–295	clay
295–410	silt with peat interlayers and wood fragments
410–540	clay with wood fragments
540–575	sandy silt with peat interlayers
575–650	peat with clay admixture,
650–750	lacustrine chalk
750–850	sandy silt with pebbles

sequence at depth of 1.25–1.35 m, overlain with silt, yields a date of 880±80 BP (Gd-6513) [980–730 b2k] (Table 1). The fourth sequence at the Besko-Zapowiedź site (4) is situated in a marginal part of the Wisłok alluvial fan at 288 m a.s.l. (Fig. 1C). The depositional sequence according to Koperowa (1970) is provided (Table 2, Fig. 3A). The borehole Besko-Zapowiedź II, drilled 20 m far from the first site, was sampled for the grain-size analysis and radiocarbon datings (Koperowa, Starkel 1972). The depositional sequence Besko-Zapowiedź II is provided (Table 3).

The geological cross-sections of the Wisłok and Pielnica alluvial fans, present theirshape, size and geological structure (Fig. 2A). In the central part of the Wisłok fan, the Quaternary bedrock, covered with gravel, is located at depth of 6 m. In the eastern part, at the Besko-Zapowiedź site this top, also overlain with fluvial gravel, occurs at 10 m depth, while at the Zarszyn site – at 2.5 m. In the western segment of the cross-section, at the Bianiny site the Quaternary bedrock occurs at depth of 2 m. The cross-section in the central part of basin, transversal to the proximal part of the Pielnica alluvial fan and the central part of the Wisłok fan, proves that in the NE part of the Besko Basin, the Quaternary bedrock is located at depth of 0.6–1.5 m (Fig. 2B). In the western part of the basin, close to the Milcza village the Quaternary bedrock is at similar depth (0.5–1.5 m). Toward the west the Quaternary bedrock occurs in a distance of 1.5 km from the riverbed and extends to the Milcza village in a distance of about 2.5 km. These observations indicate that almost half of the flat ba-

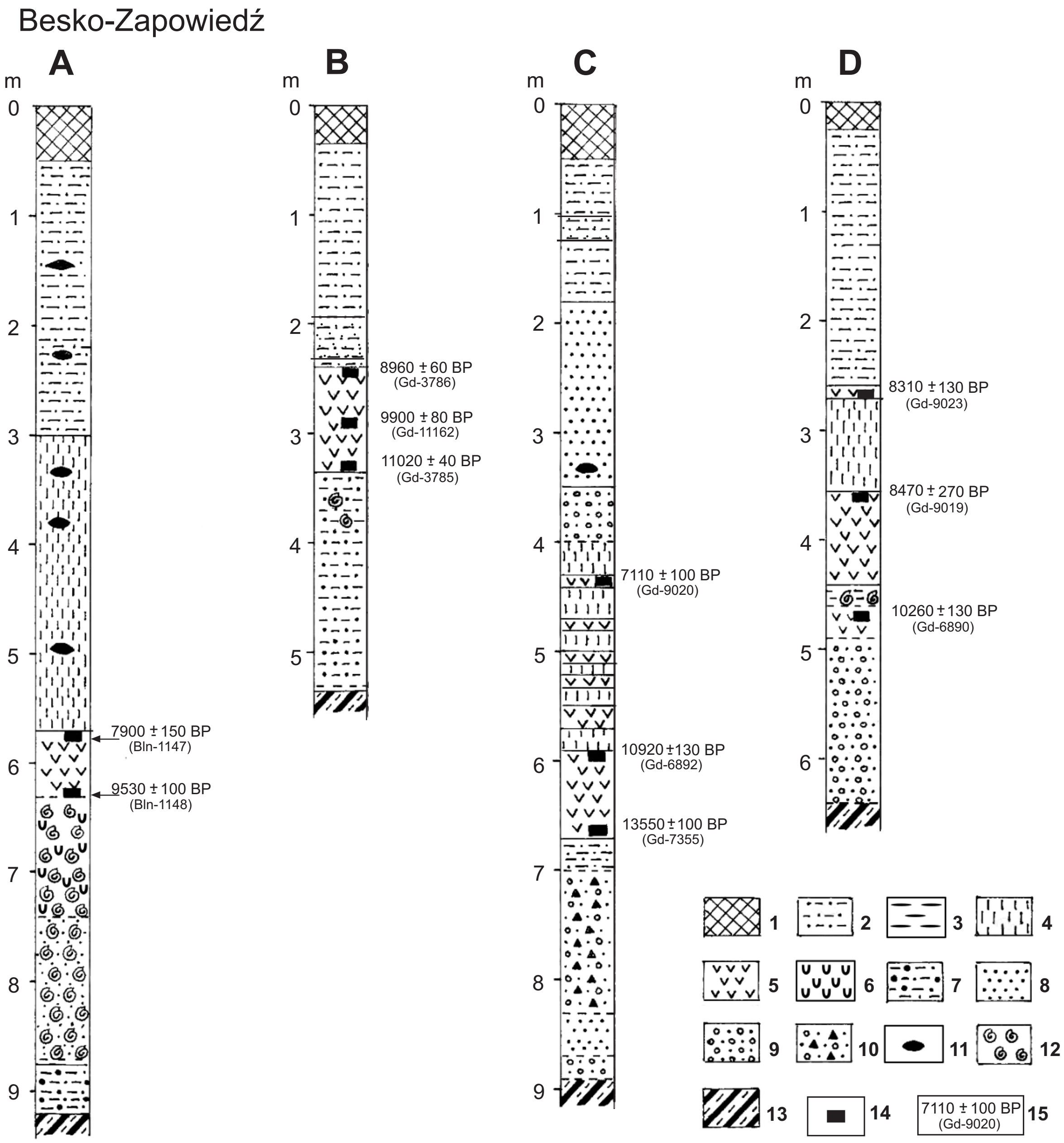

Fig. 3. The main lithological sequences radiocarbon dated and sampled for palynological analysis in the Besko Basin, Jasionów Basin and Humniska Basin (prepared by T. Gerlach). A. Besko-Zapowiedź sequence (Koperowa, 1970, Koperowa, Starkel, 1972); B. Górki 1 sequence; C. Humniska 18 sequence; D. Humniska 6 sequence. Location of sites (sequences) – see Fig. 1C. Explanation of symbols: 1 – Holocene soil, 2 – sandy silt, 3 – silt, 4 – clay, 5 – peat, 6 – lacustrine chalk, 7 – sandy silt with pebbles, 8 – sand, 9 – sand with pebbles, 10 – sand with pebbles and debris, 11 – wood fragment, 12 – snail shells, 13 – Quaternary bedrock (Krosno Beds), 14 – samples for radiocarbon dating, 15 – radiocarbon dating (not calibrated).

sin floor is of erosional origin. Only in the central part of the basin the Quaternary bedrock occurs deeper than 4.5 m in a zone 3.5 km wide.

Besko-Zapowiedź depositional sequence

In the depositional sequence at the Besko-Zapowiedź site 158 samples were collected (each in a distance of 5 cm) to depth of 905 cm, from which 140 samples were used to pollen and macrofossil analysis (Figs. 3A, 4). Results of the pollen analysis were published by Koperowa (1970), as the 'Besko' pollen diagram. We present reinterpretation of the lower part of this pollen diagram, because in 1972 two samples from the peat bed, 60 cm thick, in this sequence were radiocarbon dated (Koperowa and Starkel, 1972; see also: Gradowski and Nalepka, 1984) (Table 1). The present diagram (named "Besko-Zapowiedź") includes curves of taxa, selected from the first "Besko" diagram (Fig. 4).

Pollen diagram from the Besko-Zapowiedź, prepared by Koperowa (1970), after reinterpretation of the lower section of the sequence (840–885 cm), presents history of vegeta-

Table 4. Besko-Zapowiedź I. Description of pollen assemblage zones (L PAZ), distinguished by K. Szczepanek and D. Nalepka in pollen diagram elaborated by Koperowa (1970: Fig. 3A), and correlation with chronostratigraphy according to Mangerud *et al.* (1974).

Depth [cm]		L PAZ	L SPAZ	Description		Chronozone (Mangerud *et al.* 1974)
				L PAZ	L SPAZ	
185–470	185–380	*Abies–Fagus–Carpinus*	*Abies–Fagus*	High amount of *Abies* pollen grains, lowering upwards. *Fagus* and *Carpinus* pollen percentage slightly lowering upwards. In the lower part of the zone *Alnus* pollen percentages is very high. Along with the decrease of *Alnus* pollen percentage a few grains of *Plantago lanceolata* pollen and pollen of *Secale* and *Urtica* are observed.	Immediate drop of *Alnus* undiff. pollen percentage; significant content of Poaceae pollen.	Subatlantic
	385–470		*Alnus–Abies–Fagus–Carpinus*		High amount of *Alnus* undiff. and Cyperaceae pollen grains.	
475–560		*Alnus–Abies–Fagus–*		Slight decrease of *Ulmus* and increase of *Corylus* and *Picea* pollen amount. High percentages of *Alnus* and *Tilia*. The curves of *Carpinus*, *Fagus* and *Abies* get going. A few pollen grains of *Plantago lanceolata*, *P. media* and *Rumex* are observed.		Subboreal
565–600		*Alnus–Ulmus–Corylus–Tilia*		Distinct increase of *Corylus* and *Tilia curves*, high pollen percentages of *Ulmus*. The beginning of curves and high amount of *Picea abies*, *Alnus*, *Quercus* pollen grains.		Early Atlantic
605–615		*Picea–Ulmus–Corylus*		The maximum of *Ulmus* and *Picea* pollen grains (maximum of spruce pollen in the pollen diagram). The beginning of *Corylus* and *Tilia* pollen curves. Drop of high of *Pinus* t. *sylvestris* and *Betula* pollen curves.		Boreal
620–630		*Pinus–Picea–Ulmus*		Disappearance of pollen of *Pinus cembra*, *Larix*, *Populus*, *Ephedra* and of some plants-indicators of arid climate. Increase of percentage of *Pinus* t. *sylvestris* and *Picea abies* pollen. Continuous curve of *Ulmus* pollen percentage gets going.		Preboreal
635–710		*Pinus–Pinus cembra–Larix–Juniperus–Artemisia*		Predomination of *Pinus* t. *sylvestris* pollen grains, upward gradual increase of *Betula* pollen percentages with maximum at the top of the zone. Continuous curves of *Larix*, *Populus*, *Juniperus*, *Ephedra distachya* pollen appeared. Increase of pollen percentage of *Poaceae*, *Cyperaceae*, *Artemisia*, Chenopodiaceae, *Centaurea scabiosa* and *Filipendula*.		Younger Dryas
715–835		*Pinus–Pinus cembra*		Predomination of *Pinus sylvestris* and *P. cembra* pollen percentage with participation of *Betula*, Poaceae, Cyperaceae pollen. Higer pollen curves of *Alnus*, Picea, *Abies* and *Artemisia*.		Allerød
840–885				Domination of *Pinus* t. *sylvestris* pollen percentage, maximum amount of *Betula* pollen. Considerable fluctuations of pollen curves are observed. Spores of *Selaginella selaginoides* occur in the lower pollen specta of the zone. Relatively numerous pollen grains of trees of higher (temperate) climatic requirements (*Picea*, *Alnus*, *Ulmus* and *Abies*) could be delivered from remote areas or from eroded older sediments.		

tion from the Late Vistulian, i.e. Allerød and Younger Dryas through the following Holocene phases: Preboreal, Boreal, Atlantic, Subboreal and Subatlantic (Table 4). The decline of the Vistulian in the pollen diagram is attributed to bottom layers of sandy silt with pebbles, clay, and lacustrine chalk.

Jasionów Basin

In the Jasionów Basin, the log of the Górki 1 borehole (297 m a.s.l.), situated in the longitudinal transect of SE-NW orientation that crosses Górki village, was sampled in the nineties of 20th century by T. Gerlach and K. Szczepanek. The borehole was situated in distal part of Górecki Stream alluvial fan, that passes into the flat basin floor (Figs. 1C, 3B, 5).

In the Górki 1 sequence (Table 5; Figs. 3B, 5), Tadeusz Gerlach distinguished three depositional units.

Table 5. The lithological description of the Górki 1 borehole (Jasionów Basin).

Depth [cm]	Description of sediment
50–190	silt
190–230	fine-grained sand
230–240	clay
240–245	black peat pretty decomposed
245–310	pitchy black peat with wood fragments
310 - 335	black peat (without wood fragments)
335–370	sandy clay and sand
370–415	sand with pebbles
415–450	clay with a few pebbles
450–535	steel-grey sandy clay and clayey sand with a few pebbles at the bottom
535–540	weathered Krosno Beds (pre-Quaternary substratum)

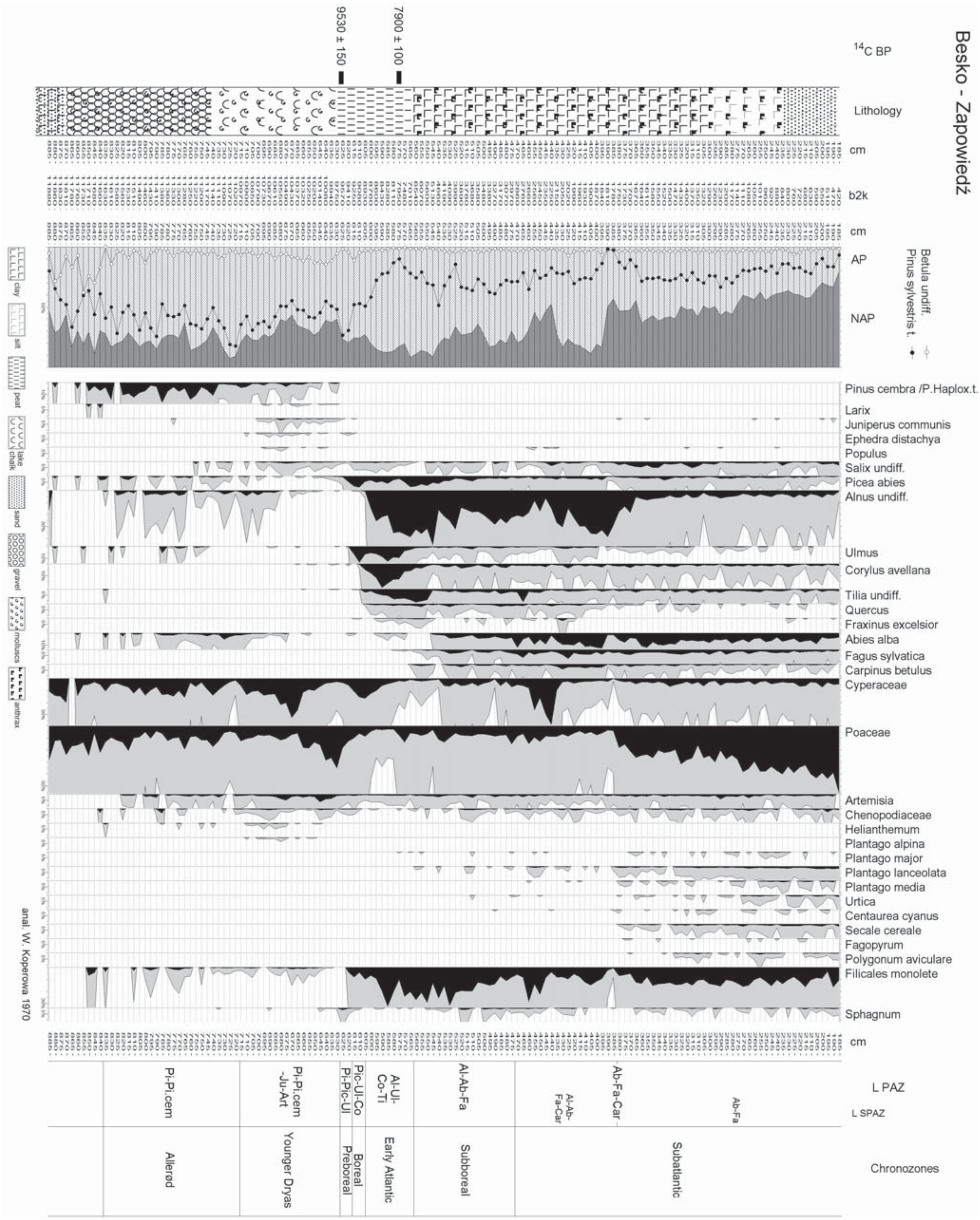

Fig. 4. Percentages pollen diagram Besko from the Besko-Zapowiedź site (Koperowa, 1970, modified), selected taxa. Explanation of signatures (see on the graph): clay. silt, peat, lake chalk, sand, gravel, molluscs, anthrax.

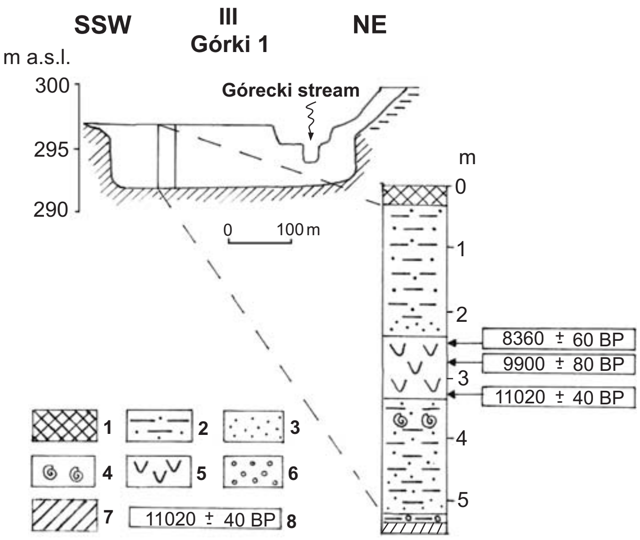

Fig. 5. Geological cross-section of the upper part of the Jasionów Basin with the depositional sequence of the Górki 1 standard log, located in the area of the Górecki Stream alluvial fan (prepared by T. Gerlach). Explanation of symbols: 1 – Holocene soil, 2 – sandy silt, 3 – sand, 4 – mollusc shells, 5 – peat, 6 – gravel, 7 – Quaternary bedrock (Krosno Beds), 8 – radiocarbon dating (not calibrated).

1) Overbank clay and sand that overlie the Krosno Beds,

2) Peat, 0.95 cm thick, accumulated in a palaeochannel or a flood basin, dated at depth of 3.25–3.20 m at 11,020±40 BP (Gd-3785) [13,0650–12,815 b2k], and at depth 2.85–2.80 m at 9,900±80 BP [11,735–11,250 b2k]. Dating of the upper part of peat at depth 2.45–2.40 m yielded the age 8,360±60 BP (Gd-11162) [9,530–9,205 b2k],

3) Overbank silt, sand and clay accumulated after 8,360 BP. Unit of overbank sand and silt (depositional unit 1) was recognised also in a proximal part of the Górecki alluvial plain at Wzdów by Malata and Zimnal (2003, 2013). Palynological analysis and radiocarbon dating 11,820±360 BP (Gd-17153) [14,870–13,015 b2k] indicate the Late Vistulian age of overbank accumulation in the Jasionów Basin (Malata and Zimnal, 2013).

In the pollen diagram Górki 1 (Fig. 6) five local pollen assemblage zones (L PAZ) and five chronozones (after Mangerud *et al.*, 1974) are distinguished (Table 6). A bottom part of the Górki 1 pollen diagram contains incomprehensive records – in one of the bottom spectra (325 cm) none pollen grain of *Pinus sylvestris* was found, while high amount of *Pinus cembra* pollen was observed. In the spectrum of the directly upper sample, pollen of *Pinus sylvestris* ranges pretty high percentage (ca 50%), while pollen curve of *P. cembra* drops to several percent and *Larix* appears ranging high percentages. Therefore these spectra can be combined into a single L PAZ *Pinus cembra–Larix*,

Table 6. Górki 1. Description of local pollen assemblage zones (L PAZ) (Fig. 6), and correlation with chronostratigraphy according to Mangerud *et al.* (1974).

Depth [cm]	L PAZ	Description L PAZ	Chronozone (Mangerud *et al.* 1974)
241–256	*Alnus –Ulmus–Corylus–Tilia*	The lowest pollen amount of *Pinus* t. *sylvestris* and low amount of *Betula* t. *Alba* and *Picea pollen grains. Significant percentages of Ulmus*, *Corylus*, *Alnus* and *Tilia* pollen. Slight increase of amount of *Quercus* pollen grains. Among the herbaceous plants: the percentage of Poaceae is regular, ranging less than 5%, the percentage of Cyperaceae and Polypodiaceae/Filicales is slightly higher. At the top sample a few pollen grains of *Plantago lanceolata* were found, while in the middle one a few spores of *Pteridium aquilinum* were observed.	Early Atlantic
259–265	*Picea–Ulmus–Corylus*	Continuation of diminish of *Pinus* t. *sylvestris* and *Betula* t. *Alba* pollen curves. After the culmination it the bottom spectra, a decrease of *Picea* pollen percentage. Continuous high amount of *Ulmus* pollen and increase of *Corylus* percentage up to the culmination. The beginning of continuous pollen curves of *Alnus* and *Tilia*, as well as low curve of *Quercus*. Among herbaceous plants, the following groups predominate: Poaceae, Cyperaceae and Polypodiaceae/Filicales.	Boreal
268–286	*Pinus–Picea–Ulmus*	Evident and immediate drop of *Pinus* t. *sylvestris* pollen curve and growth of *Betula* t. *Alba* pollen curve. Gradual decrease and disappearance of pollen of *Betula* t. *nana*, *Larix*, *Juniperus*. Continuous high percentage of pollen of *Artemisia* and Chenopodiaceae. The beginning of continuous and increase curve of *Picea* pollen. At the top part of the section very high amount of *Ulmus* pollen grains and low but continuous percentage of *Corylus pollen*, and possibly also *Alnus*. Among herbaceous plants: distinct increase of *Poaceae* pollen percentage, as well as increase of spores of Polypodiaceae/Filicales, *Equisetum* and *Sphagnum*.	Preboreal
289–322	*Pinus–Larix–Artemisia*	Domination of pollen of *Pinus* t. *sylvestris*, co-existing with *Pinus* t. *cembra* (occasional), *Betula* t. *Alba*, *Betula* t. *nana* as well as *Larix*, *Populus* and *Salix*. Among herbaceous plants typical are continuous pollen curves of *Artemisia*, Chenopodiaceae, Poaceae and – at the top part of the zone – Cyperaceae.	Younger Dryas
325–328		High amount of *Pinus cembra* pollen (probably *Pinus* t. *haploxylon* of the Neogen origin). Other pollen grains of the Neogen origin were not determined, and they were included in the taxon: Indet. Varia). Aboundant pollen grains of *Larix*, a few spores of *Selaginella selaginoides*. Among herbaceous plants Poaceae, *Filipendula* pollen grains and *Sphagnum* spores predominate.	?

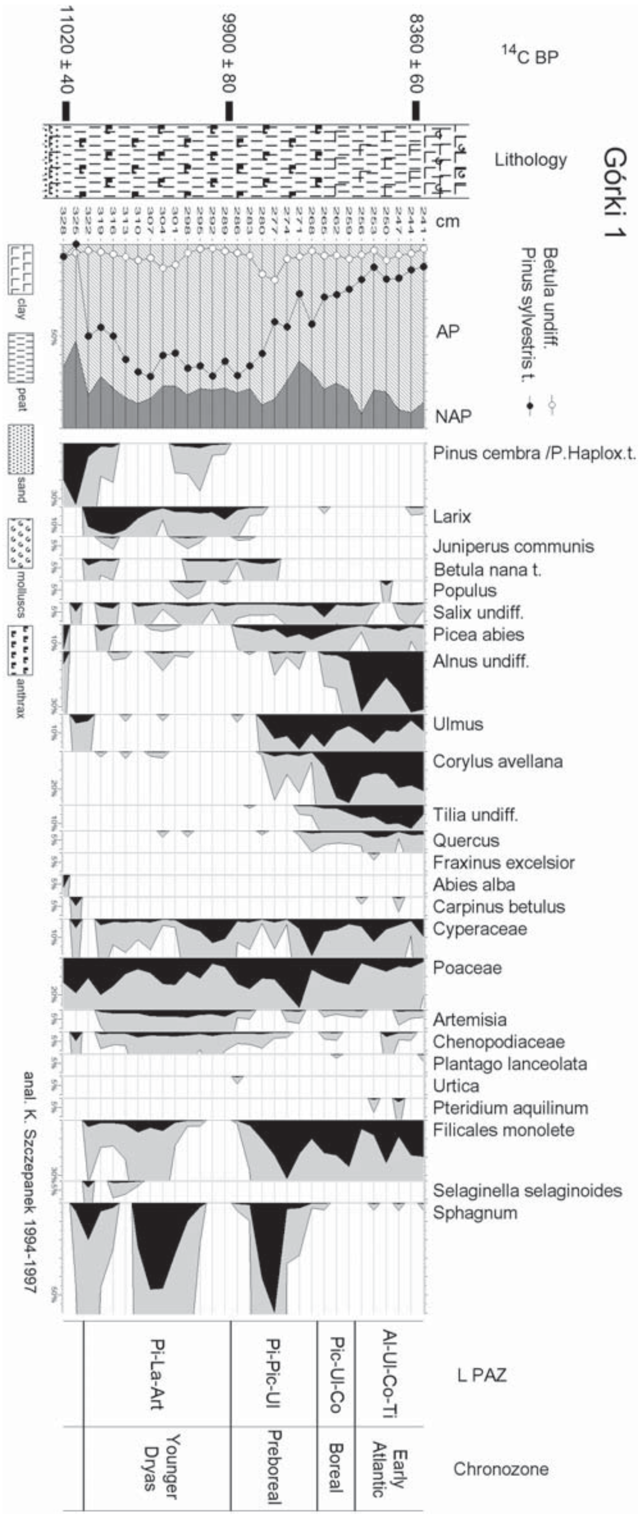

Fig. 6. Percentages pollen diagram from the Górki 1 sequence in the Jasionów Basin. Explanation of signatures (see on the graph): clay, peat, sand, molluscs, anthrax.

concluding that it can be referred to the time preceding the Younger Dryas (it cannot be fixed more exactly, due to lack of adequate pollen material). The shape of curves of local taxa (spores *Sphagnum*, *Equisetum* and Filicales) suggests hiatuses, which are not indicated in a lithological sequence. This is evident in the place where the pollen curves of *Ulmus* and *Corylus* appear. In turn, peat (with top at depth 241 cm), dated at 8,360± 60 BP (Gd-11162) [9,530–9,205 b2k], is overlain by overbank clay, which was not sampled for paleontological analysis.

Humniska Basin

Humniska 18 log (depositional sequence)

The samples for the palynological analysis and the radiocarbon dating were collected by Tadeusz Gerlach from the Humniska 18 (276 m n.p.m.) borehole log, located in the transect IV in the floodplain of the Stobnica River, 3.5 m high and 30 m to the northeast of the streambed (Figs. 1, 3C, 7).

In the Humniska 18 sequence, Tadeusz Gerlach distinguished five lithostratigraphic units (Table 7; Figs. 3C, 7) above the Quaternary bedrock composed of the Krosno Beds:

1) lower unit of channel sediments (gravel with sand) and overbank silt deposited probably in the Oldest Dryas

Table 7. The lithological description of the Humniska 18 borehole (Humniska Basin).

Depth [cm]	Description of sediment
0–060	humic, brown loam (soil)
060–100	yellow-brown silty loam, with rusty lamins
100–130	yellow-gray fine-grained sand with rusty stains
130–150	gray-brown clayey silt with rusty lamins
150–180	olive-yellow-grey silt with rusty stains
180–310	gray, slightly clayey sand
310–350	gray sand with brown wood fragments
350–400	gray, coarse-grained sand with pebbles up to 1 cm in diameter
400–430	dark gray clay
430–440	peat (samples no. 51 and 52)
440–475	dark gray clay
475–480	peat (sample no. 53)
480–500	dark gray clayey silt, with peaty layers
500–510	peat
510–520	dark gray clayey silt with peaty layers
520–530	clayey peat
530–550	dark gray clayey silt (without plant fragments)
550–570	black-brown peat (sample no. 54)
570–590	blackish brown peaty silt
590–600	peat (sample no. 55)
600–660	black peat, slightly clayey at the bottom part
660–670	brown friable peat
670–680	black peaty silt
680–700	dark grey, sandy silt
700–840	dark gray gravel and sand bearing pebbles up to 5 cm in diameter
840–870	fine- and medium-grained sand
870–900	gravel with sand
900–	very hard rock, possibly Krosno Beds of the pre-Quaternary substratum

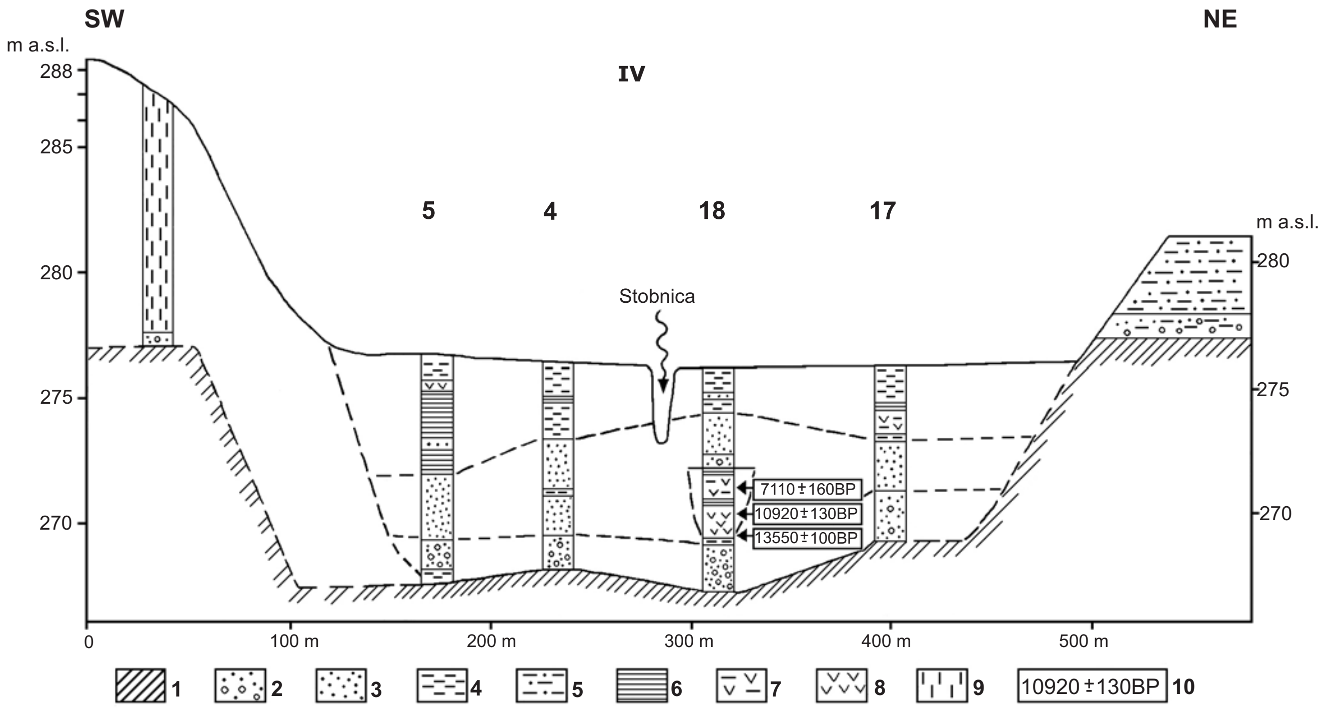

Fig. 7. Geological cross-section of the northern part of the Humniska Basin with the main depositional sequence of the Humniska 18 log: Stobnica valley transect (IV). Location – see Fig. 1C (prepared by P. Gębica based on borehole logs described by T. Gerlach). Explanation of symbols: 1 – Quaternary bedrock (Krosno Beds), 2 – sand with pebbles, 3 – sand, 4 – overbank silt, 5 – overbank sandy silt, 6 – clay, 7 – peaty silt, 8 – peat, 9 – loess, 10 – radiocarbon dating (not calibrated).

and at the decline of the Late Plenivistulian (older than 13,550±100 BP (Gd-7355, Table 1);

2) unit of palaeochannel sediments that include peat bed, 0.8 m thick, deposited from the Oldest Dryas to the Allerød (however, the palynological analysis indicates rather the Younger Dryas), peat bottom dated at 13,550±100 BP (Gd-7355) and peat top at 10,920±130 BP (Gd-6892, Table 1);

3) unit of palaeochannel clay and silt with peat interlayers, 3 m thick, truncated at the top, deposited from the Younger Dryas(?) up to the Atlantic Phase, dated at the top at 7,110±100 BP (Gd-9020) [8,200–7,765 b2k];

4) upper unit of channel sediments (gravel and sand, in places with wood fragments), 2.2 m thick, deposited during the Atlantic Phase (since ca. 7,000 BP);

5) unit of floodplain sediments with overbank silt and sandy clay, 1.8 m thick, deposited during floods of the Stobnica River in the Late Holocene. The pollen analysis of this sequence does not provide unequivocal evidence to distinguish the chronostratigraphic zones.

In the Humniska 18 sequence, four horizons of organic sediments (peat) of varying thicknesses (10–80 cm) were recorded. They are separated by clay and clayey silt, and overlain by sand with pebbles and loam (Fig. 3C). Pollen analysis of three samples of organic sediments from thin interlayers at depths of 430 cm, 510 cm and 550 cm, and 12 samples from the interval 590–670 cm were performed (Fig. 8). In the bottom part (660–670 cm), a pollen content was low or very low and numerous pollen grains were corroded,

Table 8. Humniska 18. Description of local pollen assemblage zones (L PAZ) (Fig. 8) and correlation with chronostratigraphy according to Mangerud *et al.* (1974).

Depth [cm]	L PAZ	Description	Chronozone (Mangerud *et al.* 1974)
420; 510; 550;		Occurrence in various percentages of pollen grains of taxa of trees of higher ecologic/ climatic requirements: *Ulmus*, *Corylus*, *Alnus*, *Picea*, *Tilia*.	Early Holocene
590–690	*Pinus–Larix–Artemisia*	Predomination of *Pinus sylvestris* t., pollen percentages. Low content of *Betula* pollen and low, but continuous pollen curve of *Artemisia*. Occurrence of pollen of *Larix*.	Younger Dryas
660–670		Variable predomination of *Betula* t. *alba* and *Pinus sylvestris* t. pollen percentages (the destruction of grains does not enable to distinguish pollen grains of *Pinus cembra*). Occurrence of a few pollen grains of *Larix*. Herbaceous plants are represented by low but continuous pollen curve of *Artemisia*; however pollen grains of Cyperaceae, Poaceae oraz and a few pollen grains of Chenopodiaceae pollen are also present.	?

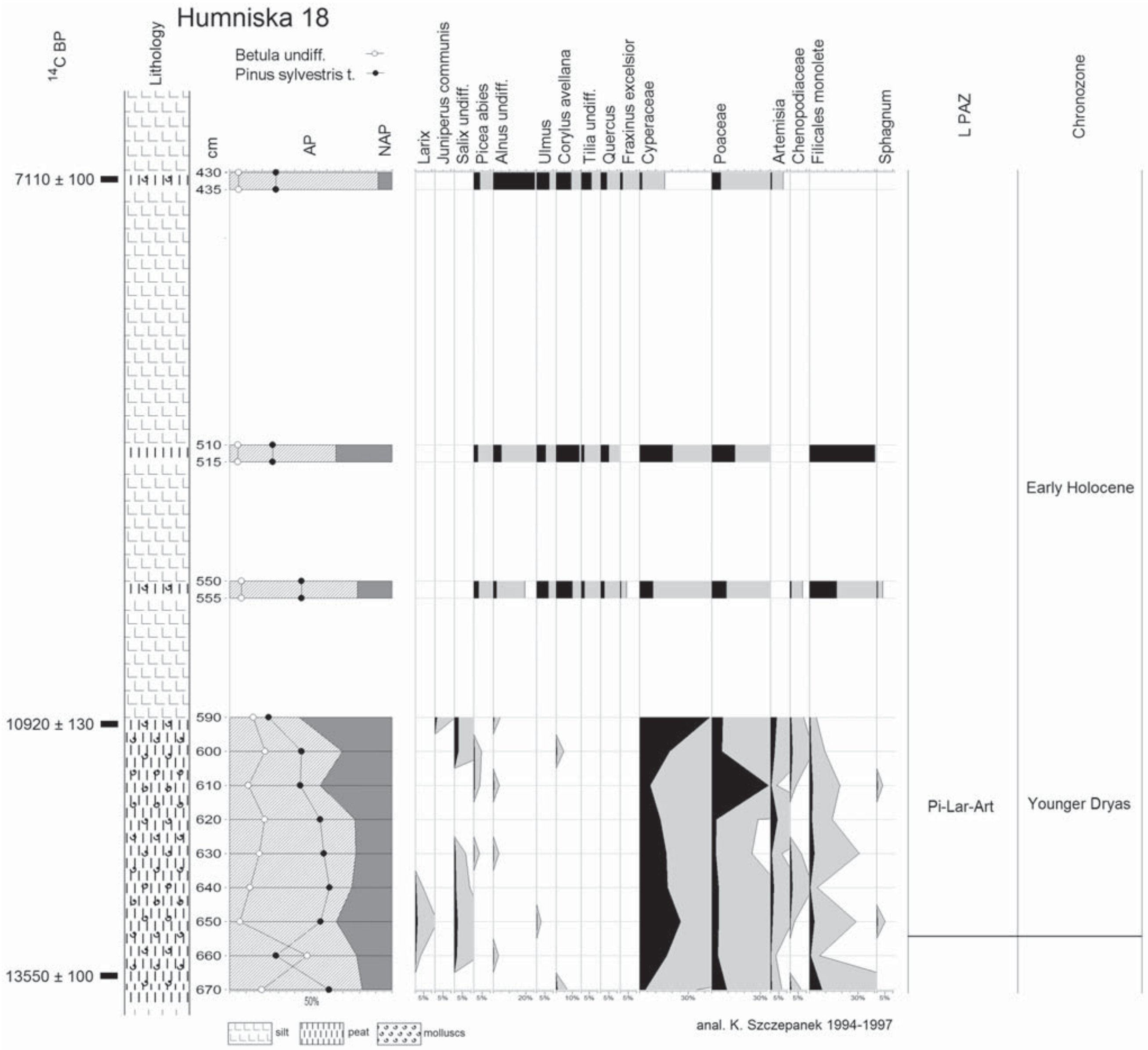

Fig. 8. Percentages pollen diagram from the Humniska 18 sequence in the Humniska Basin. Explanation of signatures (see on the graph): silt, peat, molluscs.

degraded and thus they could not be easily identified. In the lower part of the diagram two local pollen assemblage zones were distinguished with an exclusion of uppermost three single palynological spectra (Table 8, Fig. 8), because they are not suitable to palaeocological interpretation.

The pollen analysis from the Humniska 18 log does not provide evident data for palynological interpretation. Radiocarbon dating does not exclude proposed interpretation, except for the bottom dating that is older than indicated by pollen spectra (Allerød).

Humniska 6 depositional sequence

The Humniska 6 borehole in the transect V, located in the central part of the floodplain of the Leluta Stream

Table 9. The lithological description of the Humniska 6 borehole (Humniska Basin).

Depth [cm]	Description of sediment
0–025	soil
025–260	sandy-clayey silt
260–270	peat
270–355	clay
355–440	peat
440–460	silt with lacustrine chalk and snail shells
460–490	peat
490–640	gravel with sand
640–660	pre-Quaternary substratum of the Krosno Beds, weathered in the topmost part

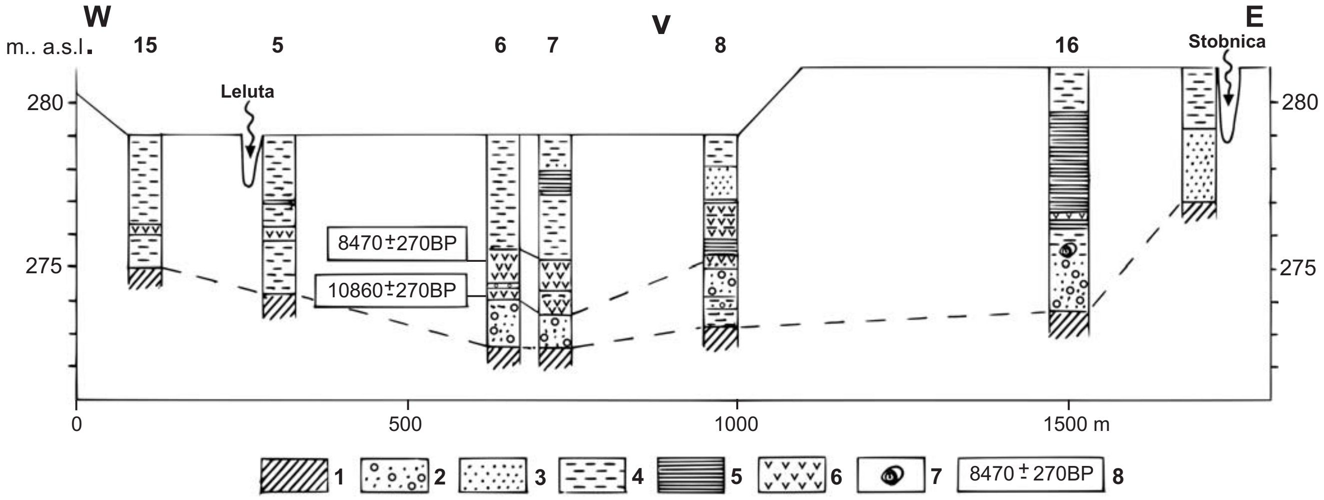

Fig. 9. Geological cross-section in the central part of the Humniska Basin with the key sequence of the Humniska 6 log: transect V. Explanation of symbols: 1 – Quaternary bedrock (Krosno Beds), 2 – sand with pebbles, 3 – sand, 4 – silt, 5 – clay, 6 – peat, 7 – tree trunk fragment, 8 – radiocarbon datings (not calibrated); for location of the cross-section see Fig. 1C (prepared by T. Gerlach).

(Stobnica River tributary), 3 m above the river channel (Figs. 1C, 3D, 9). In the Humniska 6 depositional sequence the following lithological units were distinguished (Table 9; Fig. 3D):

a) unit of channel sediments (gravel with sand), deposited in the Late Vistulian;

b) palaeochannel sediments (peat, silt with lacustrine chalk and clay) deposited during the Late Vistulian (10,260±130 BP; Gd-6890) [12,535–11,470b2k], peat from the Early Holocene (Preboreal, Boreal, 8,470±270 BP (Gd-9019) [10,210–8,785 b2k]), and peat from the Atlantic Phase (8,310±130 BP; Gd-9023) [9,565–9,040 b2k]) (Fig. 9, Table 1);

c) overbank sediments – sandy silt, deposited during the Late Holocene.

The peat and organic silts overlying lacustrine chalk in the Leluta floodplain (Humniska site) at depth 2.92 m yielded an age 9,190±590 BP (Gd-18171) [12,245–8,985 b2k] (Malata and Zimnal, 2003, 2013).

In the Humniska 6 depositional sequence (Tables 9, 10; Figs. 3D, 9) three horizons of organic sediments (peat) occurred at depths of 260–270 cm, 355–440 cm and 460–490 cm (Table 10). In total 22 samples were used for the palynological analysis, i.e. one sample from depth 260–265 cm, 18 samples from the interval 360–440 cm and 3 samples from depth 455–490 cm. Consequently, the pollen diagram from the Humniska 6 site (Fig. 10) includes results of pollen analysis from three horizons of organic sediments.

ORIGIN AND EVOLUTION OF BASINS IN THE LATE VISTULIAN AND HOLOCENE – A DISCUSSION

The presented above characteristics of landforms and stratigraphy of sediments, based on radiocarbon datings and pollen analysis enabled reconstruction of basin develop-

Table 10. Humniska 6. Description of local pollen assemblage zones (L PAZ) (Fig. 10) and correlation with chronostratigraphy according to Mangerud *et al.* (1974).

Depth [cm]	L PAZ	Description	Chronozone (Mangerud *et al.* 1974)
260	*Alnus–Corylus–Tilia*	Predomination of *Aqlnus* pollen grains, high amount of pollen of *Tilia* and relatively high pollen curves of *Picea*, *Ulmus*, *Corylus*.	Early Atlantic
360–420	*Picea–Ulmus–Corylus*	Maximum amount of *Corylus* pollen peercentages, high percentage of *Ulmus* pollen and increase of *Pinus* pollen. Relatively high percentage of P*icea* and *Tilia* pollen. Significant decrese of Cyperaceae pollen curve and increase of number of spores of Filicales.	Boreal
425–445	*Picea–Ulmus*	Predomination of herbaceous pollen grains (NAP), among which are pollen grains of Poaceae and Cyperaceae. Relatively high percentage of *Ulmus* pollen. Low but continuous pollen curves of *Picea* and *Corylus*. Small amount of *Tilia* and *Quercus* pollen.	Preboreal
480–490	*Pinus–Larix–Artemisia–*Chenopodiaceae	Predomination of *Pinus sylvestris* t. pollen. Occurrence of *Larix* as well as *Artemisia* and Chenopodiaceae pollen grains.	Younger Dryas

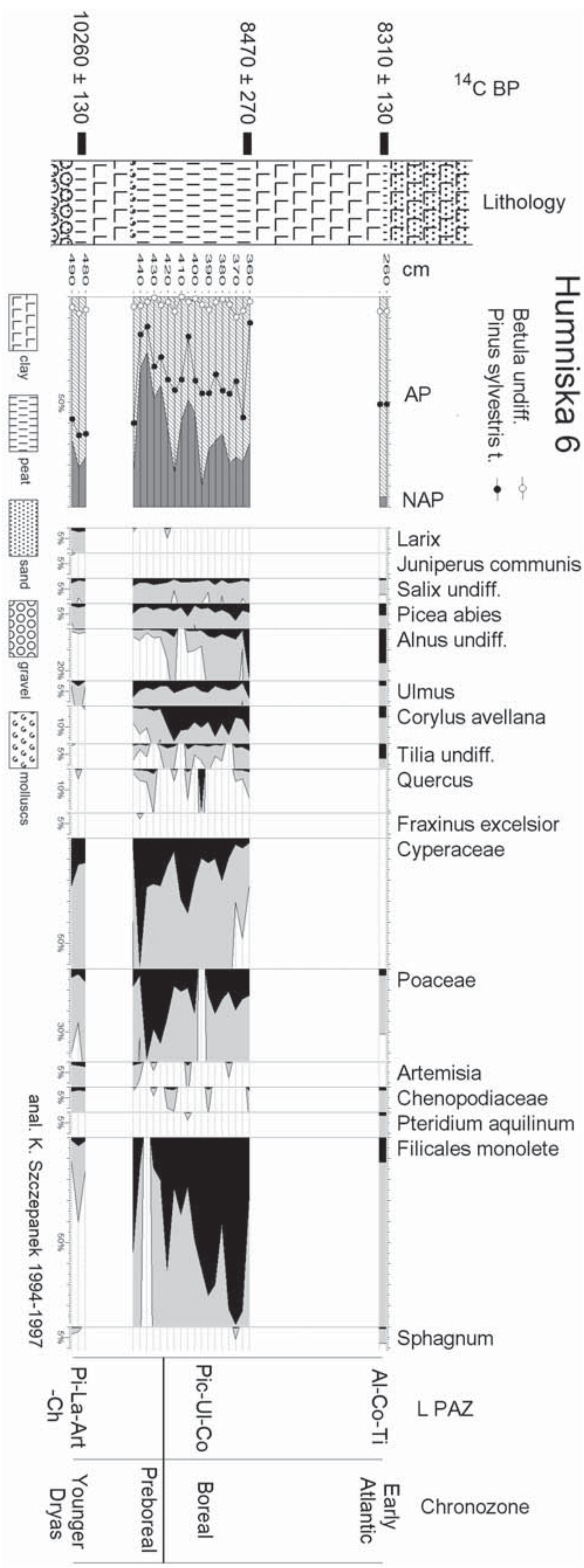

Fig. 10. Percentages pollen diagram from the Humniska 6 sequence in the Humniska Basin. Explanation of signatures (see on the graph): clay, peat, sand, gravel, molluscs.

ment in the eastern segment of the Jasło-Sanok Depression during the Late Vistulian and Holocene. Depositional landforms of the Besko Basin floor are: Wisłok alluvial fan (area 12 km^2) and much smaller Pielnica Creek alluvial fan (area 3 km^2). Apart from these landforms, several shallow depressions and flat alluvial plains occupy more than half of the basin area. Within them, small denudational hummocks (outliers) up to more than 10 m high occur.

The channel gravels up to 3 m thick fill a shallow but wide (up to 3 km) erosional trough and are the evidence of the occurrence of the Wisłok River in the Besko Basin during the Plenivistulian. Consequently, the hypothesis of Wdowiarz and Zubrzycki (1991), that the Wisłok entered this basin in the Holocene, strictly in the Atlantic Phase was not confirmed. The channel gravel is overlain by lacustrine, oxbow-lake and overbank fluvial sediments, deposited in various periods of the Late Vistulian and Holocene. Lack of lacustrine sediments in a large part of the basin does not confirm the hypothesis formulated by Koperowa (1970) on existence of a large lake in the Besko Basin in the Late Vistulian. Lacustrine deposits occur at a few sites and most likely were deposited in paleochannels of the Wisłok River.

Lack of sediments older than the Plenivistulian, small thickness of the Plenivistulian gravel series and large areas devoid of thick weathering and solifluction covers indicate that physical weathering, fluvial erosion and in particular, effective removal of silty-clayey material prevailed over accumulation processes during the Vistulian. This statement is confirmed by presence of sandy-silty slope deposits at the Grabówka site, TL-dated at 13,000±1800 (Lub-4106) [19,685–10,400] at depth 4.5 m (Malata and Zimnal, 2013). Deflation was probably the most efficient morphological process in the basins as suggested by thick loess covers of Carpathian type, correlated with these processes and documented in the Humniska Basin (Gerlach *et al.*, 1991, 1993). Occurrence of faceted cobbles, elongated hills and deflation troughs covered with lacustrine and oxbow-lake sediments, as well as present degradational (erosional) wind activity in the Low Beskid (Beskid Niski) foothills (Gerlach *et al.*, 1986; Gerlach 1977, 1990, 1991) suggest that the Besko, Jasionów and Humniska Basins in the eastern part of the Jasło-Sanok Depression were the area of deflation processes. Near Zagórz, 25 km to the east of the Humniska Basin and within the Sanok Basin in the San River valley, Tadeusz Gerlach found aeolian silt, 15 m thick that covered a high terrace of the San (Gerlach *et al.*, 1997).

Wójcik (2003) assumes that among the processes that modelled the Besko Basin floor in the Upper Plenivistulian, ground ice activity and thermokarst processes played an important role. He compared formation of the Besko Basin to development of alases in Siberia and stated that lacustrine sediments at the Besko-Zapowiedź site fill a depression of a hydro-laccolith, although he does not confimed this hypothesis with any geological evidence.

In the Late Vistulian, in the palaeochannels of Wisłok lacustrine and oxbow-lake sediments were deposited. A beginning of their accumulation in the Besko Basin and

Table 11. Correlation of chronozones and local pollen assemblage zones (L PAZ) of all profiles in the eastern part of Jasło–Sanok Depression (Polish Carpathians).

<table>
<tr><td>Chronozone / L PAZ</td><td colspan="2">Besko</td><td>Górki 1</td><td>Humniska 18</td><td>Humniska 6</td></tr>
<tr><td rowspan="2">Subatlantic</td><td rowspan="2">Abies–Fagus–Carpinus</td><td>Abies–Fagus</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Alnus–Abies–Fagus–Carpinus</td></tr>
<tr><td>Subboreal</td><td colspan="2">Alnus– Abies–Fagus</td><td></td><td></td><td></td></tr>
<tr><td>Early Atlantic</td><td colspan="2">Alnus –Ulmus–Corylus– Tilia</td><td>Alnus–Ulmus–Corylus–Tilia</td><td></td><td>Alnus–Corylus–Tilia</td></tr>
<tr><td>Boreal</td><td colspan="2">Picea–Ulmus–Corylus</td><td>Picea–Ulmus–Corylus</td><td></td><td>Picea–Ulmus–Corylus</td></tr>
<tr><td>Preboreal</td><td colspan="2">Pinus–Picea–Ulmus</td><td>Pinus–Picea–Ulmus</td><td></td><td>Picea–Ulmus</td></tr>
<tr><td>Younger Dryas</td><td colspan="2">Pinus–Pinus cembra–Larix–Juniperus–Artemisia</td><td>Pinus–Larix–Art</td><td>Pinus–Larix–Artemisia</td><td>Pinus–Larix–Artemisia–Chenopodiaceae</td></tr>
<tr><td>Allerød</td><td colspan="2">Pinus–Pinus cembra</td><td rowspan="2">Pinus cembra</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Bølling</td><td colspan="2">Pinus–Betula–Larix</td></tr>
</table>

Humniska Basin falls into the pre-Allerød period as palynological analysis indicates. In the Younger Dryas, in the marginal part of the Wisłok alluvial fan (Besko-Wierzbiny site) and in the Pielnica alluvial fan a peat bed, dated at 10,790–10,990 BP [13,070–12,300 b2k] (Table 1), was covered by overbank clay and silt. Organic deposition in the Pielnica river valley in the south-eastern part of Besko Basin terminated as indicated by radiocarbon dating at 10,070±140 BP (Gd-15452) [12,240–11,310] at depth 3.4 m at Zarszyn (Malata, Zimnal, 2013). Intensification of fluvial activity in the Younger Dryas is proved by a peat-bog sequence at the Tarnawa site in the San valley, where the age of the mineral insert was framed by the following radiocarbon dating at 10,750±160 ^{14}C BP [13,045–12,210 b2k], and 10,340±160 ^{14}C BP [12,645–11,505 b2k] (Ralska-Jasiewiczowa and Starkel, 1975).

Development of vegetation in the investigated region has been characterised by correlation of local pollen assemblage zones distinguished at all four sites (Table 11; Fig. 11). Based on the radiocarbon dating and correlation with dating sites in neighbouring areas (Harmata, 1987, 1995a, b; Szczepanek, 1987; Wacnik *et al.*, 2016), as well as synthetic isopollen maps from the western part of Carpathian Mts. (Obidowicz *et al.*, 2013) they are presented in periods treated as chronozones (Mangerud *et al.*, 1974; Walanus and Nalepka, 2010).

The main pattern of vegetation development follows the Besko-Zapowiedź diagram interpretation, delivered by Koperowa (1970). Pollen data from Humniska (both sites), and Górki site encompass only fragments of episodes from the Late Vistulian and the Holocene and repeated the Koperowa's interpretation.

Late Vistulian

Pre-Allerød (lowest spectra of the pollen diagrams from Besko-Zapowiedź, Górki and Humniska 18).

Harsh climatic conditions enabled vegetation of photophilous plant taxa which tolerated a low temperature. In the predominating open habitats, the herbaceous plant associations were composed mainly of grass (Poaceae) and sedge (Cyperaceae), with significant content of *Artemisia* and Chenopodiaceae as well as *Selaginella selaginoides*. Single light demanding trees were represented by stone pine (*Pinus cembra*) and larch (*Larix*). Possibly patches of park-forests composed of pine (*Pinus sylvestris*) and birch trees (*Betula* undiff.); both in variable content. The most important features of plants growing in that time were the requirements concerning the availability of light and probably water. Relatively numerous grains of pollen of trees of higher (temperate) climatic requirements (*Picea abies*, *Alnus*, *Ulmus* and *Abies*) could be delivered from remote areas or from eroded older sediments.

The vegetation recorded by a few lowermost pollen spectra of the Besko-Zapowiedź, Górki and Humniska 18 pollen diagrams was dated to the period before the last interstadial warming (Allerød). The age cannot be exactly determined, beause of insufficient palynological data. Radiocarbon dating from a bottom of a single section (Humniska 18) ranging 13,550±100 BP, after calibration – ca. 16,000 years BP [16,710–16,085 b2k], is probably overestimated by carbonates (lacustrine chalk, shells?). This is indicated by palynological records, which suggest attribution of this section to the older part of the Allerød.

Probably, at this time, the loose open plant cover was conducive to deflation of mineral material. This led to aeolian fashioning of the valley floor.

Allerød (Besko-Zapowiedź; *Pinus–Pinus cembra* L PAZ).

A composition of the park forest changed: pine (*Pinus sylvestris*) predominated, while the amount of birch decreased. In these habitats, single photophilous trees as larch (*Larix*) and stone pine (*P. cembra*) was still important. In still existing, however smaller open areas, the herbaceous plant associations, apart of grass (Poaceae) and sedge (Cyperaceae), were composed – among others – of *Artemisia*, Chenopodiaceae, *Helianthemum* and *Selaginella selaginoides*. The occurrence of pollen of *Alnus*, *Picea* and *Abies* indicates redeposition of organic matter. The pollen assemblage zone dated to the Allerød is identified with lacustrine chalk bearing abundant malacofauna fossils. More dense vegetation, especially presence of forest patches, was not conducive to deflation.

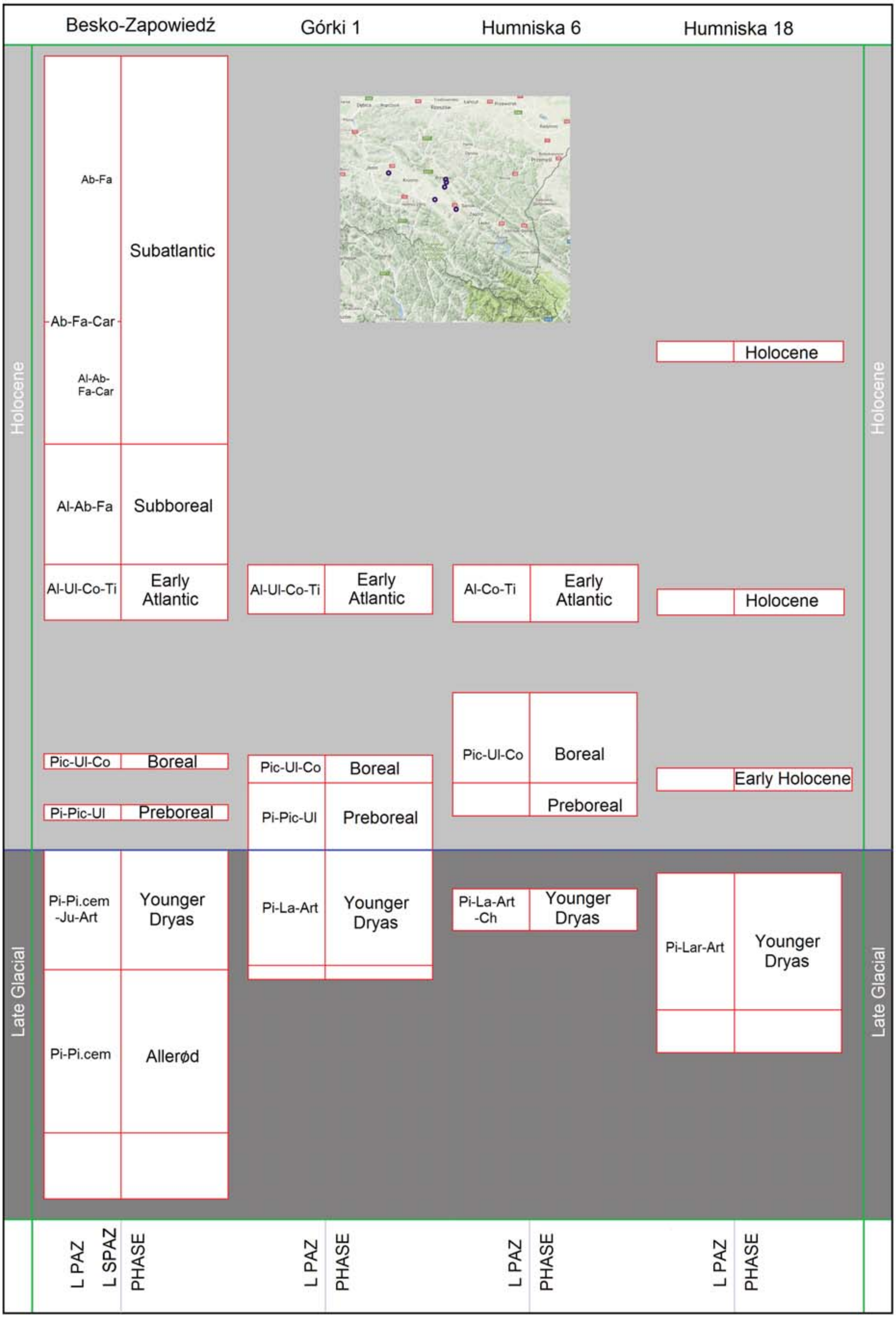

Fig. 11. Correlation of chronozones and local pollen assemblage zones (L PAZ) of all analysed profiles in the Jasło-Sanok Depression. Explanation of symbols: Ab – *Abies*; Al – *Alnus*; Ar – *Artemisia*; Be – *Betula*; Cr – *Carpinus*; Chen – Chenopodiaceae; Co – *Corylus*; Fa – *Fagus*; Ju – *Juniperus*; La – *Larix*; Pi – *Pinus*; *Pi. cem* – *Pinus cembra*; Pic – *Picea*; Ti – *Tilia*; Ul – *Ulmus*.

Younger Dryas (Besko-Zapowiedź; *Pinus–Pinus cembra–Larix–Juniperus–Artemisia* L PAZ (pure lacustrine chalk); Górki 1; *Pinus– Larix–Artemisia* L PAZ; Humniska 18; *Pinus–Larix–Artemisia* L PAZ;; Humniska 6; *Pinus–Larix–Artemisia–Chenopodiaceae* L PAZ)

The pollen assemblage zone at Besko-Zapowiedź dated to the Younger Dryas is identified with a pure lacustrine chalk. In the neighbourhood of these sites the area of open habitats increased asnd they were occupied by herbaceous plants such as sedge (Cyperaceae), grass (Poaceae) with photophilous *Artemisia* and Chenopodiaceae and *Centaurea scabiosa* (Besko-Zapowiedź). Their increase in the herbaceaous plant cover prooved climatic deterioration. Smaller areas than in the earlier period were occupied by park-forest composed of pine (*Pinus silvestris*). In the pine forest the amount of birch trees gradually increased (its pollen percentage reached maximum at the top of the section at Besko-Zapowiedź site). Stone pine (*Pinus cembra*) was still present, however its content gradually diminishad, whereas the amount of larch trees (*Larix*) apparently increased and other photophilous trees, as poplar (*Populus*) and shrubs, as juniper (*Juniperus*) and *Ephedra distachya* appeared. In the tundra wetlands dwarf birch (*Betula nana*) occurred.

Such vegetation indicates the Late Vistulian (Younger Dryas), whereas radiocarbon dating of peat from the Humniska site (Humniska 6 profile) indicates 10,260±130 ^{14}C BP [12,535–11,470 b2k] and it falls into a top part of the Younger Dryas chronozone. During Younger Dryas, sparse vegetation cover indicates probably that the wind activity was stronger, causing deflation.

Holocene

Accumulation of peat started in palaeochannels and flood basins in the early Holocene (Preboreal and Boreal Phases).

Preboreal Phase (Górki 1; *Pinus–Picea–Ulmus* L PAZ; Humniska 6; *Picea–Ulmus* L PAZ, and supplementary, single pollen spectra from Humniska 18; the Besko-Zapowiedź; *Pinus–Picea–Ulmus* L PAZ, where this phase is identified with dense, accurately decomposed peat and includes two pollen spectra, it does not present comprehensive description of vegetation in this phase).

A change in plant composition occurred: the area occupied by pine park-forest apparently decreased, because the pine share decreased. In the forest, new tree taxa appeared, such as spruce (*Picea abies*), elm (*Ulmus*) and hazel (*Corylus avellana*), as well as – in the younger part of this phase (Górki 1 site) – lime (*Tilia*) and oak (*Quercus*). The still existing open areas were occupied by plant associations with grass (Poaceae) and sedge (Cyperaceae), as well as by *Artemisia* and Chenopodiaceae. The occurrence of dwarf birch pollen (*Betula* t. *nana)* and *Ephedra* at the bottom of this zone (Górki 1 site) could indicate deformation of sediments, which is not recorded in the lithological structure.

Radiocarbon dating (Besko-Zapowiedź site) at 9,530±150 BP (Bln-1148) [11,250–10,450 b2k] of peat bottom is consistent with results of palynological analysis. A bottom of this pollen assemblage zone (Górki 1) radiocarbon dated includes 2 pollen spectra: typical for the Younger Dryas (with *Betula nana*) and for the Preboreal (*Ulmus*, *Picea abies*). The dating at 9,900±80 (Gd-11162) [11,735–11,250 b2k] indicates the turn of the Younger Dryas and the Preboreal Phase.

Since the start of the Holocene, the increased of forest density hampered processes of wind erosion. In the palaeochannels lacustrine chalk was deposited, followed organic deposition when palaeochannels were overgrown.

Boreal Phase (Górki 1; *Picea–Ulmus–Corylus* L PAZ; Humniska 6; *Picea–Ulmus–Corylus* L PAZ; and single pollen spectra of the Besko-Zapowiedź; *Picea–Ulmus–Corylus* L PAZ;)

Plant associations with greater content of deciduous trees and shrubs developed near the sites. The trees of higher climatic requirements such as elm (*Ulmus*), hazel (*Corylus*) and lime (*Tilia*), played an important role in this plant association, while spruce (*Picea*) could have been an admixture. Mixed forest predominated, although in its composition pine (*Pinus sylvestris*) still played an important role, the content of spruce (*Picea abies*), alder (*Alnus*), elm (*Ulmus*) and lime (*Tilia*) increased. Hazel (*Corylus avellana*) intensively grew in clearings and marginal parts of a forest.

Changing landscape consisted in replacement of coniferous forest by mixed forest with pine (*Pinus sylvestris*), with significant amount of hazel (*Corylus avellana*) and higher content of elm (*Ulmus*), spruce (*Picea abies*) and lime (*Tilia*). Significant fluctuations of pollen curves of these taxa could suggest discrete (discontinuous) record of vegetation evolution at the Humniska 6 site. Despite suggested hiatuses, this section can be correlated with the Boreal Phase, which is confirmed by radiocarbon dating of the top part of peat, which yields 8,470±270 ^{14}C BP (Gd-9019) [10,210–8,785 b2k].

At the vicinity of Besko-Zapowiedź site, a content of pine decreased, whereas spruce (*Picea abies*) and elm (*Ulmus*) became significant components of a forest. Hazel (*Corylus avellana*) and lime (*Tilia*) appeared at the site or its vicinity. Principally, based on the only two pollen spectra one can postulate an increase of forested areas and reduction of areas favourable for photophilous plants.

Although the plant cover was not uniform in the examined area, as at Górki 1 site further decline of pine is noted, diminished content of elm and spruce and increase of hazel and lime, such a plant cover could be still correlated with a part of the Boreal Phase.

Older part of the Atlantic chronozone (early Atlantic) (single pollen spectra from all diagrams: Besko-Zapowiedź; *Alnus–Ulmus–Corylus–Tilia* L PAZ; once more lacustrine chalk); Górki 1; *Alnus–Ulmus–Corylus–Tilia* L PAZ); Humniska 6; *Alnus–Corylus–Tilia* L PAZ).

A mixed deciduous forest predominated. In various habitats elm (*Ulmus*), spruce (*Picea abies*), and lime (*Tilia*) were the principal components. Oak (*Quercus*) and ash (*Fraxinus*) revealed, hazel (*Corylus*) intensively grew in

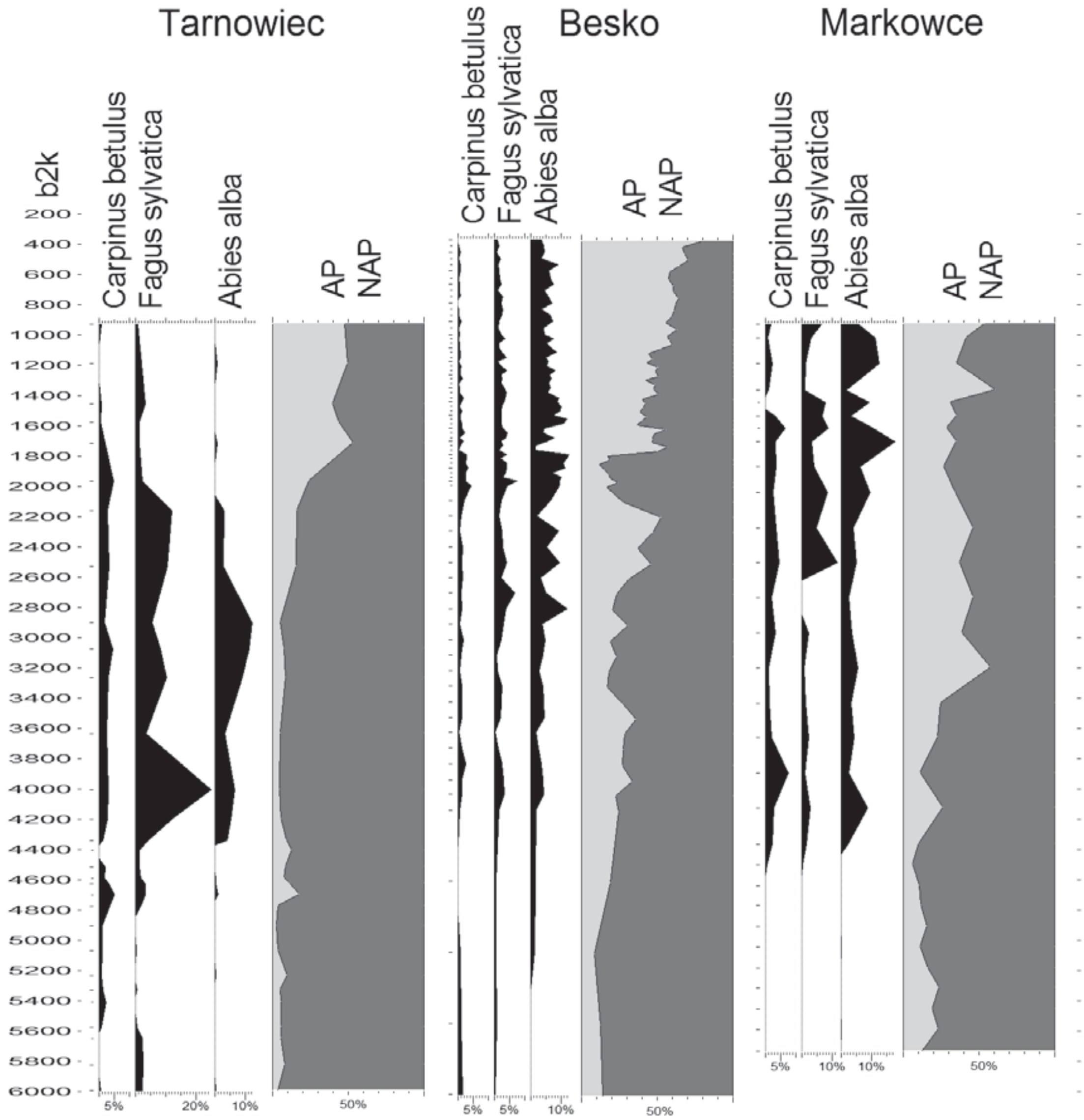

Fig. 12. Correlation of upper parts of pollen diagrams from Tarnowiec, Besko and Markowce sites presenting transitional period in the Late Holocene history of woodland communities as well as changes of human impact on vegetation (after Wacnik *et al.*, 2016, changed).

clearings and marginal parts of a forest. A content of pine (*Pinus sylvestris*) was still decreasing, while birch (*Betula*) was a subordinate component of forest associations. A development of forest associations with predominant alder (*Alnus*) was noticed in wetlands.

In the depositional sequence and pollen diagram at the Besko-Zapowiedź site, above the dating of 7,900±100 BP (Bln-1147) [9,040–8,540 b2k], a hiatus occurs up to ca 2,900–2,300 years. Such gap in is similar to palynological hiatuses in sequences of Roztoki b, (Harmata, 1987) and Podgrodzie (Alexandrowicz *et al.*, 1981).

The early Atlantic age is proved by radiocarbon dating at 8,360±60 BP (Gd-3786) [9,530–9,205 b2k] in a peat top at Górki 1. However, presence of single spores of bracken (*Pteridium aquilinum*) in the middle part of the zone does not exclude presence of humans in the vicinity of the investigated site. This fact, together with single pollen grains of the ribwort plantain (*Plantago lanceolata*), present in the one of the upper samples (241 cm), may suggest a younger age of this part of the section.

A composition of the pollen spectrum at Humniska 6 suggests the plant association of the climatic optimum (Atlantic Phase). Radiocarbon dating yields 8,310±130 BP (Gd-9023) [9,565–9,040 b2k] and is slightly older, but the sample was collected from a thin peat layer which possibly includes also older sediments. Large laboratory uncertainty (±130) suggests lower precision of the dating. Nevertheless, large percentage of *Alnus* is a reason that this spectrum was ascribed to the Atlantic Phase.

At the begining of the Atlantic Phase (ca 8,600–7,900 BP) organic accumulation was finished, and the deposition of clayey overbank sediments commenced. In the younger Atlantic (after 7,100 BP) even the deposition of channel sediments above the organic deposits is observed in basin floors (Harmata, 1987, 1995a, b; Koperowa, 1970; Ralska-Jasiewiczowa and Starkel, 1975, 1988; Koperowa and Starkel, 1972; Szczepanek, 1987). For a similar time, an insert of silt and sand in the Tarnawa peat-bog (located in the Upper San River valley) was dated between 8,370±100 [9,565–9,135 b2k] and 7,840±100 BP [9,025–8,485 b2k] (Ralska-Jasiewiczowa, 1980). Similarly, tree trunks dated at 8,500–8,100 BP were buried in the channel fluvial deposits of the Lower Wisłok River (Gębica *et al*., 2014).

Subboreal Phase (Besko-Zapowiedź; *Alnus–Abies–Fagus* L PAZ; clay).

In mixed and deciduous forests the main forest components such as elm, oak, lime, ash and hazel significantly decreased, whereas beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*) and fir (*Abies alba*) became their main elements.

The wetlands were occupied by alder (*Alnus*) with decreasing spruce (*Picea abies*). During this phase, the first evidences of man are recorded, i.e. a few grains of synanthropic plant pollen grains, such as *Plantago lanceolata*, *P. media* iand *Rumex* sp. as well as spores of *Pteridium aquilinum*. An increased spruce (*Picea abies*) pollen amount prooves higher humidity and cooling. This phenomenon, in turn, influenced growth of river activity, and accelerated accumulation of overbank sediments in the basins. An example of this fluvial precesses is the increase of silty-sandy accumulation recorded in the Besko-Zapowiedź section (Koperowa and Starkel, 1972) (Fig. 3A).

Deforestation caused by increasing human pressure on natural environment in the area is not the same. Strong deforestation is clearly visible in a pollen diagram from the Tarnowiec site (Harmata, 1995b) and decreases in eastwards (Wacnik *et al*., 2016) (Fig. 12). The lower preasure on forest is shown in the Besko-Zapowiedź diagram (Koperowa, 1970) and is even less visible in the pollen diagram from the Markowce site (Wacnik *et al*., 2016).

Subatlantic Phase (Besko-Zapowiedź; *Abies–Fagus–Carpinus* L PAZ; clay).

This phase is characterised by significant changes in the vegetation. During the older part of this phase (*Alnus–Abies–Fagus–Carpinus* L SPAZ), alder (*Alnus*) and fir (*Abies alba*) were the significant elements of a mixed forest, which still played important role, while spruce (*Picea abies*) and other deciduous trees where co-components in these associations. During the younger part of this phase (*Abies–Fagus* L SPAZ) the area of alder forest significantly decreased, whereas open areas got enlarger. They have been occupied by plant associations with significant content of plants connected with human activity, such as cultivated ones: rye (*Secale cereale*) and buckwheat (*Fagopyrum*).

A beginning of extensive deforestation was dated to the Roman Iron Age or the Early Middle Ages (Wacnik *et al*., 2016). A description of the present vegetation in the Jasło-Sanok Depression was presented by Oklejewicz (1993, 1996). At this time an increased human impact on the vegetation cover is visible together with climate change. Forest transformation during the Late Holocene (Subboreal and Subatlantic phases) is described in great detail, interpreted and discussed (Wacnik *et al.,* 2016). Besko and other sites (Górki i Humniska) indicate similar vegetation development as depicted in the area of Beskid Niski. Despite the fact that on the north ridge of Beskid Niski, vegetation development was similar to that of the western part of the Carpathian Foreland (Obidowicz *et al*., 2013).

CONCLUSIONS

1. The evidences presented in this paper confirm the thesis formulated by the late Professor Tadeusz Gerlach (Gerlach, 1991, 1994; Gerlach *et al*., 1993) that the "Beskid Niski Gate" and its foothills were a zone of intensive wind activity and deflation in the Vistulian. In the periglacial climate with limited precipitation and lack of tight vegetation cover, the following processes were active: (i) blowing out of fine-grained material from the basins, formation of deflation hollows, troughts and pavements, (ii) aeolian transport of mineral material and polishing of cobbles and pebbles that produced faceted forms (ventifacts) (iii) deposition of silt-clay material in front and behind the morphological obstacles. In this way, in the marginal zones of the Jasło-Sanok Depression and Carpathian Foothills, in particular in their eastern segment, loess covers of the Carpathian type were formed. The northern Carpathian margin is the intermediate zone between the Carpathian type loess built of material transported from the south and the central European loess composed of material transported in a longitudinal (W-E) direction (Gerlach, 1991, 1994; Gerlach *et al*., 1993).

2. At the end of the Late Vistulian and Holocene the alluvial plains of Wisłok, Pielnica and Stobnica rivers, and Potok Górecki stream were overbuilt with alluvial fans that pass into vast levees, which occupy estimatedly half of the area of the Besko Basin. In the Younger Dryas and in particular, at the turn of the Boreal and Atlantic Phases (8,600–7,900 BP), intensive fluvial activity was observed in the basins, which was earlier proved in the valleys of the upper Vistula river catchment (Starkel, 1999). Therefore, foundation of the Besko Basin morphology is of pre-Vistulian and neotectonic origin, whereas its floor relief represents relatively flat surface of erosional origin shaped during the Plenivistulian. In the Holocene this erosional plain was overbuilt with sediments up to 8 m thick.

3. The described changes in vegetation during the Late Vistulian and Holocene are in accordance with vegetation evolution typical for this part of the Polish territory, which were described in details in the western part of the Jasło-Sanok Depression (e.g. Harmata, 1987, 1995a, b; Szczepanek, 1987; Wacnik *et al*., 2016; Fig. 1). These transformations were also summarised in synthetic studies based on isopollen maps (Ralska-Jasiewiczowa *et al.* (Eds), 2004; Obidowicz *et al*., 2013). More detailed comparison with neighbouring areas were not performed, because studies of material from the Humniska and Jasionów Basins

were carried out based on a small number of pollen samples. In turn, the Besko pollen diagram (Koperowa, 1970), was not radiocarbon dated. Two radiocarbon datings, realised several years later, are in accordance with the palynological data and confirmed presence of a hiatus, at least in the older Holocene section.

In the Late Vistulian, harsh climatic conditions favoured growth of photophilous vegetation (*Artemisia*, Chenopodiaceae, *Selaginella selaginoides*, *Helianthemum*) that occupied large areas, with occurrence of single trees (*Pinus cembra*, *Larix*) and shrubs (*Juniperus*). Such loose, heliophilous and herbaceous plants were conducive to deflation processes. The Allerød warming favoured development of pine forest that covered large areas, while during the following colder climate in the Younger Dryas, the area occupied by these forest decreased again.

Since the beginning of the Holocene, along with climate amelioration, the vegetation was modified. Pine forest was diversified with spruce (*Picea abies*) and deciduous trees (*Ulmus*, *Tilia*, *Quercus*), whereas in the clearings, the hazel brushes (*Corylus avellana*) grew. During the climatic optimum the study area was occupied by mixed deciduous forest composed of elm (*Ulmus)*, lime (*Tilia)*, oak (*Quercus)*, ash (*Fraxinus)*, alder (*Alnus)*, spruce (*Picea abies)* and hazel (*Corylus avellana)*. In the subsequent phase, a forest composition was transformed again: deciduous trees were replaced by fir (*Abies alba*), beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*). Increasing humidity and progressing cooling caused intensification of flood deposition. First synanthropic plants (*Plantago lanceolata*, *Rumex*) appeared in this period, suggesting the prehistoric man activity in the vicinity of the Besko-Zapowiedź site (other analysed sequences do not include the younger Holocene sediments). Intensification of anthropogenic activity (deforestation, agriculture, selective use of wood) is very clearly visible in pollen spectra of the Subatlantic Phase. Human activity brought about the extensive reduction of forest, in particular of hornbeam and spruce-alder forest which were replaced by willow agglomerations or boggy-meadow plant assotiations. As a result, the afforestation of this region is small today. Thus, the Subatlantic Phase is also a period of significant modification of the vegetation.

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