RECORD OF THE MESO- AND NEOHOLOCENE PALAEOENVIRONMENTAL CHANGES IN THE JESIONOWA LANDSLIDE PEAT BOG (BESKID SĄDECKI MTS. POLISH OUTER CARPATHIANS)

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Abstract: The paper presents an analysis of depositional sequences of landslide peat bog situated in the depressions developed within the landslide landforms Jesionowa in the Beskid Sądecki Mts. (Outer Carpathians). The peat bog, with depositional sequence 2.80 m long, started to form at the beginning of the Atlantic Phase ca. 6390-5910 cal BC. Palynological and lithological analyses as well as several (14) radiocarbon age determinations of different horizons in the sediments enabled the reconstruction of palaeoenvironmental changes during the Meso-and Neoholocene. The increase in climate humidity at the beginning of the Subboreal and Subatlantic Phases was observed as delivery of minerogenic material to the peat bog basin and formation of a mineral horizon and an illuvial level within the peat. The particularly intensive delivery of allochthonous material to the peat bog took place at the beginning of the Subboreal Phase and was the result of both significant humid climate and increased human impact (colonization of the Funnel Beaker Culture) in the landslide area. Similar influence of younger colonisations of landslide area (Przeworsk Culture and, later, Valachian colonisation) was also recorded within the deposits of peat bog (illuvial and mineral horizons) in the early Subatlantic Phase. Rejuvenation of the landslide zone and formation of the younger landslide were connected with the increase in climate humidity at the beginning of the Subboreal Phase. The peat bog deposits situated within this younger landslide, which are ca. 1.8 m thick, are significantly contaminated with mineral material.

Keywords: landslide peat bogs, palaeoenvironmental changes, Middle and Late Holocene, Human impact, Polish Flysch Carpathians.

1. INTRODUCTION

Peat bogs occurring within landslide depressions (called landslide peat bogs) are sensitive indicators of palaeoenvironmental changes in mountains during the Late Glacial and the Holocene (Margielewski, 2006a; Obidowicz and Margielewski, 2008; Margielewski *et al.*, 2010a, b). An increase in the amount and frequency of extreme hydrometeorological events (downpours, long-lasting rains), typical of humid climatic phases, generated

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intensive delivery of mineral material to the peat bog sediments. This material formed illuvial and minerogenic horizons within the peat bog sequences. Intensification of these phenomena was also caused by human activity, e.g. burnout of forests for agriculture (applied since the prehistoric time), intensive pasturing or cultivation (Starkel, 1988, 1989; Margielewski and Zernitskaya, 2003; Margielewski, 2006a).

Jesionowa site in the Beskid Sądecki Mts. is one of the landslide peat bogs, within which the climatic changes during the Meso- and Neoholocene were recorded (**Fig. 1**). It is situated in the region of Polish Carpathians, within which the palaeoenvironmental changes have not been sufficiently investigated yet. The set of analyses of

Fig. 1. *The map of Jesionowa Landslide (A) with cross section (B) and orthogonal projection of hipsometry of landslide area in "z" value (C). On draws, the position of analysed peat bogs was signed (as 1 and 2), according to description in the text. Legend symbols: 1 – scarps; 2 – trenches; 3 – landslide body; 4 – colluvial tongues; creeping; 5 – crags (a) and rock blocks and debris (b); 6 – swamps (a) and peat bogs (b) – with places of drilling; 7 – colluvial material (on cross section); 8 – bedrock and landslide body (on cross section): a – sandstones; b – shales; 9 – buildings (a) and roads b).*

peat bog sediments (e.g. lithological and palynological analyses, radiocarbon dating) enabled to reconstruct palaeoclimatic changes as well as stages of prehistoric man activity in this region since the Atlantic Phase, when the landslide formed.

2. STUDY AREA

Landslide description

The Jesionowa landslide is situated in the eastern part of the Beskid Sądecki Mts. (Western Outer Carpathians; N49° 28,609'; E20° 44,937', 850 m a.s.l.), which is built of flysch rock of the Krynica Subunit, Magura Unit (Nappe) (Chrząstowski *et al.*, 1995). The landslide was formed on the slope of south-side subordinate ridge to the main ridge of the Jaworzyna Krynicka Range and it is situated in the upper segment of the Łomnicka stream valley. The landslide zone, developed in thick bedded Magura sandstones (forming the southern part of the Runek-Łabowska Hala-Pisana Hala syncline), consists of a set of successive landslide structures. Landslides were successively formed by several mass movement generations stimulated by headward erosion (oldest stages) and lateral erosion of the Łomnicka stream (younger stages of mass movements). Older landforms are represented by two systems of circular landslide head scarps, 150-100 m long and ca. 10-20 m high (**Fig. 1**). During the subsequent mass movements a vast trench was formed in the lower part of the landslide zone (Margielewski, 1997a). Landslide represents complex, translational-rotational (displaced consequently to beds dip) type of gravitational displacements (see Dikau *et al.*, 1996; Margielewski, 2006b).

During one of the older stages of gravitational displacements, in the upper part of the landslide zone, the depression (40 m long and 24 m wide) situated at the foot of one of the landslide heads a scarp was formed (**Fig. 1A-1**). This depression, whose maximum depth is ca. 2.8 m, is filled with organic-minerogenic deposits of fen type peat bog (minerogenic mire) (Jesionowa 1 – **Fig. 2**). The second peat bog (Jesionowa 2) occurs within the lower part of the landslide zone, at the bottom of the main trench (**Fig. 1A-2**).

Recent vegetation

An analysed fen is located in the beech-fir forest belt, close to the forest clearing. The site is partially surrounded by *Fagus sylvatica* woodland with a small admixture of *Abies alba* (**Fig. 2**). There are also *Betula pendula* patches and single specimens of *Juniperus communis* and *Salix* sp. in the close vicinity of the site. Wetter parts of the fen surface, especially along the stream, are overgrown by *Scirpus sylvaticus*, *Eriophorum angustifolium*, *Carex flava*, *Typha latifolia*, *Juncus buffonius*, *J. articulatus*, *Caltha palustris* and *Equisetum uliginosus*. Dryer sections of the mire are covered by plants typical of wet-
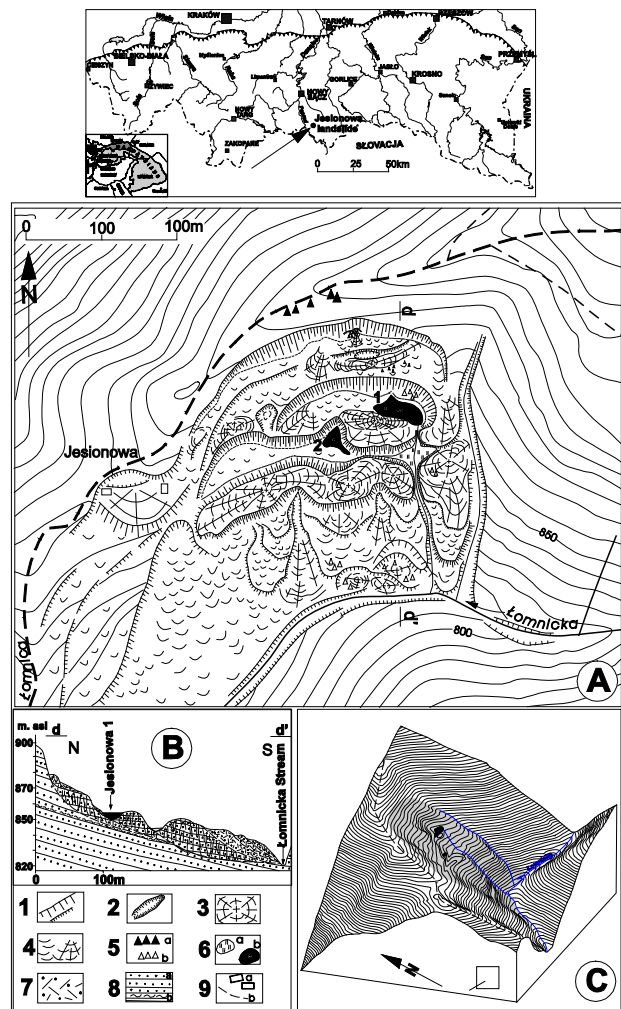
Fig. 2. *View on main peat bog (Jesionowa 1), with location of logs (position of peat bog on orthogonal projection of hypsometry in "z" value).*

ter parts combined with species, which are characteristic of the clearings used as mown meadows and/or pasturelands e.g. *Briza media*, *Potentilla erecta*, *Luzula luzuloides*, *Mentha arvensis*, *Lychnis flos-cuculi*, *Lathyrus* sp. and *Alchemilla* sp. The highest sectors of the fen (located close to the rocky slope) are overgrown by *Epipactis palustris* and *Mentha longifolia* which form a homogenous patch close to the place of the core collection. The additional element in the forest/fen ecotone is *Urtica dioica* which suggests higher nitrification of this part of the mire.

3. MATERIALS AND METHODS

Complex analyses (using also pollen and lithological analyses) were made on the core obtained from the deepest part of the fen.

Three cores were drilled and taken from the Jesionowa 1 peat bog using INSTORF sampler (Russian peat sampler), 6 cm and 8 cm in diameter. Loss on ignition analyses at a temperature 550ºC based on sequential heating of the samples in a muffle furnace for 4 h (Heiri *et al.*, 2001) were made for each 2.5 cm long section of the logs. Loss on ignition curves (percentage) were constructed for every log on the basis of these analyses (**Fig. 3**).

Peat sediments were analyzed by A. Obidowicz, who made also detailed identification of plant macrofossils.

Minerogenic sediments occurring within the peat bog were identified on the basis of Bouyoucos-Casagrande aerometric analyses modified by Prószyński (Mycielska-Dowgiałło and Rutkowski, 1995). Identification of these sediments was performed according to the Pettijohn classification (Pettijohn, 1975; Battaglia *et al.*, 2003) using Wentworth's scale of grain size (Wentworth, 1922). The granulometric indexes: mean grain size (Mz) and stand-

ard deviation (σ_1), were calculated for analysed mineral sediments (after Folk and Ward, 1957) (**Fig. 4**).

Conventional radiocarbon ages reported in the article were carried out using various materials in the Radiocarbon Laboratory of the Silesian University of Technology in Gliwice, Poland (laboratory code – Gd, GdS, GdC) and in the Radiocarbon Laboratory of the Ukrainian Academy of Sciences in Kiev (laboratory code – Ki) and in Radiocarbon Laboratory of AGH University of Sciences and Technology in Cracow (laboratory code – Kr). Calibration of the radiocarbon dates (expressed as cal yr BC/AD time intervals with probability 95%) was carried out using the calibration data set IntCal09 (Reimer *et al.*, 2009) and OxCal (version 4.1) calibration program (Bronk Ramsey, 2009). Generally, within the described peat bog 14 radiocarbon age determinations were carried out (**Fig. 3**; **Table 1** and **Table 2**).

A complete palynological analysis was conducted for the deepest log of the main Jesionowa 1 peat bog (**Fig. 5**; **Table 3**). Drilling of the profile from Jesionowa 1 was performed in September 2009. The core was sampled at intervals of 5 cm and subsequently 39 subsamples (1 cm³ volume) were selected and prepared using modified Erdtman acetolysis (Erdtman, 1943) with an addition of hydrofluoric acid (Faegri and Iversen, 1989). To every sample a weighed *Lycopodium* tablet was added for further calculations of pollen concentration (Stockmarr, 1971). More than 500 arboreal pollen grains per sample were counted at 400× and 1000× magnification.

The pollen taxa were determined with the assistance of the modern pollen slide collection of the Władysław Szafer Institute of Botany, Polish Academy of Sciences, and special keys and atlases (Faegri and Iversen, 1989; Reille, 1992; Beug, 2004). The identification of non-pollen palynomorphs (NPPs) was done by comparison with photographs and descriptions available in the literature on NPPs (e.g. Van Geel, 1978; Van Geel *et al.*, 1980, 2003 and 2007) (**Fig. 6**). The percentage values of individual taxa were calculated in the ratio to AP+NAP (arboreal pollen+non-arboreal pollen) excluding telmatophyte (with Cyperaceae) and limnophyte pollen as well as spores of Pteridophyta and Bryophyta and NPPs. The percentages of excluded taxa and NPPs were calculated in the ratio to AP+NAP+taxon. Pollen diagrams were plotted using POLPAL software (Walanus and Nalepka, 1999; Nalepka and Walanus, 2003). Additionally, a dendrogram of the similarity between pollen spectra plotted using the ConSLink method was prepared using a program within POLPAL software.

In the second peat bog (Jesionowa 2) situated within the lower part of the landslide zone (**Fig. 7**) one borehole log was drilled with the peat sampler INSTORF. The sediments of this peat bog (mainly silts with organic admixture) have not been studied in detail at this stage of research. One radiocarbon date was carried out for the bottom part (tree trunk) of this peat bog (**Table 2**).
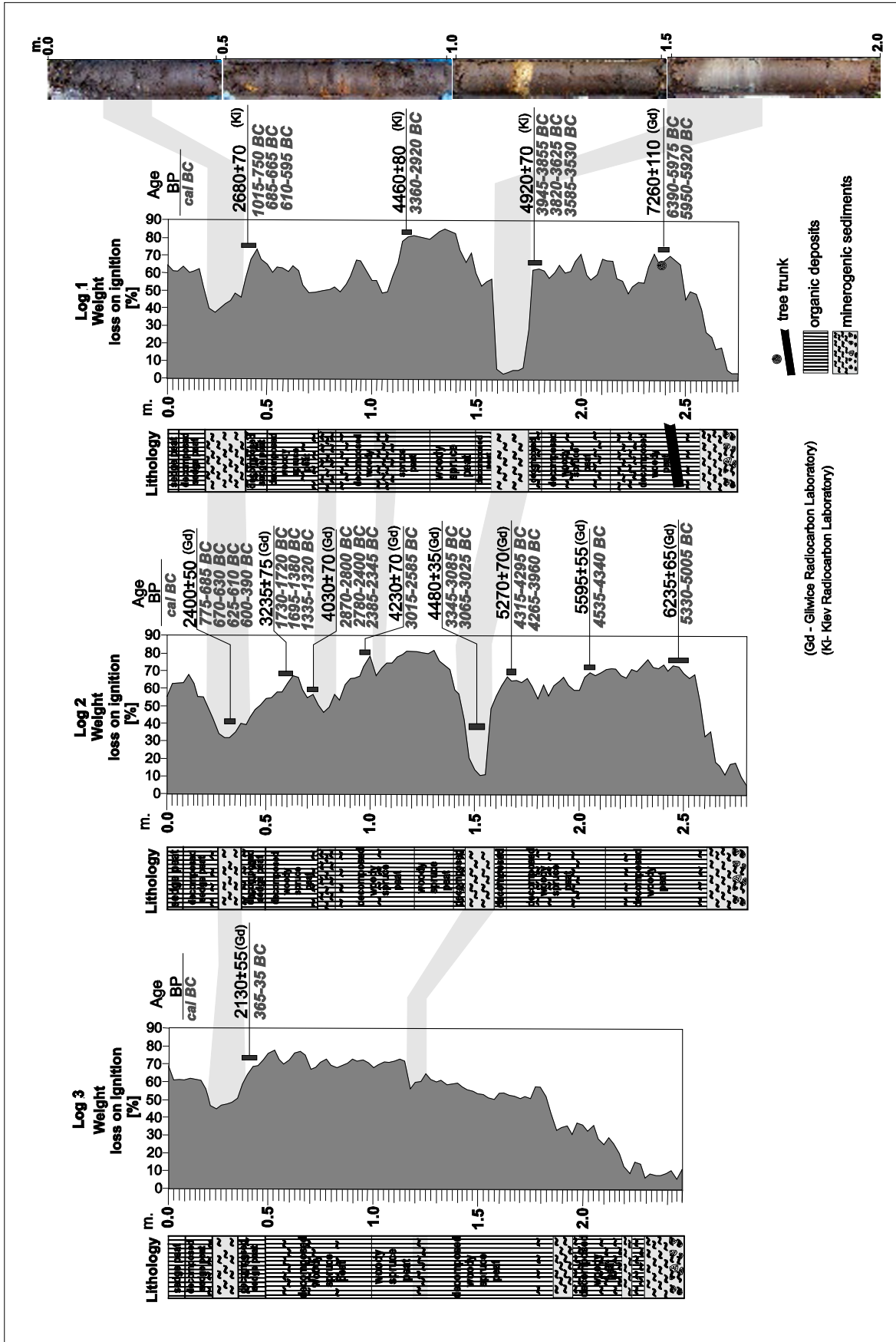
Fig. 3. *Lithological sequences of the Jesionowa 1 landslide peat bog with loss on ignition curves. Position of logs on Fig. 2 (signatures and calibrations of datings – see Table 1). On the photo – fragment of log, with minerogenic horizons.*

Table 1. *Radiocarbon dates of the Jesionowa 1 landslide's peat bog (calibration using OxCal computer program v. 4.1 (Bronk-Ramsey, 2009) on the basis of IntCal09 calibration curve (Reimer et al. 2009). The column "Calendar age 2σ" presents results of calibration of radiocarbon dates, whereas the column "Modelled calendar age 2σ" shows intervals connected with theses radiocarbon dates obtained as a result of age-depth model construction.*

Depth (cm)	Material	Lab. Code	Age ^{14}C (yr BP)	Calendar age 2σ (cal yr BC)	Modelled calendar age 2σ (cal yr BC)	Context of dating
Log 1						
38-45	Peat	Ki-13120	2680±70	1015-750 (94%) 685-665 (1%) 610-595 (0.4%)	not included in age-depth model	start of mineral horizon deposition
113-117	Peat	Ki-13121	4460±80	3360-2920 (95.4%)	not included in age-depth model	Illuvial horizon deposition
170-177	Peat with wood detritus	Ki-13119	4920±70	3945-3855 (9.9%) 3820-3625 (81.3%) 3585-3530 (4.2%)	not included in age-depth model	Thick mineral horizon within peat
230-235	Wood (tree trunk)	Gd-4957	7260±110	6390-5975 (93.5%) 5950-5920 (1.9%)	not included in age-depth model	Start of peat deposition
Log 2						
30-35	Peat with silt	GdC-327	2400±50	775-685 (16%) 670-630 (5.8%) 625-610 (1.2%) 600-390 (72.4%)	750-685 (9.8%) 670-635 (4.1%) 625-610 (0.7%) 600-385 (80.8%)	start of mineral horizon deposition
56-63	Wood fragment	GdS-1004	3235±75	1730-1720 (0.3%) 1695-1380 (94.4%) 1335-1320 (0.7%)	1745-1435 (95.4%)	Start of gradual delivery of mineral material to peat bog
70-75	peat	GdS-1007	4030±70	2870-2800 (9.9%) 2780-2400 (83.2%) 2385-2345 (2.3%)	2630-2285 (95.1%) 2250-2240 (0.3%)	End of mineral horizon sedimentation
95-100	peat	GdS-1005	4230±70	3015-2585 (95.4%)	3020-2695 (95.4%)	Start of gradual delivery of mineral material to peat bog
148-155	Wood fragment	GdS-990	4480±35	3345-3085 (89.2%) 3065-3025 (6.2%)	3345-3080 (86.7%) 3070-3025 (6.2%)	Thick mineral horizon deposition
165-170	peat	GdC-357	5270±70	4315-4295 (1.5%) 4265-3960 (93.9%)	4215-3945 (93.9%) 3855-3815 (1.5%)	Start of thick mineral horizon deposition
202.5-210	Peat	GdC-325	5595±55	4535-4340 (95.4%)	4610-4380 (95.4%)	Series of weak delivery of mineral material to peat bog
242.5-252.5	Peat with wood detritus	GdS-1008	6235±65	5330-5005 (95.4%)	5300-4955 (95.4%)	Start of peat deposition / formation of landslide depression
Log 3						
37.5-45	Peat with wood	GdC-359	2130±55	365-35 (95.4%)	not included in age-depth model	Start of mineral horizon sedimentation

Table 2. *Radiocarbon dates of the Jesionowa 2 landslide's peat bog (calibration using OxCal computer program v. 4.1 (Bronk-Ramsey, 2009) on the base of IntCal09 calibration curve (Reimer et al. 2009).*

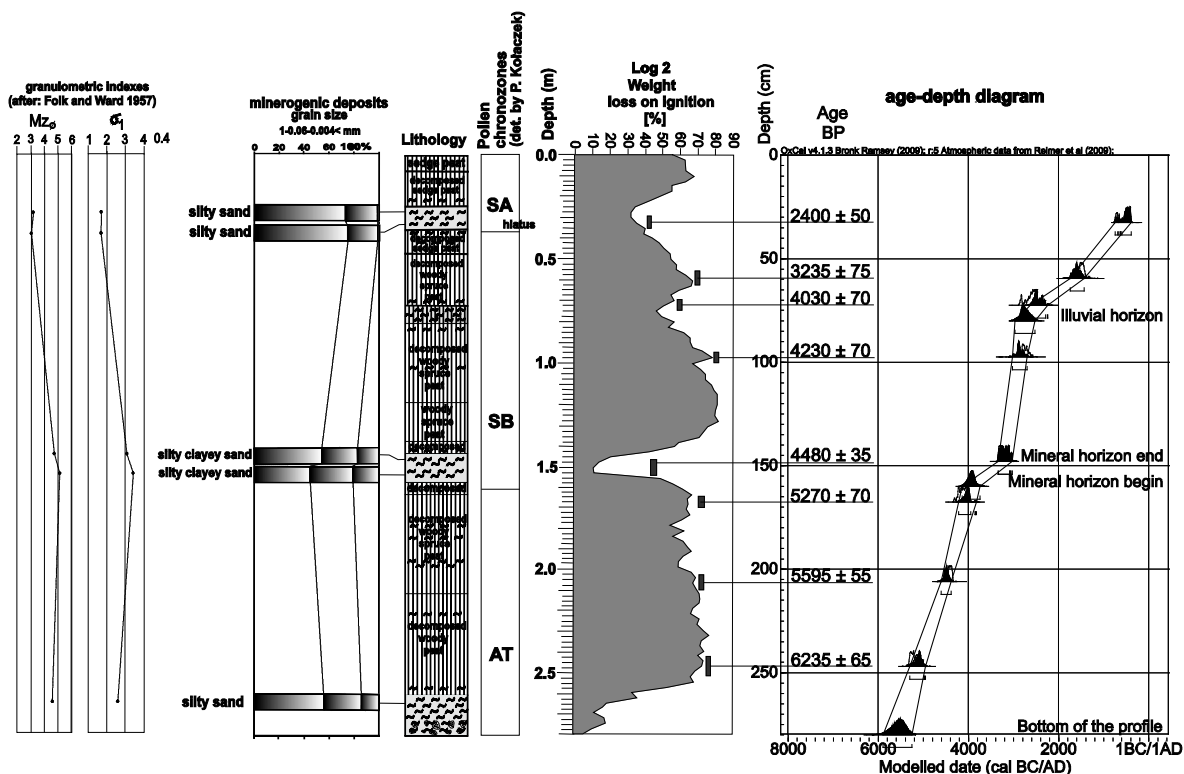| Depth (cm)	Material	Lab. Code	Age ^{14}C (yrs BP)	Calendar age 2σ (cal yr BC)	Context of datings
Log 1					
200	Wood (tree trunk)	Kr-150	4790±90	3765-3725 (1.8%) 3715-3365 (93.5%)	Formation of landslide depression

Fig. 4. *Lithostratigraphic sequence of the central log of Jesionowa 1 peat bog (see log 2 on Fig. 3) and age-depth model of deposits. Log showing types of peat and grain size (areometry) of minerogenic sediments, with granulometric sequences and loss on ignition curve. Explanation of symbols is given in Fig. 3.*

Table 3. *Description of Local Pollen Assemblages Zones of the Jesionowa 1 peat bog (det. by P. Kołaczek).*

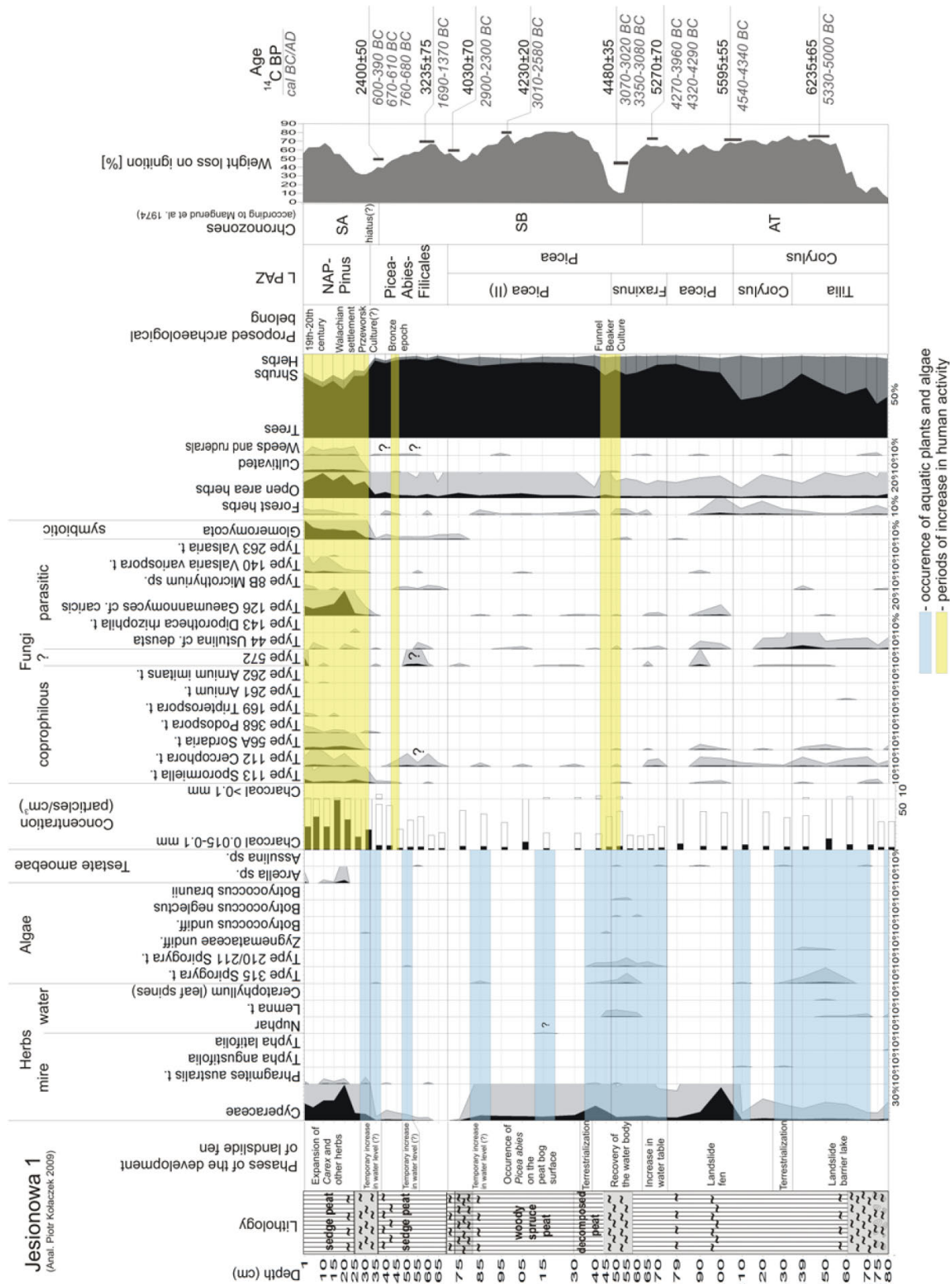| L PAZ	Depth (cm)	L PAZ description	Top boundary description
Jes1-1. *Corylus*	280-205	Domination of *Corylus avellana* (21-55.5%), the highest values of *Ulmus* (15%), *Tilia cordata t.* and *Acer*. Constant occurrence of limno- and telmatophytes with maximum of Type 315 *Spirogyra* t. (2%), continuous curve of Type 44 *Ustulina* cf. *deusta* (max. 4.5%) and Type 112 *Cercophora* t.	Decrease in *Corylus avellana*, increase in *Picea abies*
a *Tilia*	280-234.5	Maximum of *Tilia cordata t.* (14.5%) and *Ulmus*, domination of *Corylus avellana*.	
b *Corylus*	234.5-205	Domination of *Corylus avellana*, decrease in *Tilia cordata*	
Jes1-2. *Picea*	205-70	Domination of *Picea abies* (max. 72.5%), sharp decrease in *Corylus avellana* curve.	Increase in *Abies alba* and Filicales monolete
a *Picea*	234.5-174.5	Rapid increase in *Picea abies* curve, maximum and decrease in Cyperaceae.	
b *Fraxinus*	174.5-147.5	Fall in *Picea abies*, clear rise in *Fraxinus excelsior* curve (max. 31%), slight increase in *Corylus avellana*; single findings of Cerealia t. (at the depths 145 and 150 cm); appearance of limno- and telmatophytes pollen with algae in the upper part of the subzone.	
c *Picea*	147.5-70	Stable increase in *Picea abies* values to its maximum in profile (72.5%), decrease in *Fraxinus excelsior* and *Corylus avellana*.	
Jes1-3. *Picea-Abies*-Filicales	70-32.5	Although slight decline in *Picea abies* values still dominates, visible rise in *Abies alba* curve (max. 20.5%), constant increase in *Pinus sylvestris* t., rise in *Fagus sylvatica* and *Carpinus betulus*; The highest values of Filicales monolete in profile (max. 53%).	Sharp decrease in *Picea abies*; increase in NAP
Jes1-4. NAP-*Pinus*	32.5-1	Sharp decrease in *Picea abies* values, maximal values of *Pinus sylvestris* type (max. 33%), slight increase in *Alnus*, *Fagus sylvatica* (max. 8.5%), and *Juniperus*; the highest frequency of NAP, continuous curves of: Cerealia t. (max. 1.4%), *Secale cereale* (1.8%), *Plantago lanceolata* (2.7%), Cichorioidae, *Potentilla* t. (2.8%), *Rumex acetosa* t. (2.2%); visible rise in Cyperaceae (42.5%) and Bryales (29%); fall in Filicales monolete. Sharp increase in charcoal particles (0.0015-0.1 mm). Simultaneous rise in the number of coprophilous fungi (types: 56A, 112, 113 and 368), *Valsaria variospora* t. and Glomeromycota chlamydospores (max. 22.5%). Rapid increase in the charcoal particles (Ø 0.0015-0.1) concentration: 16000-61400 particles/cm^3	

Fig. 5. *Percentage pollen diagram of the Jesionowa 1 peat bog (log 2 in Fig. 3), with lithological column (explanation of symbols is given in Fig. 3) (Anal. P. Kołaczek).*

Fig. 6. *Percentage diagram of non-pollen palynomorphs, with lithology, and phases of minerogenic mire development of peat bog (including high water table in reservoir), and stages of human activity (Anal. P. Kołaczek).*

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Fig. 7. *A view of Jesionowa 2 landslide peat bog, with place of drilling.*

4. SEQUENCES OF DEPOSITS

Jesionowa 1

At the bottom part of the peat bog, within the interval 2.80-2.65 m, mineral sediment (coating the bottom of the depositional basin) occurs. The sediment is represented by silty sand (Mz=4.6φ), which is poorly sorted (σ₁=2.6) and high content of sand fraction in it is typical of high-energy sediment (*sensu* Kotarba, 1996), deposited due to intensive delivery of allochthonous material to the basin. Upon this sand, in the interval 2.65-1.70 m, highly decomposed woody peat occurs. In the lower part of the sequence peat contains numerous wood fragments of *Salix* sp. and rare partings of *Picea abies*. Above the depth of 2.1 m, woody spruce peat occurs with predominating spruce fragments (>40%) and in place with an admixture of Ericaceae and *Salix* sp. partings. It is covered by thin (7 cm) horizon of strongly decomposed peat (**Fig. 3**). The beginning of the peat accumulation was dated by radiocarbon at 6235±65 BP (5330-5005 cal BC). The radiocarbon date obtained from the bottom of peat layer in the second log is older: 7260±110 BP (6390-5975; 5950-5920 cal BP). This is caused by the fact that in the latter case a fragment of tree trunk thrown into the basin during the landslide formation (and lying at the bottom of depositional sequence) was dated. Therefore this date reflects the moment of the depression and landslide formation in the early stage of the Atlantic Phase (Margielewski, 1997a). It also indicates that, the peat accumulation began slightly later (**Fig. 3**, logs: 1 and 2). The palynological analysis confirms that, the lowermost peat layer within the sequence was accumulated during the Atlantic Phase (**Figs. 4** and **5**). At its top, the slight and cyclic supply of the mineral material to the peat bog is marked on the loss on ignition curves.

Upon woody peat, in the interval 1.6-1.4 m, horizon of homogenous mineral deposits is marked (in various logs the losses on ignition range 5-10%). It is represented by silty clayey sand (Mz=4.7-5.1 φ) (**Fig. 3**, logs 1-2) which is very poorly sorted (σ₁=3.1-3.4) with high content of sand fraction related to the high dynamics of the allochthonous material delivery to the basin. The radiocarbon dating of the bottom of this horizon (5270±70 BP and 4920±70 BP – see **Table 1**) indicate, that it was accumulated at the beginning of the Subboreal Phase.

Above the mineral horizon 5 cm thick strongly decomposed peat occurs. It is overlain by a layer of woody peat, reaching the depth of 0.50 m. The lower section of this layer (1.35-1.20 m) is represented by slightly decomposed woody spruce peat which contains up to 80% wood of *Picea abies*. Within the higher section of the layer (1.20-0.65 m) spruce peat is strongly decomposed (humification degree >45%) and contains up to 40% wood of *Picea abies* as well as fragments of *Sphagnum* S. *Cuspidata*, *Sphagnum* sp., *Thelypteris palustris* and, in places, wood partings of *Salix* sp. Within the uppermost section (0.65-0.50 m) woody peat is strongly decomposed and contains detritus of *Carex* sp. and wood of *Larix* sp., *Alnus* sp., *Picea abies*.

Within the layer of woody peat, an illuvial horizon is marked in the loss on ignition curve by gradual decrease in losses from 80% to 40% (**Fig. 3**, log 2). Its bottom was dated at 4230±70 BP (3015-2585 cal BC), while top at 4030±70 BP (approximately 2870-2345 cal BC) (in the other log, the date of the bottom of analogous horizon is older: 4460 ±80 BP (3360-2920 cal BC).

The top part of peat (the last 0.50 m of the sequence) is formed of strongly decomposed sedge peat, covered by a thin layer of sedge peat which did not undergo humification. It contains up to 60% fragments of *Carex* sp., as well as some detritus of *Equisetum palustre*. Within this layer, an illuvial horizon occurs, that contains in its middle part a mineral horizon ca. 0.15 m thick (**Fig. 3**). The granulometric composition of this mineral sediment (analysis of fresh, unheated sample as well as a sample after heating to the temperature of 550°C) indicates that the minerogenic horizon is formed of silty sand (Mz=3.1-3.0φ), typical of high-energy sediments. In various logs the supply of allochtonous material to the basin was dated at 2400±50 BP (approx. 775-390 cal BC); 2680±70 BP (approx. 1015-595 cal BC – see **Table 1**) and 2130±55 BP (365-35 cal BC). The early Subatlantic age of this illuvial horizon is indicated also by palynological analysis which confirms the occurrence of hiatus in its bottom part (**Figs. 4** and **5**).

Jesionowa 2

At the bottom of the extensive trench connected with the youngest stage of the landslide zone rejuvenation a small (ca. 40 m in diameter) depression filled with organic sediments 1.8 m thick is situated. Within the lowermost part of its sequence (peaty silt) a tree trunk was found. The wood sample was dated by radiocarbon at 4790±90 BP (3765-3725; 3715-3365 cal BC) (Margielewski, 1997a).

5. PALYNOLOGICAL ANALYSIS

The pollen diagram was divided into local pollen assemblage zones (L PAZ) according to Birks (1979, 1986) and Janczyk-Kopikowa (1987) (**Fig. 5**). The diagram was also divided into chronozones proposed by Mangerud *et al.* (1974). Numerical analysis ConSLink confirmed spectra grouping into L PAZs, as well as it confirmed division of some of them into subzones. The results of palynological analysis are presented in **Table 3**, **Figs. 5** and **6**. Time intervals of the pollen assemblage zones were estimated using the age-depth model discussed in a later chapter.

Local vegetation development and human activity

Jes1-1. L PAZ Corylus. (from approx. 5900-5300 cal BC to 4600-4365 cal BC)

Hazel (*Corylus avellana*) thickets – a dominating community in the vicinity of the site – coexisted with patches of spruce forest. Single alder (*Alnus*) and ash (*Fraxinus excelsior*) trees surrounded the water body which originated in the landslide depression. The lower part of the mountains was overgrown by mixed forest with elm (*Ulmus* sp.), maple (*Acer* sp.) and lime (*Tilia cordata*). The last taxon occurrence declined in the Jes1-1b subzone. Domination of hazel and broadleaved trees during the climate optimum is stressed by the highest frequency of *Ustulina* cf. *deusta* spores – parasitic/saprophytic fungus whose optimal temperature for ascospores germination is 25-30°C (Van Geel and Andersen, 1988). The surface of the landslide barrier lake was overgrown by Lemnaceae (*Lemna* t.). Its subsequent shallowing favoured algae blooming which is demonstrated by the increase in *Spirogyra* t. (type 315) and the occurrence of other unidentified zygnemataceous zygospores (**Fig. 6**).

Jes1-2. L PAZ Picea. (from 4600-4365 cal BC to 2520-2045 cal BC)

This zone is divided into 3 subzones. Cooler and wetter climatic conditions in the Jes1-2a subzone favoured the expansion of spruce (*Picea abies*) which prevented hazel from growing in the shady understorey and replaced it from most of its habitats. This phenomenon started ~4540-4340 cal BC. In the Jes1-2a subzone the landslide barrier lake developed into fen overgrown mostly by Cyperaceae, but temporary higher water level on its surface was demonstrated by single findings of *Spirogyra* zygospores.

In the Jes1-2b subzone higher humidity attributed to the Atlantic/Subboreal Phases transition caused the expansion of ash (*Fraxinus excelsior*) in the vicinity of the site. This species can grow well under conditions of high surface moisture and high groundwater level and is tolerant of seasonal inundation and floods (Faliński and Pawlaczyk, 1995). Low competitiveness of ash, which is

compensated by the production of large quantities of seedlings capable of rapid growth (Ellenberg, 1996), as well as the fact of the relatively low pollen productivity of this taxon (comp. Pohl, 1937 following Tobolski and Nalepka, 2004) suggest considerable disappearance of spruce (more competitive taxon) in the closest vicinity of the site. What is more, the percentage values of ash pollen significantly (up to ~10 times) exceed its patterns presented in the isopollen maps (comp. Tobolski and Nalepka, 2004). The constant occurrence of Lemnaceae, as well as the presence of *Spirogyra* zygospores (type 210/211 and 315) point to the increase in water level and recovery of the water body. This filamentous algae genus is related to shallow lakes (Kadłubowska, 1972).

The Jes1-2c subzone presents the subsequent expansion of spruce, which rapidly replaced ash from most of its sites. Lowering of the water level caused fen regeneration and enabled the expansion of spruce on its surface. On the boundary between the Jes-1b and c subzones single Cerealia t. pollen grains were found. This fact was probably the effect of the agricultural activity of the people of Funnel Beaker Culture, whose occurrence in the Western Carpathian Mountains is dated to 3700-1900 BC (Valde-Nowak, 1988 and 2001; Kadrow, 2001). This phenomenon was not correlated with a visible decrease in AP (arboreal pollen) values and increase in the occurrence of synanthropic taxa, so then it might have been the effect of distant transport from lower parts of the mountains and/or human activity in the surrounding of mire was not significant.

Jes1-3. L PAZ Picea-Abies-Filicales (from 2520-2045 cal BC to approx. 760-390 cal BC)

Expanding fir (*Abies alba*) and beech (*Fagus sylvatica*), which began replacing spruce from some of its habitats, started to form beech forest typical for lower mountain forest belt. Ferns dominated in those woodlands groundcover. In lower parts of the mountains hornbeam (*Carpinus betulus*) slightly broadened its range. The higher values of coprophilous fungi spores from the *Cercophora* t. might suggest temporal grazing activities, whereas finding a pollen grain of *Linum usitatissimum* with the simultaneous presence of *Polygonum aviculare* at the depth of 45 cm suggests agriculture activity in the vicinity of the site between 1690 and 390 BC. These findings might be traces of the settlements of people of the Lusatian Culture (the Bronze epoch and early Iron epoch) spread in the Carpathians between 1400-300 BC (Kozłowski and Kaczanowski, 1998; Valde-Nowak, 2000). The temporal higher water level on its surface was demonstrated by single findings of *Spirogyra* zygospores (**Fig. 6**).

Jes1-4. L PAZ (from approx. 760-390 cal BC to 2000 cal AD)

This zone reflects visible deforestation where previously dominant spruce was replaced by fir and beech in most of the sites (development of lower mountain forest). An increase in *Pinus sylvestris* t. values was probably affected by distant transport. Open area communities were exploited as pastures. This is visible in the rise in Poaceae undiff., *Potentilla* t., *Rumex acetosa* t. pollen and coprophilous fungi (*Cercophora* t., *Sordaria* t., *Sporormiella* t. and *Podospora* t.) values (**Figs. 5** and **6**). Those areas might have been also used as mown meadows and this contributed to the spread of *Plantago lanceolata*. In lower parts of the mountains (may be also in the vicinity) cultivation of cereals (Cerealia t. and *Secale cereale*) supplemented by *Fagopyrum* and *Linum usitatissimum* was developed (**Fig. 5**). High amounts of charcoal particles in size between 0.0015 and 0.1 mm suggest fires whereas low frequency of particles above 0.1 mm related to local fires, according to Toney and Anderson (2006) points to a distant transport of those particles. However, the expansion of *Pteridium aquilinum* may suggest the occurrence of local fires because soil acidifcation after fires favours the germination of its spores, so that young plants appear in a great number on soils fertilized by ash (Page, 1986; Oberdorfer, 1990). These changes may have been triggered by the peoples of the Przeworsk Culture (ca. 200 BC-450 AD) (*see*: Madyda-Legutko, 1996; Kozłowski and Kaczanowski, 1998), and was continued later, during Slavonic settlements spread since 6th Century, and Valachian colonization of the Carpathians who migrated from the south in the 15th-16th century (Godłowski and Kozłowski, 1979; Pietrzak, 2002). Even though radiocarbon data would suggest continuous settlement from the beginning of the Subatlantic Period and pollen spectra suggest high level of deforestation since then, archaeological data does not confirm this fact and point the demographical crisis during the Migration Period, which usually should have been recorded in pollen spectra. The continuous occurrence of charcoal particles in the Subatlantic deposits was rather caused by fire made by Valachian settlers or there is sediment discontinuity between the period of the Przeworsk Culture activity and the period of the Valachian domination in the region. Both groups of people used fire to obtain new area for pastureland. Taking into consideration the *Ambrosia artemisiifolia* type appearance, which according to Makra *et al*. (2005) reflects the expansion of the American species of ragweed in the southern Europe in the 19th century, the age of the uppermost 10-15 cm of this zone may be approximated to the 19th-20th century.

Species from the Cyperaceae family along with other herb taxa spread on the fen surface in this zone. These processes might be correlated with the occurrence of chlamydospores of symbiotic fungi from the Glomeromycota class. Some authors link their presence in the lacustrine sediments with intensification of erosion (Van Geel, 2001).

6. AGE-DEPTH MODEL FOR JESIONOWA 1 BASED ON RADIOCARBON DATES

Table 1 presents radiocarbon dates of samples collected from the Jesionowa 1 landslide's peat bog. A total number of dated samples is 13, but they were taken from three separate peat profiles (see **Fig. 3**) called Log 1 (4 samples), Log 2 (8 samples) and Log 3 (1 sample). Then, in order to avoid any problems connected with a correlation of depths in different profiles, it was decided to construct an age-depth model for the peat bog based only on radiocarbon dates from Log 2. The age-depth model has been constructed using OxCal 4.1 function *P_Sequence*, which is one of the new functions of the OxCal program dedicated to an age-depth model building (Bronk Ramsey, 2008). The model calculated by this function assumes that a deposition rate was not constant, but it was undergoing random fluctuations. The use of *P_Sequence* function requires estimation of the k parameter, which describes a magnitude of the fluctuations from a constant deposition rate. At the age-depth model for Jesionowa 1 we assumed that the k parameter is equal to 1 cm^{-1} which is a mean value from a range of reasonable values of k parameter according to Bronk Ramsey suggestions (Bronk Ramsey, 2008; posts on oxcal@googlegroups.com). Such value of k parameter was also suggested by results of tests made by one of the authors (Hajdas and Michczyński, 2010; Michczyński, 2011).

As it was described above, there are three distinct mineral or illuvial horizons in the peat profile Jesionowa 1 (**Fig. 3**). They are connected with phases, when climate humidity increases and extreme hydrometeorological events are much more frequent. Therefore in the age-depth model for Jesionowa 1 we made an assumption that sudden and significant changes of the deposition rate might have taken place for these phases. In order to include this assumption in our age-depth model we use *Boundary* command of OxCal 4.1 program (Bronk Ramsey, 2008). Because the uppermost sample included in the age-depth model (GdC-327, depth 30-35 cm) is located a bit below the upper mineral (illuvial) horizon, only two of three horizons are taken into consideration. In the future we are going to supplement our age-depth model by including additional radiocarbon dates of a sample (or samples) collected from the uppermost part of the peat profile. More details concerning the construction of the Jesionowa 1 age-depth model are presented in another publication (Michczyński, 2011).

The results of the age-depth model of Jesionowa 1 peat profile are presented in **Fig. 4** (right side of the graph – the age-depth relation) and **Table 1** (95.4% - 2σ – confidence intervals of radiocarbon dates included in the model). An overall agreement index of the model

amounts to 71.8%, which is more than a suggested critical value (60%), which allows to accept a model as reliable. It means that the assumptions of our model are in concordance with radiocarbon dates. It is clearly visible, that there are significant changes of a deposition rate connected with phases when intensive delivery of minerogenic material was observed (see **Fig. 4**). At the lower part of the profile, which was deposited at the Atlantic Phase, the deposition rate is equal ca. 0.73 mm/year. At a depth of about 150 cm (beginning of the Subboreal Phase), above the mineral horizon, the deposition rate increases substantially and reaches a value of ca. 1.5 mm/year. This deposition rate remains unchanged till the middle of the Subboreal Phase and decreases above the next larger delivery of mineral material which appears at the depth of about 80 cm. Beyond this illuvial horizon the deposition rate is equal to only about 0.21 mm/year. During the Subboreal Phase we have observed two different rates of the deposition process – very high rate in the early Subboreal and low rate in the middle and late Subboreal.

The age-depth model by its extension to a depth related to the bottom of the investigated peat profile allows us to estimate an age of the formation of landslide depression (see **Fig. 4**). It gives us 95% (2σ) confidence interval, which comes to 5890-5250 cal BC. This interval is still younger than the age of the wood sample from the Log 1 peat profile (Gd-4957: 6390-5975 cal BC and 5950-5920 cal BC), but is close to it. This result supports our explanation of difference between dates from bottom parts of Log 1 and Log 2 (see **Table 1**).

7. DEPOSITIONAL RESPONSE ON PALAEOENVIRONMENTAL CHANGES

The radiocarbon dating as well as the palynological analysis indicate that the landslide depression was formed in the early stage of the Atlantic Phase. The tree trunk buried in the sediments coating the bottom of the depression dated at approximately 6390-5920 cal BC (Gd-4957) was undoubtedly connected with the destruction of forest by the landslide transforming slope of the Łomnicka stream valley (Margielewski, 1997b). The development of the landslide was related to the increase in climate humidity. The intensification of hydrometeorological phenomena generated formation of numerous landslides in the area of Polish Carpathians (Margielewski, 2006a). Common climate changes during this time (cooling and humidity increase) in Europe, caused a growth of the fluvial activity of Upper Vistula River (Starkel *et al.*, 1996), as well as a rise of water table in the subalpine lakes (Magny, 1993 and 2004). The climate cooling caused advances of Alpine glaciers (Frosnitz glacial advance – Bortenschlager, 1982) (**Fig. 8**). Intensification of rains (downpours, long-lasting rains) was recorded in peat bog deposits as delivery of mineral material. The mineral layers underlying peat are typical of high-energy
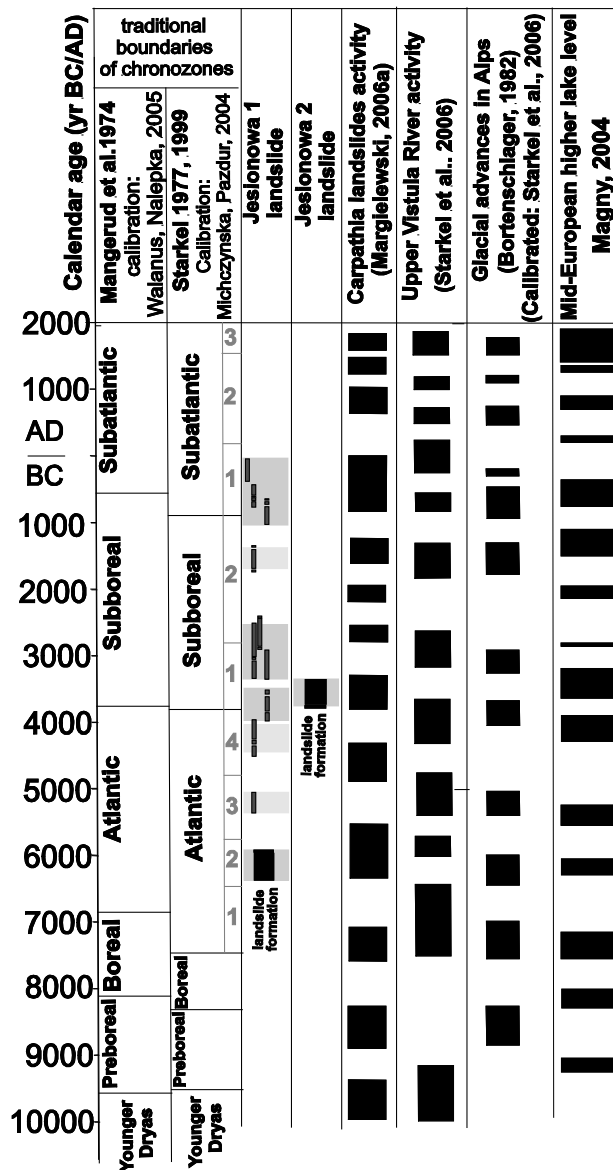

Fig. 8. *Correlation of signals recorded in Jesionowa peat bog, with global climatic changes (after various authors – see at the picture).*

sediments, the sand fraction predominates in these sediments (**Fig. 3**).

Organic accumulation (woody peat) within the depression commenced with the delay reaching about 1000 years. Its beginning was dated (GdS-1008) at 5330-5005 cal BC (**Fig. 3**). The delay of the peat accumulation cannot be explained by long-lasting coating of the depression bottom, enabling the formation and existence of the permanent water basin which was successively overgrown by peat-forming plants. Palynological analysis indicates that a permanent water body existed there just since the moment of the depression formation (**Figs. 5** and **6**). Start of the peat accumulation coincided with one of the climate humidity increase in the middle stage of the Atlantic

Phase, during which the growth of fluvial activity of the Upper Vistula River was recorded (Starkel *et al*., 1996 and 2006) as well as a rise in water table in the subalpine lakes was observed (Magny, 1993 and 2004). Probably the rise in the water table in the basin could have triggered the organic material accumulation: on the palynological diagram the gradual increase in *Lemna* type and algae (*Spirogyra* t.) content is observed (**Figs. 5** and **6**).

The peat from the lowermost, Atlantic section of the sequence is strongly decomposed, however, the content of mineral material is relatively low (reaching ca. 30%) (**Figs. 3** and **4**). This indicates limited delivery of mineral material in that time. Strong humification of peat can also suggest a relatively long-lasting drying of the peat bog after the end of the humid climate phase (Żurek and Pazdur, 1999; Żurek *et al*., 2002). Temporal, slight supply of mineral material to the peat bog is marked at the decline of the Atlantic Phase. Small regressions (reaching 10%) visible on the loss on ignition curves of various logs, suggest repetition of the supplies connected with heavy rains. At that time slightly decomposed woody spruce peat was accumulated. Palynological analysis (of sporomorphs and palynomorphs) indicates a rise in the water table of the lake, caused by a strong increase in climate humidity during the transition of the Atlantic and Subboreal Phases. Relatively high frequency of duckweed (*Lemna*) pollen and the reed (*Phragmites australis*) pollen occurrence is then observed (**Figs. 5** and **6**). At the beginning of the Subboreal Phase intensive delivery of high-energy sediment to the basin generated formation of mineral horizon (silty clayey sand) about 0.2 m thick, which was dated at approx. 4315-3960 cal BC (bottom – GdC-357 – see **Table 1**) as well as approx. 3345-3025 cal BC (middle part – GdS-990). Significant content of sand fraction in this sediment proves high intensity of the surface flow and slopewash (**Fig. 4**).

The rejuvenation of the lower segments of the landslide zone is related to the same climate humidity increase. At that time extensive trench with depression filled with minerogenic mire formed (Jesionowa 2 – see **Figs. 1A-2** and **7**). Significant climate cooling and moistening during the transition of the Atlantic and Subboreal Phases was of common character. It generated not only a significant growth of fluvial activity of the Upper Vistula River (Starkel *et al*., 1996 and 2006), but a water table rise in Central European lakes as well (Magny, 2004). Extreme hydrometeorological phenomena caused intensification of mass movements in the Carpathians (Alexandrowicz, 1996 and 1997; Starkel, 1997; Margielewski, 2006a; Pánek *et al*., 2010), Alps and Dolomites (Dapples *et al*., 2002; Soldati *et al*., 2004) as well as in the Scottish Upland (Ballantyne, 2002). In the Alps the climate cooling stimulated the advance of glaciers (Rotmoos/Piora Phase) (Bortenschlager, 1982) (**Fig. 8**). In the area surrounding the peat bog this cooling caused, typical for such climate changes, spruce regression which is visible on the palynological diagram (**Fig. 5**).

The palynological analysis indicates human activity on landslide flats during this climate cooling and moistening. It is proved by cereal pollen as well as pollen of *Urtica* typical of synantropic communities. Deforestation in some places is marked by a slight drop of tree pollen concentration (**Figs. 5** and **6**). This human activity episode (connected with the cultivation of cereals) was probably related to the colonization of the Funnel Beaker Culture, spreading over the Carpathians in that time. About 3000 BC, an intensive migration of this culture people from over-populated Małopolska Upland toward mountains took place (Kruk, 1993; Kruk and Milisauskas, 1999; Kadrow, 2001). In turn, intensive floods related to the early Subboreal increase in climate humidity, forced migration of this population to higher, dry parts of mountains (Valde-Nowak, 2001; Margielewski *et al*., 2010b). Flat areas of stabilized landslides, characterized by fertile soils and abounding with water were attractive places for settlement (Margielewski, 2000; 2006a; Margielewski *et al*., 2010b). The next delivery of allochtonous material to the peat bog producing the illuvial horizon (relative drop of loss on ignition curve reaches maximum 25%), took place before 4030±70 BP (approx. 2870-2345 cal BC – see **Table 1**) and has bipartite character (**Fig. 3,** logs: 1 and 2). The older episode, distinctly marked in the central log (**Fig. 3**, log 1) occurred after 4.46 ka BP, while the younger one took place between ages: 4230±70 BP (3015-2585 cal BC) and 4030±70 BP (approx. 2870-2345 cal BC) (**Fig. 3**, log 2). The palynological analysis indicates temporal water table rise of the lake during deposition of the older illuvial horizon (**Fig. 6**). This can prove the temporal increase in climate humidity in that time. Since the growth of fluvial activity of the Upper Vistula River was recorded about 4.5-4.1 ka BP (Starkel *et al.,* 1996), two episodes of allochthonous material delivery to the Jesionowa peat bog can be correlated with this stage of humidity increase of the Subboreal Phase. In this period the phase of mass movement intensification was recorded in Polish Carpathians (Alexandrowicz, 1997; Margielewski, 1998, 2006a) as well as in the Alps (Dapples *et al*., 2002; Soldati *et al*., 2004). In the Tatra Mts. debris flows took place, which are recorded in the lacustrine sediments (Baumgart-Kotarba and Kotarba, 1993).

The youngest stage of mineral material delivery to the peat bog is distinctly marked on the loss on ignition curves of all logs at the depth of 0.5 m as drop of losses reaching 40%. In various logs this supply is gradual (**Fig. 3**, logs 2-3) or more immediate (**Fig. 3** – log 1) and is finalized with deposition of thin (maximum 20 cm thick) mineral horizon, represented by silty sand – high-energy sediment (**Fig. 4**). Gradual delivery of mineral material to the peat bog is marked in one of the logs as early as the decline of the Subboreal Phase (date: 3235±75 BP; approx.: 1730-1320 cal BC – see **Table 1**), however, deposition of mineral horizon took place at the beginning of the Subatlantic Phase. This is proved by

radiocarbon age determinations of this horizon bottom, pretty consistent in every logs (2130±55; 2400±50; 2680±70 BP – **Fig. 3** and **Table 1**), and confirmed by palynological analysis which also indicates, that at the bottom of mineral horizon a depositional gap (hiatus) occurs (**Fig. 5**). Moreover, this analysis confirms the existence of a water body during deposition of the mineral horizon (**Fig. 6**). This fact enables to state that hiatus was not a result of a lack of deposition related to the peat bog desiccation (which was usually suggested – *see* e.g. Żurek and Pazdur, 1999), but to erosional removal of a part of the sediments during the early Subatlantic increase in climate humidity. Such hiatuses, developed due to erosion are common in landslide peat bogs (Margielewski and Zernitskaya, 2003; Margielewski, 2006a; Margielewski *et al.*, 2003 and 2010a).

Deposition of mineral horizon in the Jesionowa peat bog is undoubtedly connected with a particularly significant increase in climate humidity at the beginning of the Subatlantic Phase (**Fig. 7**) (Starkel, 1990). Climate moistening and cooling in this period caused the phase of distinct growth of fluvial activity of the Upper Vistula River recorded ca. 2350-1800 BP (Klimek, 1988; Starkel *et al.*, 1996; Starkel, 2002). A rise in water table in subalpine lakes (Magny, 1993 and 2004) and in the northern part of Polish territory (Ralska-Jasiewiczowa, 1989) was also observed. Significant escalation of gravitational mass movements in the Carpathians (Alexandrowicz, 1996; Starkel, 1997; Margielewski, 1998 and 2006a) as well as in other mountain ranges in Europe (Ballantyne, 2002; Dapples *et al.*, 2002; Soldati *et al.*, 2004) is also attributed to this period. Intensive deposition of high-energy material in lakes of the Tatra Mts. was recorded, too (Baumgart-Kotarba and Kotarba, 1993). As a result of the climate cooling, the Alpine glaciers' advance was escalated (Goeschener 1 Phase – Bortenschlager, 1982; Hormes *et al.*, 2001).

Contemporary with the beginning of the mineral horizon deposition, a particularly intensive human activity is recorded on the palynological diagram. This is marked by the appearance of continuous curves of cultivated plants, as cereals (*Secale cereale*) as well as synantropic plants (*Plantago lanceolata, Rumex acetosa*) (**Fig. 5**). Also charcoal, abundant in the sequence, indicates intensive human activity. Character of cultivated plants and sediments proves agricultural settlement of the Przeworsk Culture (ca. 200 cal BC-450 cal AD) commonly using the forest burnout technique for the cultivation of cereals (preferably rye *Secale cereale*) (Madyda-Legutko, 1996) (**Figs. 3** and **6**). Consequently, particularly high-energy character of sediments was influenced by both climatic and anthropogenic factors seen as evidence of burnout and intensive cultivation on the landslide flats (Margielewski, 2000 and 2006a; Margielewski *et al.*, 2010a, b).

Regarding the occurrence of hiatus, intensive human activity could have taken place earlier, during the Celtic expansion and the La Tène Culture connected with it (Madyda-Legutko, 1996), or even with the decline of the Lusitian Culture, spread in the Carpathians between 1400-300 cal BC (Kozłowski and Kaczanowski, 1998; Valde-Nowak, 2000). Pollen of cultivated plants (*Linum usitatissimum*), weeds (*Polygonum aviculare*) and plants preferring open habitats (*Rumex, Plantago lanceolata*) also occurs below the hiatus (**Figs. 5** and **6**). This phase of human activity (which is confirmed also by other anthropopression factors – **Fig. 6**), could also have influenced (apart from climate) the accelerated delivery of mineral material to the peat bog. It was commenced at the declining part of the Subboreal Phase and finalized with deposition of mineral horizon (**Fig. 3**, log. 2).

Intensive human activity has been continued till nowadays, both during the Slavonic expansion (since the 6th century) and subsequent Valachian colonization in the Carpathians (**Fig. 6**).

8. CONCLUSIONS

In the depositional sequence of the Jesionowa landslide peat bog the records of the palaeoenvironmental changes in this part of Carpathians during the Meso- and Neoholocene has been preserved. In particular, distinct and commonly occurring climate changes (cooling and increase in humidity) at the beginning of the Subboreal and Subatlantic Phases were recorded as inserts (horizons) of mineral sediments in peat sequence, which were connected with the delivery of allochthonous material to depositional basin. During the older climate moistening the rejuvenation of the landslide zone took place, with the subsequent generation of mass movement. Within the lower parts of the landslide the trench dated at the beginning of the Subboreal Phase, was formed. Humans played an essential role in the character and distinctness of the records of depositional changes in peat sequence. Humans used this flat and water abounding area within the landslide zone since the prehistoric time: especially in the time of expansion (on the Carpathians) of the Funnel Beaker Culture (the beginning of the Subboreal Phase) and colonization of the Przeworsk Culture (approximately the beginning of the Subatlantic Phase) and/or the Valachian settlement. The climatic changes (humidity increase) during the older stage of the Subboreal Phase (4.5-4.1 ka BP) are less distinct and less uniform (different in various logs) marked in the sequence.

The pollen profile from Jesionowa presents the succession from the beginning of the Atlantic chronozone up to the modern period. The vicinity of the site in the Atlantic period was dominated by *Corylus avellana* thickets. About 4600-4360 cal BC spruce (*Picea excelsa*) expanded rapidly and displaced hazel from most of its habitats. An increase in climate humidity related to the transition between the Atlantic and the Subboreal Period, as well as to the beginning of the Subboreal Period, caused the expansion of ash (*Fraxinus excelsior*) in the surroundings

of the site. The second expansion of spruce started about 3350-3020 cal BC and this species dominated in woodlands up until 2520-2040 cal BC when the fir (*Abies alba*) and subsequently beech (*Fagus sylva*tica) started to spread. Pollen spectra from the Subatlanic Period reflect strong deforestation, simultaneous with the development of pasture and agriculture.

The study conducted at the Jesionowa site proves that landslide peat bogs are sensitive indicators of palaeoenvironmental changes, both climatic and related to human activity. The research significantly expands the knowledge about the palaeoenvironmental changes in this part of the Carpathians.

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