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MULTI-PROXY ANALYSES OF SUBATLANTIC PEAT BOG SEDIMENTS FROM THE WESTERN TATRA MTS. (POLAND)

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Abstract: The main aim of our study was to analyse local slope processes, vegetation changes and human impact during the last millennium in the Pyszniańska Valley (Western Tatra Mts.) on the basis of palynological and lithological analyses combined with radiocarbon datings from a small peat bog in the Pyszniańska Valley. These data were supplemented by a lithological analysis of cirque bottom-slope deposits from a depression within the Pyszniański cirque. Sedimentation at the site probably began in the 14th-15th century, which is suggested by pollen analysis. The sediments are dominated by fine grain material (sands and silts) transported by surface and linear slope washing with the interbedding of distinctive layers of coarse clastic material, which are indicators of high-energy geomorphic processes. The first phases of vegetation development (TZNP-1,2 zones) are characterized by visible deforestation caused by fire clearances and/or development of mining and metallurgical centers. The high number of hazel (*Corylus avellana*) pollen grains is probably the effect of the redeposition of sediments originating in the Boreal or Atlantic period from the higher elevation of the valley. In the TZNP-3 zone the Pyszniańska Valley was affected by a most catastrophic high-energy geomorphic event, recorded as a continuous layer of coarse material. The upper phase (TZNP-4a subzone) signifies pasture development based on animal husbandry. Regular determination of *Ambrosia artemisifolia* type pollen combined with radiocarbon data points to the 19th-20th century. The TZNP-4b subzone reflects the succession of *Carex rostrata* on the peat bog and reforestation in the vicinity of the site caused by the establishment of the Tatra National Park in 1954. The cirque floor sediments consist of massive, 1.65 m thick, very coarse layers of gravels and boulders, which represent dynamic sedimentation caused by the activity of high magnitude slope processes (debris flows).

Key words: Tatra Mountains, Subatlantic period, slope processes, human impact, palynological analysis, granulometry

1. Introduction

The pioneering research on Western Tatras sediments was performed by J. Dyakowska (1932), who analyzed a peat bog core from a site in the vicinity of the Smreczyński Staw Lake (the Kościeliska Valley) and the Molkówka glade (the mouth of the Chochołowska Valley). Further works at the Molkowka site provided more detailed pollen profiles, which indicated continuous Younger Dryas - Holocene sedimentation (Koperowa 1962; Obidowicz, 1996). Unfortunately, the chronology of these sites is based on pollen stratigraphy. Other research on lacustrine sediments from the Smreczyński Staw Lake in the Koscieliska Valley revealed organic Holocene layers (Skierski, 1984). A new set of data on post-glacial relief transformation was provided by the research on slope-derived sediments occurring in a high-elevated terrain depression within glacial cirque bottoms (Libelt, 1988; 1990; 1994; Kaszowski et al., 1988; Libelt and Obidowicz, 1994). A fossil peat bog in the Western Tatra Mountains (1545 m a.s.l.) at the Siwe Sady site (the upper Kościeliska Valley) provided an opportunity to reconstruct Holocene changes in the dynamics of slope processes and vegetation changes near the timberline (Libelt and Obidowicz, 1994).

The first clearings (glades) in the Tatra Mountains were effected by Walachian settlers, who migrated from the Balkans and South Carpathians in the 15th-16th century. As time went by, they assimi-

lated into the local community and used alpine meadows and glades in the Tatras as natural pastures during summer. In the 15th century mining rapidly developed and the first mine was probably located under Ornak, where copper and silver was mined during the reign of Sigismund I (Kutaś, 2005). In 1520 a pit shaft was dug in a place called 'Na Kunsztach'. In 1765 there was more mining activity – a mine called 'Czarne okno' under Ornak - in the 'Pod Banie' gully began, the exploitation of which probably lasted till the 19th century (Jost, 1962; Kutaś, 2005). In 1927 the then owner of this glade-Władysław Zamoyski totally banned pasturage. In 1947 the first nature reserve in the Tatra Mountains, Tomanowa-Smreczyny, was established (Radwańska-Paryska and Paryski, 1995).

The main aim of this study was a reconstruction of local slope processes, vegetation changes and human impact during the last millennium in the Pyszniańska Valley (Western Tatra Mts.) on the basis of palynological (pollen and non-pollen palynomorps) and lithological analyses of a small peat bog in the Pyszniańska glade supplemented by radiocarbon dating.

2. Study area

The study area is located in the western Tatra Mts.(Poland) which are the highest mountain range within the Carpathians. The morphology of the Pyszniańska Valley was transformed by the activity of both glacial and periglacial processes, which are evidenced by the presence of glacial cirques, a system of moraine ridges and relict protalus lobes/ talus rock glaciers (Romer, 1929; Klimaszewski, 1988; Kaszowski et al., 1988; Kłapyta, 2008). The Pyszniańska Valley etches into the crystalline basement rocks of the Western Tatra Mts., which comprise gneisses and mylonites interbedded with granodiorites. These rocks are tectonically disturbed by the major Ornak tectonic dislocation, which determined the course of the upper Pyszniańska valley as well as the lowest depression within the main Tatra ridge (Pyszniańska pass 1787 m a.s.l.) and led to the development of deep seated slope failures (sackung) on the E slopes of the Ornak massif. (Jaroszewski, 1965). The present natural timberline on the northern slope of Tatra Mts. is located at ca. 1550 m a.s.l. (Obidowicz, 1996). The present course and elevation of the upper timberline is highly affected by geomorphic processes and human activity (Krzemień et al., 1995).

The main sediment core was collected from a small peat bog, situated at the lower edge of the Pyszniańska glade (49°12'31"N, 19°51'10"E) at an altitude of 1294 m a.s.l. in the upper mountain vegetation belt. The length of the peat bog is 45 m with a mean width of 25 m and a maximum depth of 2 m (Fig.1). Its surface is overgrown with *Carex rostrata* and *Sphagnum*. The peat bog developed in a stadial end-moraine depression, behind a pronounced stadial end-moraine ridge (Halicki, 1930; Młodziejowski, 1930; Klimaszewski, 1988, Fig.1).

Supplementary data were collected from cirque bottom-slope deposits from a depression located along the axis of the main debris flow track in the E part of the Pyszniański cirque. An outcrop was dug in the upper part of the Pyszniański cirque, under the Pyszniańska Pass (49°12'04"N, 19°51'09"E) at an altitude of 1500 m a.s.l. Sediments fill out a small terrain depression, which has been dammed by the lateral ridges of a stadial moraine and a relict rock glacier (Fig.1).

3. Materials and methods

3.1. Fieldwork

The bathymetry and total thickness of sediments from the Pyszniańska glade mire were investigated using an avalanche sampler in two transects, which allowed us to find a suitable place to collect a core (Fig. 1). A 170 cm long sediment core was collected from the deepest part of the depression with an 'Instorf' sampler (Russian sampler).

A 165 cm long outcrop was dug in the Pyszniański cirque depression and 8 sub-samples were collected from the main sedimentary units exposed in the profile.

3.2. Analytical methods

27 samples, 1 cm^3 in volume, were sampled in the laboratory and prepared using a standard laboratory treatment (Stockmarr, 1971, Faegri and Iversen, 1989). In most of the samples more than 500 arboreal (if the frequency was low, 200 grains was the minimal value) sporomorphs were counted and identified with the assistance of special keys (Moore et al., 1991; Beug, 2004) and the reference collection of the Władysław Szafer Institute of Botany Polish Academy of Sciences.

Non-pollen palynomorphs were identified using photos and descriptions from scientific papers (e.g. Speranza et al., 2000; van Geel et al., 2003). Terrestrial plant pollen percentages were calculated on

the basis of the sum of AP+NAP as the basic 100% sum, and the percentages of aquatic and wetland plants (including Cyperaceae), spores and charcoal particles were calculated on the basis of the sum of AP+NAP+taxon. Pollen diagrams were plotted using the POLPAL program (Nalepka and Walanus, 2003).

A sum total of 41 samples from both profiles was taken for lithological analysis. Sieving was used

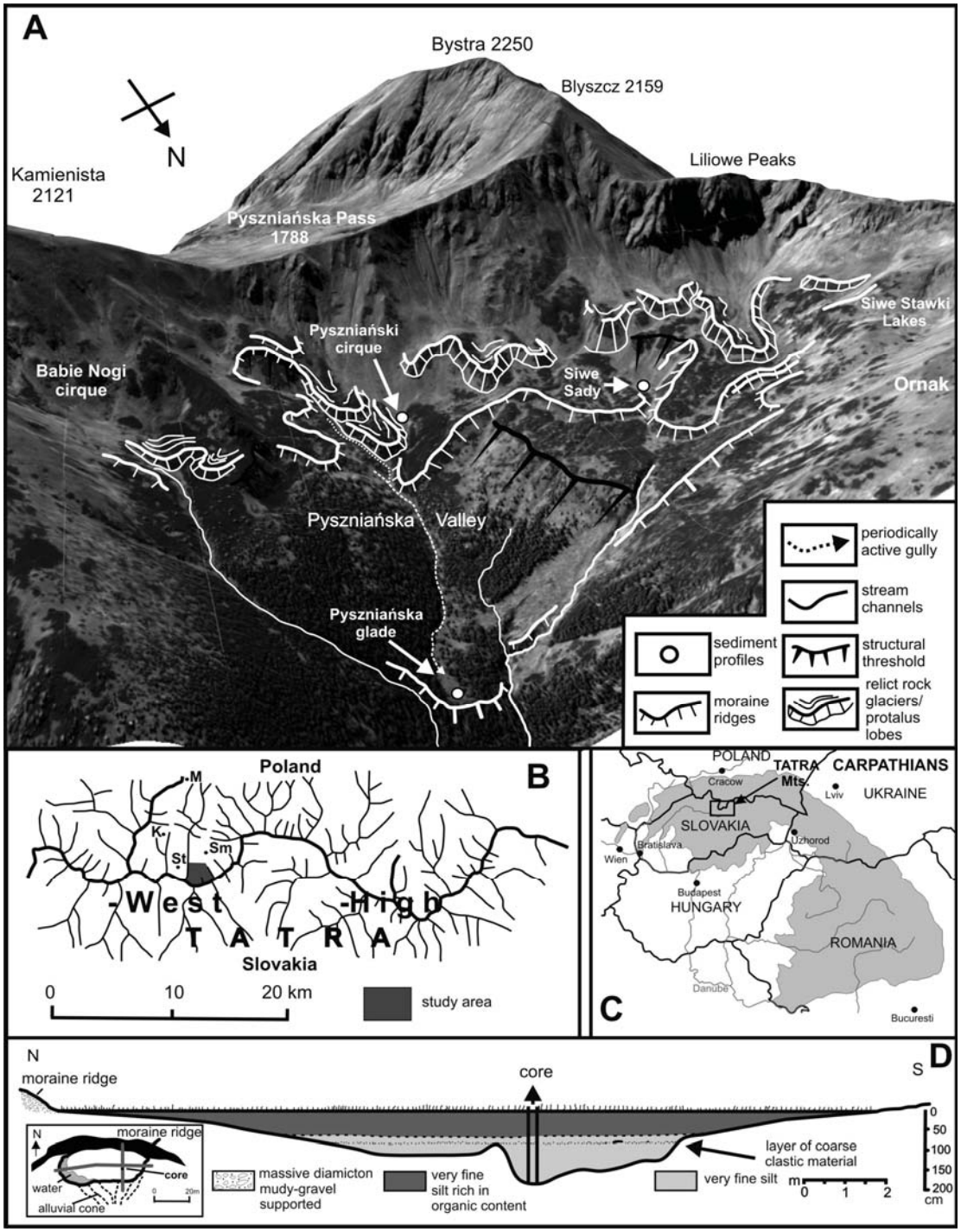

Fig.1. The location of the site. A. Visualization of the geomorphology of the upper Pyszniańska Valley, localization of the sediment sites discussed in the text is marked by white circles; B. A location map of the Tatra Mts. and places discussed in the text (M: Molkowka glade, K-Krowi Żleb, St-Staroroboci ański cirque, Sm-Smreczyńsi Staw lake; C. A sketch map of Carpathians with a location of the Tatra Mts.; D. A plan and cross section of the Pyszniańska glade peat bog with the location of the sediment core.

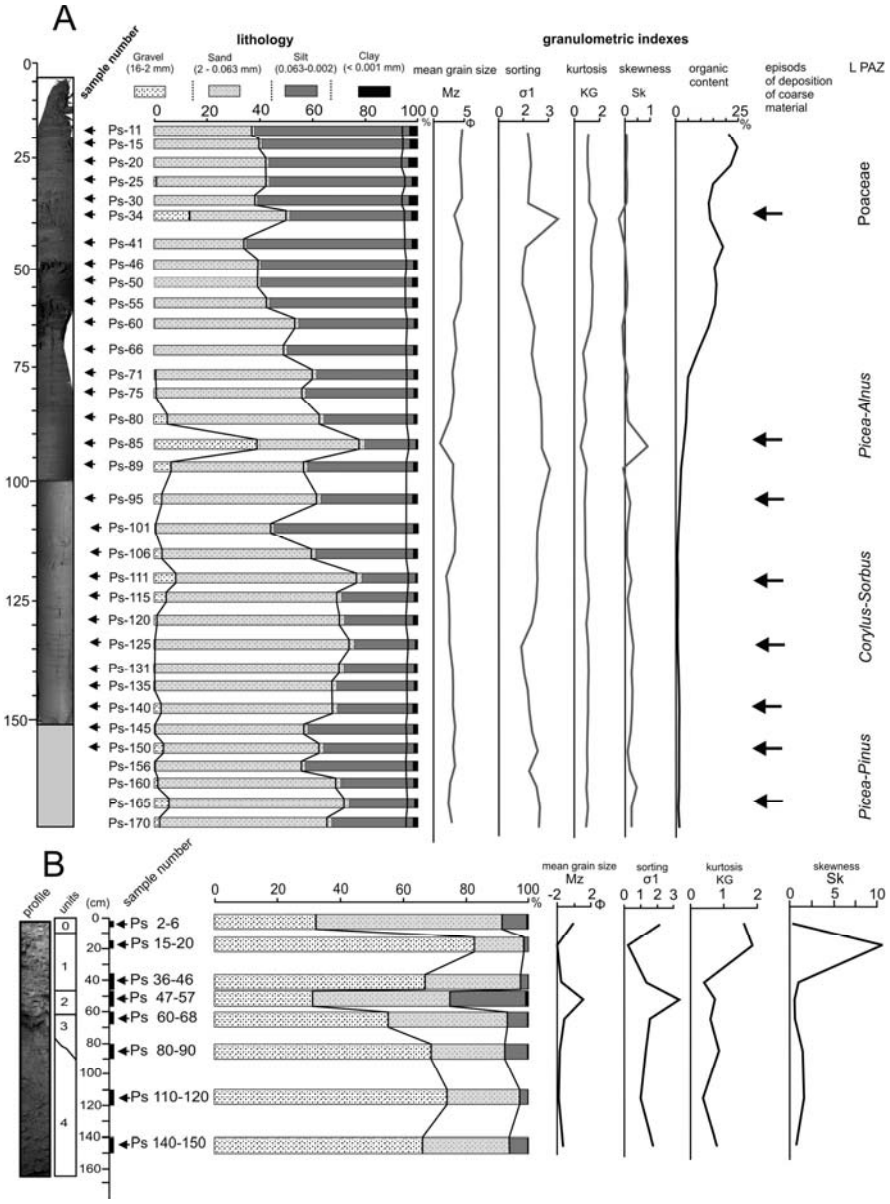

Fig. 2. Lithology and grain size parameters of sediments from the Pyszniańska glade (A) and the Pyszniański cirque (B).

for sediments with grains larger than 1 mm, while for smaller grains a Fritsch laser granulometer analyser 'Analysette 22' was used. Lithological classification and grain size parameters were done using Gradistad 4.0 software (Blott, 2004) based on R. L. Folk and W. C. Ward (1957), modified from J. A. Udden (1914) and C. K. Wentworth (1922). The percentages of organic matter from the Pyszniańska glade core were estimated using a Tiurin method (Myślińska, 1998).

Radiocarbon datings were carried out in the Poznań Radiocarbon Laboratory and were calibrated using the OxCal v 3.10 program (Bronk Ramsey, 2005), according to the calibration curve IntCal 04 (Reimer et. Al., 2004). The results are presented in Table 1.

4. Results and discussion

Sediments between depths of 147-168 cm (TZNP-1 zone) are dominated by sands (55-75%) and silts (20-45%) with a very low (0.5-1%) percentage of organic content. Two episodes of coarse material deposition were identified within the analyzed section (Fig. 2).The percentage values of herbs in the TZNP-1 zone (Fig. 3, 4) suggest visible deforestation with patches of spruce forest in the vicinity. Where there are streams *Alnus incana* and *Betula* species could have occurred more frequently along

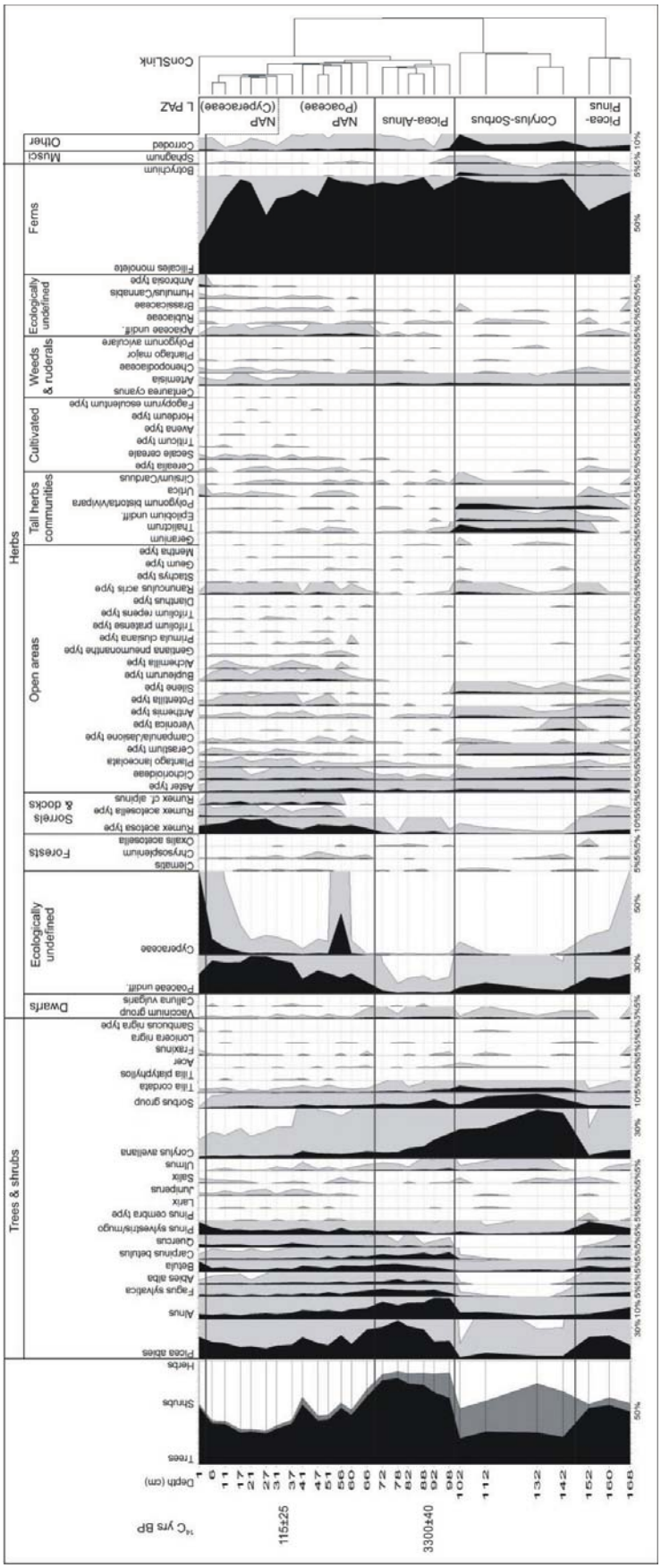

Fig. 3. Pyszniańska glade – a simplified pollen diagram.

their banks. The presence of *Abies* pollen suggests that the core is from later than the Atlantic age, because this taxon appeared in the lower part of the Tatra Mountains about 4500 BP (4970-5320 cal. BP) (Obidowicz et al., 2004). Continuous curves of coprophilous fungi spores, as well as high percentages of Poaceae undiff., indicate grazing activity in the vicinity of the site. High values of charcoal particles of >0.1 mm would likely be traces of fires and/or local mining and metallurgical centers in the last millennium. The connection between the occurrence of layers of charcoal particles and man-made fires is supported by the radiocarbon date from the Staroroboci ańska valley (2.3 km north of the examined site), where this kind of layer was dated 360±50 ^{14}C BP (Liebelt, 1990). There is also the date 345±30 ^{14}C BP from a charcoal layer detected in 'Krowi Żleb' (5 km northern-west of the Pyszniańska glade) (Tab. 1) The TZNP-2 zone (147-100 cm) reflects a period of dynamic sedimentation which is reflected in a series of episodes of coarse material deposition, and lent additional credibility by the lowest content of organic matter in the whole profile (Fig. 2). This zone has the lowest frequency of trees pollen, which indicates almost total deforestation. *Sorbus aucuparia* thickets developed on the steep debris-mantled slopes. The sharp rise in the hazel (*Corylus avellana*) curve and the increase in the *Tilia cordata* percentage values might be explained by redeposition of sediments from the Atlantic period from the upper part of the valley. The trend of the hazel percentage curve in the TZNP-2 zone is very similar to the values it reached in the B and C_1 zones from the Siwe Sady profile, which were dated back to the Atlantic age (Fig. 4B, Libelt and Obidowicz 1994). Findings of *Abies* pollen grains below the TZNP-2 zone suggest that it evolved earlier than in the Atlantic period (Fig. 3). Moreover profiles, previously palinologically examined do not show a positive correlation between deforestation and a strong expansion of hazel thickets during the last millennium (Obidowicz, 1996; Rybníčková and Rybníček, 2006). Strong slope washing processes might have accompanied an influx of pollen and charcoal particles, which would have been the effect of human activity (forest burning and/or mining and metallurgical activity).

In the TZNP-3 zone (100-69 cm) the upper Pyszniańska Valley was affected by a most catas-

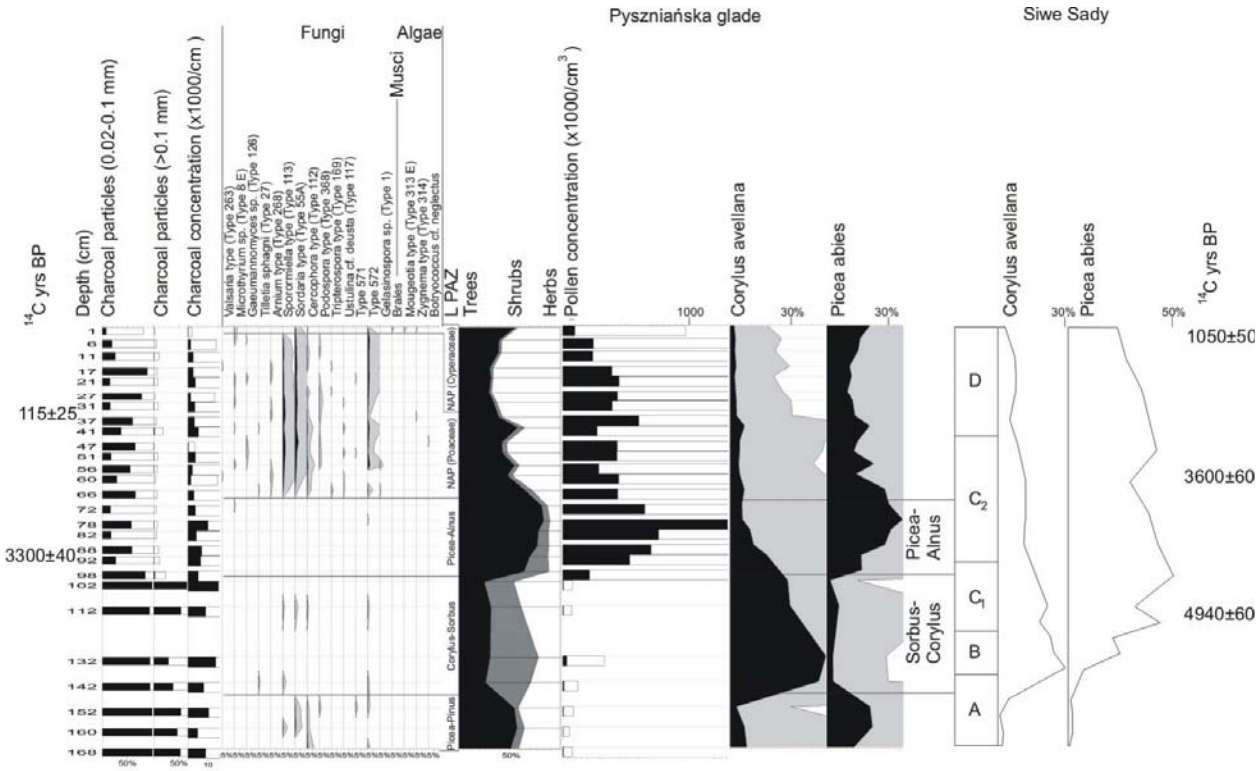

Fig. 4. Pyszniańska glade - simplified palynological diagrams. A. Non-pollen palynomorps, charcoals and pollen concentration vs. human activity phases; B. Similarities between pollen spectra of *Corylus avellana* and *Picea abies* from the Pyszniańska glade and the Siwe Sady profiles (Liebelt and Obidowicz 1994), grey bars point the similar parts of diagrams.

trophic high-energy geomorphic event, recorded as a continuous layer of coarse material at a depth of 85 cm and characterized by a large amount of gravels (38%) and sands (41%), as well as by an increase in mean grain size, where M_z = 1.2 φ (22.68 ì m) (Fig. 2). The beginning of this zone has been dated 3300±40 ^{14}C BP. The significant rise in pollen concentration in this zone, has previously been thought to be the effect of a decrease in the sediment accumulation rate caused by forest expansion (Kłapyta and Kołaczek, 2009). However, in the light of this radiocarbon dating it is better seen as the effect of the redeposition of pollen material from upper elevations of the valley combined with the influx of sporomorps accompanied by that of charcoal particles. This theory is confirmed by similarities between the pollen spectra of this profile and the one from Siwe Sady, as well as by the fact that the core collected from the depression located in the upper of the Pyszniański cirque was filled with mineral material without any organic inserts (Fig. 2B, Fig 4). This material is dominated by poorly sorted gravels (70-85%) and sands (20-40%) which indicate high activity of slope processes (Fig 2B).

Pollen spectra from the TZNP-4a subzone (69-3.5 cm) reveal significant deforestation with a rapid expansion of open area communities, demonstrated by a simultaneous increase in the percentage values of numerous herb pollen taxa. The appearance of *Rumex alpinus* - species, which occurs close to cotes, correlated with an increase in the frequency of the coprophilous fungi spores indicates the beginning of an animal husbandry period (Fig. 3, 4). At a depth of 34 cm another strong geomorphic episode was recorded which is shown by a higher gravel content (14 %) in sediments was recorded, specifically characterized by a decrease in organic content and weak sorting with a standard deviation σ = 3.4. In the upper part of the cirque this stimulus probably led to the sedimentation of a massive 35 cm thick layer of gravels and sands (unit 1 on Fig 2B) in the depression under the Pyszniańska Pass (Fig. 1).

The radiocarbon date obtained from a depth of 35 cm gives a broad indication that the TZNP-4a subzone developed in the17th-20th century (Table 1). Taking into consideration the appearance of *Ambrosia artemisifolia* type which took place in the southern Europe in the 19th century, according to Makra et al. (2005), the age of the upper part of this subzone might be restricted to the 19th-20th century. This coincides with historical data, which point to the 19th century as the period of the strongest influence of grazing activity on the environment in the Western Tatra Mountains (Hołub-Pacewiczowa, 1931). The content of gravel and sand in sediments at depths of 32-11 cm is the lowest in the whole profile. This correlates well with herb pollen percentages. Altogether, this indicates an improvement in vegetation cover in the vicinity of the site.

The uppest subzone-TZNP-4b (3.5-1 cm) represented by a single spectrum records a modern phase of the basin development, and reflects the expansion of *Carex rostrata* on the peat bog surface. The AP pollen curve slightly increases, which could well be the effect of reforestation probably due to the establishment of the Tatra National Park in 1954.

Table 1. Radiocarbon dates from the Pyszniańska glade profile and the 'Krowi Żleb' gully.

Lab. No.	Location	Depth (cm)	Material	^{14}C BP	Callibrated age
Poz-30389	Pyszniańska glade	35	Twig	115±25	68.2% probability 1690AD (16.4%) 1730AD 1810AD (43.6%) 1890AD 1900AD (8.2%) 1930AD 95.4% probability 1680AD (27.6%) 1740AD 1750AD (1.1%) 1770AD 1800AD (66.7%) 1940AD
Poz-30789	Pyszniańska glade	90	Pollen concentrate	3300±40	68.2% probability 1675BC (68.2%) 1570BC 95.4% probability 1740BC (95.4%) 1540BC
Poz-30388	Krowi Żleb' gully	280	Charcoal layer	345±30	68.2% probability 1480AD (24.3%) 1530AD 1550AD (43.9%) 1640AD 95.4% probability 1460AD (95.4%) 1640AD

5. Conclusions

1. The sediments which fill the depression at the Pyszniańska glade site are a sensitive recorder of slope processes dynamics in the last millennium, as well as of changes in vegetation patterns and human impact in the Western Tatra Mts. The sediments are dominated by fine grain material (sands and silts) transported by surface and linear slope washing with the interbedding of the distinctive layers of coarse clastic material, which indicates high-energy geomorphic processes in the surroundings of the upper Pyszniańska Valley.

2. Sedimentation in the site probably began in the 14^{th}-15^{th} century. The first phase of vegetation development is characterized by visible deforestation caused by fire clearances and/or the development of mining and the metallurgical centers. The high number of hazel (*Corylus avellana*) pollen grains is probably the effect of redeposition from sediments (from the Boreal or Atlantic period) that lay above the site. Although after this episode, the pollen diagram has suggested a period of reforestation, radiocarbon dating suggests that this layer is due to redeposition during high-energy slope processes. The upper phase recorded in sediments signifies pasture development based on animal husbandry. The uppermost pollen spectrum records the most recent phase of basin development revealed in the expansion of *Carex rostrata* on the peat bog surface and in the recovery of forest in the vicinity of the site after the establishment of the Tatra NP.

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