S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A
Vol. XLIII, 2009: 145–163 PL ISSN 0081-6434
L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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THE LAST MILLENIUM SLOPE PROCESSES AND ANTHROPOGENIC ACTIVITY RECORDED IN THE SEDIMENTS FROM THE PYSZNIAŃSKA GLADE, WESTERN TATRA MOUNTAINS (POLAND)

Abstract. In order to reconstruct the last millenium evolution of slope processes and human impact, sediment core from the Pyszniańska glade (Kościeliska Valley, Western Tatra Mountains) was analyzed. Peat depression is filled with fine, 1.7 m thick, minerogenic sediments with the intercalations rich in coarse clastic material. These layers were interpreted as episodes of a high supply of allochthonous material washed away from the slopes to the depression during extreme hydrometeorologic events. Coarse levels are distinct indicator of high-energy geomorphic processes and deforestation of slopes surrounding the Pyszniańska Valley. The four pollen assemblages zones correspond to the main periods of vegetation changes and anthropogenic activity in the surroundings of Pyszniańska glade site. Pollen and charcoal analysis suggests that the beginning of sedimentation did not start earlier than in the 14th–15th centuries. The upper part of profile contains sediments from the 20th century, which is confirmed by regular presence of *Ambrosia* type pollen.

Key words: Tatra Mountains, Pyszniańska glade, human impact, slope processes, pollen analysis

INTRODUCTION

The Holocene history of the natural environment and climate changes in the contemporary unglaciated high-mountain areas has been recorded as sediments fillings in natural terrain depressions: glacial lakes (Bozilova and Tonkov 2000; Catalan et al. 2006; Tonkov et al. 2008), cirque bottoms (Libelt 1988; Libelt and Obidowicz 1994), landslides (Reneau at al. 1990; Corsini et al. 2001) and peat bogs (Weiss et al. 1997; Obidowicz 1996; Tantău et al. 2005). These sediments are sensitive, suitable recorders of the past and present environmental changes, reacting to intensification of hydrometeorologic phenomena in the form of levels of high-energy deposits, which are connected with the activity of debris flows and high slope runoff (Ballantyne 2002; Catalan et al. 2006; Kotarba 1995; Margielewski 2006).

Intensive palaeoenvironmental research on deposits from the Tatra Mountains — the highest alpine range in the Carpathians, provided insight into the origin and evolution of climate, patterns of vegetation, geomorphic processes and human impact. The issues of the Holocene relief transformation; evolution of vegetation, and vertical migration of geoecological belts in the Western Tatra Mts. are relatively poorly recognized when compared to the High Tatras (Baumgart-Kotarba et al. 1990, 1993; Kotarba 1996; Kotarba et al. 2002). These are caused by different lithology and relief, which resulted in small number of natural sedimentary reservoirs, which could have recorded non interrupted palaeoenvironmental changes. The pioneering research on the Western Tatras sediments was performed by J. Dyakowska (1932), who analyzed peat bog sediments from the site in the vicinity of Smreczyński Staw Lake (Kościeliska Valley) and the Molkówka glade (mouth of the Chochołowska Valley). Further works at the Molkówka site (Koperowa 1962; Obidowicz 1996) were supplemented by more detailed pollen spectra and have indicated continuous Late Glacial–Holocene sedimentation, which started from the Younger Dryas (Obidowicz 1996). Unfortunately, these studies are lacking in suitable numerical dating and their chronology is based on pollen stratigraphy. Research on lacustrine sediments from Smreczyński Staw Lake (Skierski 1984) revealed the Holocene organic gyttja and peat layers, which relates to quite sedimentation with its onset in the Boreal period.

New set of information on postglacial relief transformation was achieved by the research on slope-derived sediments occurring in high-elevated terrain depression within glacial cirque bottoms (Libelt 1988, 1990, 1994; Kaszowski et al. 1988; Libelt and Obidowicz 1994). Several drillings in sediments from the bottoms of the Starorobociański and Pyszniański cirque revealed dominance of debris flows activity during the whole Holocene. A unique discovery of highest elevated fossil peat bog in the Western Tatra Mountains (1,545 m a.s.l.) at the Siwe Sady site (upper Kościeliska Valley) gave the possibility to reconstruct the Holocene changes in dynamic of slope processes and vegetation changes near the timberline (Libelt and Obidowicz 1994). The sediments clearly show stable sedimentary conditions during the most of the Holocene (from the Boreal to the middle Subatlantic) and intense activity of debris flows during the Little Ice Age (after 1,050 ± 50 ^{14}C years BP).

In discussions of the late Holocene environment evolution of the Tatras, special interest must be paid to the period of intense human impact on high mountain environment during the significant climate deterioration of the Little Ice Age. Due to climate dynamics and significant human impact, the boundaries of vegetation belts and vertical zones reacted rapidly, which led to changes in dynamic and spatial scale of geomorphological processes.

One of such environments of sedimentation where Late Holocene minerogenic material occurs, was discovered in the bottom of Pyszniańska Valley in the upper Kościeliska Valley (Western Tatra Mts.) Dating of coarse minerogenic levels in sediment core as well as pollen analyses will allow to reconstruct phases of geomorphologic processes, human activity, and vegetation pattern changes during the late Subatlantic in the vicinity of a peat-bog. This paper is a preliminary step forward in an attempt to present a comprehensive picture of the last millenium environmental changes of the northern slope of the Western Tatras.

The first clearings (glades) in the Tatra Mountains were affected by the Walachian settlers, which migrated from the south in the 15th–16th century. As time went by, they assimilated into the local community. The first information about pastoral exploitation of Pyszniańska glade comes from 1655, then this area belonged to the highlanders from two villages: Klikuszowa and Obidowa. In 1927 a contemporary owner of this glade — Władysław Zamoyski banned sheep and cattle grazing totally. In 1947 the first nature reserve in the Polish part of the Tatra Mountains — Tomanowa-Smreczyny was established here (Radwańska-Paryska and Paryski 1995).

In the 15th century mining developed rapidly and the first mines were probably located under the Ornak, where copper and silver was mined during the reign of Sigismund I The Old. In 1520 the mines in the Ornak were extended to the Kościeliska valley side where a pit shaft on the Pyszna glade ("Na Kunsztach") was digged. In 1765 another mining activity under the Ornak ("Pod Banie" gully) began, this mine was called "Czarne okno". In the mouth of this gully a metallurgical installation used to heat copper and silver ores was built. Exploitation of the tunnel lasted probably till 19th century, that time iron ore deposit discovered in the 18th century was depleted. Between 1783 and 1841 a copper mill was working on the Stare Kościeliska glade (http://galaxy.uci.agh.edu.pl/~7dni/hist.htm).

STUDY AREA

The Pyszniańska Valley is the main, upper prolongation of the Kościeliska Valley system, which etches out on the northern side of the main Western Tatra Mts. ridge (Fig. 1). From the south the Pyszniańska Valley is surrounded by steep, debris mantled and rocky slopes of Blyszcz (2,158 m a.s.l.), Kamienista (2,121 m a.s.l.) and Pyszniańska Pass (1,787 m a.s.l.), the latter is one of the lowest depressions within the main Tatra ridge. During the Pleistocene, the morphology of the whole Pyszniańska Valley was transformed by the activity of both glacial and periglacial processes, which are evidenced by the presence of glacial cirques, system of moraine ridges and relict rock glaciers (Romer 1929; Klimaszewski 1988; Kaszowski et al. 1988; Kłapyta 2008). In comparison with the High Tatras the glacio-erosive forms in the more rejuvenated northern slope of the Western Tatras, are less extensive (Klimaszewski 1961). Glacial cirques of the Kościeliska Valley system are relatively small, with inclined and slightly overdeepened bottoms, and headwalls, dominated by steep rocky and

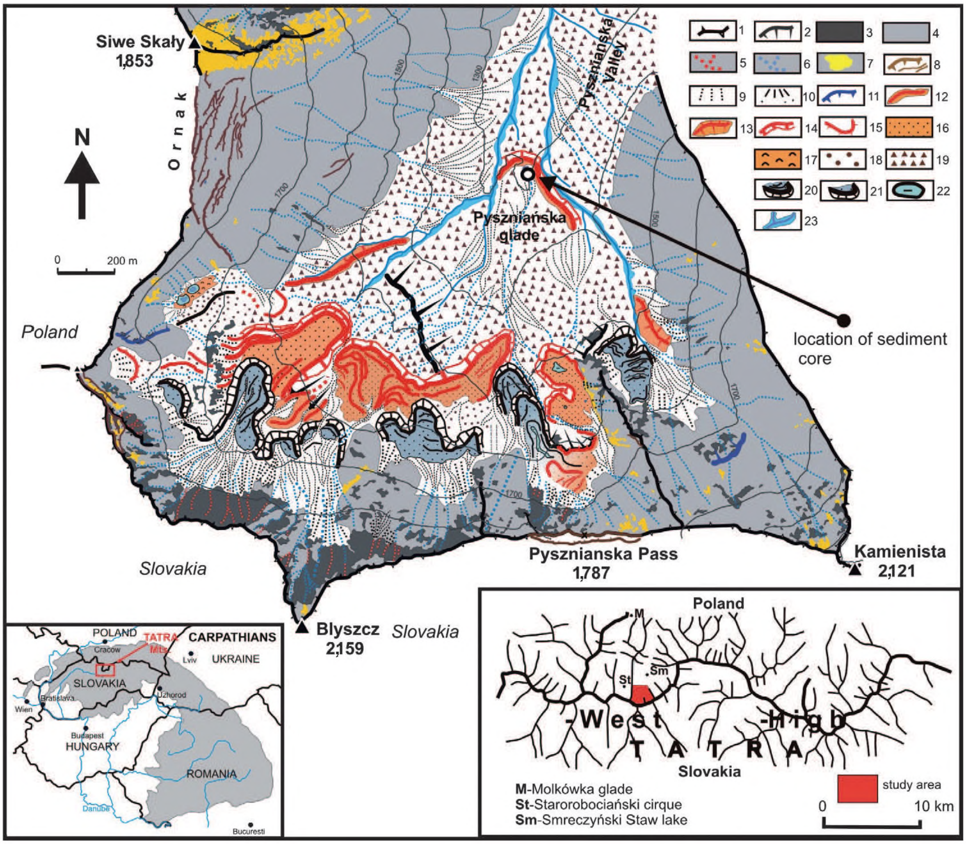


Fig. 1. Geomorphological map of the upper part of the Pyszniańska Valley (according to P. Kłapyta), 1 — crest, 2 — structural treshold, 3 — rocky slopes and rockwalls, 4 — debris mantled slopes, 5 — chutes, 6 — gullies, 7 — periglacial debris covers, 8 — system of fissures and sackung scarpes, 9 — rockfall talus, 10 — alluvial cone, 11 — glacial cirque edge, 12 — symmetrical moraine ridge, 13 — asymmetrical moraine ridge, 14 — massive fronts moraines, 15 — protalus ramparts, 16 — ablation moraine covers (blocky type), 17 — ablation moraine covers (hummocky moraine), 18 — weathered, discontinuous moraine covers, 19 — ground moraine covers, 20 — relict rock glaciers, 21 — protalus bulges, 22 — dead-ice depression, 23 — stream channels

debris mantled slopes with the small number of rock walls (Fig. 2; Klimaszewski 1988; Kaszowski et al. 1988). During the whole Holocene debris flows were the main relief-forming process above the tree line, and their activity has formed a dense system of gullies and alluvial fans descending up to 1,5 km down slope, which partially fossilized debris landforms (Krzemień 1988).

The study area is situated on the crystalline basement rocks of the Western Tatra Mts., which comprises gneisses, mylonites interbedded with granodiorites (Jaroszewski 1965). The rocks are tectonically disturbed with the major Ornak tectonic dislocation, which gave the course of the upper Pyszniańska valley as well as the depression of Pyszniańska pass and led to development

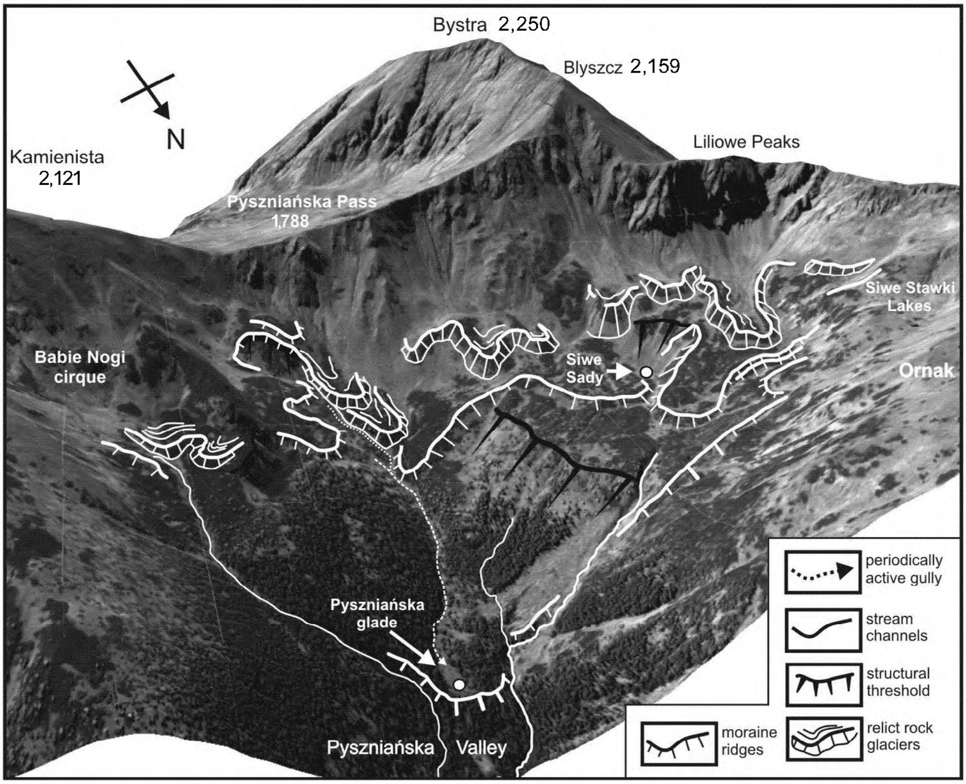


Fig. 2. Visualization of the geomorphology of the upper Pyszniańska Valley, localization of the sediments in the text are marked by the white cirques

of deep seated slope failures (sackung) on the E slopes of the Ornak massif. (Jaroszewski 1965).

The sediment core was collected from the small peat bog, situated at the lower edge of the Pyszniańska glade (49°12'31"N, 19°51'10"E) at an altitude of 1,294 m a.s.l. in the upper montane vegetation belt (Figs 1 and 2). The contemporary course and elevation of the upper timberline (1,400–1,480 m a.s.l.) is highly affected by geomorphic processes activity and human impact (Krzemień et al. 1995).

The length of the peat bog is 45 m, with mean width 25 m, maximum depth 2 m (Fig. 3). The peat bog has developed in the stadial end-moraine depression behind a pronounced stadial end — moraine ridge (Halicki 1930; Młodziejewski 1929; Klimaszewski 1988; Figs. 1 and 3). This transverse moraine ridge plays role as a natural barrier for transport of clastic material down valley to the channel subsystem. During the extreme hydrometeorological events, the site locality has direct connection with the glacial cirque slope sub-system from which coarser material is transported and redeposited in

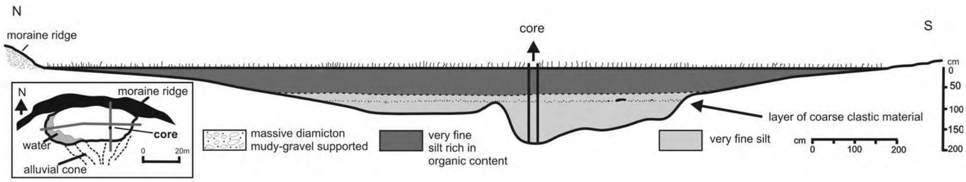


Fig. 3. Plan and cross section of the peat bog from the Pysznińska glade with the location of sediments core

the peat-bog depression. Thereby, the location of the site gives possibility of observing evidence of the past, high-energy geomorphic events.

MATERIALS AND METHODS

A bathymetry and total thickness of the sediments were investigated by avalanche sampler in two transects, which allowed to distinguish the place of core localization (Fig. 3). A sediment core 170 cm long and 8 cm in diameter was recovered from the deepest part of the depression with a Instorf (Russian sampler). 19 sub-samples (1 cm^3 in volume) were sampled in laboratory and prepared using modified Erdtman's acetolysis (Faegri and Iversen 1989) with the addition of cold hydrofluoric acid and mounted in glycerol. To permit estimation of pollen concentration, weighted tablets with a known concentration of *Lycopodium* were added to each sample before preparation (Stockmarr 1971). More than 500 arboreal pollen grains per sample were counted at 400× and 1000× magnification. From sub-samples with low pollen concentration 200 arboreal pollen grains were the minimum. Sporomorphs were 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 Science to the lowest possible taxonomic level. Non-pollen palynomorphs were identified using photos and descriptions from the scientific papers (Speranza et al. 2000; van Geel et al. 2003). In addition, the amount of charcoal fragments was estimated. Terrestrial plants pollen percentages were calculated on sum of AP + NAP as a basic 100% sum, percentages of aquatic and wetland plants (including Cyperaceae), spores, and charcoal particles were calculated on the sum of AP + NAP + taxon. Pollen diagrams were plotted using the POLPAL program (Nalepka and Walanus 2003).

The mineral sediments were subjected to granulometric analyses. Total sum of 33 samples were taken for lithological analyses at intervals of 5 cm. Sieving was used for sediments with grain size larger than 1 mm and for sediments lower than 1 mm, grain sizes were measured using the Fritsch laser granulometer analyser "Analysette 22". Lithological classification and grain size parameters were done using Gradistad 4,0 software (Blott 2004) based after R.L. Folk and W.C. Ward

(1957), modified from J.A. U d d e n (1914) and C.K. W e n t w o r t h (1922). The percentage of organic matter was estimated by the Tiurin method (M y ś l i ń s k a 1998). Selected sample was dated by the Poznań Radiocarbon Laboratory. Radiocarbon dating was calibrated using OxCal v 3.10 program (B r o n k R a m s e y 2005), according to calibration curve IntCal 04 (R e i m e r et al. 2004). The results are presented in Table 1.

Table 1

AMS ^{14}C measurement from the Pyszniańska glade site

Lab. No.	Depth [cm]	Material	^{14}C dates years BP conv. uncal.	Callibrated age
Poz-30389	35	Twig	115 ± 25 BP	68.2% probability 1690 AD (16.4%) 1730 AD 1810 AD (43.6%) 1890 AD 1900 AD (8.2%) 1930 AD 95.4% probability 1680 AD (27.6%) 1740 AD 1750 AD (1.1%) 1770 AD 1800 AD (66.7%) 1940 AD

RESULTS

GRANULOMETRY

The depression is filled with mineral sediments 170 cm thick underline by rock debris (Fig. 4). The upper most part (0–16 cm) contains silty peat with 20–25% organic content. Below the peat the sediments are built up mainly of minerogenic material. In the upper part, between depth of ca 70–16 cm organic sandy mud dominates with 10–20% organic content. Below ca. 70 cm sediments turn into the high minerogenic type, dominated by slightly gravelly muddy sands containing 0.5–1% of organic content. Lithological analysis has shown that the sediments are dominated by sands and silts (65–90%) with mean grain sizes M_z= 3,5 φ (104 μm). The sediments are poorly sorted, standard deviation is δ_I = 2,4. The low index of skewness (S_k 0.1) similarly as the low kurtosis index (K_G 1.1), indicate that sediments were precipitated from suspended matter and redeposited in the lake depression. The analyzed core section bears a record of quite sedimentation, which was punctuated by episodes of high supply of allochthonous material recorded as distinctive layers of coarse clastic material (angular fragments of granites). These layers have been identified by increase in mean grain size, content of gravels, sands (up to 50–80%), and weak sorting. The 8 episodes of coarse material supply have been distinguished (Ps-34, Ps-85, Ps-95, Ps-111, Ps-125, Ps-140, Ps-150, Ps-165; Fig. 4).

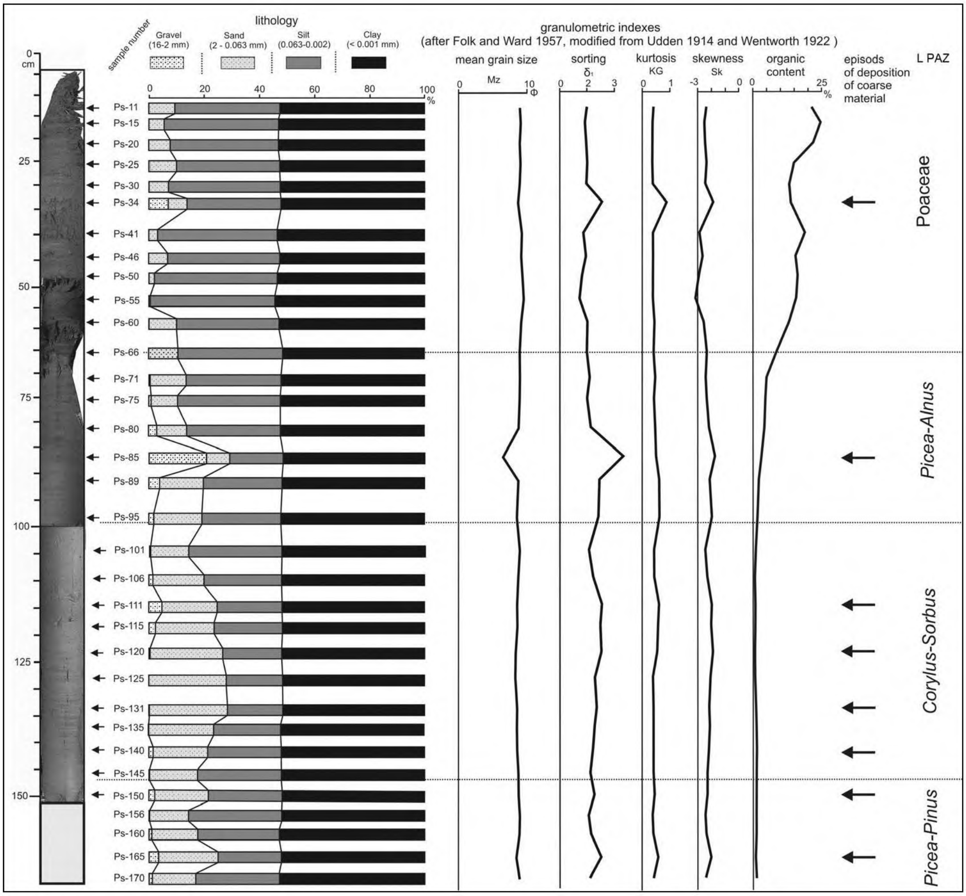


Fig. 4. Lithology and grain size parameters of the sediments core from the Pyszniańska glade

The most pronounced pulses of coarse clastic material were identified at depth of 85 cm (sample Ps-85) and 34 cm (sample Ps-34). The first is characterized by large amount of gravels (38%) and sands (41%), and increase in mean grain size, where M_z= 1.18 φ (438 μm). The sediments are extremely poorly sorted with standard deviation δ = 3.38. This high energy level is present within entire depression and was identified by avalanche sampling as compact, continuous layer at 80–90 cm depth (Fig. 3).

The latter episode is characterized by decrease of organic content, increase content of gravels (14%) and sands (37%), and weak sorting with standard deviation δ_I = 3.1. These sediments were redeposited in dynamic conditions which is indicated by increase in indexes of and kurtosis (K_G 1.3).

The older episodes (from Ps-111 to Ps-170, Fig. 4) cluster into the series, which indicate the period of dynamic condition of sedimentation. The grain sizes and lithology of core suggest that the sediments were washed away from the slopes and bottom of the Pyszniański cirque and precipitated from suspended matter in the lake depression. Distinct intercalations of levels rich in clastic material could have been deposited during the most extreme hydrometeorologic events connected with the activation of slope processes (debris flows, slope washing).

RADIOCARBON DATINGS

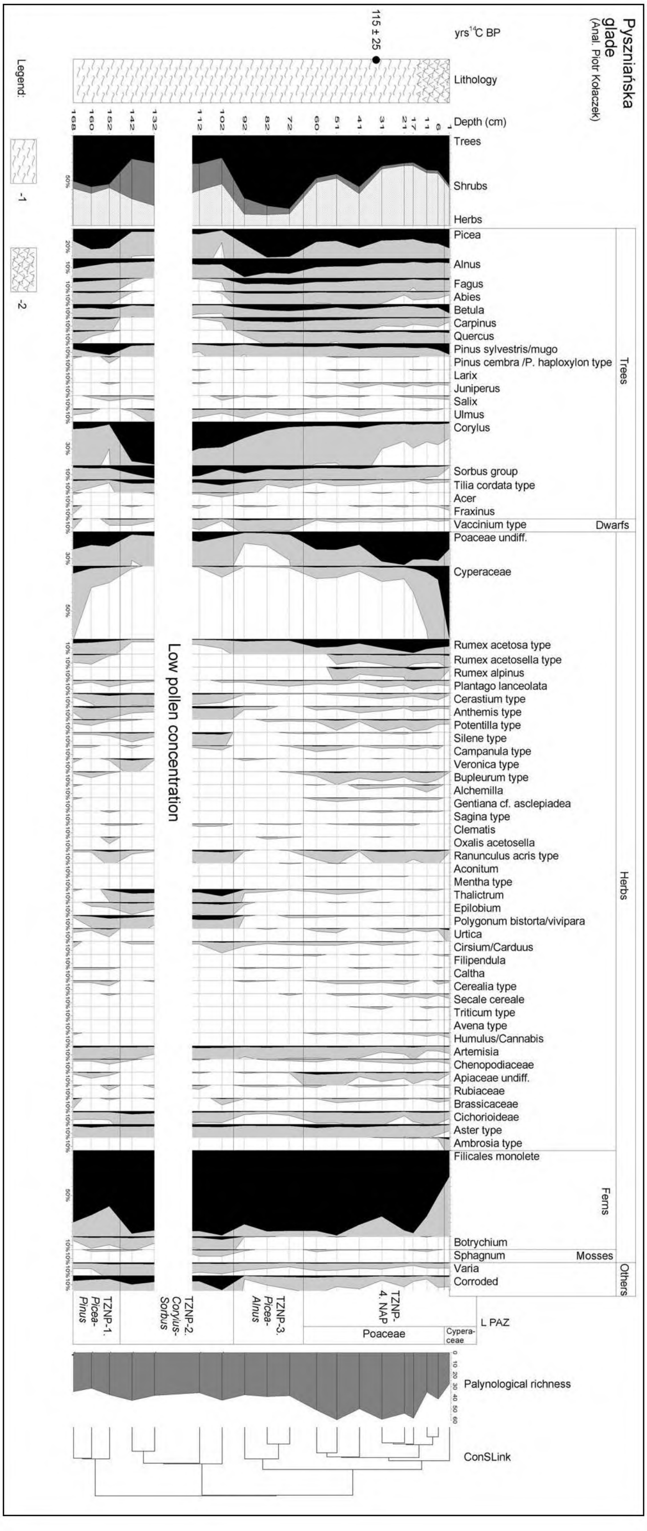
VEGETATION CHANGES

The pollen diagram has been divided into four local pollen assemblage zones (L PAZ) according to recommended rules (Janczyk-Kopikowa 1987) with the assistance of samples similarity dendrogram prepared using ConSLink method (Birks 1986). Pollen zones correspond to the main periods of vegetation changes and anthropogenic activity in the surroundings of the Pyszniańska cirque site (Fig. 5, Fig. 6).

TZNP-1. *Picea-Pinus*. 168–147 cm. The first zone is characterized by the low pollen concentration. Percentage values of herbs sporomorphs suggest visible deforestation. Pollen spectra indicate spruce as a major component of forests (13.5–22.5%), whereas *Alnus incana* occurs more frequently along streams. Findings of *Abies* (1.5–2%) pollen grains in the bottom part of the profile suggest Subatlantic age of the analyzed core. Continuous curve of coprophilous fungi spores as well as high percentages of Poaceae undiff. (15–19.5%) signify pastoral farming in the vicinity of the site. High percentage values of charcoal particles bigger than 100 μm length seem to be the traces of fires or/and local mining and metallurgical centres (Fig. 6).

TZNP-2. *Corylus-Sorbus*. 147–97 cm. The zone is characterized by the lowest frequency of trees pollen. Percentage values of spruce sporomorphs fall to their minimum in the profile, which indicates almost total deforestation. Increase of the *Sorbus* pollen curve (4–14%) could be correlated with *Sorbus aucuparia* thickets that had developed on the steep debris-mantled slopes. A sharp rise of the *Corylus* curve (28.5–47%) could be the local phenomenon connected with the forest degradation. Decline of the water retention led to an increase in stream number. This caused tall herbs communities development, which is visible in the higher percentage values of *Thalictrum* (3.5–8%), *Epilobium* (1–2.5%), *Polygonum bistorta/vivpara* (1–5%) and *Silene* type (0.5–2.5%). This zone is characterized by small frequency of coprophilous fungi spores correlated with Poaceae undiff. curve decline what may indicate lower pasture intensity. Charcoal frequency maintains the same level as in the previous zone and suggests fire clearings or local metallurgical centers activity (Fig. 6).

TZNP-3. *Picea-Alnus*. 97–66 cm. Pollen concentration rises significantly which could be an effect of a decrease of the accumulation rate caused by forest


Pyszniańska glade
(Anal. Piotr Kołaczek)
yrs 14C BP
115 ± 25
Lithology
Depth (cm)
Trees
Shrubs
Herbs
Picea
Alnus
Fagus
Abies
Betula
Carpinus
Quercus
Pinus sylvestris/mugo
Pinus cembra /P. haploxylon type
Larix
Juniperus
Salix
Ulmus
Corylus
Sorbus group
Tilia cordata type
Acer
Fraxinus
Vaccinium type
Dwarfs
Poaceae undiff.
Cyperaceae
Rumex acetosa type
Rumex acetosella type
Rumex alpinus
Plantago lanceolata
Cerastium type
Anthemis type
Potentilla type
Silene type
Campanula type
Veronica type
Bupleurum type
Alchemilla
Gentiana cf. asclepiadea
Sagina type
Clematis
Oxalis acetosella
Ranunculus acris type
Aconitum
Mentha type
Thalictrum
Epilobium
Polygonum bistorta/vivipara
Urtica
Cirsium/Carduus
Filipendula
Caltha
Cerealia type
Secale cereale
Triticum type
Avena type
Humulus/Cannabis
Artemisia
Chenopodiaceae
Apiaceae undiff.
Rubiaceae
Brassicaceae
Cichorioideae
Aster type
Ambrosia type
Filicales monolete
Ferns
Botrychium
Sphagnum
Mosses
Varia
Corroded
Others
Low pollen concentration
TZNP-1. Picea-Pinus
TZNP-2. Corylus-Sorbus
TZNP-3. Picea-Alnus
TZNP-4. NAP
Poaceae
Cyperaceae
L PAZ
Palynological richness
ConSLink
Legend:
-1
-2

expansion and soil stabilization. There has also been detected the lowest antropopression in the vicinity of studied site, which is demonstrated by the rapid increase in the AP curve (mainly spruce and alder) in the pollen diagram. Pollen percentage values of taxa characteristic for lower subalpine forest such as beech (6–7.5%) and fir (2.5%) increase visibly. Frequency of *Corylus* decreases gradually (6–18%). Pollen record shows regional forest succession during this period. The most significant fall of Poaceae undiff. (1.5–3%) frequency and lack of coprophilous fungi spores suggest distinct reduction of the pasture activity (Fig. 5). Charcoal curve decreases significantly and remains on the same level up to the upper part of the profile. It has probably been affected by the termination of using fire in forests clearings or/and reduction of local metallurgical centers.

TZNP-4a. NAP (Poaceae), 66–3.5 cm. This zone shows deforestation (fall of the AP curve). Percentage values of taxa associated with open areas such as Poaceae undiff. (14.5–37%), *Rumex acetosa* typ (9.5–15.5%), *Ranunculus acris* typ (1–2%), *Rumex acetosella* typ (0–1.5%), *Bupleurum* typ (0.5–1.5%), *Potentilla* typ (0.5–1.5%), *Campanula* typ, *Gentiana* cf. *asclepiadea* and *Alchemilla* increase simultaneously. This as well as coprophilous fungi spores suggests extension of the grazing area. Appearance of *Rumex alpinus* pollen (0–3.5%) — taxon, which prefers nitrophilous habitats is correlated with the presence of the coprophilous fungi curve (Fig. 5, Fig. 6). Nowadays, these species occur in tall herb communities or close to cotes, therefore pollen finding may indicate the beginning of an animal husbandry period. Pasture pattern recorded in the bottom part of the profile (zones: TZNP-1 and TZNP-2) shows different model, which point to transhumantion in the site vicinity. Cereals pollen grains were detected in each sample, which might show regional extension of agriculture. From the 16 cm depth up to the surface, gradual succession of the basin caused by Cyperaceae (*Carex rostrata* ?) is observed. Radiocarbon dating from the depth 35 cm reveals 18^{th}–19^{th} century as the most probable age of this sediments.

TZNP-4b. NAP (Cyperaceae), 3.5–1 cm. This subzone is represented by a single spectrum, which records contemporary phase of the basin development. The highest percentage value of *Cyperaceae* grains points out an expansion of *Carex rostrata* — species of vascular plant that dominates on a peat bog surface. Decline of taxa characteristic for the previous subzone, which was associated with open area, is visible. The AP pollen curve increases slightly, which is an effect of another reforestation caused probably by establishment of the Tatra National Park in 1954 and lasts till now. A significant rise of *Ambrosia* type pollen grains might be connected with the invasion of American species of this genera in Poland and Slovakia (Fig. 5). Appearance of this curve at the depth of 31 cm is probably an effect of the beginning of the invasion of these taxa in southern

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Fig. 5. Pyszniańska glade — simplified pollen diagram. 1 — silt, 2 — silt with sedge peat

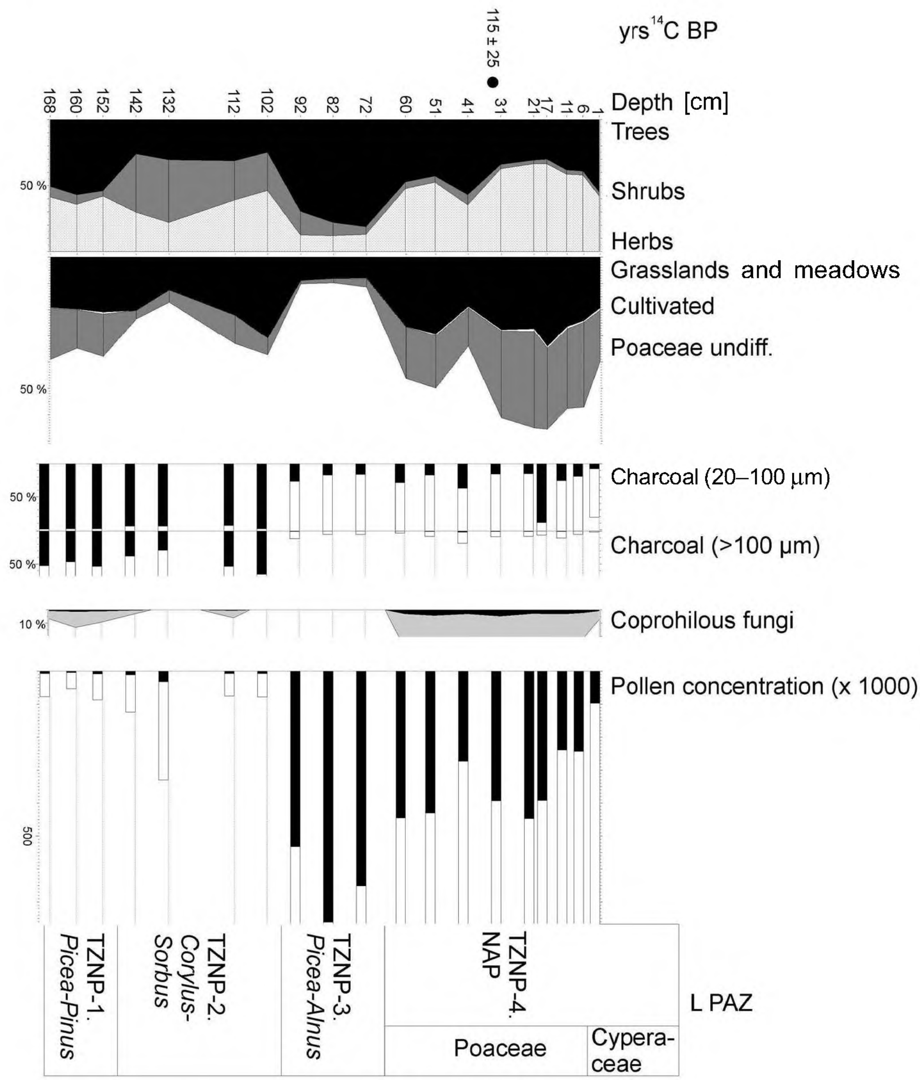

Fig. 6. Pyszniańska glade — human impact. Simplified pollen diagram

Europe (Hungary?) after the First World War (Makra et al. 2005). This fact as well as a decrease of the coprophilous fungi curve at the top of the profile might suggests that prohibition of sheep and cattle grazing established in the Pyszniańska valley in 1927 (Radwańska-Paryska and Paryski 1995) was not rescpected by shepherds.

DISCUSSION

During the last millenium short but significant episode of the evolution of the high-mountain relief of the Western Tatras was the period of the last 300–400 years, which coincides with the climatic deterioration of the Little Ice Age as well as a period of intense human impact (Libelt 1988; Krzemień and Libelt 1996). It has been well imprinted in the sediments filling high-elevated depressions in the bottoms of the Starorobocianski and Pyszniaski glacial cirques. During the late part of the Subatlantic, thick (1,5–2 m) series of bouldery and gravely sediments (B_3 series, according to Libelt 1988, 1990) were deposited here, which points to significant increase in dynamic, frequency and scale of slope processes. The onset of sedimentation of B_3 series varies in altitude and depends on the location of sedimentation basin. In the high-elevated cirque bottom depressions started from the 1,050 ± 50 ^{14}C years BP (883–1150 AD) which pinpoint 85 cm thick, massive layer of bouldery gravel sediments, which have fossilized peat bog in the Siwe Sady site (1,545 m a.s.l; Libelt and Obidowicz 1994). In the lower locations dynamic sedimentation started ca. 500 years later which shows the basal age of the bottom of coarse layers (360 ± 50 ^{14}C years BP, 1449–1639 AD) exposed in the bottom of the Starorobociański cirque (1,450 m a.s.l., Libelt 1988, 1990).

The dominance of very coarse, mineral material and high dynamic of sedimentation in the cirques prevent from preservation of pollen and organic matter, which make it impossible to reconstruct the environmental changes in more details.

Previously examined pollen profiles from the Western Tatra mountains e.g. Siwe Sady (Libelt and Obidowicz 1994) and the Molkówka glade (Koperowa 1962; Obidowicz 1996), present scarce information about the vegetation changes during the last millennium. In the Siwe Sady site continuous peat bog accumulation lasted till 1,050 ± 50 ^{14}C years BP (883–1150 AD) and was replaced by large activity of debris flows (Libelt and Obidowicz 1994), which hindered the most recent palynological background. No information about high number of charcoal particles and lack of *Ambrosia* type grains in the Subatlantic part of the pollen profile from the Molkówka glade (956 m a.s.l.) cause problems with making comparisons with the pollen profile from the Pyszniańska glade. What is more, profile from the Molkówka is lacking in suitable radiocarbon dating spanning of this time period (Koperowa 1962; Obidowicz 1996).

In the upper part of the glacial cirques the main processes of relief transformations were caused by high energy debris flows and ground avalanches, which deposited very coarse sediments, in the lower locations the sedimentation was dominated mainly by fine material (silts and clays) transported by surface and linear slope washing. Sediment profile from the Pyszniańska glade site gives some new insight into the last millenium dynamic of geomorphologic processes, vegetation changes, and human impact in the upper Kościeliska Valley. Relatively large distance (1–1.2 km) of Pyszniańska glade site from the slopes makes its location particularly useful for distinguishing the most pronounced events on slopes, which have been masked by large activity of debris flows in the upper sites. The episodes of high supply of allochthonous material recorded as distinctive layers of coarse clastic material are reflection of the most catastrophic slope processes surrounding the upper Pyszniańska Valley.

The oldest period of dynamic condition of sedimentation consists of five episodes (Ps-111, Ps-120, Ps-131, Ps-140, Ps-150, Ps-165) and corresponds with the TZNP-1 and TZNP-2 pollen zones (Fig. 4). It is marked by higher content of gravels (3–8%) and sands (60–75%), which suggests that slope backwashing was a major process of pollen deposition within the basin. Low pollen concentration and the highest percentage values of corroded sporomorphs, suggest fast sedimentation rate. The pollen spectra indicate intense human impact, which caused forest degradation and almost total deforestation.

A trend of the percentages curve of hazel (*Corylus avellana*) in zone TZNP-2 is very similar to zones B and C_1 zones from the Siwe Sady profile (Libelt and Obidowicz 1994). Radiocarbon dating from Siwe Sady site at the depth slightly above the *Corylus* maximum revealed Atlantic age of sedimentation (4,940 ± 60 ^{14}C years BP, 5,889–5,586 cal. years BP; Libelt and Obidowicz 1994). The age of zone TZNP-2 from the Pyszniańska glade seems to be much younger, which is confirmed by the presence of fir (*Abies alba*) pollen grains in zone TZNP-1 (Fig. 5).

This taxon appeared in the lower part of the Tatra Mountains about 4,500 BP (4,970–5,320 cal. years BP) (Obidowicz et al. 2004). Lack of high number of charcoal particles (especially above 100 μm lenght) in zones TZPN-3 and TZPN-4 seems to exclude the possibility of contamination in this zone by younger sediments during collection of the profile. This distinct increase of percentages of hazel pollen could have been an effect of expansion of this shrub on deforested area which was an effect of the Walachian settlers activity in the lower and higher mountain belt or/and mining and metallurgical development in the upper Kościeliska Valley (Jost 1962). This phenomenon could not have taken place earlier than in the 14th–15th century. The second reason, which caused such significant increase of number of *Corylus* pollen grains in zone TZNP-2 could be connected with high activity of geomorphic processes, which led to slope washing and redeposition of older (Boreal or the Atlantic) sediments from the up valley locations (Fig. 5). This process could have been simultaneous with contemporary pollen and charcoal particles influx. It must be emphasized that neither of the previously examined palinologicaly Tatra profiles from the younger part of the Subatlantic chronozone presented positive correlation between deforestation and such strong extension of hazel distribution (Obidowicz 1996; Rybníčková and Rybníček 2006).

The next period (corresponds with zone TZNP-3) characterized by succession of forest and soil stabilization, which could be correlated with decreasing antropopression (sheep and cattle grazing, forest clearings and metallurgy). During this stage the upper Pyszniańska Valley was affected by the most catastrophic high-energy geomorphic event, which was recorded as the continuous layer of coarse material in the lake depression (Figs. 3 and 4). The appearance of coarse clastic material (38% of gravels, 41% of sands) at the depth of 85 cm is correlated with debris flows activity and intense slope washing (Fig. 4).

The youngest period (corresponds with zone TZNP-4) yielded evidence of second deforestation, which was caused by intense animal husbandry and extension of the grazing area. At the depth of 34 cm the last pronounced pulse of coarse mineral input was deposited in the lake depression (Fig. 4). Interesting issue, which is visible in this part of pollen diagram is the appearance of *Rumex alpinus* pollen curve. Pollen profile from the Pyszniańska glade is the first where the presence of this taxon was detected (Fig. 5). This species grains are probably part of percentages values curves of: *Rumex*, *Rumex acetosa* type lub *Rumex acetosa/acetosella* in the another profiles from the Tatra mountains. The separation of pollen of *Rumex acetosa* type and *Rumex alpinus* was made on the basis that *R. alpinus* sporomorphs are larger, have coarser surface and pores and the pores are vertically elongated in comparison to pollen of *Rumex acetosa* type (Maude and Moe 2006). Identification of this taxon in the Carpathians pollen profiles might be important in the analysis of environmental changes caused by humans.

The most recent phase (subzone TZNP-4b) recorded in the sediments indicates another reforestation caused probably by total cessation of human management and establishment of strict protection of natural environment by the Tatra National Park (TPN) in 1954.

CONCLUSIONS

The sediments filling the depression on Pyszniańska glade site are a sensitive recorder of the last millennium slope processes dynamic, changes in vegetation pattern and human impact in Western Tatra Mts. The sediments are dominated by fine grain material (silts and clays) transported by surface and linear slope washing with intercalations of distinctive layers of coarse clastic material, which are indicators of high-energy geomorphic processes surrounding the upper Pyszniańska Valley.

Taking into account pollen spectra, sedimentation in the described site began probably in the 14^{th}–15^{th} centuries. The first phase of the vegetation development is characterized by a visible deforestation caused by fire clearances or/and mining and metallurgical centers development. High number of hazel (*Corylus avellana*) pollen grains could have been an effect of local occurrence of this shrub on a deforested area or redeposition from sediments (originated from the Boreal or Atlantic period) that lay above the described site. After this episode, pollen diagram suggests period of reforestation and after that another phase of pasture development based on animal husbandry.

ACKNOWLEDGMENTS

This research was financially supported by the Ministry of Sciences and Higher Education (Ministerstwo Nauki i Szkolnictwa Wyższego) — grant No. N N306 282235. We wish to express our gratitude to Wojciech Kłapyta and Monika Karpińska-Kołaczek for the improving the English and Prof. Adam Kotarba and Prof. Leszek Starkel for helpful comments and corrections on the previous version of this paper.

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