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HIGH-MOUNTAIN ENVIRONMENT OF THE TATRAS IN THE PERIOD OF PLEISTOCENE AND HOLOCENE TRANSITION

Abstract

Cores recovered from Lake Czarny Staw Gąsienicowy and dead-ice depression of Żabie Oko, supplemented with detailed geomorphological mapping of deglaciation landforms in main Tatra valleys were investigated to examine high-mountain environmental changes in the period of Pleistocene and Holocene transition. Recessional stages of glaciers in the High Tatra Mountains are parallelized with Alpine Late Glacial and Holocene deglaciation phases. Lacustrine sediment record reflect climatic and floristic changes during early Holocene warming. We suggest that during the cool period of the Holocene (Venediger stade) small glaciers existed in the High Tatra Mountains only in the uppermost locations, i.e. above 1,950 m a.s.l. After 8,300 years BP these glaciers totally melted and upper timberline shifted above 1,400 m a.s.l.

INTRODUCTION

The Tatra massif is the highest located high-mountain area in the Carpathians between the Alps and the Caucasus. Due to its central position in Europe the discussed massif represents the high-mountain environment in the transitional zone between mountains influenced by a maritime climate and Eurasian mountains influenced by continental climate. On the northern slopes the upper timberline currently occurs at height of 1,550 m a.s.l. According to Hess (1965) the present-day orographic snowline documented by permanent existence of large snow patches is at the height of 2,200 m a.s.l. and is determined by the isoline of the mean annual temperature of −2°C. Because of steep slopes and narrow rocky crests above this height accumulation of snow in the Tatras is not possible except for shaded places on the N-facing slopes. According to Lukniš (1973) the present-day climatic snowline occurs at the height of 2,250–2,650 m a.s.l. on the northern Tatra slopes and at the height of 2,700–2,800 m a.s.l. on the southern Tatra slopes where the mean annual temperature reaches almost −4°C and multiannual snow patches occur 600–700 m below, i.e. at the height of 2,000–2,300 m a.s.l. The snowline during the maximum Würm glaciation, as reconstructed by Lukniš (1973), occurred, according to

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calculations of the Höfer method, at the heights of 1,520–1,570 m a.s.l. and 1,600–1,700 m a.s.l. on the northern and southern slopes, respectively. Therefore, the maximum depression of the snowline of 700–1,000 m can be accepted. A definite climatic teleconnection, confirmed by dendroclimatological studies of the Eastern Alps and Tatras (BEDNARZ, 1984) substantiates the attempts to parallel the high-mountain environmental changes in the Alps and the Tatras in the Pleistocene and Holocene.

The studies on the Pleistocene glaciations of the Tatras were initiated as early as in the second half of the 19th century while the attempts to parallel deglaciation phases in the Tatras and in the Alps were undertaken, among others, by PARTSCH (1923), GADOMSKI (1926), KLIMASZEWSKI (1967, 1988) and LUKNIŠ (1973). The most complete presentation of the Tatra glaciers retreat, both from the Slovak and Polish sides, has been provided by LUKNIŠ (1973) who has distinguished, besides the maximum Würm stades (A, B, C), the recessional stades D1, D2, E1, E2 and E3 as well as the stade WH at the Holocene interface and the Holocene stade H. KLIMASZEWSKI initially presumed 6 recessional phases (1967) and then 8–11 such phases (1988).

In the 1970s and 1980s modern studies of lacustrine deposits of the High Tatras were launched by a team of geographers of Warsaw University (KONDRACKI, 1984; WICIK, 1979, 1984; WIĘCKOWSKI, 1984). The first radiocarbon datings of the gyttia deposits filling the lake basins (10,000 ± 140, ITA 1,006 and 9,900 ± 120, ITA 1005) were made in the Tallin laboratory. These datings and the interlaminae with fauna occurring below the gyttia deposits enabled one to draw up an opinion that in the Bölling there were already no glaciers (WICIK, 1979; DZIERŻEK, LINDNER, NITYCHORUK, 1987) at the height of 1,700 m a.s.l. in the Pięć Stawów Polskich valley. When correlating the extents of the moraines BAUMGART-KOTARBA and KOTARBA (1979) formed a hypothesis concerning deglaciation in the Biała Woda and Rybi Potok valleys in relation to the results obtained in the Austrian Alps (PATZELT, 1975). In the case of the moraines surrounding Morskie Oko Lake supposition was that these moraines could be correlated with the alpine Daun-stade.

In the recent years the authors of this paper have obtained a number of new datings of lacustrine deposits and sediments filling the dead-ice depression in the foreland of Morskie Oko Lake (BAUMGART-KOTARBA, KOTARBA, 1993; BAUMGART-KOTARBA, KOTARBA, OBIDOWICZ, 1994). Palynological analyses of the sediments mentioned above were made by A. OBIDOWICZ (1993). In the lacustrine deposits of the High Tatras there are recorded changes of the high-mountain environment of the Tatras. Sedimentological properties of these deposits supported by palynological analyses and by absolute datings allow for reconstruction of conditions which have existed in the surroundings of the lakes and especially on the slopes being in the direct contact with the lakes. The aim of this paper is to present the changes of the high-mountain environment of the Tatras in the period of the Pleistocene and Holocene transition until the Subboreal.

RETREAT OF GLACIERS IN THE POLISH HIGH TATRAS

Climatically conditioned changes of the high-mountain environment of the Tatras are evidenced by a sequence of frontal and lateral moraines. This sequence indicates the maximum extent of glaciers during the last glaciation and the glaciers recession. The TL-dating method should not be employed because it is not reliable for the moraine age determination although it has been used in the Tatras by LINDNER, DZIERŻEK, NITYCHORUK (1990), so the study should be based on geomorphological evidence and on the sites whose deposits are documented by lithological-sedimentological indication, ^{14}C-dates and palynological analyses. In the Polish part of the Tatras there are 4 such sites up to now. These are the mentioned in the introduction deposits of Przedni Staw Lake in the Pięć Stawów Polskich valley, deposits of Czarny and Zielony Staw Gąsienicowy lakes and deposits of the moraine depression Żabie Oko in the foreland of the moraines of Morskie Oko (Fig. 1). The paper presents the main evidence from two sites: Czarny Staw Gąsienicowy Lake and Żabie Oko.

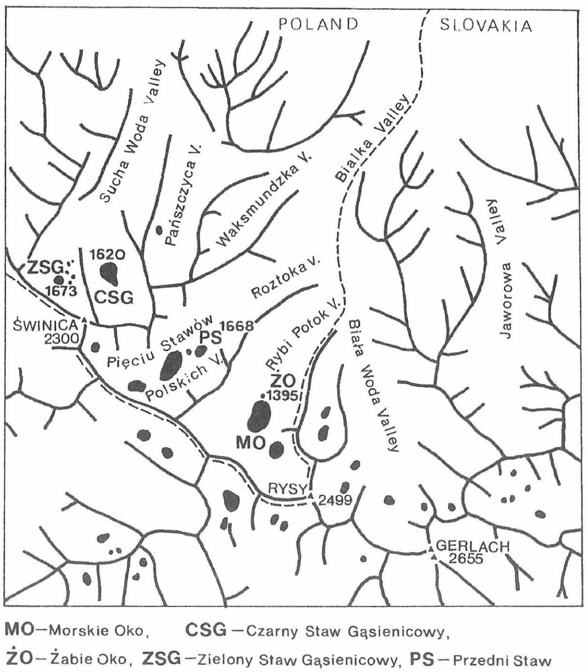

Fig. 1. Location of study areas in the High Tatra Mountains

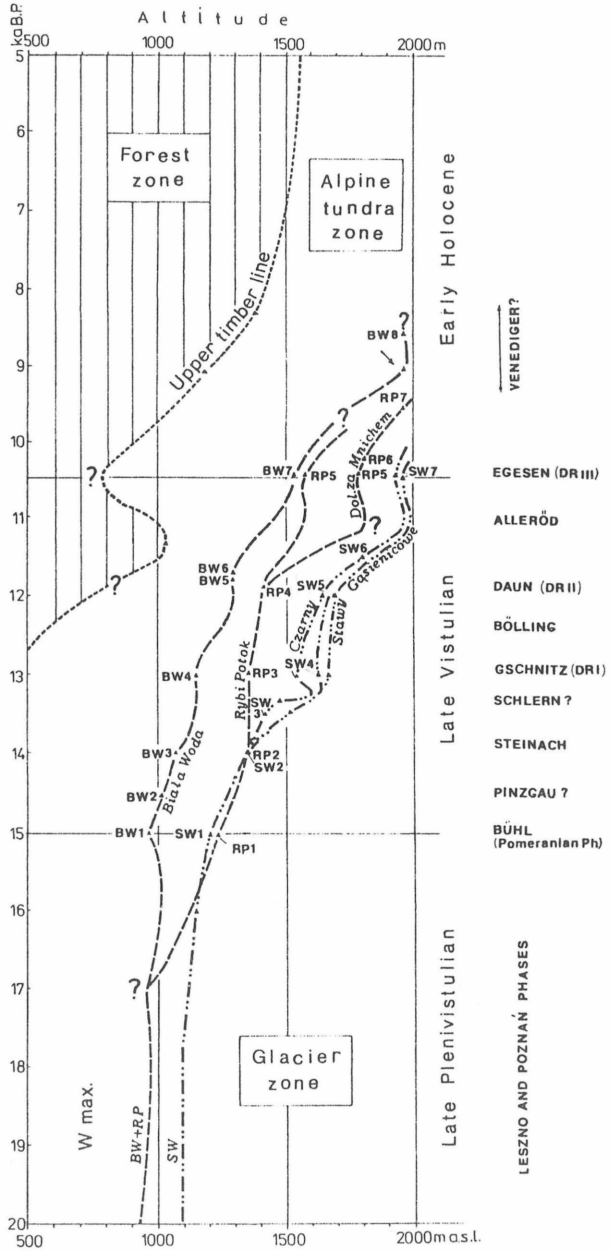

Fig. 2. The course of deglaciation and formation of alpine tundra zone and forest zone in the High Tatra Mountain between 20 ka and 5 ka BP

The extent of largest valley glaciers: BW – Biała Woda glacier, RP – Rybi Potok glacier, SW – Sucha Woda glacier

Results of the 1:10,000 geomorphological mapping in a few Tatra valleys which has been carried out since 1985 are summarized in the longitudinal profiles of these valleys. In the profiles there are also marked the extents of maximum glaciations and the recession stages, the frontal and lateral moraines as well as the clear outwash fans which are substantial if the moraines have poorly been preserved. Moreover, there have been introduced the indicators of positions of the moraines providing evidence of junction of the main and tributary glaciers. An independent numbering 1–7 (8) preceded by a letter has been accepted to indicate recession stages in particular valleys: BW – Biała Woda Valley, RP – Rybi Potok Valley and SW – Sucha Woda Valley. In this paper, Figure 2 presents the attempted correlation of recession stages of the two largest valleys – the Biała Woda and Sucha Woda valleys. Among the valleys yielding to the Biała Woda valley only that of Rybi Potok has been considered. The curve illustrating the position of the upper timberline has been drafted based on the data of KOPEROWA (1962) and OBIDOWICZ (1975, 1993).

Location of moraines, found at the height of 1540 m a.s.l., i.e. below Czarny Staw Gąsienicowy Lake (SW4), turned out to be important in constructing the synthetic scheme of deglaciation. Based on the analysis of the deposits filling Czarny Staw Gąsienicowy and on the date 12,500 ± 420 BP (Gd-4,540) the above location has been accepted the age corresponding to the alpine moraines of Gschnitz stade dated at 13 ka BP (BAUMGART-KOTARBA, KOTARBA, 1993). The equivalents of the SW4 stade in the Dolina Stawów Gąsienicowych valley are found below Litworowy Staw Lake (1,660 m a.s.l.). They were easy to have been correlated due to similar shape of the moraines which provides the evidence of the glacier advance into the foreland (an oscillation). In the case of the Rybi Potok Valley substantial factors have become the age and the type of sediments filling the Żabie Oko dead-ice depression (1,390 m a.s.l.), the latter occurring at the foreland of the Morskie Oko moraines (1,416 m a.s.l.). The Morskie Oko moraines (RP4) have been accepted to correspond to the alpine Daun stade (12 ka BP) while the moraine ridge RP3, occurring at the height of 1,360 m a.s.l. to Gschnitz stade (Fig. 3). Moraines RP2 delimit the extent of the much more immense and thicker glacier tongue yet terminating similarly at the height of 1,360 m a.s.l. Stade RP2 has been accepted to correspond to the alpine Steinach stade. It seems that stade RP1 with the moraines at the height of 1,300 m a.s.l. was the first stage of the retreat of the glacier of the Rybi Potok Valley which had not fed the glacier of the Biała Woda Valley. Stade BW1, marked by LUKNIŠ (1973) with symbol WD in the Biała Woda Valley, is the equivalent of Stade RP1. The extent of stade BW1 in the largest glaciated Tatra valley was only slightly smaller than the location of the maximum moraines, however, it represented only a tiny and narrow glacier which, as to the thickness, cannot be compared

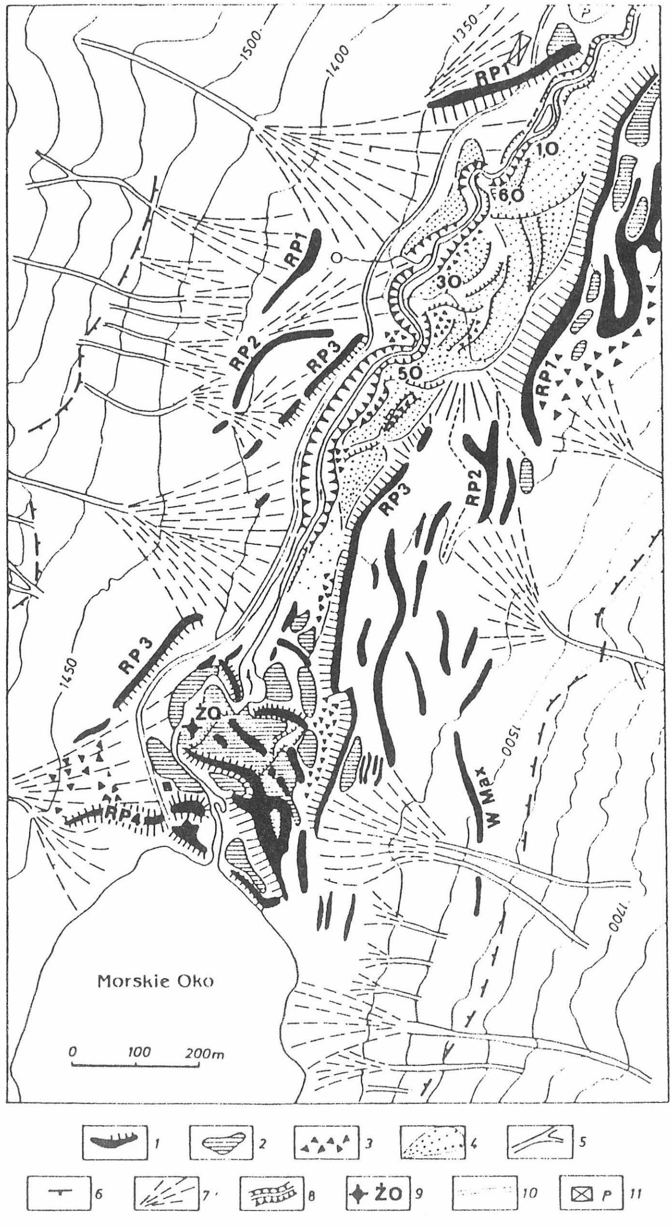

Fig. 3. Moraine-ridge sequence on the foreland of Lake Morskie Oko
1. distinct moraine ridge, partly steep; 2. dead-ice depressions locally filled with glacifluvial deposit and peat cover; 3. rockfall/rockslide or glacial drift boulders; 4. glacifluvial terrace or cone; 5. rocky chute; 6. glacial trough extent on slope; 7. alluvial/avalanche talus cone; 8. erosional scarp and present channel; 9. location of Żabie Oko core; 10. road; 11. parking place and buildings

with the glacier of the Biała Woda Valley at the period of feeding by glaciers of all the tributary valleys. Stades BW1 (960 m a.s.l.), RP1 (1,300 m a.s.l.), SW1 (1,216 m a.s.l.) seem to correspond to the alpine Bühl stade and to the Pomeranian stage in Polish Lowland. Large height differentiation of this stade extent is conditioned by a size of supply areas. The extent was the farthest in the case of the Biała Woda glacier fed by some tributary glaciers.

RECONSTRUCTION OF DEGLACIATION IN THE RYBI POTOK VALLEY ON THE BACKGROUND OF THE ANALYSIS OF THE DEPOSITS OF THE ŻABIE OKO DEAD-ICE DEPRESSION, 1,390 M A.S.L.

In the direct foreland of the Morskie Oko moraines (RP4) the system of crevasse forms and dead-ice depressions associated with melting of dead-ice (Fig. 3) has developed. The crevasse genesis of the ridges can be inferred from their geometrical distribution, and especially from their crossing at the right angle. Proglacial waters drained the Żabie Oko depression. The latter, located at the height of 1,390 m a.s.l. was subsequently filled with various mineral deposits, and then by layers of silty deposits with some organic materials, mainly plant detritus, and next it was again filled with mineral deposits, mainly sandy ones, and finally with organic silts on which peat (Fig. 4) had been forming since 8,300 BP. In the Żabie Oko deposits there are records of geomorphic processes from the glacier retreat in this part of the valley until the Holocene accumulation of peats (Baumgart-Kotarba, Kotarba, Obidowicz 1994). The lithological-sedimentological analysis of the deposits laid down in the depression, supported by the ^{14}C-dates, allows one to reconstruct the timing of the processes modelling the valley bottom. The palynological analysis performed by A. Obidowicz provides arguments as to the climatic conditions – points to alternating periods of cooling and warming. The deposits sampled from the Żabie Oko are 5.5 m thick, within which there is 3.5 m of peat. Coarse sands and gravels (the lower ones 70 cm) indicate the largest discharges which accompanied the filling of the dead-ice depression. Such conditions could only have existed during the more intensive washing out of the Morskie Oko moraines. The resting on these deposits, laminated yellow and ferruginous silts and yellow sands, are the deposits of slowly flowing and drying out waters. They had been developing under the cold mountain tundra climate. A large percentage (40–50%) of herbaceous pollen evidences the above while the pollen grains of *Betula*, *Pinus cembra*, *Pinus silvestris/mugo* indicates a significant distance from the forest limit (Obidowicz, 1993). The overlying silts contain laminae with plant detritus, and the pollen points to the increase of the *Pinus* curve and to the decrease in the herbaceous plants to 20%. Undoubtedly, this is the proof of the warm-

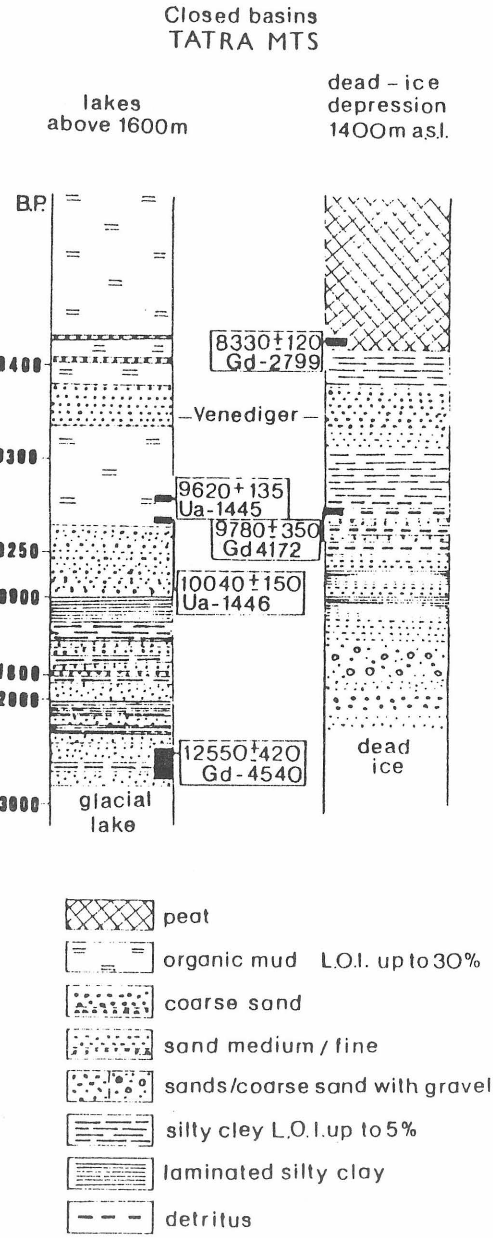

Fig. 4. The stratigraphy of Lake Czarny Staw Gąsienicowy sediment (left column) and Żabie Oko dead-ice depression sediment (right column)

ing which is attributed by the authors to the beginning of the Holocene and by A. OBIDOWICZ to Allerød (BAUMGART-KOTARBA, KOTARBA, OBIDOWICZ, 1994). The Holocene age of this warming is evidenced by the date 9,780 ± 350 BP, percent of detritus, and the change in colour of the deposits from yellow to dark grey brownish when wet, resembling a clear Holocene border known from the lacustrine deposits (WICIK 1979; BAUMGART-KOTARBA, KOTARBA, 1993).

Geomorphic processes in the vicinity of Żabie Oko can be reconstructed as follows:

– formation and occurrence of the dead-ice in the period Bølling–Daun;

– glacier stagnation on the Morskie Oko moraines (RP4) in the Daun period;

– intensive melting of the glacier and formation of Morskie Oko Lake, and the associated deposition of coarse sands and gravels in the Żabie Oko depression during the Allerød;

– hanging glaciers stagnation on moraines RP5 (Czarny Staw pod Rysami Lake 1,600 m a.s.l., the Dolina za Mnichem valley 1,793 m a.s.l.) in the period of the Younger Dryas; very small outflow from Morskie Oko Lake to Żabie Oko Lake probably under conditions of prolonged freezing of the lake;

– intensive melting of glaciers at the beginning of the Holocene; in the Żabie Oko depression the silts with detritus provide evidence of fairly stable discharges controlled by outflow from Morskie Oko Lake;

– increased drainage of Morskie Oko Lake and deposition of sands (20–40 cm below the peat series) during the period of a definite cooling, being probably the equivalent of the alpine Schlaten Stade or Venediger Stade;

– permanent accumulation of peat during the last 8,300 BP evidences the large stability of the environment at the foreland of the dissected Morskie Oko moraines;

– the date 8,300 BP indicates the termination of the Ice Age in the Tatras as since then the upper timberline has raised already above 1,400 m a.s.l. which is evidenced by 10% of herbaceous plant (NAP).

The Żabie Oko deposits had provided palynological evidences of the cooling in the Boreal period during which the herbaceous plants again reached 40–50%. Increased discharges (deposition of sands), despite the control of the lake, indicate that this period was characterized by larger summer precipitation. At that time there were still appropriate climatic conditions for the presence of glaciers in the Tatras, although the warming of the beginning of the Holocene could likely have caused disappearance of many glaciers (Fig. 2). Probably, during the Venediger cooling the glaciers survived in the uppermost vertical zones of the Biała Woda Valley, and a small glacier at the height of 1,950 m a.s.l. in the Dolina pod Cubryną, in the Rybi Potok Valley.

RECONSTRUCTION OF ENVIRONMENTAL CHANGES ON THE BACKGROUND OF THE LACUSTRINE DEPOSITS ANALYSIS

In the sediments of Czarny and Zielony Staw Gąsienicowy lakes as well as of Przedni Staw lake in the Pięć Stawów Polskich Valley there is the most pronounced border between the Late Glacial, light grey mineral section and the Holocene dark brownish one due to the fast increase in the organic matter content from 1–5% to 15–25% (loss on ignition). This border is noticeable both in the deposits of the lakes to which material is delivered directly from the debris cones at the foot of the rocky walls (Czarny Staw Gąsienicowy lake) and in the deposits of the lakes separated from the rocky walls by relatively long slopes. The date obtained in the bottom of dark silts was 9,620 ± 135 BP (Ua-1,445) in Czarny Staw Gąsienicowy Lake, 10,040±150 BP (Ua-1,446) in Zielony Staw Gąsienicowy Lake (Baumgart-Kotarba, Kotarba, 1993) and 9,900±120 BP (ITA-1,005) in Przedni Staw Lake (Wicik, 1984). The well documented profile of Czarny Staw Gąsienicowy Lake provides a good basis for the analysis of a few elements of the discussed border. There is a coincidence between a rapid increase in the absolute concentration of pollen (Obidowicz, 1993) and an increase in the values of the loss on ignition: 3–5–8–18%. The lithological border is best correlated with the increase in the absolute pollen concentration and agrees with the content of organic matter exceeding 5%. On the other hand, the date 9,620 BP corresponds to the horizon with the organic matter content of 18%. The border between the Younger Dryas and the Holocene based on the pollen percentage diagram (Obidowicz, 1993) is marked 10 cm below within the massive sands with the 1.5% content of organic matter which causes some doubts.

Lithology and sedimentation structures of lacustrine deposits of Czarny and Zielony Staw Gąsienicowy lakes, depicted on X-ray photographs, are not only the records of sedimentation processes but also the reflection of the geomorphic processes on the slopes directly surrounding the lakes (Fig. 5) and of the processes in the upper parts of the drainage basins, especially under conditions of melting glaciers. In the Late Glacial section of the deposits of Czarny Staw Gąsienicowy Lake there are pronounced 15–20 cm thick, massive sands and silty sands of the Younger Dryas. These sands point to intensive geomorphic processes, probably of debris flow type, developing on slopes in this period. Below, in the 65 cm long core there are alternating 2–3 cm thick massive layering and thin layering resembling the laminated deposits. Based on lithological-sedimentological differentiation, the more massive layering has been related to the cooler period while the clear fine laminae to the periods of warming in Bølling and Allerød (Baumgart-Kotarba, Kotarba, 1993). The massive layering refers to sands with silts (M_{50} =130 and 180 µm – based on the laser analy-

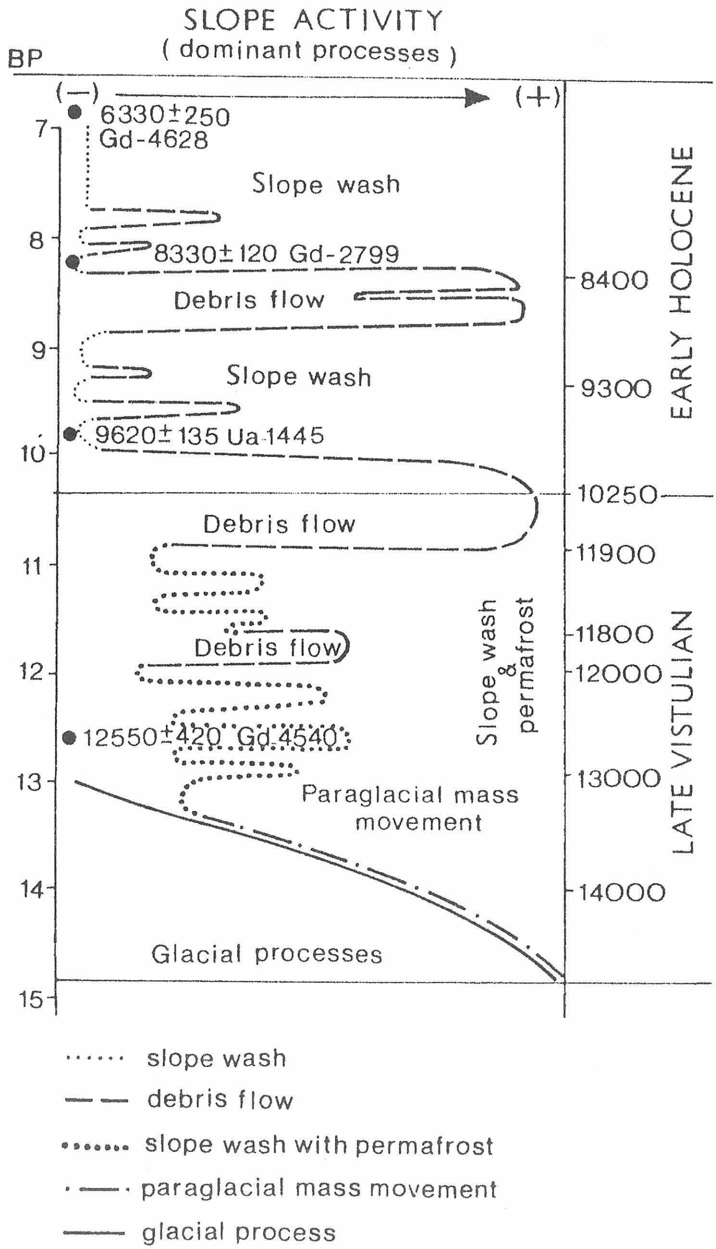

Fig. 5. Slope activity in the High Tatra Mountains above 1600 m a.s.l. between 15 ka and 7 ka BP. Lake sediments provide a high-resolution record of past geomorphic processes

sis by "Analysette" of Fritsch Co.) and to clayey-silty deposits (M_{50} between 11 and 14 μm). The laminated, lighter deposits are characterized by the median value of 42 μm while the darker ones by 7–12 μm. The lithologically determined periods of warming are confirmed by larger pollen concentrations (Obidowicz, 1993) but not by the pollen percentage diagram. Based on the pollen percentage analysis the warmings of the Bølling and the Allerød are better expressed in the palynological profile and in the distinguished diatom phases in Przedni Staw lake in the Pięć Stawów Polskich Valley (Krupiński, 1984: Marciniak, Cieśla, 1983).

The geomorphological and sedimentological studies in the glaciarized mountains point to the intensive phase of formation of debris slopes just after the retreat of the glacier. This phase has been called "paraglacial" (Johnson, 1984). It is characterized by degradation of permafrost, increase in thickness of an active layer and relaxation of the rocky surfaces after the glacier retreat. Therefore, the beginning of the lacustrine sedimentation was associated in the Tatras with intensive mass movement. In the whole Late Glacial period the debris slopes were probably modelled by solifluction and slope wash in summer seasons. The X-radiographs of the lacustrine deposits which currently are developing in the mountains of the northern Scandinavia at the direct foreland of small valley glaciers and cirque glaciers indicate that these are irregularly laminated sediments and they do not show features of the varved clays (Jonasson 1991). The content of organic matter in these deposits is similar (2–5%) and sedimentologically they very much resemble the Late Glacial sediments in Czarny Staw Gąsienicowy Lake. The sedimentary similarity of thin layers within the laminated deposits provides the evidence that in the periods of warmings of Bølling and Allerød, in Czarny Staw Gąsienicowy Lake, there were similar conditions of the supply of material directly from the slopes and from the glacier melting in the upper part of the valley. At that time sedimentation was influenced by the prolonged freezing of the lake.

A drastic change of the lake deposits since the beginning of the Holocene (Fig. 4) indicates fundamental changes in delivery from the slopes. The increased content of organic matter, up to 20% in Czarny Staw Gąsienicowy Lake and 30% in Zielony Staw Gąsienicowy Lake is probably associated with the development of the first soil and plants on the slopes. The silty-clayey deposits with the median of 10–20 μm evidence the lower energy processes on the slopes as the turbidity currents did not transport sandy deposits to the centre of the lake. Both the Boreal and the Atlantic period were characterized by the predominating calm sedimentation interrupted by singular sandy inserts (Fig. 4). These inserts show up very well on X-ray photographs and are the evidences of the catastrophic rains or rather of the periods with intensive rains which generated debris flows on talus cones. The so induced turbidity currents supplied sandy materials, sometimes with granite particles, to the centre of the lake. At the Boreal/Atlantic interface, in all 4 cores sampled from the lake there are massive sandy layers of the thickness of 4–10 cm. These layers are called series "a" (BAUMGART-KOTARBA, KOTARBA, 1993). The size of sand grains with the median grain-size value of 260–300 μm points to a large dynamics of geomorphic processes. The dynamics was also as large in the Subboreal period when the 1–2 cm thick sandy interbeddings with the median value of 220–310 μm appeared on the organic silts. The age determination of this intensified sandy sedimentation was not successfully accomplished in the case of the deposits of Czarny Staw Gąsienicowy. Therefore, this period has been correlated with the alpine Venediger Stade (Fig. 4) by comparison with the position of sandy deposits in the Żabie Oko dead-ice depression. With respect to sedimentology the series "a" in the lacustrine deposits resembles indeed the sandy series of the Younger Dryas. Thus, these two series were likely deposited under severe climatic conditions. At this height, the Boreal period was still very cold which is indicated by the NAP value of 30–40% (OBIDOWICZ, 1993). The NAP value of 10–20% in the Atlantic period indicates the rise of the climatic-vegetation vertical zones. Based on the palynological profile of Czarny Staw Gąsienicowy Lake the spruce forest reached its maximum height just at the beginning of the Subboreal period (OBIDOWICZ, 1993).

CONCLUSIONS

In the period which passed from the maximum extent of the Würm glaciations (Vistulian) in the main Tatra valleys, correlated with the Leszno and Poznań phases in Polish Lowland, until the final deglaciation before the Atlantic three stages of the development of the Tatra environment can be distinguished:

a) the stage of recession of long glacier tongues; in this stage the main tongue was receiving the smaller and smaller supply from the tributary ones and the latter were becoming separated glaciers. This stage includes the period since the development of recession moraines related to the alpine Gschnitz stade. This period probably lasted ca. 4 thousand years;

b) the stage of Gschnitz-Daun-Egesen recession; the extent of the Gschnitz Stade reconstructed on the basis of the sites of the deposits of Czarny Staw Gąsienicowy Lake and Przedni Staw Lake in the Pięć Stawów Polskich Valley is represented by pronounced moraine ridges evidencing the longer glacier stagnation. Recession in the Gschnitz-Daun-Egesen period has been reconstructed based on the sediments of the site in Żabie Oko. Intensive mass movements in this period are also indicated by the lacustrine deposits in the valley free from ice (Czarny Staw Gąsienicowy Lake).

Predominance of the slope delivery is confirmed by the fact that larger underwater deltas have not developed in the proglacial Tatra lakes due to the small sizes of the catchments located above the lakes and due to the significant role of the block bottom moraines in trapping fine materials. This stage lasted ca. 3 thousand years;

c) the early Holocene stage of warming and glacier decay in majority of the valleys (the Preboreal, Boreal); during the last cold oscillation (Venediger) small glaciers were preserved only in the Biała Woda Valley and probably in the uppermost parts of the Rybi Potok Valley and Pięć Stawów Polskich valley. This cooling, expressed in increased values of NAP to 40%, was the period of larger summer precipitation as it has caused a significant deposition of sands in the lacustrine environment Czarny Staw Gąsienicowy Lake as well as in the drained Żabie Oko depression. The Holocene upward shift of the altitudinal belts of the alpine tundra and dwarf pine has been stopped by the Venediger cooling. Therefore, the zone of the upper timberline reached the height above 1,400 m a.s.l. at the turn of the Boreal and Atlantic periods (8,300 BP) and its next rise occurred in the Subboreal period (Obidowicz, 1993).

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