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WÜRM GLACIATION IN THE BIAŁA WODA VALLEY, HIGH TATRA MOUNTAINS

INTRODUCTION

Glacial landforms and sediments were identified in the Tatra Mountains in 1856 by Polish geologist L. Zeuschner. Since that time many researchers visited the area and important synthesis has been published. The most important theses were put forward by J. Partsch (1923), E. Romer (1929), B. Halicki (1930), M. Lukniš (1973) and M. Klimaszewski (1964, 1987, 1988). Synthetic work of M. Klimaszewski (1988) documents long-time history of the research on glacial morphology of the Polish Tatra Mountains. Despite long-standing recognition of the wide spread occurrence of glacial features in the Tatras summarized in the geomorphological map in the scale 1:30,000 published by M. Klimaszewski (1988) our understanding of the glacial sedimentary sequences, the chronology and geomorphological significance of Pleistocene glacial activity is still disputable. J. Partsch synthesis published in 1923 contains description of three glacio-fluvial levels with boulders and gravels outside the Tatra Mountains.

E. Romer (1929) has distinguished four glaciations. The more modern researchers are supporting the idea of three glaciations (Halicki 1930, Lukniš 1973, Klimaszewski 1964, 1987, 1988), while L. Lindner et al. (1993) say even about five glaciations during the last 500 thousand years. However, this chronology is based on thermoluminescence. J. Partsch (1923) identified the maximum extents of Pleistocene glaciers in the High Tatra Mts (length, width, thickness of glaciers), finding the Riss extent larger than the Würm one and recognised four recessional moraines formed during the Late Würm. M. Klimaszewski (1964) found six stages or six to eight stages (Klimaszewski 1988), while M. Lukniš (1973) found eight moraine ice frontal positions. According to J. Partsch idea, the Tatra Mountains were covered by extensive ice cap. Modern syntheses support the opinion that valley glaciers dominated during the glaciations in the Tatra Mountains.

The aim of this paper is to document the results of our field studies which we have been carrying out since 1976 (Baumgart-Kotarba and Kotarba

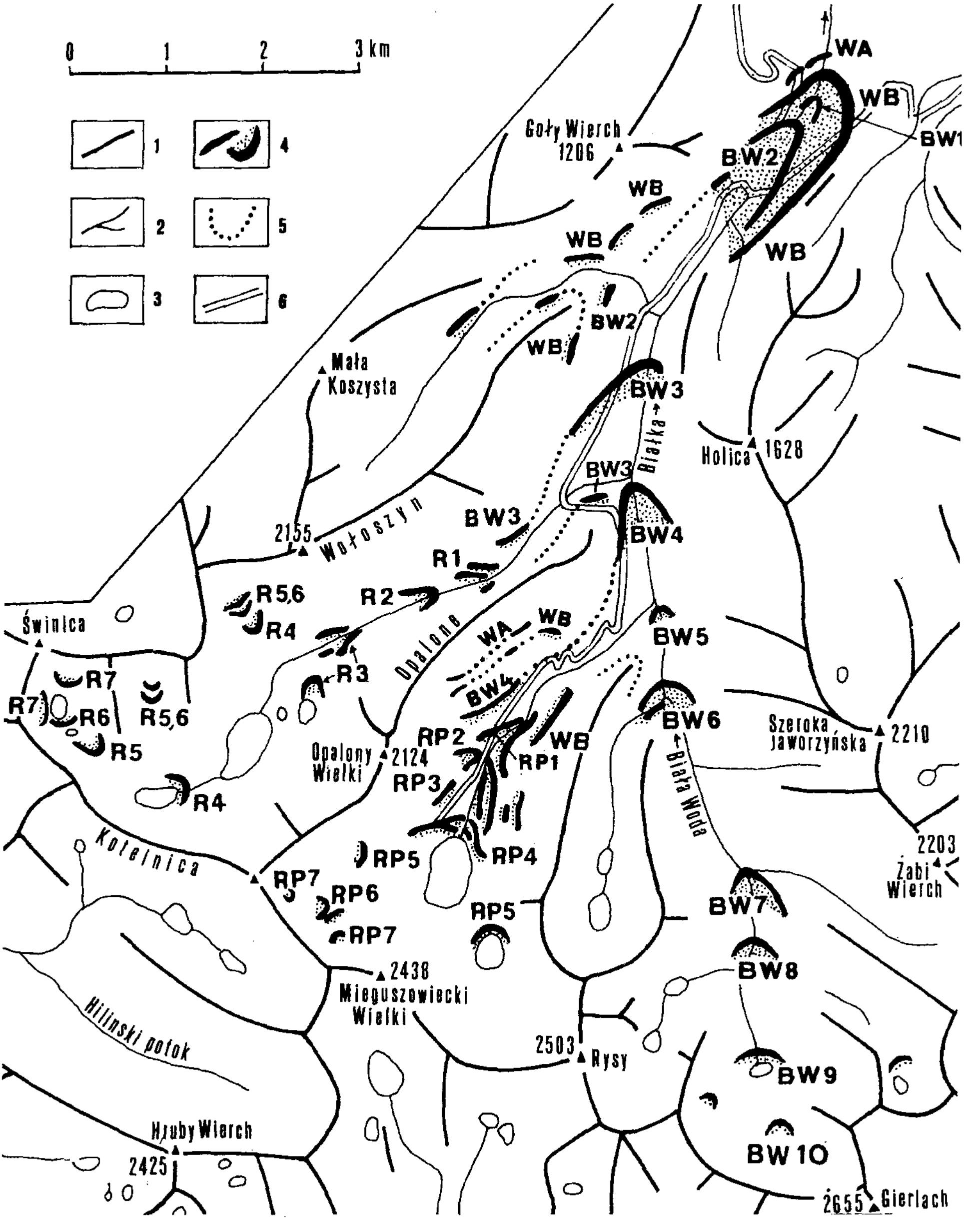


Fig. 1. The extent of Würm glaciation in the Biała Woda valley (WA, WB) and its recessional stages (BW1–BW10) and in tributary valleys; Roztoka Valley (R1–R7), Rybi Potok Valley (RP1–RP7). 1 — mountain ridges, 2 — streams, 3 — lakes, 4 — moraine ridges, 5 — reconstructed extents, 6 — turist road Łysa Polana–Morskie Oko

Ryc. 1. Zasięg lodowca würmskiego w Dolinie Białej Wody (WA, WB) i jego stadia recesyjne (BW1—BW10) oraz w dolinach zasilających; Roztoki (R1–R7), Dolinie Rybiego Potoku (RP1–RP7). 1 — grzbiety górskie, 2 — potoki, 3 — jeziora, 4 — wały morenowe, 5 — rekonstruowane zasięgi, 6 — szosa Łysa Polana–Morskie Oko

1979). This study refers to the Würm glaciation, mainly to the main stadial and its recessional stages. The second purpose is to discuss the results of similar research performed in the Tatra Mountains.

GEOGRAPHICAL SETTING

The central portion of the High Tatra massif forms the highest part of the mountains where elevations exceed 2,500 m a.s.l. The Biała Woda valley is the longest valley on the northern slope of the Tatra Mountains, and in the past, it formed the longest glaciated system in this highest massif of the Carpathian arc. The Biała Woda valley is dominated by extensive, large-scale erosional features, i.e. glacial cirques and troughs forming hanging system (Fig. 1) carved into the hard granodiorite bedrock and the wide spread glacial drift (a series of terminal and recessional moraines) with associated glacio-fluvial landforms. In the northern portion of the area the Mesozoic sedimentary series are folded and thrusted on "autochtonous" series laying directly on a crystalline core. The Biała Woda valley follows the fault zone between tectonic depressions of the Szeroka Jaworzyńska and the Koszysta elevation, main transversal structures of the High Tatra. Although this massif raises above the upper timberline and the mean annual air temperature on the highest peaks reaches –4°C, glaciers do not exist at present. The area is classified as a true high-alpine glaciated relief without recent glaciers.

CURRENT STUDIES ON GLACIAL GEOMORPHOLOGY IN THE HIGH TATRA MOUNTAINS DURING THE LATE WÜRM PERIOD

Results of the 1 : 10,000 geomorphological mapping in the main Tatra valleys which has been carried out by the authors of this paper are compiled in the longitudinal profiles of these valleys. Both the extents of maximum glaciations and the recession stages marked by frontal and lateral moraines are introduced as indicators of positions of glaciers during the Late Glacial period. An independent numbering system has been introduced to indicate recession stages in particular valleys: BW — Biała Woda valley, RP — Rybi Potok valley and R — Roztoka valley. In the recent years the authors of this paper have obtained a number of radiocarbon datings of lacustrine deposits from Czarny Staw Gąsienicowy Lake, Zielony Staw Gąsienicowy Lake and sediment filling the dead-ice depressions; Żabie Oko in the foreland of Morskie Oko frontal moraine ridge (Baumgart-Kotarba, Kotarba 1993, 1994, 1995, Baumgart-Kotarba et al. 1994) and Kurtkowiec Lake in the Sucha Woda valley. In addition, palynological analyses (Obidowicz 1993) and sedimentological properties of these deposits allow for reconstruction of deglaciation conditions which existed in Tatra valleys. The above mentioned data are compared with J. Partsch's (1923), M. Lukniš's (1973) and M. Klimaszewski's (1988)

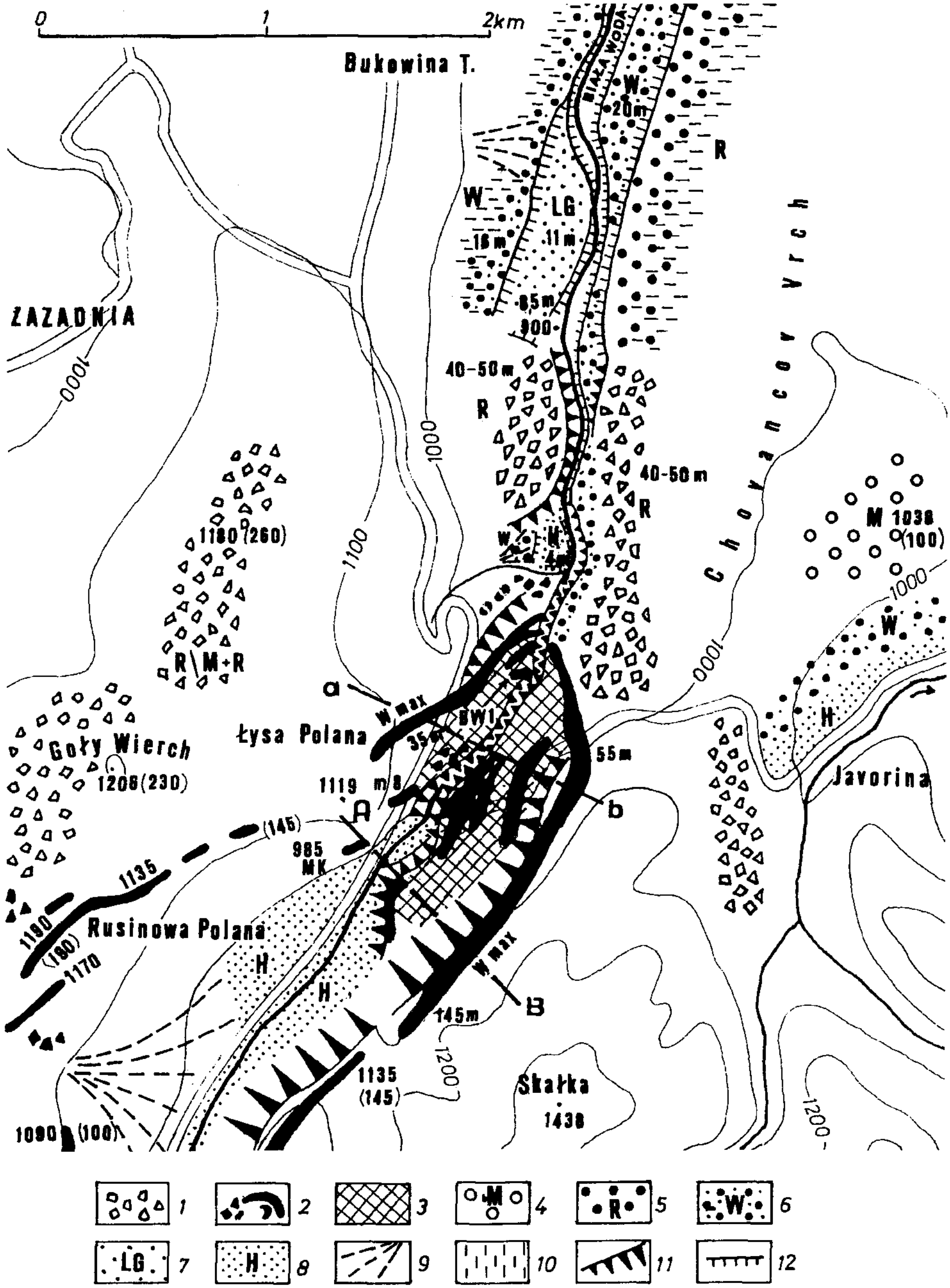


Fig. 2. Landforms and sediments related to deglaciation in the area of terminal moraines in the Biała Woda Valley. 1 — glacial drift deposits (boulders), Riss/Mindel–Riss in age, 2 — moraine ridges, frontal and lateral with boulders, Würm, 3 — terminal depression of Łysa Polana, 4 — glacio-fluvial cover ("Schotterdecken" according to Partsch 1923), Mindel, 5 — glacio-fluvial cover, Riss, 6 — glacio-fluvial cover, Würm, 7 — glacio-fluvial terrace, Late Glacial, 8 — fluvial terrace, Holocene, 9 — alluvial cone, 10 — solifluction cover, 11 — erosional undercut, scarp, 12 — terrace edge

findings and with other more modern studies which are based on palynological data (Wicik 1984, Krupiński 1984, Lindner et al. 1990 and others). The new geological map of the Tatra Mts (Nemčok et al. 1995) presents the last opinion about the deglaciation, but the presented chronology is very disputable.

MAXIMUM EXTENT AND TWO RECESSIONAL OSCILATIONS OF THE BIAŁA WODA GLACIER NEAR ŁYSA POLANA

The most complete presentation of the Tatra glaciers retreat, both from the Slovak and Polish side, was provided by M. Lukniš (1973) and M. Klimaszewski (1988). They used geomorphological criteria for reconstructing recessional stages. In this paper we combine results of our field study with geomorphological data from the maps and synthetical works of both famous scientists, as well as we correlate recessional stages of the largest valley in the Polish Tatra Mountains with those from the Austrian Alps (Patzelt 1975, 1995). In the Tatra Mts there are three main sites that are very important for evaluation of deglaciation chronology: Czarny Staw Gąsienicowy Lake in the Sucha Woda valley, Żabie Oko in the Rybi Potok valley (Baumgart-Kotarba, Kotarba 1994, 1995, Baumgart-Kotarba et al. 1996) and Przedni Staw Lake in the Five Polish Lakes valley (Dolina Pięciu Stawów Polskich) and the Roztoka valley (Wicik 1984, Krupiński 1984, Dzierżek et al. 1987). Based on the analysis of the deposits filling Czarny Staw Gąsienicowy Lake (1,620 m a.s.l.) and on the date 12,500 ± 450 BP (Gd-4,540) for the moraine SW4 located in front of the lake, the age corresponding to the alpine moraines of the Gschnitz stage has been accepted (Baumgart-Kotarba, Kotarba 1994). In the case of the Rybi Potok valley substantial factors have become the age and type of sediments filling Żabie Oko dead-ice depression (1,390 m a.s.l.), the latter occurring at the foreland of Morskie Oko moraines (1,416 m a.s.l.). Therefore, Morskie Oko distinct moraine ridge have been accepted to correspond to the alpine Daun stade (12 ka BP) (Baumgart-Kotarba, Kotarba 1994).

The maximum extent of the Würm glaciation in comparison with larger extent of the Riss glaciation was described by J. Partsch (1923) in the Biała Woda valley. The larger Riss extent is documented by coarse moraine and glacio-fluvial boulders in the valley bottom at the height of 940–950 m a.s.l. (40–50 m relative height) and on the levelled ridges at the height 1,200–1,180 m (230–260 m relative height) (Fig. 2). Highly elevated moraine deposits on the

Ryc. 2. Formy i osady związane z deglacjacją w strefie moren końcowych lodowca Białej Wody. 1 — głazy morenowe, riss/mindel-riss, 2 — wały morenowe czołowe i boczne z głazami, würm, 3 — zagłębienie końcowe Łysej Polany, 4 — pokrywa glacifluwialna („Schotterdecken" wg Partsch 1923), mindel, 5 — pokrywa glacifluwialna, riss, 6 — pokrywa glacifluwialna, würm, 7 — terasa glacifluwialna, późny würm, 8 — teresa rzeczna, holocen, 9 — stożek napływowy, 10 — pokrywa soliflukcyjna, 11 — podcięcie erozyjne, 12 — krawędź terasy

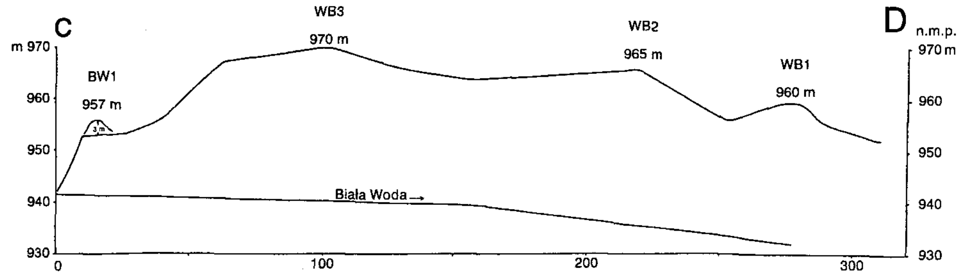


Fig. 3. Profile across moraine ridges marking maximum extent of Würm glaciation, and position of the ridge BW1 — the first recessional moraine (small oscilation)
Ryc. 3. Profil w poprzek wałów morenowych wyznaczających maksymalny zasięg zlodowacenia würmskiego oraz pozycja wału BW1 znaczącego pierwszą morenę recesyjną (mała oscylacja)

ridge documents an existence of more than 230 m thick glacier tongue during the Riss glaciation. Such very high position of the Riss material is also related to the valley bend near Łysa Skała. The Goły Wierch–Hurkotne ridge is located on prolongation of 4 km long and straight valley section.

The extent of the Würm glaciation is marked by distinct moraine ridges WB1, WB2, WB3 on the Polish side and WB in Slovakia (Fig. 3, 4). In front of the moraine ridge WB1 on the Polish side one can observe bouldery deposition — remnant of previous frontal moraine ridge (WA). It can be correlated with Stadial A (Rakytovec) according to M. Lukniš (1973). Longitudinal profile near Łysa Polana area documents the following complexes of forms — terminal and lateral moraine ridges with terminal depression and transitional cone with coarse moraine/glacio-fluvial blocks up to 3 m in diameter (Fig. 6). The maximum length of the largest Biała Woda glacier was 13.3 km. We can distinguish the maximum Würmian extent of the Biała Woda glacier as a zone of big moraine blocks named WA at the height of 945–950 m a.s.l. and two distinct terminal ridges at the heights 960 and 965 m (WB1, WB2) on the Polish side and very well preserved lateral moraines WB on both sides of the Biała Woda valley. On the Polish side the ridge WB3 has the maximum height 970 m (Fig. 4, 6). The terminal moraines WB1, WB2, WB3 are correlated with Leszno and Poznań phases in the Polish Lowland as distinguished by S. Kozarski (1981, 1991). Between 18–15 ka BP the main ice tongue was probably receiving the smaller and smaller supply of ice from the tributary hanging valleys. It is possible to reconstruct two oscillations: BW1 and BW2 (Fig. 5, 6). The latter could be related to alpine stage Bühl. Thus, the Biała Woda glacier existed 15 ka BP ago (Pomeranian phase on the Polish Lowland), although it was probably very thin (16 m) in comparison to maximum stage (Fig. 5), even if relatively long. It is possible to evaluate incision in relation to moraine ridge and transitional cone and in relation to terminal depression during the distinguished two oscillations (Fig. 6). Moraine ridge BW1 was formed after incision of terminal depression at Łysa Polana, related to WB1 phase, up to 2–3 m while before the second oscillation BW2, marked by transitional cone, incision

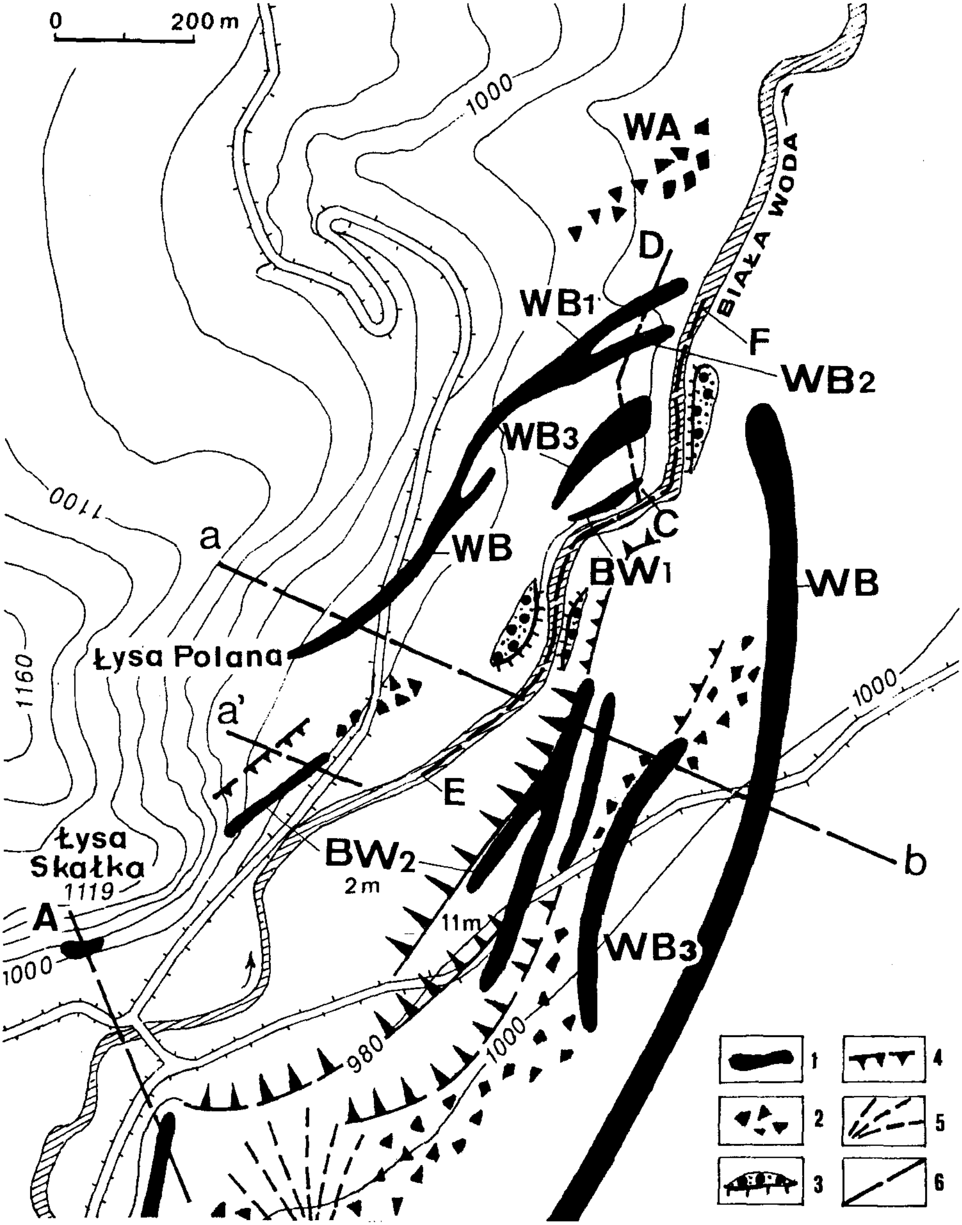


Fig. 4. The extent of Würm moraines and location of cross-profiles: A — B, a — b, a' (see Fig. 5) and profile C — D across moraine ridges (see Fig. 3), and longitudinal profile of river channel E — F. 1 — moraine ridges, 2 — bouldery covers, 3 — transitional cone, 4 — edge of kame terrace, 5 — road, 6 — course of the profiles

Ryc. 4. Zasięg moren würmskich i lokalizacja profili poprzecznych: A — B, a — b, a' (por. ryc. 5) oraz profil C — D przez wały morenowe (por. ryc. 3) i profil wzdłuż koryta E — F. 1 — wały morenowe, 2 — pokrywy głazowe, 3 — stożek przejściowy, 4 — krawędź terasy kemowej, 5 — droga, 6 — przebieg profili

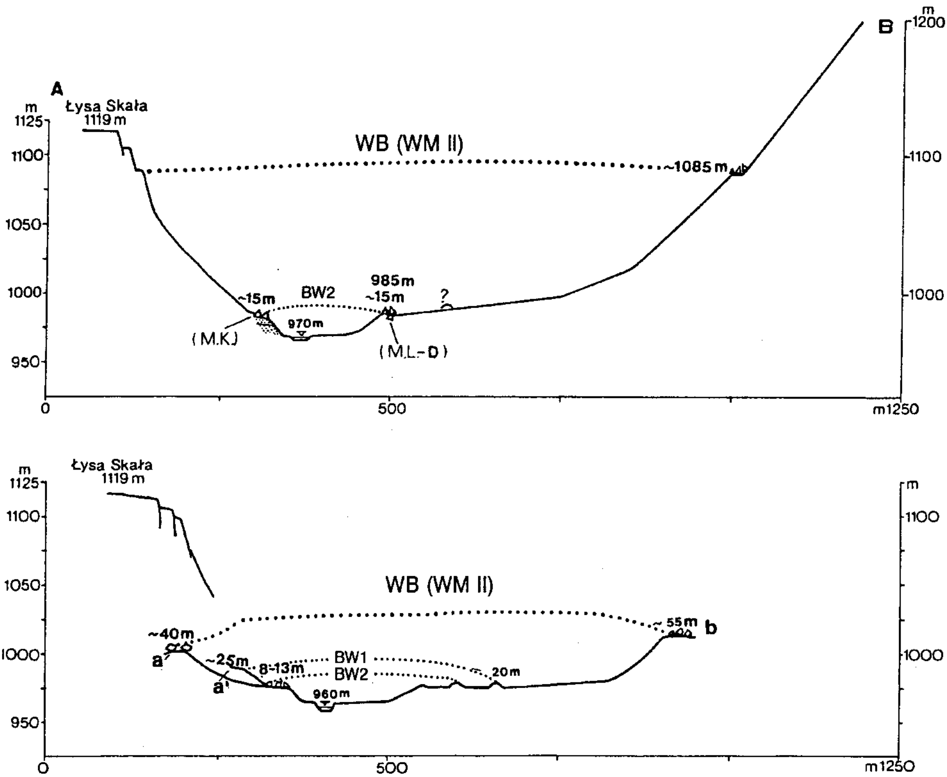


Fig. 5. Cross-profiles in the area of Łysa Skała (A—B) and Łysa Polana (a—b), and reconstructed extents of the Biała Woda glacier during maximum stadium WB and recessional stadium, oscilation BW2. MK — site at Łysa Skała described by M. Klimaszewski (1961), ML — moraine ridge D according to M. Lukniš (1973)

Ryc. 5. Profile poprzeczne w rejonie Łysej Skały (A—B) i Łysej Polany (a—b) z rekonstruowanymi zasięgami lodowca Białej Wody w stadium maksymalnym WB oraz w stadium recesyjnym oscylacji BW2. MK — stanowisko pod Łysą Skałą opisane przez M. Klimaszewski (1961), ML — wał morenowy D wg M. Lukniš (1973)

was up to 5–6 m in relation to terminal depression from BW1 phase. The fact that a lateral moraine associated with oscillation BW2 was formed on southern part of the Łysa Polana terminal depression confirms also a pronounced role of this readvance. Probably this readvance could be related to the position of moraine block layer 2 m thick deposited on 10 m glacio-fluvial sands with gravel material at the outcrop described by M. Klimaszewski (1961). On the Slovak side, lateral moraine BW2 have a prolongation at the height 20–15 m above an old Slovak Custom Office (995–985 m a.s.l.). According to M. Lukniš (1973) it is D stadium (Fig. 5, 7). The term "stadium" is used in German terminology, and is accepted for the Alpine stages of Late Würm chronology.

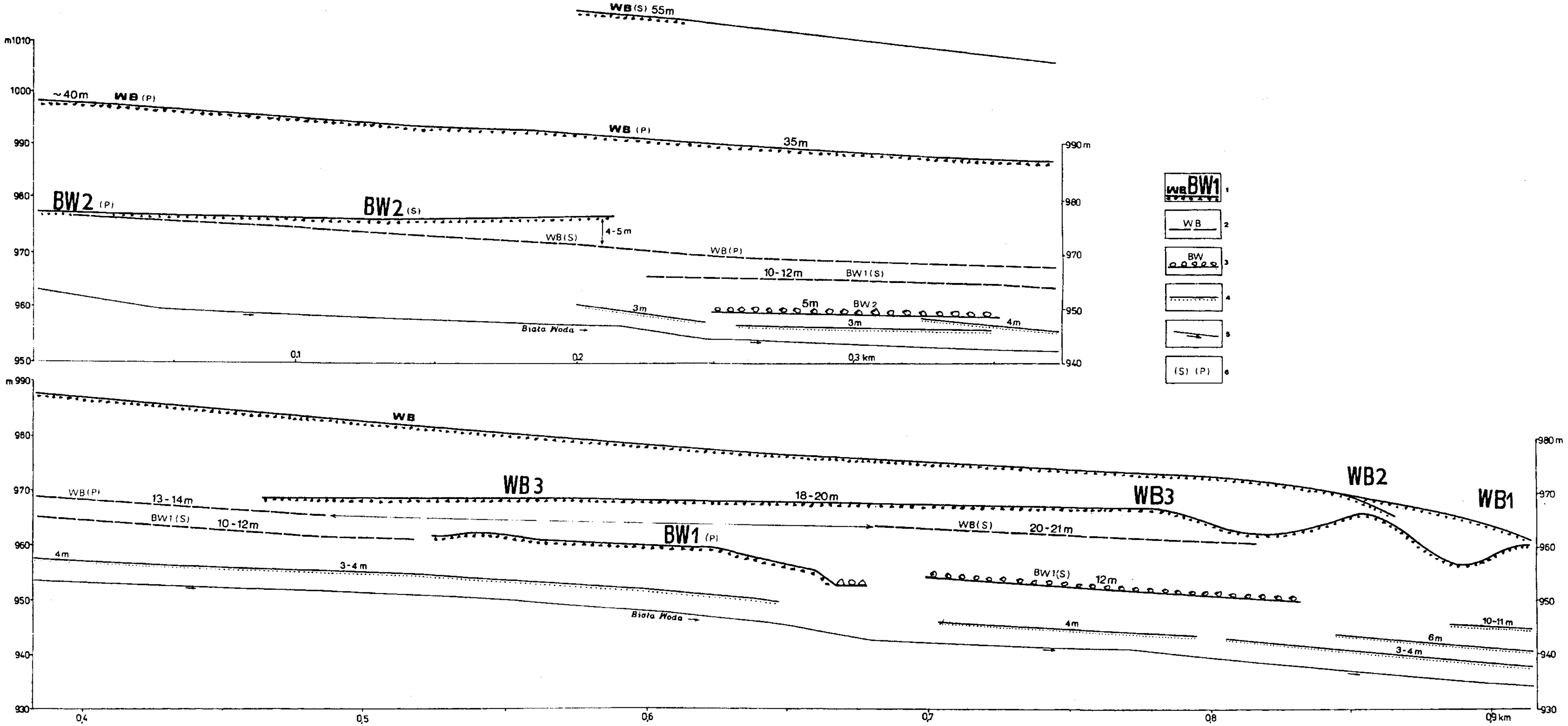
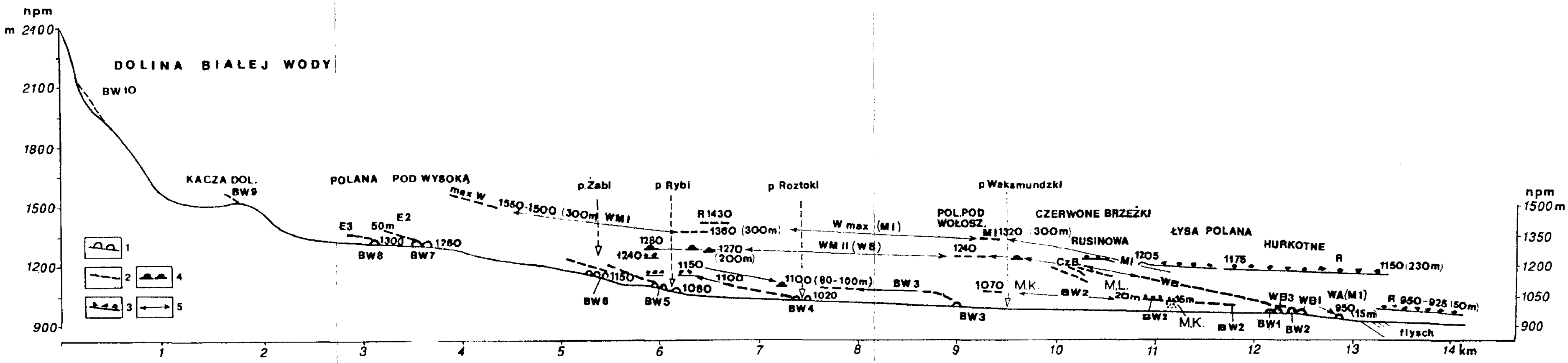


Fig. 6. Longitudinal profile of the Biała Woda channel within terminal depression of Łysa Polana and moraine gorge. 1 — lateral moraines (WB), and terminal moraines (WB1), 2 — terminal depression, 3 — transitional cone, glacio-fluvial, 4 — terraces, 5 — profile of the river, 6 — P (Polish side), S (Slovak side)

Ryc. 6. Profil podłużny koryta Białej Wody w rejonie depresji końcowej Łysej Polany i przełomu przez moreny. 1 — wały moreny bocznej (WB) i moren końcowych (WB1), 2 — depresja końcowa, 3 — stożek przejściowy, 4 — terasy, 5 — profil rzeki, 6 — P (strona polska), S (strona słowacka)



M. Lukniš	H	HW	E3	E2	E1			D2	D		C B		
M. Klimaszewski VII		IV 1600	III 1300	II 1280		I 1080					970		935
MA Kotarba	BW 10	BW9	BW8	BW7	BW6	BW5	BW4	BW3		BW2 BW1	WB	WA	
Venediger? Schlaten?		Egesen	Daun		Gschnitz Gardno	Schlern II	Schlern I	Steinach		Bühl Pomeranian	Chodzież Leszno-Poznań		
9.5 - 8.4 ka		10.7-10.2 ka	12 ka		13 ka			14 ka		15 ka	17.2	20-18	>60ka

Fig. 7. Longitudinal profile of the Biała Woda valley and the extent of frontal moraines WA (M I), WB1, WB2, WB3 (WM II) as well as recessional moraines. 1 — frontal moraine ridges, 2 — lateral moraines, 3 — bouldery covers, 4 — moraines marking sites where tributary glaciers were in contacts with the main glacier, 5 — reconstructed extents of glaciers

Ryc. 7. Profil podłużny Doliny Białej Wody z zasięgiem moren końcowych WA (M I), WB1, WB2, WB3 (WM II), oraz moren recesyjnych. 1 — wały moren czołowych, 2 — moreny boczne, 3 — pokrywy głazowe, 4 — wały morenowe wyznaczające miejsca łączenia lodowców bocznych z lodowcem głównym, 5 — rekonstruowane zasięgi lodowców

RECESSIONAL STAGES OF THE MAIN BIAŁA WODA GLACIER AND ITS RELATION TO RYBI POTOK AND ROZTOKA GLACIERS

The longitudinal profile of the Rybi Potok valley shows the main deglaciation landforms produced in the period which passed since the maximum extent of the Würm glaciation until the final ice decay (Fig. 7). The described readvance BW2 was correlated with the stage Bühl in the Alps and the Pomeranian phase in the Polish Lowlands. The next recessional stage BW3 is marked by accumulation of big blocks on large asymmetrical ridge preserved on the Polish side only, on the southern border of Dolna Polana pod Wołoszynem at the height of 1,000 m a.s.l. (Fig. 1, 7). During this period the main glacier lost the supply from the Waksmundzka Valley but its thickness on the cross-profiles at a confluence with the Roztoka tributary glacier was 100 m at least according to the height of lateral moraine. This stage is correlated with the Steinach stadium in the Austrian Alps (14 ka BP).

Stage BW4 is documented by a flat moraine ridge with blocks at 1,025 m a.s.l. close to Stara Roztoka tourist lodge on the Polish side and at Biała Woda Glade on the Slovak side. The extent of stage BW4 is well preserved on the Polish slope above Stara Roztoka Glade, in the form of a lateral moraine ridge at the heights 1,050–1,070 m on the 100 m distance. This stage BW4 could be related to stadium D2 according to M. Lukniš map (1973). During stage BW4 the Roztoka glacier became independent on recessional position marked by moraine ridges (R1) at the height 1,220–1,260 m (Fig. 9). It was the last period when the Rybi Potok glacier fed the main Biała Woda glacier. The Rybi Potok glacier at the confluence with Biała Woda glacier covered the flateness of Wanta at the height up to 1,150 m — thus, the thickness of Biała Woda glacier in this cross-profile was 70–80 m at least. The extent of this stage in the Rybi Potok valley can be correlated with a very well preserved lateral moraine ridge build of big boulders up to 5 m in diameter. This lateral ridge raises above the road to Morskie Oko Lake from the height 1,286 to 1,390 m a.s.l. (80 m above the parking at Włosienica). During BW4 stage of recession the glacier filling the Rybi Potok valley at Włosienica cross-profile was at least 80 m thick and 500 m wide, while in the mouth reach of the valley, the tongue, 250–300 m in wide and 40–50 m thick flowed to the Wanta flateness where it reached the main glacier. The lateral extent of this tongue in the bottom reach of Opalone slope roughly coincides with the tourist trail crossing the serpentine road. That means that the left side of the tongue was descending from 1,275 to 1,160 m a.s.l. Stage BW4 of the Biała Woda glacier, and stage R1 of the Roztoka could be related to the Schlern stadium in the Alps.

Stage BW5 is marked by a very small remnant of a morainic ridge on the Slovak side, opposite to the present-day hanging mouth of the Rybi Potok Stream. This stage, named Rybi Potok mouth stage, was distinguished by M. Lukniš (1973) as stage E1. It was rather a short period during recession.

Stage BW5 of the Biała Woda glacier could be correlated with the stage of Włosienica (RP1) in the Rybi Potok valley and with stage R2 in Roztoka. This stage can be interpreted as a small recessional stop, younger than the Schlern stadium in the Alps. The relatively smooth, 2–3 m high, moraine ridge RP1 is dissected by the road to Morskie Oko Lake near a restaurant at Włosienica and raises close to Szałasiska Glade, then it is covered by a large alluvial cone from Głęboki Żleb Ravine (Fig. 10).

It must be emphasized here that close to the confluence of the hanging Rybi glacier and the main Biała Woda glacier on the external slope there was a favourable area to preserve fragments of three, old lateral moraines (Riss, WM I, WM II — Fig. 7, 8). At the height of 1,400–1,430 m, occurrence of morainic boulders on two flatness, probably structure-controlled confirm the maximum extent of the Riss glaciation (370 m thick) and simultaneously confirms M. Klimaszewski's (1988) opinion shown on his geomorphological map of the Tatra Mts (1:30,000). According to M. Klimaszewski these boulders are deposited on a fragment of the youngest planation surface named "valley-side planation surface". At the height of 1,360 m a.s.l., on Polanka pod Czubą, two small moraine ridges stuck in a slope confirm maximum thickness of the ice during the Würm glaciation (WM I). The ridges are c. 280–300 m above the Biała Woda valley and at least 160 m above the mouth reach of the Rybi Potok valley (Fig. 7). Below Polanka pod Czubą site, close to serpentine road at the height of 1,280–1,300 m a.s.l., one (or several according M.Klimaszewski's map) moraine ridge is distinguished. This ridge belongs probably to the maximum WB (WM II) stage. On the opposite side, at the height of 1,280 m a.s.l., close to a steep slope of Żabia Grań, the system of two very well developed lateral moraine ridges "terminates in the air". The external ridge documents the maximum stage WB (WM II) and the phrase named "terminate in the air" means the confluence of the Biała Woda and Rybi Potok glaciers at the height of 1,280 m at least (Fig. 7). Probably these lateral ridges marked also the extent of glacial tongue of the Rybi glacier untill stage BW3 (Steinach) or even BW4 (Schlern).

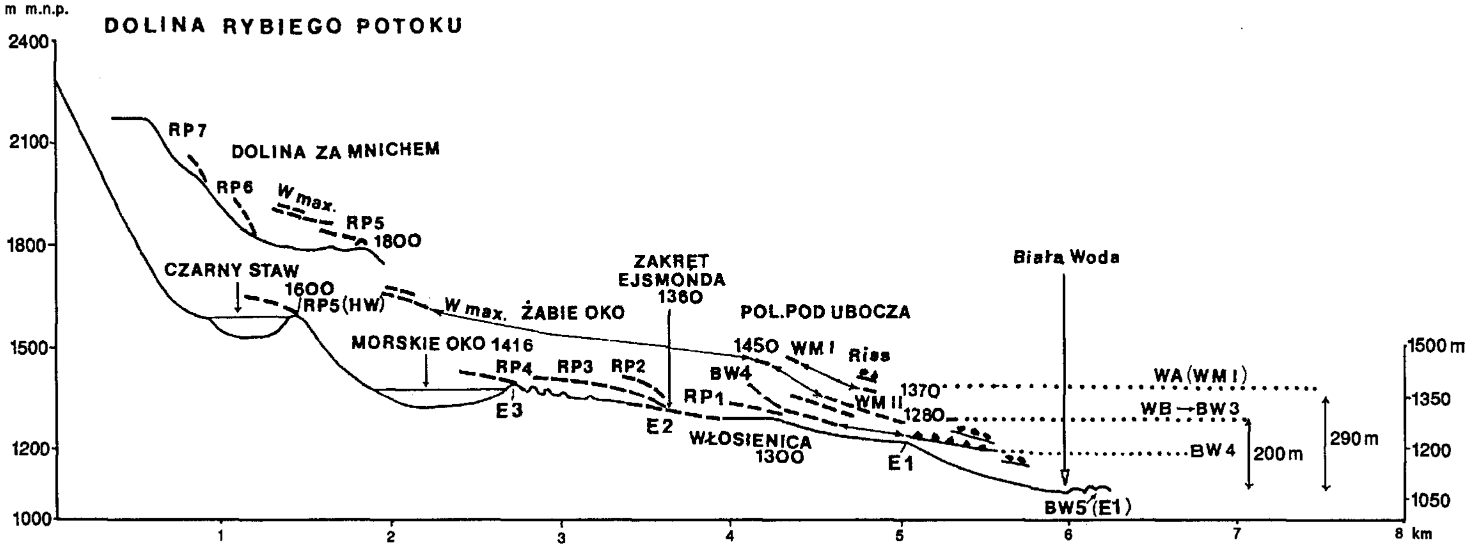
There is also another characteristic feature, i.e. asymmetry of deglaciation in the lower reach of the Rybi Potok valley controlled by different topoclimatic conditions. On the right hand side in a shadow of the Żabia Grań ridge, there is a complex system of moraine ridges and depressions differing in size, that can be interpreted in the terms of dead ice topography despite prevailing parallel and oblique moraine ridges. When the most external ridges are interpreted as the WB to BW3/BW4 lateral moraine, the most internal ridge at the height 1,300 m a.s.l., and the glacio-fluvial cone can be related to Włosienica (RP1) stage of the Rybi glacier recession (correlated with BW5 of the main glacier).

Very well marked moraine ridges in the Biała Woda (BW6), Rybi Potok (RP2) and Roztoka valleys (R3) document a significant cooling. Their terminal depressions and distinct moraine ridges, double in the Biała Woda and Rybi

Potok valleys (RP2, RP3), indicate a longer stop during the Late Glacial recession. These distinct moraine ridges were correlated with the Gschnitz stage represented by a very distinct moraine ridge in the Gschnitz valley in the Austrian Alps. In the Roztoka–Five Polish Lakes valley, lacustrine sediments from Przedni Staw Lake, in its Late Glacial part of a core, were interpreted as Bölling and Alleröd (Krupiński 1984, Wicik 1984). According to this datum, moraine ridges R3 situated below Przedni Staw Lake were described by J. Dzierżek et al. (1987) as "the phase of Five Polish Lakes I" and compared to alpine Gschnitz and the Oldest Dryas. In Fig. 9, the Roztoka valley and the hanging Five Polish Lakes valley are shown. In this figure it is possible to study different opinions about recession of the Roztoka glacier. According to the authors of this paper, during the Gschnitz stage (R3) there were two glacial tongues; one hanging over the Siklawa rocky step with terminal moraine ridges at 1350 m a.s.l., and the second one in front of the Przedni Staw Lake documented by moraine ridges at 1,580 m a.s.l.

In the Rybi Potok valley, the Gschnitz stage is represented by two distinct moraine ridges named "moraine of Zakręt Ejsmonda" (RP2, RP3). The Rybi Potok glacier terminated during this period at the height of 1,360 m a.s.l. Moraine ridges RP2 document a larger (450 m) and thicker glacier tongue (at least 40 m) in comparison with a smaller one RP3 (200 m and 20–25 m), but being of the same length. In the Biała Woda valley the recessional stage BW6 with terminal moraine ridges at the mouth of Żabi Stream and distinct terminal depression was followed by period of rather important climatic amelioration which could be confirmed by evident areal deglaciation (dead--ice topography) on a relatively long distance (1.5 km). The same landform pattern can be recognized in the Rybi Potok valley between the RP2/RP3 and RP4 recessional moraines (Fig. 10). In the Five Polish Lakes valley, the distance between the stages R3 and R4 is about 2 km (Fig. 9), but the forms, which are related to areal deglaciation, are developed close to the Przedni Staw Lake only. This period of climate amelioration has been related to Bölling. The next stage of recession is correlated with alpine stage Daun. With this recessional stage we can combine the Morskie Oko moraine ridge (RP4) in the Rybi Potok valley, the R4 moraine flat ridge in the Five Polish Lakes valley (phase of the Five Polish Lakes II according to J. Dzierżek et al. 1987). In the main valley, stages BW7 and BW8 named "ridges of Polana pod Wysoką I and II" (1,280 and 1,300 m a.s.l.) seem to be related to the Daun stage in the Alps.

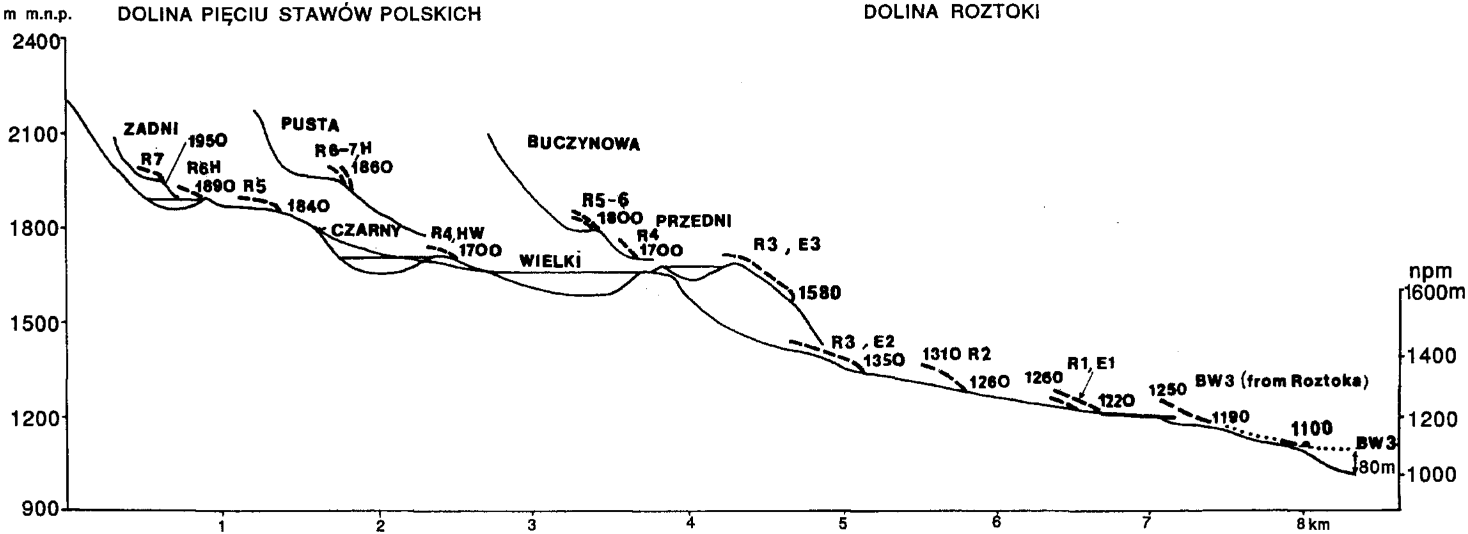
The age of the Morskie Oko moraines (1,416 m a.s.l.) was evaluated based on the sediments which were studied in the Żabie Oko dead-ice depression (Fig. 10). This depression was drained by proglacial waters and subsequently filled with various mineral deposits. The coarse sands with gravel deposits are covered by very fine laminated, yellowish-ferrogineous silty-clay which are correlated with a cool period and, then, by layers of silty and organic material



J. Partsch	IV 1800, 1597	III 1393			II 1220	
M. Lukniš	HW	E3	E2		E1	E1
M. Klim.	VII 2070 VI 1800 V 1590	IV 1400	III 1395 II 1360		I 1260	
L.Lindner, J.Dzierżek, J.Nitychoruk		Faza 5 St. Pol.		Faza Włosienicy	> 14 ka	
M i A. Kotarba	RP7 RP6 RP5	RP4	RP3 RP2	RP1	BW 4	BW5
	Vened.? 8.7-8.4 ka Schlaten? 9.5 ka Egesen 10.7-10.2 ka	Daun 12 ka	Gschnitz 13 ka	Schlern II	Schlern I	Schlern II

Fig. 8. Longitudinal profile of the Rybi Potok valley and the extents of moraines showing maximum and recessional stages

Ryc. 8. Profil podłużny Doliny Rybiego Potoku z zasięgami moren świadczących o stadiach maksymalnych i recesyjnych



J. Partsch	IV 1910	III 1672		II 1342 - 1245		
M. Lukniš	H 1920 H 1890 HW 1737		E3 1672	E2 1342,1357	E1 1280	
M. Klimaszewski	VII 1895 V 1730		IV 1680 III 1590	II 1340	I 1280	
J. Dzierżek	IV (Bor) III II 1810-1760	Faza 5 St. Pol.	I 1710-1660 (Gschnitz)		Faza Włosienicy (Bühl)	
MAKotar	R7 R6 R5 R4		R3	R2	R1	BW3
	Vened ? 8.7-8.4 ka; Schlat. 9.5 ka; Egesen 10.7-10.2 ka; Daun 12 ka	Bölling	Gschnitz 13 ka	Schlern II	Schlern I	Steinach 14 ka

Fig. 9. Longitudinal profile of the Pięć Stawów Polskich valley and the Roztoka valley, and recessional extent of the Biała Woda glacier, when the Roztoka glacier fed the main ice body, and resessional stages R1–R7

Ryc. 9. Profil podłużny Doliny Pięciu Stawów Polskich i Doliny Roztoki z zasięgiem recesyjnym Białej Wody (BW3), w czasie którego lodowiec Roztoki jeszcze zasilał lodowiec główny i stadia recesyjne R1–R7

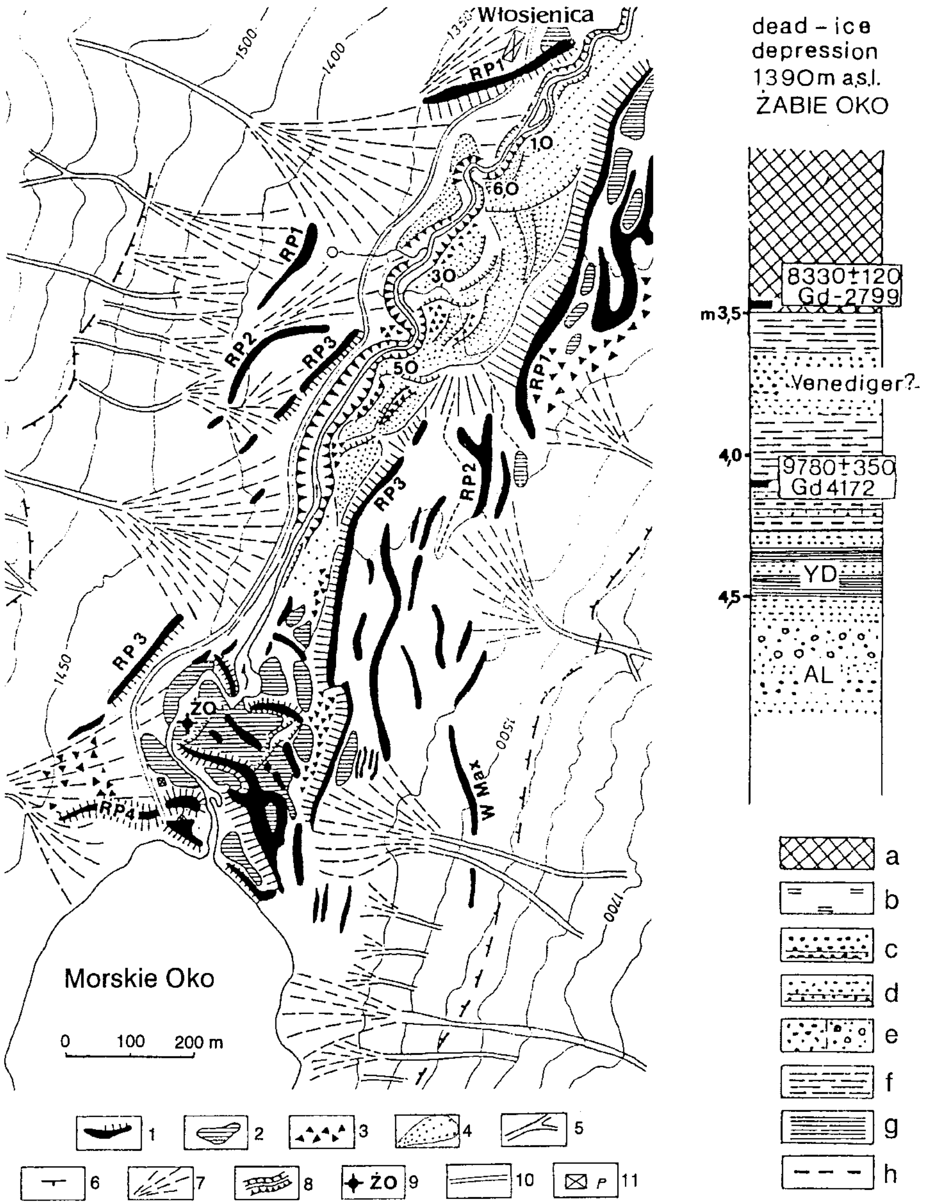


Fig. 10. Moraine-ridge sequence in the Rybi Potok valley between Morskie Oko Lake and Polana Włosienica, and sediments infilling dead-ice depression of the Żabie Oko. 1 — distinct moraine ridge, partly steep, 2 — dead-ice depression locally filled with glacio-fluvial deposit and peat, 3 — rockfall/rockslide or glacial drift boulders, 4 — glacio-fluvial terrace and cone, 5 — rocky chute, 6 — glacial trough extent on slope, 7 — gravitational/alluvial/avalanche talus cone, 8 — erosional scarp and present-day channel, 9 — location of Żabie Oko core, 10 — road, 11 — parking place and building; a — peat, b — organic mud, L.O.I. up to 30%, c — coarse sand, d — sand, medium/fine, e — sand/coarse sand with gravel, f — silty clay L.O.I up to 5%, g — laminated silty clay, h — detritus

(9,780 ± 350, Gd-4,172). This cooling was considered as the Younger Dryas period. After the Pre-Boreal and Boreal deposition of silty-clay with organic matter, the depression was again filled with mineral coarse deposits, which according to A. Obidowicz's (1993) interpretation belong to rather a cool period. There is an opposite opinion about stratigraphic position of these two coolings (Baumgart-Kotarba et al. 1994). According to the authors of this paper the second cooling is interpreted as the Venediger readvance in the Alps. Finally, organic silts and peat deposits had been forming at the begining of the Atlantic period. According to our opinion, both absolute datings, sedimentological properties and palynological analysis (Obidowicz 1993) make possible correlating the formation of the dead-ice depression of the Żabie Oko with the period Bölling-Daun. Consequently, formation of the Morskie Oko Lake could be associated with the Alleröd warming. Unfortunately, up to now we have no dated sediments older than c. 7 ka BP from the Morskie Oko Lake.

During the final stage of the Late Glacial–Younger Dryas, hanging glaciers existed probably in the Za Mnichem valley (moraine ridges RP5 at 1,793 m a.s.l.) and in a glacial cirque below Rysy Mt (moraine RP5 at 1,600 m a.s.l. — Fig. 8). The absolute date 8,330 ± 120 BP (Gd-2,799) in the Żabie Oko depression, taken from the bottom of the Atlantic peat at the depth of 3.5 m below the surface, indicates probably termination of the Ice Age in the Polish High Tatra. At that time the upper timberline raised already above 1,400 m a.s.l. This last statement is evidenced by 10% of herbaceous plants (NAP) on the pollen diagram published by A. Obidowicz (1993).

DISCUSSION OF THE RESULTS AND CONCLUSIONS

The years long studies carried out in the Tatras and cognition, thanks to the sincere help of Prof. G. Patzelt and Prof. K. Kerschner, of the classic sites in the Alps in 1986, that document the Lateglacial and Holocene phases of deglaciation, allowed the authors to compare published works and maps, especially those by J. Partsch, B. Halicki, M. Lukniš, M. Klimaszewski, L. Lindner, J. Dzierżek and J. Nitychoruk with field findings. The materials dealing with the extents of frontal

Ryc. 10. Układ wałów morenowych w Dolinie Rybiego Potoku między Morskim Okiem a Polaną Włosienica oraz osady wypełniające zagłębienie wytopiskowe Żabiego Oka. 1 — wyraźny wał morenowy, częściowo o stromych zboczach, 2 — zagłębienie wytopiskowe wypełnione osadami fluwioglacjalnymi i torfem, 3 — głazowiska pochodzące z obrywów, zsuwów skalnych lub morenowe, 4 — terasa i stożek glacifluwialny, 5 — żleb skalny, 6 — zasięg żłobu lodowcowego, 7 — stożek grawitacyjny ze spływów gruzowych i lawinowych, 8 — podcięcia erozyjne we współczesnym korycie, 9 — Żabie Oko, lokalizacja miejsca pobrania prób do analiz sedymentologicznych i palinologicznych, 10 — droga dojazdowa do schroniska, 11 — parking i budynki; a — torf, b — muł organiczny, c — piaski grube, d — piaski drobne i średnie, e — piaski i żwiry, f — mułki ilaste, g — laminowane, żelaziste mułki ilaste, h — detrytus roślinny

Table 1 — Tabela 1

Attempt to paralelize recession of the last glacier in the Biała Woda valley
and tributary glaciers in the Rybi Potok valley and Roztoka valley.
Synchronization of Tatra glaciation with the Austrian Alps and Polish Lowland
Próba paralelizacji recesji ostatniego lodowca Białej Wody i zasilających lodowców z doliny
Rybiego Potoku i Roztoki oraz korelacja zlodowacenia Tatr Wysokich z Alpami Austriackimi
i Niżem Polskim

Alpine stages and Polish Lowland phases	BP ka	Biała Woda	Rybi potok	Roztoka
Venediger Schlaten	8.7–8.4 9.5	BW10 1,950 1,760	RP6–RP7 > 1,840 2,050	R7 1,950
Egesen	10.7–10.2	BW9 1,600	RP5 1,600 (1,800)	R5–R6 1,840 1,890
Daum	12	BW8 1,300 BW7 1,280	RP4 1,416	R4 1,700
Gschnitz/Gardno Ph.	13	BW6 1,150	RP2–RP3 1,360	R3 1,350 (1,580)
Schlern II	—	BW5 1,080	RP1 1,300	R2 1,260
Schlern I	—	BW4 1,020	tributary glacier	R1 1,220
Steinach	14	BW3 1,000	tributary glacier	
Bühl/Pomeranian	15	BW2 980		
Chodzież Subphase	17.2	BW1 957		
Poznań Phase	18.4	WB3 970		
Leszno Phase	20	WB1–WB2		
Kaszuby Stadial	> 60	WA 950		

and lateral moraines in the main valley and the contributing ones in the maximum and recessional stages allowed for relating the extent of the Biała Woda glacier to that of the glaciers in the largest two valleys, forming the complex glacial system on the northern slope of the High Tatra (Table 1).

PROBLEM OF THE OLDER STAGE

The discussion on the formerly distinguished stages of the last cold stage in the Tatras has not been attempted in this paper. It has been accepted that there was a certain maximum stage WM I named WA in relation to stage A (Rakytovec) distinguished by M. Lukniš (1973) and Halouzka (1977, 1992), Halouzka and Horniš (1995). That is a post-Eemian stage, as at the foreland of moraine WA there is a 20 m high bench of glacio-fluvial terrace preserved on the Polish side in the gap valley reach. The gap is incised in 45–50 m high level with a bouldery cover changing into an inclined transitional cone with large boulders as well (Fig. 2). The layer with boulders rests on a high rocky socle and was accepted as of the Riss age (Partsch 1923, Baumgart-Kotarba and Kotarba 1979). As the heights of the transitional cone, being associated with the maximum moraines WM II (WB), and of the terrace increase downstream from 13.5 m through 16 m to almost 20 m close to the junction with the Jaworowy stream (Baumgart-Kotarba and Kotarba 1979), the position of the 20 m high terrace at the maximum Würm moraine WM I indicates that they are older than the main stage of glaciation (WB — Leszno phase). It cannot be excluded that stage WA is older than the older human culture registered in layer XIX in Obłazowa Cave (Valde-Nowak et al. 1995a, 1995b), i.e. from before 50–60 ka. The following reasoning leads to the above conclusion. The leveling of the top face of the fluvio-glacial gravels in Obłazowa Cave in relation to the present-day Białka channel and the levelling of the neighbouring, Würm terrace level (Halicki 1930, Baumgart-Kotarba 1983) indicates that the top face of the terrace alluvia is situated by 2–3 m higher than the top of the alluvia in Obłazowa Cave. It is likely that the first post-Eemian aggradation of the Białka river was associated with the older stage (layer XXI), and then there was a long period of inhabiting the cave (layers XIX–VIII). After the E-Gravettian culture zone, there was a significant cooling of climate that induced rockfalls in Obłazowa Cave (layer VII). Aggradation of the terrace alluvia by 2.3 m was related to the main stage and caused the river bed to be above an arched opening (door). The age of the 9 m high terrace near Obłazowa is also confirmed by the terrace layout that can be traced upstream the Białka valley to the moraines of the main stages WB1 and WB2. The archeological findings (boomerang) as well as animal bones and teeth document the steppe-tundra and/or forest steppe environment. In Obłazowa Cave, the sequence of layers occurring between the top face of the alluvia and the blocks from the maximum cold period, provides evidence that there was only one period of the very cold climate in the recent 60 ka and this period is named “main stage”. Using archeological methods it is possible to determine the end of aggradation of the alluvia from the main stage. In a direct surrounding of Obłazowa Hill, a young, structureless loess rests on the terrace. An open archeological site, originating from the Younger Paleolithic was found in this loess. So, it is reasonable to expect the alluvia in situ in Obłazowa Cave to be older than the oldest human culture stated there, i.e. from before 60 ka BP, and to correspond to the largest in extent but the shortest glaciation WM I (WA). This glaciation can be correlated with the largest glaciation described from the French Alps and dated at 70–50 ka (Mojski 1993).

It seems that the results obtained thanks to dating of calcareous dripstones in the Tatric caves (Hercman et al. 1987) can be the basis for chronological ordering of climatically controlled events in the Tatras in the Vistulian. However, large intervals covered by the datings cause the limits obtained this way to be vague. On the other hand, stratigraphy relying on the TL method does not provide reliable basis not only due to difficulties involved in the method and due to ambiguous interpretation of the results, but also due to a rough location parameters of the sites that were sampled (Lindner et al. 1990). An exceptional case is documentation from the Mała Łaka valley. The stratigraphic position of WA stage in the High Tatra, the stage that has not been described in the Biała Woda valley yet, was considered to be older than the Brörup warming. M. Lukniš (1973) and R. Halouzka (1977) assumed that the glaciation took place 70–60 ka ago. Recently, R. Halouzka and J. Horniš (1995) have assigned the Rakytovec stage moraines (WA) to the Riss cold stage. Accepting that blocky ridge WA was formed in the first stadial(?) of the Vistulian, it can be correlated with the Kaszuby Stadial (Mojski 1993). Yet, numerous stages (stadials?) (of Sucha Woda, Bystra and Bialka) and four phases of glaciation in the Tatras (Hurkotne, Łysa Polana, Włosienica, Five Polish Lakes) that have been distinguished by L. Lindner and L. Marks (1996), based on TL dating and rather mechanically correlated with paleolitic cultures from Obłazowa, seem to be in contradiction with results of the studies from the Austrian Alps. Results from the site in Baumkirchen (Fliri 1976, Fliri et al. 1970, Patzelt 1995), that have been perfectly elaborated based on the pollen and macroremnants analyses as well as on 13 datings by ^{14}C method, evidence that the climate in the period between 31 and 27 ka BP was similar to the present one on the timberline and that glaciation in this area could hardly happen before 25 ka BP. Moreover, freshness of ridges WB1, WB2, WB3 on te Polish bank of the Białka river as well as the marked ridge WB and WB3 on the Slovak side evidence that they belong to the main stadial (Leszno–Poznań phase).

MAIN STADIAL AND RECESSION OF THE BIAłA WODA GLACIER

Chronology of deglaciation corresponds to the scheme developed in the Austrian Alps but is also widely based on the study results from the Tatras, mainly from lacustrine deposits and deposits of dead-ice depression at the foreland of Morskie Oko Lake. It should be noticed here that the studies on deep lacustrine deposits were possible owing to the cooperation with C. Jonasson of the Uppsala University. Application of the techniques developed in Sweden for obtaining cores and RTG analysis used in lithological-sedimentological characteristics contributed to the headway in that field if compared to the studies carried out under Prof. J. Kondracki's leadership before 1980 and then by B. Wicik and K. Więckowski. The studies on the Würm glaciation in the Biała Woda valley have not been finished yet, as investigations on thickness of Quaternary deposits are still going on in cooperation with geophysists from the University of Mining and Metallurgy under supervision of Prof. R. Ślusarczyk. Until now, it has been possible to conclude that a rock step occurs at the depth of 25 m, below the moraine ridge of Morskie Oko. The 18 m deep incision into the rocky step (c. 43 m below of the tourist lodge on the Morskie

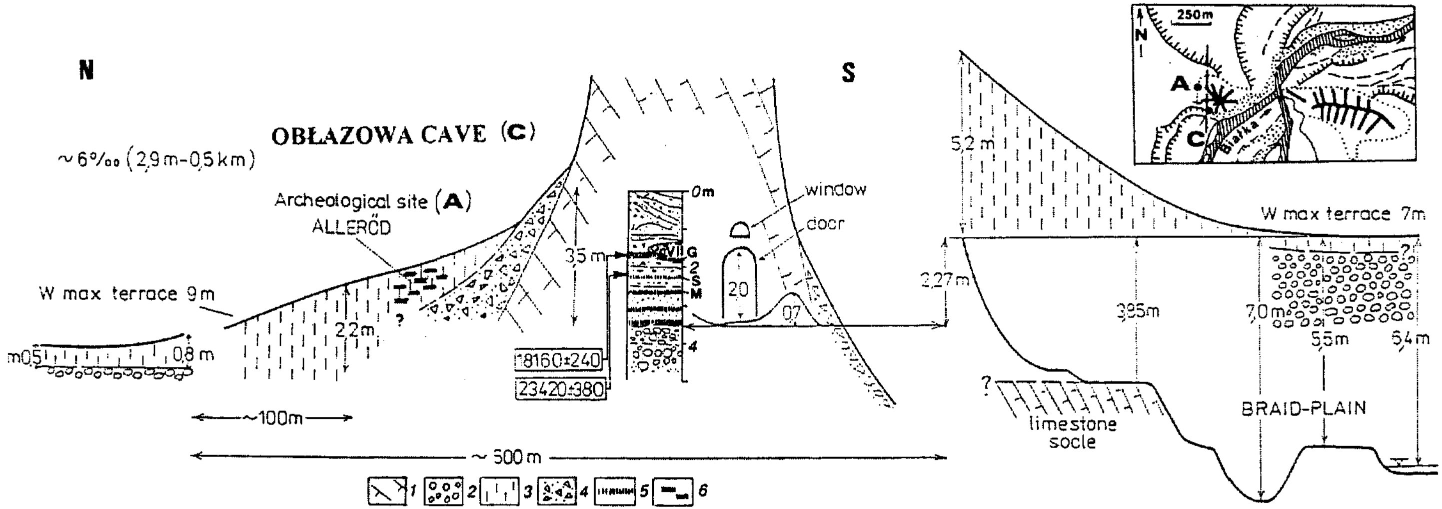


Fig. 11. Relation between the top of the alluvial cover in the Obłazowa Cave and the top of glacio-fluvial terrace, main stadial — Leszno–Poznań Phase. 1 — limestones, 2 — alluvial deposits, 3 — loess (Older and Younger Dryas), 4 — debris covers, 5 — lithic-bearing layers, 6 — artefacts within loess. Deposits in the cave according to P. Valde-Novak et al. (1995a); M — top of the Mousterian series, S — Szeletian, G — Gravettian, VII — layers composed of boulders related to the main stadial

Ryc. 11. Profile niwelacyjne ilustrujące relacje między wysokością stropu aluwiów w jaskini Obłazowej do stropu aluwiów terasy glacifluwialnej z głównego stadiału (faza Leszna i Poznania). 1 — wapienie, 2 — aluwia, 3 — lessy, 4 — pokrywy gruzowe, 5 — poziomy z artefaktami, 6 — artefakty w osadach lessowych. Osady w jaskini wg P. Valde-Nowak et al. (1995a); M — strop serii mustierskich, S — poziom szelecki, G — poziom grawecki, VII — rumowisko skalne z okresu maksymalnego ochłodzenia

Oko moraine), representing an older outflow from Morskie Oko Lake (Baumgart-Kotarba et al. 1996) has also been stated.

In the Biała Woda valley, the two maximum stages: WM I in the initial phase of the Vistulian (probably 70–60 ka BP) and WM II with the extent smaller only by 200 m have been identified. In the Biała Woda valley during these stages the ice thickness reached 300 m in the zone of junction of the glacier from the Rybi Potok valley, and 200 m in the second stage. Well preserved ridges of terminal moraines mark the maximum extent, while the highest ridge WB3 preserved on internal side of the ridges points to both the smaller extent and thickness of the tongue. Thus, ridges WB1 and WB2 can be correlated to the Leszno phase, and ridge WB3 to the Poznań phase (18.2 ka BP). When seeking further analogies to the Scandinavian glaciation in the Polish Lowland, it can be accepted that the first recessional stagnation BW1, indicating a small oscillation, is correlated with the Chodzież sub-phase (17.2 ka BP). On the other hand, the large oscillation BW2 has been related to the Pomeranian phase (15.2 ka BP) and simultaneously to the Bühl stage in the Alps [dates of the phases in the Lowland after S. Kozarski (1991)].

It appears important to notice, that the Biała Woda glacier, probably 14 ka ago (the Steinach stage in the Alps), was still fed by the Roztoka and Rybi Potok glaciers. During the alpine Schlern recessional stage, the Roztoka glacier became an independent body, and then the Rybi Potok glacier. The stagnation 13 ka ago, an equivalent of the Gschnitz stage (stadium) in the Alps and of the Gardno phase in the Lowland [13,200 according to S. Kozarski (1991)], was an important step in the deglaciation. It must be added, that according to last results the age of Gardno phase is older, and can be correlated with Steinach (14 ka) in the Alps (Rotnicki and Borówka 1995). In the Tatras, this period is documented by the date 12,500 BP from Czarny Staw Gąsienicowy Lake and by the palynological analysis of the lacustrine deposits from Przedni Staw Lake in the Polish Five Lakes valley. An important role of the Bölling warming is evidenced by areal deglaciation in the Biała Woda valley behind moraines BW6 and in the Rybi Potok valley behind recessional moraines RP2/RP3 as well as a fairly large distance to the moraines of Polana pod Wysoką and of Morskie Oko (Daun). If compared to the Daun moraines, the stage (stadium) of the Younger Dryas (Egesen) had much smaller extent and glaciers were in a form of cirque glaciers.

The Younger Dryas period as well as Venediger cooling in the Tatras manifested not only in preservation of the glaciers but also in activation of slope processes, solifluction and debris flow, recorded in rather sandy, often massive deposits in lake basins (Baumgart-Kotarba and Kotarba 1993, 1995). Rock-glaciers, not numerous in the High Tatra, are mainly related to the Younger Dryas (Kotarba 1991–1992) yet also to the Venediger cooling. Enormous extents of the glaciers in the Preboreal and Boreal Periods, marked on the Geological Map of the Tatra Mountains, 1:50,000 (Nemcok et al. 1995), are puzzling. On this map the extent of the Holocene glaciation is marked on the moraines of Ejsmond's bend (1,360 m a.s.l.) in the Rybi Potok valley. In the Five Polish Lakes valley — this is the extent of the glacier in Przedni Staw Lake and at the sill of the Siklawa waterfall; and in the Biała Woda valley the extent is marked to the moraines of Polana pod Wysoką glade (1,280–1,300 m a.s.l.). The above findings do not withstand comparison with the palynological analysis and with the radiocarbon dating of the deposits from Przedni Staw and Żabie Oko lakes. The authors of this paper generally do not accept the chronology of the Last Glaciation in the Tatras as it has been presented in the subsequent papers by R. Halouzka published in 1977–1995. R. Halouzka adopts M. Lukniš (1973) nomenclature for the moraines but changing his opinion about the age. M. Lukniš related moraines A–E3 to the Würm period, but the moraines at the edge of the Kacza, Czarny Staw pod Rysami, and Za Mnichem valleys to the Würm–Holocene border; only the highest located cirques he associated with the Holocene glaciation. For the latter, he reconstructed the snow line at 2,550 m a.s.l. on the northern slopes.

The number of recessional stages was increasing from 4 (Partsch 1923, Halicki 1930) to 8 and more (Klimaszewski 1967, 1988) in successive works. It seems that the number of stagnations was controlled not only by changes in the climate during the Late Glacial but also by a form of a glacial valley floor. Graded reaches of the valleys provided better conditions for forming and preservation of the moraines associated with stagnations than in the zone of the steps and hanging outlets of the tributary valleys. Moreover, a discontinued feeding by the glaciers from the successive tributary valleys caused the abrupt changes in the length and thickness of the main glacier. Nevertheless, the first two recessional stages BW1 and BW2 as well as the stagnation of the Gschnitz stage on the moraines R3, RP2, BW6 indicate climatic oscillations while the period of glacier's retreat from the Gschnitz moraines indicates areal deglaciation that evidences a fast decay of a longer section of the glacier.

The opinion of the authors, on interpretation of the oscillation of the glacier fronts, different from M. Klimaszewski's (1988) view should be emphasized. M. Klimaszewski interpreted the arcs of frontal moraines occurring together with the lateral moraines to be the effect of a significant retreat, and then, an advance. From the length of the co-occurring lateral moraines he estimated the magnitude of oscillation. The authors of present paper interpret such situation as an effect of decrease in the length of the glacier tongue simultaneously with its narrowing and thinning. Thus, any subsequent retreat of the glacier tongue was accompanied by the decrease in its width and thickness. The best examples here are the moraines of Ejsmond's bend RP2 and RP3, where the glacier's width and thickness decreased, but the length remained almost unchanged.

The presented process of glaciation and its recession in the High Tatra, with the Biała Woda Valley as an example, coincides well with the glaciation in the Austrian Alps, in the Inn valley. The similarities refer not only to the chronology of the main stage (stadial) and the Late Glacial recession, but also to the preceding period. In the Inn valley in the period 31–25 ka BP there was no glacier. The climatic conditions (reconstructed on the base of macroremnants) show cooling climate conditions as they can be observed at present in the range of timberline. It is likely that there were no glaciers in the Tatras 50–20 ka BP, because the conditions typical of steppe-tundra and forest-tundra prevailed on the direct foreland of the mountains (Obłazowa, Podhale Basin).

A similarity in climatic changes in the Austrian Alps and the Tatras is associated not only with their proximity but also with the location within the same air circulation zone. The ongoing dendrochronological and climatic studies confirm the teleconnection between the Tatras and the Alps.

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STRESZCZENIE

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WÜRMSKIE ZLODOWACENIE W DOLINIE BIAŁEJ WODY W TATRACH WYSOKICH

Wieloletnie badania terenowe prowadzone w Tatrach oraz poznanie w Alpach Austriackich klasycznych stanowisk dokumentujących późnoglacjalne i holoceńskie fazy deglacjacji umożliwiły autorom ustosunkowanie się do opublikowanych prac i map dotyczących Tatr, a w szczególności J. Partscha, B. Halickiego, M. Lukniša, M. Klimaszewskiego oraz L. Lindnera, J. Dzierżka i J. Nitychoruka. Materiały odnośnie do zasięgów moren czołowych i bocznych w systemie dolinnym Białej Wody, w stadiach maksymalnych i recesyjnych, pozwoliły oszacować relacje pomiędzy zasiegiem lodowca Białej Wody i lodowcami dwóch największych polskich dolin Rybiego Potoku i Roztoki tworzących złożony system glacjalny na północnym skłonie Tatr Wysokich.

Wyniki badań uzyskane dzięki datowaniom nacieków wapiennych w jaskiniach tatrzańskich (Hercman i in. 1987) oraz datowane węglem ^{14}C osady jeziorne i osady wypełniające wytopiska martwego lodu na przedpolu Morskiego Oka, stanowią podstawę do ustalenia chronologii zdarzeń w vistulianie uwarunkowanych klimatycznie. Chronologia deglacjacji dowiązuje do schematu opracowanego w Alpach Austriackich, lecz opiera się na wynikach badań w Tatrach.

W Dolinie Białej Wody stwierdzono istnienie dwóch maksymalnych stadiałów WM I w początkowej fazie piętra vistulianu, przypuszczalnie między 70 i 60 ka BP oraz drugiego WM II o zasięgu zaledwie 200 m mniejszym. W Dolinie Białej Wody w okresie tych stadiałów miąższość lodu w strefie łączenia się lodowca z Doliny Rybiego Potoku sięgała 300 m, a w drugim okresie 200 m. Dobrze zachowane wały moren końcowych znaczą zasięg maksymalny, natomiast najwyższy wał WB3 zachowany po wewnętrznej ich stronie świadczy o mniejszym zasięgu i mniejszej

miąższości jęzora. Dlatego wały WB1 i WB2 można korelować z fazą Leszna a wał WB3 z fazą Poznania (18,2 ka BP). Szukając dalszych analogii ze zlodowaceniem skandynawskim na Niżu Polskim można przyjąć, że pierwszy postój recesyjny BW1 świadczący o małej oscylacji, koreluje się z subfazą Chodzieży (17,2 ka BP). Natomiast duża oscylacja BW2, została powiązana z fazą pomorską (15,2 ka BP), a zarazem ze stadium bühl w Alpach [daty faz na Niżu wg S. Kozarskiego (1991)].

Przypuszczalnie w okresie 14 ka BP (steinach w Alpach) lodowiec Białej Wody był jeszcze zasilany przez lodowce Roztoki i Rybiego Potoku. W czasie alpejskiego stadium recesyjnego schlern lodowiec Roztoki usamodzielnił się, a kolejno także lodowiec Rybiego Potoku. Istotnym etapem w deglacjacji był postój 13 ka temu, tj. podczas alpejskiego stadium gschnitz i fazy gardneńskiej na Niżu Polskim. W Tatrach okres ten dokumentuje data radiowęglowa 12 500 lat BP z osadów Czarnego Stawu Gąsienicowego oraz analiza palinologiczna z osadów jeziornych Przedniego Stawu w Dolinie Pięciu Stawów Polskich. W czasie ocieplenia bölling nastąpiła deglacjacja arealna w Dolinie Białej Wody powyżej moren BW6 i w Dolinie Rybiego Potoku powyżej moren recesyjnych RP2/RP3 oraz powstał znaczny dystans do moren Polany pod Wysoką i moren Morskiego Oka (daun). Stadium młodszego dryasu (egesen) miało o wiele mniejszy zasięg, a lodowce przyjęły formę lodowców cyrkowych.

Zarówno okres młodszego dryasu jak i ochłodzenie venediger przejawiły się w Tatrach nie tylko przetrwaniem lodowców, lecz także ożywieniem procesów stokowych, soliflukcji i spływów gruzowych (Baumgart-Kotarba, Kotarba 1993, 1995). Nieliczne w Tatrach Wysokich lodowce gruzowe wiązane są głównie z okresem młodszego dryasu, a nie wykluczone, że także z oziębieniem venediger. Autorzy artykułu generalnie nie zgadzają się z chronologią ostatniego zlodowacenia w Tatrach przedstawianą w kolejnych pracach R. Halouzki, opublikowanych po roku 1977.

Przedstawiony przebieg zlodowacenia i jego recesji w systemie dolinnym Białej Wody dobrze koreluje z przebiegiem zlodowacenia w Alpach Austriackich w Dolinie Innu. Podobieństwo dotyczy nie tylko chronologii głównego stadiału i późnoglacjalnej recesji lecz także okresu poprzedzającego. W Dolinie Innu w okresie 31–25 ka BP nie było lodowca, a rekonstruowane na podstawie makroszczątków warunki klimatyczne wskazują na istnienie chłodnego klimatu przypominającego współczesne warunki klimatyczne górnej granicy lasu. W Tatrach przypuszczalnie w okresie 50–20 ka BP nie było lodowców, gdyż na Podhalu panowały w tym czasie warunki stepo-tundry i laso-stepu. Podobieństwo przebiegu zmian klimatycznych w Tatrach i Alpach Austriackich znajduje również potwierdzenie we współczesnych badaniach dendroklimatologicznych.