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A R T I C L E S

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DEGLACIATION IN THE SUCHA WODA AND PAŃSZCZYCA VALLEYS IN THE POLISH HIGH TATRAS

Abstract. Knowledge on glaciers extents in two valleys of the Polish High Tatra Mountains around the last glacial maximum, and theirs decay are based on detailed geomorphological mapping, lake sediment studies, as well as minerogenic materials dating by use TL, OSL, SAR, ^{36}Cl and ^{14}C. The last glacial maximum lasted 21–19 ka BP. Ice built-up in two separate Sucha Woda and Pańszczyca valleys led to coalescending ice body, which created extended glacio-fluvial cones and terraces in front of terminal moraines. The retreat of glaciers is marked by recessional and oscillation moraine systems. Seven stages of ice decay have been distinguished. The glaciers vanished in both valleys before 8,300 BP, i.e. after Venediger stage.

Key words: deglaciation, moraine ridge pattern, absolute dating, High Tatra

Besides the system of the Biała Woda and Jaworowa valleys, the Sucha Woda and Pańszczyca valleys form the largest valley system on the northern slopes of the High Tatras. During the maximum phase of the last glaciation, the glaciers formed in the cirques of these valleys were joined that is evidenced by a high and steep terminal moraine that slightly spreads beyond the northern boundary of the Tatras. The area of junction of both these glaciers was discussed by B. Halicki (1951) and M. Klimaszewski (1988). It seems that the presentation of this area on the geologic map of the Tatras 1 : 10,000 (Kopieniec sheet) and on the geologic map 1 : 30,000, derived mainly from air photos, is far from the real distribution of the moraines and dead-ice hollows. The height contours drawn on the more recent topographic maps 1 : 10,000 reflect better a complicated relief developed due to deglaciation. A significant forestation of the area adds up to difficulties in retrieving a satisfactory outline. The only area where trees and dwarf pine covers are less compact is the peatland. However, the forest zones that separate the peatland in the region of the dead-ice depressions are not always the moraine ridges. Therefore, the authors draw mainly upon geomorphic field mapping with the help of the new topographic maps 1 : 10,000, and the synthetic outcome is compiled on the map of the High Tatras 1 : 15,000 (EKO-GRAF, Wrocław 1998). The arrangement of clearly distinguishable sequences of the ridges and larger peatland areas occurring in their surroundings, which were interpreted as the recessional ridges and terminal depressions, represents the subsequent stages of deglaciation. On the other hand, the location of the lateral moraines, indicating the maximum extent of glaciation is very similar to their pattern presented on majority of the published maps.

The problem of the age of the glacial forms is discussed based on the published and unpublished datings obtained by the radiocarbon, TL, OSL, SAR and ^{36}Cl methods. The scope of this paper allows only for the discussion of selected concepts expressed by various authors. Certain methodological aspects and conclusions referring to the deglaciation in the Biała Woda valley have been presented by the authors in their former paper printed in 1997, therefore, this paper does not always cites the complete evidence.

STUDY AREA

The Sucha Woda valley begins below Sucha Pass, between the summits of Kasprowy Wierch and Beskid. The system of the Sucha Woda valley is asymmetric as the side valleys join the main one from the east, i.e. from the High Tatras. Both the Stawy Gąsienicowe valley and the Czarny Staw Gąsienicowy valley with a system of step-like arranged glacial cirques are incised into the western part of the granite intrusion of the High Tatras. The broad Sucha Woda valley is controlled by an important tectonic boundary which separates the granite intrusion of the High Tatras from the so-called "Goryczkowa island and Giewont fold" (Fig. 1). Therefore, it seems that the Sucha Woda valley has an old tectonic set-up, but it cannot be excluded that the valley was subjected to active tectonics also in the Quaternary. The northern margin of the Tatras is an element of an unrecognised and, probably, a very deep structure that is visible in the satellite images. This satellite lineament has been named the lineament of the northern margin of the Tatras (Baumgart-Kotarba 1981).

The Pańszczyca valley, arranged meridionally, is much narrower, closed by the ridge of Buczynowe Turnie form the south, and descends northward as a number of hanging sections transformed glacially. From the east, the

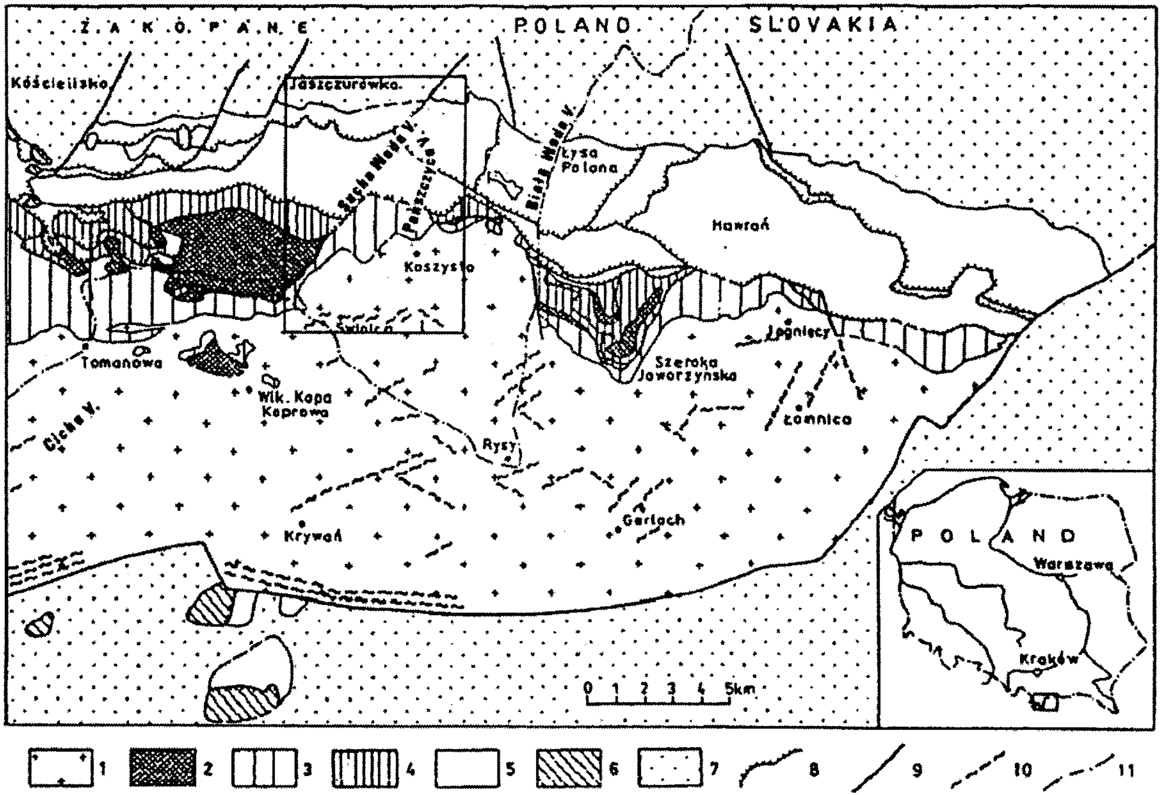


Fig. 1. Location of the Sucha Woda and Pańszczyca valleys against tectonic sketch-map of the High Tatra Mountains (acc. to Geological Map of the Polish Tatra Mountains, 1 : 30,000, 1979 modified by K. Birkenmajer, 1999). 1 — granitoids, 2 — Hightatric overthrust crystalline rocks, 3 — Hightatric Mesozoic sedimentary cover of crystalline core, 4 — High-tatric tectonic units (Mesozoic sedimentary rocks), 5 — Lower Sub-tatric nappe (Križna nappe), 6 — Middle Sub-tatric nappe (Choč nappe), 7 — Paleogene flysch, 8 — important overthrusts, 9 — important faults, 10 — young mylonites, 11 — state boundary

valley in question is joined by the only side-valley which is lithologically controlled and emerges from Przysłop Waksmundzki. A change in the orientation of the Pańszczyca valley from the meridional to the northwestern direction was likely caused by the confluence of the Pańszczyca and Sucha Woda glaciers. The geomorphologic evidences point to the confluence of these glaciers on Skoruśniak summit at 1,700 m a.s.l. The current outlet from the Pańszczyca valley hangs more than 100 m above the Sucha Woda valley. The stream draining the valley flows in a block field of the moraines which have been washed down. Presumably, the former outlet from the Pańszczyca valley was east of the ridge of Kobyła (1,234 m a.s.l.). At present, a deeply incised karst canyon of the Skalnite valley occurs here. Similar suppositions were earlier suggested by J. Partsch (1923), B. Halicki (1930) and M. Klimaszewski (1988). During the glaciation period there was the transfluence of the Pańszczyca glacier into the head part of the Skalnite valley. The glaciers whose moraines barricaded the valley fragment in the forest zone imposed a change in the original, meridional direction of the outflow from the Pańszczyca valley.

The asymmetric pattern of the Sucha Woda valley contributed to the ice supply to the Sucha Woda glacier from the east and, as a result, caused the ice masses to overflow (transfluence) to the Olczyska valley neighbouring here from the west. According to M. Klimaszewski (1988) the glacier from the Sucha Woda valley had its outlet between Wielki Kopieniec and Kotlinowy Wierch during the Riss glaciation. At the foreland of this hanging outlet an extensive glacio-fluvial cone occurs whose western flank is currently drained by the Chłabówka stream. According to B. Halicki (1930) this was the outflow of the last glaciation period, as he accepted the Riss age of the moraine plateau of Toporowe Stawy.

A very well developed complex of glacial forms makes the outlet zone of the Sucha Woda valley easily distinguishable from other Tatric valleys. Here, a kind of the moraine plateau has developed which descends as steep, 50–100 m high, moraine slope onto the extensive surface of the glacio-fluvial cone of Toporowa Cyrhla. On the plateau there are depressions occupied by the lakes the largest of which, called Toporowy Staw Niżny, is 5.6 m deep. The depressions with peat, dry and elongated, are the series of depressions differing as to their heights, that remained after the melting of ice which had preserved them. On the plateau, the outer and inner ridges ‘a’ and ‘b’, respectively, can be distinguished. The traces of the frontal recession of the still joined Pańszczyca and Sucha Woda glaciers are also found at the eastern side of the valley, north of the Pańszczycki stream. Uphill, the retreat of the glaciers took place independently and, thus, the individual recession stages of each glacier have been marked using the numbers preceded by the letters which denote particular valleys: P1, P2, P3, P4 denote the glacier position of the Pańszczyca valley and SW1, SW2, SW3 and SW4 — recession in the Sucha Woda valley. The common maximum phases are denoted in the similar way as in the papers on the deglaciation of the system of the Biała Woda valley — WB1, WB2, WB3. It is unknown whether the outlet of the Sucha Woda glacier, which according to M. Klimaszewski (1988) was of the Riss age, is really associated with the pre-Eemian cooling period. It may as likely refer to the Early Würm glaciation, called WA after M. Lukniš (1973). The Early Würm age has been accepted, based on the analysis of the longitudinal profile of the Białka river, and particularly on its relation to the washed down moraine ridge occurring on the bottom of the Białka valley downstream the clearly marked moraines WB, as well as based on the relation to the terrace covered with the young loess and having two different archaeological sites : the older one in the Obłazowa cave and the younger one — the open Late Glacial site (Baumgart-Kotarba and Kotarba 1997).

THE PURPOSE AND THE METHODS USED

The purpose of this paper is to present the extent of the maximum stadial of the Würm glaciation and its recessional stages, as well as to discuss the recessional stages of the individual Sucha Woda and Pańszczyca glaciers. The paper also aims at showing the final phases of the recession in the terminuses of the valleys forming the system of the Sucha Woda valley. The age of the glaciation and the deglaciation process are presented against the background of the geomorphological methods, palynological analyses of peatland and lacustrine deposits elaborated by A. Obidowicz (1975, 1993, 1996), the radiocarbon dating and the sedimentological analyses of the late glacial lacustrine deposits. The authors of this paper express their opinion about the number and chronology of glaciations and the late-glacial recessional stages of the Würm in the High Tatras mainly based on the facts from the system of the Biała Woda valley (Baumgart-Kotarba and Kotarba 1997; Kotarba and Baumgart-Kotarba 1999), and relate their findings to the alpine literature (Patzelt 1975; van Husen 1997). A relatively large number of the TL analyses, and recently the ^{36}Cl analyses (Lindner et al. 1990; Lindner et al. 1993; Lindner and Marks 1993; Dzierżek et al. 1999) have been carried out for the Sucha Woda valley. These analyses together with TL datings of the glacio-fluvial cones and terraces in the Biały Dunajec drainage basin in Podhale region served the authors to develop the chronology of the Tatric glaciation during the last 500,000 years. Moreover, the paper critically discusses the proposal of Warsaw geologists on the suggested three stages of glaciation (the Sucha Woda, Bystra and Białka stages) and the division of the last stage into the Hurkotne, Włosienica, Łysa Polana and Pięć Stawów phases.

The non-numerous TL and OSL datings, made by Dr. A. Bluszcz of the Luminescence Dating Laboratory in the Physics Institute of the Silesian Polytechnics at Gliwice, are presented in this paper. The OSL method is very valuable for verifying the chronology driven from the TL analyses. The SAR method, used for determination of the age of one of the moraines in the Sucha Woda valley (Baumgart-Kotarba et al. 2001) is also very promising. The dating with ^{36}Cl isotope resulted in very encouraging outcomes as well.

The essence of the Tatric studies is drawing upon the results obtained directly from the fieldwork and the comparison of these results with the earlier developed chronology of the alpine events. The palynological characteristics, datings of the lacustrine deposits in Czarny Staw Gąsienicowy Lake, and the datings of the deposits, which fill up the dead-ice depression of Żabie Oko at the foreland of the moraine of Morskie Oko Lake in the Biała Woda drainage basin, are the clues to reveal the recession of the glaciers in the Tatras. The correlation performed using the geomorphologic methods, allows one to compare various Tatric valleys.

The relative differentiation of the age of the moraine covers can be assessed based on the degree of weathering of the surface of the moraine blocks using the Schmidt's hammer (Kotarba et al. 2000). This method is useful for distinguishing the blocks of the older glaciations form those of the younger glaciations, especially in the case of extensive areas such as the Hurkotne plateau or the ridge of Skoruśniak that separates the Sucha Woda valley from the Olczyska valley.

THE MAXIMUM TERMINAL AND LATERAL MORAINES

The terminal moraines indicating the maximum extent of the joined Sucha Woda and Pańszczyca glaciers are very well developed. Not only a steep, gravitational, 50–100 m high, slope, which protrudes above the extensive and gently inclined surface of the glacifluvial cone, can be distinguished but also the extent of the maximum lateral moraines can be traced. Based on the positions of these lateral moraines one can infer about an approximate altitude of a permanent snow line (at 1,600 m a.s.l.) during the last cold stage. The calculations based on the Höfer's method, which was popular in the past, or on the other methods (Partsch 1923; Halicki 1930; Lukniš 1973) locate this line at the height of 1,500–1,760 m a.s.l. during the maximum phases. The identification of the maximum moraines is credited to the researchers of the last century (Alth 1879; Partsch 1882). These moraines used to be described several times, especially by E. Romer (1929), B. Halicki (1930,1951) and S. Lencewicz (1937), A. Gadomski (1926). M. Klimaszewski (1962, 1988) compiled the concepts of the authors mentioned above, emphasising the value of their certain outcomes and criticising the others.

The ^{36}Cl isotope datings (Dzierżek et al. 1999) determine the age of the maximum stage. The date of 21 ka allows one to correlate the moraines of Toporowe Stawy with the Leszno stage, i.e. with the maximum stage of the Scandinavian glaciation in the Polish Lowland. The other dates are younger and can be interpreted as marking the period of deglaciation and formation of dead-ice depressions. Unfortunately, there is no radiocarbon dating of the material from the drilling in Toporowy Staw Lake but the palynological analysis points to the Atlantic age (Obidowicz 1975). Such state of the research, made J. Kondracki (1986) to suggest a long period of melting of the dead ice in the zone of the terminal moraines. The buried ice in the Tatras was assumed to persist for the longer period in the zones of the maximum extent of the glaciers than in the glacial cirques that have been free of ice since 13 ka (Baumgart-Kotarba and Kotarba 1997; Wicik 1979, 1984).

In the scientific papers besides the age, the number of glaciations and recessional phases, a type of deglaciation (frontal or areal) has been discussed. In the case of the moraines of Toporowe Stawy the direction of the terminal moraines is important. It provides the evidence of the outflow of glacial waters due to west and northwest while the present-day outflow from the Sucha Woda valley is eastward along the northern margin of the Tatras. In the discussion on the age, the maximum stage was assumed to be of the Riss. Such supposition is given by B. Halicki (1930). However, M. Klimaszewski demonstrated that freshness of these moraines and the origin of the depressions related to the dead-ice melting, indicating the areal deglaciation, are the evidence of the young age of the terminal moraine. M. Klimaszewski (1988) assigns the Riss age to the outlet of the Sucha Woda glacier west of Kotlinowy Wierch through the Polana Kopieniec Glade to the zone hanging at 1,200 m a.s.l., i.e. 120 m above the broad young Würm glacio-fluvial cone, which, at present, is being dissected on both flanks; on the western flank by Chłabówka stream flowing to the Olczyski stream in Podhale, and on the eastern flank by the Chowańcówka stream merging the Poroniec stream near Majerczykówka (Fig. 2). The radial pattern of the valleys fragmenting the foreland of the Tatras, which is built of the Podhale flysch, can be interpreted as the dissected old cone of the Sucha Woda between the stream from Olcza in the west and the stream from Małe Ciche in the east. This area is drained to the Poroniec stream, i.e. to the Biały Dunajec drainage basin. The alluvial covers have been preserved in the zone of the weakly dissected apex of the cone (the Capowski Las Forest) while the remaining areas of it are incised in the flysch. The initiation of this cone can be related to the widely understood Quaternary or maybe even to the Upper Pleistocene. The cone and the history of its dissection can be interpreted in reference to dissection of the northern flank of the Tatras.

It seems that J. Partsch's (1923) interpretation of the origin of the moraines of Toporowe Stawy related to the frontal deglaciation during the maximum extent of the Sucha Woda glacier joined with the Pańszczyca glacier is the best. The

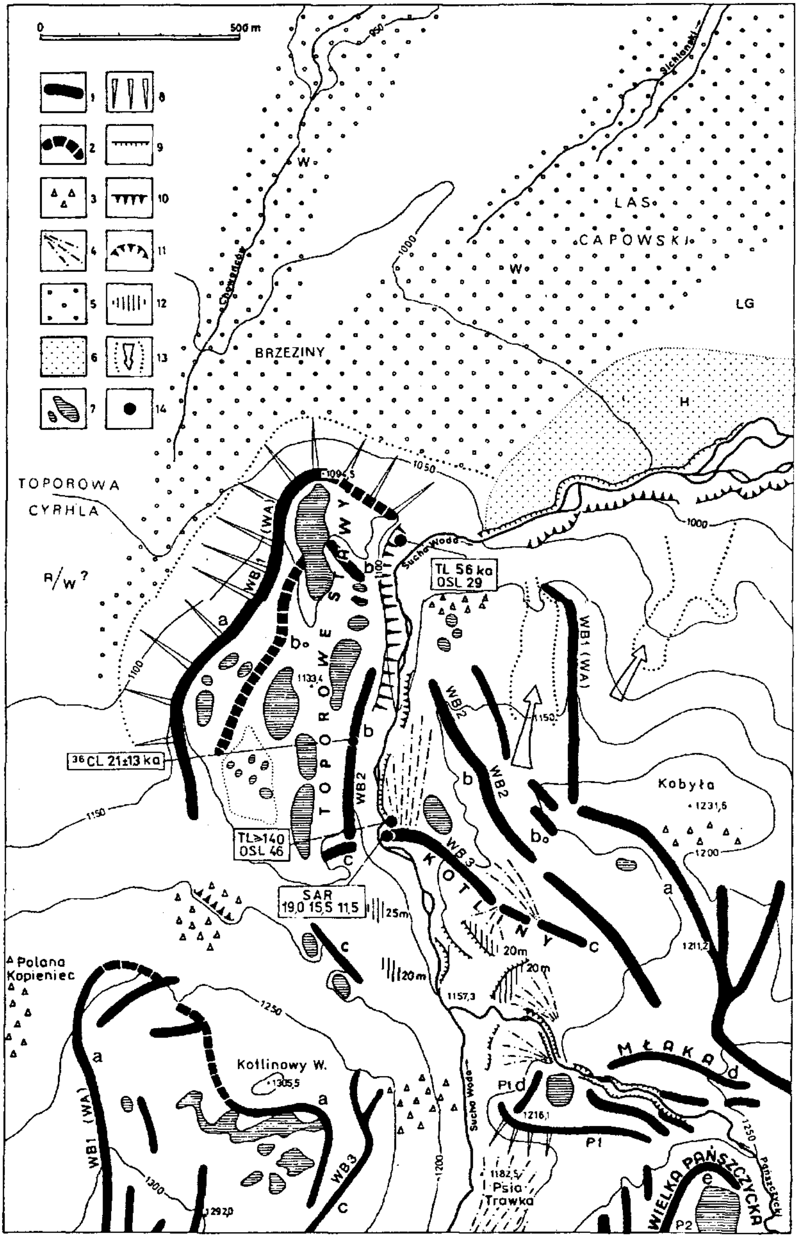


Fig. 2. Terminal Toporowe Stawy moraine system of the Sucha Woda and Pańszczyca valleys. 1 — distinct moraine ridge, 2 — reconstructed moraine ridge, 3 — glacial boulders, 4 — glacio-fluvial cone, 5 — main glacio-fluvial cone, 6 — Holocene terrace, 7 — dead-ice depressions, 8 — steep slope of moraine ridge, 9 — terrace edge, 10 — erosion scarp, 11 — landslide niche, 12 — glacio-fluvial terrace, 20–25 m in hight, 13 — reconstructed outflow of meltwater during maximum stand of Würm glaciation, 14 — TL, OSL, SAR and ^{36}Cl sampling sites, LG — Late Glacial terrace, H — Holocene terrace, W — Würm glacio-fluvial cone, from max. stadial

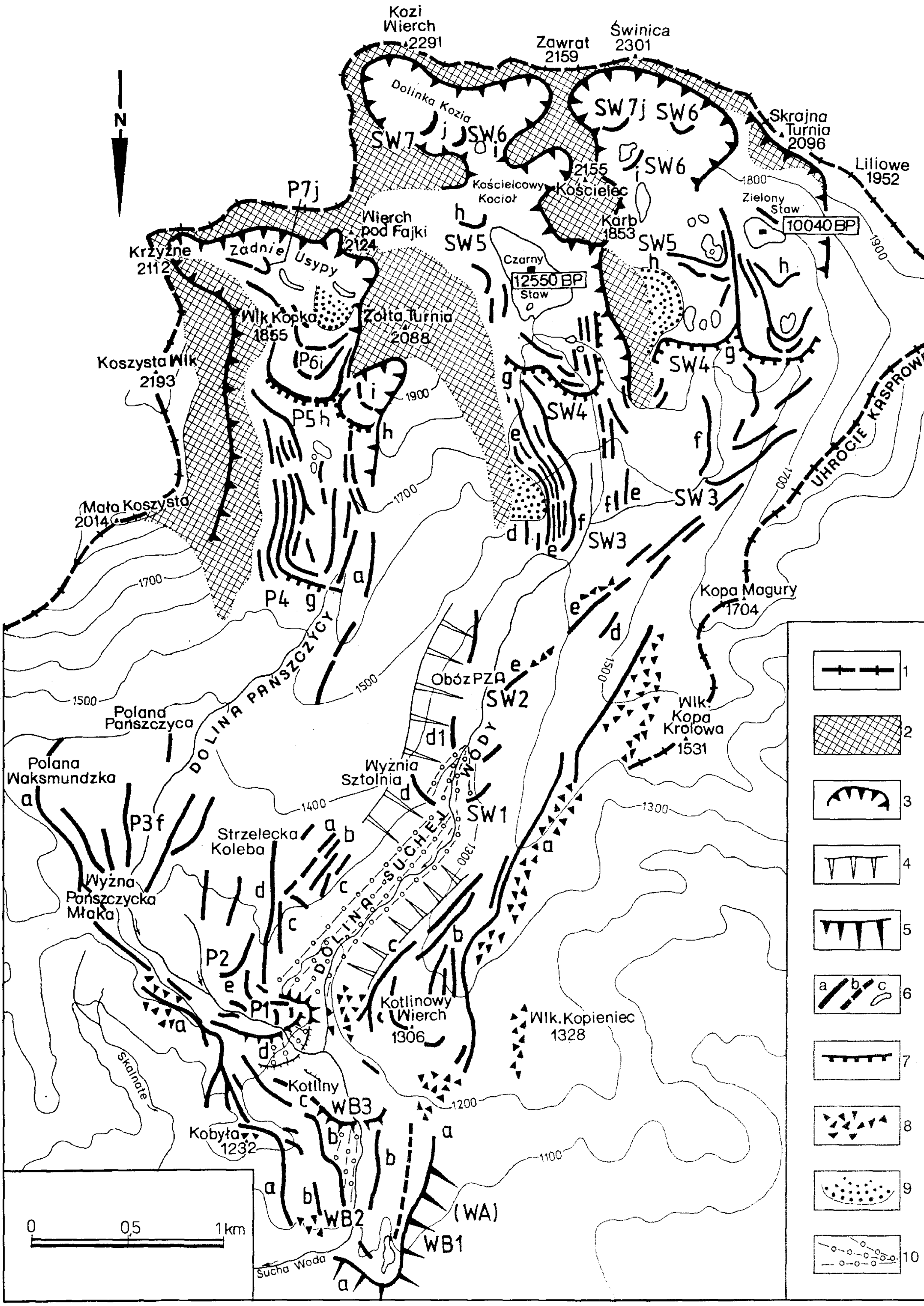
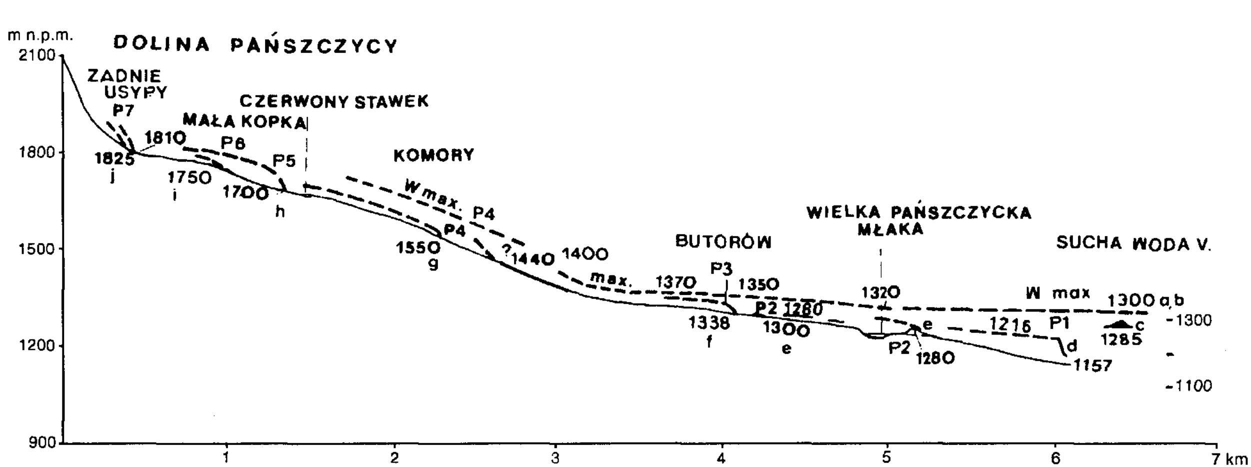


Fig. 3. Moraine-ridges sequence in the Sucha Woda and Pańszczyca valleys. 1 — valley divide, 2 — rockwall/rocky slopes, 3 — glacially-steepened rockwall, 4 — steep slope of glacial trough, 5 — steep slope of moraine, 6 — moraine ridge distinct (a), reconstructed (b), glacial lakes (c), 7 — front of oscillation moraine, 8 — morainic boulder field, 9 — relict rock glacier, 10 — glacio-fluvial fan

amphitheatre of the outermost maximum moraines 'a' (WB1) opens towards the outlet section of the Pańszczyca valley (Fig. 2). The orientation of this amphitheatre evidences that its arrangement was controlled by the ice masses of the Pańszczyca glacier which was more active in this region. That is also confirmed by the right-hand-side moraine rising from 1,100 m east from the Sucha Woda channel to 1,230 m at the foot of Kobyła. The left-hand-side moraine rises from 1094 m in the most northward part of ridge 'a' to 1,170 m at the foot of the steep slope of Kotlinowy Wierch. The N–S oriented recessional ridge 'b' separates the depressions of Niżny and Wyżny Toporowy Staw from the depression drained by the Sucha Woda stream. The altitude of this ridge is 1,150–1,120 m a.s.l., and the present-day channel of the Sucha Woda stream descends from 1,120 to 1,060 m, while the intra-moraine depression of Toporowe Stawy declines from 1,135m to 1,088 m. The maximum moraines occurring east of the present-day bottom of the Sucha Woda valley, corresponding to phases WB1 and WB2 merge at 1,250 m a.s.l., and then ascend to 1,345 m a.s.l. leaving the peatland of Wyżnia Pańszczycka Młaka in the extraglacial position, and barricading on their way the presumed primary orientation of the Pańszczyca valley in the zone of Czerwone Brzeżki (1,323 m a.s.l.). The right-hand side moraine of the Pańszczyca valley reaches 1,400 m at the maximum at the margin of Polana Waksmundzka Glade, at the foot of the steep slope of Mała Koszysta (Fig. 3).

This huge right-hand-side moraine, identified by all the researchers reconstructing the glaciation of the Sucha Woda and Pańszczyca valleys, provides the evidence of the tremendously extensive development of the Pańszczyca glacier in the forest zone. Here, the glacier reached the width of 1.5 km. Almost all the researchers stated the transfluence of the Pańszczyca glacier both in the zone of Czerwone Brzeżki and south of the summit of Kobyła (the Polana pod Kobyłą glade) (Fig. 3). The height of 1,400 m a.s.l. evidences the very low position of the permanent snow line during the maximum of the Würm glaciation, i.e. the much lower position than it has been accepted in all the reconstructions hitherto. The left-hand-side, uppermost located moraine of the Pańszczyca glacier, which starts at the height of ca 1,680 m at the water-divide ridge and separates the flattening of Dubrawiska over the Sucha Woda valley from the part of the Pańszczyca valley with the system of recessional moraines Komory, descends northward through Wolaczyska (1,618 m) onto the moraine ridge of Skoruśniak–Strzelecka Koleba, and here, at the height of 1,310 m, it becomes the middle moraine of the Pańszczyca and Sucha Woda glaciers (Fig. 3).

The huge left-hand-side moraine of the Sucha Woda–Pańszczyca system can be traced from 1,580 m at the Rówień Królowa Glade in the zone of the transfluence of the Sucha Woda glacier to the upper Olczyska valley. This moraine descends towards Kotlinowy Wierch to the height of 1,377 m where it diverges into a series of ridges. The above evidences the decreasing thickness of the glacier, that in the zone of the broad flattening of Kotlinowy Wierch at 1,305 m a.s.l. made the



J.Partsch 1923.			IV 1660	III 1480			II 1245	
M.Klimaszewski 1988.	VI 1840,1810	V?	III i IV 1560		II 1310	I 1280		
M.and A.Kotarba 2001.	P7	P6	P5	P4	P3	P2	P1	WB3
Morainic ridges.	j	i	h	g	f	e	d	c
Ka BP.	8,7–8,4	10,7	12	13	14	14	14–15	

Fig. 4. Longitudinal profile of the Pańszczyca Valley, terminal and recessional stages ('a' to 'j'). Ages of moraine ridges by M. and A. Kotarba correlated with moraine system distinguished by J. Partsch (1923) and M. Klimaszewski (1988)

moraine ridges to spread over a 700 m width. The outermost ridge ‘a’ (WB1) points to the transfluence toward the Polana Kopieniec Glade while the noticeable innermost ridge, which has still been preserved on the broad flattening of Kotlinowy Wierch, descends from 1,350 m to 1,260 m (Fig. 3). Based on the analysis of the geomorphological map it cannot be stated definitely, whether this is the ridge ‘b’ indeed. Probably, it might be ridge ‘c’ because here a number of ridges between ridges ‘a’ and ‘c’ correspond to the position of ridge ‘b’. Below the altitude of 1,250 m, on the steep slope, only moraine blocks are present. Then, ridge ‘b’ continues in the moraine plateau of Toporowe Stawy as the ridge of the phase of Toporowy Staw Niżni II and it is oriented meridionally. On the other hand, the transversally oriented ridge ‘c’ points to a younger advance of the glacier that reached down-valley to 1,160 m a.s.l.

The authors correlate the phase of Toporowe Stawy I with the Leszno phase at the Polish Lowland, and the ridge of Toporowe Stawy II with the Poznań phase. The last moraine evidencing the common tongue of both the glaciers occurs at 1,160 m and has been called the phase of „Kotliny”. It is the noticeable moraine ridge dissected by the Sucha Woda stream to the depth of 30–40 m. The pattern of this moraine documents its oscillating character (Fig. 2). This moraine can be related to phase BW1 in the Biała Woda valley and can be correlated with the sub-phase of Chodzież at the Polish Lowland.

In the forest zone, the Sucha Woda glacier reached its maximum width — 1,600 m. The unusual growth of the glacier width was associated with the role of the ridge of Kotlinowy Wierch that was an obstacle to the ice masses and imposed the wide spreading of the glaciers westward, 700–800 m outside the glacial trough. The maximum thickness of the Sucha Woda in the zone of Kotlinowy Wierch was at least 120 m, and 2 km up-valley it was even 170 m. The maximum thickness of the Pańszczyca glacier reached ca 150 m in the upper granite part of the valley, while in the cross-profile in the zone of the sedimentary rocks of Czerwone Brzeżki-Skorusniak it reached only 100 m. In the upper part the width of glacier tongue was 700 m while in sedimentary zone reached 1500 m.

THE RECESSION OF THE PAŃSZCZYCA VALLEY

In the zone of the hanging outlet of the Pańszczyca stream, the very pronounced steep amphitheatre of the moraines, which are dissected by the Pańszczycki stream, has been stated. That is phase ‘d’, which is undoubtedly the oscillation phase. It is called the „Młaka” phase (P1) and is related to the Pomeranian phase at the Polish Lowland and to the Bühl stage in the Alps. At that time, the tongue of the Pańszczyca glacier partially blocked the main valley of Sucha Woda in the zone of the presumed, terminal depression of phase WB3, whereas the Sucha Woda glacier occurred over 2 km farther southward (SW1). The boreholes have been drilled in the peatland filling up the terminal depression of this phase. The peat was not deeper than 2 m. The ridge enclosing the peatland rises as the distinct, steep slope to the height of 10 m and descends outside as the 20 m high slope to the level of the Pańszczyca glacio-fluvial cone, and as the 30 m high slope above the bottom of the Sucha Woda valley at the site called Psia Trawka 1,182 m a.s.l. (Figs 2, 3; Table 2).

The subsequent phase 'e', called the phase of Wielka Pańszczycka Młaka (1,280 m a.s.l.), is the evidence of the recession of the Pańszczyca glacial tongue by 600 m. The borehole in the centre of the peatland drilled and interpreted by A. Obidowicz (1975) points to the succession of boreal forests (*Picea*). In this borehole, the late glacial fragment of the deposits was not confirmed. The dates from this region: 7,280 ± 110 years (Strzelecka Koleba 1,320 m a.s.l.) and 6,160 ± 90 years at 1,275 m, which refer to the clayey material, containing detritus and sticks and spreading over the floors of the flattenings among the ridges, indicate the disintegration of the tongue of phase 'e' (Fig. 3). The obtained Holocene dates prove the Early Atlantic age of the sediments, likely originating from washing down of the moraine ridges that were forested at that time. The younger dates provide the evidence that such processes also occurred in the Subatlantic (Table 1). The tongue of the Pańszczyca glacier in phase 'e' was still ca 1 km wide, while during the next

Table 1

The oldest radiocarbon data in the Sucha Woda valley system

Location	Altitude [m a.s.l.]	No. of sample	Radiocarbon age BP
(1) Dolina Pańszczyca, wooden detritus below peat bog	1,275	Gd-5051	6,160 ± 90
(2) Dolina Pańszczyca, Strzelecka Koleba wooden detritus in clay	1,320	Gd-2574	7,280 ± 110
(3) Dolina Pańszczyca, Wyżnia Pańszczycka Młaka, peat-bog	1,345	Gd-2323	4,570 ± 100
(4) Czarny Staw Gąsienicowy, Lake sediment	1,621	Gd-4540	12,550 ± 420
(5) Czarny Staw Gąsienicowy, Lake sediment	1,621	Ua-1445	9,620 ± 130
(6) Czarny Staw Gąsienicowy, Lake sediment	1,621	Gd-4923	10,700 ± 300
(7) Zielony Staw Gąsienicowy Lake sediment	1,670	Ua-1446	10,040 ± 150
(8) Undrained depression close to Zielony Staw, peat-bog	1,675	Gd-2739	4,110 ± 100
(9) Kurtkowiec Lake, Lake sediment — gytija	1,688	Gd-9151	10,190 ± 300

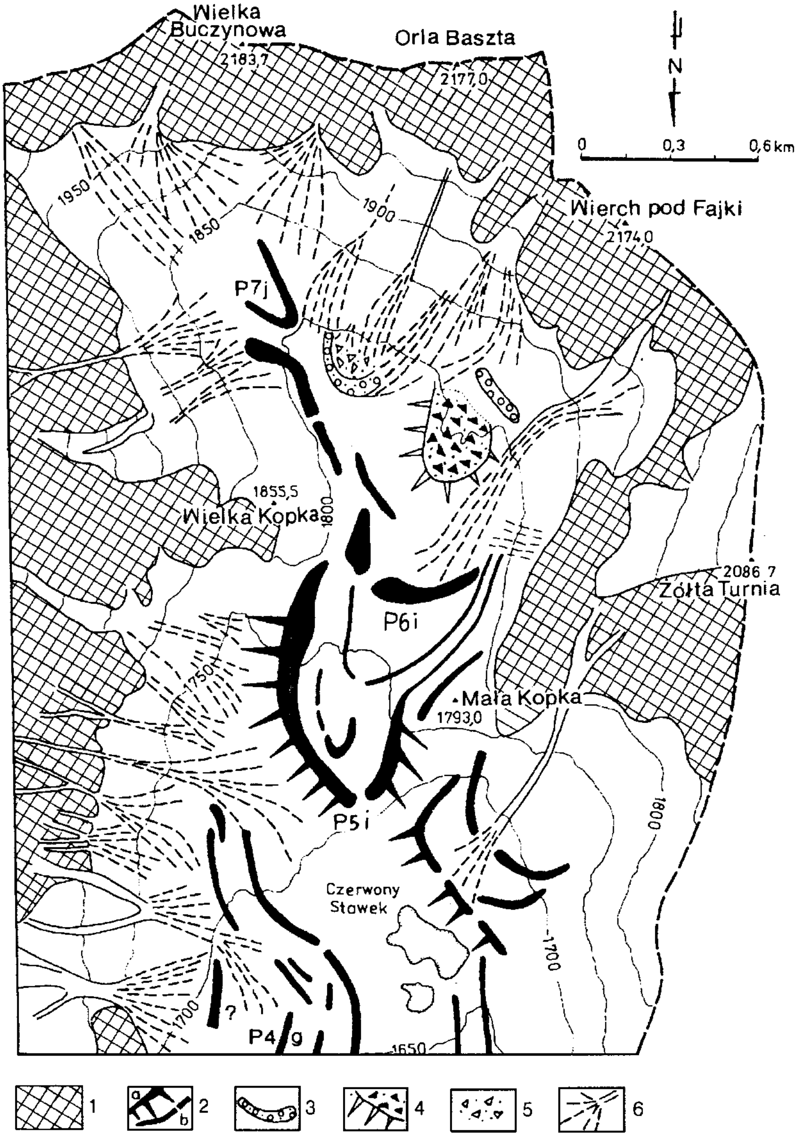


Fig. 5. Landforms marking ice-position in valley head of the Pańszczyca valley. 1 — rockwall/rocky slope, 2 — moraine ridge marking readvance (a), recession (b), 3 — nival moraine, 4 — relict rock glacier, 5 — rockslide, 6 — chute and talus cone

recessional phase ‘f’ (Butorów) it was only 300 m wide in its terminal part. Therefore, it seems that the moraine ridges ‘e’ and ‘f’ should be related to phase Steinach (14 ka). During this phase the outlet of the Pańszczyca glacier was at height of 1,280 m (ridge ‘e’), and then retreated to the height of 1,300–1,338 m a.s.l. (phase ‘f’) (Figs 3, 4, 7).

The subsequent, well-defined recessional phase 'g' (P4) points to the retreat of the glacier front by 2 km. Phase P4 had the oscillating character and is marked by 3 well-defined moraine ridges occurring at the altitude of 1,550 m (Fig. 4). The terminal depression of this phase is locally named "Komory". The moraine ridges, overgrown with dwarf pine, can be traced easily from the air photos. The similar development of 2–3 ridges below glacial step of Czarny Staw Gąsienicowy Lake (1,540 m) and the moraines of Litworowy Lake (1,608 m) and Dwoisty Lake (1,650 m) in the Stawy Gąsienicowe valley, allows one to assume them to be of the same age. Because the late glacial fragment of the core of the lacustrine deposits of Czarny Staw Gąsienicowy is dated at 12,500 years BP, the phase 'g' has been related to the alpine Gschnitz phase (13 ka) (Baumgart-Kotarba and Kotarba 1993).

Table 2

Recession of Late Würm glaciers in the Sucha Woda valley system

Alpine stages and Polish Lowland phase	Age BP ka		Approximate altitude of recessional moraines (m a.s.l.)				
			Sucha Woda valley			Pańszczyca valley	
			Stawy Gąsienicowe v.		Czarny Staw v.		
Venediger	8.7–8.4	SW7 'j'	Zadnie Koło 1,950 m		Kozia Dolina v. 1,940 m	P7	Zadnie Usypy 1,810 m
Egesen	10.7–10.2	SW6 'i'	Zadni Staw 1,850 m	Świnicka K. 1,887 m	lower Kozia v. 1,830 m	P6	Kopka II 1,750–1,770 m
Daun	12	SW5 'h'	Kurtkowiec 1,688 m	Zielony 1,675 m	upper Cz. Staw 1,630 m	P5	Kopka I 1,700 m
Gschnitz/ Gardno	13	SW4 'g'	Dwoisty 1,660 m	Litworowy 1,608 m	lower Cz. Staw 1,540 m	P4	Komory 1,550 m
Steinach II	13.5?	SW3 'f'	Mokra Jama 1,530 m		Czarna Pasza 1,420–1,450 m	P3	Butorów 1,338 m
Steinach	14	SW2 'e'	Obóz PZA 1,340–1,350 m			P2	Wielka Pańszczycka Młaka 1,280 m
Bühl/ Pomeranian	15	SW1 'd'	below Wyżnia Sztolnia "d" 1,280 and "d 1" 1,300 m			P1	Młaka 1,216 m
Chodzież Subphase	17.2	WB3 'c'	Kotliny 1,160 m (17.2 ± 2.2 ka — ^{36}Cl)				
Poznań Phase	18.4	WB2 'b'	Toporowy Staw II 1,130–1,150 m (21.0 ± 1.3 ka — ^{36}Cl)				
Leszno Phase	20	WB1 or WA 'a'	Toporowy Staw I 1,094 m				

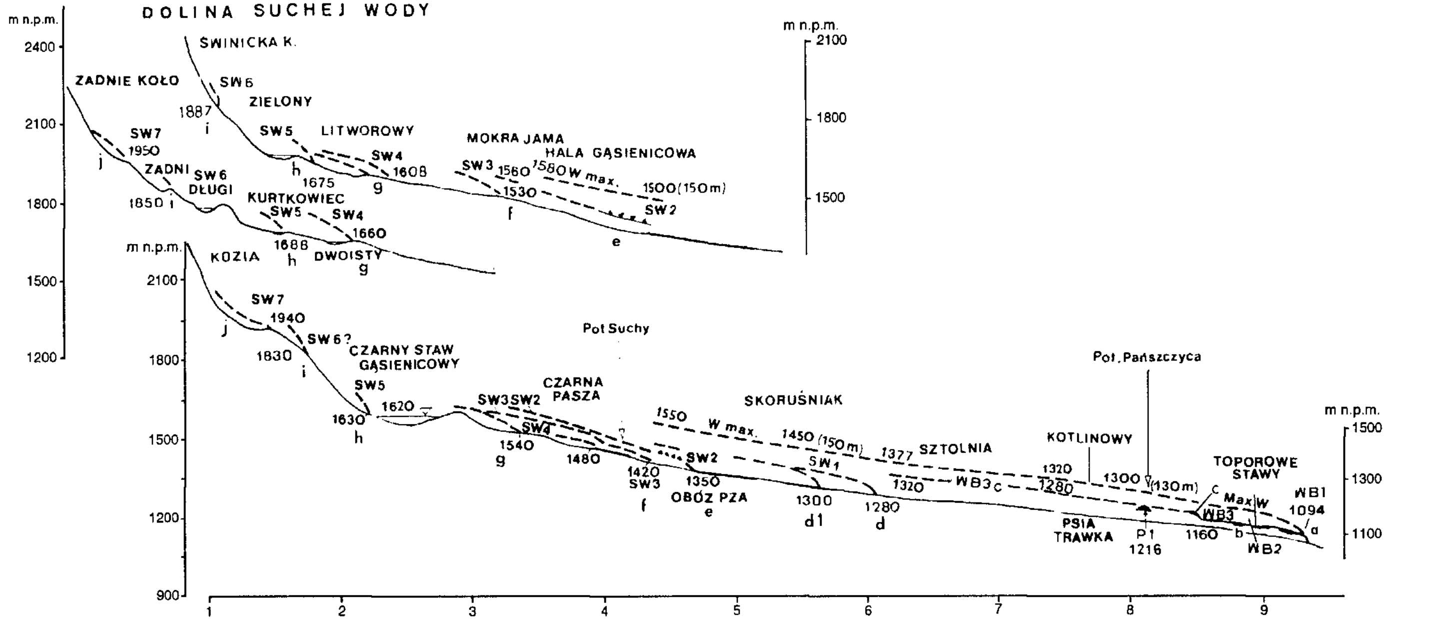
The further recession of the Pańszczyca glacier has manifested itself as the stagnation of the glacial front in the distance of 1 km (phase 'h'). This phase is represented by 3–4 moraine ridges at the height of 1,700–1,770 m (the phase of Mała Kopka). At the similar height there are moraine ridges associated with the small glaciers incising into the eastern slopes of Żółta Turnia (Fig. 5). The shallow Czerwony Staw Lake occurs below moraines 'h'. Phase 'h' (P5) has also an oscillating character. The Mała Kopka phase (P5) corresponds probably to the alpine Daun phase. The moraine of Morskie Oko Lake in the Rybi Potok valley was related to this phase according to Małe Żabie Oko profile (Baumgart-Kotarba and Kotarba 1997). Because of significant differences in heights, it cannot be excluded that the moraine ridges at 1,770 m a.s.l. mark the next phase of the Egesen advance (the Younger Dryas). Therefore, the higher ridges 'i' have been called phase P6 (Fig. 5).

During the final phase, the Pańszczyca glacier formed morainic ridge at the height above 1,800 m (Zadnie Usypy 1,810 m — P7, phase 'j') (Fig. 4, 5; Table 2). It is likely that small rock glaciers whose fronts are below 1,800 m were also forming at that time. These rock glaciers were supplied with the material by the chutes and debris cones of Pańszczyckie Czuby (Kotarba 1992). The youngest forms observed below the rocky slope are protalus ramparts (Fig. 5).

THE RECESSION OF THE GLACIERS IN THE SUCHA WODA VALLEY

The glacier in the Sucha Woda valley formed in the cirques of two valleys: Czarny Staw Gąsienicowy and Stawy Gąsienicowe. The first recessional stage — phase 'd' manifest itself only as flattenings on the slopes, because on the valley floor the ridges have likely been washed down during glacier recession. This stage, denoted SW1, expresses phase 'd' (Fig. 3) related to the Pomeranian stage at the Polish Lowland and to the alpine Bühl stage (15 ka). The moraines of phase 'd' are in the distance of 2.1 km from the morainic ridge WB3 that mark moraine extent still coalescending with the Pańszczyca glacier. In the longitudinal profile of the valley, the difference in height between moraines 'c' and 'd' is 40 m. The intra-moraine fragment of the valley floor represents the extensive and slightly inclined (ca 2%) floor of the glacial trough. Besides the apex of the cone, which spreads over 2 km in the described valley part, 400 m up-valley, there is the apex of another younger cone that evidences the subsequent younger stagnation (d_1) (Fig. 6). This problem, however, requires further field studies.

During stage 'c', the glacier width between lateral moraines deposited on the flattenings of Kotlinowy Wierch and Skoruśniak ridge was ca 600 m,. and thickness of 90 m at the minimum (Figs 3, 6), but during stage 'd' it was 500 m wide and only 50 m thick in its lower part. About 1.5 km up-valley, the presence of 700 m wide glacier of the similar minimum thickness of 50 m can be



	j	i	h	g	f	e	d1	d		c	b	a
J.Partsch 1923.				IV.1620	III.1400				II.1172		I.1030	max 1094
M.Klimaszewski 1988.	VII 1960	VI 1860	V 1670*	IV 1540	III 1420		II 1300		Psia Trawka	WIII	WII	WI
M.and A.Kotarba 2001.	SW7	SW6	SW5	SW4	SW3	SW2	SW1			WB3	WB2	WB1/WA
Morainic ridges.	j	i	h	g	f	e	d1	d		c	b	a
Ka BP.	>8,4	>10,5	12	13	14		14 - 15?			17? 19-15?	21?	22? >60

Fig. 6. Longitudinal profile of the Sucha Woda valley, terminal moraines 'a' to 'c' belong to both Sucha Woda and Pańszczyca glaciers recessional moraine stages ('d' to 'j')

reconstructed. The fragments of the left-hand lateral moraine of phase ‘e’ have been preserved which point to the minimum thickness of the glacier of 80 m and width of 750 m at the Hala Gąsienicowa cross section. Thus, a radical change in the glacier length took place between phases ‘c’ and ‘d’. The subsequent recessional moraines of phase ‘e’ (SW2) are in the distance of only 750 m (PZA* campsite). It is evident that much larger gradient of the valley (5.3%) between the moraines SW1 and SW2 exists (Figs 3, 6). This reach is characterised by the channel incision by 5–6 m deep relative to the fragment of the glacio-fluvial cone. The channel itself is incised in the solid rock. On the valley floor, the recessional moraines of phase ‘e’ have been washed down, but their position is revealed from the apex of the glacio-fluvial cone which is dissected nowadays. The left-hand-side moraine of phase ‘e’, rising from 1340 to 1500 m at Hala Gąsienicowa, has been preserved. The fragments of this moraine are developed as ramparts or on the steep part of the slope, where the serpentine road ascends, the course of this moraine is evidenced by the zone of large moraine blocks of 1.5–3 m in diameters. On the right-hand-side on steep slope below the Pańszczycka Skałka, the moraines are not preserved, but in the zone of the cone of the Żółty Potok stream they might have been buried.

The subsequent phase ‘f’ indicate that the glaciers of Czarny Staw Gąsienicowy and the Stawy Gąsienicowe were independent bodies. The frontal zone of phase ‘f’ of Czarny Staw Gąsienicowy has been washed down while phase ‘f’ in the Stawy Gąsienicowe valley, called the Mokra Jama phase, allows one to reconstruct the glacier tongue of a clear triangular shape. The morainic ridge of phase ‘f’ in the Czarny Staw valley descend from the height of 1,450 m below glacial rocky step of Czarny Staw Lake to 1,420 m in the zone of the valley axis (Table 2). The right-hand-side moraine ‘f’ has been called the moraine of Czarna Pasza. The local name of Czarna Pasza corresponds to the flattening at the foot of the slope that is mantled with parallel ridges of the lateral moraines pointing to the decreasing width of Czarny Staw Gąsienicowy glacier from over 500 m (in phase ‘e’) to 270 m (in phase ‘f’). The minimum thickness of the tongue was ca 40 m in phase ‘e’ and 20 m in phase ‘f’ (in the cross-profile following the tourist trail leading to the Pańszczyca valley).

The next distinct phase ‘g’, as the oscillation one, indicates the readvance of the Czarny Staw Gąsienicowy glacier and stop in the distance of 900 m from the moraines of phase ‘f’, while in the Stawy Gąsienicowe valley the similar distance is to the moraine of Staw Litworowy Lake. The authors associate the forth, recessional stop of the Sucha Woda glacier (Fig. 3; Table 3) on the moraines SW4 (‘g’) with the Gschnitz phase (13 ka). This stop is delimited by the clear, parallel-arranged ridges that resemble the moraines of phase ‘g’ in the Pańszczyca valley

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Table 3

TL and OSL data in the Sucha Woda valley

Location	Altitude [m]	Age [ka] TL	Age [ka] OSL
Moraine, max extent (25 m below surface, well-rounded boulders in sandy-silty matrix	1,050	56.6 ± 5.9 (GdTL-552)	29.3 ± 5.7 (GdTL-553)
Granitic, sharp-edged material, fluvial origin, 2.5 m above stream	1,150	>= 135 ka (GdTL-556)	49.7 ± 4.6 (GdTL-557)
Granitic, sharp-edged material, fluvial origin, 2 m above stream	1,150	>= 140 ka (GdTL-560)	46.6 ± 4.9 (GdTL-561)

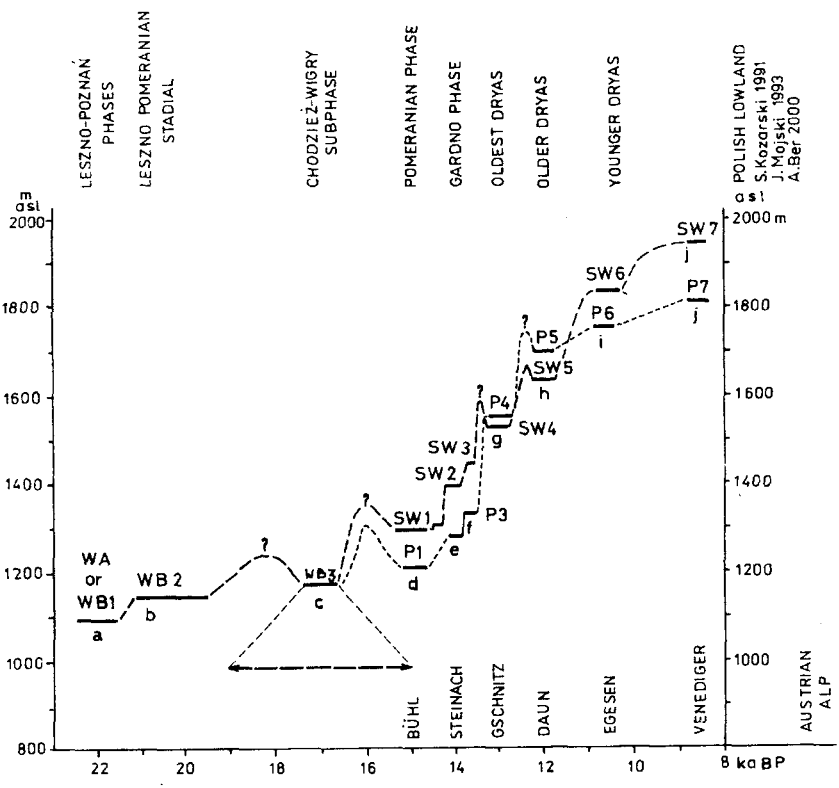

Fig. 7. Recession of Late Würm glaciers of the Sucha Woda and Pańszczyca valleys. Correlation with Polish Lowland/Scandinavian ice sheet retreat and with Austrian Alps chronology. Age of WB3 ('c') moraine ridge discussed in the text

(P4) and provide evidence on the frontal deglaciation. Phase 'g' in the Czarny Staw Gąsienicowy valley (1,540 m) is called the phase of glacial step of Czarny Staw, because in this phase of the frontal recession the glacier was hanging from the rock sill. In the Stawy Gąsienicowe valley, phase 'g' is characterised by splitting of the broad, 900 m wide lobe, into two individual tongues separated by the medial moraine. During its recession, the eastern lobe, delimited by the moraine of Dwoisty Staw (1,650 m), formed the subsequent moraines: the phases of Kurtkowiec — SW5 ('h'), Zadni Staw — SW6 ('i') and Zadnie Koło — SW7 ('j') (Figs 6, 7, Table 2). The recession of the western lobe, is marked by medial moraines enclosing Litworowy Staw Lake (1,608 m, 'g'), the moraines below the Zielony Staw (1,675 m, 'h') and the moraine preserved in the Świnicki cirque (1,887 m). The authors associate phase 'h' (SW5) with the alpine Daun phase, and phase 'i' with the Egesen (Younger Dryas).

THE RECONSTRUCTION OF THE LATE GLACIAL AND HOLOCENE EVENTS AGAINST THE BACKGROUND OF LACUSTRINE SEDIMENTS

During the period from 1986–1993 the sediments from the bottom of selected lakes were examined in order to determine the age of the post-glacial evolution of the relief. Unfortunately, peatland developed in the depressions within the roche moutonnées has not been found in the Polish Tatras. In the Austrian Alps such cases were very suitable to determine the age when the surface became free of glaciers, i.e. to date precisely the recession of the glaciers. In the Tatras, moraine blocks and weathering covers are very well permeable, therefore a large time hiatus was determined between the presumed glacier disappearance and the sealing of the depressions favouring the accumulation of peat. The peatland of Wyżnia Pańszczycka Młaka, occurring at the height of 1,340 m, where the maximum right-hand lateral moraine of the Pańszczyca glacier (ridge 'a') blocks the karstic waters of the western slopes of Sołtysie Kopy have bottom date 4,570 ± 100 BP (Table 1). Under such circumstances, only the lacustrine deposits allow for the reconstruction of the age of the late glacial events. The date of the floor of the deposits is the most important to determine the time of retreat of the glacier.

The oldest date, 12,500 ± 420 BP, has been obtained from Czarny Staw Gąsienicowy Lake (Fig. 3; Table 1). The sufficient amount of the organic matter has been obtained from the late glacial fragment of the core taken from the depth of 192–187 cm below the present-day bottom of the lake. This date served to determine the age of the moraines occurring below rock riegel blocking this lake and allowed one to relate these moraines to the alpine Gschnitz stage dated at 13 ka.

In the lake sediments, the beginning of the Holocene is characterised by an abrupt increase in the content of the organic matter from the value below

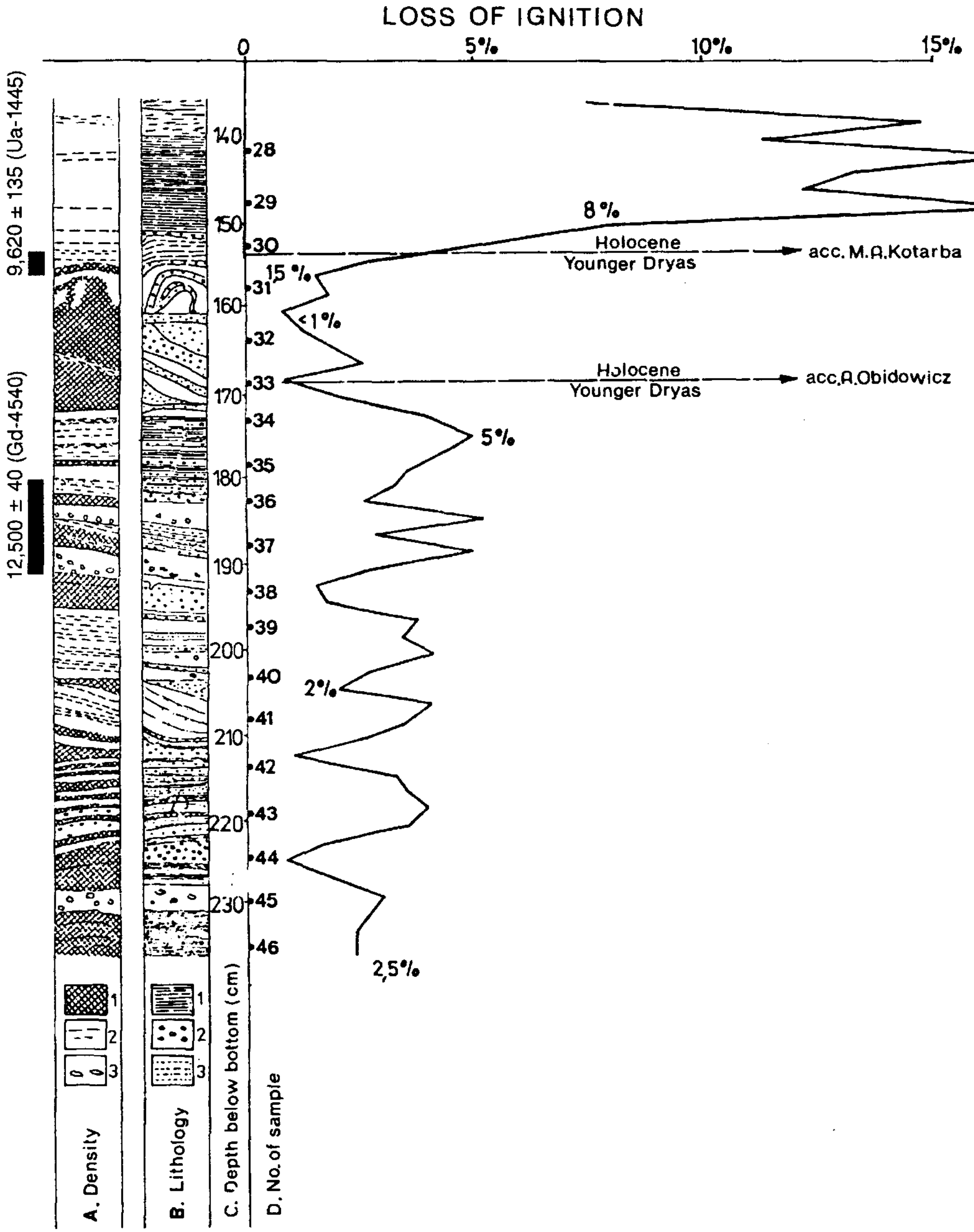

Fig. 8. Lithological column and loss of ignition in sediment core recovered from the Czarny Staw Gąsienicowy Lake. Boundary between Younger Dryas and Holocene sediments according to palinological (A. Obidowicz) and sedimentological properties (M. and A. Kotarba). A. 1 — dense minerogenic sediment, 2 — low density sediment, 3 — coarse gravel. B. 1 — organic silty clay, gyttja, 2 — coarse gravel, 3 — sandy/silty sediment

1.5% to over 20% (Fig. 8). Because of that, the beginning of the Holocene in the Tatric cores is the best evidenced by a change in colour from light grey to black while in the radiogram — by a definite change in density of the sediment: from the mineral, dense sediment characteristic of the Younger Dryas and equivalent of the alpine stage Egesen, to the less dense of an increasing content of organic matter in the pre-Boral period. Such changes are characteristic of the lacustrine sediments occurring in the Tatras close to the present-day upper forest line (1,500–1,550 m a.s.l.). Here, the examples are: Zielony and Czarny Staw Gąsienicowy (Baumgart-Kotarba and Kotarba 1993; Jonasson 1991), Przedni and Czarny Staw lakes in the Pięć Stawów Polskich valley (Wicik 1979).

The detail palynological analysis performed by A. Obidowicz (1993, 1996) and lithologic, x-ray and grain size analyses showing the structural properties of the sediments, allowed for concluding that depending on the criterion accepted the boundary between the Younger Dryas and Holocene may be shifted in the range of 12 cm (Fig. 8). The authors of this paper are of opinion that the boundary of the sediment density i.e. the lithologic boundary, controlled by a change in the processes acting on the slopes supplying the material directly to the lake, which manifests in a change of the sediment colour (black colour is associated with an abruptly increased production of the organic matter in the direct vicinity of the lake and with a decreased supply of the mineral matter), documents more precisely the climatic changes in the high mountain region than do the changes in the percent of pollen. In the case of Czarny Staw Gąsienicowy it was possible to state that the pollen pattern shows earlier characteristic changes in vegetation of the beginning of the Holocene than the change in a type of the lacustrine sediments (Fig. 8). The above can be explained in the following way. The pollen from a more remote transportation provides information about a change in vegetation earlier than climatically controlled changes in the slope process. It is difficult to assume the physical penetration of naturally light-weight pollen into dense mud and sand of the Younger Dryas, thus remote pollen transport give the first signal of climatically conditioned changes in vegetation in submontane basins. In Zielony Staw Gąsienicowy Lake it was possible to obtain the date from the base of organic matter — 10,040 ± 150 BP — which indicates the beginning of the Holocene (Table 1).

The similar difficulties are encountered in determination of the timing of the pollen zones in mountain areas. A. Obidowicz (1996), when studying the present-day pollen deposition, in the altitudinal profile of the Tatras, tried to indicate to whether the pollen diagrams reveal the real proportions between the occurring plants, or they reflect the effects of the remote transportation. In the case of the northern slopes of the Tatras, the transportation of the pollen from the surrounding basins and the effects of föhn winds, especially, seem to be important. The lack of macro-remnants of trees does not allow for the assessment whether the timberline at any moment during the Holocene was higher than it is now as suggested by K. M. Krupiński (1984) and A. Obidowicz (1996). On the other hand, it depends on the location of the lake whether the palynological data reflects local succession of vegetation and informs about encroachment of new climatic-vegetation vertical zones on the Tatric slopes or whether this palynological data represents, to a large degree, the Holocene history of the forests in the Liptów, Poprad Orawa and Podhale basins. The question arise with interpretation of the appearance of *Fagus* and *Abies* pollen during a significant decrease in the percent of spruce pollen. Whether the change in the pollen can be explicitly attributed to changes in vegetation controlled by the climatic factors in the Tatra Mts and whether the changes are related to global circulation enabling large influence of Atlantic Ocean in Europe. Can these events be indeed associated with the beginning of the sub-Boreal or the sub-Atlantic periods, or with the tree succession in the mountains that is reflected in the lacustrine sediments. The sediments of large lakes are open to the remote transportation, e.g. the lakes in the broad valley of Pięć Stawów Polskich, located on a high elevation, being the corridor which favours the transportation through the main ridge of the Tatras. The verification of the timing when new pollen zones appear is difficult, because the dating of the lacustrine sediments is less precise than the dating of the peat.

Another criterion pointing to the climatic changes is activating of the slope processes. The appearance of sand intercalations or numerous mineral laminas in the gyttja sediments indicates activating of the slope processes triggered by the catastrophic precipitation. The intensification of the slope processes manifests itself in the changed type of the lacustrine sedimentation. In the lacustrine cores of the Tatras, such period can be distinguished from 4,000 BP in the zone of the present-day timberline, while the dated floor parts of the peat deposits assign a more humid period to the beginning of the sub-Boreal (ca 5,000 BP).

Based on the palynological, lithologic and structural analyses of the lacustrine sediments occurring above the present upper timberline, one can state that small glaciers still occurred in the highest parts of the glacial cirques in the Younger Dryas. The massive silty sand series from Zielony Staw Lake older than 10,040 ± 150 BP indicate that the ridge 'i' in the height 1,850 m a.s.l. (Zadni Staw Lake) can be related to Younger Dryas phase. Phase 'i', which manifest as the morainic ridge P6 at 1,770 m a.s.l. in the Pańszczyca valley and at 1,830 m a.s.l. in the zone of the rocky steps between the Zmarzły Staw Lake and the hanging Kozia valley as well as in the particular reaches of the Stawy Gąsienicowe valley: the Świnicki cirque — 1,887 m and Zadni Staw Lake — 1,850 m, has been accepted as the equivalent of the Egesen phase in the Alps and the Younger Dryas phase in Scandinavia (Fig. 3, 7; Table 2). The moraines of phase 'j' occurring at 1,950 m a.s.l. (Zadnie Koło below Świnica) probably represent the small glacier persisted to the period from 8,700–8,400 BP, called the Venediger oscillation in the Alps (Patzelt 1975). The reconstructed extents of the glaciers in the most shaded fragments of the system of the Biała Woda valley below Cubryna and below Szpiglasowy Wierch (Baumgart-Kotarba and Kotarba 1997) are correlated with that period. Probably, this cool phase is marked in the sediments of Czarny Staw Gąsienicowy Lake in the form of two massive sandy inserts which appear in all the examined cores. Unfortunately, these inserts have not been dated by ^{14}C method. This phase was undoubtedly older than the beginning of the peat deposition which is dated at 8,300 BP, and simultaneously younger than the date of 9,700 BP (Baumgart-Kotarba and Kotarba 1997). This cooling is documented by intensified fluvial activity which has been stated below the base of the 3.5 m thick peat in the dead-ice depression of Małe Żabie Oko at the foreland of the morainic ridge that close Morskie Oko Lake.

THE RECONSTRUCTION OF DEGLACIATION AGAINST THE BACKGROUND OF TL AND OSL DATINGS

The chronology of glaciations in the Polish Tatras has been elaborated based on the thermoluminescence dating by the Warsaw team lead by Prof. L. Lindner (Lindner et al. 1990; Lindner and Marks 1993; Lindner et al. 1993). In the Tatras, besides the deposits in the caves (Hercman et al. 1987) and the breccia, which in the Tomanowa valley is assumed to be the interglacial one (Kotański 1961), the documented deposits older than the last glaciation have not been stated. Since the synthesis by E. Romer (1929) and B. Halicki (1930, 1932) it has been accepted that the presence of the older glaciations is revealed from the alluvia of the older terraces, which are developed in the form of the broad fluvio-glacial cones deposited by the Czarny Dunajec, Biały Dunajec and Białka rivers. The synchronism of the Tatric and Scandinavian glaciations has been stated by M. Klimaszewski (1937, 1961, 1965).

Recently, based on the thermoluminescence datings such correlation has been attempted by L. Lindner and L. Marks (1993). The sediments in the Tatras and in their direct foreland were dated by TL: on the Würm cone between the Kuźnice moraine and Zakopane, Mindel glacio-fluvial level of Antałówka and Riss level of Bystre, indicated already by J. Partsch (1923), and the sediments of moraine ridges of Toporowa Cyrhla and Murzasihle alluvial cover. L. Lindner et al. (1993) attempted to assess the whole glacial epoch of the Tatras drawing from the old dates obtained by the TL method in the Nowy Targ Basin and along the Białka terraces from the last cold period. It should be remembered that the TL method is permanently modified and the obtained results are often disputable.

The authors of the paper possess only three TL and OSL samples from the Sucha Woda valley (Fig. 2). Two samples refer to the fluvial deposits directly underlying the moraine deposits building the ridge of recessional moraine 'c' (WB 3). These deposits have the character of a massive, fairly sharp-edged granite debris. It does not contain large, well-rounded blocks of the diameter above 1 m, being characteristic of the moraine and fluvio-glacial deposits. In Podhale, the deposits from all the Quaternary terraces contains such rounded blocks and because of that is considered as fluvio-glacial. Such blocks are redeposited in the alluvia of the Holocene terraces, and also occur on the present-day deposits of the Białka and Czarny Dunajec rivers. Therefore, it seemed reasonable to date them, because these deposits could have been associated with the very cold phase of the Quaternary when the sharp-edged product of the granite weathering was transported. The debris of the diameters up to 10 cm can originate from the frost weathering. Two samples from the insert of the fine-grained sandy silt sediments have been dated. The samples occurred ca 2 m below the place where the described series was erosionally cut off by the fluvial/fluvioglacial sediment deposited in the direct foreland of the moraine ridge 'c'. The sediment, fluvioglacial one probably, contains the blocks of over 2 m in diameters which are characteristic of the Tatras and which are filled by brownish-ferrous sandy-gravel matrix. The samples were taken by Dr. A. Bluszcz. He has also dated them by the TL and OSL methods (Table 3). These samples according to TL dates provide the evidence on the pre-Eemian age; the corresponding OSL dates point to the period of the order of 50 ka. The interpretation of such datings seems to be as follows. Probably, the blocks of the Riss glaciation were subjected to strong frost weathering in the early or even middle Würm, and then they were transported by mass in the axis of the valley that is evidenced by only a few imbricated pieces. The sharp-edged granite fluvial material points to its origin from the upper part of the Sucha Woda and Pańszczyca valleys. The series of the sharp-edged, poorly rounded sediment contains intercalations of fine material of the thickness up to 2 m and became exposed due to the flood of 1997. The sandy-silt layer, similarly to the granite debris, crops out at the both sides of the river and underlies both the moraine material of the ridge 'c' and the fluvioglacial sediment (or the fluvial one). The above confirms the river activity under periglacial conditions. If the OSL date gives a younger age of sedimentation, then the sediments were deposited ca 50 ka ago. The averaged OSL date obtained from the loamy material occurring in the moraine ridge 'c' was estimated at 17.1 ka BP. But, to establish more precisely the age of morainic material from internal part of WB3 ridge, the new SAR method was used (Baumgart-Kotarba, Bluszcz, Kotarba 2001). This method presents three groups of data: 19, 15.5, and 11.5 ka BP. If the last one can be interpreted as dead-ice controlled processes, the age of 'c' ridge on Figure 7 was marked between 19–15 ka BP.

The material being the matrix of the moraine material underlying the moraine ridges of Toporowe Stawy has been dated as well (Fig. 2). The sample has been taken from the depth of ca 25 m below the ridge culmination, from the slope undercut by the present-day Sucha Woda stream (ca 15 m above the stream channel). Due to a very well rounding of the material, it can be assumed that it is the glacio-fluvial or fluvial deposit. The obtained TL date 56.6 ± 5.9 ka BP indicates the older Würm stage prior to the Interpleniglacial, but the date 29.3 ± 5.7 ka BP points to the Interpleniglacial age of the final deposition. The dated loamy material was deposited together with the well-smoothed moraine blocks. That material is completely different from the sharp-edged massive material described earlier dated by OSL as ca 50 ka BP.

The position of the blocks of ridge 'a' can be interpreted as the oldest ridge of the Leszno phase, which was deposited on the fluvial material from the Interpleniglacial (OSL date — 29.3 ka). However, the problem requires further study, and application of the chloride method on ridge 'a', especially. This opinion is in agreement with M. Klimaszewski (1988) idea, but in contrary to B. Halicki (1930, 1951) who accepted Riss age for the ridges of Toporowe Stawy, and Würm age for the Kopieniec Glade.

The dating by the cosmic chloride of the moraine ridges of Toporowe Stawy seems to approximate the age of the moraines of Toporowe Stawy much better. The oldest date 21.0 ± 1.3 ka BP originates likely from the middle part of ridge 'b' (Fig. 2) is the oldest (Dzierżek et al. 1999). The dates 17.9 ± 2.3 and 17.2 ± 2.2 ka BP should be related to ridge 'c' (WB3). They confirm the correlation with the oscillation subphase of Chodzież at the Polish Lowland (according to Kozarski (1991) — 17.2 ka BP). The remaining chloride dates from the moraine upland are slightly younger and correspond to the alpine stage Bühl 15.3 ± 0.5 ka BP (one date) as well as to Gschnitz (13.6 ± 0.5 two dates) and they should be interpreted as a successive melting of dead ice (ice-cored moraine). The remaining two dates 11.6 ± 2.3 and 11.5 ± 0.5 ka BP show that the ice blocks till melted in the Allerød.

The chloride datings within the moraines of Toporowe Stawy did not confirm the TL datings in the Sucha Woda valley that had earlier been published by the Warsaw team (Lindner et al. 1990; Lindner and Marks 1993). These authors distinguished the Sucha Woda stage (90–80 ka BP), Bystra stage (57–42 ka BP), Białka stage with the phases of Hurkotne (32–25 ka BP) and the phase of Łysa Polana (23–17 ka BP) as well as the younger phases of Włosienica and Pięć Stawów Polskich. At the moment there are no data to distinguish the stage of Such Woda, Bystra or Hurkotne in the Tatras. The OSL method better approximates the age of deposition, and because of that it better dates the sediment and indirectly the landforms. Only in the case of Biała Woda valley there are geomorphologic arguments to discern the older stage which has been called stage WA in correspondence to Lukniš's (1973) concepts and whose age has been determined at the early Würm based on the archaeological evidence from the Obłazowa cave.

DISCUSSION ON THE AGE OF THE MORAINES

Summarising the discussion on the age of formation of the maximum moraines of the confluenced Sucha Woda and Pańszczyca glaciers, two maximum phases can be assumed. These are the Toporowe Stawy I and Toporowe Stawy II phases, called ridge 'a' and ridge 'b' or WB1 and WB2 according to the terminology accepted for the Biała Woda valley (Baumgart-Kotarba and Kotarba 1997) (Figs 2, 3; Table 2). The moraines of oscillation WB3 (ridge 'c') are the final stage of recession which was common to both the glaciers. The moraine ridge 'c' point to the glacier readvance. Despite ridges 'a' and 'b' look young B. Halicki (1930) presumed that they are of the former glaciation, so he assigned the status of the maximum Würm advance to the moraines of Kotlinowy Wierch. Both, M. Klimaszewski (1988) and earlier E. Romer (1929) considered the ridges of Toporowe Stawy as originating from the last glaciation. A new aspect of the interpretation presented here by the authors is that ridges 'a' and 'b' are treated as two parallel maximum ridges (frontal and recessional). These ridges have been correlated with the Leszno and Poznań stages while the oscillation ridge 'c' has been associated with the oscillation moraine (WB3) at Łysa Polana when the Biała Woda glacier reached its maximum extent again, but it was much thinner.

In the zone of the moraine upland of Toporowe Stawy the problem whether ridge 'a' should be related to the Leszno stage and ridge 'b' to the Poznań stage remains still unsolved. M. Lukniš (1973) presumed the occurrence of the older Würm stage WA, which R. Halouzka (1992) used to associate with Riss II stage. Based on the correlation of the terraces and the maximum moraines of the Białka glacier, the early Würm, which has been assigned the age of ca 80 ka BP in the French Alps, should be considered (Mojski 1993). Such age seems to be confirmed by the relation between the Würm terrace, traced from moraines WB1 at Łysa Polana to the Obłazowa cave containing archaeological cultures of the last 60 ka BP (Valde-Novak et al. 1995). The Palaeolithic cultures in the Obłazowa cave are older than the maximum of the last glaciation. This period of the maximum cold resulted in the accumulation of blocks falling from vault on the cave loam, where the tools and bones occur. The same period caused the aggradation in the Białka channel (Baumgart-Kotarba and Kotarba 1997). The recently obtained datings of the loess covering the 9 m high terrace level show that the loess accumulated in the period from 12.9 ± 4 and 10.8 ± 3 ka BP (OSL datings) and originate from blowing of the alluvia of the Białka river which were deposited at 28.6 ± 4.8 and 33.5 ± 3 ka BP (TL dating), respectively (Baumgart-Kotarba, Bluszcz, Kotarba 2001). The OSL dates document the cold periods of the Late Vistulian (Gschnitz and Egesen periods). Because the loess deposits are over 2.5 m thick and the samples were taken from the depth of 1.4 and 2.15 m in the distance of only 150 m from the open archaeological sites of the Bølling and Allerød periods, the timing of the sediment formation can be confirmed. One can state that the process of the loess accumulation in this period was uninterrupted. The monotonous loess deposits, of beige-yellowish colour, without any interlaminations, organic inserts or washing, evidence that. The grain size analyses of these deposits by the Fritsch (laser) method confirm the uniform conditions of the sedimentation. The sedimentation was controlled by whirls around the Obłazowa Skała.

B. Halicki (1930) interpreted the moraines of Toporowe Stawy as the Riss moraines and did not accept the areal deglaciation which was questioned by M. Klimaszewski (1988) who, in this case, agreed with E. Romer (1929) emphasising a fresh character of the moraines of Toporowe Stawy. Undoubtedly, the freshness of the landforms is associated with melting of the dead ice. J. Kondracki (1986), based on the studies by A. Obidowicz (1975), presumed the Atlantic age of the melting. J. Partsch was the first scientist who noticed the dominant role of the Pańszczyca glacier in the arrangement of the moraines of the Toporowe Stawy. Indeed, the ridges 'a' and 'b' indicates the direction of the advance of the glacier masses from east to west. On the other hand, B. Halicki was the first who determined the directions of the water outflow from the Sucha Woda glacier. Looking at the huge moraine blocks on the glade between Kopieniec and Kotlinowy Wierch, he interpreted them as the material carried away from the Würm glacier, while the cone of the Toporowa Cyrhla descending towards Chłabówka and Chowańcówka interpreted as the older cone of the Riss glaciation. The outflow from the deeply dissected moraines of ridge 'b' he treated as the younger, of the almost Holocene age. The geomorphologic arguments made B. Halicki (1930) to conclusion that the moraines of Toporowe Stawy are Riss in age.

It is difficult to confirm that the Sucha Woda and Bystra stages are of the period from 60–40 ka BP as postulated by L. Lindner et al. (1990), as well as to find the Hurkotne phases (32–30 ka BP) in the Białka stage. Besides the block moraine WA occurring down of Łysa Polana, correlated with the period prior to the oldest Muster culture, other geomorphic and geologic evidences from the northern slopes of the Tatras are lacking. The TL datings that served to distinguish the Bystra stage originate from the pit near the Kuźnice roundabout in Zakopane, i.e. from the sediments of the Bystra fluvioglacial cone. The Kuźnice moraines, since the times of L. Zejszner, are considered as the forms delimiting the maximum phase of the last glaciation. Similarly, it is not clear a relation of which helped to discern the oldest stage of the Sucha Woda. Till nowadays it is difficult to estimate the chronology of the events older than the Würm glaciation in Podhale. The authors cannot accept L. Lindner's and L. Marks's (1993) interpretations in which the TL dates obtained from the ridge of the dissected former Sucha Woda cone between Toporowa Cyrhla and Poroniec have been inserted to the profile of the Białka terraces from the Tatras to the Dunajec mouth. Such synthesing profile required a neotectonic interpretation in order to reveal the sequence of the TL dates. The interpretation of the subsequent younger, series of the deposits of the last glaciation in the

Białka valley in the form of the synthetic model of the profile of the foreland of the glaciated Tatras points to the subsequently higher located outlets of the Tatric valleys (the figure in the paper by Lindner and Marks 1993) would require to assume that the Tatras are pushed down, but it is the well know fact that the Tatras are uplifted and the valleys are gradually deepened. Therefore, there is no evidence about the occurrence of the stages older than the Białka stage or the Hurkotne phase older than the Łysa Polana phase.

The authors of the paper hope to make further progress in revealing the chronology of the last cold period when the dating by the cosmic beryllium (^{10}Be) will be available and when the OSL and SAR methods became more common.

The position of the moraines in the Pańszczyca and Sucha Woda valleys presented on the geomorphologic map of the Tatras by M. Klimaszewski and the description of these valleys in the book entitled *Relief of the Tatras* (Klimaszewski 1988) is definitely the best if regarding the documentation of recessional stages. The diagrams showing the proposed correlation of recession of the glaciers in the Polish Tatras are presented in these documentary issues. The vertical axis shows the position of the terminal and recession moraines above sea level. As a measure of oscillation M. Klimaszewski accepted that the co-shaped subsequent moraine ridges occur one close to another, and interpreted such situations as the retreat of the glacier tongue, and then readvance, only slightly smaller than the older one. Therefore, M. Klimaszewski determined the magnitude of the glacier retreat before the following readvance. Such situations can be interpreted much easier, i.e. as the glacier shrinking not only at its length but also at its width, that leads to the next stagnation documented by the formation of a new moraine. Such situation has been stated, among others, in the Rybi Potok valley where two moraines located in the zone of the „Eysmont bend" have been described (Baumgart-Kotarba and Kotarba 1997). There is no reason to accept the concept that the new younger ridge formed due to a significant retreat and advance of the glacier tongue, and then to assume the next large advance of the extent similar to that of the immediate older phase. Such situation is reflected best in the moraine system of „Komory" (phase 'g') in the Pańszczyca valley at the height of 1,550 m a.s.l. (Fig. 3). In the attached diagram (Fig. 7) the time scale is marked on the horizontal axis. However, it is difficult to estimate the magnitude of the oscillation, so the recessional and oscillation moraines are distinguished marking the retreat as higer position of glacier without real value, but using question mark only (Fig. 7).

In the Polish Tatras the presence of rocks glaciers have been explain in various way. J. Dzierżek and J. Nitychoruk (1986) accepted idea that the area described in this paper as stage 'f' represents the phase of rock glaciers. In our opinion, in the Sucha Woda and Pańszczyca valley only small relict rock glaciers occur in the Pańszczyca cirque at the height of 1,800 m a.s.l., (Fig. 5) while in the Czarny Staw Gąsienicowy valley at the foot of the quartzite wall of Żółta Turnia outside the lateral moraines of stages 'e' and 'f', as well as in the Stawy Gąsienicowe valley at the foot of Mały Kościelec (Fig. 3). The discussion on the rock glaciers in the Polish High Tatras is presented in the paper by A. Kotarba (1991–1992).

FINAL REMARKS

The authors are of opinion that the recession of the glaciers of the Sucha Woda — Pańszczyca system took place for the period from 18–8.5 ka and the maximum lasted relatively shortly, i.e. 21–19 ka BP. As it was the case of the Biała Woda system, the ordinary recession stages as well as the readvance stage type have been distinguished here (Baumgart-Kotarba and Kotarba 1997). The latter stages are interpreted from the appearance of the frontal moraines and their relation to the older moraines from the foreland. The ridge 'c' — (Chodzież sub-phase on the Polish Lowland), ridge 'd' especially in the Pańszczyca valley, ridges 'g' and 'h' can be included to the moraines indicate for oscillations (readvances). The ridges of moraines 'g' are definitely of the oscillation nature in the Sucha Woda valley, below the rocky riegel in the Czarny Staw valley, as well as in the Stawy Gąsienicowe valley. The ridge of the Dwoisty lobe and the neighbouring lobe of Litworowy Staw are of the similar nature. They are doubled. This feature served earlier as an indicator for the discerning the so-called „oscillation A" (Baumgart-Kotarba and Kotarba 1993). In the subsequent paper, in which the map depicting the extent of glaciation of the Sucha Woda–Pańszczyca system is presented (Fig. 7; Baumgart-Kotarba and Kotarba 1997), owing to the date 12.5 ka BP these moraines correlated with the alpine recessional phase Gschnitz (13 ka BP) have been assigned to moraines SW4 in the Sucha Woda valley and to moraines P3 in the Pańszczyca valley. In this paper moraine P3 is marked as P4. After the moraine, called ridge 'd' (P1), have been found in the lower part of the Pańszczyca valley down the moraines of Wielka Pańszczycka Młaka (1,280 m a.s.l.), which are described by all the researchers, this well-defined stage is called P4 (Komory ca 1,550 m a.s.l.) in this paper.

It should be emphasised that the attempt to correlate the stages of recessional moraines based on their altitude is very difficult and often impossible, as not only the maximum extent of the Würm glacier tongues but also their extents during the recession were controlled by the „productivity" of the supplying area. The moraines can persist easier on the flat fragments of the glacial troughs than on the rocky steps or in the steep section of the valleys. Therefore, the larger glaciers have preserved their recessional moraines at lower altitudes than the smaller glaciers. Similarly, there is the better possibility of documenting the youngest phases of the retreat of the glaciers in the valley floors located above 2,000 m a.s.l.

The last accord of the glacial history of the Tatras can be related to the period before 8,300 BP. The confirmation of this thesis should be sought in the deposits of Wielki Staw Hinczowy Lake located at 1,965 m a.s.l. in the Mięguszowiecka valley.

Due to good dendrochronological teleconnections, lichen dating and a more dynamic sedimentation in the Tatric lakes, the last significant activating of debris flows in the Tatras has been attributed to the Little Ice Age.

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STRESZCZENIE

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DEGLACJACJA W DOLINACH SUCHEJ WODY I PAŃSZCZYCY W POLSKICH TATRACH WYSOKICH

Recesja lodowców systemu Sucha Woda–Pańszczyca dokonała się w czasie od 19–8,5 ka BP, a maksimum trwało stosunkowo krótko, pomiędzy 21 i 19 ka. Rycina 7 ilustruje wiek recesji w nawiązaniu do recesji w Alpach Austriackich oraz stadiów recesyjnych lądolodu skandynawskiego. Problem wieku form polodowcowych jest dyskutowany w oparciu o publikowane i nie publikowane datowania ^{14}C, TL, OSL i ^{36}Cl. Przedstawiono zasięgi maksymalnego stadium zlodowacenia würmskiego oraz jego stadiów recesyjnych, a także recesji usamodzielnionych lodowców Suchej Wody i Pańszczycy oraz ostatnich faz recesji w zamknięciach dolin. Trudno określić ostatecznie wiek rozdzielenia się lodowca Suchej Wody i Pańszczycy, gdyż wspólny jeszcze wał morenowy świadczący o oscylacji w świetle metody SAR zawiera materiał datowany na 19; 15,5 i 11,5 ka BP. Można wyróżnić stadia recesyjne zwykłe i typu nasunięć (oscylacje). Określono wiek postojów lub oscylacji lodowców wyróżnionych w terenie na podstawie szczegółowego kartowania geomorfologicznego. Wyróżniono siedem stadiów recesyjnych. Moreny znaczące istnienie ostatnich lodowczyków w najwyższych położeniach powiązano z okresem sprzed 8300 lat BP, tj. odpowiadają alpejskiej zimnej fazie venediger.