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THE COURSE OF THE LAST GLACIATION OF THE WESTERN CARPATHIANS IN RELATION TO THE ALPS, TO THE GLACIATION OF NORTHERN EUROPE, AND TO THE DIVISION OF THE CENTRAL-EUROPEAN WÜRM INTO PERIODS

The study of glaciation in the Western Carpathians has more than a hundred years tradition. In 1856, it was begun by L. Zejschner, which gave a report on a moraine in the Bystrá valley on the northern slope of the Tatra (46).

The Tatra reaches an altitude of 2654 m about sea level at the Gerlachovský štít (Gerlach Peak), and over-top by 600—800 m the other mountain chains of the Western Carpathians, which during the Last Glaciation rose over the snow line, and nowadays it differs from the neighbouring mountain chains very much by its surface strongly remodelled by the glaciers. It looks like Alps set in the centre of a highland. As far back as in 1878, this exceptionality suggested our native research worker Fr. Dénes to noteworthy knowledge that the glaciers in the Tatra reached a thickness of 200 m. He already distinguished two glaciations. An older glaciation with the snow line at an altitude of 1550 m above sea level, and a younger glaciation with the snow line at an altitude of 1750 m above sea level. The knowledge of the traces of glaciers in the Western Carpathians, of the size of morains, of the distribution of cirques, and of the altitude of snow line was considerably extended by J. Partsch (26). After him, many supplements on the glaciation were introduced by S. Roth (34, 35), A. Rehman (32), and V. Uhlig (41). The western part of the Tatra, which is 400 m lower, was investigated especially by R. Lucerna (19). He reconstructed the extent of the Last Glaciation. From the moraines and terraced outwash plains of the water courses, and from the erosional forms of glacial valleys, he distinguished the traces of four glaciations here, and denominated them according to Penck-Brückner's Alpine terminology (30). He also distinguished the recessional moraines in the same way in the Western Tatra (Bühl, Gschnitz, and Daun). E. de Martonne (23) did not find older moraines than from the Last Glaciation.

The unsolved question, whether there are the traces of one glaciation only in the Tatra or of several ones, attracted J. Partsch to the High Tatra again. In his comprehensive synthesis from 1923 (25), he inclined to the opinion that after the moraines, the traces of two glaciations may be proved to a certainty in the Tatra, and the traces of one Old Glaciation from the valley trains. J. Partsch tried to classify also the moraines of the Last Glaciation. He lined up them into four stages and numbered them with the Roman numerals from I to IV. Partsch's values of altitudes of the snow line of the Last Glaciation in individual valleys were made precise by Fr. Vitásek (42, 43). By determinig the extent of the glaciation, and by the reconstruction of the snow line in the Belanské Tatry (Tatra of Belá), and in the Lower Tatra, Vitásek roughly completed the konwledge of extension of the glaciations in the Western Carpathians. Vitásek distinguished two glaciations.

In 1929 Romer's synthesis of the glaciation in the Tatra (33) was published. He distinguished four glaciations, and lettered them with the capital of name Hurkotne as the glaciation H+1, H, H−1, and H−2. After Romer, the glaciers of the earliest glaciation H+1 and of the second glaciation H from the Lower Pleistocene covered the large areas of the Orava-Nowy Targ intramont basin on the northern piedmont plain of the Tatra, and of the Liptov-Poprad basin in the south. As to the number of glaciations, however, B. Halicki (6) stayed on the J. Partsch's positions (25). In the moraines of the Last Glaciation, he distinguished two stadial positions of glaciers, and five recessional moraines. The Halicki's opinion was also accepted by J. Szaflarski (40). On the basis of the Halicki's and Partsch's data and his own investigations, Szaflarski gave a classification of moraines of the Last Glaciation in the High Tatra, as follows (Tab. 1).

Table 1

	Altitude of frontal moraines in m a. s. l.	Recessional phases				
		I	II	III	IV	V
Northern side	1037	1278	1355	1548	1723	1835
Southern side	1016	1255	1326	1531	1774	1957

In 1954, the moraines of recessional phases of the glaciers of the Last Glaciation in the valleys of the High Tatra exposed to the south were grouped by J. Ksandr (16) into three, in fact into four recessional phases, but without a relation to the moraines from the period of the maximum extent of the Last Glaciation.

In 1955, E. Mazúr (24) and the author (20) distinguished moraines of three Würmian stadials on the geomorphological maps of the Studený potok and Studená voda valleys in the Tatra. They considered the moraines at the corries for recessional moraines from the last stadial position only.

In 1959 and 1961 (21, 22), I set out a new interpretation of oscillations of the glaciers and of a classification of the moraines of the Last Glaciation of the High Tatra, which I will compare with the Alpine, with the Central-Europian, and the Scandinavian classifications of sediments of the Last Glaciation in the annexed table. I distinguished three glaciations according to moraines. On the piedmont plain of the Tatra, however, there are five terraced valley trains at least.

On the Polish slope of the Tatra, M. Klimaszewski distinguishes three glaciations (9, 10). For the cataglacial phase of the Last Glaciation, he records six recessional stages, namely, at altitudes 1280 — 1370, 1540 — 1580, 1660 — 1730, 1770 — 1840, 1930 — — 1960, and 2160 metres above sea level. He compares the Last Stage with Egesen in the Alps. In the guide-book of excursion that was issued on the occasion of the INQUA Congress in Warsaw in 1961, on the basis of the pollen analysis of the peat-bog „Na Grelu" at Nowy Targ (Koperowa 1958), Klimaszewski laid the snow line of the Alleröd interstadial in the Tatra at an altitude of 1050 m a. s. l. It is a conclusion identical with that of mine from 1959, to which I came by way of the interpretation of the oscillation of glaciers and of the snow line according to moraines on the opposite slope of the Tatra.

It became apparent that the High Tatra, as we call the eastern half of the Tatra, is a most suitable area for solving the problems of the division into periods of the Last Glaciation by way of the study of glacial and fluvioglacial forms. This range is a young neogene lop-sided horst. His granodiorite nucleus is limited by a fault in the south. Along this fault the southern part of the range had been highly uplifted above the paleogene flysh of the Liptov-Poprad basin, and the range inclined northward. Therefore its southern slope is very abrupt and narrow. Short valleys on it have an average slope of 8° 4'. The cirques of the southern slope, as large as on the northern one, are mostly situated at altitudes from 1900 to 2050 metres above sea level. Commonly, the smaller

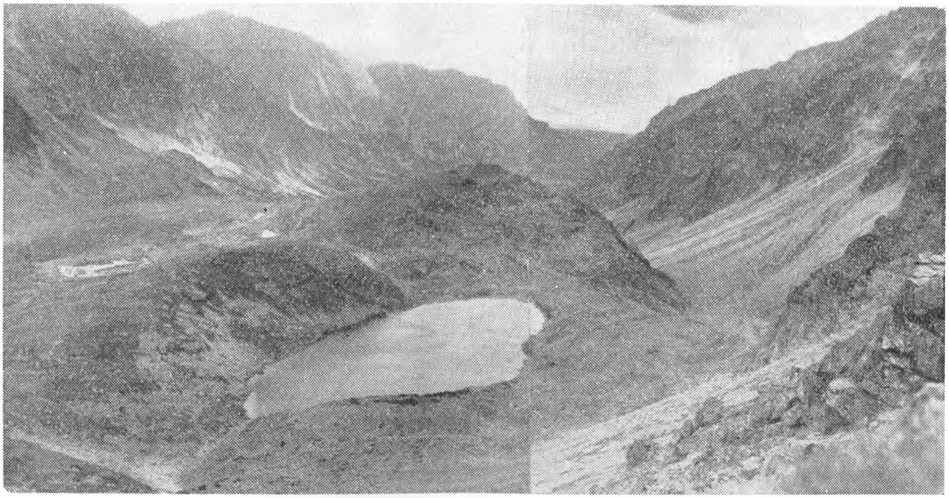
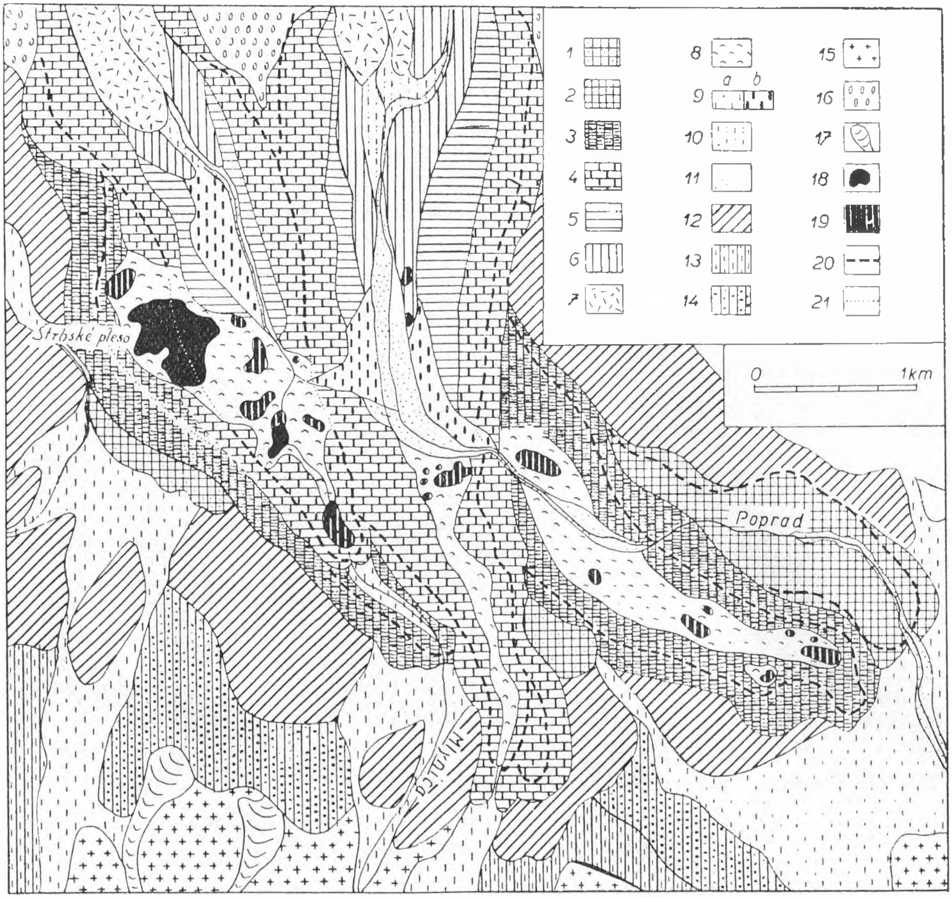


Fig. 1. The Mengušovská dolina valley on the southern side of the High Tatra. An example of the glacial valley. (Author's photograph.)

cirques of the southern slope lead immediately into an undissected abrupt slope. The glaciers of such corries easily changed the position of their bed at any younger advance. The larger cirques pass by high trough ends into well developed glacial valleys, which the glaciers descend to the bottom of the Liptov-Poprad intramontaneous basin. At the place in front of the mouth of glacial valleys into the bottom of the basin, they laid the moraine ramps. These rise to an altitude of 100 metres above the surroundings. On these moraine ramps, after an expressive retreat of the tongues, they advanced usually in another direction for a change. That is why the moraines of arcuate loops that have a nature of the stadial are divergent each to other. This favourable circumstance visible on the relief enabled to classify the moraines of the Last Glaciation of the High Tatra.

The valleys of the northern slope of the High Tatra are cut more deeply. The cirques lay at an altitude of about 1700 — 1750 m a. s. l. here. The slope of the valleys is more moderate (7° 12'). The glaciers were ended in deep valeys in the range. Therefore they could not transfer their beds. Their frontal moraines were considerably by relatively strong rivers. With the exception of the Suchá voda and Široký potok valleys, till the present time, they did not give such a feasibility for the classification of moraines of the Last Glaciation as the valleys on the southern slope.

As J. Partsch maintained (25), the southern slope of the High Tatra, though its snow



Map. 1. The map of division of the Würmian moraines of the Mengušovská and Mlynická valleys glaciers on the southern fore-land of the High Tatra. 1 — moraines of the stadial oscillation A, 2 — moraines of the stadial oscillation B, 3 — moraines of the stadial oscillation C, 4 — moraines of the stadial oscillation D, 5 — moraines of the oscillation D_1, 6 — moraines of the oscillation D_2, 7 — moraines of the stadial oscillation E, 8 — hilly moraines with depressions after melting of dead ice, 9a — fluvioglacial alluvium of the stadial oscillations A, B, C, D, 9b — fluvioglacial alluvium of the oscillations D_1 and D_2, 10 — fluvioglacial alluvium of the stadial oscillation E, 11 — holocene flood-plain, 12 — moraines of the Penultimate Glaciation, 13 — fluvioglacial alluvium of the Penultimate Glaciation, 14 — fluvioglacial alluvium of the Old Pleistocene, 15 — flysh, 16 — periglacial loamy-rocky cover, 17 — dells, 18 — lake, 19 — peat-bog, 20 — marginal moraine mounds, 21 — reconstructed course of marginal mounds.

line is a little more higly situated, had a larger area glaciated than the northern one during the Last Glaciation, since the corries of the southern slope lie 300 metres higher on an average. Of an area of 335 sq. km. the area of 255 sq. km. was covered by the glaciers and persistant snow. Of this area there was 145 sq. km. on the southern slope.

The summary of the glaciers' size and of the altitude of a deduced snow line from the period of the maximum extent of the Last Glaciation is given in the following Table 2.

Table 2

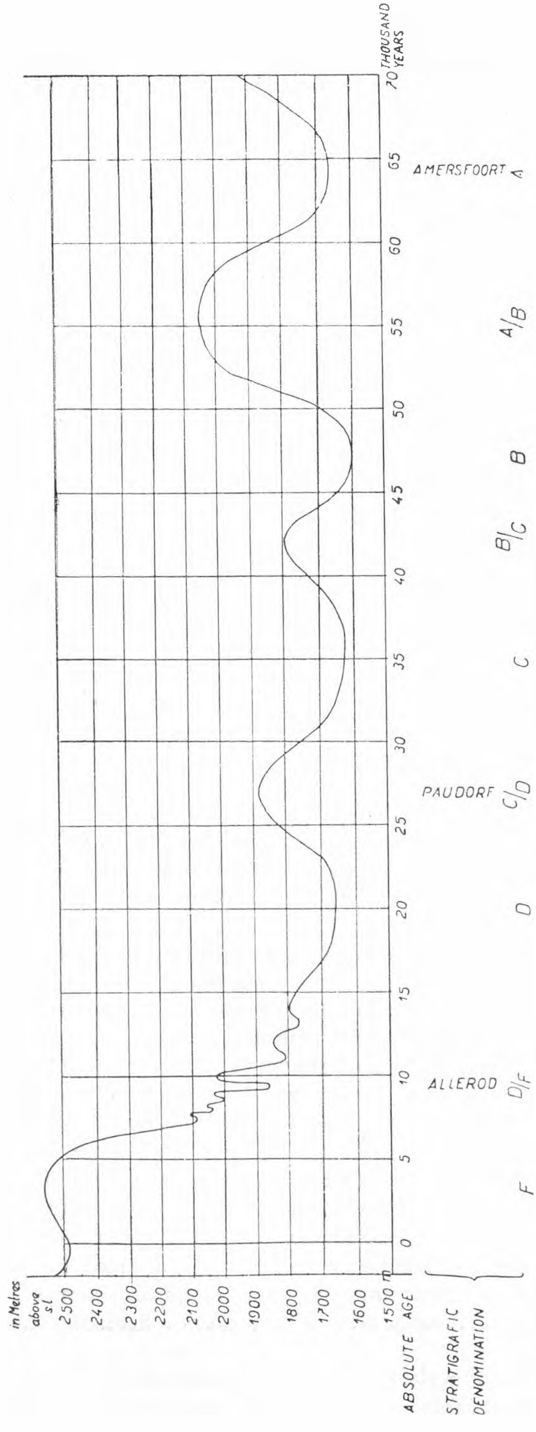
The glaciers of the High Tatra, their dimensions, the altitude of ends of the ice-streams, and the altitude of the snow line (after J. Partsch, Fr. Vitásek, B. Halicki, M. Klimaszewski, and M. Lukniš)

Southern slope					Northern slope				
Glaciers in valley (of)	Thickness in m.	Length in km.	End of ice-stream	Snowline after Höffer in m. a. s. l.	Glaciers in valley (of)	Thickness in m.	Length in km.	End of ice-stream	Snowline after Höffer in m. a. s. l.
Biele pleso	60	4.7	1270	1600	Tokársky p.	60	1.9	1000	—
Biela voda	150	7.6	1020	1610	Monkova	70	2.4	1040	—
Huncovská	60	3.0	1160	1670	Tristarská	60	2.4	1000	—
Skalnatá	90	4.1	1050	1600	Havran	75	2.1	1200	1500
Studenovodská	200	9.8	920	1570	Nový potok	50	2.1	1260	1510
Velická	110	5.4	1200	1700	Javorová	160	9.1	1035	1540
Slavkovská	70	3.8	1194	1640	Široká	80	3.4	1188	1530
Pod Kotlom	—	4.0	1320	1630	Bialka	250	14.0	935	1560
Štôlska	60	4.1	1230	1670	Suchá voda	160	8.0	1030	1520
Batizovská	130	6.4	980	1610					
Mengušovská	200	10.7	915	1610					
Mlynická	130	8.0	1150	1660					
Furkotská	80	5.2	1170	1630					
Važecká	80	5.9	1120	1620					
Kôprova	200	12.5	950	1540					

In the High Tatra, there were altogether 35 separated glaciers and firn basins. Of them, there were 18 valley glaciers, 6 hanging glaciers, 4 firn fields that were formed by an accumulation of snow downward from highly situated and abrupt slopes by avalanche moraines, under the snow line.

In the terminal moraines of the Last Tatra-Glaciation on the southern slope and piedmont plain, four oscillations of a stadial nature separated by an expressive enough recession of the glaciers may be distinguished according to the divergence of marginal moraines. I designated them with capitals A, B, C, D, and with names of typical localities on the annexed table and on the graph of oscillation of the snow line altitude. It may be seen on the graph that the glaciers reached the largest extent during the B and C oscillations, which I call the Štósy and the Tatranská Lomnica oscillations. During the A (Rakytovec) and D (Veža) oscillations the glaciers were a little shorter. After the D oscillation, the tongues of glaciers were migrating to the centre of the range. The retreat was interrupted twice. On the relief of moraines, the interruption is marked by two frontal moraines with intermediate cones and with two imbedded moraines on an inner slope of the lateral moraines. I have designated them D_1 and D_2 (oscillation of Prostredná Poľana I and oscillation of Prostredná Poľana II). In the annexed table, I compare them with the Older and Middel Dryas of Central Europe, and with moraines Schlieren and Ammersee (Bühl) in the Alps.

From the moraines of the D_2 oscillation, the glaciers retreated quickly due to a considerable warming up of the climate into highly situated corries and into back parts



Graph 1. Oscillation of snow line in the High Tatra Mts. during the Würm deduced from relation to frontal moraines.

of the glacial valleys. The snow line rose up at an altitude about 2000 m above sea level. It persisted long enough about this altitude. I deduced this persistance from the size of moraines, which then were deposited by the glaciers to the front of the hanging corries of the southern slope (21, 22). On the basis that the glaciers strongly overlain this moraine system once more, and descended also far to the valleys along the erosion furrows in them, I have designated the period of the depositing of these highly situated moraines as the D/E Interstadial and after the locality as „Senná kopa". I compare it with the Alleröd Interstadial. Then the snow line was situated about 200 metres lower. The glaciers advanced quickly along the erosion furrows of the D/E moraines and deposited the moraines far in the valleys. This outstading oscillation is designated by E, and after the locality as „Rybí potok" oscillation, since the terminal position of advance of the glaciers has been marked by the frontal morains in the Bielovodská dolina valley at an alitude of 1080 m above sea level, and closing the terminal basin above the mouth of Rybí potok river. Then the glacier in the Bielovodská dolina valley retreated into the terminal basin at an altitude of 1290 m above sea level, closed by frontal moraines. It is the E_2 oscillation (Poľana pod Vysokou I). At an altitude of 1320 m above sea level, it is marked by a terminal basin and by a frontal moraine of the E_3 oscillation (Poľana pod Vysokou II).

In the Javorová dolina valley there are preserved the moraines of these oscillations at altitudes from 1280 to 1500 m above sea level. In the larger valleys of the High Tatra, the moraines are situated at altitudes from 1300 — 1350 m to 1500 — 1620 m above sea level. The moraines of this Late Würmian advance differ from the moraines from the age of maximum development of the Last Glaciation by comprising a lots of big blocks. During the E oscillation, which has a stadial advance nature, the bottoms of glacial valleys were buried under a lot of the avalanche moraines. The situation of three described moraine accumulations from the close of the Last Glaciation of the Tatra may be compared with the Schlern, Gschnitz, and Daun oscillations in the Alps, with the Salpausselkä advance of the Scandinavian Glaciation, and with the Youg Dryas of Central Europe. Then the glaciers were reduced more and more, and according to the local conditions, they reduced to firn fields in the corries, with short streams or without them also. Owing to a warming up and a strong weathering of the rocky bordering of the corries, these firn fields being buried by a rock-waste. In the corries at an altitude of over 2000 m above sea level, extensive dumped moraines were formed from the rock-waste by its subsiding on the rocky base an the melting of dead ice. These moraines together with the active ones of the short ice-streams in the corries belong to the Oldest Holocene, and may be compared with the Egesen in the Alps (Klimaszewski 1961).

The relation between the division of the Würm in the Alps, in Northern Europe, in Central Europe, and in the Tatra is given on the comparison stratigraphic table compiled on the basis of data of G. de Geer (1940), R. v. Klebelsberg (1949), F. Firbas (1949, 1952), W. Szafer (1952), V. Ložek (1958), S. Th. Andersen — H. de Vries — W. H. Zagwijn (1960), B. Klíma — J. Kukla (1961), and P. Woldstedt (1962).

The comparison table* presupposes that all the moraines with a well preserved morainic topography in the Tatra are from the Last Glaciation. The moraines of the A stadial oscillation are the oldest ones, which may be deduced from the transgression by the other moraines of the Last Glaciation of the Tatra. The moraines of the D stadial oscillation lay on the inner side of moraines of the B and C stadial oscillation. The marginal moraines of the D moraines diverge in relation to the B and C moraines and clearly overlie them. They did not descend, however, so low as the moraines of the B and C stadial oscillations. At an altitude of about 2000 m above sea level, the moraines of the D/E interstadial have still traces of the periglacial shape. By the water-cuts of these moraines, the glaciers advanced once more downward in the valleys and deposited the moraines of a weaker E stadial oscillation, which have no traces of a periglacial shape.

The Western Tatra is 400 m lower than the High Tatra. The highest peak Bystrá reaches an altitude of 2250 m above sea level. The valleys of this range are more deeply cut than those in the High Tatra. Also here the Last Tatra Glaciation had a considerable extent. In the climatically most favourable part, i. e. in the northwest, where the snow line lay about 200 m lower, the glaciation came up to that in the High Tatra in extent. From the Kamenistá and Bystrá valleys on the southern side (— their corries lie relatively high and the bottoms of glacial valleys have a considerable slope), the glaciers reached with their ice-streams the bottom of the Liptov basin. In the other valleys, the

* In this place too, I should like to express my thanks to my friend E. Mazúr for a comment on my chronological table.

Table 3

Chronological table of Würm moraines in the High Tatra Mts.

Parallelization of Würm in the High Tatra Mts. with division of Würm in the Alps, in Central Europa and in Northern Europe. (The table is made out with using the data of G. de Geer (1940), R. v. Klebelsberg (1949), Wl. Szafer (1952), V. Ložek (1958), S. Th. Andersen — H. de Vries — W. H. Zagwijn (1960), B. Klíma — J. Kukla (1961), and P. Woldstedt (1962)

SNOW LINE IN M.	HIGH TATRA Mts.		ALPS		CENTRAL EURÓPE	NORTHERN EUROPE				ABSOLUTE AGE
2500—2700	HOLOCENE		Postglacial		Boreal	Postglacial			Magdalenien	— 7000
2100—2300			Egesen		Pre — boreal	Finiglacial				— 7900
1900—2100	E	E_3 Poľana p. Vysokou II	Late Würm	Daun	Younger Dryas	Vistulian	Gotiglacial	Salpausselkä Advance		
1800—2050		E_2 Poľana p. Vysokou I		Gschnitz						
1700—1900		E_1 Ústie Rybieho potoka		Schlern						
1900—2100	D/E	Senná kopa		Achen Warm Oscillation	Warming Up			Alleröd (Interstadial)		— 8800
1660—1880	D	D_2 Prostredná Poľana II		Ammersee (Bühl)	Older Dryas		Daniglacial	Langeland (Advance)		— 10.000
		D_1/D_2		Spiezer Warm Oscillation	Bőlling Warming Up			Warm Oscillation		
1650—1800		D_1 Prostredná Poľana I		Schlieren	Oldest Dryas			Grömitz (Advance)		—.12.000
1550—1790		Veža Stadial (Spálený vrch)	Middle Würm	Würm 3				Pomoranian Stage Frankfurt Stage Brandenburg Stage	Gravettien	— 14.000 — 20.000
	C/D	Interstadial		W 2/3	Paudorf					
1520—1710	C	Tatr. Lomnica Stad. (Varta)		Würm 2						
	B/C	Interstadial			Warming Up				Aurignacien	
1510—1690	B	Štósy Stadial (Uhlisko)								
	A/B	Interstadial	Early Würm	W 1/2	Warming Up			Brörup		— 56.000
1650—1730	A	Rakytovec Stadial (Vtáčnik)		Würm 1	Amersfoort			Rodebaek	Mousterien	
			Riss — Würm		Göttweig	EEM — Interglacial				— 70.000

glaciers ended in the range. Therefore their frontal moraines were strongly destroyed by rivers. That is why the oscillations before the Later Würm are not well enough distinguishable by the divergence of the marginal moraines.

In the Western Tatra, R. Lucerna distinguished the moraines of the Würm, the remnants of the Riss moraines, and still an older accumulation of weathered moraines. In reality the latter represents a remnant of an Old-Pleistocene valley train. R. Lucerna divides the moraines of the Youngest Glacial into the moraines of the maximum extent, and into three recessional moraines (Bühl, Gschnitz, and Daun). A similar classification of the moraines in the Western Tatra is recorded also in the works of B. Halicki (6), and

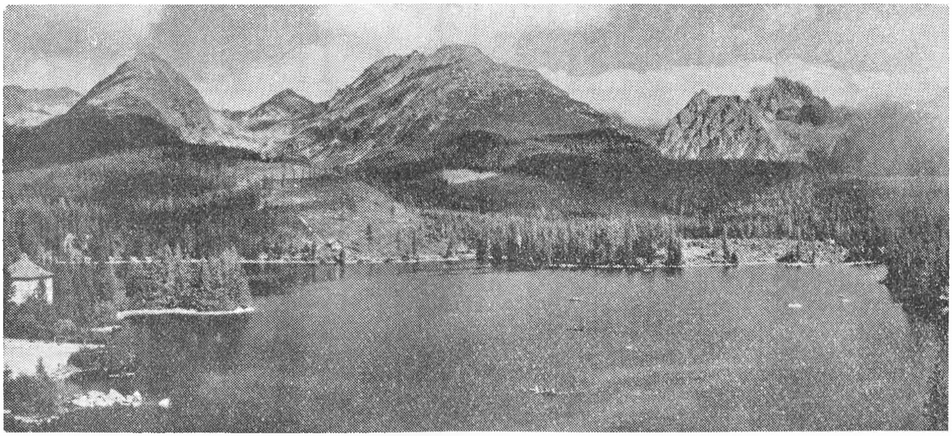


Fig. 2. The morainic landscape about Štrbské pleso (mountain lake). At the place of lake, the right-hand lateral moraine has been destroyed by melting of a dead glacier. (View-card.)

J. Szalfarski (40), who designate the recessional moraines by numbers I, II, and III. Till the present time, in the moraines of the maximum extent of glaciers of the Last Tatra Glaciation in the Western Tatra, the moraines of stadial oscillation have not been distinguished. On the basis of Halicki's and Szaflarski's moraine classification, the lowest situated sequence of the moraines in the Western Tatra (the so called outer moraines) logically corresponds to the B, in fact C stadial oscillation of the High Tatra. The second sequence of moraines (the so called inner moraines) may be compared then with the D stadial oscillation in the High Tatra. The moraines of recessional phase I correspond to the E_1 stadial oscillation (Schlern) as a matter of fact, and the moraines of the recessional phases II and III to the E_2 and E_3 oscillaitons (Gschnitz and Daun).

On the northern slope of the range, the moraines of the D stadial oscillation descend lowest in the Zuberecká valley, namely to an altitude of 1110 m above sea level (24). Highest they appear in the valley of Mała Łąka (1280 m above sea level) B. Halicki recorded moraines of phases of the E_1 oscillation with an altitude from 1300 to 1450 m above sea level. During the E_2 oscillation there were only slight firn fields in the Western Tatra, and the dumped moraines were formed. It is necessary to consider the moraines on the southern slope of the range, which Lucerna denominated as Bühl, for the moraines of E stadial oscillation in the High Tatra. At that time, the glaciers advanced to an altitude of 1300 — 1400 m above sea level, to which corresponds the snow line at an altitude of 1640 — 1850 m above sea level. The moraines of the Lucerna's Gschnitz

Table 4

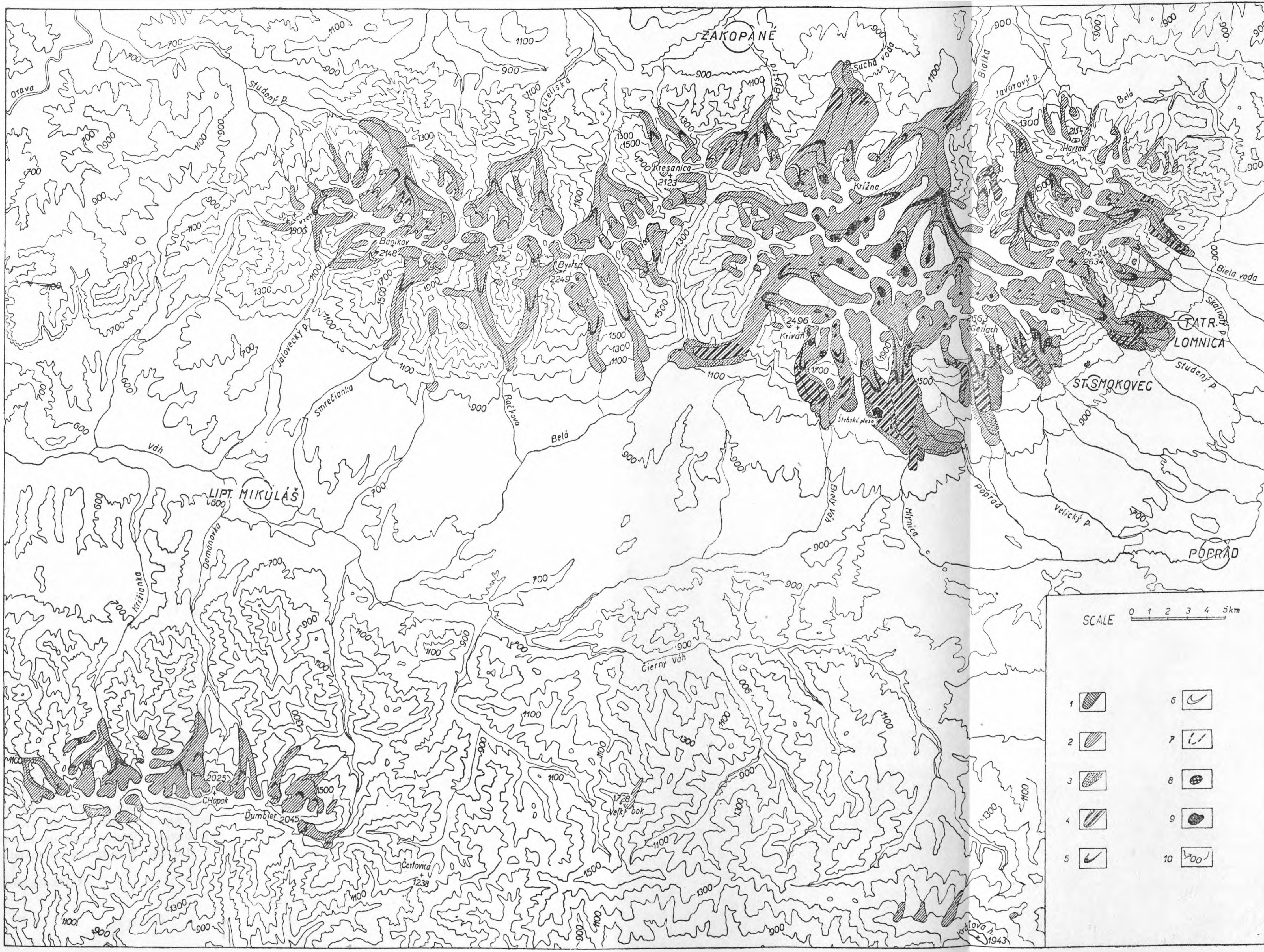
The glaciers of the Western Tatra, their thickness, length, altitude of the ends of ice-streams, and altitude of the snow line during the maximum extent of the Last Tatra Glaciation after R. Lucerna (19), J. Partsch (25), Fr. Vitásek (42), B. Halicki (6), J. Szaflarski (40), and E. Mazúr (24)

Southern slope					Northern slope				
Glaciers in valley (of)	Thickness in m.	Length in km.	Alt. of end of ice-stream in m. a. s. l.	Alt. of snowline in m. a. s. l.	Glaciers in valley (of)	Thickness in m.	Length in km.	Alt. of end of ice-stream in m. a. s. l.	Alt. of snowline in m. a. s. l.
Tichá dolina	130	5.5	1230	1620	Bystrá	100	4.6	1010	1460
Tomanová	70	2.5	1260	1590	Mala Łąka	70	3.5	1150	1520
Hlina	70	2.2	1100	1520	Miętuşia	80	3.7	1050	1550
Kamenistá	140	7.0	1020	1550	Koscieliska	120	5.5	1040	1490
Bystrá	130	5.2	1030	1550	Chocholovská	120	5.5	1040	1500
Račková					Látaná	60	2.5	1200	1470
Jamnická	160	8.0	900	1520	Zuberecká	200	9.0	940	1480
Smrečianska	160	6.5	930	1530	Dlhá Jama	50	2.1	1140	1470
Jalovecká	110	4.3	1093	1530	Volariská	50	2.2	1080	1420
Hlubokovská	100	3.8	1050	1540					

stage at an altitude of 1500 — 1700 above sea level, correspond to the E_2 oscillation. E_3 oscillation is indicated probably by the moraine in the highly situated corrie of Bystrá only. Under the rocky walls of the other corries the dumped moraines only appear.

South of the Western Tatra on the opposite border of the Liptov basin, the granite mountain chain of the Lower Tatra range stretches in the direction from the west to the east. This range is divided into two parts by the Čertovica mountain pass (1267 m above sea level). In the western part is situated the Ďumbier Mt. (2045 m above sea level). In the eastern part, the Káľova hoľa Mt. reaches an altitude of 1943 m above sea level. The western part has three corries on the southern part. In these were the firn glaciers. The northern slope has 31 corries. The glaciers, which reached a length of 5 km at most, were nourished by them. There were five glacier systems, three simple valley glaciers, and two firn fields, here. The corries stretch at an altitude from 1420 to 1650 m above sea level. In the period of the largest extent of the Last Tatra Glaciation, the longest glaciers were melting at an altitude of 1000—12000 m a. s. l.

In addition to the end moraines, Fr. Vitásek (42), Louček — Michovská — Trefná (18), and S. Láng (15) distinguished three moraines of the recessional phases. Louček — Michovská — Trefná lay them to an altitude of 1136—1203 m a. s. l., 1255—1380 m a. s. l., and 1380—1590 m a. s. l. Larger glaciers ended deep in the valleys, where the frontal moraines have been strongly destroyed. Only in the Lúčanka (1070 m a. s. l.) and the Križianka (1022 m a. s. l.) valleys, the moraines of the maximum extent of glaciers of the Last Glaciation have been found. They are moraines of the B or C stadial oscillation. The moraines of the retreat-stage I at an altitude of 1136—1203 m a. s. l. must be considered for an accumulation of the D stadial advance. The sequence of moraines at an altitude of 1255—1380 m a. s. l. then belongs to the E_1 stadial advance (Schlern), and moraines at an altitude of 1380—1590 m a. s. l. to its situation during



Map 2. The course of the Last Glaciation in the Tatra and Lower Tatra. 1 — moraines of the stadial oscillation A, 2 — area occupied by glaciers during the stadial oscillation B, 3 — moraines of the stadial oscillation C, 4 — moraines of the stadial oscillation D, 5 — moraines of the stadial oscillation E, 6 — moraines of

Table 5

Glaciers of the Lower Tatra, their dimensions, altitude of the ends of ice-streams and the snow line during the Würm, according to Fr. Vitásek (42), S. Láng (15), and Louček — Michovská-Trefná (18)

Glaciers in valley (of)	Thickness in m.	Length in km.	Alt. of end of ice-stream in m. a. s. l.	Alt. of snowline in m. a. s. l.	Glaciers in valley (of)	Thickness in m.	Length in km.	Alt. of end of ice-stream in m. a. s. l.	Alt. of snowline in m. a. s. l.
Jamy	—	2.0	1100	1420	Bystrá	90	3.0	1180	1450
Veľ. Oružné	—	2.0	1100	1420	Ludarovská	—	3.0	1200	1450
Križianka	100	5.0	1020	1420	Štiavnica	—	2.7	1300	1450
Mošnica	70	2.2	1210	1460	Veľ. Bok	—	1.6	1020	1550
Palúčanka	100	5.0	1000	1450	Brumov	—	2.5	1330	1650
Lúčanka	90	5.0	1070	1430					

the prase of the E_2 oscillation (Gschnitz). In the highest parts of corries also younger avalanche moraines have been deposited. In the late Würm, some low situated corries were glaciated no more.

The snow line deduced by Fr. Vitásek (42) after Höffer lies still lower than in the Western Tatra. It oscillated between 1410 and 1460 m a. s. l. The eastern part of the Lower Tatra has only six embryonic corries. Two small hanging glaciers were nourished by three corries of them. They were 1.6 and 2.5 km long. Only three corries had firn fields. All the corries are situated on the northern slope of the mountain range. In this more continental part of the Lower Tatra, the snow line was situated at an altitude of about 1600 m a. s. l. These glaciers were existing only during the maximum extent of the Last Glaciation.

Judging from great differences between a considerable glaciation of the northern slope of the Lower Tatra and slight traces of there firn fields on the southern slope, this mountain ridge must have been an important climatic dividing line during the Last Glacial. Western-mostly exposed still glaciated range of the Central Western Carpathians is the Malá Fatra Mts. It reaches an altitude of 1711 m a. s. l. by the Fatranský Malý Kriváň Mt. At an altitude of 1389—1580 m a. s. l., K. Paulo found 12 embryonic corries here (28). In my opinion, not all of them are corries indeed, since some of them are only the nivation hollows. The snow line is laid here, after Paulo, at an altitude of 1470 m a. s. l. Also Fr. Vitásek (43) agrees with.

Also the mountain group of the Babia hora Mt. in the flysh had smaller corries and hanging glaciers on the slope exposed to the north. L. Sawicki described 10 small corries of this place. These corries nourished small hanging glaciers only, and lodged the firn fields with an area of about 10.5 sq. km. The lowest moraines occur here at an altitude of 920 m a. s. l. The snow line deduced by Sawicki was at an altitude of 1400 m a. s. l. (36). Newly K. and T. Ziętara pointed out a sizible landslide took part in the relief shaping and at the influence upon nature of debris-slide on the northern slopes of Babia hora Mt. Therefore the question of the glaciation of Babia hora Mt. must be considered as an uncompletely solved one.

In the mountain group of Piľsko Mt. (1557 m a. s. l.) in the west of Babia hora Mt., Sawicki described three corries. In the Moravian-Silesian Beskid Mts., which is the nortwestmostly exposed mountain range of the flysh belt, L. Sawicki (36) has found a sole corrie on the Barania hora Mt. (1214 m a. s. l.) at an altitude of 1090 m a. s. l., in the climatically most favourable location.

The cirques on the slope of the Lysá hora Mt. (1325 m a. s. l.) described by R. Lucerna (19), on the slope of the Smrk Mt. (1277 m a. s. l.) desribed by J. Pelíšek (29), and also the cirque of the Barania hora Mt. raise the suspicion that they are nivation hollows, or they are starting scars, which are frequent in the flysh belt of the Carpathians. Such nivation hollows lodged no firn fields, but could preserve the spots of snow also in summer as we find elsewhere also in the Western Carpathians, e. g. on the Poľana Mt. (1459 m a. s. l.), on the Vtáčnik Mt. (1346 m a. s. l.), and on the western slope of Ploská in the Veľká Fatra Mts. (1533 m a. s. l.).

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PRIEBEH POSLEDNÉHO ZAĽADNENIA ZÁPADNÝCH KARPÁT VO VZŤAHU K ALPÁM A ZAĽADNENIU SEVERNEJ EURÓPY

Vysoké Tatry sú veľmi vhodné pre riešenie otázok periodizácie posledného zaľadnenia cestou štúdia glaciálnych a fluvioglaciálnych útvarov. Ich južný svah je veľmi strmý a úzky. Krátke doliny na ňom majú priemerný sklon 8° 4′. Kary južného svahu práve tak rozmerné ako kary na severnom svahu ležia prevažne vo výškach 1900—2050 m n. m. Menšie kary južného svahu obyčajne ústia bezprostredne na otvorený strmý svah bez dolín. Ľadovce z takýchto karov na otvorenom svahu pri každom mladšom nápore ľahko menili polohu svojho lôžka. Väčšie kary prechádzajú cez vysoké skalné závery do dobre vyvinutých glaciálnych dolín. Nimi schádzali ľadovce až na dno Liptovsko-popradskej kotliny. Pred vyústením dolín na dno kotliny uložili morénové rampy. Dvíhajú sa nad okolie do výšok aj nad 100 m. Na týchto morénových rampách ľadovce po výraznom ústupe jazykov obyčajne opäť postúpili iným smerom. Preto morény výrazných oscilácií, ktoré majú ráz štadiálov, navzájom divergujú. Táto šťastná okolnosť viditeľná v reliéfe umožnila triediť morény posledného zaľadnenia Vysokých Tatier.

Severný svah Vysokých Tatier má doliny hlbšie zarezané. Kary tu ležia vo výškach okolo 1700—1750 m n. m. Doliny majú miernejší spád (7° 12′). Ľadovce sa končili v hlbokých dolinách v pohorí. Nemali preto možnosť prekladať svoje lôžka. Pomerne silné potoky ich čelné morény značne rozplavili. S výnimkou doliny Suchej vody a Širokého potoka zatiaľ neposkytli takú možnosť na roztriedenie morén posledného zaľadnenia ako doliny južného svahu. Prehľad o veľkosti ľadovcov a o výške odvodenej snežnej čiary z doby maximálneho rozsahu posledného zaľadnenia podáva tab. 2 v anglickom texte.

Ako už uviedol J. Partsch (25), južný svah Vysokých Tatier, a to i pri niečo vyššie položenej snežnej čiare mal za posledného zaľadnenia väčšiu plochu pokrytú ľadovcami ako severný svah, lebo kary južného svahu ležia priemerne o 300 m vyššie. Z plochy pohoria 335 km^2 bolo ľadovcami a trvalým snehom zakryté 255 km^2. Z tejto rozlohy bolo na južnom svahu 145 km^2.

V koncových morénach posledného tatranského zaľadnenia na južnom svahu a úpätí pohoria sa dajú odlíšiť podľa divergencie marginálnych morén štyri oscilácie štadiálneho charakteru, oddelené výraznejšími ústupami ľadovcov. Označil som ich v tab. 3 a na grafe oscilácií výšky snežnej čiary veľkými písmenami A, B, C, D a názvami typických lokalít. Z grafu vidieť, že ľadovce dosiahli najväčší rozsah počas oscilácií B a C, ktoré pomenúvam ako oscilácia Štósy a oscilácia Tatranská Lomnica. Počas oscilácií A (Rakytovec) a D (Veža) boli ľadovce o niečo kratšie. Po oscilácii D sa jazyky ľadovcov sťahovali do vnútra pohoria. Ústup bol prerušený dvakrát. V reliéfe morén je prerušenie zaznačené dvoma čelnými morénami s prechodnými kužeľmi a dvoma vloženými morénovými stupňami na vnútornom svahu bočných morén. Označil som ich ako D_1 a D_2 (oscilácia Prostredná Poľana I a oscilácia Prostredná Poľana II). V priloženej tabuľke ich porovnávam so starším a stredným dryasom strednej Európy a s morénami Schlieren a Ammersee (Bühl) v Alpách.

Od morén oscilácie D_1 ľadovce sa rýchle stiahli následkom značného oteplenia vysoko do karov a do zadných častí glaciálnych dolín. Snežná čiara vystúpila do výšky okolo 2000 m n. m. Okolo tejto výšky dlhšie zotrvávala. Na takéto zotrvávanie usudzujem z mohutných morén, ktoré ľadovce vtedy nasypali pred visutými karmi južného svahu (21, 22). Na základe toho, že tento systém morén ľadovce ešte raz silne prestúpili a cez erózne zárezy v nich zostúpili ešte hlboko do dolín, označil som časový úsek nasypania týchto vysoko ležiacich morén interštadiálom D/E a podľa lokality „Senná kopa". Porovnávam ho s interštadiálom Alleröd. Potom musela snežná čiara klesnúť asi o 200 m. Ľadovce rýchle postúpili cez erózne zárezy morén D/E a nasypali morény hlboko v dolinách. Túto výraznú osciláciu označujem písmenom E_1 a podľa lokality oscilácie Rybieho potoka, lebo krajný zásah postupu ľadovcov zaznačujú v Bielovodskej doline čelné morény vo výške 1080 m n. m., uzatvárajúce nad ústím Rybieho potoka terminálnu panvu. Potom ľadovec v Bielovodskej doline ustúpil do terminálnej panvy vo výške 1290 m n. m., ohradenej čelnými morénami. To je oscilácia E_2 (Poľana pod Vysokou I). Vo výške 1320 m n. m. je zaznačená terminálnou panvou a čelnou morénou oscilácia E_3 (Poľana pod Vysokou II).

V Javorovej doline sú morény týchto oscilácií zachované vo výškach od 1280 m do 1500 m n. m. Vo väčších dolinách južného svahu Vysokých Tatier schádzajú do výšok od 1300 až 1350 m n. m. do výšok 1500 až 1620 m n. m. Morény tohto pozdnoglaciálneho postupu sa líšia od morén z doby maximálneho rozvoja posledného zaľadnenia tým, že obsahujú mnoho hrubých blokov. Dná dolín počas oscilácie E, ktorá má ráz štadiálneho postupu, zasypalo mnoho snehových sutinových valov. Postavenie opísaných troch morénových akumulácií zo sklonku posledného tatranského zaľadnenia možno najskôr porovnávať s osciláciami Schlern, Gschnitz a Daun v Alpách, s postupom Salpausselkä severského zaľadnenia a s mladým dryasom strednej Európy. Potom sa ľadovce ďalej redukovali a podľa miestnych podmienok sa menili v karoch na firnové ľadovčeky s krátkymi splazmi alebo aj bez splazov. Následkom oteplenia a silného vetrania skalnej obruby karov boli tieto firnoviská silne zavalované odrobeninami. Ich sadnutím na skalný podklad pri roztápaní mŕtvych firnovísk vznikli v karoch vo výškach nad 2000 m n. m. rozsiahle pasívne morény. Spolu s aktívnymi morénami krátkych ľadovcových splazov v karoch patria do najstaršieho holocénu a možno ich porovnať s Egesenom Álp (Klimaszewski, 1961).

Vzťahy medzi rozdelením würmu v Alpách v severnej Európe, v strednej Európe a Tatrách podáva porovnávacia tabuľka stratigrafická, zostavená na podklade triedenia P. Woldstedta (1962), R. von Klebelsberga (1949), F. Firbasa (1949, 1952), De Geera (1940), B. Klímu — J. Kuklu (1961), V. Ložeka (1958) a S. Th. Andersena — H. de Vriesa — W. H. Zagwijna (1960). Porovnávacia tabuľka vychádza z toho, že všetky morény s dobre zachovanou morénovou topografiou v Tatrách sú z posledného zaľadnenia. Morény štadiálnej oscilácie A sú najstaršie, lebo sú prestúpené ostatnými morénami posledného tatranského zaľadnenia. Morény štadiálnej oscilácie D sú na vnútornej strane morén štadiálnej oscilácie B a C. Kde marginálne morény D divergujú oproti morénam B a C, tak ich zreteľne divergentne prestupujú, ale nikde nezostupujú tak nízko ako morény štadiálnych oscilácií B a C. Vo výškach okolo 2000 m n. m. nasypané morény D/E interštadiálu nesú ešte stopy periglaciálnej modelácie. Cez zárezy týchto morén ešte raz ľadovce postúpili do dolín a nasypali morény slabšej štadiálnej oscilácie E, ktoré už nenesú stopy periglaciálneho premodelovania.

Západné Tatry sú o 400 m nižšie ako Vysoké Tatry. Najvyšší vrch Bystrá dosahuje výšku 2250 m n. m. Ich doliny sú hlbšie zarezané ako doliny Vysokých Tatier. Posledné tatranské zaľadnenie malo tu značný rozsah. V klimaticky najviac priaznivej časti na severozápade, kde snežná čiara bola asi o 200 m nižšie položená, vyrovnalo sa rozsahom zaľadneniu vo Vysokých Tatrách. Z Kamenistej a Bystrej doliny, na južnom svahu, ktorých kary ležia pomerne vysoko a dná dolín majú veľký sklon, ľadovce vystúpili svojimi jazykmi z pohoria na dno Liptovskej kotliny. V ostatných dolinách sa ľadovce končili v pohorí, preto ich čelné morény potoky silne rozplavili. Preto z týchto príčin nemožno tak dobre rozlišovať podľa divergencií marginálnych morén oscilácie pred pozdným würmom

V morénach maximálneho rozsahu ľadovcov posledného tatranského zaľadnenia v Západných Tatrách sa zatiaľ nerozlíšili morény štadiálnych oscilácií. Keď sa oprieme o Halického (6) a Szaflarského (40) triedenie morén, tak najnižšie položený sled morén v Západných Tatrách (tzv. vonkajšie morény) logicky odpovedá štadiálnej oscilácii B, resp. C Vysokých Tatier. Druhý sled morén (tzv. vnútorné morény) možno potom porovnať so štadiálnou osciláciou D Vysokých Tatier. Morény fázy regresie I odpovedajú vlastne ľadovcovej oscilácii E_1 (Schlern) a morény fázy regresie II a III osciláciám E_2 a E_3 (Gschnitz a Daun).

Na severnom svahu pohoria zasahujú morény štadiálnej oscilácie D najnižšie v Zubereckej doline, a to až do výšky 1110 m n. m. Najvyššie sa nachádza v doline Mala Łąka (1280 m n. m.). Morény fázy oscilácií E_2 zaznamenal B. Halicki vo výškach od 1300 do 1450 m n. m. Počas oscilácie E_3 boli v Západných Tatrách už len drobné firnoviská a tvorili sa pasívne morény. Na južnom svahu pohoria treba považovať morény, ktoré Lucerna označil ako Bühl, za morény štadiálnej oscilácie E_1 Vysokých Tatier. Ľadovce vtedy postúpili do výšok 1300—1400 m n. m., čomu odpovedá snežná čiara vo výškach 1640—1850 m n. m. Morény Lucernovho štádia Gschintz vo výškach 1500—1700 m n. m. so snežnou čiarou od 1710 do 1780 m n. m. odpovedajú oscilácii E_2. Oscilácia E_3 je pravdepodobne zaznačená morénou len vo vysoko ležiacom kare Bystrej. V ostatných karoch sú pod ich skalnými stenami len pasívne morény.

Morény z doby maximálneho rozsahu ľadovcov posledného zaľadnenia v Nízkych Tatrách sa podarilo stanoviť len v doline Lúčanky (1070 m n. m.) a Križianky (1022 m n. m.) (18). Sú to morény štadiálnej oscilácie B alebo C. Morény ústupového štádia I vo výškach 1136 až 1203 m n. m. treba podobne ako v Západných Tatrách považovať za akumuláciu štadiálneho postupu D. Potom už spájanie sa morén vo výškach 1255—1380 m n. m. prislúcha štadiálnemu postupu E_1 (Schlern) a morény vo výškach 1380—1590 m n. m. jeho postaveniu počas fázy oscilácie E_2 (Gschnitz). V najvyšších častiach karov sú ešte nasypané mladšie snehové sutinové morénky. Niektoré nízko položené kary v pozdnom würme už zaľadnené neboli.

V Kráľovohoľskej časti Nízkych Tatier, v Malej Fatre, na Babej hore a na Piľsku firnoviská a malé ľadovce existovali len počas maximálneho rozsahu posledného zaľadnenia.

Súdiac podľa veľkých diferencií medzi značným zaľadnením severného svahu Nízkych Tatier a nepatrnými stopami po troch firnoviskách na južnom svahu, musel byť tento horský chrbát počas posledného glaciálu dôležitým klimatickým rozhraním.

Obr. 1. Mengušovská dolina na južnej strane Vysokých Tatier. Príklad glaciálneho údolia.

Obr. 2. Morénová krajina pri Štrbskom plese. Na mieste jazera pravá bočná moréna je rozrušená roztopením sa ľadovca. (Pohľadnica.)

Mapa 1. Rozdelenie würmských morén ľadovcov Mengušovskej a Mlynickej doliny na južnom predhorí Vysokých Tatier. 1 — morény štadiálnej oscilácie A, 2 — morény štadiálnej oscilácie B, 3 — morény štadiálnej oscilácie C, 4 — morény štadiálnej oscilácie D, 5 — morény oscilácie D_1, 6 — morény oscilácie D_2, 7 — morény štadiálnej oscilácie E, 8 — pahorkovité morény s depresiami po roztopení mŕtveho ľadu, 9a — fluvioglaciálne alúvium štadiálnych oscilácií A, B, C, D, 9b — fluvioglaciálne alúvium oscilácie D_1 a D_2, 10 — fluvioglaciálne alúvium štadiálnej oscilácie E, 11 — holocénna niva, 12 — morény predposledného zaľadnenia, 13 — fluvioglaciálne alúvium predposledného zaľadnenia, 14 — fluvioglaciálne alúvium starého pleistocénu, 15 — flyš, 16 — periglaciálna kamenisto-hlinitá pokrývka, 17 — dellen, 18 — jazero, 19 — rašelinisko, 20 — bočné morénové valy, 21 — rekonštruovaný priebeh morénových valov.

Mapa 2. Priebeh posledného zaľadnenia v Tatrách a v Nízkych Tatrách. 1 — morény štadiálnej oscilácie A, 2 — plocha, na ktorej boli ľadovce rozšírené počas štadiálnej oscilácie B, 3 — morény štadiálnej oscilácie C, 4 — morény štadiálnej oscilácie D, 5 — morény štadiálnej oscilácie E, 6 — morény štádia E_2, 7 — morény štádia E_3, 8 — morény interštadiálu D/E, 9 — jazerá, 10 — vrstevnice.

Graf 1. Schéma oscilácií hranice trvalého snehu vo Vysokých Tatrách počas würmu, odvodená zo vzťahu ku koncovým morénam.