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AN ATTEMPT TO EVALUATE SNOW METHAMORPHOSIS ACCORDING TO ENVIRONMENTAL CONDITIONS IN THE CHOCHOŁOWSKA VALLEY (WEST TATRA MOUNTAINS)

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This paper discusses problems of seasonal snow cover metamorphosis. The attempt is made to evaluate snow cover metamorphosis according to environmental and meteorological conditions at five sites in the Chochołowska Valley in the winter seasons 1994/95 and 1995/96. The physical parameters of snow (desity, hardness, snow temperature) were measured and the descriptions and photographs of snow profiles and snow crystals were prepared. The attempt was made also to reconstruct the history of development of individual snow layers in the snow profiles.

Key word: snow cover, snow methamorphosis, Chochołowska valley, West Tatra Mountains

INTRODUCTION

Problems of snow metamorphosis are usually considered in terms of permanent snow patches and glaciers. In this aspect, the complete cycle of metamorphosis which is based on gradual transformation of snow crystals leads to development of glacier ice.

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It should be remembered, however, that processes which take place in seasonal snow cover are identical in their physical nature to permanent metamorphosis (Jania, 1993). The only substantial differences are the time of snow cover occurrence, its thickness and much milder meteorological conditions of the areas where it occurs. These factors cause that metamorphosis of seasonal snow cover takes place much faster, usually never reaches all phases of transformation and never finishes in development of glacier ice.

In the foreign literature, problems of snow metamorphosis have been discussed quite often (e.g. Gray and Male 1981, Nakaya 1981, Quervain 1963). The Polish literature concerning this problems, on the other hand, is relatively poor. Snow metamorphosis was discussed only by Kłapowa (1972, 1980) and partly by Chomicz (1960). This small number of works concerning one of the most interesting problems associated with snow cover encouraged the authors to take up this topic and to try to evaluate the snow metamorphosis in the Tatra Mountains.

AIM OF THE WORK AND METHODS OF FIELD INVESTIGATIONS

The work presents results of the investigation on evaluation of snow metamorphosis conditioned by environmental and meteorological factors. The research was carried out in two winter seasons in the Chocholowska Valley (Tatra Mountains).

The Chochołowska Valley is situated in the western edge of the Polish part of the Tatra Mountains. It is the largest, in terms of the area, valley in Polish Tatras. Its area is 35.6 km^2 and its length is 11 km. Starorobociaski summit (2176 m. a.s.l.) is the highest place in the surrounding of the valley.

The investigation of snow cover were carried out in 5 sites (Fig. 1). Each of the site represented different environmental conditions (Tab. 1). The measurements were taken in two winter seasons: 1994/95 and 1995/96. In the winter season 1994/95, one experimental measurement (28, 29 March) was done to test the applied methods and to select the location of the sites. In the winter season 1995/96, three series of measurements (28, 29 February, 15, 16 March, 13 April) were carried out. In vertical profiles, snow temperature (at every 10 cm), density and hardness were measured. To evaluate snow hardness, simple field tests were applied which show only general orientation of hardness in vertical profile (Fig. 2a). Snow density was measured using weighting snow gauge of a cross-section area of 50 cm^2 and scaled with an accuracy of 0.1g cm^{-3}. The snow depth was measured using resistance thermometer which was joined to a standard M. 4630 multimeter (B). The snow temperature was measured using measuring tape with accuracy of 1 cm. To evaluate snow metamorphosis, descriptions and photographs of snow profiles and snow crystals from field investigations were applied. The snow classification by Chomicz (1963) was applied to determine snow crystals (Fig. 2b).

The term "winter season" used in this work means a part of the year from November to June; such classification of winter season was imposed by the time of investigation and occurrence of snow cover in the area studied. This work contains only selected diagrams of physical features of snow cover which show typical situations observed during field work. The obtained results of investigation concerning physical features of snow cover and its metamorphosis were then compared with the results obtained by Kłapowa (1972).

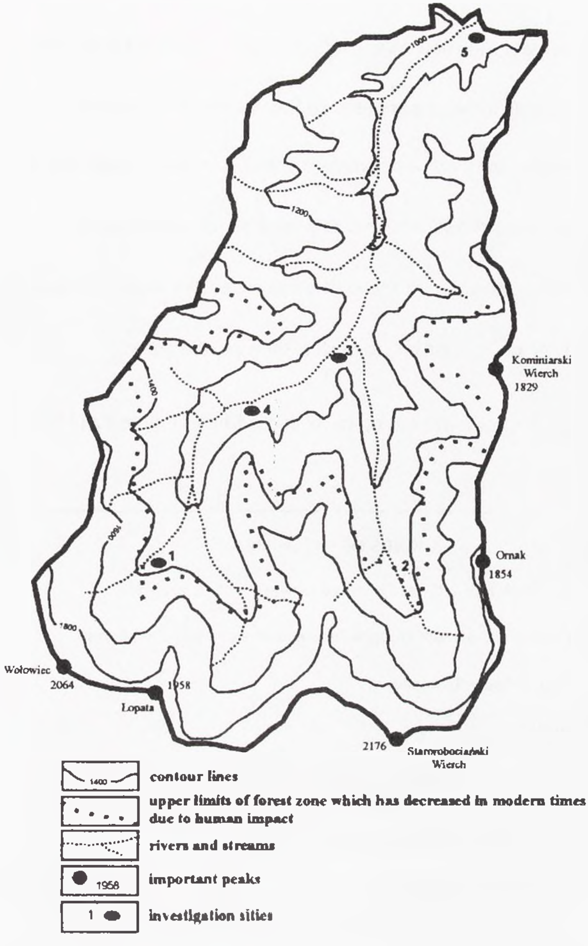


Fig. 1. Lacation of the investigation sites.

Tab. 1. Characteristic of the research sites

Site number (m a.s.l.)	Location	Altitude	Exposition	Situation
1	Wyznia Chochołowska Valley	1470	ESE	The upper limit forest, just in front of the dense forest, between individual trees
2	Starorobocianska Valley	1340	NW	Open area above the upper forest limit and above individual trees, the slope of the upper part of the valley
3	Wielki Kopieniec	1183	WNW	Coniferous forest
4	Polana Chochołowska	1150	-	The valley bottom, vast clearing
5	Dolina Chochołowska (entrance)	934	-	Vast clearing with dense forest in the south

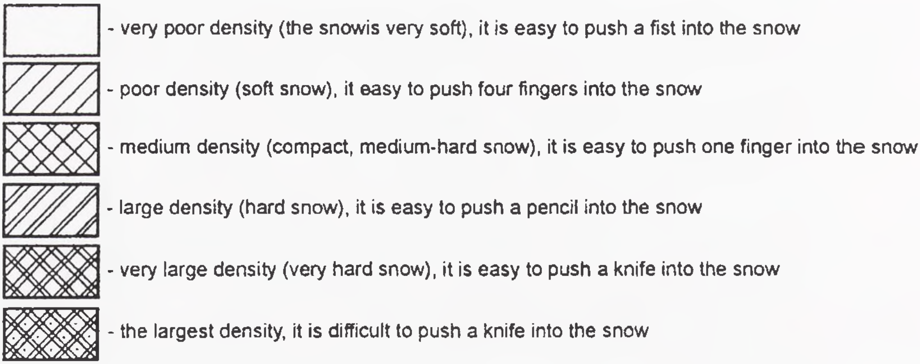


Fig. 2a. Test of hardness of snow according to Chomicz (1963).

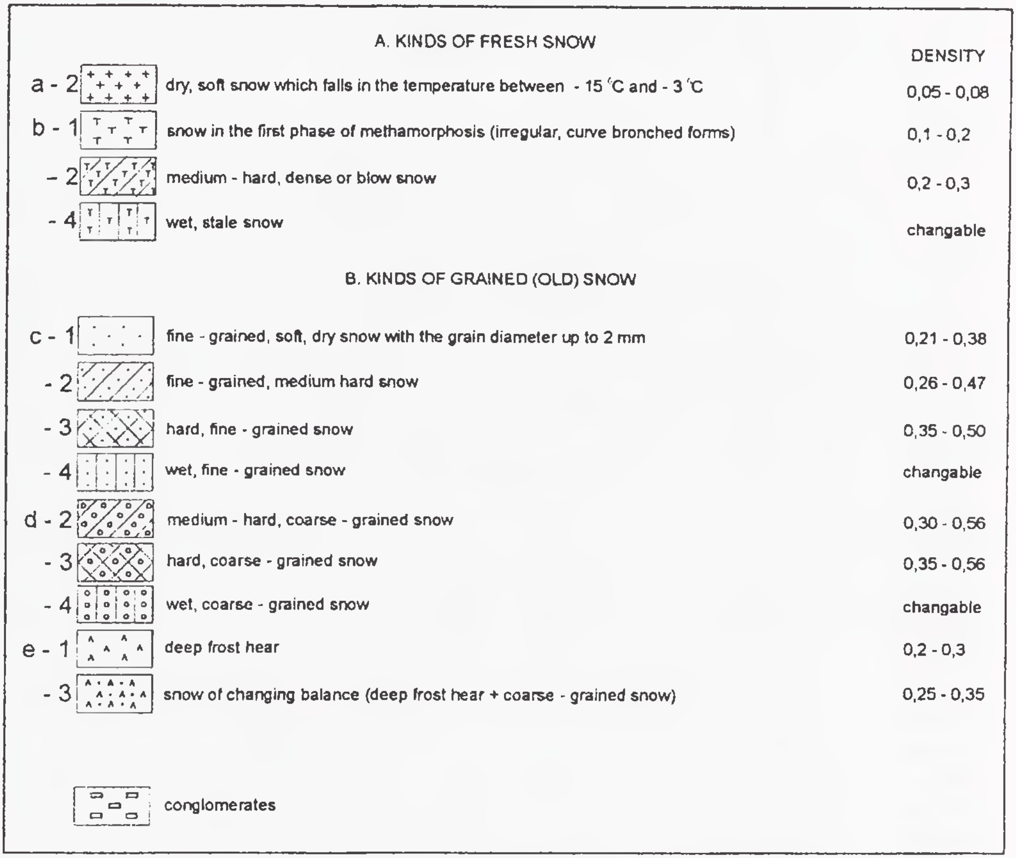


Fig. 2b. Classification of snow according to Chomicz (1963).

METEOROLOGICAL CONDITIONS OF THE WINTER SEASONS 1994/95 AND 1995/96

Mean air temperature in the winter season 1994/95 after data from Chochołowska valley (near 1150 m.a.s.l) was -1.5° C which enables to classify this winter as mild. Among all the months studied, the coldest was January (-4.5° C) and the warmest was November (+1,2° C) (Tab. 2). During the whole period studied (November 1994-April 1995), there were 105 days with the temperature below 0 oC and the largest number of such days occurred in January (27) and the smallest in April (11). There were 58 days with maximal daily air temperature below 0° C and 144 days with minimal daily air temperature below 0° C. During this winter season, there were 117 days with precipitation which included 26 days with rain and 91 days with snow. March and January were the wettest months (24 days with precipitation in March including 20 days of snow and 23 days with snow precipitation in January). The smallest number of days with precipitation occurred in December (14 days including 8 days with snow). The first snow fall took place on the 1st of October and the last on the 17th of April.

Tab. 2. Comparison of average monthly air temperatures in the period studied 1994/1995 with normal period (1931-1960)

Year	XI	XII	I	II	III	IV
1994-95	1.2	-2.0	-4.7	-0.4	-1.8	-1.5
1931-60	0.6	-3.0	-6.0	-4.8	-1.9	2.5
deviation from normal	0.6	1.0	1.3	4.4	0.1	-4.0

Source: IMGW materials, Končeк (1974)

Mean air temperature of the winter season 1995/96 was -3,3° C; it was lower by 1.8° C then the previous winter season and it was also lower by 1.2° C then the mean temperature from a period 1931-1960. February was the coldest month with a mean monthly air temperature of -6.6° C and April was the warmest month with a mean monthly air temperature of 2.5° C. As compared to the winter season 1994/95, the mean monthly air temperatures of the winter season 1995/96 were lower except of January and April (Tab. 3). During the whole winter season studied (November 1995 - April 1996), there were 129 days with mean daily air temperature below 0° C which is 24 days more as compared to the previous winter season. The largest number of days with average daily air temperature below 0° C occurred in February (28) and March (27) and the smallest number of such days occurred in April (7). There were 79 days when maximal daily air temperature was above 0° C and 159 days when minimal daily air temperature was below 0° C. In the winter season 1995/96 there were 88 days with precipitation including 66 days of snow and 22 days of rain. February and December were the wettest months (17 days with precipitation in February including 14 days of snow and 16 days with precipitation in December including 13 days with snow). The smallest number of days with snow precipitation occurred in April (6 days) and with rain precipitation occurred in January (1 day).

Tab. 3. Comparison of average monthly air temperatures in the period studied 1994/1995 with normal period (1931-1960)

Year	XI	XII	I	II	III	IV
1995-96	-2.6	-3.8	-4.6	-6.6	-4.9	2.5
1931-60	0.6	-3.0	-6.0	-4.8	-1.9	2.5
deviation from normal	-3.2	-0.8	+1.4	-1.8	-3.0	0.0

Source: IMGW materials, Končék (1974)

CHARACTERISTICS OF SNOW COVER

In the winter season 1994/95, the snow cover in the Chochołowska Valley occurred during 150 days, from 25 of November to 23 of April. The maximum of snow cover thickness occurred on 14 April (130cm) and 14 January (109 cm). The minimum occurred on 13 December (1 cm), 1 January (7 cm) and 22 February (27 cm). The largest average monthly snow thickness occurred in April (69 cm) and January (47.5 cm). During these two months, the thickness of snow cover was much differentiated (Tab. 4).

Tab. 4. Total density and vertical distribution of snow density (g cm^{-3}) at the sites studied Chochołowska Valley XI'94-IV'95

snow layers	1	2	3	4	5
I	0.20	0.31	0.06	0.22	0.20
II	0.29	0.39	0.30	0.41	0.50
III	0.40	0.41	-	0.39	0.44
IV	0.44	-	-	-	-
total density	0.32	0.37	0.21	0.36	0.42
snow cover thickness (cm)	220	133	25	47	38

In the winter season 1995/96, the permanent snow cover occurred during 157 days, from 3 November to 7 April. The average snow cover thickness reached the largest values in November (44.7 cm) and March (34.7 cm). The maximum of snow cover thickness occurred on 8 November (83 cm) and 3 March (98 cm). The minimum occurred on 24 March (9 cm). In the period from the 15 to 25 January, the snow cover thickness was rather small (12 cm) and permanent.

The results of the investigation show that the snow cover thickness depends on air temperature, snow falls, and also wind velocity and rain falls. The increase of snow cover thickness was always associated with abundant snow precipitation, however it was restrained by average daily air temperatures above zero, even if the snow falls were abundant. Snow subsidence in the conditions of average daily air temperatures below zero, small wind velocities and lack of snow precipitation caused decrease of snow cover thickness. This decrease was less rapid then in the conditions of average daily air temperature above zero. Similar results concerning snow cover dynamics were obtained by Kłapowa (1972), who concluded that the relationship of snow cover increase and amount of precipitation accompanied by other factors (temperature, wind) is not rectilinear. Permanent state of snow cover is associated with dry period and low temperature. The snow cover thickness and its structure depend on climatic-vegetation zones, surface exposition and relief.

PHYSICAL FEATURES OF SNOW COVER

Snow density

The total density is an indicator of the development phase of a snow cover. Generally, during winter, average snow cover density shows permanent increase trend and towards the end of the snow cover occurrence, a small decrease is determined (Kłapowa 1972). Basing on the results of snow density in the Chocholowska Valley it was stated that thickness and time of snow cover occurrence influence the increase of snow density and cause differentiation in vertical distribution of snow density in the profiles (Tab. 4, 5). In the sites studied, the change of snow density was different and depended on the snow cover thickness, local environmental conditions and meteorological factors (Fig. 3a, b). Changes of snow cover were usually not associated with depth and they were irregular. The lowest total densities were recorded during the first measurement series (29, 29 February) and, in case of vertical distribution of density, the lowest values were recorded in the layer I (snow surface). The highest value of total snow density occurred in the second measurement series (15, 16, 17 March) (Tab. 4). In vertical profile, the maximal values were recorded for the deepest, located at the ground surface layers of snow cover (Fig. 3a, b). The lack of snow precipitation caused decrease of snow thickness which resulted in increase of total snow density and densities of individual layers. After snow falls, the snow cover thickness increased but its average total density decreased (fresh snow shows very small density - about 0.08-0.01 g cm^{-3}).

Tab. 5. Total density and vertical distribution of snow density (g cm^{-3}) at the sites studied Chochołowska Valley XI'95-IV'96

snow layers	1			2			3			4			5		
(date)	28.II	16.III	13.IV	29.II	16.III	13.IV	29. II	15.III	13.IV	28.II	15.III	13.IV	29.II	17.III	13.IV
I	0.25	0.26	0.09	0.27	0.26	0.11	0.20	0.25	0.08	0.18	0.38	0.26	0.19	0.22	0.10
II	0.28	0.35	0.32	0.33	0.30	0.44	-	0.28	0.32	0.38	0.45	0.41	0.26	0.31	0.32
III	0.34	0.49	0.32	0.24	0.32	0.27	-	-	-	-	0.66	0.33	-	0.27	0.35
IV	-	0.46	0.39	0.43	0.38	0.50	-	-	-	-	-	-	-	0.30	-
V	-	-	-	-	-	0.42	-	-	-	-	-	-	-	-	-
total density	0.30	0.39	0.33	0.33	0.28	0.37	0.19	0.26	0.25	0.31	0.52	0.34	0.24	0.28	0.30
snow cover thickness (cm)	98	86	88	129	113	124	15	25	21	53	74	52	49	62	65

The measurements of snow density carried out by Kłapowa (1972) confirm the obtained results. The increase of snow total density in winter depends on several factors, such as temperature, time of snow occurrence and solid precipitation. The distribution of density in snow profile is irregular and changeable in time (Kłapowa, 1972). Different results were obtained in case of vertical distribution of density in the snow profile. In the Chocholowska Valley, the highest snow densities occurred in most of the sites studied in the layers situated at the ground surface. In the investigations of Kłapowa (1972), the layers of the highest density were located in the middle part of the profile.

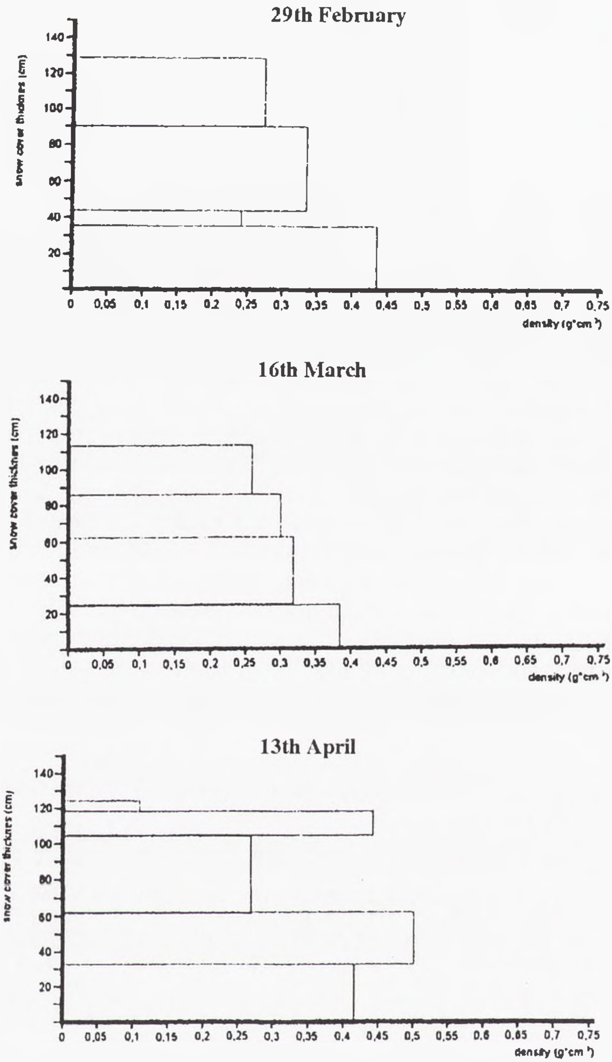


Fig. 3a. Snow density at site 2 (1996).

Snow temperature

Measurements of snow temperature were carried out on several selected days. They give, therefore, only a picture of thermal profile influenced by general weather conditions which occurred on these days in the Chocholowska Valley.

During the measurements on 23 March 1995, the weather was sunny and the air temperature was in the range from 1 to -9.7^{o} C. On the 29 March 1995, the weather changed as Tatras were overwhelmed by cyclonic trough what resulted in cloudy

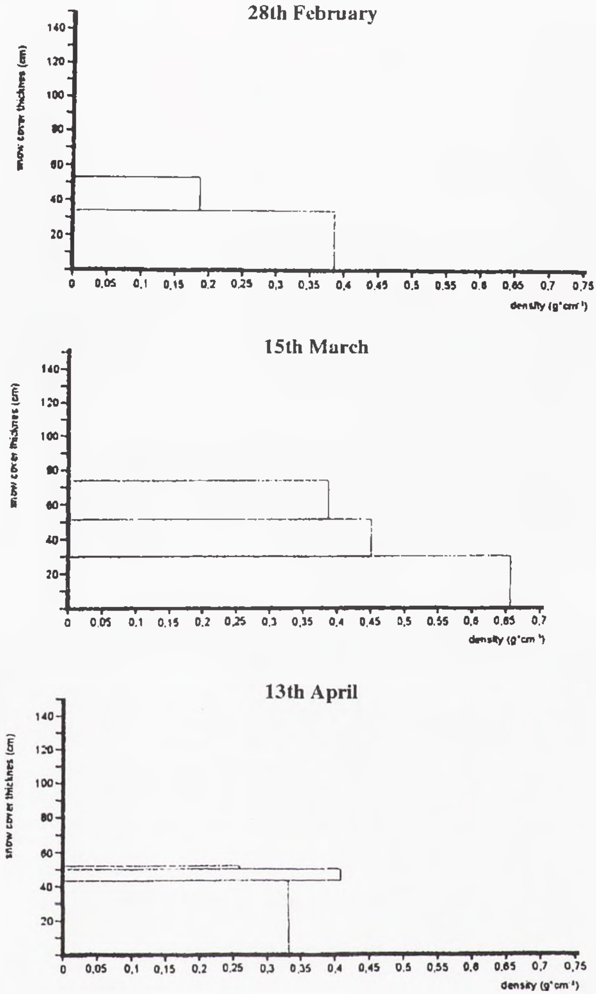


Fig. 3b. Snow density at site 4 (1996).

weather with the air temperature from 5.9 to -10.2° C. The snow temperature in the profiles was in the range from 0 to -1° C. Only the temperature of snow surface decreased below -1° C and reached even -6.9° C in the highest sites.

In 1996, two series of measurements were carried out (28, 19 February and 13 April) during which two totally different weather situations were observed. The weather was sunny on 28 and 29 February. On the first day, Tatras were overwhelmed by high pressure system in polar-continental air mass which came from the south-east. The air temperature was in the range from -3.3 to -5.7° C. On the next day, Tatras were overwhelmed by the wedge of high pressure and the air temperature was in the range from 0 to -8.3° C. The measurements on 28 and 29 February showed occurrence of low temperatures and general increase of snow temperature

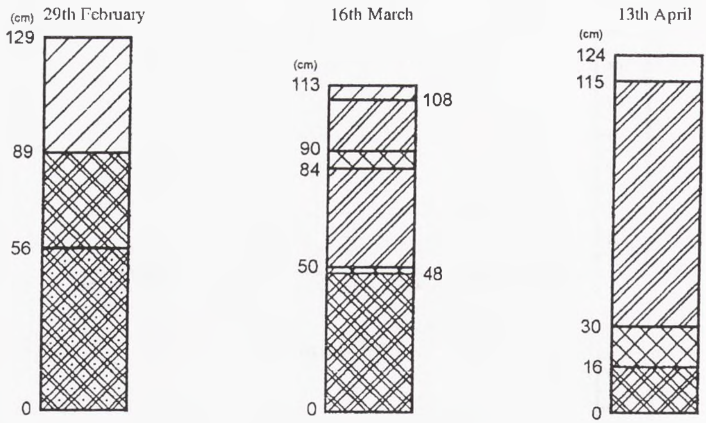


Fig. 4a. Hardness of snow at site 2 (1996).

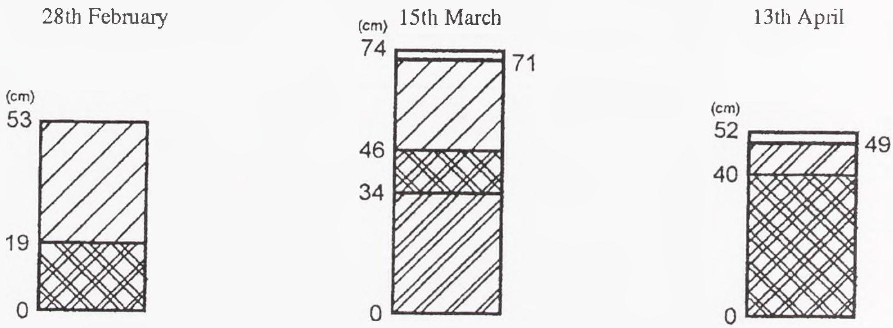


Fig. 4b. Hardness of snow at site 4 (1996).

from the snow surface down towards the ground surface. Two zones were distinguished in the increase of snow temperature. In the first zone, the temperature increased rapidly (large temperature gradient), whereas in the second, this increase was much slower (Fig. 5a). In the zone of large gradients, thermal inversion was observed which resulted from the weather conditions which occurred during the measurements. The zone of large temperature gradients is called an active layer of snow cover and it reacts to daily changes of air temperature (Kłapowa, 1972). Below the active layer, the increase of temperature took place much slower which means that vertical temperature gradient was much smaller, however, as compared to the measurements taken on 13 April 1996, it was quite high. Quite different weather occurred on 13 April. Tatras were overwhelmed then by low pressure system in the air mass which flew from the north-west. During most of the day, the weather was cloudy and it was snowing. The air temperature was in the range from -1.5 to -7.7^{o} C. The snow temperatures were even in vertical profiles (about 0^{o} C) (Fig. 5a, b). Vertical gradients of snow temperature reached small values both in the layer insensitive to weather conditions and in the active layer.

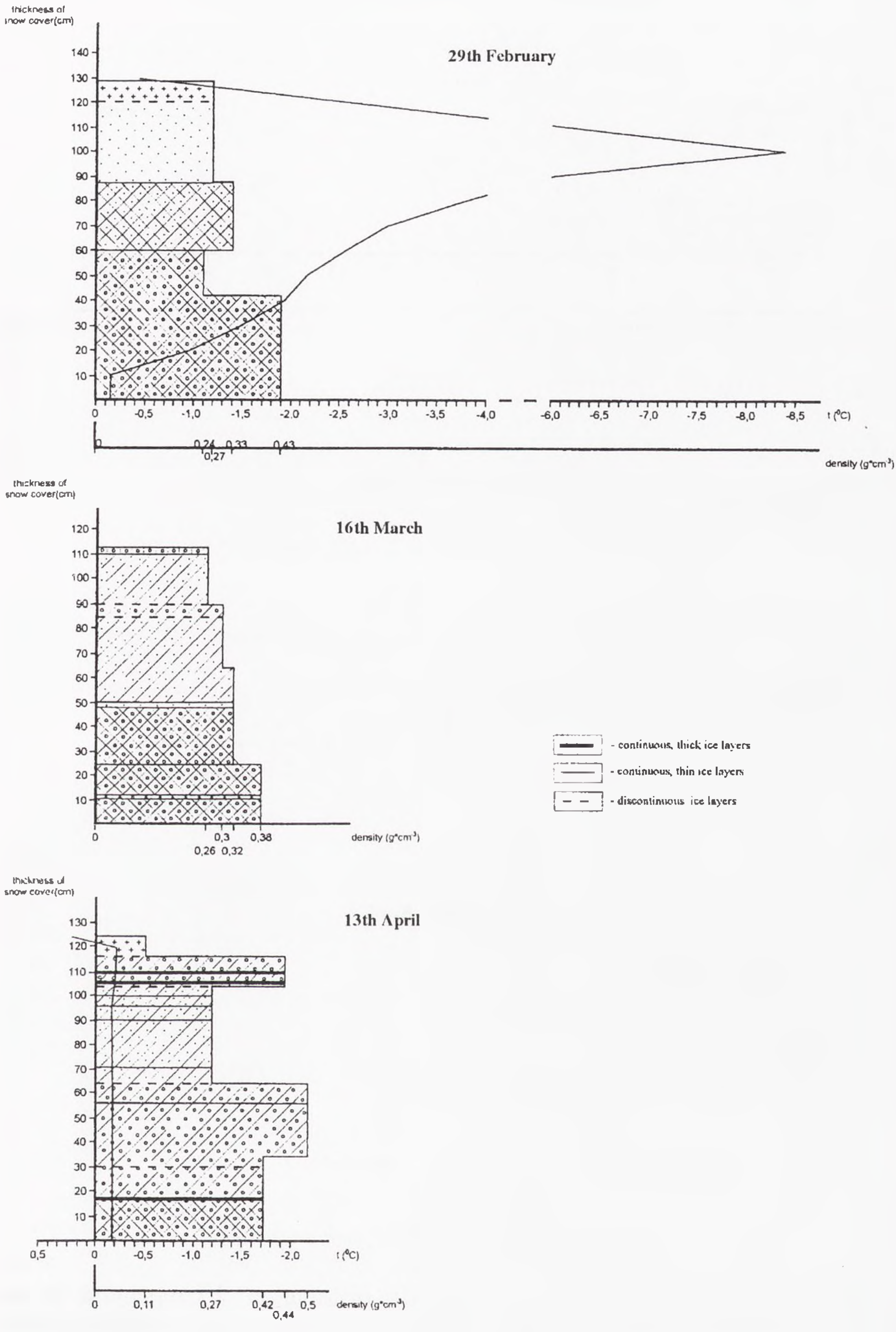


Fig. 5a. Metamorphosis of snow at site 2 (1996).

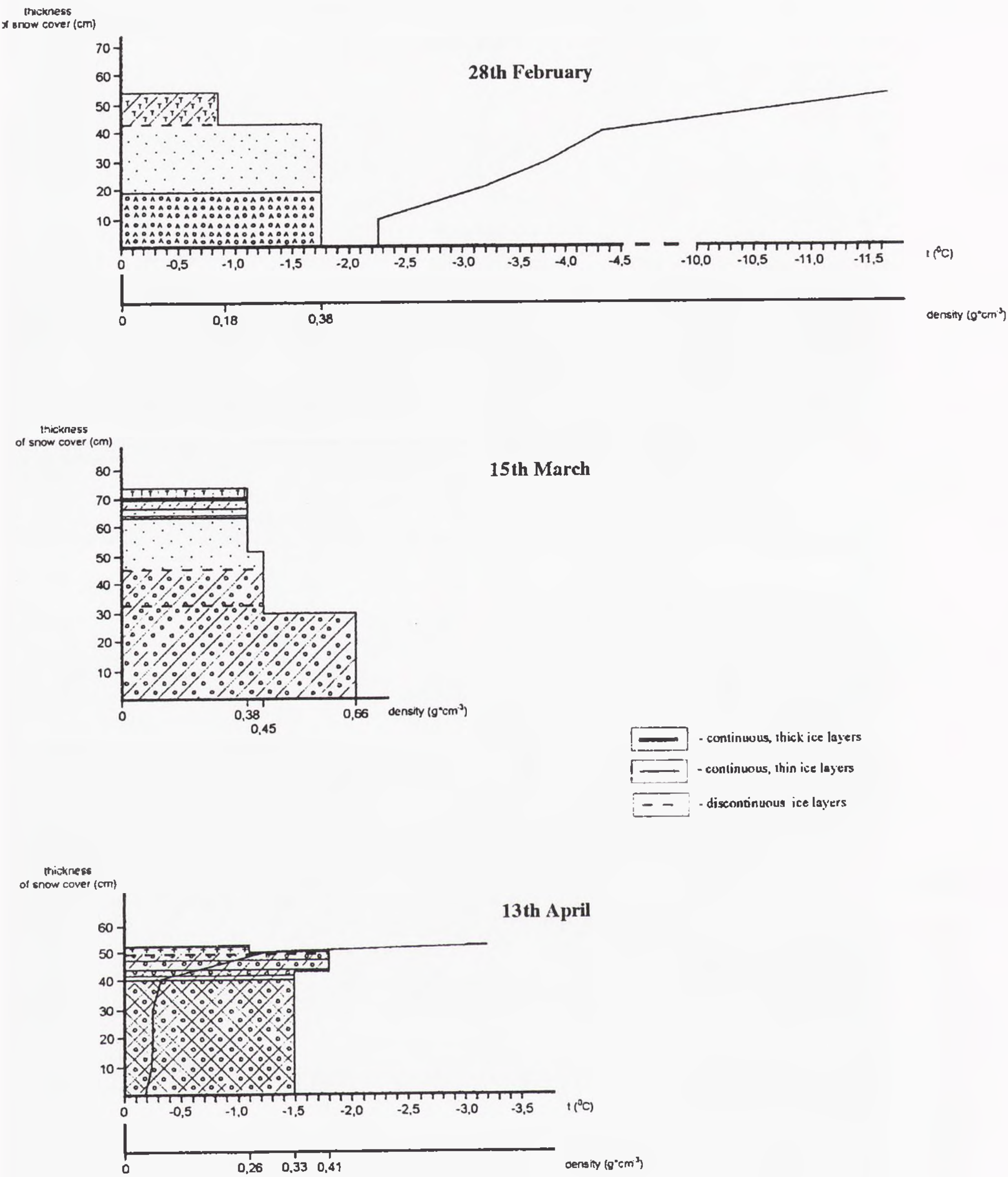


Fig. 5b. Metamorphosis of snow at site 4 (1996).

The results of measurements show that the distribution of temperature in the profile is determined by the thickness of snow cover and weather conditions which occur during measurements (air temperature, cloudiness). Increase of air temperature causes inversion in active layer of snow cover. In contrast, the thicker the snow cover is, the higher the temperatures at the ground surface are. Low air temperature causes decrease of snow temperatures, especially in the profiles of small thickness. In vertical distribution of temperature in the snow profile, two different layers were noticed: a layer of large gradients (active layer) about 15 cm thick and a layer of small gradients. The thickness of active layer depends however on the density and structure of snow. Its detailed determination requires more detailed investigations. In the initial stage of snow cover duration, the snow temperature was low and its gradients obtained large values. In the final stage, the snow temperature was even (about 0^{o} C) and gradient values were small.

Similar results concerning the snow temperature were obtained by Kłapowa (1972) who concluded that snow temperature is differentiated both in the vertical profile (presence of zones of large temperature gradient and occurrence of temperature inversion in the upper part of the snow cover) and during winter (stages of differentiated and even temperature in the vertical profile). She stated also that snow thermal conditions depend on weather conditions (cloudy and sunny days).

Snow hardness

No regularities were observed in the distribution of snow hardness in the profiles. The only recurrent result was that the upper layers (snow surface) always showed the highest hardness (Fig. 4a, b). The hardness of other layers was generally depended on weather conditions of the days preceded the measurement days and it usually was not associated with snow structure.

Snow metamorphosis

The fresh snow consists of different crystals of atmospheric snow. Falling down and accumulating on the ground surface it creates snow cover, in which, permanent evolution takes place according to atmospheric conditions. Direction and velocity of these changes depends also on local environmental conditions (Kłapowa 1980). The process of snow metamorphosis takes place in stages. In the first stage, defined as destructive metamorphism, original snow crystals are destroyed and are transformed into powder. The second stage, defined as constructive metamorphism, takes place when snow cover temperature is differentiated and leads to origin of deep frost hoar (Kłapowa, 1980). Then the crystals, influenced by water, are transformed into coarse-grained snow. This stage is called melt metamorphism (Kłapowa 1980).

Basing on long-lasting nival investigations at Hala Gasienicowa, Kłapowa (1980) distinguished three stages of snow cover metamorphosis. This classification became a model to describe snow metamorphosis in the Chocholowska Valley. The following three stages may be distinguished there:

Stage I. It takes place when the thickness of snow cover grows very slowly. Differentiated thermal gradient is observed in the snow cover but is vertical profile does not show clear differentiation of the layers. The density of snow cover is in the range from 0.21 to 0.30 g cm^{-3} and it shows increasing trend.

Stage II. The thickness of snow cover increases very rapidly and intensive subsidence of snow takes place. This increase of snow cover as well as fluctuation of air temperature cause thermal changes within the snow cover. Short thaws cause development of ice layers which are, in turn, covered by layers of fresh snow. This way considerable differentiation of layers develops within the snow cover. The density of snow profile is in the range from 0.31 to 0.40 g cm^{-3}.

Stage III. It is associated with the decay of snow cover and its subsidence. It takes place when the inner temperature of snow cover shows an even temperature of about 0^{o} C. Presence of free water in the snow cover increases the snow density to 0.41g cm^{-3}, and in extreme cases even to 0.60 g cm^{-3}. When the water from snow flows outside the cover, its density decreases to 0.40 g cm^{-3}.

The analysis of snow metamorphism was based on physical properties of snow cover. Snow density, which is a factor of snow cover transformation played a main role in this determination. Also descriptions and photographs of snow profiles taken during field work were very valuable. At the three sites (1, 2 and 4), the II stage of metamorphosis was observed, the I stage was determined at site 3 and the III stage was observed at site 5. The II stage of metamorphosis was obtained in the sites which showed the thickest snow cover and which were located in the upper parts of the mountains and in the open area. In such sites, metamorphosis developed at moderate rate. The I stage of snow metamorphosis was observed at the site where snow cover thickness was rather small and which was located in the coniferous forest at the much inclined surface. The process of metamorphosis took place at the slowest rate. The III stage of metamorphosis occurred at the site situated at the end of the valley, which was much exposed to meteorological conditions. The fastest rate of metamorphosis at this site was associated with its lowest location among all the sites observed, which , in turn, caused the earliest thawing processes.

It should be also mentioned, that snow metamorphosis did not take place at the same way in the whole profile. In each profile, layers of differentiated physical properties were distinguished. These layers showed different stages of metamorphosis.

In the winter season 1995/96, three series of measurements were carried out. The obtained results generally confirmed the conclusions concerning spatial differentiation of snow metamorphosis which were obtained in the winter season 1994/1995. There were however small differences associated with different weather conditions which prevailed during these two winter seasons. They appeared in slower process of metamorphosis at the sites studied (especially at site 5). The three series of measurement made it possible to make temporal characteristic of snow metamorphosis. Both in the time and spatial process, considerable differences were observed at the sites studied. The most stabile situation was observed at the site 3. During all the measurements, I stage of metamorphosis was observed in the snow profile. Slow process of metamorphosis at this site resulted from its location in the coniferous forest, which is an ideal snow protection and isolator from the influence of atmospheric conditions. Also at the site 2 in the Starorobociaska Valley, the snow cover showed II stage of metamorphosis during all the measurements (Fig. 5a). However, this situations was caused by different factors than at the site 3. The analysis of individual layers in the profile showed increase of their density which is an indicator of metamorphosis progress. The reason of its apparent stability or very slow development were thick layers of fresh snow of small density which decreased the density of the whole profile. As a result, the same stage of metamorphism of the profile occurred despite its progress in the individual layers. A typical process of snow metamorphosis was observed at two sites (1 and 5). At the site 1, the first investigation (28 February) showed the I stage of metamorphosis and the two next investigations (16 March, 13 April) revealed the II stage of metamorphosis. At the site 5, two first measurements (29 February, 17 March) showed the I stage of metamorphosis and the third measurement revealed the II stage of metamorphosis. This shows different rate of transformations, faster at the site 1 where snow cover is thicker, and, slower at the site 5. The fastest and the most complete process of metamorphosis were observed at site 4 in the Polana ChochoÔowska (Fig. 5b). During the first measurement (28 February), the initial phase of the stage II was observed. The second measurement (15 March) gave the advanced III stage of snow metamorphosis and the last measurement (13 April) showed decrease of snow cover metamorphosis. Such situation is normal and it is associated with the snow thawing and outflow of free water from the snow cover.

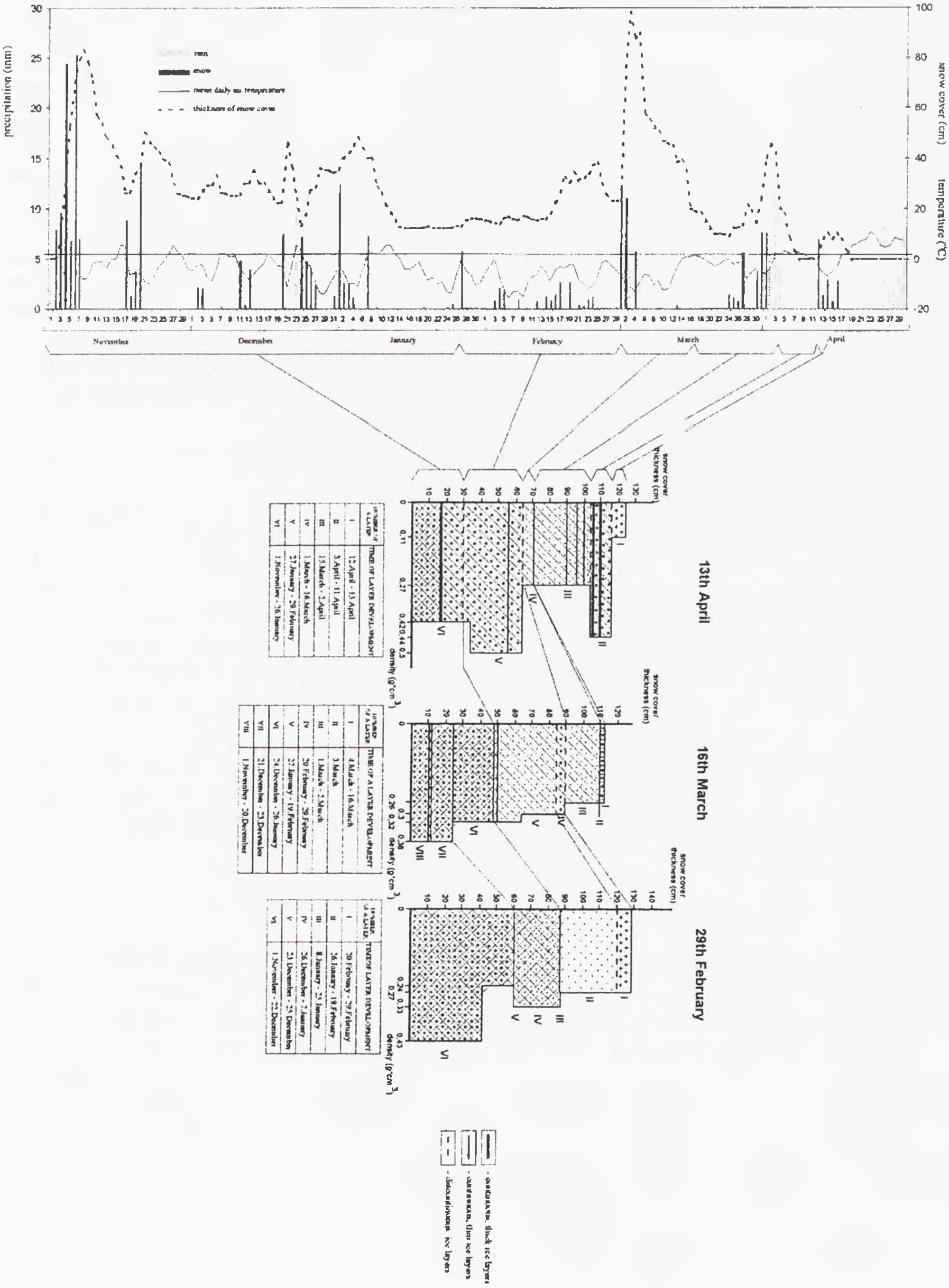
History of snow cover

To complete this paper, the history of development of individual layers of snow in the profile was determined. This was done using meteorological data from the meteorological site in Polana Chochołowska as well as photographs and descriptions of snow profiles. The results of this analysis are not very strict and should be treated as one of many possible scenarios (Fig. 6).

Reconstruction of the snow cover history made it possible to determine the influence of meteorological conditions on the metamorphosis process in the Chocholowska Valley. Among all the factors taken into account (air temperature, precipitation, thickness of snow cover, winds) the most important for the rate of snow transformation were: air temperature, precipitation and snow cover thickness respectively. The influence of wind was very small as all the sites were located below or at the upper limit of forest.

DISCUSIONS AND CONCLUSIONS

The formation of snow cover, its physical properties and process of snow metamorphosis depend on different conditions of the natural environment. Air temperature, precipitation and snow cover thickness respectively were the most important factors which influenced the snow metamorphosis in the Chocholowska Valley. The influence of wind was very small as all the sites were located below the upper limit of forest and wind activity was restrained by plants. The influence of meteorological conditions on snow metamorphosis at each site was assisted or restrained by local environmental conditions of this site. Especially important was the influence of the site neighbourhood determined by occurrence of plants (forest or open area). The location of the sites in the forest (especially coniferous) appeared in very thin snow cover. The forest restrained also considerably the influence of meteorological factors what appeared in snow cover protection. Also the distance from the limit of a dense forest (forest clearing in the bottom or on the slopes of the valley) was very important; the closer to this limit, the thicker the snow cover was. The farther from the dense forest the site was located (open area - large forest clearings in the bottom of the valley), the stronger influence of meteorological conditions on the snow cover was observed. In such sites the process of metamorphosis was faster and, depending



NUMBER OF A LAYER	TIME OF LAYER DEVELOPMENT
I	12 April - 13 April
II	3 April - 11 April
III	15 March - 2 April
IV	1 March - 16 March
V	27 January - 29 February
VI	1 November - 26 January

NUMBER OF A LAYER	TIME OF A LAYER DEVELOPMENT
I	4 March - 16 March
II	3 March
III	1 March - 2 March
IV	20 February - 29 February
V	27 January - 19 February
VI	24 December - 26 January
VII	21 December - 23 December
VIII	1 November - 20 December

NUMBER OF A LAYER	TIME OF LAYER DEVELOPMENT
I	20 February - 29 February
II	26 January - 19 February
III	8 January - 25 January
IV	26 December - 7 January
V	23 December - 25 December
VI	1 November - 22 December

on the thickness of snow cover, more complete (mainly in the layers closer to the ground). The altitude was another important factor which influenced the process of snow metamorphosis in the Chochołowska Valley. The altitude zones are associated with air temperature (decrease with an altitude) and the thickness of snow cover (increase with an altitude). Together with the altitude increase, the rate of snow metamorphosis was smaller. The influence of altitude was especially visible in the last phase of snow cover occurrence, when the melting from the lower parts of the mountains to their upper parts starts. The influence of insolation and surface exposition on snow metamorphosis were not taken into account because of the lack of data. It was possible to obtain data concerning exposition at three measurement sites, however, its influence was mitigated by other factors of local environment.

The results of the investigation on snow metamorphosis in the Chochołowska Valley showed that meteorological conditions (air temperature, precipitation), surrounding of the research sites (type of plants, distance from a dense forest) and the altitude are main factors which influence process of snow metamorphosis.

This paper is a contribution which reveals considerable differentiation of snow metamorphosis in the Tatra Mountains. It is necessary, however, to carry out systematic research and to reactivate permanent station of nival investigation in the Tatra Mountains.

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REFERENCES

CHOMICZ, K. (1960). *Śnieg i lawiny w Tatrach w 1959 r.* Prace PIHM, 58.

CHOMICZ, K. (1963). *Klasyfikacja śniegu i metodyka badań śniegowych w Polsce, Śnieg i lawiny w Tatrach w 1960 r.* Prace PIHM, 71.

GRAY, D. M., MALE, D. H., eds. (1981). *Handbook of snow. Principles, process, management and use.* Toronto (Pergamont Press).

JANIA, J. (1993). *Glacjologia.* Warszawa (PWN).

KŁAPOWA, M. (1972). *Metamorfoza śniegu w zwia1zku z warunkami atmosferycznymi i rzeźba terenu.* Maszynopis.

KŁAPOWA, M. (1980). *Metamorfoza śniegu w zależności od warunków atmosferycznych i rzeźby terenu w Tatrach.* Warszawa (IMGW).

KONČEK, M., ed. (1974). Klíma Tatier. Bratislava (Vydavateľstvo SAV).

NAKAYA, V. (1954). *Snow crystals. Natural and Ortifical.* Cambridge (Harvard University Press).

QUERVAIN, M. R. (1963). On the metamorphism of snow. In Kingery, W. P., ed. *Ice and snow. Properties, processes and applicatias.* Cambridge (MST Press).

TRAFAS, K., ed. (1985). *Atlas TPN.* Zakopane-Kraków (TPN - PTPNoZ).

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POKUS O HODNOTENIE METAMORFÓZY SNEHU V PODMIENKACH CHOCHOŁOVSKEJ DOLINY (ZÁPADNÉ TATRY)

Metamorfóza snehu je jedným z najzaujímavejších problémov súvisiacich so snehovou pokrývkou. V zahraničnej literatúre sa procesmi premeny snehovej pokrývky zaoberá množstvo autorov (napríklad: Gray a Male 1981, Nakaya 1954, Quervain 1963). V Poľsku sa venovali tomuto problému len Kłapowa (1972, 1980) a čiastone Chomicz (1990, 1963). Tento príspevok je pokusom zhodnotiť metamorfózu snehu v závislosti na meteorologických podmienkach a prostredí. Výskum sa robil na piatich miestach Chochołovskej doliny vyznačujúcich sa rôznymi podmienkami prostredia. Prvé merania (28. a 29. marca 1995) mali otestovať metódy a umožniť výber vhodných výskumných lokalít. V zimnej sezóne na prelome rokov 1995 a 1996 (28. a 29. februára 1995, 15. a l6 marca, 14. apríla) sa urobili tri série meraní. Sledovali sa nasledujúce parametre: teplota snehovej pokrývky vo vertikálnom profile (každých 10 cm), pričom sa použil odporový teplomer, tvrdosť snehu s použitím terénnych testov, celková hustota a hustota jednotlivých vrstiev kalibrovaním váhy snehu. Hodnotenie metamorfózy snehu sa zakladalo na výsledkoch meraní fyzikálnych parametrov snehu a opise s fotografiami snehových profilov a snehových kryštálikov. Pri terénnych pozorovaniach použili autori Chomiczovu (1963) klasifikáciu snehu.

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