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L.A. Kanayev and N.K. Taipayeva

May 1978

CORPS OF ENGINEERS, U.S. ARMY
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In this work an attempt is made to summarize the results of observations of the snow layer stratigraphy in different regions of the Central Asian Mountains for the purpose of establishing basic trends of its evolution. Descriptions of the stratigraphy of the snow layer cited in different regions of the mountains of Central Asia in 1959 - 1970 on 54 snow-measuring routes (at the end of each Winter month) and at 12 specialized avalanche stations or SLS (every ten days, and in certain cases daily) were used for the analysis. The

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PROCESSES OF TRANSFORMATION OF THE SNOW LAYER IN CENTRAL ASIAN MOUNTAINS

By: L. A. Kanayev, N. K. Tupayeva

The mountains of Central Asia cover an extensive territory whose natural conditions are significantly different. Transformations of the snow layer in different regions of Central Asia cannot be identical. M. P. Shcherbakov (17) was the first to point out characteristic differences in processes of snow recrystallization for regions of the inner Tyan'-Shan' and its peripheral ridges, but there is no definitive reference on the Central Asian territory relevant to this question and one only has regional articles (E. B. Krasnosel'skiy (12), I. V. Severskiy (16), and L. A. Kanayev (9)).

In this work an attempt is made to summarize the results of observations of the snow layer stratigraphy in different regions of the Central Asian Mountains for the purpose of establishing basic trends of its evolution. Descriptions of the stratigraphy of the snow layer cited in different regions of the mountains of Central Asia in 1959 - 1970 on 54 snow-measuring routes (at the end of each Winter month) and at 12 specialized avalanche stations or SLS (every ten days, and in certain cases daily) were used for the analysis. The territorial distribution of the observation posts is shown in Table 1.

It must be agreed that the utilized materials required a strictly critical control in connection with the fact that the structuro-lithological method of describing the stratigraphy recommended by the manuals (14, 15), only makes it possible to note the most general qualitative differences in the snow layer structure. Therefore, cases are frequent when two persons describe the same stratum differently. The quality of the observations is still worse on the snow-measuring routes due to the frequent change of measuring personnel and their poor qualifications.

Four interdependent systems of the snow cover were identified in the investigations of E. G. Kolomyts (10): the class of crystal forms (F), the snow horizon (SG), the snow layer (ST) and the snow cover (SP). At present, a study of the snow cover is practically being made only at the SG level. At this level, as was demonstrated in a work (7), the determination of stratigraphy is significantly hindered by the objective spatial changeability of the thickness of layers upon the transition from one point of observations in the boreholes to another. It is obvious that the character of snow cover stratigraphy is complicated in each mountain basin by the altitude-expositional differences as well as by the wind redistribution of the snow layer. Therefore, the areas of the snow-measuring posts at which observations of the stratigraphy were made were chosen on horizontal open areas where the expositional differences are smoothed-out.

It is interesting to note that at the Dukant SLS, during one of the Winters, an attempt was made to follow the changes in stratigraphy of the snow layer on specially prepared horizontal areas of slopes having different orientation (southeast and northeast). It proved that snow transformation in these areas occurs similarly, i.e., the expositional differences of the slopes did not have an essential effect on them (Figure 1).

Таблица 1

1 **Характеристика пунктов наблюдений**

	Название бассейна, в котором проводились наблюдения 2	3 Период наблюдений	4 Количество снегопунктов	5 Высотная зона, охваченная наблюдениями
6	**Казахстан**			
10	Малая Алмаатинка	1959—1970	34	1200—3650
11	Мерке	1964—1970	17	1200—3370
12	Балдыбрек	1959—1970	19	1040—2600
13	Баянкол	1964—1970	15	2000—3000
7	**Киргизия**			
14	Алаарча	1959—1970	14	1820—2715
15	Чонкемин	1959—1970	19	1840—3060
16	Джергалан	1959—1970	15	2280—3190
17	Карабалты	1959—1970	16	1450—3380
18	Гавасай	1959—1970	31	1474—2860
19	Карадарья	1959—1970	16	2158—2970
20	Каракол	1959—1963	15	2790—3335
21	Ашукошой	1959—1970	17	2650—3365
22	Чаткал	1959—1970	24	1700—2160
23	Падшаата	1959—1970	29	1360—2190
24	Афлатун	1959—1970	14	1020—2600
25	Акбура	1959—1970	9	2340—3200
26	Чонкызылсу	1959—1970	1	3400—3500
27	Атбаши	1960—1970	14	2670—3200
28	Чичкан	1960—1970	27	1380—3280
29	Сарыджаз	1961—1970	18	2740—3390
30	Сусамыр	1962—1970	5	2170—3400
31	Джаманты	1964—1969	11	2760—3115
32	Джаптык	1964—1970	8	3000—3400
33	Бешташ	1965—1970	15	1840—3380
34	Сусамыр, Чичкан (СЛС Алабель)	1960—1970	29	2400—4000
35	Кокомерен (СЛС Ат-Ойнок)	1959—1970	16	1500—2940
36	Сусамыр, Чичкан (СЛС Итагар)	1965—1970	20	1470—3670
37	Тургень-Аксу, Сарыджаз (СЛС Чонашу)	1968—1970	15	2700—3380
38	М. Долен (СЛС Тюя-Ашу, южная)	1959—1970	9	2800—3680
39	Сев. Долен (СЛС Тюя-Ашу, северная)	1959—1970	9	2600—3600
8	**Узбекистан**			
40	Кашкадарья	1959—1970	21	1390—2460
41	Гузардарья	1959—1970	14	1700—3110
42	Тупаланг	1959—1970	11	1020—2610
43	Санзар-Заамин	1959—1970	12	1520—2980
44	Наугарзан	1960—1970	11	1100—2150
45	Ангрен-Арашан	1960—1970	8	1900—2755
46	Кызылча	1960—1970	28	1320—2580
47	Чадак	1959—1966	12	2260—3080
48	Пскем	1959—1970	13	1250—2400
49	Ойганинг	1962—1970	10	2070—2750
50	Сох	1964—1970	9	1680—3000
51	Майлису	1964—1970	6	1200—2100
52	Сангардак	1959—1970	10	1320—2200
53	Шерабад	1959—1967	10	1245—3000
54	Ахангаран (СЛС Дукант)	1959—1970	3	2000—2200
55	Ахангаран (СЛС Кызылча)	1959—1970	4	2100—2180
56	Ахангаран (СЛС Наугарзан)	1959—1970	5	1760—2010
57	Пскем (СЛС Ойганинг)	1966—1970	3	2150
58	Кашкадарья (СЛС Ледник Северцова)	1965—1970	3	2780—2800
9	**Таджикистан**			
59	Магиан	1959—1970	9	1640—2840
60	Сарытаг	1959—1970	6	2400—2890
61	Ягноб	1959—1970	14	1980—2850
62	Зеравшан	1959—1970	28	2320—3160
63	Варзоб	1959—1966	3	1520—2200
64	Сарбог	1959—1964	13	1200—2440
65	Обихингоу	1959—1970	19	1340—2660
66	Кызылсу (Кулябская)	1959—1964	10	920—2100
67	Яхсу	1959—1970	10	1460—2540
68	Ванч	1959—1966	13	1960—2660
69	Гунт	1959—1970	12	2700—3960
70	Каттамаржанай	1962—1970	6	3300—3980
71	Каратаг	1963—1970	11	1040—2480
72	Сарыоб	1963—1970	7	1780—3140
73	Муксу (Ледник Федченко)	1959—1970	3	3920—4160
74	Варзоб (СЛС Харамкуль)	1964—1970	2	2826

Key for Table 1:

1 - Table 1. Characteristics of the observation posts.
2 - name of basin in which observations were made
3 - period of observations
4 - number of snow posts
5 - elevation zone encompassed by observations
6 - Kazakhstan
7 - Kirgiziya
8 - Usbekistan
9 - Tadzhikistan
10 - Malaya Almaatinka
11 - Merke
12 - Baldybrek
13 - Bayankol
14 - Alaarcha
15 - Chonkemin
16 - Dzhergalan
17 - Karabalty
18 - Gavasay
19 - Karadar'ya
20 - Karakol
21 - Ashukoshoy
22 - Chatkal
23 - Padshaata
24 - Aflatun
25 - Akbura
26 - Chonkyzylsu
27 - Atbashi
28 - Chichkan
29 - Sarydzhaz
30 - Susamyr
31 - Dzhamanty
32 - Dzhaptyk
33 - Beshtash
34 - Susamyr, Chichkan (SLS Alabel')
35 - Kokomeren (SLS At-Oynok)
36 - Susamyr, Chichkan (SLS Itagar)
37 - Turgen'-Aksu, Sarydzhaz (SLS Chonashu)
38 - M. Dolen (SLS Tyuya-yuzhnaya)
39 - Sev. Dolen (SLS Tyuya-Ashu, severnaya)
40 - Kashkadar'ya
41 - Guzardar'ya
42 - Tupalang
43 - Sanzar-Zaamin
44 - Naugarzan
45 - Angren-Arashan
46 - Kyzylcha
47 - Chadak
48 - Pskem
49 - Oygaing
50 - Cokh

continuation of key for Table 1:

51 - Maylisu
52 - Sangardak
53 - Sherabad
54 - Akahngaran (SLS Dukant)
55 - Akhangaran (SLS Kyzylcha)
56 - Akahngaran (SLS Naugarzan)
57 - Pskem (SLS Oygaing)
58 - Kashkadar'ya (SLS Lednik Severtsova)
59 - Magian
60 - Sarytag
61 - Yagnob
62 - Zeravshan
63 - Varzob
64 - Sarbog
65 - Obikhingou
66 - Kyzylsu (Kulyabskaya)
67 - Yakhsu
68 - Vanch
69 - Gunt
70 - Kattamarzhanay
71 - Karatag
72 - Saryob
73 - Muksu (Lednik Fedchenko)
74 - Varzob (SLS Kharamkul')

The character of transformation of the snow layer in regions with active wind redistribution of the snow differs by a significantly greater spatial instability and its study requires the organization of special investigations.

The single method of describing stratigraphy and measuring thickness is to compare the snow cover in different regions, identifying differences in the horizon structure. It was quite obviously confirmed that the nature of transformation of the snow layer significantly depends on the overall thickness of the snow cover, which changes strongly in different regions of Central Asia. Therefore, for the purpose of formalizing the description of the snow transformation process in different regions and during different Winters, a certain index of disintegration J_p was calculated. This index is the ratio of the layer of deep rime ice h_i or the layer which contains crystals of deep rime ice[1] to the total thickness of the layer of snow H_{tot} at a given moment in time.

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[1] According to G. Seligman (18), deep rime ice is not a homogeneous formation and is present in some amount in the crystallized form in practically any snow horizon which has reached the stage of structural metamorphism. Despite these assertions, most investigators consider only the skeletal forms of crystals to be deep rime ice. These are hollow prisms, rectangles and pyramids. All of the other crystalline forms are included in granular snow. This is reflected in manuals published by the Hydrometeorological Service of the USSR (14, 15). All of the materials the authors analyzed include definitions of deep rime ice in accordance with these manuals, but practically speaking this contains no great error, for it is in fact the horizons with such crystals which are the least stable and are of greatest interest for studying the conditions of avalanche formation.

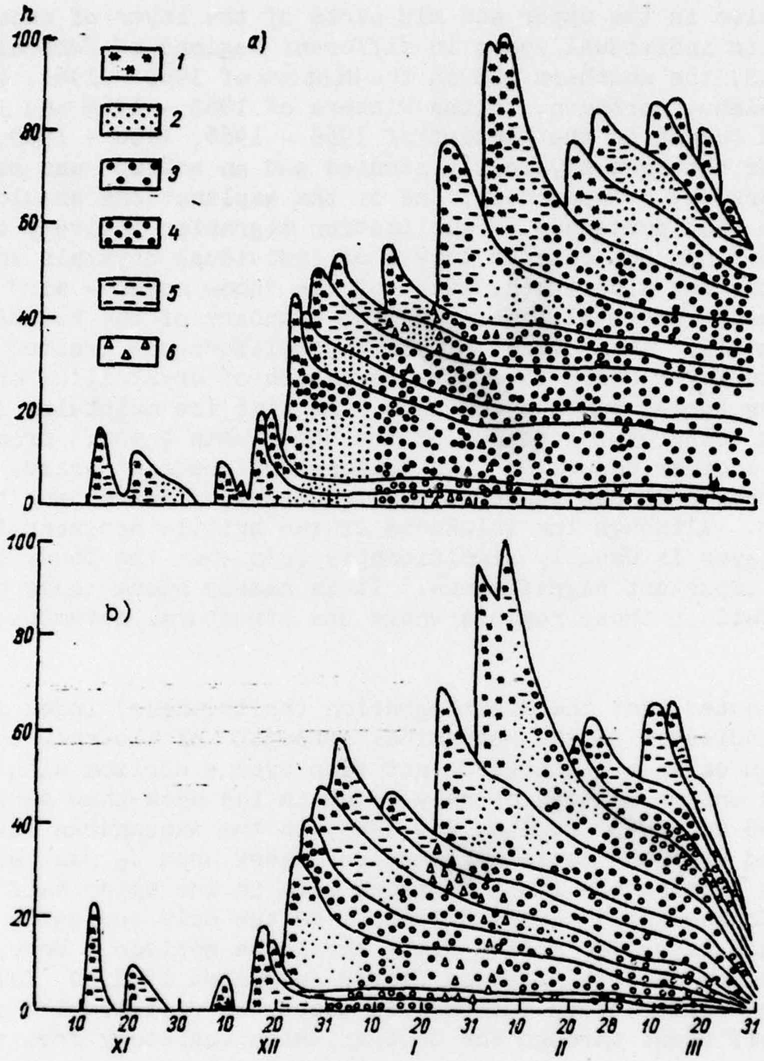

Figure 1. The temporal stratigraphic profile of the snow cover in the Winter of 1969 - 1970 on areas with a northern (a) and southern (b) exposure. 1 - freshly fallen snow; 2 - finely granular snow; 3 - moderately granular snow; 4 - large granular snow; 5 - wind stratification; 6 - deep icing.

It is obvious that during active sublimative recrystallization, which occurs most energetically at high thermal gradients in the snow layer, J_p will increase because of the increase in the thickness of the layer of deep rime ice. Of course, following heavy snowfalls this coefficient sharply diminishes, but in those regions of Central Asia where one observes the thickest snowfalls which yield an increment in excess of 30 - 40 cm, sublimational disintegration is extremely rarely observed in general - in years with a reduced snowfall and negative temperature anomalies.

According to a work (11), the layers of deep rime ice can form not only in the soil, but also in the upper and mid parts of the layer of snow, which has been observed in individual years in different regions of Central Asia (the Tyuya-Ashu SLS, the southern SLS in the Winters of 1960 - 1961, 1965 - - 1966, the Tyuya-Ashu, northern, in the Winters of 1963 - 1964 and 1964 - 1965, Kyzylcha and Dukant in the Winters of 1965 - 1966, 1968 - 1969, etc.). This phenomenon has not been physically studied and an attempt was made to explain it in a work (9). Apparently, one of the explanations should be sought in the fact that processes of sublimation migration actively occur under certain conditions not only at levels of individual crystals and layers of the snow stratum, but also at the level of the "snow cover - air" system. This causes increased recrystallization on the boundary of the two heterogeneous physical media. In a number of cases conditions are created on the surface of the snow layer which favor the formation of crystalline or granular rime ice. In being buried beneath new snow, the rime ice maintains its brittle structure. During temperature changes of the snow, when a shift from one snow structure to another occurs, a high temperature gradient arises whose existence for several days can cause strong transport of matter and the formation of a brittle layer. Although the thickness of the brittle horizons in the upper part of the snow layer is usually significantly less than the lower one, a study of its nature has important significance. It is namely along these horizons that avalanches often fall in those regions where the structural metamorphism is inhibited.

It should be noted that the disintegration (brittleness) index is only the most approximate indicator of the mechanical strength of the snow cover on slopes. In certain cases avalanches do not slip over a horizon with a high coefficient for an entire Winter, or only occur in the snow thaw period. In the Winters of 1965 and 1966 and 1968 and 1969, in the Akhangaran River basin, avalanches occurred over the loose sublimation layers when J_p was less than 0.05. During this process the loose horizons were in the upper half of the snow layer (9). Consequently, index J_p cannot be the only indicator of the capacity of the snow layer for motion along the loose horizon. Here, obviously, it is valid to use the destratification factor suggested by E. G. Kolomyts (10). Unfortunately, one cannot obtain information about the distribution of the values of this coefficient through the Central Asian territory from the materials which were used.

On the whole, the observational material of stratigraphy on the snow survey routes makes it possible to judge both on the leading trends of recrystallization of the snow layer in different regions of Central Asia and their temporal repetition. For these purposes, disintegration indices were calculated for all areas in which the stratigraphy had been determined at the end of December, January, February and March. These indices served as the basis for monthly maps of the predominant process of snow layer transformation. The significant disintegration indices have the highest repetition level (significant ones are those different from zero) beginning at the end of January. In separate years with a thin snow cover and a cold initial period of the Winter, the formation of thick horizons of deep rime ice is already observed at the end of December and even in November.

The maps drawn for the end of each Winter month were analyzed in connection with characteristics of weather of each Winter month, which yielded the following basic results.

One can identify three basic zones in the territory of Central Asia which are distinguished by a predominant tendency in the process of transformation of the snow layer (Figure 2).

The first zone, which includes the greater part of the territory of the internal and northern Tyan'-Shan', characterized by the constant development of processes of structural metamorphism, which lead to the formation of broken horizons. In separate years, even within the confines of this zone, structural metamorphism can be diminished or absent totally (the Winter of 1959 - 60). Within this same zone one can include the Zeravshan River basin, where the disintegration coefficients in all years of observations are different than zero. But without additional analysis or special observations, the latter conclusion seems premature to us.

Within limits of the second zone, which includes the basins of the rivers of Western Tyan'-Shan', Karadar'ya, the Alaysk and Turkestan ridges, which face the Fergana valley, one notes inconstancy of the predominant trend of metamorphism. Structural metamorphism over the years of observations in this zone has been noted for 2 - 5 years.

The third zone, which includes the western Pamir, the Gissarskiy and Zeravshanskiy ridges (the southern slope) and their outcroppings is characterized by the fact that structural metamorphism does not practically appear within its limits.

For the territory of Kirgiziya, the obtained conclusions confirm investigations carried out earlier (17). It is understandable that structural metamorphism appears most actively in the regions with little snow and strong rime ice (heavy frosts) (inner Kirgiziya). In regions with a heavy snow cover and frequent and deep thaws (the western Pamir, the Gissarskiy ridge), the development of the snow layer proceeds according to the destructive metamorphism type. Only in certain exceptionally snow-sparse years (the Winters of 1969 - 70 and 1973 - 74) are processes of sublimation recrystallization which lead to structural metamorphism activated in this zone as well.

Within the second zone, where an inconstant character of transformation of the snow layer predominates, the relationship of processes of snow layer transformation with weather conditions of the initial period of Winter is confirmed (8). In the territory of the remaining zones with a stable tendency of snow layer evolution, this conclusion is subject to an additional verification.

During the course of Winter, as the materials of snow-measuring surveys indicate, values of the disintegration index usually diminish. On the one hand, this is explained by the culmination of processes of structural metamorphism for 90 - 120 days (10); on the other hand it is explained by an increase in the total thickness of the snow in Winter until March or April (until May in the high mountains).

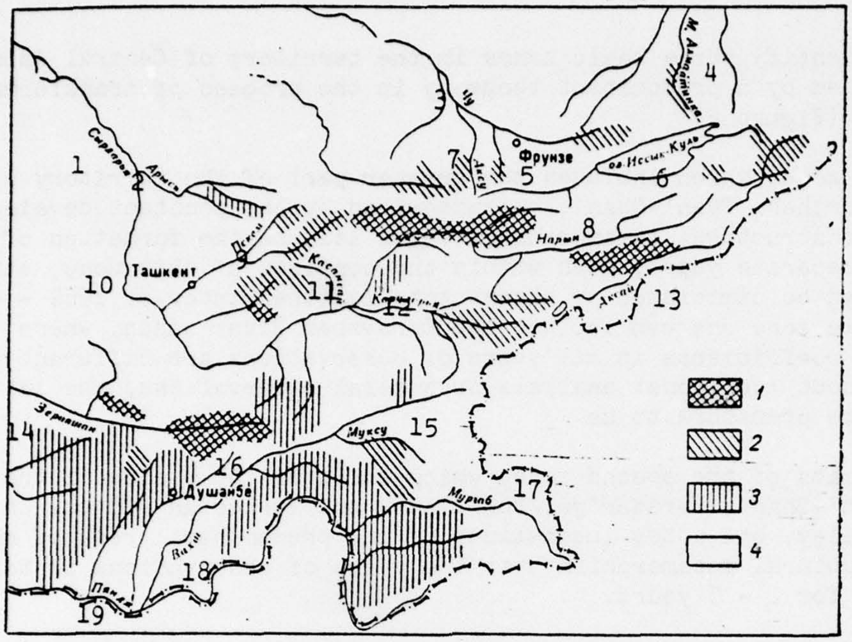

Figure 2. Map of the predominant processes of transformation of the snow layer through the territory of Central Asia in the 1959 - 1970 period. 1 - regions with predominant development of a snow layer of the disintegration type; 2 - regions with an unstable developmental character of the snow layer; 3 - regions with predominant development of a snow layer according to the packing type; 4 - regions where processes of transformation of the snow layer have not been studied.

Key:

1 - Syrdar'ya
2 - Arys'
3 - Chu
4 - M Alma atinka
5 - Frunze
6 - Issyk-Kul' Lake
7 - Aksu
8 - Naryn
9 - Pskem
10 - Tashkent
11 - Kasansay
12 - Karadar'ya
13 - Aksay
14 - Zeravshan
15 - Muksu
16 - Dushanbe
17 - Murgab
18 - Vakhsh
19 - Pyandzh

Wind redistribution of snow in regions where it is observed leads to nonzonality in the overall picture of distribution of the snow layer transformation processes. Thus, in the Naugarzhan River basin (western Tyan'-Shan') and in the basins of other rivers of the northern slope of the Kuraminskiy ridge, active wind activity causes intensive sublimation disintegration on the windward slopes. On the other hand, in the Alay valley, despite heavy freezes and a thin snow cover, structural metamorphism is not practically observed. Precisely the same picture is noted in the basins of the eastern Pamir (the Markansu River, Lake Karakul', the Murgab River, the Alichur River) according to the data of expeditionary, episodical observations. In these areas the winds are exceptionally strong. It is difficult to explain these phenomena without additional special observations.

More intensive manifestation of processes of destruction of the snow layer are characteristic for individual basins of Central Asia (Sarydzhaz River, Chonkemin River, the rivers of the Issyk-Kul'sk depression, etc.). This is predetermined by the small amount of precipitation and the low atmospheric temperatures of long duration. However, such a judgement is only a qualitative one although characteristics of weather of each Winter and even each month of the Winter generally permit one to judge the monthly changes in the character of recrystallization processes in the snow layer with a good foundation. Thus, for example, in the Winter of 1959 - 60, following intensive influxes of cold from the north and northwest, in the beginning of the Winter an early persistent snow cover formed over a large part of the mountain territory of Central Asia. In the basins of the Arysi, Naryna rivers and Issyk-Kul' Lake, the total precipitation significantly exceeded the norm. In the basin of the Zeravshan River it was somewhat lower than the norm, and was nearly normal throughout the rest of the territory. A heavy accumulation of snow led to a reduction in temperature gradients in the snow cover, as a consequence of which the horizons of deep rime ice had not formed by January. Active cyclone activity was observed in January and February. This occurred against a relatively warm temperature background. All of this facilitated the fact that processes of transformation of the snow layer after the packing type predominated. Only in the river Zeravshan basin, where the snow cover had not yet reached its normal level at the beginning of the Winter, did loose horizons form. The same thing was noted in certain basins of the rivers of internal Kirgiziya, where the processes of disintegration are predominant in all years.

In the Winter of 1964 - 1965 the stable snow cover formed late, only in December. Cold incursions during the month were everywhere due to the low air temperature background (1 - 3°C below the normal). The thin snow cover and low air temperatures led to a situation such that temperature gradients of the air were high in a number of basins and the active transport of water vapor from the near-soil horizons began, and, in association with this, a horizon of deep rime ice formed in the basins of western Tyan'-Shan' and in internal Kirgiziya. January itself proved to be very warm and the air temperatures were significantly above normal. The amount of precipitation was near the normal value and therefore conditions did not exist for the subsequent deepening of the process of deep rime ice formation. In February the weather was unstable with frequent cold incursions and active wave activity. The air temperature was nearly normal, while precipitation was very mottled in distribution: there was less than normal precipitation throughout the Naryn basin, and nearly normal precipitation throughout the other basins. The February weather introduced no changes in the spatial distribution of snow layer transformations. March was characterized by a nearly normal air temperature, but less than normal precipitation fell in most basins, which, however, had no effect on the snow stratigraphy change.

Similar qualitative relationships between weather conditions and the evolutionary character of the snow layer are also traced in the other years of observations. Despite obvious shortcomings in the quality of the original material, the authors made an attempt to describe the character of recrystallization processes with the use of stricter quantitative indicators.

For these purposes, the disintegration index was determined by means of a multidimensional statistical analysis. The authors had at their disposal material only from the ten-year observations at the snow avalanche stations of Kirgiziya and Uzbekistan, i.e., data for reliable statistical calculations were insufficient.

The methods of linear set (factorial) regression employed in problems of hydrometeorology have been described in many studies (2, 3, 4) and are not given here. For our purposes, the thickness of the loose layer H_i at the end of a Winter month correlated with the following characteristics: T_x - the lying time of a stable snow cover, Σh - the sum of snow heights, h - the mean snow height, h_{max} - maximum height, h_{min} - minimum and mean air temperatures, N_o - number of days with thaws, N_x - number of snowfalls, Σt_{cp} - total of mean daily air temperatures. All characteristics were determined for the period of stable snow cover from the data of its formation to a date with the determination of h_i at the end of December, January, February and March.

Using a program written by A. M. Ovchinnikov (SARNIGMI) and with his kind assistance, a computer was used to calculate the set regression equations which describe the changes of the dependent variable h_i for each snow avalanche station at the end of December, January, February, and March. As a measure of the "success" of the calculated equations, R was used. R is a composite coefficient of correlation of the given equation, the relative mean square error of the regression equation M_0 and the "explicable" proportion of dispersion of the dependent variable, calculated as the square of the composite correlation coefficient. In this case the value of R was used for a basic estimate of the quality of the regression equation, M_o was taken as an estimate of the accuracy and effectiveness of prediction in the hydrological forecasts, R^2 was calculated from the relationship $R^2 = \frac{D_{\hat{y}}}{D_y}$, where D_y is the dispersion of actually observed values of h_i, while $D_{\hat{y}}$ is the dispersion of the calculated values.

It is obvious that all of the predictors used in regression analysis do not have identical weight, and therefore that the aid of a method called the "seeding" method, the most informative predictor is initially chosen on the computer. The second one to it is selected so that this pair in the regression equation has the highest composite correlation coefficient. To this pair one adds a third predictor, etc., in order to achieve the best R. If the choice of the initial predictors is made on the basis of physical concepts about the nature of the predicted component, then the seeding method produces good results.

Estimates of the contributions of each of the predictors to the composite correlation coefficient are an important task of set regression. These estimates make it possible to determine the most informative predictors and to limit the seeding to the optimum quantitative steps. These estimates were made according to the G. A. Alekseyev method (1).

The results of the calculations are not given in the work, since the insignificant volume of statistical selections was apparently due to the fact that regression equations are not stable either for the individual snow avalanche stations or from month to month. Certain exceptions are the equations of regression obtained for the Kyzyloch SLS, where the most informative predictors for all of the Winter months are the duration of the period of stable lie of the snow cover to a certain date and the number of days with thaws. The obtained results of the calculations basically proved useful for confirming the general physical prerequisites accepted during the initial determination of the predictors. The sign with which any particular symbol enters the regression equation for any snow avalanche station corresponds to the physical meaning which it carries in an absolute majority of the cases.

Thus, h_i is directly proportional to the duration of lie of the stable snow cover T_x. In all regression equations, the coefficient with which this value enters the equations is positive. With an increase in the total height of snow the thickness h_i decreases, which is reflected by a negative sign of the coefficients in the regression equations. h_i for the Kyzyloch SLS correlates with the number of days with thaws. h_i decreases with the increase in N_o, which is reflected by the regression equation, etc.

In general, the limited amount of material forces one to approach the obtained results with great caution, despite the high statistical indices of the regression equations. An attempt to increase the volume of the selections by combining the data regarding h_i at the different snow avalanche stations into a single statistical collection is incorrect, since a comparison of the average and standards of deviations of values of h_i with the aid of the statistical criteria even for the neighboring stations of Dukant and Kyzyloch indicates their significant differences.

The stability of the predictors which determine the nature of the dependent variable for the Kyzylcha River basin with values of M_o that are small in comparison with those of the other snow avalanche stations, made it possible to try to test the calculations for this region on an independent material for three of the last Winters. The thickness of the layer of deep rime ice was determined according to the regressions obtained by the equations for the end of January, February, and March and the results were compared with the actual observations (Table 2).

Table 2

A Comparison of the Calculated and Actual Values of the Thickness of Horizons with Deep Rime Ice Based on the Material of the Winters 1970 - 71, 1971 - 72, and 1972 - 73

Thickness of Horizons with Deep Rime Ice	1970 - 71			1971 - 72		1972 - 73		
	I	II	III	I	II	I	II	III
Actual	25	24	0	15	14	34	29	0
Calculated	25	39	48	10	10	27	33	51

In January, the similarity of the calculated value and the actual one is greatest, the deviation increases in February, while in March one cannot discuss a similarity of the values. This is due to the fact that in March, in the medium mountainous zone of western Tyan'-Shan', the processes of structural metamorphism are not observed, temperature gradients in the snow layer significantly decrease, and the regelation processes increase.

Evidently, the essence of the fine physical processes which occur in the snow is not detected by the data of statistical analysis. The process of structural metamorphism, according to E. G. Kolomyts (10), should culminate in 90 to 120 days, but under the conditions of Central Asia, the Caucasus, the Carpathians, etc., it can more likely terminate earlier due to the thaws which lead to the appearance of water in the liquid phase, to processes of regelation, sharp settling of the snow cover as the result of the melting of crystals at contacts and of destruction of the primary snow structure. Evidently, in this association one also finds the process of regressive metamorphism under conditions of Central Asia in a limited way.

During the analysis of the materials of observations at snow observation posts located in different elevation zones within limits of a single river basin, such as, for example, basins of the Chichkan, Susamyr, and other rivers, the question of the relationship of h_i with the absolute elevation was examined.

It should only be pointed out that in connection with the differences in the times of formation of the snow cover in the upper zones of the mountain basin, all stages of the processes of its transformation also have a different duration. Nevertheless, in regions with the predominant development of processes of sublimation disintegration, the standard information of the snow-measuring routes and snow avalanche stations does not make it possible to establish any principles in the change of h_i with absolute elevation.

In regions with an unstable type of snow layer evolution, it is in fact differences in the duration of processes in the upper and lower elevation zones that can serve as the definitive avalanche predicting sign, since in the upper elevation zones the snow layer in a number of Winters develops after the loose snow type, while in the lower elevation zones the predominant evolutionary process is packing. In the elevation zones below 2000 m, over the 1960 - 1970 period, the snow cover developed according to the sublimative disintegration type was observed only twice in the Winters of 1961 - 1962 and 1968 - 1969, while broken snow occurred in the middle of the snow layer in the Winter of 1968 - 1969 (this was already discussed above). In the Winter of 1960 - 1961, heavy snowfalls in November led to the formation of a snow cover which, because of the heavy deficit in the amount of precipitation in December in the high elevation zones lower than 2000 - 2300 m above sea level departed in all locations, for its thickness significantly diminished. The long periods of clear cold weather led to an intensification of processes of breaking-up of the snow layer which encompassed the entire territory of western Tyan'-Shan' and extended far to the south of Central Asia. Subsequently, in the period of thaw, large avalanches were noted over these horizons in the basins of the Akhangaran, Pskem, Padshaata and other rivers. Similarly, processes of development of the snow layer occurred in western Tyan'-Shan' in the Winters of 1971 - 72, 1972 - 73 and 1973 - 74. The snow cover in these Winters in the zones below 2000 m formed late, in the middle to the end of December. Higher, the thin snow cover was subjected to intensive cooling, which led to its disintegration. Later, in February and March, and even at the beginning of January in the Winter of 1972 - 73, heavy avalanches appeared along these horizons which reached record volumes in the Dukant River basin. It is interesting to note that in this Winter, in the Kyzylcha River basin, avalanches occurred over the very same loose horizons three times or even seven times each. Such a phenomenon was observed for the first time in 15 years of observations of avalanches under the conditions of western Tyan'-Shan'.

At the snow avalanche stations a study was also made of the possibility of determining the principles of the evolution of the snow layer on slopes with different orientation. In the general form, it is difficult to establish any relationships here. One can only state with certainty that in regions where processes of structural metamorphism appear in the greater part of a series of observations they encompass both northern and southern slopes. In this case, as the data of M. P. Shcherbakov indicate (17), processes of break-up of the snow layer do not appear actively on the northern slopes either, frequently because of wind packing. In regions where these processes are episodically observed, on slopes with a southern orientation processes of sublimation break-up are seldom noted, which is associated with the powerful energetic effect of sunlight (although under certain conditions in the Pskem River basin avalanches occur over the broken horizons even on southern slopes; it is possible that this is due to the effect of the wind on the snow layer).

In the south of Central Asia, as was shown above, sublimation processes are significantly inhibited, and do not appear even at elevations of 2500 - 3000 m on southern slopes.

The basic results of the work are the following.

1. A certain concept has been obtained regarding the territorial distribution of basic tendencies of evolution of the snow layer under conditions of Central Asia. The conducted regioning is confirmed by statistical data about the percentage quantity of avalanches which form over the break-up horizons in different regions of Central Asia. According to the data of a work (6),

84% of the avalanches in regions of the internal Tyan'-Shan' and the Issyk-Kul'sk depression broke away along a contact with deep rime ice or other loose snow layers. In regions of western Tyan'-Shan' the percentage of such avalanches sharply diminishes (according to observations made in the Dukant River basin in 1958 - 1969, up to 29% of them). According to the data of observations made in the upper waters of the Kashkadar'ya River (the Lednik Severtsova SLS), over the last 8 years avalanches of sublimation diaphoresis were only observed in the Winter of 1971 - 72, although these reports should be viewed as approximate ones.

2. The attempt that was made to establish the numerical correspondence of the thickness of loose horizons to weather conditions, and predominantly snow accumulation, enables one to express certain hopes for the future of such research, although the method needs an additional test using more statistically reliable material.

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