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# ESTIMATION OF THE VOLUME OF GROUND ICE IN THE TIEN SHAN MOUNTAINS

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The paper presents the estimates of evident ground ice contained in the permafrost of the Tien Shan Mountains based on the available geocryological maps of various scales. The maps represent patterns of permafrost distribution reflected in the regional structures depending on geocryological zonality. Using the data on the areal extent, thickness and ice content of permafrost, the volumes of permafrost and ground ice have been determined. In has been revealed that the largest volumes of ground ice occur in active rock glaciers and recent moraines. The volume of glaciers relative to that of ground ice has been ascertained to decrease significantly due to glacial degradation.

*Permafrost, ground ice, glacier, rock glacier, moraine*

## INTRODUCTION

Evaluation of the current state of permafrost and of ground ice is especially relevant due to the important role these natural phenomena play in the runoff of rivers and the increasing shortage of fresh water under conditions of the climate change and essential degradation of glaciation.

In the mountainous regions of Central Asia, where modern glaciers are widespread, permafrost and frozen rocks are always present. However, they may be found also in those mountains where there are no glaciers: in Kazakhstan, on some ridges of the Altay Mountains, on the Ketmen Ridge Tarbagatay, and in other mountain massifs. Hence, permafrost is more widely spread in the mountains of Kazakhstan than glaciers.

**Fig. 1. The buried part of a glacier in the Ak-Tash moraine, Inner Tien Shan (the photo by A.P. Gorbunov).**

Ground ice is a component of the frozen rocks in the mountains, determining their characteristic structure and properties. The shape and size of the ground ice depend on the composition of the rocks, the moisture content in them, the freezing conditions, etc. This study deals only with evident ground ice – metamorphic, icing, lacustrine, and river ice.

The largest volumes of the ground ice in the region are found in moraines, rock glaciers, screes, kurum-screes and rubble masses (Figs. 1, 2). The volumes of certain masses of buried ice in them may reach many hundreds and thousands of cubic meters.

Segregation, injective, vein, and other types of ground ice have been formed directly in the mass of the mountain rocks (Figs. 3–5). Some of these types were formed due to ice formation in freezing sedimentary rocks, the others were formed as water penetrated under head into the freezing system, while the third ones were formed when surface waters infiltrated and water vapor penetrated, due to convection, into the frozen rocks, mainly clastic and bedrocks. A special type is represented by ground ice, filling seismogenic and thermal contraction cracks.

Evaluation of the volume of permafrost and of ground ice is a rather complicated task, as the information required for this purpose is often incomplete



**Fig. 2. Altiplanation ice under a moss cover in a kurum, Altay (*a*), and in a friable fragmental scree, Northern Tien Shan (*b*) (the photo by E.V. Severskiy).**

and not always relevant due to the fact that the mountainous regions are insufficiently investigated.

This is related to the fact that the spread and structure of permafrost in the mountains depend on many factors: on the geographical position of the locality, the absolute height, the composition and structure of the mountain rocks, their water content, etc. Solution of this task is based in revealing the regional structure of the altitudinal permafrost zonality [*Gorbunov and Severskiy, 1979, 2006; Gorbunov et al.,*

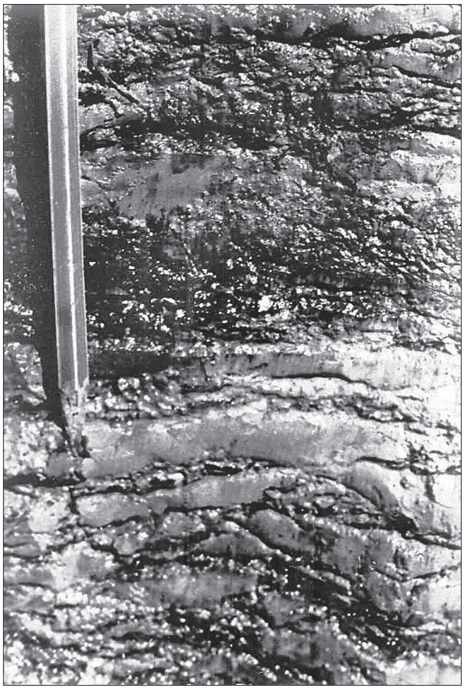

**Fig. 3. The laminar-reticular permafrost structure in frozen lacustrine loams, the hollow of Chatyrkol, Inner Tien Shan (the photo by A.P. Gorbunov).**

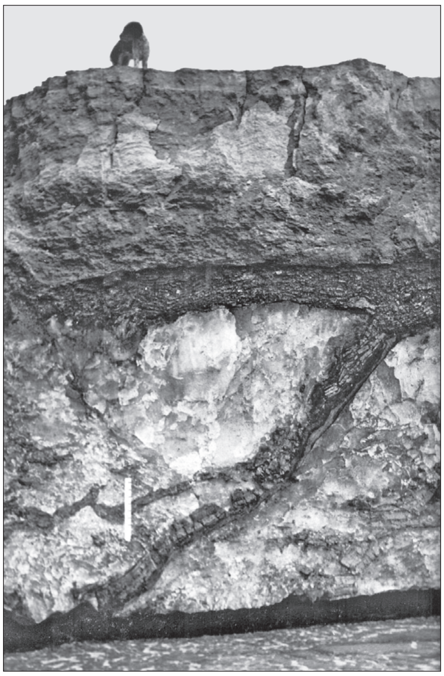

**Fig. 4. Injective ice in permafrost sediments of the second terrace of Karakul Lake, Eastern Pamir (the photo by E.V. Severskiy).**

**Fig. 5. An outcrop of injective ice in a hydrolaccolite, the hollow of Zorkul Lake, Eastern Pamir (the photo by A.P. Gorbunov).**

*1996*]. In the given mountainous region, subzones of isolated, discontinuous and continuous permafrost are identified in the permafrost zone. In the subzone of isolated permafrost, permafrost is mainly found on northern slopes; in the subzone of discontinuous permafrost, western and eastern slopes contain permafrost; next to the northern slopes, while in the subzone of continuous permafrost, permafrost is found nearly everywhere, including southern slopes. Permafrost is absent in some places – along active tectonic faults, under large deep lakes, beds of water-rich rivers, under certain glaciers and in the places of ground water leakage. Due to such diversity of conditions, the calculations of the areas under permafrost, especially in the subzones of isolated and discontinuous permafrost, rather have the character of approximation.

The total area of the permafrost regions for the isolated subzone was taken to be 10–20 %, that for the discontinuous permafrost was assumed to be 60–70 %, and that for continuous permafrost was taken to be 90 % of the total areas of those subzones. In some cases, depending on the specific situation, certain corrections were made in the estimates of the permafrost areas [*Gorbunov and Severskiy, 1998*].

A number of researchers estimated the amount of ground ice. The first attempt was made to determine the volume of ground ice in the Tien Shan Mountains by *B.I. Vtyurin* [*1975*], using the original materials collected by *A.P. Gorbunov* [*1967*]. He estimated the volume of evident ground ice in Tien Shan within the borders of the USSR to be 45 km$^3$, and that in Pamir to be 15 km$^3$. To compare, in the 1970s, the volume of all the glaciers of the Tien Shan Mountains within the borders of the USSR was estimated to be approximately 357 km$^3$ [*The Catalogue..., 1967*]. The monograph by *D. Barsch* [*1996*] contains an estimate of the amount of ground ice in the Swiss Alps within the absolute heights of 2600–3000 m. This volume constitutes more than 6 km$^3$. It is to be noted that the amount of ice in the Alps was estimated only in the isolated and discontinuous permafrost zones, in the area of 3321 km$^2$. There are no materials on the volumes of evident ground ice for the other montane systems.

## METHODS AND RESULTS

Beginning with the late 1970s, the researchers of the Kazakhstan Alpine Permafrost Laboratory, Melnikov Permafrost Institute, SB RAS, have conducted a series of estimations of the amount of ground ice in the mountains of Central Asia. The first calculations were made based on a permafrost map with the scale 1:1 000 000.They demonstrated that the volumes of the ground ice of Tien Shan and Pamir provided by B.I. Vtyurin were essentially underestimated. In our estimates, the volume of ground ice in Tien Shan is 412 km$^3$ [*Gorbunov and Ermolin, 1981*]. Later evaluation based on a permafrost map with the scale 1:500 000 and using certain specifying materials allowed the scientists to reduce this volume to 320 km$^3$. It is to be noted that, according to the data provided by *E.N. Vilesov and I.V. Belova* [*1989*], the volume of the glaciers of this mountainous region in those years was about 423 km$^3$.

This paper presents the results of the subsequent works related to calculation of the volumes of permafrost and ground ice in Northern Tien Shan, including the Dzhungar Alatau Range. This region occupies the territory of Kazakhstan and partly of northern Kyrgyzstan. The calculations were made based on a permafrost map of the scale 1:500 000, using new data on the occurrence and thickness of permafrost and the content of ice in it.

The information on the areas with different types of occurrence of permafrost and frozen rocks in the montane regions of Northern Tien Shan are shown in Table 1.

The area of permafrost occurrence in Northern Tien Shan constitutes about 20,600 km$^2$, or approximately 35 % of the entire montane territory of this region. The total area of occurrence of frozen rocks here is nearly 2 times less (10,700 km$^2$), as the remaining area is occupied by seasonally frozen rocks and open taliks.

Based on the materials of permafrost studies, geological and mapping materials of different organizations, we used averaged values of permafrost thickness for rocks and friable fragmental sediments overlapping the rocks to calculate the volumes of permafrost by montane permafrost zubzones.

Within the isolated permafrost type, the permafrost mass is mainly composed of friable fragmental sediments, its thickness taken to be 20–30 m. About one-half of this mass is composed of friable fragmental surface sediments overlapping the rocks, where posi-

Table 1. **Proportions of the areas occupied by different types of permafrost and frozen rocks, km$^2$**

| Region | Permafrost occurrence: continuous | discontinuous | isolated | Total |
|---|---|---|---|---|
| Zaili, Kungey, Terskey Alatau and Ketmen (the basin of Balkhash Lake) | 1177/1054 | 964/848 | 3143/797 | 5284/2699 |
| Zaili and Kungey Alatau (the basin of the Chu River) | 672/605 | 734/442 | 675/67 | 2081/1114 |
| Kungey Alatau (the basin of Issyk-Kul Lake) | 717/650 | 1002/600 | 1000/100 | 2719/1350 |
| Dzhungar Alatau | 2962/2666 | 2700/1890 | 4818/964 | 10 480/5520 |
| Total | 5528/4975 | 5400/3780 | 9636/1928 | 20 564/10 683 |

N o t e. The nominator contains the area of permafrost occurrence, the denominator shows the area of permafrost. The table shows permafrost characteristics for the entire Zaili and Kungey Alatau, and the characteristics of permafrost in Terskey Alatau and Ketmen are provided only for the regions located in Kazakhstan. The lower borderlines of permafrost subzones for Northern Tien Shan by the absolute height (m) are the following: isolated permafrost – 2700, discontinuous permafrost – 3200, continuous permafrost – 3600; in Dzhungar Alatau, they are shifted down by 200 m.

tive temperatures are formed. The outcrops of the permafrost rocks on the surface are extremely rare here.

In the subzone of discontinuous permafrost occurrence, the thickness of permafrost was determined separately for rocks and friable fragmental sediments. When crystalline rocks were deeply (more than 20 m) seated under friable fragmental sediments, permafrost thickness was taken to be 50 m in the calculations. When they were seated nearer to the ground surface, the average value of permafrost thickness was taken to be 100 m. It is to be noted that the thickness of friable fragmental sediments in moraines, rock glaciers and on rockslide masses reaches 30–40 m.

In the subzone of continuous occurrence of permafrost, the volume of only permafrost rocks was calculated. The average thickness of permafrost depending on the height of the mountains and the slope exposure was assumed to be 100 or 200 m. Occurrence of friable fragmental sediments in this subzone is much rarer than that of permafrost rocks, especially if this refers to their thickness. However, in the other regions of Tien Shan, in particular, in Inner Tien Shan, other proportions in the occurrence of permafrost rocks and friable fragmental permafrost rocks are indicated. We used this information provided in scientific papers and geological survey materials to study the geological conditions of permafrost occurrence and in calculating the volume of permafrost of ground ice in it.

Analyzing the data we had collected and the information on the regions of Siberia provided by other researchers [*Kogan and Krivonogova, 1978; Shesternev and Yadrishchensky, 1990*], we assumed the ice content for permafrost rocks to be equal to 1 %, considering that fact that the large part of them is related to the frozen type containing no ice. In the zones of tectonic fragmentation and in the weathering crust of rock masses, the volume ice content may reach 30 % and more.

Evaluation of the ice content in friable fragmental sediments in the region varies widely. In accordance with the long-term studies of formation and

Table 2. **The volume of permafrost and of ground ice in Northern Tien Shan, km$^3$**

| Region | The volume of permafrost in the rocks | | | The volume of ground ice in the rocks | | |
|---|---|---|---|---|---|---|
| | rocks | friable fragmental sediments | Total | rocks | friable fragmental sediments | Total |
| Zaili, Kungey, Terskey Alatau and Ketmen (the basin of Balkhash Lake) | 366.1 | 56.84 | 422.94 | 5.66 | 17.05 | 22.71 |
| Zaili and Kungey Alatau (the basin of the Chu River) | 143.1 | 12.84 | 155.94 | 1.47 | 3.85 | 5.32 |
| Kungey Alatau (the basin of Issyk-Kul Lake) | 160.0 | 4.50 | 164.50 | 1.60 | 4.80 | 6.40 |
| Dzhungar Alatau | 438.1 | 57.05 | 495.15 | 4.38 | 17.12 | 21.50 |
| Total | 1107.3 | 131.23 | 1238.53 | 13.11 | 42.82 | 55.93 |

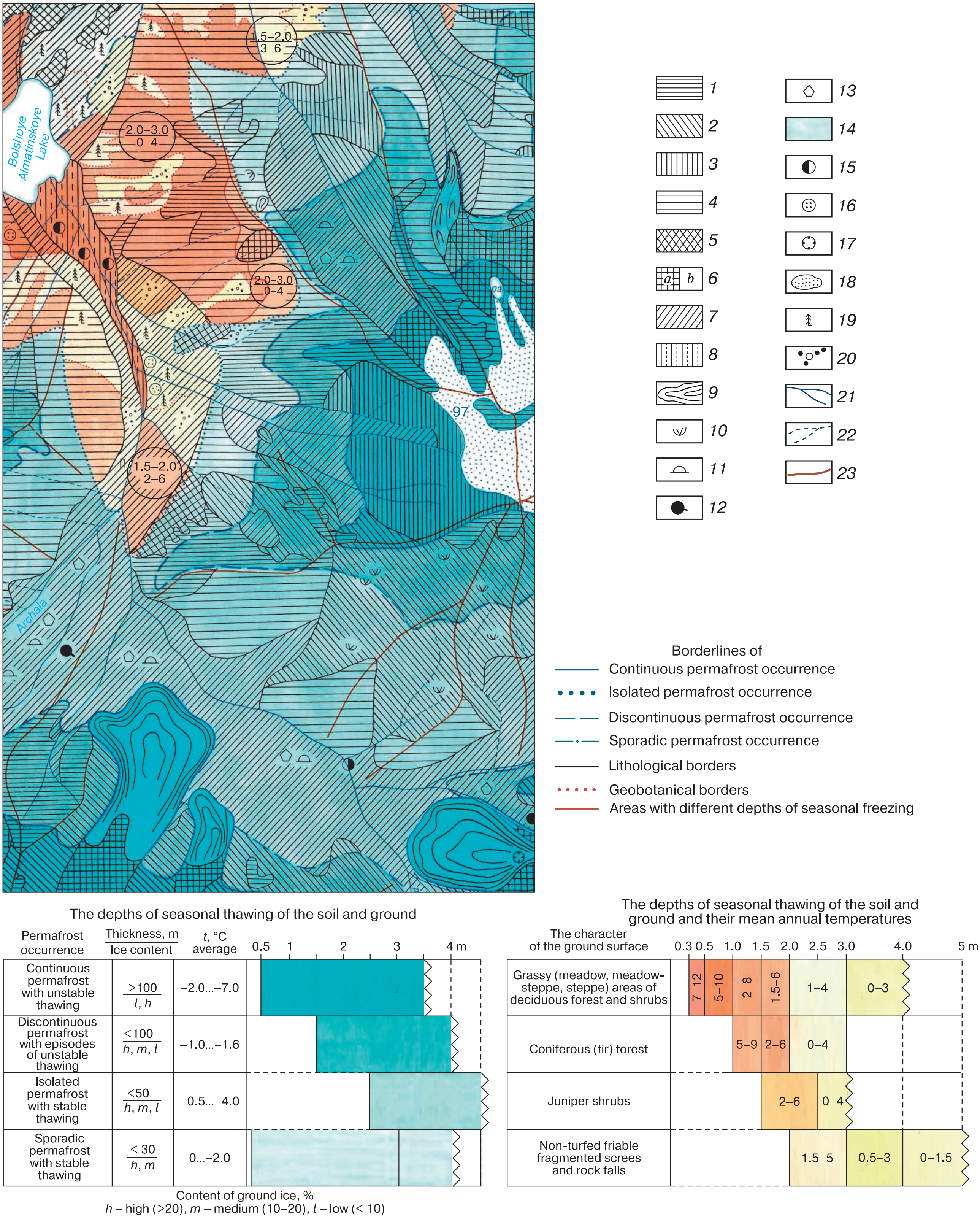


**Fig. 6. A fragment of the permafrost map of the basin of the Bolshaya Almatinka River (Zaili Alatau Ridge).**

*1* – intensely cracked rocks, sometimes small screes 0.5 m thick or less; *2* – slope (grpl $Q_{III-IV}$) sediments: blocks, rubble, gruss with outcrops of bed rocks on the ground surface, 3–5 m thick; *3* – slope block-and-rubble sediments with sand-and-clay filler (dgr, dpl, gr $Q_{III-IV}$), 3–7 m thick and more; *4* – slop rubble-and-loam sediments with sand, gruss and blocks (dgr, dpl $Q_{III-IV}$), up to 3–5 m thick; *5* – non-turfed block-and-rubble sediments of screes and rock falls (gr $Q_{III-IV}$) up to the absolute height of 2700 m; *6* – block-and-rubble sediments of moraines (*a*) and active rock glaciers (*b*) with sandy loam, sand and gruss filler (gl $Q_{III-IV}$), 5–40 m thick; *7* – block-and pebble and block-and-rubble sediments with gruss-and-sand and sand-and-clay filler (40–60 %) of the lower parts of the valley slopes, ancient moraines, and rock glaciers (fgl, gl, alpl $Q_{III-IV}$), 10–50 m thick; *8* – boulder-and-pebble, rubble-and-block, gruss-and-rubble sediments of mudslides and floods (alpl, fgl $Q_{III-IV}$) in broad flood plains of rivers; *9* – active rock glaciers; *10* – structural solifluction formations (tongues); *11* – pingos (tufurs); *12* – listric boulders; *13* – fissured polygonal formations; *14* – permanent snow patches; *15* – river water icing; *16* – ground water icing; *17* – thermokarst sags; *18* – glaciers and their catalogue numbers; *19* – fir forest; *20* – juniper shrubs; *21* – beds of permanent watercourses; *22* – beds of temporary watercourses; *23* – watersheds. In circles: the nominator – depth of seasonal freezing, m; the denominator – the mean annual rock temperature, °C.

bedding of ground ice in different alpine regions of Central Asia [*Gorbunov et al., 1996; Severskiy et al., 2014; Galanin et al., 2017*], in the calculations of the volume of ground ice , the ice content of friable fragmental sediments was taken to be 20 %; however, sometimes in moraines, active rock glaciers, lake masses, rubble, screes, and kurum-screes, the ice content could reach 40–50 % and more.

In accordance with the above information on occurrence, thickness and ice content of permafrost in different rocks, the amount of ground ice in Northern Tien Shan was evaluated to be 56 km$^3$, constituting about 4.5 % of the volume of the entire permafrost mass in the region (Table 2).

Compare the volume of ground ice and ground glaciation in the region in question. The volume of all the glaciers in Northern Tien Shan is evaluated approximately as 90 km$^3$ [*The Catalogue..., 1967; Vilesov and Belova, 1989*], the volume of ground ice is about 56 km$^3$, which is approximately 62 % of the total volume of the glaciers. Such proportion for the entire Tien Shan (without its Chinese part) is 76 %. It should be noted that only in the Dzhungar Alatau Range the volume of ground ice is 21.5 km$^3$, or 64 % of the total volume of the glaciers in 1956 (33.3 km$^3$) and 120 % of the total volume of the glaciers in 2015 (17.8 km$^3$). Such a change in the proportion of the volumes of glaciers and ground ice is caused by essential degradation of glaciation over the recent 59 years [*Vilesov, 2016*].

More relevant calculation of the volume of ground ice was made for the basin of the Bolshaya Almatinka River and of the Prokhodnaya River using a permafrost map of the scale 1:25 000 [*Severskiy, 1979*] and a somewhat different method [*Gorbunov and Severskiy, 1998*]. A fragment of this map is shown in Fig. 6.

The map contains essential geological characteristics for calculating the volumes of permafrost and of ground ice – areas of different composition and thickness of friable fragmental sediments, indicated on the map of engineering and geological zoning of the conditions of formation of mudslides in the basins of the Bolshaya Almatinka River and the Malaya Almatinka River in the scale 1:25 000, made by the Alma-Ata hydrogeological expedition headed by V.N. Vardugin [*The Map..., 1974*]. Here the permafrost mass is represented by frozen friable fragmental sediments of different compositions and by fractured rocks. Frozen rocks are concentrated in non-fractured rocks, mostly granites. Friable fragmental sediments are represented by two characteristic varieties. The first variety is represented by block-and rubble sediments with fine sandy-loam and loam filler. These sediments are characteristic of alluvial and proluvial rocks slope sediments, ancient moraines, and rock glaciers. The second variety consists of friable fragmental stone-rubble sediments, in which filler is either absent or incompletely fills the voids among the fragments. Due to high porosity of these sediments, intense convective and conductive heat exchanges take place, and in most cases, voids are filled with ice. This variety of the sediments is characteristic of modern moraines, active rock glaciers, friable fragmental screes, and seismogenic rock slide masses.

Based on the materials of the engineering and geological survey (drilling, pit making, geophysical survey, etc.), it was established that in the basin of the Bolshaya Almatinka River permafrost occupies about 17 km$^2$ in the rocks (19 % of the total permafrost area – 88.4 km$^2$), friable fragmental sediments without filler occupy 44.2 km$^2$ (50 %), and those with filler, 27.2 km$^2$ (31 %).

The information on permafrost thickness was obtained from the materials of geological [*The Map..., 1974*], geophysical and geothermal studies and from the geological permafrost map [*Gorbunov et al., 1996; Severskiy et al., 2014*]. Permafrost thickness was determined for each contour on the map by layers separately, depending on the composition of the rocks and the absolute height by permafrost subzones (Table 3).

The data shown in Table 3 should be commented on as follows. For the most part, permafrost is nonhomogeneous for its structure, i.e., it consists of rocks and overlapping friable fragmental sediments, the proportion of which varies depending on the absolute height and the geomorphological conditions. In general, the occurrence and thickness of permafrost depending on the composition of the rocks and the absolute height agree with the altitudinal distribution of the types of ground surfaces indicated by *I.S. Sosedov* [*1967*] for the central part of Zaili Alatau; we used the figures to describe the regional structure of the permafrost zonality (Fig. 7).

To calculate the volume of ground ice, information about the ice content in them is required. For

Table 3. **Permafrost thickness in the basin of the Bolshaya Almatinka River depending on the absolute height and the rock composition**

| Permafrost occurrence | Absolute height, m | The permafrost composition and its thickness, m | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Rocks | Friable fragmental sediments | | | | | |
| | | | No filler (NF) | | | With filler (WF) | | |
| | | | Total | NF | Rock | Total | WF | Rock |
| Continuous | >3600 | 150 | 100 | 20 | 80 | 100 | 5 | 95 |
| Discontinuous | 3200–3600 | 100 | 50 | 30 | 20 | 50 | 20 | 30 |
| Isolated | 2700–3200 | 50 | 20 | 15 | 5 | | 15 | |
| Sporadic | 2000–2700 | – | | 5 | | | – | |

permafrost composed of rocks, it was taken to be 1 % [*Kogan and Krivonogova, 1978; Shesternev and Yadrishchensky, 1990*]. For friable fragmental sediments without ground filler, the volume ice content was found to be 40 %, for those with filler, it was 20 %.

All the above data on the occurrence areas, thickness and the ice content allowed us to estimate the total permafrost volume in the basin of the Bolshaya Almatinka River to be 6.8 km $^3$ (in rocks – 5.5 km$^3$, friable fragmental sediments without ground filler – 0.83 km$^3$, those with filler, 0.47 km$^3$), and the volume of ground ice – 0.6 km$^3$.

Compare these estimates with the figures characterizing the ground surface glaciation in this territory. In 1955, the total volume of the glaciers referred to the basin of the Bolshaya Almatinka River was evaluated to be about 1.1 km$^3$, and in 2008, it was estimated to be 0.4 km$^3$. Hence, over those years, the volume of ground ice as a proportion of that of the glaciers changed significantly – from 54.5 to 150.0 % due to degradation of the glaciers. It is to be noted that the volume of ground ice remained nearly unchanged, while that of the glaciers changed essentially due to their degradation. The supposition regarding the permanent nature of the amount of ground ice is based on the fact that no significant degradation of permafrost was recorded in the period in question [*Severskiy et al., 2014*].

The largest deposits of ground ice are located in modern moraines and in active rock glaciers (Fig. 1). To this testify the materials of comprehensive geocryological studies, in which the most advanced geophysical methods were employed, conducted by the researchers of the Melnikov Permafrost Institute, SB

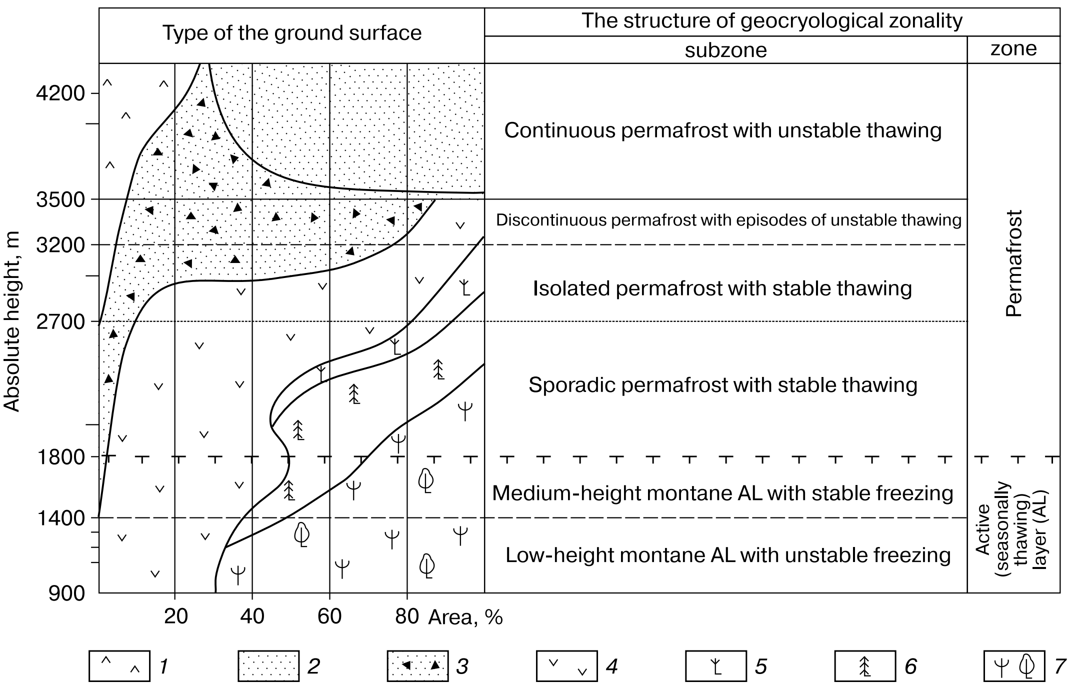


**Fig. 7. Permafrost zonality and types of ground surface of the central part of the northern slope of Zaili Alatau (according to: [*Sosedov, 1967*], with our supplements).**

*1* – rocks; *2* – glaciers; *3* – screes; *4* – meadows and steppes; *5* – juniper shrubs; *6* – fir forests; *7* – deciduous forests and shrubs.

Table 4. **The structure of the active rock glacier, part of the Gorodetsky Glacier**

| No. | Age generations, years ago | Area of the generation, $km^2$ | Permafrost | | | | | Volume of ice, $km^3$ |
|---|---|---|---|---|---|---|---|---|
| | | | Area, $km^2$ | Fraction of the generation, % | Thickness, m | Volume, $km^3$ | Ice content, % | |
| 1 | 690 ± 80 | 0.35 | 0.1 | 30 | 25 | 0.003 | 10 | 0.0003 |
| 2 | 340 ± 65 | 0.48 | 0.3 | 60 | 25 | 0.007 | 50 | 0.0035 |
| 3 | 180 ± 60 | 0.50 | 0.5 | 100 | 30 | 0.02 | 80 | 0.016 |
| | Total | 1.33 | 0.9 | | | 0.03 | | 0.02 |

RAS, and of the Trofimuk Institute of Petroleum Geology and Geophysics, SB RAS, headed by A.A. Galanin, on the active rock glacier of the Gorodetskiy Glacier located in the basin of the Bolshaya Almatinka River (Zaili Alatau, Northern Tien Shan). The researchers discovered three age generations on the rock glacier, in which the amount of frozen masses and ice reduced from the young upper generation to the ancient marginal generations (Table 4).

In the first, most ancient, generation, there are up to 30 % of fossil blocks of metamorphic ice in the thawed rocks. In the second generation, the area of the permafrost rock masses increases to 60 %, in the third generation, the youngest and completely frozen one, large lenses and blocks of fossil metamorphic ice are bound by frozen rubble and blocks. The volumetric ice content of permafrost increases in the same way: from 10 % in the first generation to 50 % in the second one and 80 % in the third one. In the latter two generations, the increase in the ice content is related to the existence of large masses of buried parts of the paleo-glacier [*Galanin et al., 2015, 2017*]. In total, the volume of ground ice in this rock glacier is estimated to be 0.02 $km^3$.

In Tien Shan, Dzhungar Alatau and Pamir-Altay, there are about 8,000 active rock glaciers [*Gorbunov and Gorbunova, 2010*]. With the average area of a rock glacier being 0.2 $km^2$, the total area of the rock glaciers is about 1600 $km^2$. With the average thickness of the frozen icy rocks in the rock glaciers being about 10 m, their total volume reaches 16 $km^3$. With the ice content of permafrost constituting 30 %, the volume of ice here is estimated to be 4.8 $km^3$.

Modern moraines have a significant ice content. For example, several Late Pleistocene moraines with a high content of ice have been discovered in Inner Tien Shan. The largest moraine is located in the valley of the Taragay River in the upper reaches of the Syr-Darya River at the absolute heights of 3300–3560 m. This moraine consists of two masses with the total area of about 126 $km^2$, the thickness of permafrost in it is estimated to be about 50 m, and its volume is about 6.3 $km^3$. In our estimate, the ice content of the rocks in the moraine is not less than 50 %, while the volume of ice is about 3.1 $km^3$. The moraine contains buried masses of the glacier, segregation ice, possibly, injective ice, and, of course, cement ice.

## CONCLUSION

Analyzing the materials of long-term research on occurrence, thickness and ice content of permafrost in different regions of Tien Shan, we have first estimated the volume of ground ice there. Evaluation of the resources of ground ice is relevant due to the important role they play in the runoff of rivers and the increasing shortage of fresh water under conditions of the climate change and essential degradation of glaciation.

It has been found that the total area of permafrost occurrence in the mountains of Northern Tien Shan, including Dzhungar Alatau, is about 20,600 $km^2$ (35 % of the entire area of the region), with permafrost occupying 10,700 $km^2$. The volume of permafrost here is estimated to be about 1,240 $km^3$, and that of ice in it is estimated to be 56 $km^3$, which is about 4.5 % of the volume of permafrost and 62 % of the volume of glaciers, 90 $km^3$.

The calculations have demonstrated that only in Dzhungar Alatau the volume of ground ice constitutes about 21.5 $km^3$ (4.3 % of the volume of permafrost), or 64 % of the volume of glaciers estimated for 1956 (33.3 $km^3$) and 120 % of the volume of glaciers estimated for 2015 (17.8 $km^3$). The volume of glaciers in relation to that of ground ice has essentially decreased due to their degradation, especially over the recent 60 years, and this trend remains to be relevant for all the montane regions of Central Asia.

More precise calculations of the amount of ground ice have been made on the key site in the basin of the Bolshaya Almatinka River (Zaili Alatau, Northern Tien Shan) based on the materials of engineering and geological survey and of permafrost studies.

The total volume of permafrost here is about 6.8 $km^3$, whereas the volume of ground ice in it is estimated to be 0.6 $km^3$, or approximately 9 %. The total volume of glaciers in the basin of the Bolshaya Almatinka River in 1955 was 1.1 $km^3$, in 2008 – 0.4 $km^3$. Hence, over those years, the volume of ground ice changed essentially – from 54.5 to 150.0 %. It is to be noted that the volume of ground ice remained practically unchanged, while the volume of glaciers was found to have essentially reduced due to their degradation.

It has been revealed that the significant amount of ground ice is contained in active rock glaciers.

Only in one rock glacier of Gorodetsky Glacier, the volume of ground ice is estimated to be 0.02 $km^3$. In Tien Shan, Dzhungar Alatau and Pamir-Altay, there are up to 8000 active rock glaciers, their total area is about 1600 $km^2$, and the volume of ground ice in them is about 4.8 $km^3$.

Large deposits of ground ice are concentrated also in the Late Pleistocene moraines of Inner Tien Shan. The volume of ground ice in one of them in the valley of the Taragay River is about 3.1 $km^3$.

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