Jaromír Demek *

Brno

CRYOPLANATION TERRACES IN YAKUTIA

Abstract

The present writer describes the cryoplanation terraces in highland and mountainous regions of nortern and southern Yakutia on the basis of his observations collected by August and September, 1966. In southern Yakutia he studied the cryoplanation terraces in the Aldanskoye Nagorye where they occur in schists and eruptive rocks at altitudes from 1100 m to 1600 m. He dealt with the terraces in the Kular Ridge in the surroundings of the locality of Kular in the northern part of Yakutia. In this part of the Ridge the terraces can be found in shales and sandstones at altitudes of about 250—280 m. Observations showed that cryoplanation terraces are very common in the regions investigated. On the basis of test pits it was found that the terraces level rocks of various resistance. The influence of the geological structure manifested itself but in the marked features of the frost-riven cliff or scarp. Not even the influence of the exposition is decisive in the terrace development. The terraces develop due to the parallel retreat of a frost-riven cliff and scarp. Snowpatches are active at the retreat of the frost-riven cliff and scarp. In the further terrace development frost weathering and solifluction together with running water activity are of main importance. Most of the individual factors in the terrace development change on the one hand in dependence on the properties of weathering products and on the other hand on the stage of the form development. The cryoplanation terraces in the areas investigated in Yakutia develop even now but it may be supposed that there were periods of more intensive development of these terraces during the Pleistocene. Cryoplanation terraces are an important element of the relief of the nival (subnival) climamorphogenetic zone and more attention should be paid to them.

Yakutia is one of the coldest regions on the globe. Almost one half of its territory is situated behind the North Polar Circle and bordered in the north by the Arctic Ocean. At the same time, mountain ranges separate Yakutia from the influence of both the Atlantic and the Pacific Oceans. Its geographical situation together with the diversity of relief caused the characteristic natural conditions closely resembling those in Europe at the end of the last glaciation. Permafrost occurs over the whole territory of Yakutia, its thickness is up to 1500 m (P. I. Melnikov, 1966). Therefore, many features of the Pleistocene periglacial landscape have been preserved in Yakutia up to the present time whereas in other regions they have been obliterated (I. P. Gerasimov, 1952, p. 17). These natural conditions, together with the occurrence of permafrost, cause the extensive development of cryogene processes and forms.

One of the characteristic cryogene forms very common in the highlands and mountains of Yakutia, are the cryoplanation terraces. During my stay in the Yakutsk A.S.S.R. from August 6 till September 2, 1966

* Czechoslovak Academy of Sciences, Institute of Geography, Brno, ČSSR.

I studied the cryoplanation terraces in the Aldanskoye Nagorye in the southern part and on the Kular Ridge in the northern part of Yakutia.

The cryoplanation terraces in Yakutia are often mentioned in the literature. But these are mostly fragmentary reports in regional papers often hardly available.

TERMINOLOGY

Some terms used in this paper may be understood and explained in different ways. I should like, therefore, to give their definitions in the sense in which they are here used.

By the term *cryoplanation terrace* I understand a denudation form, incised into the solid rock and created by the activity of a complex of cryogene processes (especially those of frost weathering, solifluction) and running water (mainly rain wash and rill erosion) in the nival (subnival) climamorphogenetic zone. In the world literature various terms are used for such forms (in Russian: *nagornaya terrasa* — J. Makerov, 1913, p. 761, *golcovaya terrasa* — J. P. Dengin, 1930, p. 166, *soliflukcionnaya* (*nagornaya*) *terrasa* — S. Obruchev, 1937 p. 27; in English: *altiplanation terrace* — H. M. Eakin, 1916, p. 67, *goletz terrace* — J. Dengin, 1930, p. 185, *high terrace* — J. B. Mertie, Jr., 1937, p. 32, *mountainous terrace* — S. G. Boch, & I. I. Krasnov, 1946, p. 69, *nivation benches* — K. J. Gregory, 1966, p. 115, *rock-cut benches* — C. A. Lewis, 1966, p. 295; in French: *haute terrasse* — L. Duparc & F. Pearce, 1905, p. 369, *terrasse goletz* — G. Jorre, 1933, p. 347, *terrasse d'altiplanation, replat goletz* — A. Guilcher, 1950, p. 64, *replat d'altiplanation* — M. Derruau, 1965, p. 171, *terrasse de nivation* — D. St.-Onge, 1965, p. 12, *replat de nivation* — F. Gullentops, 1966, p. 19, *terrasses de cryoplanation* — M. Pécsi, 1965, p. 94; in German: *Hochterrasse* — A. N. Aleschkow, 1936, p. 143, *Goletz Terrassen* — J. Dengin, 1931, p. 292, *Nivationsleisten* — J. Hövermann, 1953, p. 25, *Golecterrassen* — B. Frenzel, 1959, p. 82, *Golezterrassen* — H. Richter, 1963, p. 183, *Kryoplanationsterrassen* — M. Pécsi, 1963, p. 178).

I prefer the term *cryoplanation terrace* to the term *altiplanation terrace.* H. M. Eakin writes in his work from 1916 (p. 78) where he has introduced this term: „The author has suggested the term „altiplanation" to designate a special phase of solifluction that, under certain conditions, expresses itself in terrace-like forms and flattened summits and passes, that are essentially accumulations of loose rock materials." This definition can involve both, the cryoplanation terraces i.e. erosional forms, and accumulation forms i.e. solifluction terraces. In my opinion the new explicitely defined term *cryoplanation terrace* should be introduced for the sake of accuracy. I find this term even better than *nagornaya terrasa* (J. Makerov, 1913, p. 761) and *golcovaya terrasa* (J. P. Dengin, 1930, p. 166). The term *nagornaya terrasa* (mountainous terrace, mountain terrace, high terrace, Bergterrasse, Hochterrasse) tells nothing about the genesis of the form. The term *golcovaya terrasa* is based on the fact that the terraces occur in mountainous regions in the Alpine (sub-Alpine) zone over the timber line. The term *golec*, comes from Siberia and indicates the mountains rising over the timber line, usually circular in plan and with a flat top (A. A. Grigoryev, 1960, p. 470). Even this term, however, indicates merely the position of the terraces. The term *cryoplanation terrace* is, in my opinion, more general and gives immediate indication of the genesis of the form.

By the term *cryoplanation* (K. Bryan, 1946, p. 640) I understand the planation of the surface due to the activity of cryogene processes, i.e. of frost weathering and subsequent denudation of the material accumulated by solifluction, running water and wind activity.

I call *frost-riven cliff* (in Russian: *moroznyy zaboy* — S. G. Boch & I. I. Krasnov, 1951, p. 27; in English: *frost-riven cliff* — L. C. Peltier, 1950, p. 225) the steep, vertical up to overhanging rock wall, developed due to frost weathering and the subsequent denudation of the loose material.

The term *frost-riven scarp* (in Russian: *ustup terrasy* — S. G. Boch & I. I. Krasnov, 1951, p. 27) denotes a more steeply inclined (usually 20—60°) slope segment limiting the inner part of the terrace. The frost-riven scarp developed also as a result of frost weathering and subsequent denudation of the debris. In contradistinction to the frost-riven cliff the bedrock does not outcrop to it over a larger area, but is usually covered with coarse waste or even with soil and vegetation. The frost-riven scarp represents in some cases the advanced stage of development of the frost-riven cliff, while in less resistant rocks it comes into existence at the development of the cryoplanation terrace.

I call *frost scar* the narrow (from 1 up to several metres) and elongated (up to several hundred metres) trenches developing due to the widening of fissures in massive rocks by the activity of vein ice. Water acts in them usually after the melting of ice. They are filled with block waste in top parts.

I call *nivation funnels* the niches, circular or even oval, in places where frost scars cross. After the melting of the ice veins in solid rocks, the bedrock is usually more distintegrated in places of intersection, and the waste derived from the surface penetrates into the widened fissures. Due to this a depression develops because snow persists here longer than it does on the surrounding surface. After snow melting, water remains in the depression and cryogene processes continue widening the fissures. Even during rains the water accumulates in the depressions in the same way as in the sink-holes in karst regions. Nivation funnels usually occur on less sloping surfaces.

It is necessary to distinguish from cryoplanation terraces the solifluction terraces that are, in some cases, of similar shape but belong to accumulation forms. Sometimes, however, combined forms of cryoplanation and solifluction terraces can also be found.

I denote with the term *tump* (from Russian) a hill of pyramidal form bordered by frost-riven cliffs or, more often, by frost-riven scarps. In their further development the tumps turn gradually into castle-koppies and tors.

CRYOPLANATION TERRACES IN THE ALDANSKOYE NAGORYE

The Aldanskoye Nagorye is a complex mountain range in the southern part of the Yakutsk A.S.S.R. This mountain range, of 800—1100 m above sea level, is characterized by features typical of highland and old-mountain relief. Geologically the range is a part of the Siberian Platform called the Aldanskiy Shield. The base of the Shield consists of an intricate complex of pre-Cambrian folded rocks in which schists and mainly granite and granite-gneiss prevail. The crystalline rocks outcrop in the central part of the range. On the margins the horizontally, or sub-horizontally, bedded Cambrian and Jurassic sediments mantle the crystalline fundament. Both, the fundament and the platform cover, are penetrated by intrusions of basic rocks of post-Jurassic age (porphyries, porphyrites, syenites).

During my stay I paid special attention to the cryoplanation terraces in the part of the mountain range bordered approximately in the north-west and the north-east by the Aldan River, in the south-east by the Timpton River, and in the south by the line running between the villages of Yukhta and Bol. Khatymy.

This particular unit of the mountain range may be divided into several parts of diverse relief-forms. The northern part is composed of the so-called Aldanskiye and Elkonskiye Goltsy which show a dissected old-mountain relief. The relief of this region consists on the one hand of conic mountains with steep sides (up to 35°) whose altitude is up to 1700 m and their relative heights 200—600 m, and on the other hand of a flat pedestal with elevations of 700—1100 m above sea level. The flat

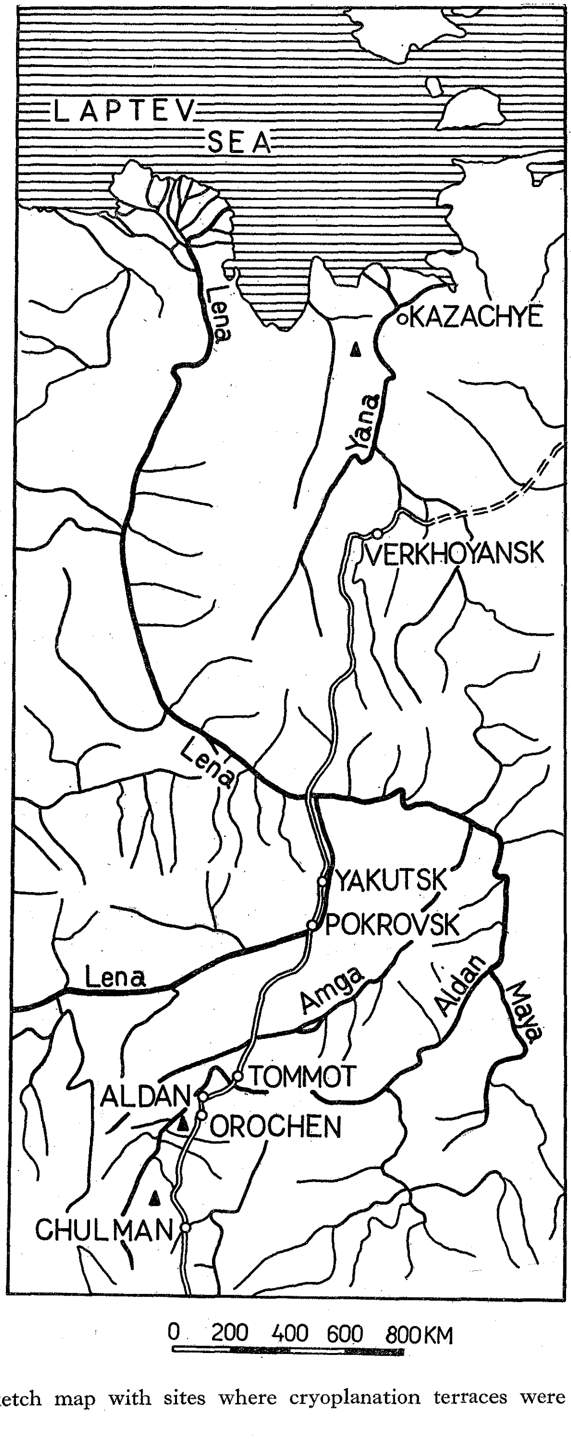


Fig. 1. Sketch map with sites where cryoplanation terraces were studied

pedestal slopes gently from the foot of the conic hills towards the brooks and rivulets. The conic hills occur sporadically or in groups. The hills are built mostly of exhumed post-Jurassic eruptive rocks, whereas the gentle slopes are built of Cambrian sediments or of crystalline rocks. The hills are mostly without vegetation and their slopes are more often than not covered with coarse waste. This part of the mountain range resembles in general the inselberg and pediment landscape known from tropical and subtropical regions.

The central part of the mountain range, 800—1400 m above sea level, displays a gently undulating relief of flat watersheds and wide shallow valleys with numerous peat bogs. Not only isolated mountains but also castle-koppies and tors, often of bizarre form, project above this flat surface. An example of isolated mountains is e.g. the Golaya Mt. (1386 m) near the village of Malyy Nimnyr. Castle-koppies and tors also occur in the area between the villages of Malyy Nimnyr and Bol. Nimnyr, especially on the flat ridges between the valley of the Tikhiy Brook and that of the Mikhaylovka Brook at an altitude of about 1150 m.

The southern part is formed of the Zapadnye Yangi Ridge also with a prevailing old-mountain relief. The dissected relief developed partly due to mountain block movements and partly due to exhuming of the more resistant rocks of post-Jurassic intrusions. The landscape presents a number of mountain massifs with steep slopes (angle of slope 25—30°) covered with debris. In some valley heads the cirque remnants occur. The Evota Massif reaching a height of 1603 m is the uppermost part of the ridge.

The climate of the Aldanskoye Nagorye is very cold. The mean annual temperature at Aldan is −6.5 °C and at Chulman −9.5 °C. The annual temperature amplitude is 44.8—46.5 °C. The mean annual temperature on the ground surface in the mountains is below 0 °C. Due to this fact permafrost is of great extent in the Aldanskoye Nagorye. In the northern and southern parts with dissected relief the permafrost occurs over the whole area reaching a thickness of 400 m. On the peaks snow lies for 10—10.5 months in the year. In the central highland area the permafrost occur only in islands and has variable thickness. Below larger peat bogs the permafrost is 50—100 m thick, elsewhere, below pingos only 3—5 m (K. A. Kondratyeva, 1966, p. 122—133).

The physico-geographical and geological conditions of the Aldanskoye Nagorye are favourable for the extensive development of cryogene processes. The cryoplanation terraces play an important role among the forms created by these processes. The cryoplanation terraces in some typical sites are described below.

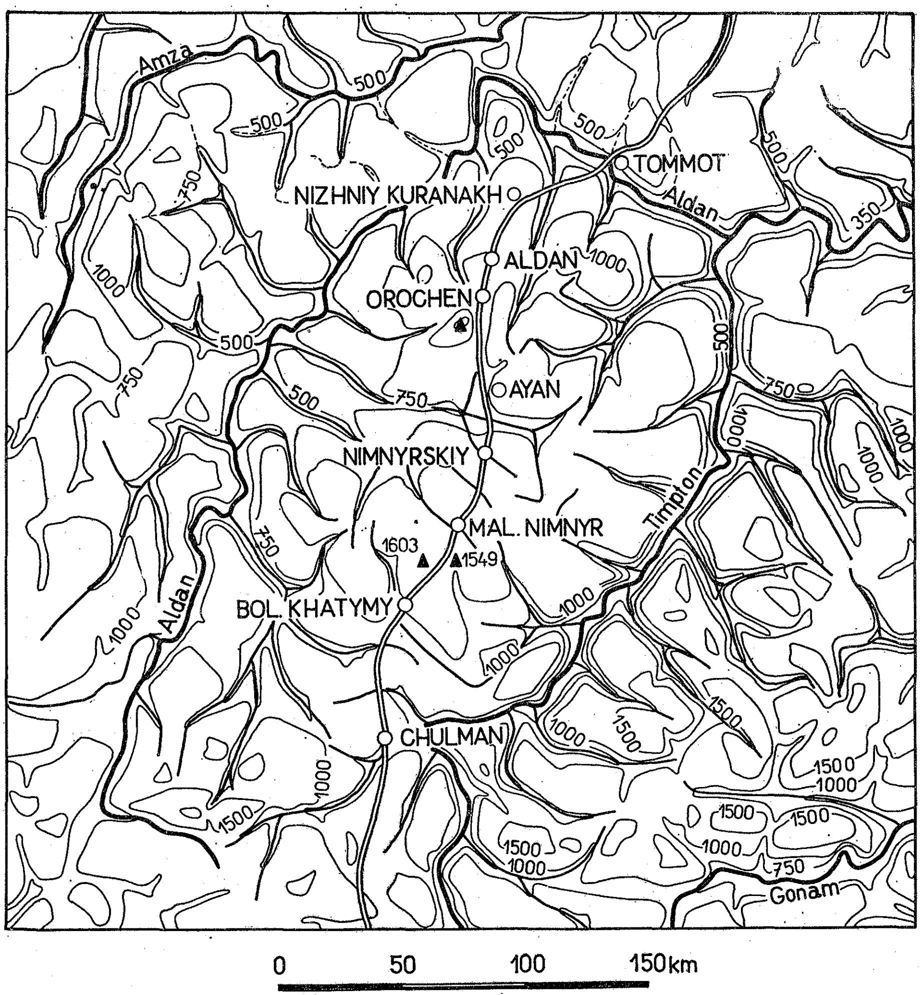


Fig. 2. Sketch map of the Aldanskoye Nagorye

Black triangles show the sites described in the text

CRYOPLANATION TERRACES IN THE ALDANSKIYE GOL'TSY REGION

In the Aldanskiye Gol'tsy Region we made a detailed study of the cryoplanation terraces on Mt. Shapka Monomakha (1271 m) about 40 km south of the town of Aldan. The Mt. Shapka Monomakha is the south-western part of the group of two peaks projecting above the pass through which leads the Aldan—Chulman road, about 8 km south of the village of the 1st Orochyon. The conical mountain is oval in plan and its longer axis is elongated in the north—south direction to about 1 km. In transverse profile the mountain is assymetric. The upper slope segments are remarkably steeper than all the others. The top is very flat. It is bordered on the western and south-western sides by a rock step above which tors rise. The upper slope segments are distinctly stepped, the lower ones are smooth and covered with debris.

The relative height of the mountain above the pass is about 270 m. The flat surface at the mountain foot is covered with taiga. Above it there is an almost impenetrable zone of the dwarf pine (*Pinus pumila* (Pall.) Rgl.). The top rises above the timber line and is overgrown with grass, mosses and lichens.

The cryoplanation terraces are best-developed in the upper parts of the southern and south-western slopes. On the other slopes they are smaller and narrower.

Figure 3 shows the terraces on the south-western slope. The summit flat is of considerable extent and is inclined at about 2°. On this summit the stone polygons up to 5 m in diameter occur. Most polygons are inactive and overgrown by grass. Only in some places there are smaller active polygons in the centres of stone polygons. Test pit No. 1 (Fig. 3) on the summit flat displays the following profile:

0.00—0.25 m yellow-brown sandy loam with quartzite and granite fragments,

0.25—1.50 m frost loosened quartzites *in situ.*

The thickness of slope deposits is not great on the flat, the flat being an erosional surface cutting the granites and the quartzites.

Above the flat there rises a slight elevation with a triangulation point. It is covered with large angular fine-grained granite blocks and bordered by frost-riven scarps. This may be considered as a tump i.e. the remnant of the upper flat. Granite tors rise on the margins of the summit flat. The tors on the western slope show some traces of macroexfoliation indicating that the top could be an exfoliation dome levelled by cryoplanation terraces. From the break of slope, at the margin of the summit flat, the frost-riven scarp falls down to the lower terraces. The frost-riven scarp is of irregular shape. In places parent rocks outcrop on it, in other sections it is covered with waste passing into block streams in places of flat depressions. Test pit No. 2 at the foot of a small frost-riven scarp between the 2nd and 3rd terraces revealed that the thickness of the slope deposits is negligible.

The test pit displays the following profile:

0.00—0.30 m small fragments of porphyric granite,

0.30—0.50 m frost loosened quartzite *in situ.*

The width of the slope terraces is relatively small and ranges from

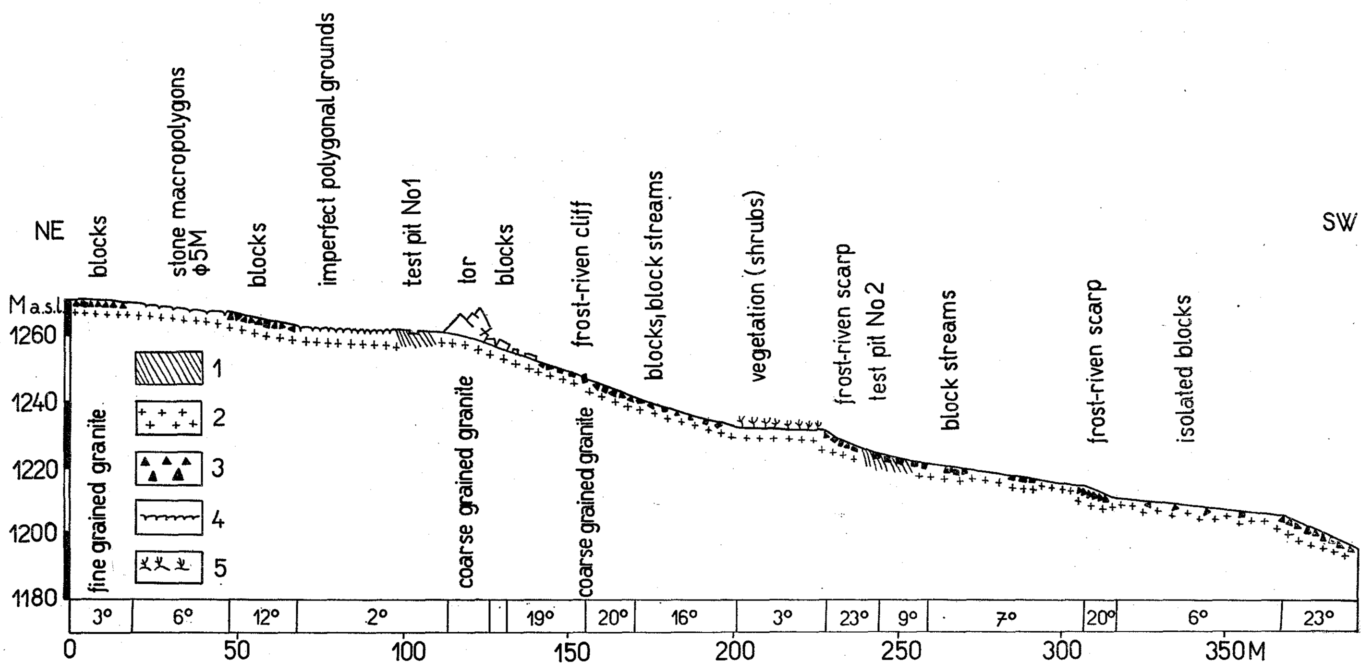


Fig. 3. Profile of the south-western slope of the isolated hill Shapka Monomakha (Constructed by J. Demek, drawn by V. Holešová)

1. quartzite; 2. granite; 3. angular blocks; 4. polygonal grounds; 5. bushy vegetation

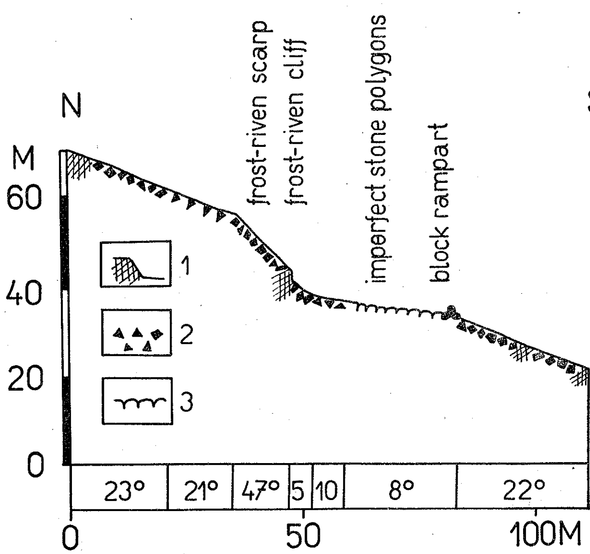


Fig. 4. Profile of the cryoplanation terrace on the west-south-western slope of Shapka Monomakha (Constructed by J. Demek, drawn by V. Holešová)

1. bedrock outcrops (granite); 2. angular blocks; 3. polygonal grounds

30 to 140 m. Their length is not uniform and usually ranges from 100 to 300 m. The terraces are sickle-shaped. In the place where the upper terrace becomes flat, the lower terrace begins.

Figure 4 shows the section through one of the lower terraces in the west-south-west direction. The terrace is sickle-shaped, about 35 m wide and 160 m long. There is to be seen a scree developed at the foot of the frost-riven scarp bordering the terrace. Above the scree a frost-riven cliff rises to a height of 3 m. The upper steep part (47°) of the frost-riven scarp is covered with debris and passes continuously into a gentler slope covered with blocks up to 2.5 min their longer axes. At the undulate foot of the frost-riven scarp some traces of snow-patch erosion can be found as the snow does not thaw before the very summer. The fine-grained granite of the frost-riven cliff is loosened and the distinct traces of block splitting can be seen. On the steep section of the frost-riven scarp (47°) conspicuous traces of gliding of blocks can also be found. But on the terrace flat there are no traces of material removal, and there are only indistinct stone polygons developed on the terrace. The material accumulates evidently in the scree and overlaps gradually the frost-riven cliff.

Traces of transport down the frost-riven scarp were observed also on the adjoining cryoplanation terrace. In contradistinction to the previous cryoplanation terrace, on this terrace block streams begin at the foot of the frost-riven scarp carrying away part of the material. But even here the quantity of the material transported from the frost-riven scarp will probably be larger than that of the material removed by denudation.

CRYOPLANATION TERRACES IN THE EVOTA MASSIF

The Evota Massif forms the central part of the Zapadnye Yangi Ridge. The massif is irregularly oval, elongated in the east—west direction. The central part of the massif is formed of two peaks separated from each other by a pass through which the road Chulman—Aldan runs. The western peak of the Evota Massif reaches the height of 1603 m. The Evota peak has the plan of a dissected oval with cirque valley heads. In the head part of the Tiit Brook there appears a cirque with snow-patches. The upper slope segments are distinctly terraced, the lower slope parts being smooth and covered with debris. The eastern top of 1549 m is dissected by cirque-like valley heads of brooks. Lower spurs between the brooks are also distinctly terraced. The whole massif rises above the timber line.

CRYOPLANATION TERRACES ON THE EVOTA SUMMIT (1603 m)

On the Evota summit the cryoplanation terraces were investigated in the summit part where they are well developed. The top is about 2.5× ×1.5 km in extent. The whole peak is of a pyramidal shape with cryoplanation terraces in the upper parts of all slopes, the best developed terraces being on the southern and eastern slopes. The top is built of coarse- and fine-grained granite. In figure 5 the profile of the upper part of the southern top slope can be seen. Round the triangulation point there spreads a large summit flat with an inclination of 2°. Typical stone polygons of about 3 m in diameter are developed on it. The macropolygons in the margins pass into stone-stripes where the inclination increases to about 7°. The cryoplanation terraces on the southern slope are notable for their large dimensions and their small inclination. Some of them reach the width of 0.5 km and a length of about 1 km. The inclination varies from about 5—7° at the foot of the frost-riven scarps whereas in the centre and in the outer margin of the terraces it decreases to 1—2°. The cryoplanation terraces are separeted from each other by frost-riven scarps with an inclination of 10—23° and are covered with large angular granite blocks.

On the surface of the cryoplanation terraces polygonal grounds of various size are developed. These are mostly stone polygons of 3—6 m in size. The stones in the polygon rims are often vertically oriented. The centres of inactive polygons are overgrown with grass, mosses and lichens. The centres of active polygons are frequently divided into smaller polygons with moss and grass rims. The centres of these smaller polygons consist of brown loam with small (up to 10 cm) rock fragments. The loam centres are convex and elevated over the rims. The polygons occur mostly in the less sloping parts of the terraces. On the steeper parts of the polygons they are elongated in the direction of inclination of the cryoplanation terraces and pass gradually into stone stripes.

On the central flat, round the triangulation point and on the upper terraces, no sections were found. Therefore, it was impossible to determine the thickness of the weathering products and of the slope deposits on the terraces. But from the profile it clearly comes out that the bedrock outcrops directly to the surface of the lower terraces.

CRYOPLANATION TERRACES ON THE ELEVATION OF 1549 m

The cryoplanation terraces were also studied on the western spur (elevation 1549 m). The spur rises to a height of 1400 m and is separated from the summit by a saddle. It extends in the east—west direction and has a very flat top and step-like slopes. The cryoplanation terraces are situated mainly on the western, southern, and south-eastern slopes of the spur.

The flat spur top inclines about 2°. It is covered with coarse waste in which angular blocks of 0.3—0.4 m in diameter prevail. A polygonal pattern of frost scars is developed on the surface. In places where the polygonal scars cross, oval funnel-shaped depressions of a depth of 1—1.5 m and diameter of 2—5 m have developed. The frost fissures were evidently filled with vein ice. During thawing of the ice wider frost scars appeared and in the intersections of the frost scars depressions of nivation funnels developed at melting. The snow lies longer in the depressions and causes nivation processes. Water from the melting snow carries away the fine material and gradually enlarges the depressions.

The summit flat is bordered on the south-east, south-, and west by a distinct frost-riven scarp which plainly marks the border-line of the spur top to a length of 840 m. The frost-riven scarp and the cryoplanation terraces at its foot are presented in Figures 6 and 7. The frost-riven scarp of uneven height is mostly covered with block debris. Its foot is undulate on the western side. In places of shallow hollows, solid granite outcrops to form the frost-riven cliffs — never very high. The foot of the frost-riven cliff is mostly distinct. The shallow amphitheatrical niches

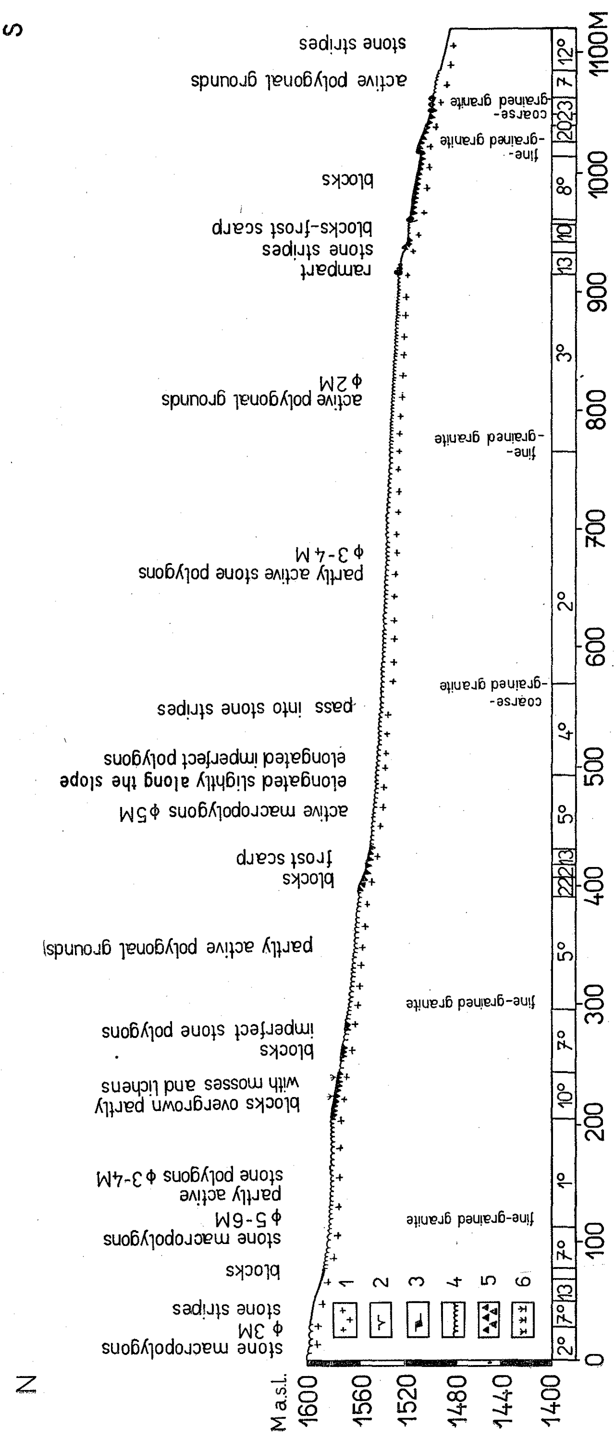


Fig. 5. Profile of the cryoplanation terraces of the southern part of Mt. Evota (1603 m)
(Constructed by J. Demek, drawn by V. Holešová)

1. granite; 2. nivation funnels; 3. bedrock outcrops (granite); 4. polygonal grounds; 5. angular granite blocks; 6. low bushes

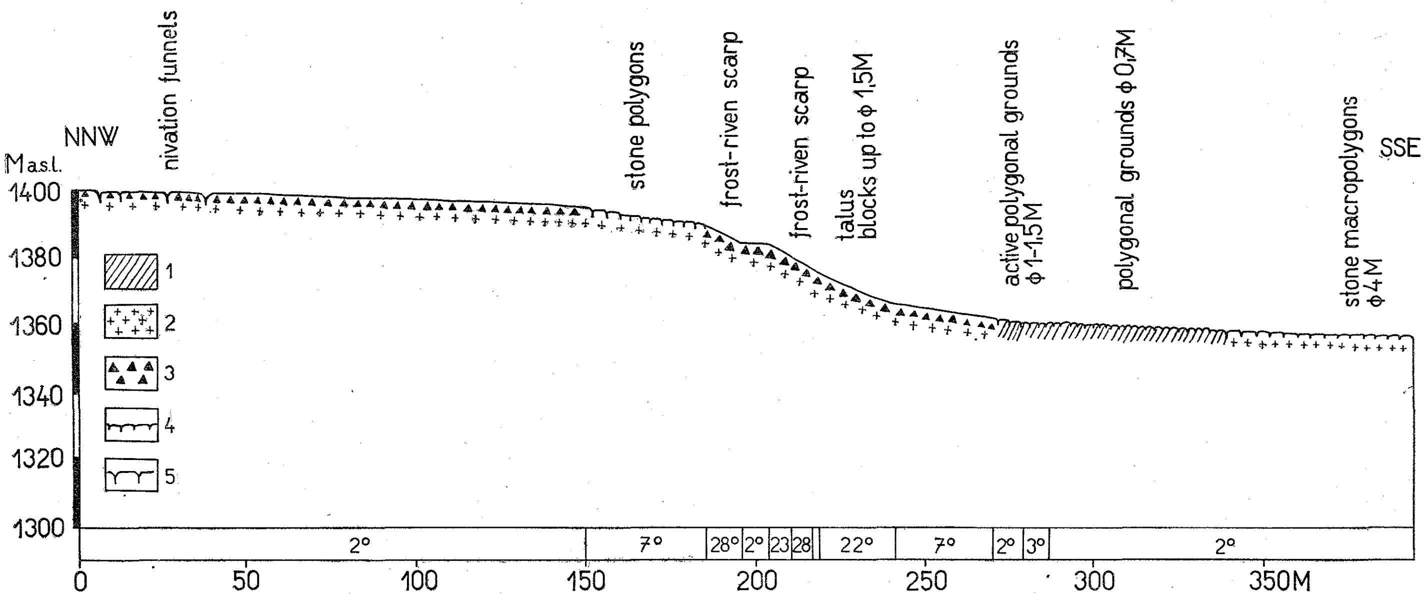


Fig. 6. Profile of the cryoplanation terraces on the southern slope of elevation 1549 in the Evota Massif (Constructed by J. Demek, drawn by V. Holešová)

1. quartzites, quartzy schists; 2, granite; angular blocks; 3. polygonal grounds; 4. nivation funnels

in the frost-riven scarp are evidently places where snow-patches are preserved for a long time and where the frost-riven cliffs retreat parallelly. A cryoplanation terrace is developed at the foot of the frost-riven scarp. The cryoplanation terrace is best developed on the southern slope where its width is about 150 m. It is narrower on the western side, its width being about 50 m. The inclination of the terrace is about 7° at the foot of the frost-riven scarp and it decreases to 2° towards the outer margin. The cryoplanation terrace levels the rocks of various resistance, i.e. granites and quartz schists and even quartzites. At the foot of the frost-riven scarp the terrace is usually covered with angular blocks. Farther from the foot generally appear active polygonal grounds. The polygonal grounds are better developed on quartz schists and quartzites than on granites. On the margins of the cryoplanation terraces there appear solifluction streams; the largest of them was found on the western slope, its length being 12 m and its width at the base, 8 m. On its sides and front there were distinct traces of the present-day movement of solifluction material over the stone blocks.

Conspicuous active solifluction terracettes and solifluction streams were found on the margin of the cryoplanation terrace also on the south-eastern slope. On this slope, below the uppermost terrace, there are further lower steps of cryoplanation terraces. Lower cryoplanation terraces and nivation hollows (*cf.* Fig. 7) on the south-western slope were also investigated.

CRYOPLANATION TERRACES ON THE KULAR RIDGE

The Kular Ridge is part of the Yano-Indigirskoye Nagorye in the northern part of Yakutia. The ridge extends over a distance of about 350 km from the Omoloy River sources behind the Yana River that breaches in cascades through the gap. The central part of the ridge has an irregular relief with altitudes of about 1000 m. The highest mountain reaches 1289 m above sea level.

We studied the cryoplanation terraces in the northern spur of the Kular Ridge, that spreads between the Kyuchchuguy Kyuegyulyur and Yana Rivers. The spur called Ulakhan Sis, is elongated in the SSW—NNE direction to a length of about 55 km and is 20—30 km wide. The ridge has a relatively low relief. The maximum altitudes occur in the south (501 m). The height of the flat surface decreases northwards.

The sites investigated are situated in the northern part of the Ulakhan Sis spur in the surroundings of the locality of Kular. Here the ridge is dissected by open valleys of no great depth — of the parallel right tribu-

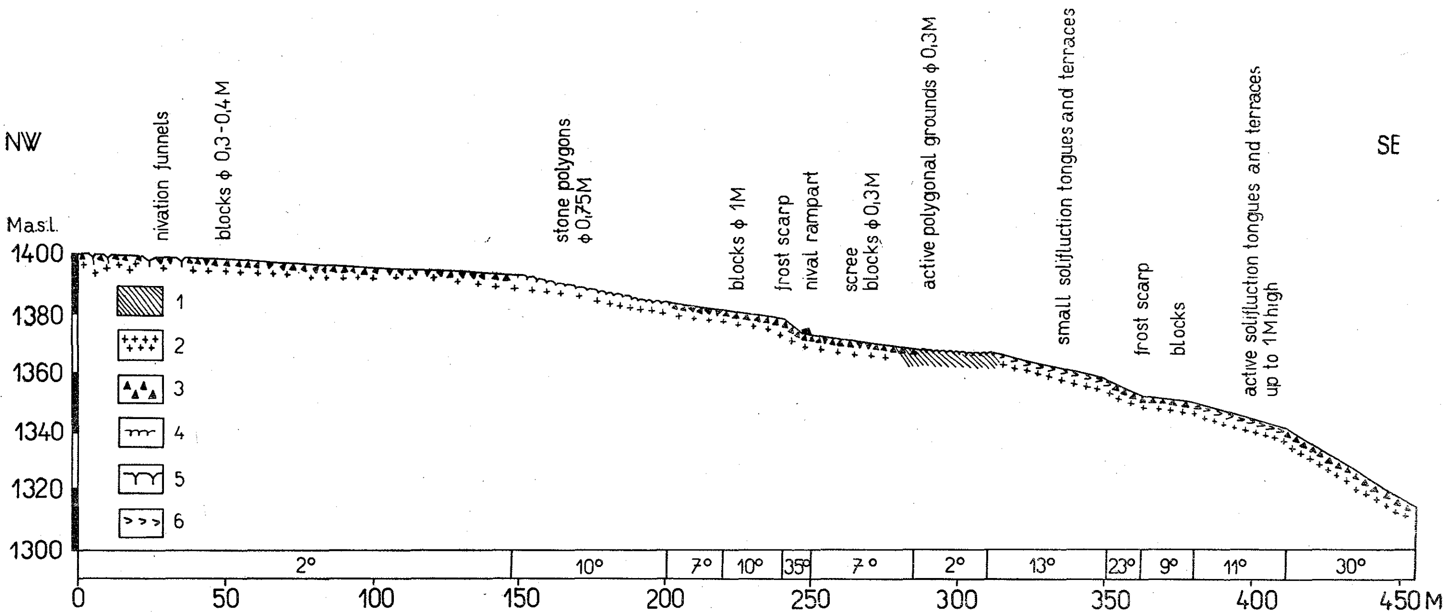


Fig. 7. Profile of the cryoplanation terraces on the south-eastern slope, elevation 1549, in the Evota Massif (Constructed by J. Demek, drawn by V. Holešová)

1. quartzites, quartzy schists; 2. granite; 3. angular blocks; 4. polygonal grounds; 5. nivation funnels; 6. solifluction streams

taries of the Kyuchchuguy Kyuegyulyur River into rounded ridges extending in the west—east direction. The assymetric rectangular river pattern is characteristic of this territory. The main rivers, like Kyuchchuguy Kyuegyulyur and Ulakhan Kyuegyulyur, flow from the south to the north and the tributaries join them at right angles. In the region investigated, the watershed ridges are 250—300 m high.

From geological point of view, the territory is composed of sandstones and shales of Permian and Triassic ages. In Permian beds mainly sandstones prevail, whereas in Triassic the predominance of shales with thin sandstone beds can be observed. The rocks are slightly metamorphosed.

The area investigated is situated on the boundary between the forest tundra and the tundra. The forest tundra occupies the lower slope portions and the valley bottom. The summits of the watershed ridges and the head parts of the tributaries of the Kyuchchuguy Kyuegyulyur River are already in the tundra.

In the whole area permafrost is of about 500—600 m in thickness. The climate is very severe. The mean annual temperature, in the nearest station of Kazakh'ye, is −12 °C. The first snow falls in the middle of September and melts towards the end of May and at the beginning of June. The active layer thaws to 0.8 m (seldom 0.9 m) on the slopes facing south, and to 0.4 m on those exposed to the north.

Cryoplanation terraces are very common in the central part of the ridge. During low flight in an ANT 2 plane, we observed that most tops were flat, as though cut off. On the slopes a number of cryoplanation terraces (often 6—8) were observed. Castle-koppies and tors occur on some tops.

The cryoplanation terraces in the neighbourhood of the locality of Kular are described in detail below.

CRYOPLANATION TERRACES ON THE SUMMIT OF THE TURKU HILL

The Turku Hill extends about 5 km north-west of the locality of Kular on the watershed between the right tributaries of the Kyuchchuguy Kyuegyulyur River, i.e. the Burguat River, and the un-named neighbouring parallel tributary. The ridge runs in the east—west direction and consists of flat tops with stepped slopes separated by rather deep saddles. The Turku Hill consists of two tops separated by a flat saddle. The south-eastern top reaches a height of 278 m above sea level and the north-western top, 283 m above sea level.

In profile (Fig. 8) the section through the summit flat (elevation 278) and the cryoplanation terrace on the southern slope are presented. The

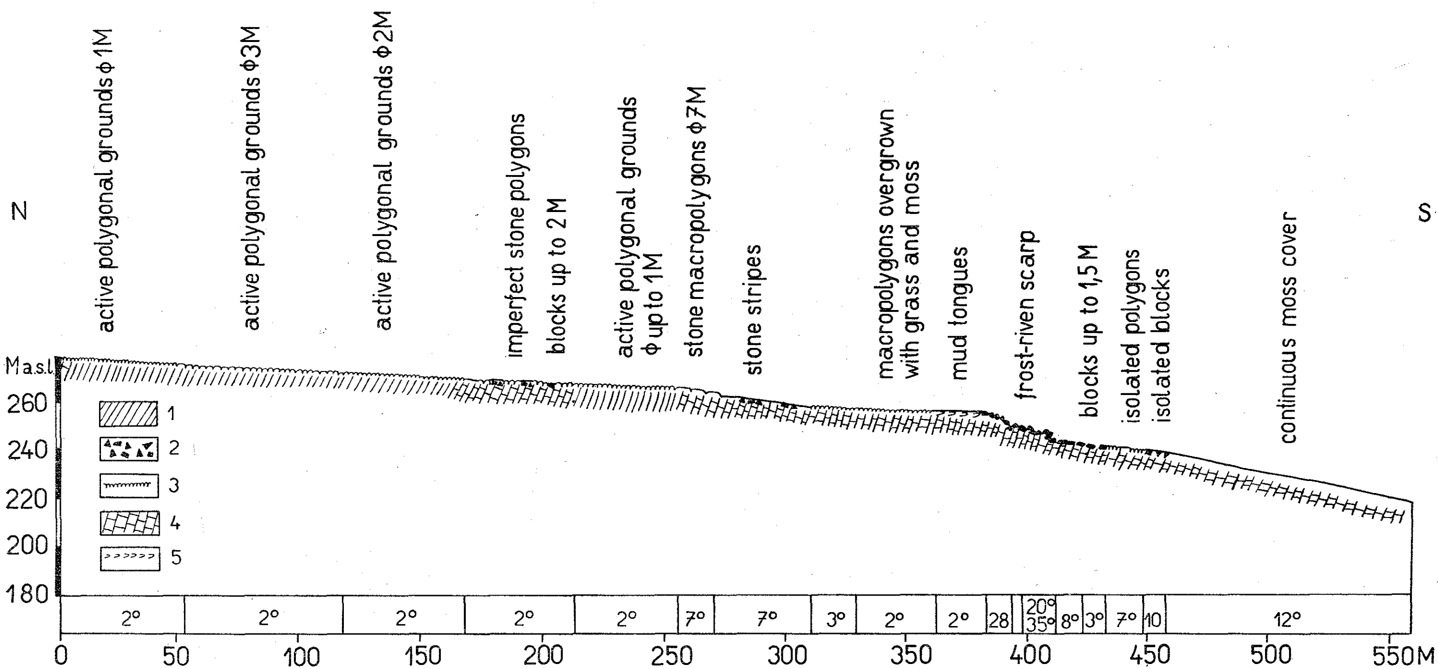


Fig. 8. Profile of the cryoplanation terraces on elevation 278 of the Turku Hill in the Kular Ridge
(Constructed by J. Demek, drawn by V. Holešová)

1. shales; 2. angular sandstone blocks; 3. polygonal grounds; 4. sandstone; 5. mud tongues

summit flat on elevation 278 is quite extensive and levels a strip of shales and a strip of sandstones. Active stone polygons, 1—3 m in diameter, are developed on the shale regoliths on the surface sloping 2—3°. The surface built of sandstones is more inclined (2—7°) and the stone polygons are here greater (up to 7 m in diameter). But a considerable part of these polygons is overgrown with grass. The macropolygons pass into stone stripes at the slopes of greater inclination (7°). At the southern margin of the summit flat inactive mud tongues can be found today and polygonal grounds are gradually developing on them. The vegetation on the northern slope of the summit flat is very scattered. Here, on a slope of 3°, the polygonal grounds with convex loam centres are developed. The scarce vegetation occupies only the depressions between the convex polygon centres and forms narrow rims, about 10 cm wide. The melting of vein ice in the polygons causes a higher moisture content in the soil and promotes the development of vegetation. On the surfaces of 8°, the polygons become elongated and vegetation occurs in straight bands between the individual loam fields on which rill erosion operates.

On the southern slope the summit flat is bordered by a frost-riven scarp of about 250 m presented in the profile (Fig. 8). The frost-riven scarp is bordered at the foot by a scree composed of large boulders up to 1.5 m in their longer axes. The flat is about 50 m wide; in central part it is slightly inclined (3°) while towards the margins it slopes up to 10°.

The elevation of 283 m also forms a summit flat slightly inclined in the central part (1°). The test pits on the flat (*cf.* Fig. 9) present the following profiles:

test pit No. 1

0.00—1.00 m brown sandy loam with sandstone fragments,

1.00—1.90 m sandstone with quartzite veins loosened by frost weathering;

test pit No. 2

0.00—0.45 m grey-brown clayey loam with fragments of shales and sandstones,

0.45—1.15 m black-grey shales.

The test pits proved that the summit flat is an erosion surface that levels the shale and sandstone beds. But the thickness of the weathering products is very small. The inclination of the flat increases up to 8° towards its margins. On the north-eastern slope of elevation 283, three distinct cryoplanation terraces can be found. The two upper terraces are presented, together with the summit flat, in profile (Fig. 9). The upper cryoplanation terrace is about 180 m wide with an inclination of 2—5°. Inactive solifluction streams, flowing out either from the foot of the frost-

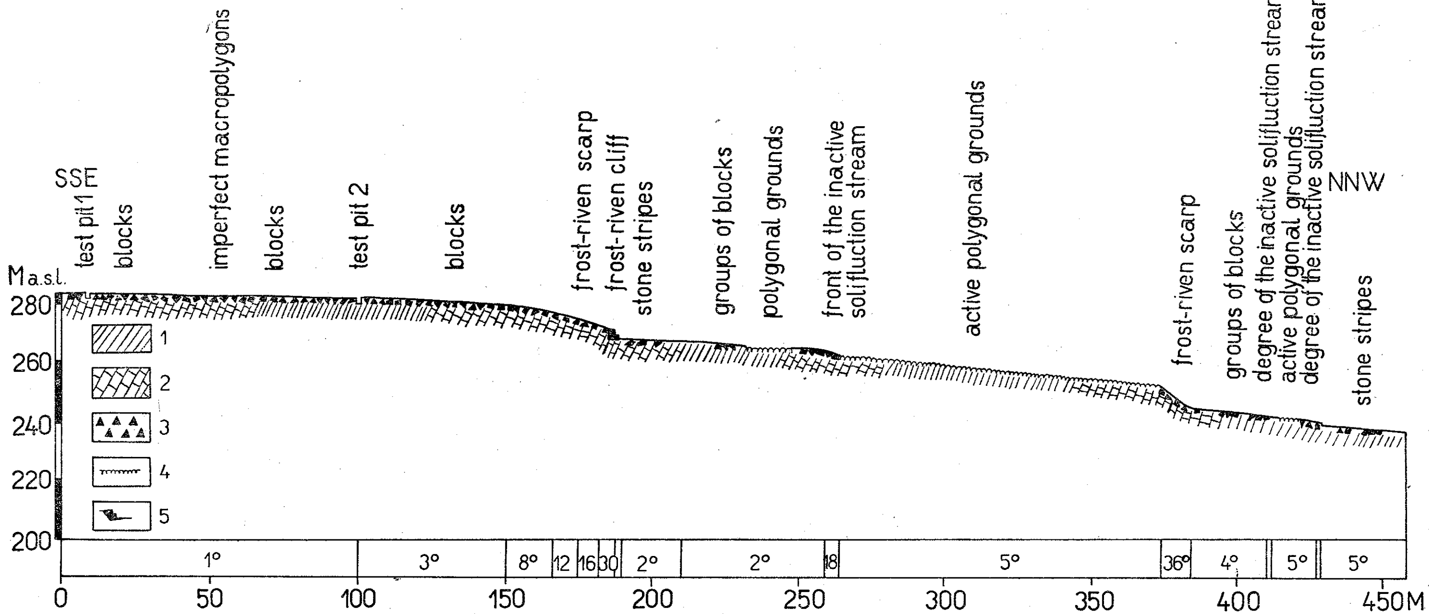


Fig. 9. Profile of the cryoplanation terraces on the north-eastern slope, elevation 283, of the Turku Hill in terraces Kular Ridge (Constructed by J. Demek, drawn by V. Holešová)

1. shales; 2. sandstone; 3. angular sandstone blocks; 4. polygonal grounds; 5. sandstone outcrop in the form of a frost-riven cliff

riven scarp at the north-eastern margin of the summit flat, or directly off the summit flat, are characteristic of this terrace. The upper terrace is separated from the lower one by a frost-riven scarp of 36°, built of debris, and in places of debris and loam. Even on the lower terrace inclined at 4—5° solifluction streams can be found. The lower solifluction stream, presented in the profile, is partly active and ostioles (spotted tundra) are developed on its surface. Besides the solifluction streams stone stripes also occur on the terrace flat covered with debris.

CONCLUSION

The cryoplanation terraces and the cryoplanation summit flats are very common phenomena in the mountains and highlands in Yakutia.

The test pits and the sections on the terraces and summit flats have clearly shown that they are denudation forms where the bedrock outcrops either directly, or is covered with only a thin layer of material transported down the terraces or the flats.

The cryoplanation terraces are developed in various rocks (granites, schists, shales, quartzites, sandstones). The terraces and flats are cut in rocks of various resistance to exogenous processes. A certain dependence in the development of the cryoplanation terraces upon lithological conditions was recognized. Frost-riven cliffs and frost-riven scarps develop most often, according to observation, at the contact of variously resistant rocks where there had probably been a previous break of slope.

The parallel retreat of the frost-riven cliff and frost-riven scarp is decisive for the development of cryoplanation terraces. The frost-riven cliff retreats parallelly due to splitting of blocks along the fissures. The bedrock outcrops, to a greater or lesser extent, even on frost-riven scarps, in the most exposed places. In the parallel retreat of the frost-riven cliffs and scarps snow patches and snow drifts at their foot are of importance. In spring, the material coming from the upper cliff and scarp portions is transported by supranival processes down the snow surface. The foot of the cliff and scarp is slightly buried under the loose material, so the parallel retreat of the cliff and scarp can occur. Traces of snow patches were most often found in the amphitheatre bends of the frost-riven cliffs and scarps that displayed fresh traces of retreat. At the head of the amphitheatre the bedrock usually outcroped to the surface and the blocks on the cliff or scarp displayed traces of movement.

A whole complex of cryogene processes mentioned already in the description of the individual sites operate on both the terrace and summit

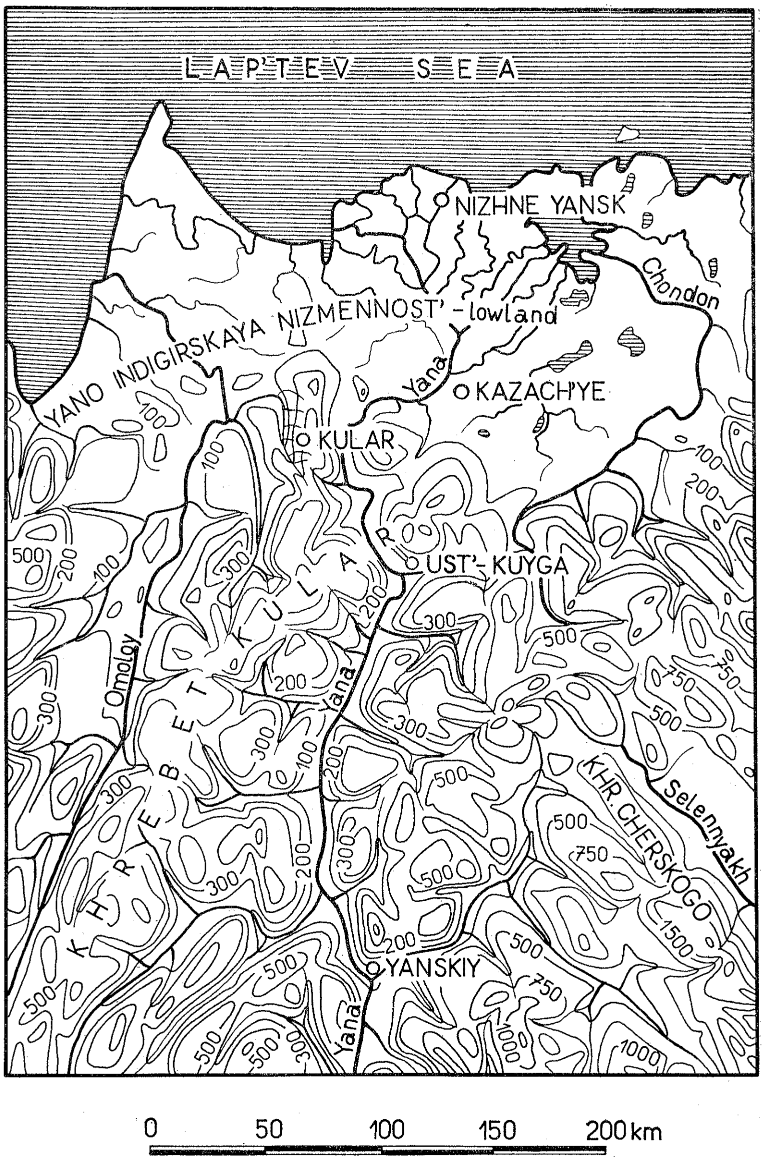


Fig. 10. General map of the Kular Ridge

flats. These processes are: (1) frost-splitting (congelifraction) disintegrating the material coming from the frost-riven cliffs and scarps and (2) solifluction carrying away the loose material. As can be concluded from the description of the individual sites, mud tongues and solifluction streams

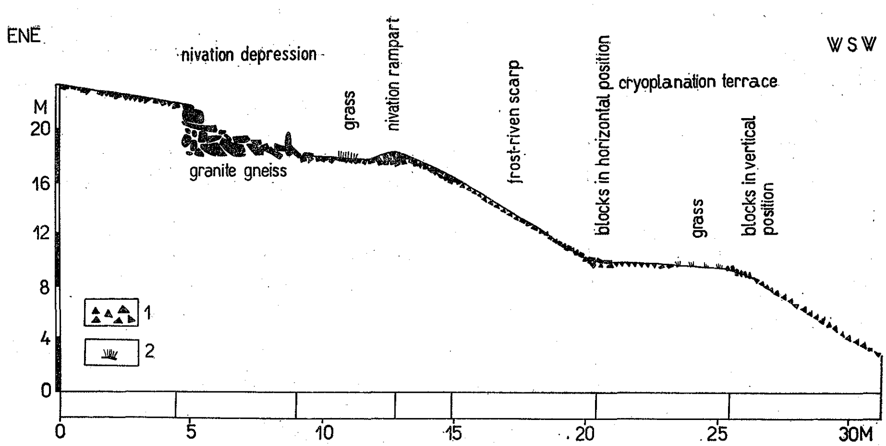


Fig. 11. Cross-profile of the nivation niche on the western slope of elevation 1549 in the Evota Massif in the Aldanskoye Nagorye (Levelled by J. Demek, drawn by V. Holešová)

were observed on the terraces. The solifluction phenomena were observed more often on terraces in the first stages of development, and in the marginal parts of the terraces where microgelivation created a larger quantity of fine material. On the inner part of cryoplanation terraces at Kular, at the foot of the frost-riven scarps, a sufficient quantity of fines derived from weathered shales facilitated the development of solifluction streams. In the granites of the Aldanskoye Nagorye at the foot of the frost-riven cliffs and scarps where block waste with a small content of fines occurs, mud tongues were found on the marginal parts of the terraces. Sheetwash and rill erosion are further agents. These agents are evidently most effective in the later stages of terrace development, especially in that of the summit flats. The summit flats are mostly covered with coarse-grained material. Under such conditions sub-surficial washing away of the fines (suffosion) will probably be of considerable importance. On the surface of the terraces the frost sorting of material also takes place, leading to the origin of various kinds of patterned grounds and stone stripes.

Most of individual agents in the development of cryoplanation terraces and flats change according to both the properties of the loose material and the stage of the development of forms.

Several stages in the development of cryoplanation terraces can be distinguished (*cf.* T. Czudek & J. Demek, 1961; G. F. Gravis, 1964; E. A. Vtyurina, 1966). The first stage is that of the nivation niche on the slope. Fine examples of this stage were found on the western slope, elevation 1549 m, in the Evota Massif (*cf.* Fig. 11). The second stage is the cryoplanation terrace with an inclination of about 7° and a well developed frost-riven cliff or scarp. The third stage begins immediately when the frost-riven cliffs or scarps on opposite slopes cross each other and disturb the older topographic surface. On the summit flat steep-sided tumps or tors of various size and dimension remain, that indicate approximately the position of the former topographic surface. The last stage is the extensive cryoplanation summit flat.

The rate of the development of cryoplanation terraces is various. The most rapid development probably takes place in a severe climate with sufficient snow which melts relatively soon in spring. Duration of temperature oscillations around freezing point which maintain sufficient soil humidity is also important. The cryoplanation terraces in the areas investigated in Yakutia, are still in formation, but there is a good cause to believe that in the past there was a period of more intense development of cryoplanation terraces.

ACKNOWLEDGEMENT

I am most grateful to prof. P. I. Melnikov, S. D., Director of the Institut Merzlotovedeniya of the Siberian Department, the Academy of Sciences of the U.S.S.R., for his generous help during my stay and for guidance and all valuable information on cryogene phenomena that in Yakutia.

I also wish to express my thanks to G. P. Gravis, scientific worker of the same Institute, for his assistance in field work and discussion on numerous problems concerning the cryoplanation terraces.

I wish to make grateful acknowledgement to E. M. Katasonov and I. V. Klimovski for their guidance in the field.

References

Aleschow, A. N., 1936 — Über Hochterrassen des Urals. *Ztschr. f. Geomorphologie*, Bd. 9; p. 143—149.

Boch, S. G., Krasnov, I. I., 1946 — K voprosu o granice maksimalnogo chetvertichnogo oledeneniya v predelakh Uralskogo khrebta v svyazi s nablyudeniyami nad nagornymi terrasami (summary: On the boundary of the maximum Quaternary glaciation in the Urals in the connection with the observations of mountainous terraces). *Bull. Kom. po izuch. chetvertichnogo Perioda*, no 8; p. 46—72, Moskva—Leningrad, Akad. Nauk S.S.S.R.

Boch, S. G., Krasnov, I. I., 1951 — Proces golcovogo vyravnivaniya i obrazovaniye nagornykh terras (Process of cryoplanation and origin of mountain terraces). *Priroda,* 1951, no 5; p. 25—30.

Bryan, K., 1946 — Cryopedology — the study of frozen ground and intensive frost action. *Amer. Jour. Sci.,* vol. 244; p. 622—642.

Czudek, T., Demek, J., 1961 — Význam pleistocenní kryoplanace na vývoj povrchových tvarů České vysočiny (summary: The importance of Pleistocene cryoplanation at the landscape development of Bohemian Highland). *Anthropos,* 14 (N. Ser. 6); p. 57—69. Brno.

Dengin, J. P., 1930 — Sledy drevnego oledeneniya v Yablonovom khrebte i problema golcovykh terras (Traces of past glaciation in the Yablonovoy Range and problem of goletz terraces). *Izvestiya Gosud. Russkogo Geogr. Obshchestva,* t. 62; p. 153—187.

Dengin, J. P., 1931 — Spuren früherer Vergletscherung in der Jablonovoikette und das Problem der Golezterrassen. *Ztschr. f. Geomorphologie,* Bd. 6; p. 292—298.

Derruau, M., 1965 — Precis de Géomorphologie. Paris; 415 p.

Dolgushin, I. J., 1961 — Geomorfologiya zapadnoy chasti Aldanskogo nagorya (Geomorphology of the western part of the Aldan Mts.). Moskva; 206 p.

Duparc, L., Pearce, F., 1905 — Sur la présence de hautes terrasses dans l'Oural du Nord. *La Géographie,* Bull. Soc. Géog. t. 11; p. 369—384.

Eakin, H. M., 1916 — The Yukon-Koyukuk Region, Alaska. *U.S. Geol. Survey, Bull.* 631; 88 p.

Frenzel, B., 1959 — Die Vegetations- und Landschaftszonen Nord-Eurasiens während der letzten Eiszeit und während der postglazialen Wärmezeit. I. Teil: Allgemeine Grundlagen. *Akad. d. Wissenschaften und d. Literatur, Agh. d. Mathem. Naturwiss. Klasse,* Jhg. 1959, Nr. 13; p. 937—1099.

Gakkelya, J. J., Korotkevich, E. S., 1962 — Severnaya Yakutia (Northern Yakutia). *Trudy Arkticheskogo i Antarkticheskogo Nauchno-Issledovatelskogo Instituta,* no. 236; Leningrad.

Gerasimov, I. P., 1952 — Sovremennyye perezhitki pozdnelednikovykh yavleniy vblizi samoy kholodnoy oblasti mira (Conternporaneous traces of post-Pleistocene phenomena near the very cold area of the world). *Izvestiya Akad. Nauk SSSR, Ser. Geog.,* 1952, no. 5; p. 16—22.

Gerasimov, I. P. (red.), 1965 — Yakutia. Moskva; 466 p.

Gravis, G. F., 1964 — Stadiynost v razvitiyi nagornykh terras (na primere khrebta Udokan) (Sequence of development of mountain terraces). *Voprosy Geog. Zabyakalskogo Severa*; p. 133—142, Moskva.

Gregory, K. J., 1966 — Aspect and landforms in north-east Yorkshire. *Biuletyn Peryglacjalny,* no. 15; p. 115—120.

Grigoryev, A. A. (red.), 1960 — Kratkaya geograficheskaya enciklopediya (Short geographical encyclopaedia). Moskva.

Guilcher, A., 1950 — Nivation, cryoplanation et solifluction quaternaires dans les collines de Bretagne Occidentale et du Nord de Devonshire. *Revue Géomorph. Dynamique,* t. 1; p. 53—78.

Gullentops, F., Mullenders, W., Schaillee, L., Gilot, E., Bastin-Servais, Y., 1966 — Observations géologiques et palynologique dans la Vallée de la Lienne. *Acta Geog. Lovaniensia,* no 4; p. 192—204, Louvain.

Hövermann, J., 1953 — Die Periglazial-Erscheinungen in Harz. *Göttinger Geog. Abhandl.*, H. 14; p. 1—39.

Jorré, G., 1933 — Le problème des „terrasses goletz" siberiennes. *Revue Géog. Alpine*, t. 21; p. 347—371.

Kondratyeva, K. A., 1966 — Osnovnyye osobennosti rasprostraneniya mnogoletnemerzlykh porod Aldano-Timptonskogo mezhdurechya (Main characteristics of permafrost extent in the area of the Aldan-Timpton interfluve). *Merzlotnyye Issledovaniya*, t. 5; p. 122—133, Moskva.

Kornilov, B. A., Timofeev, D. A., 1962 — Chetvertichnyye oledeneniya i drevniye i sovremennyye periglacialnyye obrazovaniya yugovostoka Sibirskoy platformy (Pleistocene glaciations and old and recent periglacial modelling of the south-eastern Siberian platform). *Voprosy Kryologii pri Izuchenyu Chetvertichnykh Otlozheniy*; p. 53—65.

Lewis, C. A., 1966 — The nivational landforms and the reconstructed snowline of Slaettaratindur, Faeroe Islands. *Biuletyn Peryglacjalny*, no 15; p. 293—302.

Makerov, J., 1913 — Nagornyye terrasy v Sibirii i proiskhozhdeniye ikh (Mountain terraces in Siberia and their origin). *Izvestiya Geol. Komiteta*, t. 32; p. 761—801.

Melnikov, P. I., 1966 — O glubokom promerzanii verkhnoy zony zemnoy kory v Yakutii (On deep freezing of the ground in Yakutia). *Sbornik Konfer. Geotermiya i Ispolzovaniye Tepla Zemli*; Moskva.

Mertie, J. B., Jr., 1937 — The Yukon-Tanana Region, Alaska. *U.S. Geol. Survey, Bull.* 872; p. 1—276.

Obruchev, S. V., 1937 — Soliflukcionnyye (nagornyye) terrasy i ikh genezis na osnovanii rabot v Chukotskom kraje (Solifluction (mountain) terraces and their origin in view of researches in the Chukotsk area). *Problemy Arktiki*, t. 3, p. 27—48; t. 4, p. 57—83.

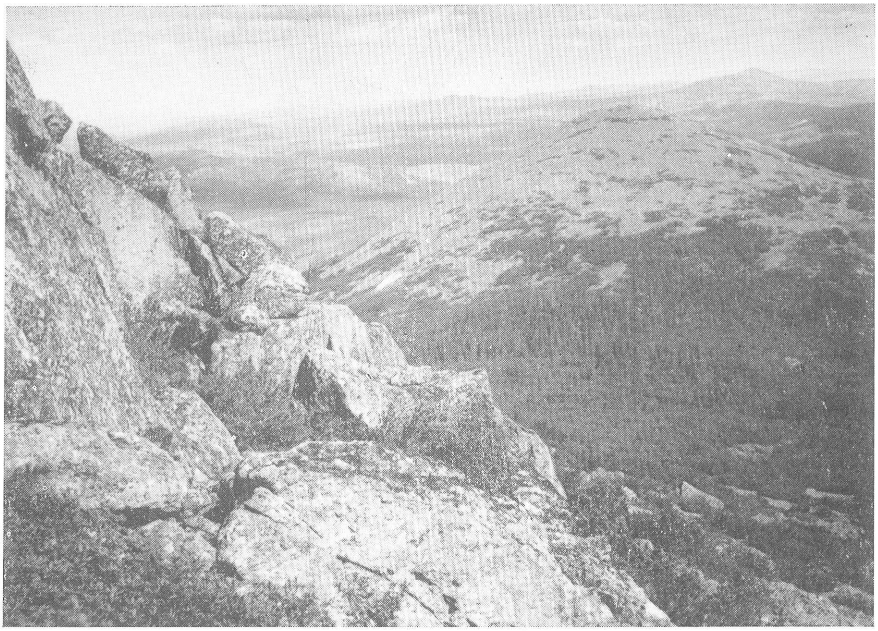
Pécsi, M., 1963 — Die periglazialen Erscheinungen in Ungarn. *Petermanns Geog. Mitteil.*, Jhg. 107; p. 161—182.

Peltier, L. C., 1950 — The geographic cycle in periglacial regions as it is related to climatic geomorphology. *Annals Assoc. Amer. Geographers*, vol. 40; p. 214—236.

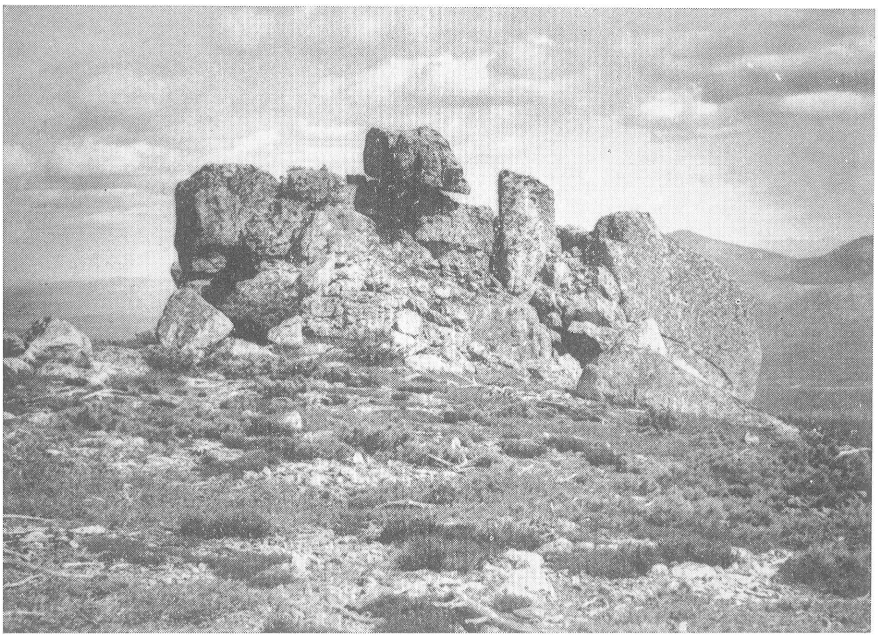
Richter, H., 1963 — Die Golezterrassen. *Petermanns Geog. Mitteil.*, Jhg. 107; p. 183—192.

St.-Onge, D., 1965 — La géomorphologie de l'Ile Ellef Ringnes, Territoires du Nord-Ouest, Canada. *Étude Géographique*, no. 38; 46 p., Ottawa.

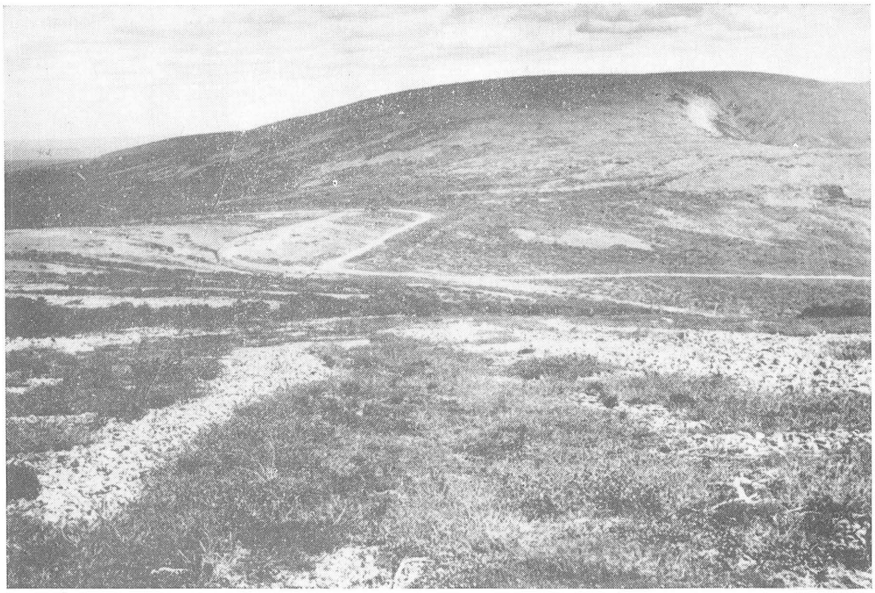
Vtyurina, E. A., 1966 — Kriogennyye sklonovyye terrasy (Cryogenic slope terraces). Moskva, 95 p.



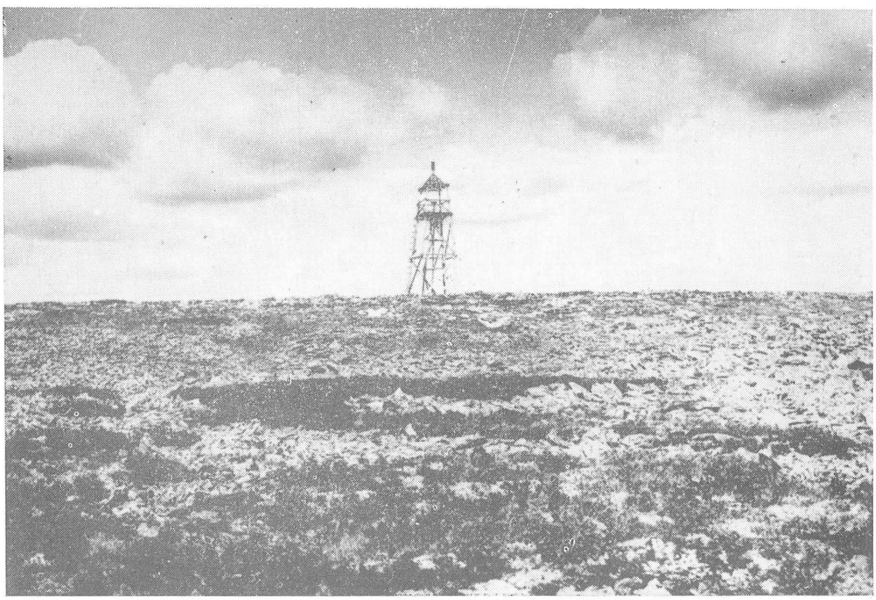
Pl. 1. General view of the relief of the so-called Aldanskiye Gol'tsy
In the foreground: granite rocks on the slope of Mt. Shapka Monomakha (1271 m)



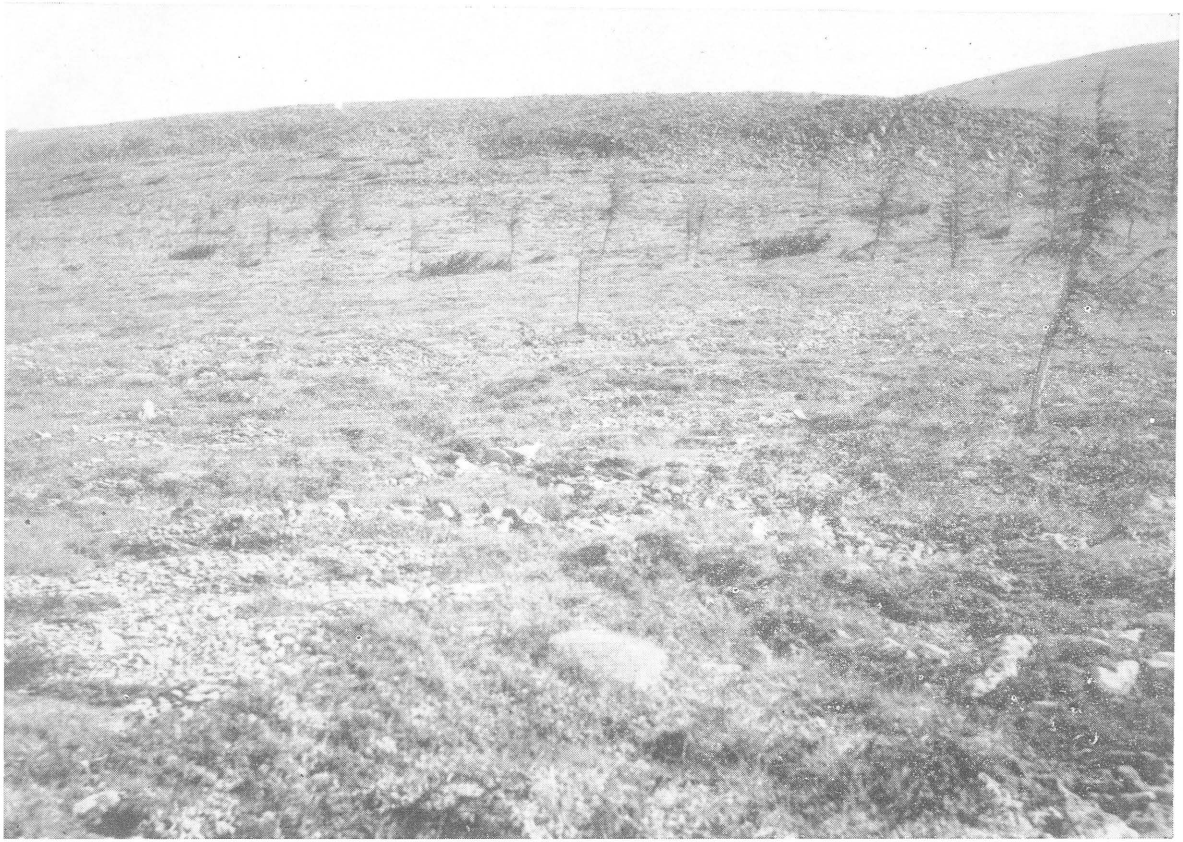
Pl. 2. Tors on the cryoplanation summit flat on Mt. Shapka Monomakha (1271 m)
In the foreground: polygonal grounds



Pl. 3. General view of elevation 1549 m in the Evota Massif in the Zapadnye Yangi Ridge
In the foreground: stone stripes on the eastern slope of Mt. Evota (1603 m)

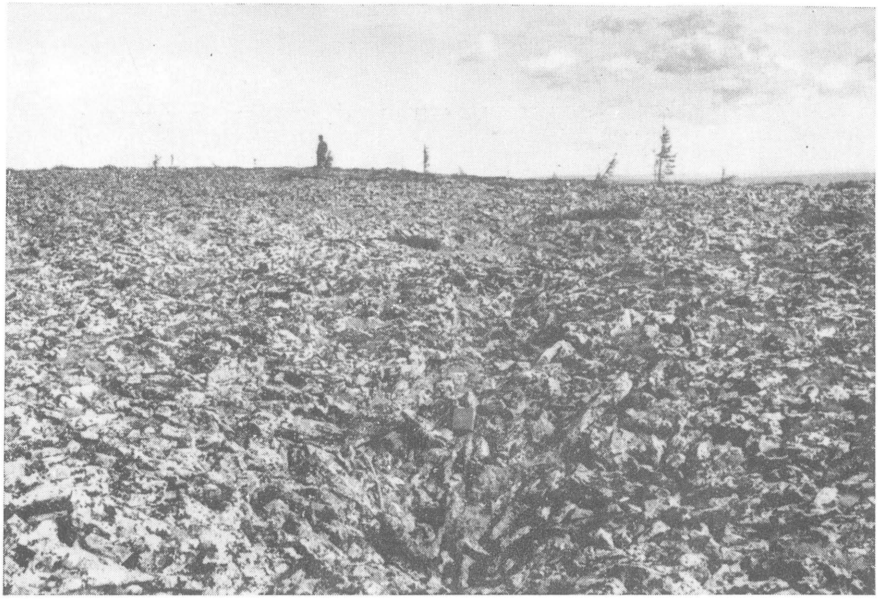


Pl. 4. Cryoplanation summit flat on Mt. Evota (1603 m)
In the foreground: macropolygons

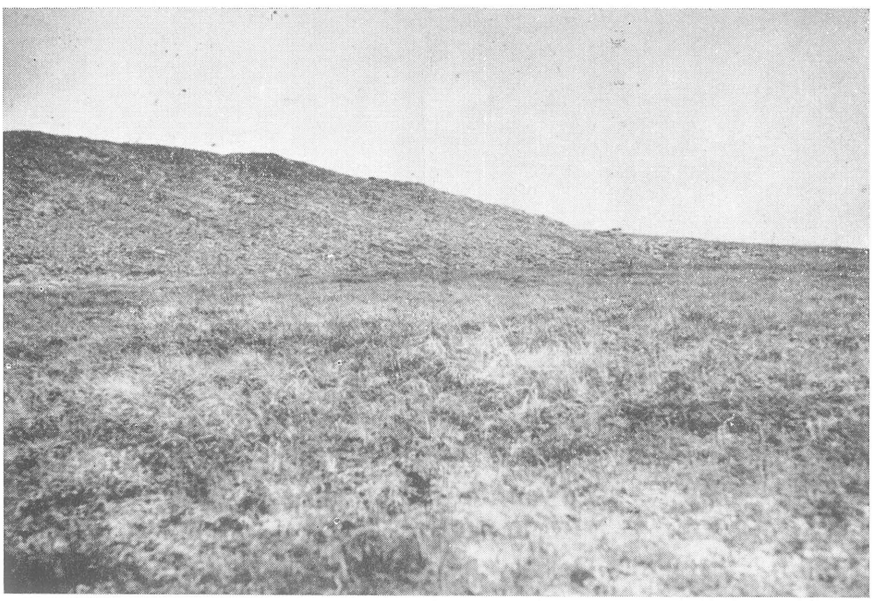


Pl. 5. Cryoplanation terraces on the western spur of elevation 1549 in the Evota Massif

In the background: a summit flat and below it a frost-riven scarp. In the foreground: polygonal grounds



Pl. 6. Cryoplanation summit flat on the spur of elevation 1549 m
A frost scar and in the foreground a nivation funnel can be seen



Pl. 7. Cryoplanation terrace on the southern slope of the Turku Hill in the Kular Ridge

Pl. 8. Polygonal grounds on the cryoplanation summit flat on the Turku Hill in the Kular Ridge
The polygonal grounds are developed in shale products of weathering