G. F. Gravis
Moscow

FOSSIL SLOPE DEPOSITS IN THE NORTHERN ARCTIC ASYMMETRICAL VALLEYS

Climate plays an important role in the accumulation of slope deposits. Its changes induce modifications in a whole range of slope processes reflected in the composition and structure of the correlate deposits. Such glучtuations are well known from the fossil periglacial zone of Europe (K e s s l e r, 1925; B ü d e l, 1937, 1953; D y l i k, 1955, 1961; A l e x a n d r e, 1960; Ž e b e r a, 1961; P é c s i, 1964, 1966), clearly related to glacial and interglacial times. Similar fluctuations were also recently recognized in the south of Eastern Siberia (L o g a c h e v, *et al.*, 1964; R o v s k i j, *et al.*, 1964; G o r s h k o v, 1967a, b). No climatically controlled changes in accumulation of slope deposits were, however, sofar recognized in northern and north-eastern Siberia. Does this mean that climatic oscillations were absent from these regions and that the slopes underwent uniform evolution throughout the whole Pleistocene?

This question can only be answered by the study of fossil slope deposits. Such deposits are rarely encountered (V a s y u n i n, 1958; S h i l o, 1961). Some irregularities are also observed in areas where slope processes are intensive, accumulation of slope deposits seems to be almost absent. It is certainly due to an insufficient knowledge of the Siberian slope sediments which are frequently believed to be of another origin. This assumption was confirmed by the writer's field studies in the Kular range, northern Yakutia, in 1963-66.

DISTRIBUTION OF SLOPE DEPOSITS IN THE NORTHERN PART OF THE KULAR RANGE

The Kular range is a rather low mountain complex mainly composed of Permian and Triassic sandstones, aleurites and shales folded NE-ward, and in some places disrupted by granite intrusions. On the Malyj Kyuegyulur—Yana interfluve the Kular northern foothills form a ridge-like landscape of Ulakhan-Sis, 150-310 m in altitude. The ridge consists of low, oval-shaped hills whose slopes grading 3-8° are overgrown with sub-Arctic tundra vegetation. Sparse deciduous forests occur only in deep valleys.

Elongated N—Sward the Ulakhan-Sis ridge decreasing in height northward passes gradually into a sea-shore plain. The river- and stream valleys are broad and asymmetrical (pl. 1) with generally long and gentle south-facing slopes. Most gentle are the west-facing slopes of the exceptional northerly oriented valleys.

In the asymmetrical valleys three main elements may be distinguished: (a) the valley floor, an innundation terrace and sometimes one above-flood terrace, (b) a terrace bench with a flat surface and better developed at the foot of south- (or west-) facing slopes, (c) the valley-sides built of smooth bed-rock thinly mantled with loose sediments.

On the valley bottom and under the terrace bench, pre-Quaternary formations and their eluvium are overlain by a pebble bed, 2-3 m (in some very few places up to 7-10 m) in thickness. The pebble horizon is covered with grayish-brown silts: on the valley bottom they have scarcely some tens of cms and on terrace benches — about 25-30 m in thickness. The silts are dissected by ice veins whose tops, 6-8 m in width occur at 1-1.5 m beneath the surface; downwards, they frequently wedge into the bedrock eluvium. In many cross-sections ice veins occur in several horizons. Further, silts show irregularly dispersed lenses and layers of segregation ice and in some horizons — ice lenses of injectional origin.

According to estimates by the geologists working in this region, the silts are of Upper Pleistocene age. They sometimes contain bones of Upper Pleistocene fauna and their pollen spectrum shows a reduced pattern (G o n c h a r o v, 1967). This and other workers' views on the origin of these silts are however divergent. The silts are generally regarded as alluvial-lacustrine sediments accumulated in deltas (K u z n e c o v a, 1967). The present writer, however, thinks they are mainly slope deposits because of some characteristic peculiarities in grain composition and occurrence.

SLOPE ORIGIN OF THE SILTS OCCURRING IN THE KULAR ASYMMETRICAL VALLEYS

The silts in the asymmetrical valleys of the Kular range occur predominantly on south- (or west-) facing slopes whereas they are scarcely some mts. in thickness or completely absent from the opposite slopes. On both valley sides the deposits within the active layer are sufficiently water-saturated and liable to solifluxion and/or creeping. Numerous solifluxion lobes and elongated tundra spots occur on the gently sloping surface of terrace benches and on valley sides. The valley bottom is separated from the terrace bench by festoon-like steps up to 0.5 m in height, composed of solifluxion ground. However, the rate of solifluxion on both the opposite valley sides varies according to the depth of seasonal thaw. On south-facing slopes thaw penetrates 50-70 cm deep whereas on the opposite sides the thawed layer scarcely attains 20-30 cm. Deeper penetrating thaw promotes more vigorous creeping on south-facing slopes and therefore from their foot or terrace benches long ground lobes extend downwards onto the flood plain. These lobes cause the stream channels to shift toward the leeward slopes which, being undercut, frequently show bare patches of bedrock. These observations suggest that the stream gradually widened the valley towards the leeward slopes whereas the opposite valley-bottom part is filled with slope deposits overlying alluvium sediments. Such an accumulational pattern is frequently observed in cross-sections through terrace benches where unstratified silts up to 30 m thick generally overlie river pebbles.

It is very characteristic that the silts building the terrace benches gradually decrease in thickness upwards along the valley sides but extend as far as to the bedrock outcrop on the interfluve. Their composition and structural properties, however, are similar.

Some characteristics of composition and structure testify to the slope genesis of the silts. The silts lack stratification. Only in some profiles there are marked discordantly dipping thin and short sandy lenses. The whole silty series is dissected by tiny grass rootlets *in situ*. This indicates that the deposits were accumulated under subaerial conditions because subaqueous (lacustrine and/or marine) sediments are deprived of such rootlets.

Debris stripes, 10-15 m long, extend downslope from all the bedrock outcrops. In silts debris fragments disperse gradually away and further from outcroping bedrock the solid particles are more weathered. The stone stripes (or "scythe" horizons according to S. S. Voskresenskij, *in*: Voskresenskij & Ananev, 1961) overlying silty series occur in such places where the valley bottom has terrace-like bedrock steps which undergo intensive denudation. Similar stone stripes including river pebbles originate also in places where rocky valley floor under terrace benches and river pebbles is considerably inclined towards the valley axis. Such stone stripes could be formed only as a result of transport of loose rocky material downslope by solifluxion.

In the silts building the terrace bench, thin intervenning layers of autochtonic peat occur locally composed mainly of moss remains. These layers are in general crumpled, twisted and broken. Similar deformations occur also in present-day solifluxion material.

The slope, or strictly the solifluxion origin of the silts is further manifested by their cryogenic character. Thin bands of segregation ice dip according to the slope surface. Cryogenic structures in permafrost are analogous to those in present-day solifluxion deposits, a fact that will be discussed below. Finally, various silty horizons show twisted and "ramified" asymmetrical ice veins (pl. 2). Similar veins are formed to-day but only on slopes where solifluxion is active (G r a v i s, 1962). If an ice vein is oriented transversally to the slope line, the forst fissure above undergoes shifting downslope due to solifluxion. The plane of least resistance to cracking, crossing through the fissure and ice vein, is inclined. New frost fissures originating successively join the ice vein at a small angle, always from below. Therefore the vein grows on one side and becomes asymmetrical. If the material is transported by rapid solifluxion, a "fan" of separated elementary fissures forms at the tip of the vein: it looks like a ramified vein.

All these characteristics of silts' structure and their distribution in the asymmetrical valleys of the Kular are clearly interconnected and testify to a slope i.e. solifluxion genesis of these deposits. There is no evidence of lacustrine-alluvial or deltaic properties except for the bottom part of the silty series which sometimes shows a faintly marked bedding and numerous non-deformed peaty layers and tree- or shrub remains. For instance, in the Burguat valley standing tree trunks were exposed *in situ*. Parallel and mainly horizontal ice layers are very distinct. Because of these characteristics the deposits may be defined as flood sediments. They were mantled with solifluxion already after their accumulation. The alluvial sediments of the flood terrace have no more than 1.0-1.5 m in thickness.

It has been put forward as evidence disproving the slope origin of the silts that they frequently lack debris and quartz particles. Frost weathering producing of the debris disintegration must be, however, taken into account. Due to processes of freeze—thaw quartz also disintegrates as demonstrated by laboratory experiments (M a z u r o v & T i k h o n o v a, 1964). The farther the distance of mass movement the longer did the ground undergo freeze-and-thaw; quartz is therefore hardly likely to remain preserved within the ground. Thus argillite and shale fragments disappear altogether at a distance of 10-15 m from the bedrock outcrops.

The assumption that the silts do not contain any debris particles because of frost weathering, is indirectly supported by the following facts. Vertically oriented sandy-shale rock fragments and quartz particles are frequently concentrated along the borders of ice veins developed in stone-free silts. Obviously, these rock fragments could seep from the surface only down frost fissures that were parallel to the ice-vein borders rather than those in the center. As the stones were incorporated into the frozen layer they could not be further disintegrated whereas these rock fragments contained in the active layer underwent continuous disintegration as a result of the aggrading permafrost table.

CRYOGENIC STRUCTURE OF FOSSIL SLOPE DEPOSITS

The cryogenic structure of the fossil slope deposits filling the Kular asymmetrical valleys is very complex. Apart from some differences found in a number of sections the deposits fall into two types.

The first type (fig. 1) is characteristic of the upper segments of asymmetrical valleys where the terrace benches are not well shaped and the slope deposits form gentle lobes. A similar pattern is also typical of the valleys situated in the zone where the Kular range passes into maritime lowland. Relative heigths are here scarcely more than 50 m, and the valleys are very broad; long and very gentle lobes with small outward fronts extend on both their sides.

In all the valleys such lobes exhibit 6 horizons differing in composition and cryogenic structure. Three horizons — 2, 4, and 6 (from the top: fig. 1) — each 2-8 m thick, similar in structure are composed of grayish-brown silts containing numerous grass roots *in situ*. No other plant remains were found.

The silts contain faintly visible, irregularly dispersed ice lenses. Small ice balls occur as well. In the top of each horizon the ice lenses are more numerous and form thin (from a fraction of 1 mm to 5-6 cm) bands which join the "ramifications" of large ice veins. This testifies to their syngenetic origin (Katasonov, 1958). Moreover, the whole pattern suggests that ice veins grew lateraly, especial-

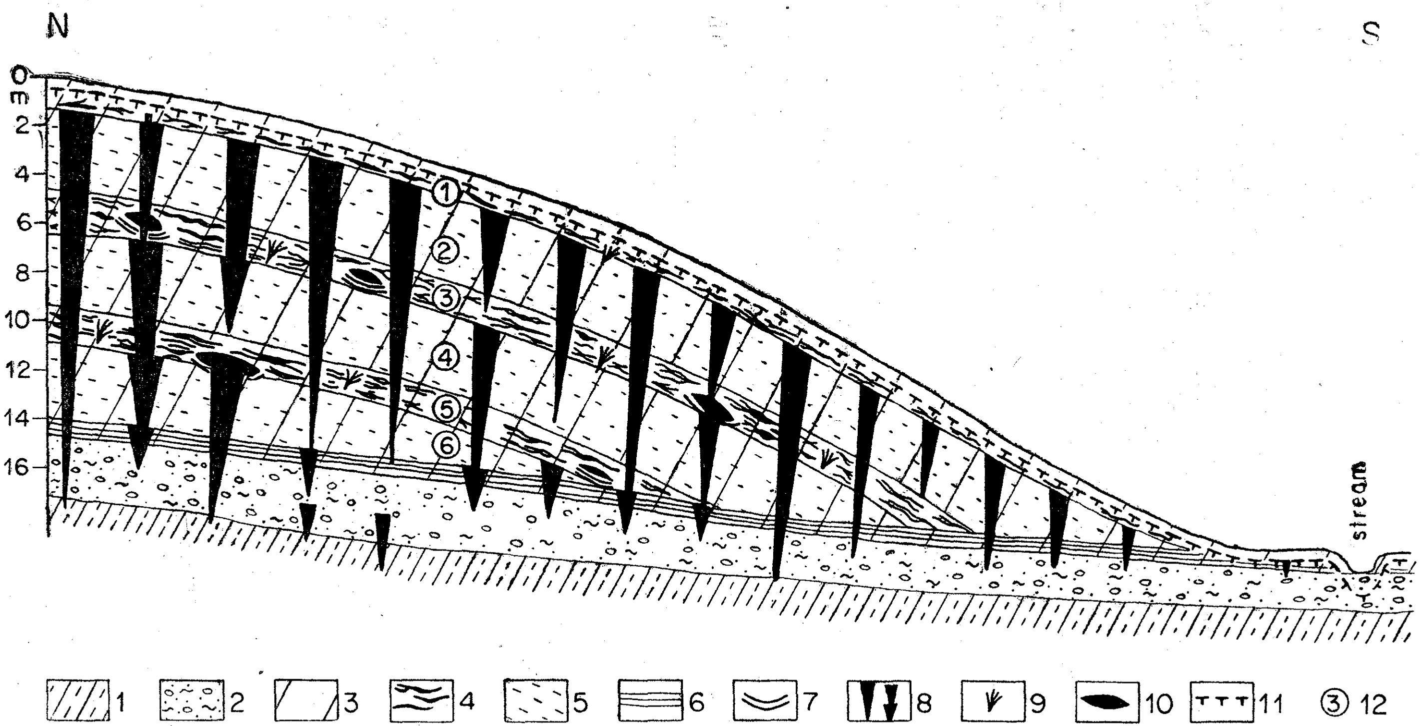


Fig. 1. Schematic cross-section through slope deposits in the asymmetrical valleys of the northern Kular range (first type)

1. bedrock; 2. river pebbles; 3. silt; 4. indistinct and discontinuous ice layers in solifluxion deposits; 5. thin ice bands in solifluxion deposits; 6. horizontal ice layers in alluvial sediments; 7. arcuate ice layers in lacustrine sediments; 8. ice veins; 9. "ramified" ice veins; 10. injection-ice lenses; 11. permafrost table; 12. numbers of the slope-deposit horizons

ly during the accumulation of the silts with small ice bands. New ice veins originated at that time.

Horizons 3 and 5 are composed of gleyed bluish-gray silts with deformed peat interlayers and shrub- and tree remains. Trunk fragments are encountered far in the tundra zone from where forest vegetation is absent to-day. The horizons are 1-3 m, rarely up to 5 m in thickness. The silts show numerous and large ice lenses up to 0.5 cm thick. They constitute a background for larger but indistinctly outlined and disrupted ice layers. In some places, however, there are no such interlayers and cryogenic structure is manifested only be ice lenses with their tips joined. Both the horizons show often small "ramified" and discontinuous ice veins.

Composition and cryogenic structure clearly change in the middle parts of these horizons: there occur rather small superimposed lense--like beds of lacustrine sediments (several mts in length and less than 1 m in thickness). Their lacustrine origin is indicated by horizontal stratification of a varved type. Tiny tree roots disappear in these lenses. In some places are small intrusions of vivianite.

The lacustrine silty lenses are underlain by arcuate, thin and parallel ice layers which truncate the ice intrusions in the silts below. The mineral ground between and above the bent ice layers is closely dissected by vertical or inclined short ice veins. Moreover, small lenses of injection ice occur within the top of the lacustrine sediments.

Most of the lense-like lacustrine beds including injection ice overlie fossil ice veins. For, only a part of the ice veins grew laterally and upwards during the sedimentation of horizons 3 and 5, whereas some veins ceased to develop or underwent thawing from the top downward.

The silty upper horizon (1) shows a somewhat different composition. It also contains crumpled peat layers but tree remains occur only in the deposit of those slopes which are forested to-day. The bottom part of this horizon is correlated with the tops of large ice veins whereas its top forms the downward surface of the active layer. Its thickness is only rarely more than 1-1.5 m. Cryogenic structure in the lower part of this surficial horizon is revealed by ice lenses, up to 0.5 cm thick. Upwards, the intrusions of segregation ice increase in volume. Hence, the wings of the horizon are mostly ice--filled: 15-20 cm thick ice layers are distributed 5-7 cm apart, indistinct and disrupted in the tundra area (pl. 3), and well-defined on forested slopes.

In this horizon ice veins are scarce and rather short. In most cases they are rather „insertions" into the large ice veins occurring below.

Thus the frozen slope deposits typified by the first kind of profiles show a composite cryogenic structure. Evidence of this are the rhythmically alternating horizons described above and some regularities in the changes of a cryogenic pattern within each of these horizons. This pattern is strongly obliterated due to the presence of ice veins, because some of them developed continuously only sometimes expanding laterally (within horizons 2, 4, and 6), while other ice veins were interrupted during their formation. Therefore, the big veins intersecting the whole bed may be accompanied by small ones.

The second type of profiles (fig. 2) is characteristic of those asymmetrical valley parts in which the terrace benches have an entirely smooth surface (1-3°) and clearly formed risers (15-20°). Four horizons are found here differing in cryogenic structure.

The first horizon — from the top — of frozen slope deposits does not essentially differ from the surficial horizon of the afore-described profile type. Silts of this horizon entirely mantle the terrace bench and its risers encroaching on the valley sides.

Horizon 2 is only connected with the gentle surfaces of the terrace benches. Up to 6 m in thickness, it is composed of gleyed bluish-gray silts containing small tree roots and remains of peaty plants. The horizon is characterized by a high content of segregation ice and large ice veins whose top parts attain 6-8 m in size. The ice veins form polygons whose mineral centers have no more than 4-5 m across. Silts in polygonal blocks are interbedded with closely spaced concave ice bands intersected by small ice lenses. Small lenses of injection ice often occur in the most concave parts of these ice bands. The concavity of the ice layers is partly primary — due to formation of polygonal-and ridge-like microrelief forms on gentle slopes, and is partly secondary because of the lateral growth of ice veins: expanding veins pressing against the frozen ground, caused its slow deformation and upward bend along the ice-vein borders.

Horizon 3 forms the main part of the terrace benches. Only their fronts are covered with thin deposits of surficial horizon 1. Horizon 3 varies from 2-3 to 10-15 m in thickness and is composed of brownish-gray silts with small and thin tree roots. Apart from very small ice lenses there are nest-like ice concentrations but very often

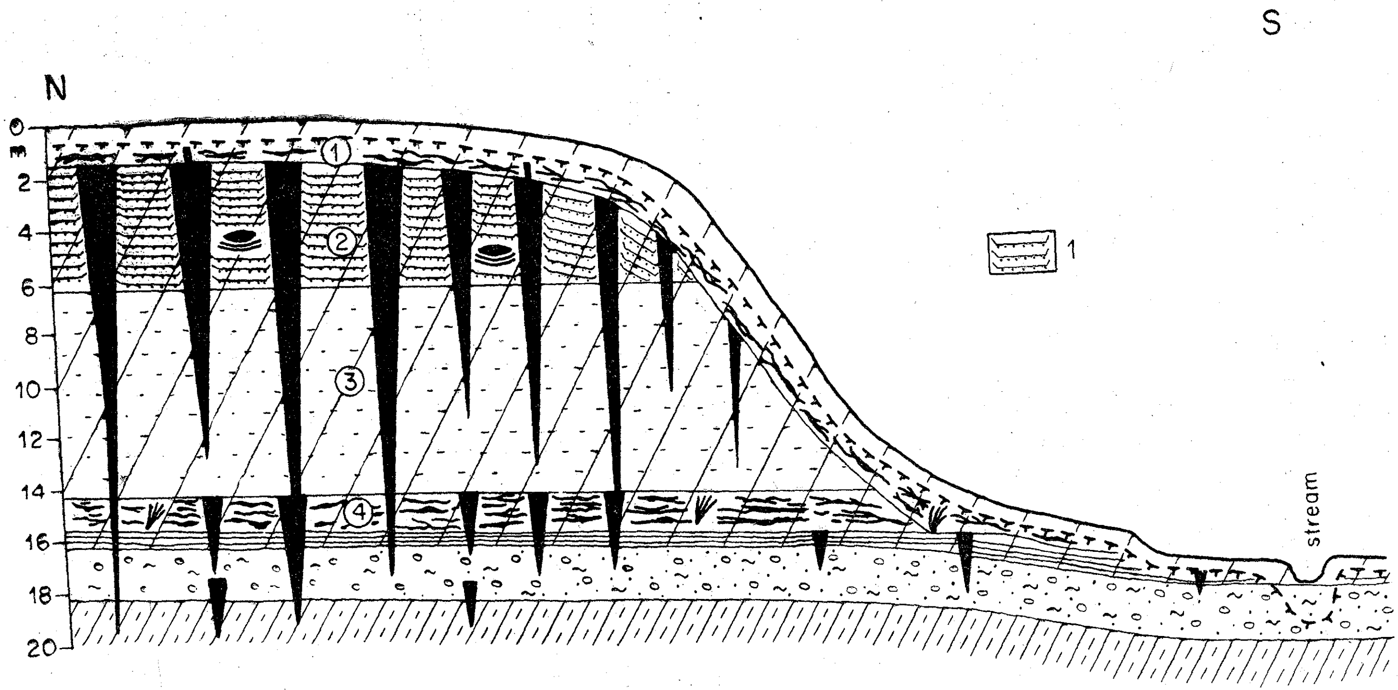


Fig. 2. Schematic cross-section through slope deposits in the asymmetrical valleys of the northern Kular range (second type)

1. bent and deformed ice layers and streaks in polygonal mineral blocks; other signatures — see fig. 1

ice of both forms is absent even though the ground is entirely moist. At first sight the silts resemble those of horizons 2, 4, and 6 of the first type profiles. The ice veins form a loose network thus giving the impression as if some of them, penetrating from above, had wedged out in this horizon.

Horizon 4 directly overlies river pebbles or flood sediments. It is 1-2 m thick and composed of blueish-gray silts containing remains of peaty plants and shrub twigs. There is a great number of 0.5 cm ice lenses as well as indistinct and disrupted ice layers. The polygonal network of ice veins becomes more dense because the formation of ice veins began in the underlying flood sediments and continued its evolution during the sedimentation of horizon 4. In some places, the ice veins are inclined and ramified.

The profiles of the second type do not show any such a rhythmic alternation of structure as is characteristic of the first-type profiles.

PRESENT-DAY CORRELATES OF CRYOGENIC STRUCTURE OF FOSSIL SLOPE DEPOSITS

For a correct recognition of the paleogeographic conditions under which fossil slope deposits were accumulated — taking into account their cryogenic structure — it is necessary to examine thouroughly the corresponding present-day deposits. It should be further remembered that the type of cryogenic structure of syngenetically freezing sediments depends in general on the facial conditions of accumulation and upfreezing of the deposits.

Inclined and "ramified" ice veins, the presence of bent layers in slope waste, and of crumbled peaty bands, various solifluxion surface forms on the terrace benches, are all characteristics of the solifluxion origin of the slope deposits. Therefore, the present-day analogues of the cryogenic structure of fossil deposits should be looked for in solifluxion deposits.

Investigations in various regions of Yakutia have shown that frozen solifluxion deposits contain a large quantity of ice. In the most mobile segments of solifluxion terraces, -streams, and -covers, a dense network of ice lenses originates during upfreezing of the sediments, but ice layers and bands are absent. However, short, thin and indistinct ice bands appear on the background of the ice-lense network in such places in which the material is not so mobile and overgrown at the surface with a dense moss-cover. On the more stabilized slopes with episodic and discontinuous solifluxion, previously observed broken ice layers have become longer and thicker (pl. 4). At last, clear ice layers elongated downslope appear on slopes that are saturated with water and entirely moss-covered, from which solifluxion is to-day altogether absent.

According to the above-mentioned observations it may be stated that the type of cryogenic structure in silts on mostly water-saturated slopes is — first of all — controlled by the dynamics of slope processes varying under different facial conditions. The more denudation and accumulation are intensive the more mobile is the permafrost surface and the less clear are the ice layers under this surface.

This is due to the growing of ice layers and ice bands throughout many years within the syngenetically freezing subaeral deposits. These ice layers grow on the permafrost table owing to coalescence of new ice lenses with those previously formed. Such freezing together is possible only in years with warmest summers when thawing attains its maximum depth. Thick and distinct ice layers grow only if the permafrost table does not change its level over a longer period.

Vigorous denudation and accumulation on slopes are causes of changes in the permafrost table. Ice lenses cannot freeze one to another and therefore they do not form ice layers though the deposits are strongly saturated with water.

This important regularity permits to determine the conditions of accumulation of the fossil slope deposits belonging to horizons 1, 3, and 5 in the sections of the first type. The cryogenic structures of these horizons are similar to those described above belonging to the range of cryogenic structures formed synchronously within the solifluxion deposits. Such structures are characteristic of sub-Arctic tundra and forest-tundra zones. Therefore, it may be assumed that similar conditions existed in this area during the accumulation and upfreezing of the deposits belonging to the fossil horizons mentioned above.

As these cryogenic structures have no correlates in the present-day deposits of this area, it is difficult to recognize the conditions of formation of horizons 2, 4 and 6. Because of the absence of peaty interlayers and of any other tree- or shrub remains these deposits must have presumably originated in a very severe climate. Therefore the present-day correlates of such series should be looked for farther north of the sub-Arctic tundra, i.e. in the Arctic tundra or/and in the cold desert zone. In the latter zones there occur smooth foothills which are almost entirely devoid of a turf cover; structural solifluxion is here active producing elongate tundra spots (*pyatna medaliony*) and solifluxion lobes. The present writer, however, was unable to examine such lobes because his studies were limited to some reduced areas of north-facing slopes with structural solifluxion in the sub-Arctic tundra. It appeared that the frozen deposits in the area investigated contain less ice than the adjacent turf-covered slopes on which amorphous solifluxion occurs but from which elongate tundra spots and solifluxion lobes are completely absent.

Moreover, ice lenses are small in places where structural solifluxion operates on the surface: closely spaced lenses merge into one another forming ice bands, but ice layers proper do not develop. However, nest-like ice concentrations occur filling voids which in dusty sediments are due to disturbances of their tixotrophic structure.

Deposits on slopes with structural solifluxion do not contain any peat layers because the slope surfaces are devoid of turf. Moreover, the silts are not gleyed because air-circulation in the ground is possible due to summer desiccation of tundra spots and solifluxion lobes.

Although ice intrusions in slope deposits of structural solifluxion are not fully identical with very thin ice lenses in fossil slope deposits all their similarities, however, seem to confirm the assumption that the silts in horizons 2, 4, and 6 of the first type profiles were accumulated under conditions of Arctic tundra and/or Arctic desert.

RHYTHMIC ALTERNATIONS IN THE STRUCTURE OF THE SLOPE DEPOSITS AS A RESULT OF PERIODICAL CLIMATIC CHANGES

(Profiles of the first type)

Figure 1 shows that the main bulk of the terrace benches is composed of deposits belonging to horizons 2, 4, and 6, which were accumulated and frozen under severer climatic conditions than those prevailing to-day (most likely: Arctic tundra or cold desert). The deposits providing evidence of a severe climate are intersected by those formed in sub-Arctic- and/or forest-tundra (horizons 3 and 5);

at that time the forest limit extended farther northward than to-day. Horizon 1 was also formed in a milder climate.

Thus, during the Upper Pleistocene (Würm) and the Holocene, sub-Arctic tundra of forest-tundra alternated with Arctic tundra or cold desert. These alternations were controlled by three great waves of cold climate separated by relatively warmer phases.

The age of these coolings and relative warmings of climate is as yet imperfectly known. They are believed to have been paralleled with the würmian stadials and interstadials, according to the regional stratigraphy of the Quaternary deposits of the Siberian platform (Alekseyev, Ravskij & Cejtlin, 1966). The last milder phase — surficial horizon 1 — is commonly regarded as Holocene in age.

Hence the two first cold phases would correspond to the two stadials of the Zyryan glaciation, and the last one — to the Sartan glaciation. Consequently, the first milder phase would be correlated with the Zyryan interstadial while the second one with the Kargin age.

At the close of the Lower Pleistocene and in the Kazancov period, broad and deep valleys were formed in the northern border of the Kular range. Trees grew on the flood plains situated above the present-day tree line. Permafrost however existed at that time because the gravels of the same age contain small ice layers which were formed due to adhesive upfreezing to the permafrost table.

The first cold phase promoted the activity of slope processes. Under the conditions of Arctic tundra or cold desert, the valley slopes being poorly covered with turf became areas of deluvial (colluvial) processes (*vide*: discordant and diagonal sandy series in silts) and of structural solifluxion that was especially intense on deeper thawing south-facing slopes. Huge masses of deposits derived from these slopes caused the stream channels to shift towards the opposite lee-slope; these deposits mantled river pebbles and alluvium. Accumulation in stream channels increased because the highly overloaded streams were inapt to remove the slope material.

Vigorous slope processes induced uninterruptedly rapid changes in the permafrost table. Therefore, smaller ice lenses that orginated while the silts froze up, did not freeze to each other for the upper part of permafrost was entirely and uniformly impregnated with ice. Within the slope deposits increasing in thickness, ice veins were formed, but such that were oriented according to the line of slope. Thus the polygons became elongated.

Later, the rate of accumulation decreased; as a result the permafrost table acquired a certain degree of stabilization and the ice lenses could begin joining each other. Consequently thin intervening ice layers were formed which are visible as bands in the top part of horizon 6. Ice-vein formation continued but, due to a slow rate of accumulation, the veins grew intensively in width. Owing to the development of veins oriented across a slope there was also deformation of polygons.

With the decrease of slope processes grew the activity of streams which deepened and widened the valleys by transporting the accumulated material.

The direct reasons for which accumulation decreased are so far unknown. Most probable however was the decreasing humidity of climate in the mid- or late phase of the cold periods, as it is stated already for the Pleistocene periglacial zone of Europe and Southern Siberia (Büdel, 1953; Sekyra, 1961; M. P. Grichuk & V. P. Grichuk, 1960; Giterman, Golubeva, *et al.,* 1965). The growing aridity of climate inhibited structural solifluxion though intensive deluvial (colluvial) processes were still active.

The subsequent amelioration of climate favoured the invasion of sub-Arctic- or forest-tundra (horizon 5). The slopes became covered with grass, shrub and moss vegetation. The depth of seasonal thawing was thereby reduced though the climate was milder. Structural solifluxion was replaced by amorphous solifluxion, and colluvial processes ceased almost entirely. The rate of ice-vein growth was considerably reduced, and some of the previously developed veins became inclined due to solifluxion.

Moss-and-peaty cover on gentle slopes, growing gradually in thickness, reduced the depth of seasonal thawing. Solifluxion is practically absent if thawing reaches 20-30 cm. Those conditions favoured ice-vein growth; polygons with ridges bordering the wedge sides (= low centered polygons) developed therefore on the gentle slopes. In the concave polygon centers appeared marshes or shallow lakes.

Widening and deepening of valleys continued. Streams undercutting the slope deposits formed scarps; thus colluvial processes were intensified (above the scarps), mainly along the grooves above the ice-veins. These grooves were being widened and deepened, ice veins partly melted away. All this contributed to the enlargement of troughs in which stagnant water accumulated. Traces of such small water basins are visible in the form of the above-mentioned lenses of varved deposits with arcuate intervening ice layers.

Successive climatic changes — cooling and increasing humidity — partly reduced the moss cover on slopes promoting a wider distribution of moss and cotton grass. As a result, seasonal thawing was penetrated deeper and therefore solifluxion was more vigorous. Polygonal microrelief on slopes became obliterated, the depressions containing small lakes were filled with sediments in which lenses of injection ice were formed during subsequent freezing. Traces of solifluxion are recognizable within horizon 5 in the form of crushed peaty layers, "ramified" veins, or broken and discontinuous intervening ice layers.

As a result of further cooling of the climate, forest-tundra or sub--Arctic tundra retreated and Arctic tundra or cold desert prevailed again (horizon 4). During this and the next — Sartan — cooling as well as during the milder — Karginsk — interphase, slope processes were likewise differentiated. The reduced rate of solifluxion and increasing development of peat- and moss covers during the Holocene induced a progressive growth in thickness of the ice layers, their well-marked outlines and length towards the top of this horizon. Minor phases of Holocene solifluxion, either increasing or decreasing, are not revealed by the structure of the slope deposits.

THE INFLUENCE OF GEOMORPHIC AGENTS UPON THE STRUCTURE OF SLOPE DEPOSITS

(Profiles of the second type)

Profiles of the second type do not show any rhythmic pattern of structure and their description was therefore omitted in the foregoing chapter. The character of permafrost depends on the part of well-formed terrace benches on which the deposits were accumulated and frozen: in lobe margins, at the lobe base, on the lobes themselves, or on the surface of terrace benches partly overlain by slope deposits.

The sediments of horizon 4 are of solifluxion or slopewash origin. They were deposited and frozen on the margins of lobes encroaching on the flood plain, in front of a terrace bench. Here, the surface is entirely saturated with water seeping from the terrace bench boggy and overgrown with moss, even under Arctic-tundra conditions. The active layer is fairly thin, no more than some tens of cms. Structural solifluxion is absent, and even amorphous solifluxion is weak because of negligible inclination. Ice veins, which began to form on the flood plain, underwent further growth in the deposits forming the border parts of lobes though they are here often inclined and "ramified".

The deposits of horizon 3 being of solifluxion origin accumulated and froze up in the upper and steeper parts of the lobes which form the front of the terrace benches. The presence within them of ice lenses and ice "nests" tesifies to the cold conditions under which this horizon originated; slope processes became more active, and lobes encroached upon the flood plain and shifted the stream channels sidewards.

The deposits of horizon 2 are also of solifluxion origin. They accumulated and froze up on the relatively gentle surface of terrace benches grading no more than 1-3°. As a result, the slope processes are slow, the permafrost top is stable, and ice lenses can freeze up to each other forming streaks and intervening closely spaced layers. Simultaneously large ice veins are formed.

The deposits of horizon 1 are present throughout the whole surface of the terrace benches. These solifluxion deposits are identical with those of horizon 1 of the first type sections. They are probably Holocene in age.

No periodical climatic changes, whose evidence would be recorded in the slope deposits, have been found in those parts of the asymmetrical valleys where the terrace bench has a well-formed riser. Thin horizons containing indistinct and disrupted ice layers were formed on steep lobe risers at the front of terrace benches during relatively cool periods. They were destroyed at the time of recurrent cooling and revival of slope processes. Thus, deposits from various cool phases merge together into one horizon (3). Thin but overlapping horizons, corresponding to separate cold and warmer phases, occur within the deposits which mantle the levelled surface of terrace benches. Cryogenic structures are homogeneous but strongly deformed by large ice veins. Therefore, the paleogeographic conditions could not be determined on the basis of examination of these deposits. It might be possible only when studying these deposits in those parts of asymmetrical valleys where terrace benches lack distinct risers.

In other regions of northern Yakutia, lobes composed of slope deposits have a similar structure. This evidence from the Kular range permits to assume a generalized occurrence of paleoclimatic oscillations.

CONCLUSIONS

In the asymmetrical valleys of northern Yakutia there are thick covers of slope deposits. Until now many scientists regarded them as formations of another origin. In the upper valley segments the lobes composed of slope deposits show rhythmic alternations in their structure due to periodical changes of climate and of slope accumulation.

In northern Yakutia, solifluxion deposits, poor in organic remains correspond to cool phases during which slope processes operated intensively. They include an abundance of thin ice lenses and nest-like ice intrusions and exhibit large ice veins. During the warmer oscillations the rate of slope processes decreased whereas solifluxion deposits grew in thickness becoming gleyed and enriched with organic matter, such as: disturbed and nest-like peaty layers, shrub twigs and fragments of tree trunks. These deposits contain rather large intrusions of segregation ice: ice bands and discontinuous ice layers. Ice veins are often asymmetrical, inclined and "ramified". There are also some small lenses of lacustrine sediments containing injection ice.

In northern Yakutia three würmian phases of increasing climatic severity have been distinguished which are correlated with two stadials of the Zyryan glaciation and with the Sartansk glaciation. Warmer oscillations correspond with the interstadials and the postglacial time.

Traduction de Ł. Dutkiewiczowa

References

Alekseev, M. N., Ravskij, E. I., Cejtlin, S. M., 1966 — Osnovnye geokhronologicheskie etapy antropogena Sibirskoj platformy (Main geochronological stages of the Anthropogene of the Siberian platform). *Izv. Akad. Nauk SSSR, ser. geol.*, No. 3.

Alexandre, J., 1960 — La succession probable des phases morphologiques au cours d'un cycle climatique quaternaire en Haute Belgique. *Biuletyn Peryglacjalny*, No. 9.

Büdel, J., 1937 — Eiszeitliche und rezente Verwitterung und Abtragung im ehemals nicht vereisten Teil Mitteleuropas. *Petermanns Geog. Mitteil.*, Ergzh. 229.

Büdel, J., 1953 — Die „periglazial"-morphologischen Wirkungen des Eiszeitklimas auf der ganzen Erde. *Erdkunde*, Bd. 7.

Dylik, J., 1955 — Rhythmically stratified periglacial slope deposits. *Biuletyn Peryglacjalny*, No. 2.

Dylik, J., 1961 — Analyse sedimentologique des formations de versant remplissant les depressions fermées aux environs de Łódź. *Biuletyn Peryglacjalny*, No. 10.

Giterman, R. E., Golubeva, L. V., *et al.*, 1965 — Osobennosti rastitelnogo pokrova vremeni zyryanskogo oledeneniya Sibiri (Some characteristics of vegetation cover of Zyryansk glaciation time in Siberia). *Izv. Akad. Nauk SSSR, ser. geol.*, No. 3.

Goncharov, V. F., 1967 — Stratigrafiya chetvertichnykh otlozhenij Kularskogo zolotonosnogo rajona (Stratigraphy of Quaternary deposits of the Kular gold-bearing region). *Geologia i Geofizika*, No. 4.

Gorshkov, S. P., 1967a — O genezise i vozraste sklonovykh glybovo-shchebnisto-suglinistykh otlozhenij severa Yenisejskogo kryazha i severo-zapada Vostochnogo Sayana (On the origin and age of debris-silty deposits of the N-Yenisej range and NW-part of the E-Sayan). *Doklady Akad. Nauk SSSR*, t. 172, no. 3.

Gorshkov, S. P., 1967b — O trekh etapakh v razvitii sklonov denudacionnykh massivov na yuge Krasnoyarskogo kraya (Three stages of slope development of the denudational massifs in the southern Krasnoyarsk region). *Vestnik Mosk. Gos. Univ.*, ser. V: *geog.*, No. 2.

Gravis, G. F., 1962 — Ledyanye zhily v deluvialno-soliflukcionnykh otlozheniyakh (Ice veins in deluvial (colluvial) and solifluxional deposits). In: *Voprosy Geografii Yakutii*, vyp. 2; Yakutsk.

Grichuk, M. P., Grichuk, V. P., 1960 — O prilednikovoj rastitelnosti na territorii SSSR (On peri-glacial vegetation within the U.S.S.R. territory). In: *Periglacialnye yavleniya na territorii SSSR*, MGU ed.

Katasonov, E. M., 1958 — Ledyanye zhily i prichiny izgibaniya sloev v merzlykh chetvertichnykh otlozheniyakh (Ice veins and causes of layer bending in Quaternary frozen deposits). *Materialy k osnovam uchen. o merzlykh zonakh zemnoj kory*, vyp. 4; Moscow.

Katasonov, E. M., 1962 — Kriogennye tekstury, ledyanye i zemlanye zhily kak geneticheskie priznaki mnogoletnemerzlykh chetvertichnykh otlozhenij (Cryogenic structures and ice- and ground veins as genetic indicators of Quaternary permafrost). In: *Voprosy kriologii pri izuchenii chetvertichnykh otlozhenij*; Akad. Nauk SSSR ed, Moscow.

Kessler, P., 1925 — Das eiszeitliche Klima und seine geologischen Wirkungen im nicht vereisten Gebiet. Stuttgart.

Kuznecova, T. P., 1967 — Nabludeniya za poligonalno-zhilnymi ldami v predgoryakh Kularskogo khrebta (Observations on poligonal vein ice in the Kular foothills). *Podzemnyj led*, vyp. 3; MGU ed.

Logachev, N. A., Lomonosova, T. K., Klimanova, V. M., 1964 — Kajnozojskie otlozheniya Irkutskogo amfiteatra (Cenozoic deposits in the Irkutsk amphitheater). Nauka ed., Moscow.

Mazurov, G. P., Tikhonova, E. S., 1964 — Preobrazovanie sostava i svojstv gruntov pri mnogokratnom zamorazhivanii (Composition- and properties changes of grounds by repeated freezing). *Vestnik Leningradskogo Univ.*, No. 18: *ser. geol.-geog.*

Pécsi, M., 1964 — Chronological problems of the patterned soils of Hungary. *Biuletyn Peryglacjalny*, No. 14.

Pécsi, M., 1966 — Problèmes quaternaires de la recherche géomorphologique des montagnes centrales Intracarpathiques. *Geographica Polonica*, No. 10; Warsaw.

Ravskij, E. I., Aleksandrova, L. P., *et al.*, 1964 — Antropogenovye otlozheniya yuga Vostochnoj Sibiri (Anthropogene deposits of southern East Siberia). *Trudy Geol. Inst. Akad. Nauk SSSR*, Vyp. 105.

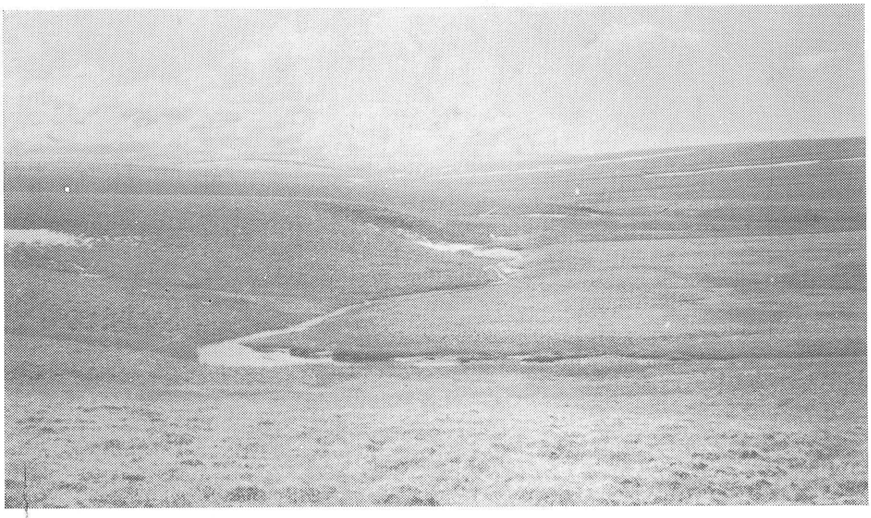
Sekyra, J., 1961 — Periglacial phenomena. *Prace Inst. Geol.*, t. 34, part 1; Warsaw.

Shilo, N. A., 1961 — Chetvertichnye otlozheniya Yano-Kolymskogo zolotonosnogo poyasa, usloviya i etapy ikh formirovaniya (Quaternary deposits of the Yana-Kolyma gold-bearing zone — conditions and stages of their formation). *Trudy VNII-I*, t. 16, vyp. 66: *geol.*

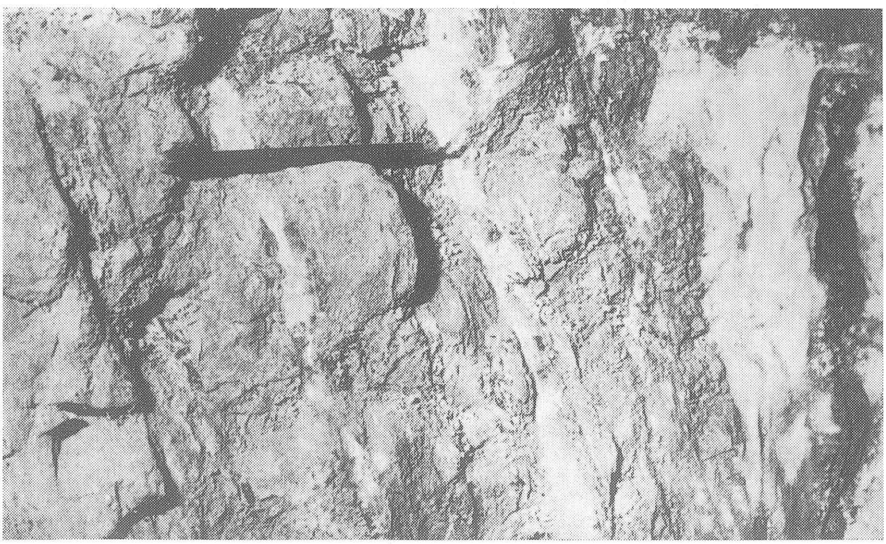
Vasyunina, E. D., 1958 — Nekotorye osobennosti geologii zolotonosnykh chetvertichnykh otlozhenij ulino-Tenkinskogo rajona (Some geologic characteristics of Quaternary gold-bearing deposits of the ulin-Tenkin region). *Trudy VNII-I*, t. 8: *geol.*

Voskresenskij, S. S., Ananev, G. S., 1961 — O stroenii sklonovykh otlozhenij Zabajkalya (On the structure of slope deposits in Transbaikal). *Vestnik Mosk. Gos. Univ.*, ser. 5: *geog.*, No. 6.

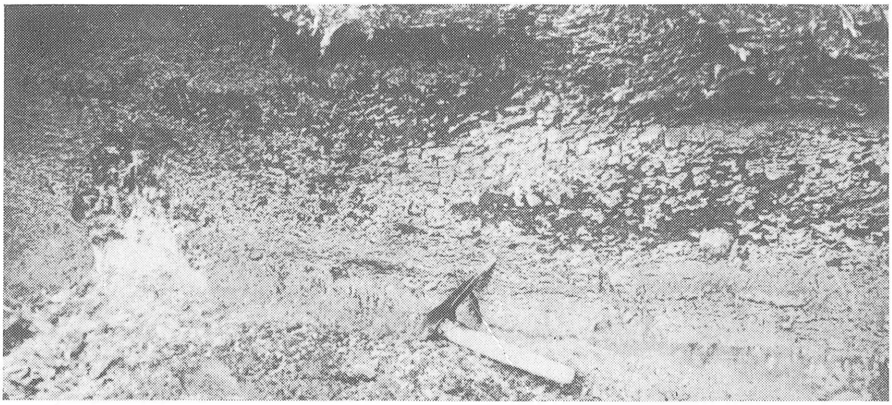
Žebera, K., 1961 — Deluvial and talus deposits. *Prace Inst. Geol.*, t. 34, part 1; Warsaw.



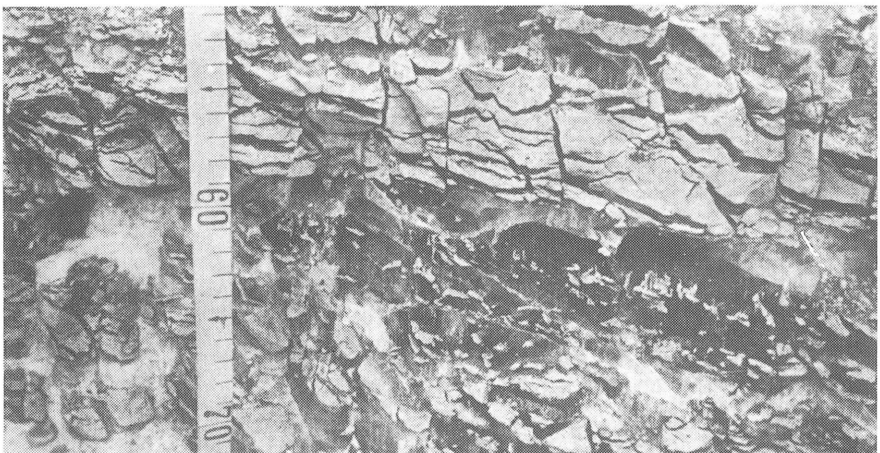
Pl. 1. Asymmetrical valley of the Kebireel-Yurega river in the northern Kular range. Terrace bench is at the foot of the south-facing slope (on the right side)



Pl. 2. Lower part of an ice vein, ramified due to solifluxion



Pl. 3. Discontinuous and indistinct ice layers in solifluxion deposits



Pl. 4. Fragment of indistinct ice layers in solifluxion deposits