*P. A. Soloviev**

Yakutsk

THERMOKARST PHENOMENA AND LANDFORMS DUE TO FROST HEAVING IN CENTRAL YAKUTIA

Abstract

The excursion to the interfluve area between the rivers Lena and Amga attempted to show the participants of the Symposium the characteristics of alass-type landforms, the stages in the development of thermokarst, and the hills (bulgunniakhs) which result from prolonged frost heaving and are closely related to alass basins. In addition, a study was made of the lake basins on the Peystyakh terrace (though they are essentially non-thermokarstic) and the relationships were examined between these and several types of landforms.

Discussions in the field largely omitted the main topics of the excursion and concentrated instead on little-known and unsolved problems of the development of the environment in Central Yakutia. Many questions were raised about the age, morphogenesis and structure of the landforms. These are discussed and elucidated in the present paper.

The excursion route crossed the complex of low (Upper Pleistocene and Holocene) terraces of the Lena and continued across the middle (Pleistocene) terraces, i.e. the Bestyakh (Q_{2-3}), Tyungyulun and Abalakh (Q_{1-2}) terraces.

The low terraces are typical flood-plain levels and it is on them that the best examples of polygons, bulgunniakhs, and old thermokarstically-enlarged depressions are to be found (e.g. north of the village of Namčir). Cryogenic phenomena typical of that area of the low terraces visited by the excursion are omitted from the present description: more attention is given to the thermokarst relief on the upper terraces.

Thermokarst is a geological phenomenon characterized by landforms due to subsidence and collapse and/or the formation of relatively large sub-surface voids which result from the localized and deep thawing of permafrost and from the melting of underground ice. Thermokarstic processes are in general associated with other phenomena such as subsidence of the ground, translocation of frozen deposits due to gravity, the downslope flowage of a semi-fluid ground mass accumulated in water, etc. The above definition of thermo-

* Institute of Permafrost Research, Siberian Branch of the Academy of Science of the U.S.S.R., Yakutsk.

karst has been rendered necessary by the fact that the term is sometimes equated with the simple physical process of the melting of ice (Mukhin, 1960).

In some places thermokarst is associated with surface and sub-surface wash, solifluction, suffosion, abrasion, etc. Hence, there exist landforms of dual origins: erosional-, suffosion-, thermokarstic, etc. and such processes as thermo-erosion, thermo-abrasion, etc. Thermo-denudation (or thermo-planation) is caused by the removal of surficial material (the depth of seasonal thawing remains unchanged) and leads to the lowering of a surface which lacks depressions typical of those formed by the melting of ground ice. Slight subsidence of the ground due to ice melting within the seasonally active layer can be regarded as thermo-subsidence, and gives rise to hydro-thermal deformations, etc.

All the features mentioned above have a thermokarstic origin: the more detailed descriptions which follow are for those landforms whose origin or appearance merits it.

There are various kinds of thermokarst relief, each having a morphology and evolution conditioned by the dominant type of ground ice and sediments. The thawing of vein, segregation, or injection ice produces landscapes and landforms which are essentially different from each other. Unfortunately, most publications do not attach any great importance to the differing origins of thermokarst relief. The most characteristic feature of Central Yakutia is the thermokarst landscape of the alass type, with its alluvial and lacustrine--alluvial accumulation plains whose upper horizons are composed of syngenetically frozen aleurites which contain large quantities of vein and segregation ice. These horizons are called *the ice-complex*, since their ice content exceeds 50%.

There are two main stages in the geomorphological evolution of accumulation plains formed of ice-complex zones: the first corresponds to the period of accumulation and ice formation, while the second relates to the time of melting and shrinkage of the ice mass. The first of these stages is omitted in the present description (see Soloviev, 1962).

The development of an alass landscape is conditioned by relatively intense local melting of ground ice (i.e. by degradation of the ice-complex). This occurs in those regions which favour the existence and further development of permafrost and which do not experience the general development of thermokarst. In Central Yakutia the present-day formation of vein ice is a very slow process, and one observes more frequently degradation of the ice-complex zones, and the slow, progressive lowering of the plains as they are refashioned by thermokarstic processes. On the coastal plains of Northern Yakutia the melting of ice and the formation of new generations of the ice-complex, in places refashioned by thermokarst, take place with equal intensity. Ice-com-

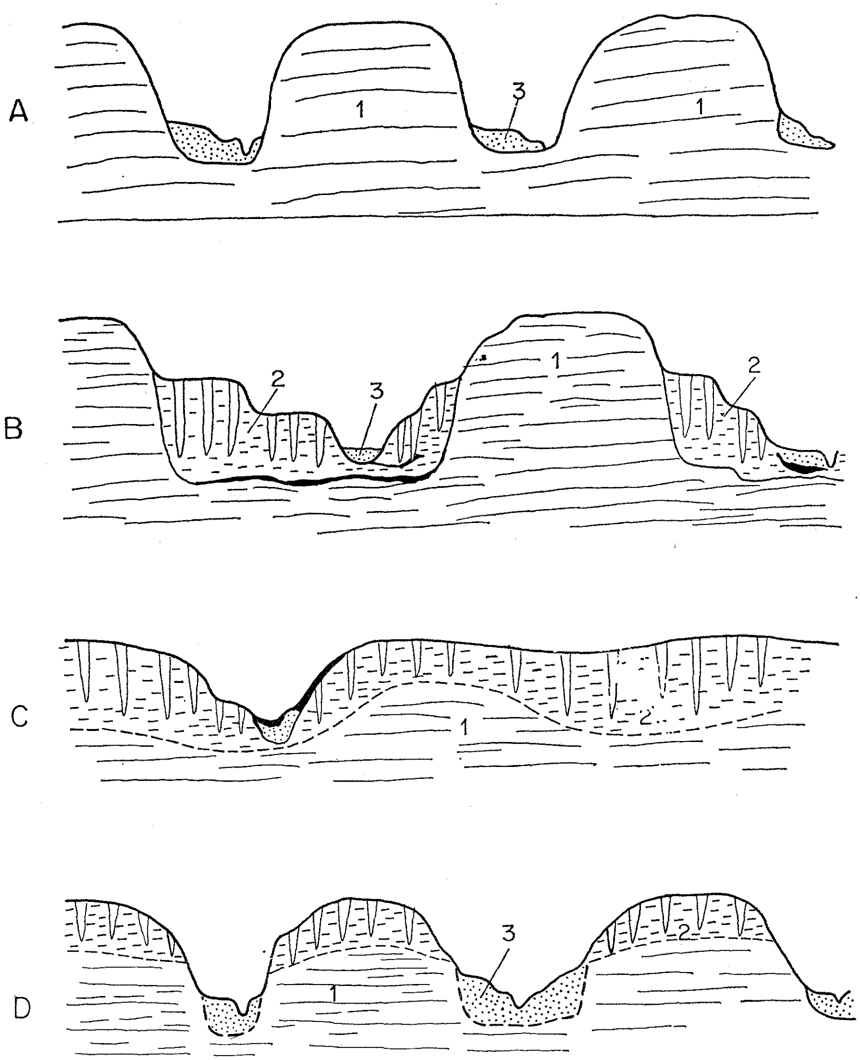

Fig. 1. Morphological types of alass topography

A – erosional and erosional-accumulational topography; B – alass-valley topography; C – alass plains; D – erosional-alass topography

1. sediments older than ice-complex; 2. ice-complex, dissected by thermokarst depressions; 3. sediments younger than ice-complex

plex plains undergo some regeneration in low-lying situations. Where neotectonic movements are relatively weak and the thickness of the ice-complex zones is small, a new but very thin complex develops in the same place as a previous one (e.g. in the basin of the Anadyr).

The term *inter-alass forms* is used for those arched features which are composed of ice-complex and which are separated by thermokarstic depressions of a characteristic shape (i.e. the alasses).

In the area between the Lena and Amga valleys the characteristics of inter-alass forms provide the basis on which the following morphological types are distinguished (fig. 1):

(1) erosional and erosional-accumulational topography which lacks ice--complex,

(2) alass-valley topography – areas constituting the floors and terraces of the older valleys,

(3) alass-plain topography – areas almost entirely mantled by the ice--complex,

(4) erosional-alass topography, which forms due to the pronounced dissection of ice-complex plains.

The first of these relief types occurs mainly on the low river terraces, on the Bestyakh terrace and on the pre-Quaternary plains. The second is characteristic of the Magan ($N\text{-}Q_1$) and the older terraces and of the plains. The third and most important, together with the fourth, is typical of the Abalakh and Tyungyulun terraces.

The general evolution of alass topography is marked by the progressive destruction of inter-alass areas as a result of thermo-denudation, etc. One can distinguish four stages in this process (fig. 2):

(1) formation of alass depressions – little dissection of the area between the alass basins,

(2) formation of alass valleys – inter-alass areas are divided into separate blocks, mainly by valleys and valley-like forms which have developed through the joining of alasses,

(3) formation of inter-alass remnants – only small areas of inter-alass topography exist. They are surrounded by lower ground which has resulted from the degradation of the ice-complex zones,

(4) post-alass stage – disappearance of even the inter-alass remnants.

All four stages in the development of alass topography exist on the area's terraces and plains. In general, however, dissection of the inter-alass terrain becomes weaker away from the axes of the valleys. Depressions of a non--thermokarstic origin may form at each stage in the development of alass topography, but are of significance only in the last two.

The erosional-accumulational relief of inter-alass areas was formed over

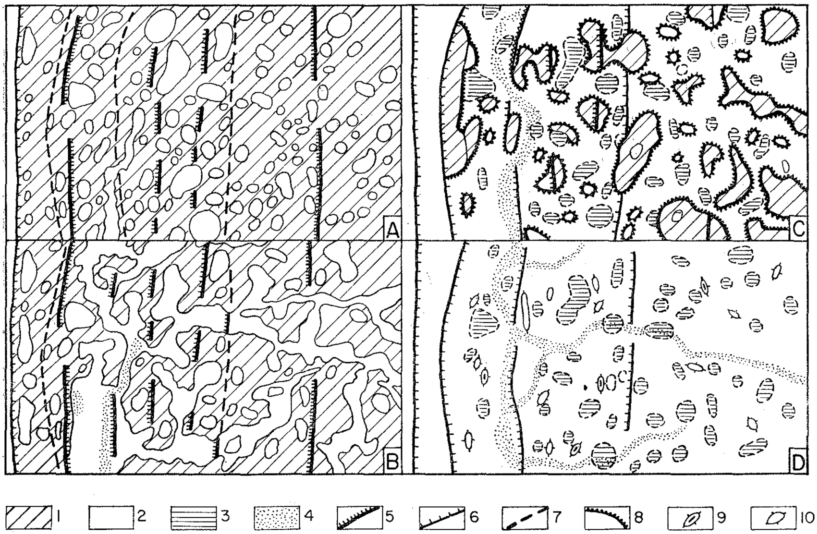

Fig. 2. Diversity of alass landforms (in plan) and successive stages of their development

A – alass depressions; B – alass-valley topography; C – alass remnants; D – post-alass stage
1. inter-alass surface; 2. alass floors and post-alass plains; 3. post-alass depressions; 4. present-day valleys; 5. terrace edges resulted from thermokarts; 6. edges of old river terraces; 7. edges of river terraces mantled by ice-complex (steps of inter-alass surfaces); 8. terminal edge of inter-alass surface; 9. bulgunnyakhs; 10. remnants of thermokarst

a long period and does not have the same origins. Previous generations of the ice complex have often been eroded and replaced by later ones. Various processes, mainly thermo-denudation and those characteristic of the initial stages of thermokarst development, operate and fashion the accumulational topography. Therefore, previous generations of the ice-complex are often preserved in those places where the upper horizons contain only a small amount of ground ice. Later generations of ice-complex zones occur mainly in strips corresponding to the older flood plains of streams.

Near the village of Maiya there is a good example of a series of alasses connected by valley-like depressions (fig. 3). The great alass of Moro, situated 2–3 km to the west of the village and having an area of c. 12 km^2, is the end form in the whole system of alasses and valley- or trough-like lowerings. This alass system begins 60–70 km east of the village of Maiya and is paralleled by an elongated depressions on the Abalakh terrace. This depression, 20–40 m deep and 3–5 km long, narrows eastwards: there is a row of alasses on its floor.

The above-described alass system does not have a permanent stream in it: there is, in fact, a channel only in some of its parts. According to oral

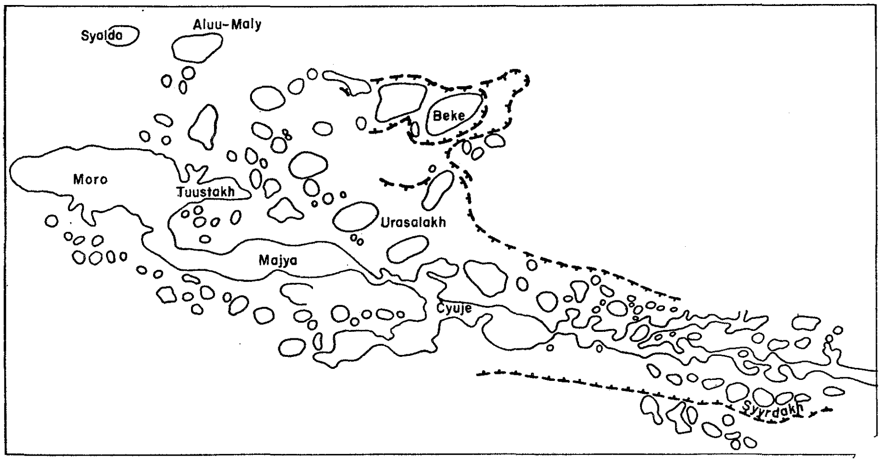

Fig. 3. System of alass valley Tabaga-Moro near the village of Maiya

information, a chain of lakes existed c. 200 years ago and these then joined to form a valley-like depression. This resulted from the overflowing of lake Tabaga (situated 16 km east of the village of Maiya) and the consequent flooding of inter-lake areas. In the alasses of Tuustaakh and Moro remnants of tree trunks are preserved: they show that the forest was flooded up to a depth of 2 m for a lengthy period. The trees were cut in winter when the lake was frozen. Their trunks are evidence of repeated changes in lake level, of cyclic oscillations in water content and of alternate filling and drying out of the lakes.

Inter-alass surfaces exhibit degraded terrace-like steps, 5–10 m high, which in some instances correspond to various ice-complex generations and in others reflect changes in thickness of the ice-complex owing to thermo-denudation. These areas are characterized by a smooth undulating landscape with relief differences of up to 20–40 m on the Abalakh terrace.

The origins and evolution of the initial forms of thermokarstic subsidence can sometimes take place during one generation. Twelve stages of development can be distinguished (fig. 4, 5):

(1) Present-day thermokarstic processes are initiated mainly by an increase in the depth of seasonal thawing or by the partial removal of surficial material. This is a time when the initial *bylar* (a flat-surfaced block) is formed and dissected by grooves and cracks which result from the collapse of ground above ice veins.

(2) Bylar – similar to the feature just described, but has a distinct polygonal network of troughs above the ice veins. Between these, upstanding forms with flat tops develop (hillocks, bajdzharakhs) (fig. 4b). Ice melting is assisted by

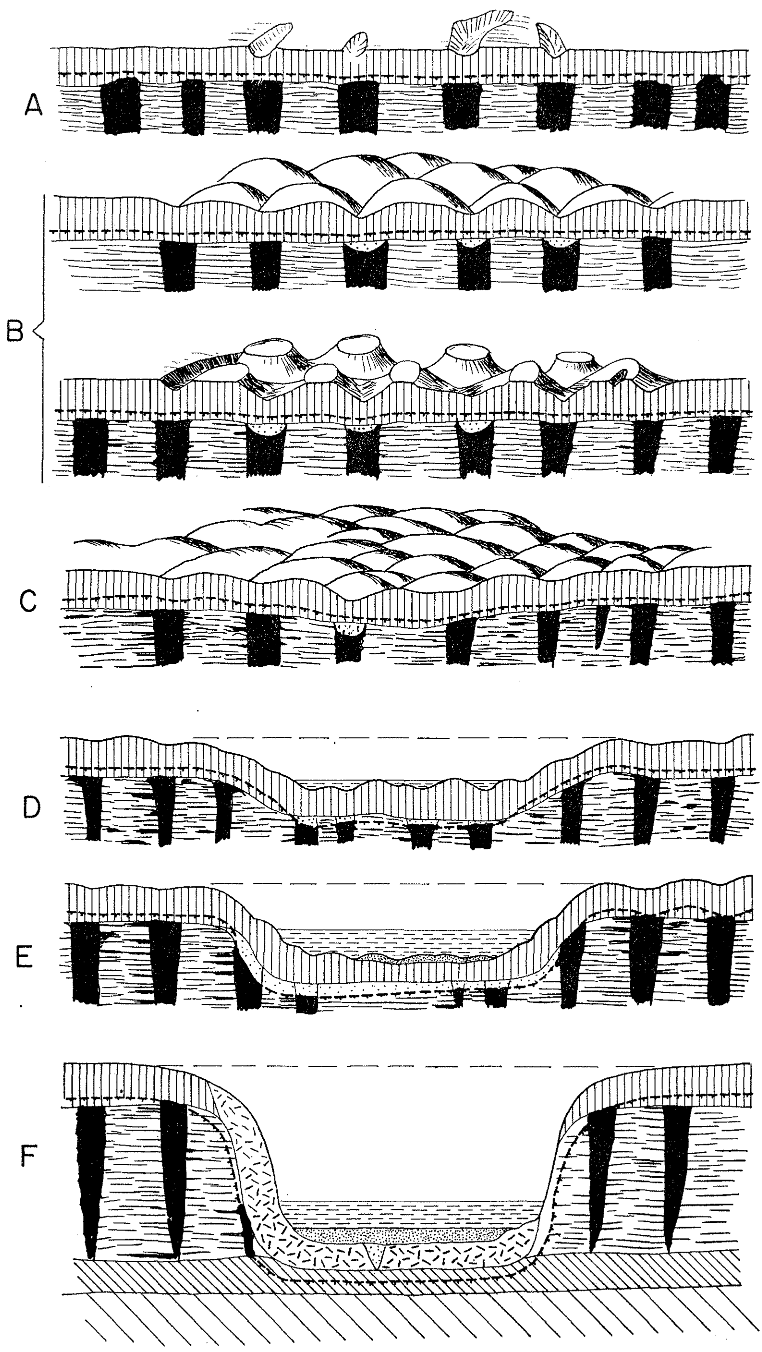

Fig. 4. Scheme of successive stages (initial stages) of alasses in thermokarst topography

A – initial bylar; B – bylar; C – iyo; D, E – dyuyodya; F – tympa
explanations, see fig. 5

water penetrating fissures either through erosion along the troughs or by subsurface removal of mineral particles.

(3) Iyo – an indistinct depression, usually in the centre of a bylar. The growth of hollows is promoted by a deeper thawing caused by the warming effects of water which has stagnated in shallow depressions.

Initially, thermokarst formation is discontinuous, because of the pools drying up. When this occurs, uneven surfaces formed by settling may undergo thermo-planation. Deepening of hollows is resumed when a pool or stream reforms.

(4) Dyuyodya – a not very deep hollow with distinct borders and a hummocky floor. The form of the latter is perpetually being renewed due to the melting of existing ice veins and the formation of pseudomorphoses.

(5) Tympa(s) – are formed when all the ice-complex undergoes thawing. They are depressions with a flat or gently concave floor and steep or hummocky borders. Their floors experience both planation and the depostion of alass sediments and therefore do not show a general deepening: their borders are modified by landslips, lake-abrasion, etc.

(6) Simple alass – unlike the tympa, cross sections of its margins show profiles of equilibrium. On its floor there is a large hollow formed by the thawing of sediments underlying the ice-complex zones. Along its borders one finds colluvial fans and a slightly higher strip of ground which is affected only by thermo-denudation. Areas below the water table do not thaw.

(7) Complex alass – has a pronounced micro-relief pattern in its lowest areas and raised edges due to frost heave at a time when the sub-lacustrine talik begins to refreeze. Depressions are remodelled when there is differential thawing or the joining of adjacent cavities. As a result of thermo-denudation, an area of lower ground (i.e. a peripheral depression) forms around an alass.

(8) Mature alass – due to frost heave its floor often displays small hummocks, frost-heaved ridges, bulgunnyakhs, secondary cavity lakes, etc.

(9) Terminal alass – joins the adjacent, lower-lying areas which lack ice--complex zones because the inter-alass surface has been completely removed on one of its sides.

(10) Khonu – post-alass depression with a floor like that of the mature alass but fringed by low, gentle slopes which are the remnants of inter-alass areas preserved despite the complete degradation of the ice-complex.

(11) Relic post-alass depression – a vaguely outlined hollow persisting even after permafrost has disappeared from the area. Some of the West Siberian lowland in the European part of the USSR are probably of this origin.

(12) Valley-like thermokarst and alass valleys – may originate (a) through the joining of existing alass depressions or (b) by the alternation throughout

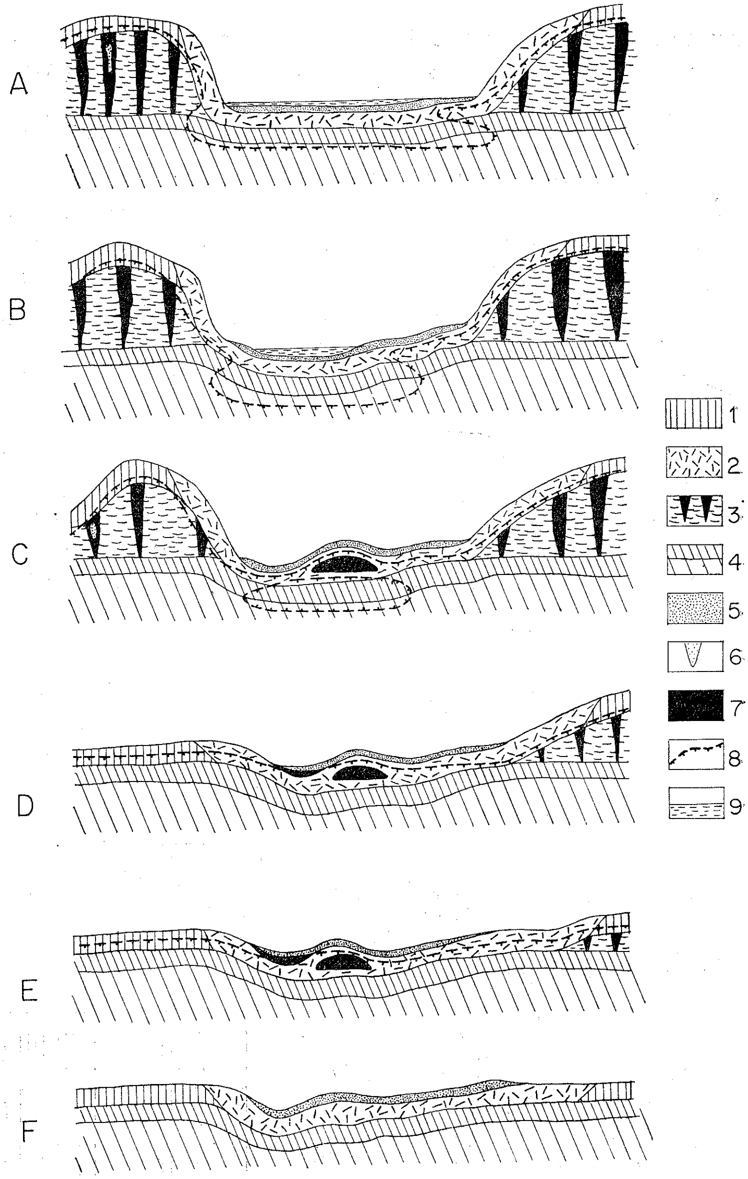

Fig. 5. Scheme of thermokarst topography of the alass type (further stages; initial stages see fig. 4)

A – simple alass; B – complex alass; C – mature alass; D – terminal alass; E – khonu post-alass depression; F – relic post-alass depression

1. silts, partly *in situ*, partly displaced due to thermokarst processes; 2. covering silts and ice-complex sediments, mixed and often displaced due to thermokarst processes; 3. ice-complex (ice-veins in silts, aleurites and aleurite sands); 4. deposits underlain ice-complex; 5. lacustrine sediments and lake-muds in alasses; 6. deposits infilled pseudomorphoses after ice-veins; 7. injection-and segregation ice of bulgunnyakhs and of frost-heaving grounds; 8. permafrost table; 9. lake water

their development of erosion and thermokarstic processes. The formation of similar alass valleys has been described elsewhere (Soloviev, 1963).

Alass valleys are characterized by the alternation of wide and narrow sections. It is not uncommon to find that their long profile, which is not in equilibrium, has sections sloping in opposite directions. There are many parallel and dead-end tributaries which are connected to lake basins (fig. 6).

Some mature alasses have a complex structure. 7 km NE of the village of Maiya is the large, half-enclosed basin of Bekyo which is floored with ice--complex and is on a level corresponding to that of the Tyungyulun terrace. The basin itself has developed out of a gently sloping plain which may be regarded as corresponding to the Abalakh terrace and which is also mantled with the ice-complex. On the floor of this basin a western and eastern alasses are connected by a narrow trough. Three other small and round alasses lie west of Bekyo (fig. 7).

The origin of the Bekyo is as follows. During formation of the Tyungyulun terrace, when it was a flood-plain, the river eroded an extensive depression within the Abalakh terrace. On its bottom (then a valley floor) the ice-complex

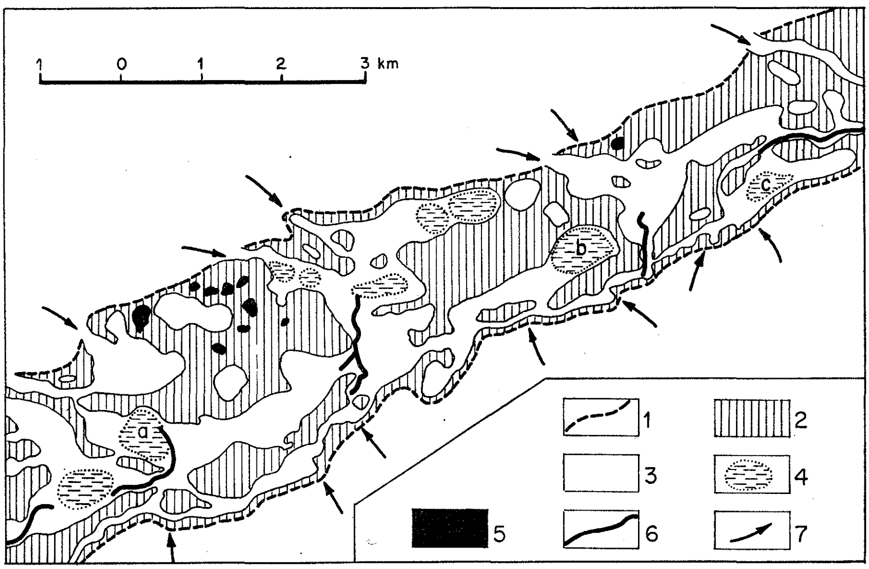

Fig. 6. Mature alass valley of the river Kočara. The valley floor during the period of observation was dry, except hollows a, b, c

1. lower valley edge; 2. flood-plain of old valley, occurring as inter-alass convexities; 3. bottom of alasses and alass-valleys; 4. lake basins on the alass-valley floor; 5. initial thermokarst hollows, often water-filled; 6. well--formed dry beds; 7. outlines of dry side valleys

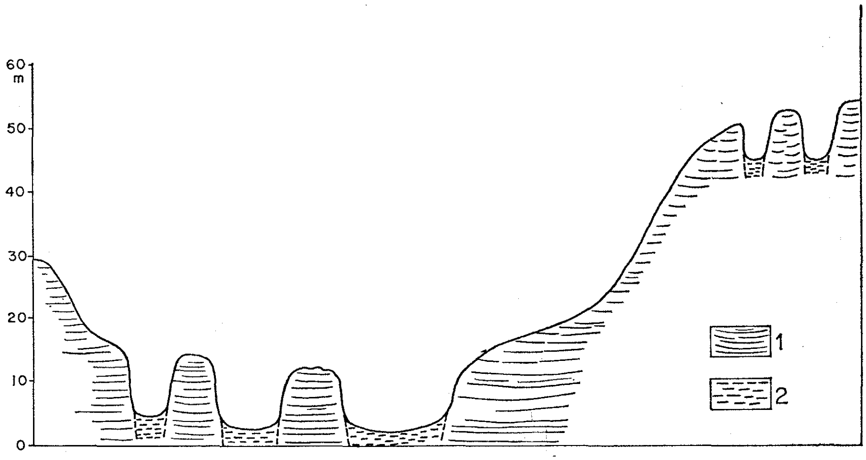

Fig. 7. Schematic cross-section through the place called Bekyo

1. ice-complex and covering deposits; 2. alass sediments

zones belonging to the Tyungyulun terrace were formed. Alasses developed within these ice-complex zones during the Holocene.

Typical badland originates when numerous thermokarst centres develop within a small area, chiefly on gently sloping inter-alass terrain which adjoins higher ground on one of its sides. There is a good example at Ebe-Carang, some 40 km east of Maiya. Young thermokarst depressions (dyuyodas, tympas and transitional forms) are here divided by narrow ridges, in some places only 2–5 m wide, which are deformed bylars and furrows due to collapse. Sometimes the ridges have been dissected by suffosion and old erosional troughs. These latter must have been thermokarst centres during the initial stages of its formation in this area. Like mature alasses, these basins have their borders destroyed by fissures resulting from subsidence, earth falls due to undercutting, landslips, underground erosion, suffosion, and thermo-erosional gullies (fig. 8).

Relatively old tributaries of the Lena running across the ice-complex zones have broad flood-plains diversified by erosional-accumulational relief. In places these flood-plain join the alass floors (fringing alasses) which are at about the same level or slightly lower.

In the Suola valley, NE of Maiya, the left bank flood-plain is being enlarged by the thermo-denudational backwearing of the valley side.

The present article omits some general problems of thermokarst development because they have been thoroughly discussed by S. P. Kačurin (1961): there is also no mention of the geological background to thermokarst

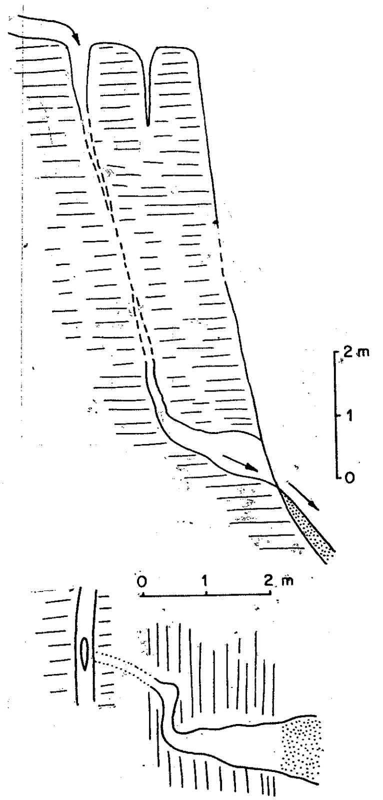

Fig. 8. Underground void formed by out-washing in the scarp of the Abalakh alass
cross-section – above, in plan – below

formation in the area as this has been described in an earlier paper (Soloviev, 1959). However, it must be noted that abundant field evidence has shown the structure of alass floors to be essentially like that of inter-alass areas; the only difference is the lack of ground ice on alass floors and its occurrence in the intermediate areas.

A continuous polygonal pattern is formed by the ice veins within inter-alass areas and the furrows on depression bottoms; this proves that the formation of thermokarst depressions succeeds that of adjacent areas. Furrows in the depressions occur above the pseudomorphoses and some contain the remains of vein ice. A good example is found on a ridge between the alasses of Maiya and Udenekhtekh: here there is a dyuyoda with hummocky relief on its sides and floor, whereas a quite recent polygonal net of subsidence furrows occurs on the sides of the Udenekhtekh alass.

An excavation pit at this site revealed the upper part of an ice vein together with the narrow tops of ice veins of a much younger generation (fig. 9). These tops are 1.9 m below the surface. A little deeper thawing of the ground

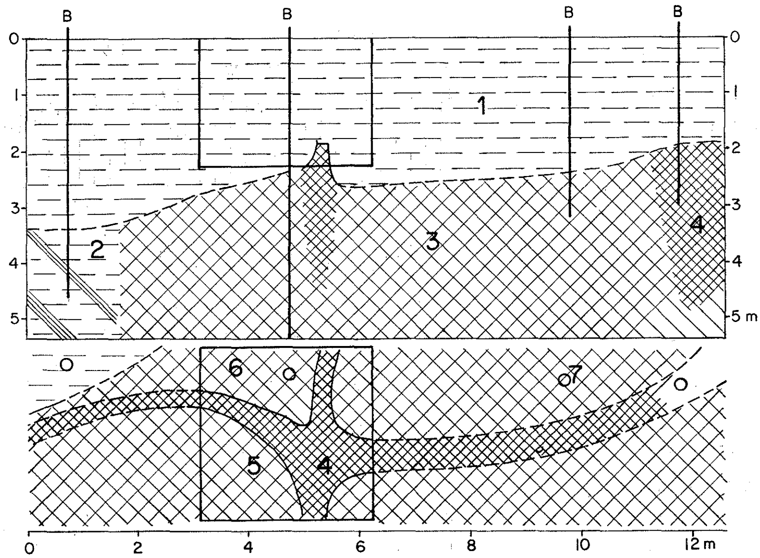

Fig. 9. Two generations of secondary vein ice in the area near Maiya. Cross-section – above, plan of a section – below

1. covering silts; 2. ice-complex aleurites; 3. secondary vein ice; 4. epigenetic veins; 5, 6. old syngenetic vein; 7. borings; quadrangle – the pit of examination

may induce their wastage and the formation of a polygonal system of furrows. As shown in the diagram, further thermokarstic development produces a furrow system related to former ice veins. If the depth of thawing does not increase, the surface undegoes planation.

The mature alass depressions which have an old appearance date from the early Holocene or the Late-Pleistocene climatic optimum: this is indicated by the vegetational remains in the lower part of alass-like sediments. The discovery of Neolithic implements around the edges of some of the older-looking lakes (Soloviev, 1959) testifies to their existence about 2–4 thousand years B. P. (Molčanov, 1969). In general, therefore, the alasses are of various ages and include some which were formed in historic times.

Frost heaving may be seasonal or it may last years: it gives rise to hummocks of varying sizes, to surfaces of heaving, etc. Under the appropriate conditions, forms due to seasonal heaving are consolidated by freezing or the intrusion of a ground mass. Hummocks due to prolonged heaving (bulgunnyakhs) are formed by intrusion of water under pressure into frozen ground or are associated with the freezing of partially or wholly separated taliks.

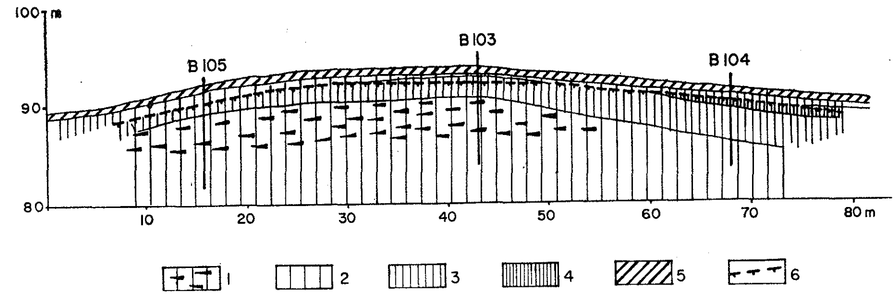

Fig. 10. "Flat" bulgunnyakh No. 2 in the Olong-Erien alass

1. silts containing small lenses and thin layers of segregation ice; 2, 3, 4. various silts; 5. soil; 6. permafrost table

Not only are bulgunnyakhs common in the area under consideration, but they also represent its most striking landforms.

The bulgunnyakhs have formed in depressions on the various surfaces of accumulation. They are especially typical of alasses, c. 20–30% of which have bulgunnyakhs on their floors. The "flat" bulgunnyakhs (gentle dome-like elevations, 2–5 m high) have a frozen core; their sediments contain small ice lenses (fig. 10). Large bulgunnyakhs, 10–20 m, and in Central Yakutia up to 40–50 m high, possess not only small ice lenses but also huge ice masses 5–-10 m thick (fig. 11). The ice in bulgunnyakhs has several origins and is produced by the injection of varying amounts of water and the increase of primary ice layers by freezing of water derived from the talik to their underside.

"Flat" bulgunnyakhs should be regarded as initial forms in the development of a particular type of mound due to heaving. Sometimes their evolution goes

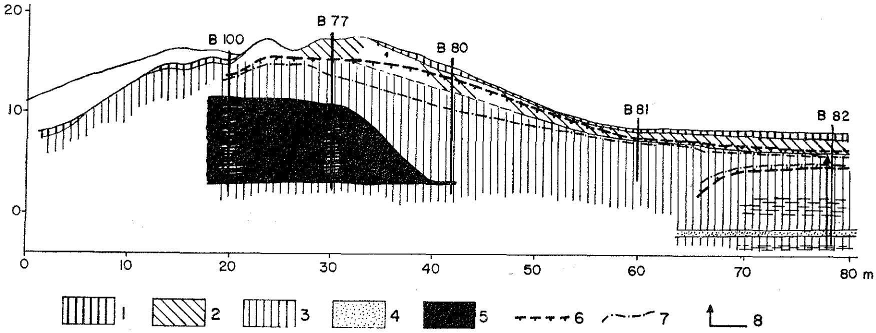

Fig. 11. Large bulgunnyakh in the Olong-Erien alass

1. soil; 2. sandy silt; 3. silt; 4. sand; 5. ice; 6. permafrost table; 7. core enriched with segregation ice; 8. water-bearing horizon, its depth and direction of water pressure

no further than this stage (e.g. if the taliks rapidly freeze). Under favourable conditions, however, these gentle swellings are transformed into large bulgunnyakhs.

A flat-topped elevation on which there occurs a steep mound is a very common feature of large bulgunnyakhs. Cryotectonic cracks and fissures develop on the top of the mound. Differential uplift of individual blocks and faulting are the initial signs of a bulgunnyakh's destruction. Craters due to collapse can often be seen on their tops. The remnants of a degraded bulgunnyakh look like remparts surrounding a depression.

The evolution of bulgunnyakhs is controlled by their occurrence on alass floors, the compensatory depressions which are connected with the displacement of water or supersaturated ground into the mound, and slope asymmetry. This is clearly displayed in bulgunnyakhs situated within the Olong-

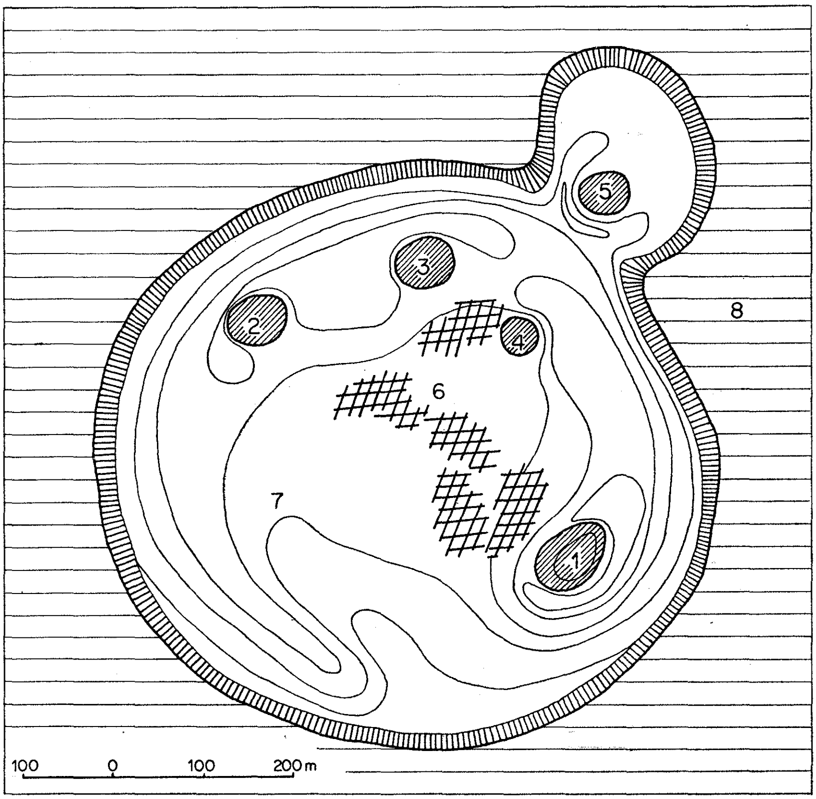

Fig. 12. Alass Olong-Erien near Abalakh

1. large bulgunnyakh; 2, 3, 4, 5. "flat" bulgunnyakhs; 6. polygonal network of frost fissures; 7. alass floor; 8. inter-alass area

-Erien alass, 1 km west of Abalakh (fig. 12). The central part of the alass underwent heaving when the talik beneath the lake started to freeze. As the lower borders of the alass floor were freezing, the bulgunnyakhs started formation due to heaving. One of them is of the very large variety with an ice core (fig. 11).

The ice core was formed by repeated injections of water, as is proved by the lenses of silt within the ice and the fracturing of ice body into thin plates near its edges. The top of the bulgunnyakh has been affected by cracking which occurred after the mound had been formed and was being subsequently remodelled. These cracks are filled by mineral material flowing down their sides; in cross-section they resemble the pseudomorphoses of ice veins. Sometimes they contain ice, which is probably frozen water forced into them from below. Immediately beneath the ice core of some bulgunnyakhs there is ground water under pressure: the alass of Khotonok provides an example (fig. 13).

On the sides and round the base of the bulgunnyakh there is a variety of small deformations and a net of young frost fissures.

In „flat" bulgunnyakhs the zone of greatest accumulation usually occurs at the base of the mound (fig. 10). The moisture in the cores of these landforms varies by weight from 40% to 140%.

The following characteristics are typical for the different stages in the evolution of bulgunnyakhs: (1) the general heaving and dome-like bending of

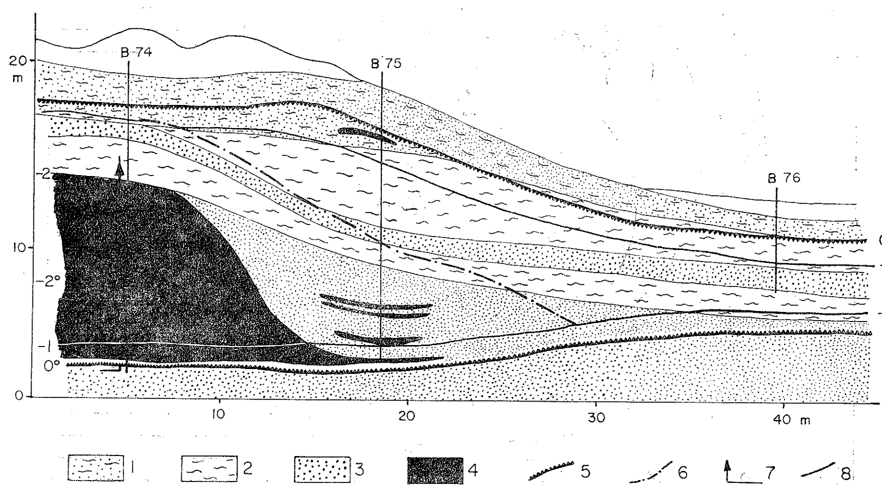

Fig. 13. Large bulgunnyakh in the alass Khotonok

1. sandy silt; 2. silt; 3. sand; 4. ice; 5. permafrost table; 6. limit of a core enriched with segregation ice; 7. water-bearing horizon, its depth and direction of water pressure; 8. isotherms

ground overlying the talik as it begins to freeze; (2) the marked arching of the weakest areas of frozen ground due to increased pressure in the closed talik, injection of water or supersaturated ground; (3) the progressive heaving of the mound due to segregation of the ice core and freezing of ascending water; (4) the vibrating of a bulgunnyakh sometimes produces a monoclinal layer pattern at the base of a mound: such vibrations may occur during freezing of the remaining parts of talik immediately under the bulgunnyakh.

The phenomena listed under (1), (2) and (3) can occur in both a closed system and during summer in an open system. It is more difficult for bulgunnyakhs to form when the talik is composed of only slightly permeable material or when it becomes drained.

The great bulgunnyakh in the alass of Byutieydyakh-Erien adjacent to the alass of Olong-Erien certainly developed in an open system, such as an island of unfrozen ground within a lake basin.

The dome-like bending of layers, their partial stretching in places, and the narrowing and wedging out of some horizons in the top part of the mound are characteristic of large as well as „flat" bulgunnyakhs. In some examples the ice layers increase in thickness due not only to the growth of segregation and injection ice, but also to the intrusion of „soil" into the centre of the mound during frost heaving (fig. 13).

Examination of temperature distributions within bulgunnyakhs shows that they occur on that part of the alass floor where cooling of the sediments is most intense. The bottom of the ice mass reaches almost to the talik. In such conditions the ice mass is augmented from below by ice segregation on its underside.

By geological standards bulgunnyakhs are short-lived. We have no data concerning their age. However, their rate of formation may be inferred from observations at Nyamčir in the Suola valley, 8 km SW of Abalakh (fig. 14). This place is a broad alass depression which is joined to the Suola valley flood plain. The intervening area has been destroyed partly by thermokarst and partly by water erosion. The lowest part of this depression was once an elongate ellipsoidal basin which contained a lake. There are eyewitness accounts claiming that 50 years ago a vast area was affected by heaving as a result of progressive drying out and freezing of the lake towards the eastern part of the depression. The bulgunnyakhs in the south of the Nyamčir depression have increased their height by c. 0.5 m per annum. This slow growth indicates that their ice cores developed through the formation of ice layers which are themselves due to water from the talik ascending towards the freezing front. A borehole in the zone of heaving revealed a 4.3 m horizon of silty aleurites containing a large number of segregation ice lenses underlain by medium-grained sands within which is a sublacustrine water-bearing talik remnant at a depth of 10 m.

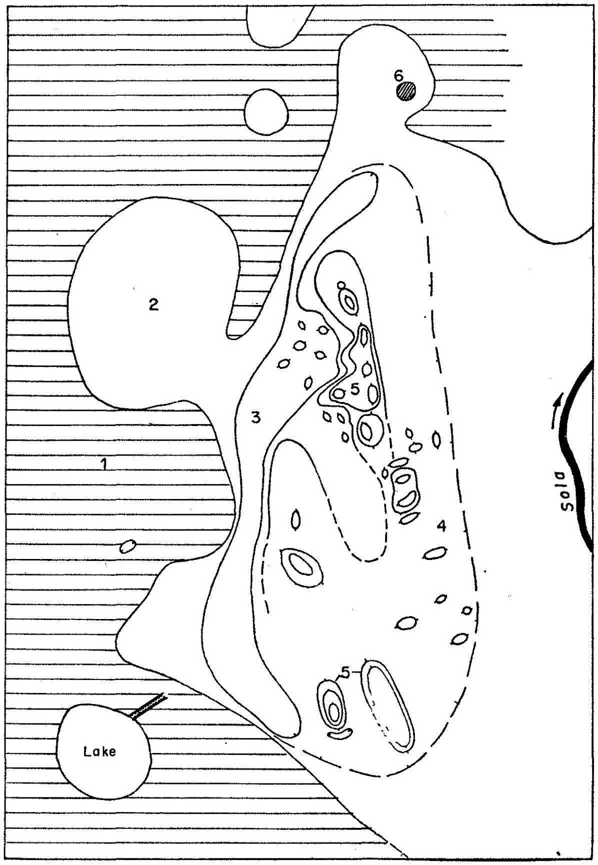

Fig. 14. Place called Nyamčir, near Abalakh

1. inter-alass area; 2. alass floor; 3. remnant parts of dried lake floor; 4. limits of an old lake; 5. bulgunnyakhs and small hillocks on the frost-heaving surfaces; 6. bulgunnyakh on the alass floor

The Bestyakh terrace of the Lena has a well-defined edge on whose upper part well-sorted, diagonally-stratified alluvial sands are exposed. Further upstream are exposures of the basal parts of this terrace. Its surface relief is low and gently undulating, and forms a linear series of broad shallow concavities 20–30 m deep running in a NW direction. To the south these concavieties become wider as they form the remnants of an older erosional-accumulational landscape.

Eolian accumulation forms and wind-blown sands 3–5 m thick are common on the Bestyakh terrace. The eolian landforms are now mostly fixed by vegetation (forests), though poorly formed and unfixed present-day dunes occur near the upper edge of the terrace. Very recent dunes 10 m or more in height appear farther south, at the mouth of the river Buotoma.

Typical of the Bestyakh terrace are chains of numerous big lakes which are related to the depressions of an older landscape referred to above. In general, these lake basins were formed by erosion, though there has been some deepening by suffosion and remodelling by thermo-abrasion. It may be assumed that the floors of some lakes collapsed due to the melting of deep--lying lenses of segregation and injection ice present in sandy alluvial material. The lakes Beleken and Abaga-Kyuel near the village of Bestyakh are of this type. They have a depth of 6–12 m and their shores rise 10–15 m above the water table: their floors and sides are of sand.

Water in the lakes of the Bestyakh terrace ranges from almost fresh (e.g. in the lakes of Beleken and Abaga-Kyuel) to highly mineralised. In the eastern part of the Čaj-Kyuel lake it contains various salts ($NaHCO_3$, $NaCl$, etc.) in concentrations of up to 8–10 g/l, whereas in the western basin of this same lake it is almost fresh. This proves that the low, narrow inter-basin ridge is frozen. The reasons for these differences in mineral content of the water are unknown.

The bottom sediments of lakes with highly mineralised water are formed by organic-mineral clays and deposits of a chemical origin. It is a remarkable fact that the fresh-water lakes are overgrown by vegetation.

Places such as Čogolutta, Dirin-Kyuel, and Khommut near the village of Bestyakh are associated with many shallow and indistinct concavities which are the remains of earlier big lakes. Their bottom sediments are represented by lake-swamp clays or material derived from surrounding slopes by downwash. Sometimes thin layers of buried lake ice occur. Shallow, so-called „migrating lakes" occupy these depressions: while one of their shores is being destroyed and therefore retreats, the other advances as sediments are deposited in the lake and are then fixed by freezing. In some places there are relic lakes whose depth is usually <2 m.

These peculiar lake depressions may be observed along the boundary between the Bestyakh and Tyungyulun terraces. It seems that they are located on the margins of an area of ice-complex zones. An example of such a depression contains the lake of Tyumetime, 10 km from Bestyakh. It has a gently--sloping western shore which is composed of sands analogous to those on the Bestyakh terrace, whereas its eastern part is bounded by a distinctly steeper slope typical of alass borders.

The edge of the Tyungyulun terrace is indistinct owing to a cover of aleurites and silts. This cover probably represents a colluvial glacis and is thin, though the silty part does thicken somewhat towards the east. Typical alasses occur 0.5–1 km from its edge.

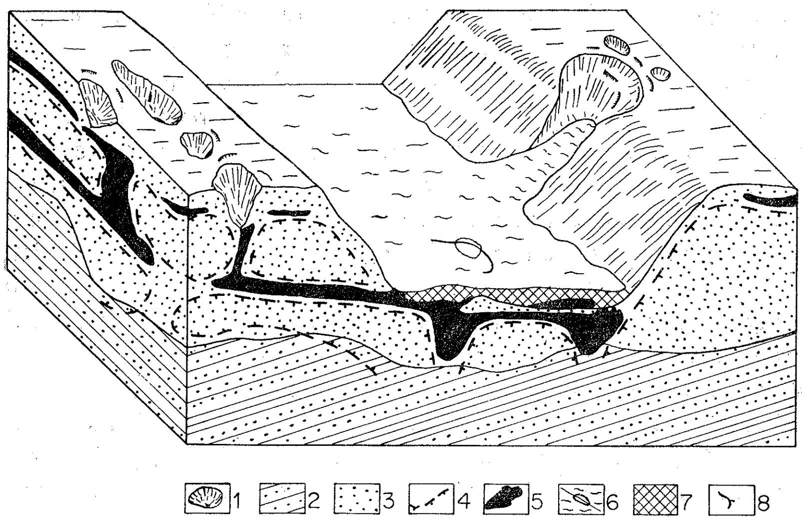

Fig. 15. Schematic diagram of land relief and geological structure near the spring Ulakhan--Taryn (after A. I. Efimov)

1. sink-hollows; 2. Jurassic sandstones and slates; 3. sands of the Bestyakh terrace; 4. permafrost table; 5. unfrozen water-bearing sand; 6. surface of icings and icing-hillocks; 7. icing in cross-section; 8. springs

Along the edge of the Bestyakh terrace there are permanent underground springs rich in water (Ulakhan-Taryn, Bulus, Sular). They are in short valleys formed mainly by the water which comes from these springs. Suffosion niches, sinks and channels occur on the sides of these valleys and nearby (fig. 15). Seasonal hummocks due to frost heaving and water-accumulated sands are frequent on the valley bottoms: numerous icings up to 2.5 m thick also occur. In some years these icings survive until autumn if mantled by sands from the upper parts of the valleys.

Translated by Ł. Dutkiewiczowa

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