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Snow Patches in Nival Landscapes and Their Role for the Ice Complex Formation in the Laptev Sea Coastal Lowlands

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Summary: Nival landscapes with snow patches are found all over in the Laptev Sea coastal lowlands and the surrounding mountains. Some of them seem to be perennially. Several snow patches were comprehensively studied in order to obtain data about structure, occurring processes, new-formed deposits and the vegetation connected with this landscape. Therefore, the new terms „chiononoconite" as niveo-eolian mixture of clastic grains and plant detritus and „extranivities" for nival deposits outside snow patch areas are created. Analytical characteristics of snow patches and their deposits are given by contents of dry residues in snow patches, the hydrochemistry of snow and meltwater and the grain size distribution of clastic detritus. The plant associations of two nival meadows and the determination of mosses and lichens found around snow patches are presented. Four different geomorphologic types of snow patches are classified. The studied phenomena and processes in recent nival landscapes are compared with those of Late Quaternary Ice Complex deposits, covering large areas in the Laptev Sea coastal zone. A possible nival genesis is supposed.

Zusammenfassung: Nivale Landschaften mit Schneefeldern findet man überall in den Küstentiefländern der Laptewsee und den sie umgebenden Gebirgen. Einige davon scheinen perennierend zu sein. Verschiedene Schneefelder wurden umfassend untersucht, um Daten über Gefüge, ablaufende Prozesse, neugebildete Ablagerungen und die Vegetation zu erhalten, die mit dieser Landschaft in Verbindung stehen. Dafür wurden die neuen Termini „Chiononoconite" als niveo-äolische Mischung aus klastischen Körnern und Pflanzendetritus und „Extranivite" für nivale Ablagerungen außerhalb von Schneefeldflächen geschaffen. Analytische Eigenschaften der Schneefelder und ihrer Ablagerungen werden mit den Feststoffanteilen, der Hydrochemie von Schnee und Schmelzwasser und der Korngrößenverteilung des klastischen Detritus angegeben. Die Pflanzenassoziation von zwei nivalen Wiesen und die Bestimmung von Moosen und Flechten aus der Umgebung der Schneefelder werden vorgestellt. Vier verschiedene geomorphologische Schneefeldtypen werden klassifiziert. Die untersuchten Phänomene und Prozesse in rezenten nivalen Landschaften werden mit denen spätquartärer Eiskomplex-Ablagerungen verglichen, die große Gebiete in der Küstenzone der Laptewsee bedecken. Eine mögliche nivale Genese wird angenommen.

INTRODUCTION

The surrounding hills and lowlands of the Laptev Sea are characterized and shaped by a nival landscape (ATLAS SU 1984). Niveo-eolian deposits of snow patches are distributed within this territory and there are close relationships between snow, firn, ice, and meltwater on one hand and soil and ground on the other. This is the zone of nivation (MATTHES 1900) where cryogenic weathering, gelifluction, slope and rillwash of soils by melt water around and below snow patches (WASHBURN 1979, FRENCH 1996) occur.

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Every snow patch of the concerned Laptev Sea coastal territory, which is featured by a perennial snow cover, can be regarded as a kind of the embryonic glaciation (GRIGORIEV 1932), independent of the mechanism and duration of its formation. Nevertheless, snow patches of any dimension and thickness do not belong to glaciers because they are neither alimentation nor depletion areas and they do not show any evidences of movement (SHUMSKY 1976). Perennial and seasonal snow patches are integral components of this nival landscape (KUNITSKY 1989). All types of snow patches of the Laptev Sea coastal zone belong to so-called „cold" snow patches, which are characterized by a base of frozen ground. These „cold" snow patches are observed in a wide range of altitudes on slopes of low mountains and in plains. However, these nival landscapes have been insufficiently studied in the Arctic and Subarctic so far.

Field observations around the Laptev Sea (Fig. 1) show the importance of nival processes for the relief formation and hydrological and sedimentological processes in this area. The nival landscape is considered to be a relatively small area, which corresponds to kars and nivation hollows and cryoplanation terraces. Snow patches were found in each of these forms, which could be regarded as places of nivation and other exogenic processes. Such exogenic geological processes are connected, for example, with the growth of algae, mosses and lichens and other lythophytes near the snow patches and certain plant associations on nival meadows. Therefore, snow patches are parts of the nival landscape, but nival landscapes can exist also without any snow patches for several years and, in general, the nival landscape is more extended than the snow patch areas.

Erosion and abrasion processes, which destruct the permafrost horizon at the Laptev Sea coast, expose the unequal distribution of ground ice. In places the top of the permafrost horizon is represented by the Ice Complex, a special horizon saturated with ice wedges dissecting silts, silty and loamy sands (SOLOVIEV 1959). They can reach a width of about 5-7 m and a height of 40-50 m and more (KUNITSKY 1989, SOLOVIEV 1959). From the geological point of view both deposits and ice wedges were considered to be of syngenetic formation (POPOV 1953, KATASONOV 1954, ROMANOVSKII 1961, GRIGORIEV 1966, GRAVIS 1969, TOMIRDIARO et al. 1972, KONISHCHEV 1981, KUNITSKY 1989, 1998). But several authors have a contrary explanation and, sometimes, alternative hypotheses for the formation of Ice Complex deposits, which are widely distributed in the coastal zone of the Laptev Sea. Ice Complex sections and nival landscapes with „cold" snow patches (nival

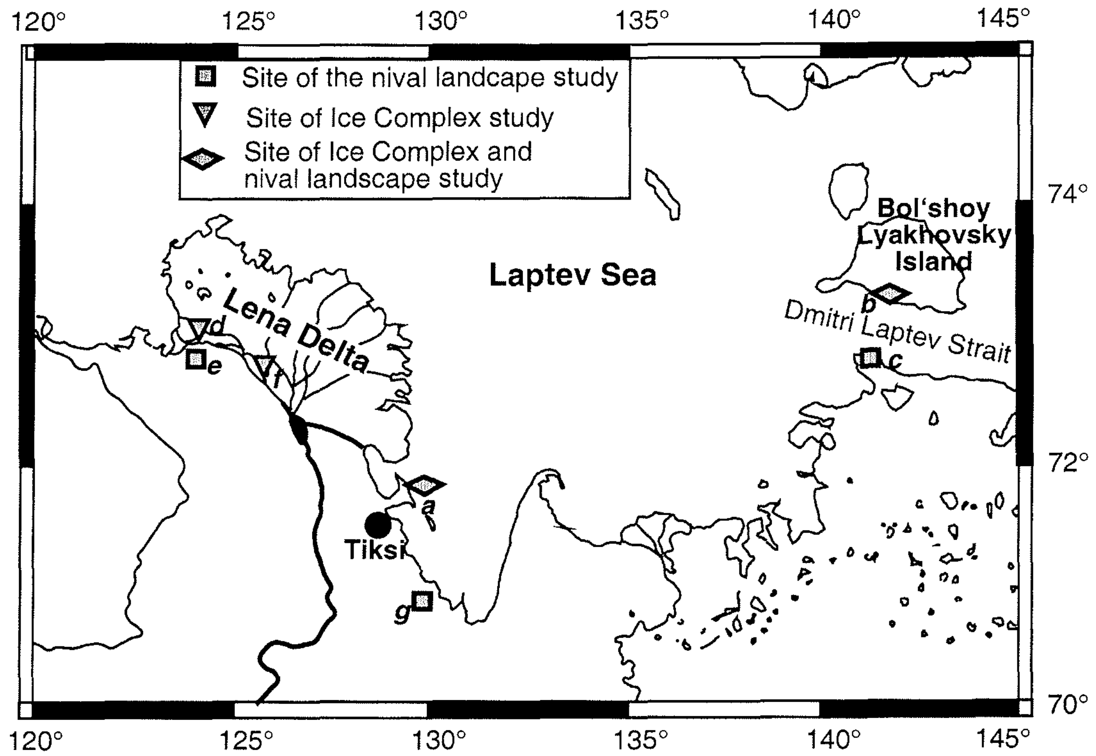

Fig. 1: Sites of studied nival landscape areas around the southern Laptev Sea. a: Bykovsky Peninsula; b: Bol'shoy Lyakhovsky Island; c: Cap Svyatoy Nos; d: Nagym (Olenyek-Channel); e: Chekanovsky Ridge; f: Buor Khaya (Olenyek Channel); g: Kunga Ridge.

Abb. 1: Standorte der untersuchten nivalen Landschaften rund um die südliche Laptewsee. a: Bykowsky-Halbinsel, b: Große Ljachow-Insel, c: Kap Svjatoy Nos, d: Nagym (Olenjek Kanal), e: Chekanowsky Rücken, f: Buor Chaja (Olenjek-Kanal).

permafrost landscapes) are both located in the coastal zone of the Laptev Sea. They were objects of field and analytical work by Russian-German teams, which worked there during the terrestrial expeditions „Lena Delta 1998 to 2000" (SIEGERT et al. 1999, SCHIRRMEISTER et al. 2002). The expeditions were carried out under the framework of the Russian-German cooperation „System Laptev Sea 2000". These paper presents first results in order to understand better the processes and relationships in nival permafrost landscapes around snow patches. The authors try to explain the role nival processes played in the formation of the upper parts of Late Pleistocene Ice Complex deposits in the Laptev Sea coastal lowlands.

STUDY AREA

The areas of the studied nival permafrost landscapes with „cold" snow patches are distributed in coastal lowlands and coastal mountains of the northeast Subarctic belt around the southern Laptev Sea (Fig. 1). Ice Complex deposits, which were studied at the same time by some of the authors (see SIEGERT et al. 2002) are very common in the same area. Altogether we have studied six snow patches (Tab. 1) and their surroundings and cryoplanation terraces in two regions (Fig. 1). The first location was a thermoerosional ravine with snow patch No. 1 on the east coast of the Bykovsky Peninsula near Tiksi. The second area is located in the northwestern part of the Chekanovsky Ridge on the slopes of kars (snow patch No. 2 and 4) and on cryoplanation terraces (snow patch No. 3 and 5). Thirdly, one snow patch (No. 6) was investigated at the slope of a kar in the Kunga Ridge southeast of Tiksi. Additionally, positions of snow patches actually without snow were studied in kars and cryoplanation terraces on the slopes near the hills of Cape Svyatoy Nos and Khaptagai Tas (Bol'shoy Lyakhovsky Island) south and north of the Dmitri Laptev Strait (Fig 1).

MATERIAL AND METHODS

Satellite pictures of Bol'shoy Lyakhovsky Island show a continuous occurrence of snow patches over some years until August (Fig. 2). Although, in 1999 we did not find any snow patches there, it was possible to study the specific periglacial geomorphologic structures, the zonality of deposits in the snow patch area, the flora of a nival meadow, and sediment phenomena in the snow patch location. Furthermore, we observed newly formed fine-grained clastic nival silt mixed with plant detritus („chionoconite") and traces of other snow patch phenomena like goletz-ice (after BILIBIN 1955, GRAVIS 1965, ALEKSEEV 1984) within the active layer.

Material was sampled from snow patch surfaces as well as from surrounding rock debris. Wind-blown plant remains and some clastic detritus were deposited on snow patch surfaces. For this material we have created the new term „chionoconite", which describes a mixture of nival silt and small pieces of plant detritus (moss, lichens, seeds and grass) accumulated on snow patch surfaces. This term is a composition of the Greek words χιων (snow) and κονια (dust). „Chionoconite" is comparable with the glaciological term cryoconite, a dark powdered dust, transported by wind and deposited on a snow and ice surface (JACKSON 1997). Deposits of „chionoconite" on the surface of the active layer were regarded as geological signal for the occurrence of snow patches. They will be used for determining the boundary of nival landscapes in the study area around the Laptev Sea.

"Cold" snow patch No.	Latitude	Longitude	Study date	Location	Hight lower border (m)	Width (m)	Length (m)	Thickness (m)	Content of clastic material (g/l)
1	71°50'10"	129°20'41"	28.08.98	Ravine; Bykovsky Peninsula	8	25	50	4	0.6
2	73°43'40"	123°00'13"	12.08.00	Nivation hollow on kar slope; Chekanovsky Ridge	240	25	50	>1.5	2.8
3	72°44'12"	123°00'25"	12.08.00	Nivation hollow on upper rim of cryoplanation terrace; Chekanovsky Ridge	107	20	30	>0.5	
4	72°44'30"	122°51'40"	13.08.00	Nivation hollow on kar slope; Chekanovsky Ridge	155	70	130	>1.5	2.8
5	72°45'00"	122°54'50"	13.08.00	Nivation hollow on upper rim of cryoplanation terrace Chekanovsky Ridge	122	10	30	>0.5	12.6
6	71°15'40"	129°21'50"	03.09.00	Nivation hollow on kar slope Kunga Ridge	210	30	60	>1.5	2.3

Tab. 1: Position, sizes and contents of clastic material of the studied "cold" snow patches.

Tab. 1: Lage, Größe und Konzentration an klastischem Material der untersuchten "kalten" Schneefelder.

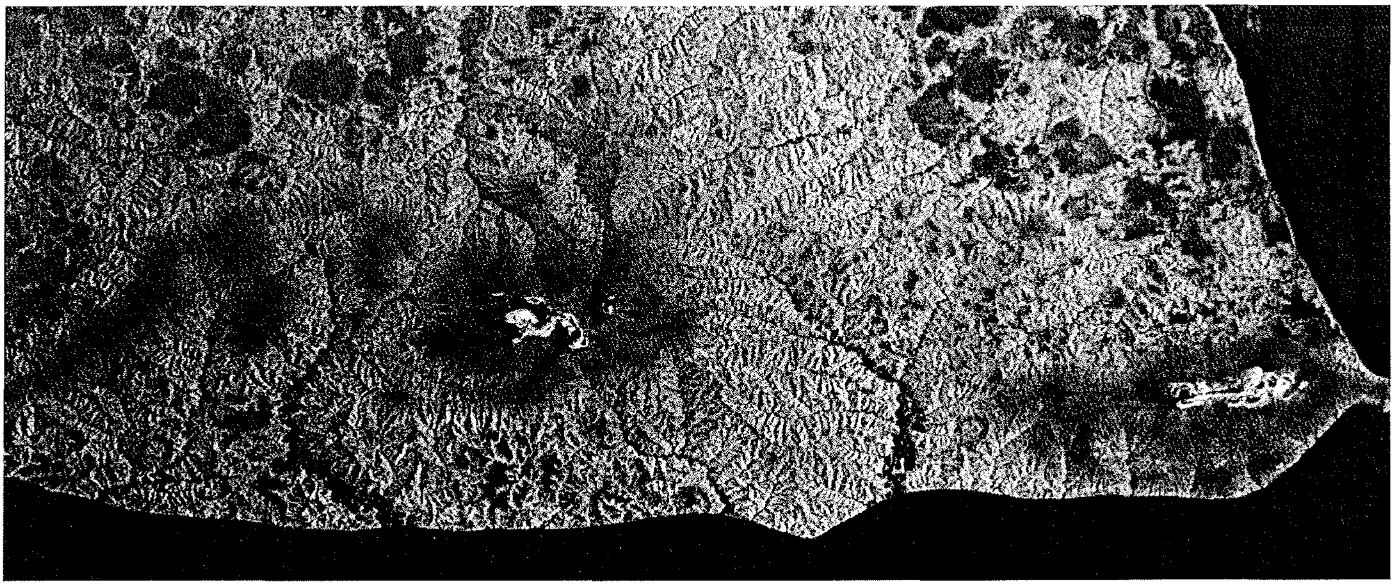

Fig. 2: Satellite image of the southeastern part of Bol'shoy Lyakhovsky Island; remains of seasonal snow cover and perenially snow patches are visible on Khaptagai Tas hills and Emii Tas hills.

Abb. 2: Satellitenfoto des Südostteils der Großen Ljakhow-Insel; Reste der saisonalen Schneedecke und perennierender Schneefelder sind an den Bergen des Khaptagai Tas und des Emii Tas zu erkennen.

Moreover, excavations were made from snow patches in order to study vertical profiles and to sample snow and firn. The measurement of the snow patch extensions was carried out by tape. In two positions on Bol'shoy Lyakhovsky Island and in the Chekanovsky Ridge plants, mosses and lichens were sampled from nival meadows and rock debris near snow patches. I. Akhmadeeva from Lena Delta Reserve, Tiksi, and F. Kienast from Potsdam performed botanical identification of nival meadow vegetation in the field whereas specialists from the Komarov Botanical Institute St. Petersburg (M. Zhurbenko, E. Kuzmina) identified mosses and lichens after the expeditions.

The sampled snow and detritus material was then analyzed in the laboratory by means of grain size analysis (sieves and Laser Particle Analyzer COULTER LS 200), the content of clastic material and hydrochemical composition (Ionomer I-1201; Piston Burette Titronic Universal) of snow, firn and meltwater.

RESULTS

Khaptagai Tas hills on Bol'shoy Lyakhovsky Island – Study of a nival landscape (Fig. 1b)

In a distance of about 15 km from the sea the country surface gradually rises to hills of 200 m a.s.l. between the coast of the Dmitri Laptev Strait in the south, the Khaptagai Tas hills in the north and between the rivers Vankina and Dymnaya. A net of thermo-erosional valleys, separate ravines and various small thermokarst lakes form dominant surface structures. Cryoplanation terraces superimpose the slopes of the Khaptagai Tas hills. Large kars with traces of repeated snow patch positions occur on the northern and southern slopes. A gradual enlargement of grain sizes of surface sediments can be seen when approaching the hills. The surface material in larger distances consists of loamy, silty fine sand without any small stones or gravel. But near the hills the frequency and size of stones in the dominated fine-grained silty material increases gradually. The hills are covered by meter-sized granite blocks, which get rare towards the feet of the slopes. Pebbles of sandstone and slates were found in larger distances in fluvial deposits. Many wet sediment patches occur between the granite. They are covered with various plants and contain a lot of fine roots.

Based on satellite images and aerial photographs of the landscape (Fig. 2), parts of Khaptagai Tas hills can be considered as areas of regularly developed single forms of an embryonic glaciation. The other part of the hills belongs to the area of the Ice Complex. Their boundary generally runs along the 80 m-

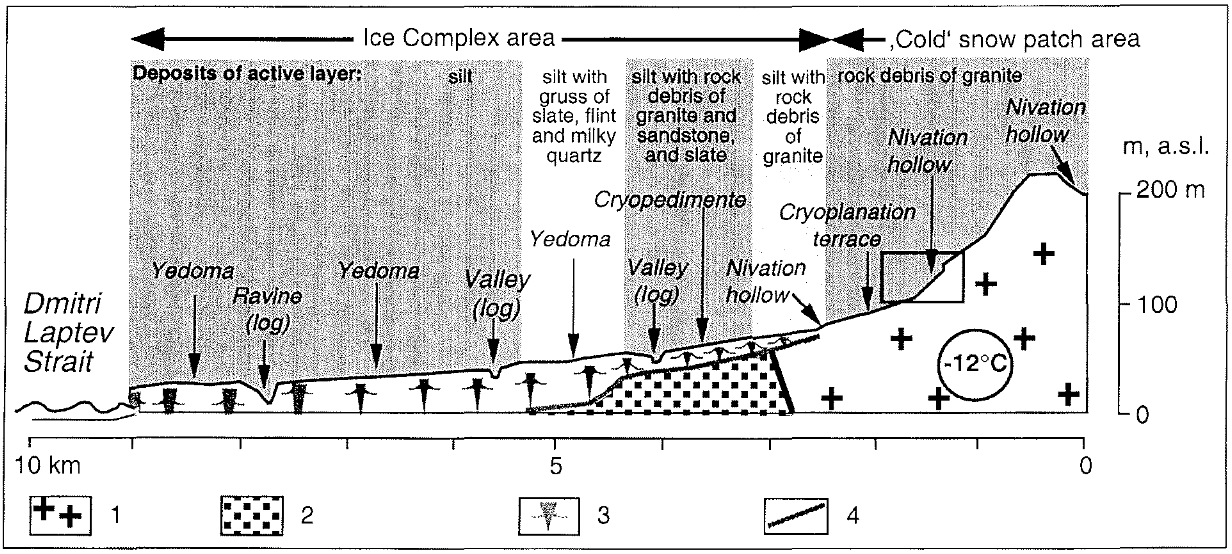

Fig. 3: Schematic profile of geocryological and geomorphological elements of Khaptagai Tas hills. 1: granite; 2: sandstone and slate; 3: Ice Complex; 4: lower boundary of the Ice Complex.

Abb. 3: Schematisches Profil der geokryologischen und geomorphologischen Elemente der Chaptagai Tas Berge. 1: Granit, 2: Sandstein und Schiefer, 3: Eiskomplex, 4: untere Grenze des Eiskomplexes.

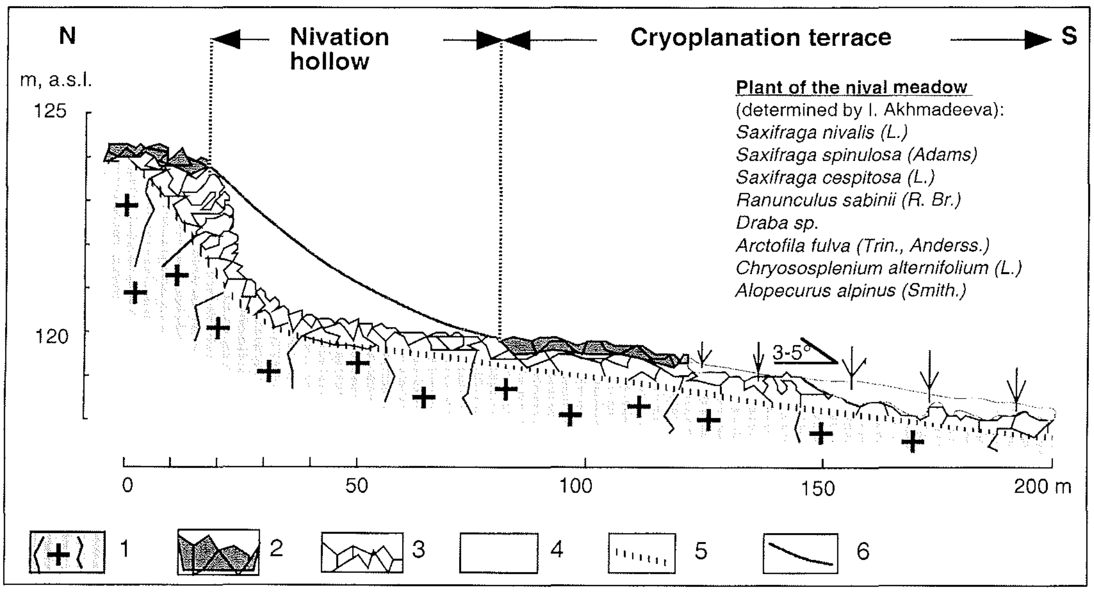

Fig.4: Detailed profile of a part of the snow patch area on Khaptagai Tas hills. 1: granite with cracks filled by ice; 2: „black stones" (granite debris with black cover of lichens); 3: „white stones" (rock debris of granite without lichens; 4: silt with rock debris of granite and many roots; 5: boundary of the active layer; 6: expected limit of snow patch.

Abb. 4: Detail-Profil von einem Teil des Schneefeld-Gebietes an den Chaptagai Tas-Bergen. 1: Granit mit eisgefüllten Klüften, 2: „Schwarze Steine" (Granitschutt mit schwarzem Flechtenüberzug), 3: „Weiße Steine" (Granitschutt ohne Flechtenüberzug), 4: Silt mit Granitschutt und vielen Wurzeln, 5: Grenze der Auftauzone, 6: Vermutete Grenze des Schneefeldes.

isohypse of the southern slope (Fig. 3). Those kars and nivation hollows are traces of snow patches. Most of the granite blocks are covered by black lichen whereas stones in the snow patch locations show a light grey color without any black lichen (Fig. 4). The bottom of a nivation hollow usually changes down the slope to less inclined places of the cryoplanation terrace with nival meadows. Therefore, meadow vegetation grows in freshly accumulated silt patches in these areas (Fig. 4). Tundra vegetation covers the distal part of the cryoplanation terrace and the cryopediment following downward the hills. Thermokarst mounds (baydzharakhs) between 80 and 60 m a.s.l. structure the cryopediment of Khaptagai Tas hills. The active layer of the cryopediment consists of silt with granite debris. The Ice Complex area comprises also a less inclined plain with polygonal patterns trenched by ravines. The altitude of this plain gradually decreases towards Dmitri Laptev Strait. At the boundary to the cryopediment the active layer of the Ice Complex consists of silt with single inclusions of gruss, but close to the sea the active layer consists only of silt, exposed in mud circles and thermokarst mounds (Fig. 4).

Detailed description of different studied snow patch areas

The bodies of snow patches are all over distributed the slopes of the study areas. According to LEWIS (1939), who distinguished between longitudinal and transverse nivation hollows, we on one hand classify longitudinal snow patches and on the other transversal snow patches. Longitudinal snow patches are located parallel to the slope incline, crossing the isohypses of the slopes. They are very often part of headwaters of brooks and rivers. Transversal snow patches are located parallel to the isohypses and crosswise to the slope incline. Additionally, snow patches were differentiated in kar type, ravine type, terrace type, and cliff type (Tab. 2.) according their geomorphologic position.

The most intensely detailed studied examples were the snow patches No. 2 and No. 4 in the northwestern Chekanovsky Ridge (Fig. 1e). These longitudinal snow patches crossed the isohypses between 240-290 m, resp. 155-280 m a.s.l. and lie in a nivation hollow of a slope kar with an angle of 30° to 35°. In the central part a dark, 1 cm thick layer of plant and mineral detritus („chionoconite“) covered the surface of the snow patches. Those snow patches consist of alternating horizons of ice, firn and snow.

Running water was observed in a depth of about 0.5 m in the lower part of the snow patches whereas in the upper part up to 1.5 m depth there was no water at all. The nivation hollow was drained by a subsurface discharge across the rock debris of the kar. The drain was noticeable by the noise of garrulously running water. The drain outcropped deeper near the rim of the kar and this trail could be observed outside of the kar as a small runnel disembogued into the brook Mus Khaya Yuryage. Consequently, the meltwater of the snow patch No. 2 supplied the brook and accumulated dissolved and clastic material into the brook. This material consists of debris of sandstone with nival silt near the thawed areas of the snow patch and of mixtures of nival silt with plant detritus („chionoconite“) (Fig. 5). Several spots of „chionoconite“ are seen on the surface of the active layer along a small strip (10-15 m wide) flanking the snow patch. This active layer formed on debris with goletz-ice has a thickness of less than 0.4 m. This strip with „naked“ stones, in spots covered by „chionoconite“ is the area to which snow patch No. 2 had been spread some time before. In larger distances where actually no snow patches were distributed black lichens and mosses covered the rock debris. Below the surface cover of coarse unrounded rock debris (10-30 cm in diameter) we found a number of subrounded and some well-rounded pebbles and gravel (1-5 cm in diameter). They indicate that running subsurface water might have been active for longer time. These rounded pebbles are covered by young

	Kar type	Terrace type	Ravine type	Cliff or shore type
Geomorphologic situation	snow blown together at bottom and slopes of large kars	snow blown in nivation hollows on steps of cryoplanation terraces	snow blown from sorrounding higher plain into narrow ravines, preserved in protected positions	snow blown across ice against coastal cliff
Facies	alluvial facies	slope facies	erosional facies, destruction of Ice Compex formations	
Runoff of Meltwater	orientated runnoff; feeds creeks and rivers	into boggy nival meadows	orientated runoff; feeds creeks	broad runoff into sea
Diameter of snow patches	0.2 to 2 km	0.1 to 0.5 km	0.1 to 0.2 km	0.1 to 0.3 km
Location and No. of "cold" snow patches	Chekanovsky / Kunga Ridges (shn 2,4,6); Khaptagai Tas hills	Chekanovsky Ridge (shn 3,5)	Bykovsky Peninsula (shn 1); Ebe Basyn Sise (near Kuba Bay)	East coast of Bykovsky Peninsula
Height (ma.s.l.)	100 to 300	50 to 100	10 to 50	≤10

Tab. 2: Types and characteristics of studies "cold" snow patches in the Laptev Sea region.

Tab. 2: Typen und Eigenschaften der untersuchten "kalten" Schneefelder in der Laptewsee-Region.

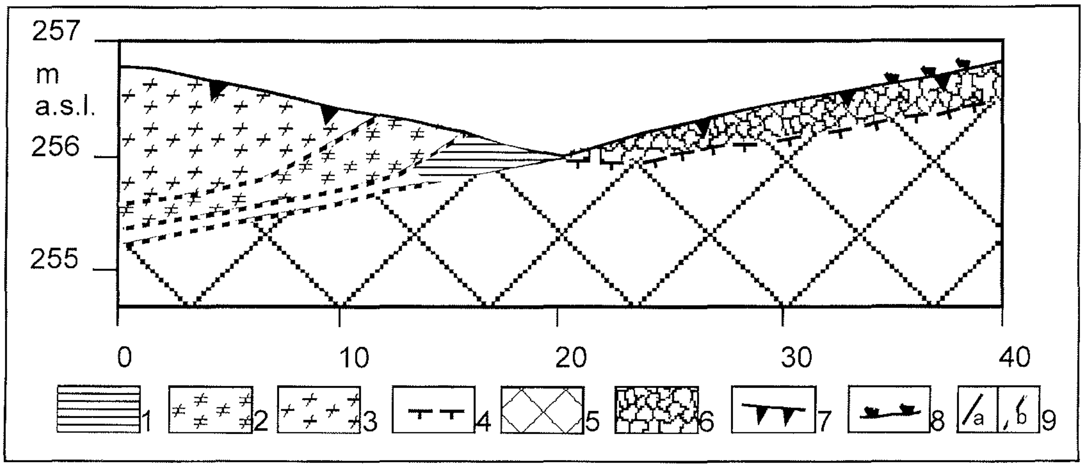

Fig. 5: Schematic cross section of the „cold" snow patch No. 2 (kar type) and the surrounded active layer of the nival landscape of Chekanovsky Ridge. 1 through 3 niveo-eolian deposits; 1: stratified ice; 2: stratified firn; 3: alternate bedded firn and coarse-grained melted and refrozen snow; 4: boundary of the active layer; 5 and 6 surfical cryogenic eluvium: 5: debris of sandstone with basal or conglomeric cryogenic texture; 6: loose and crumbly debris of sandstone; 7: several spots of „chionoconite" (silt with plant detritus) at debris active layer and at the surface of the snow patch; 8: mosses, lichens and other lithophytes in several spots; 9: lithologic boundaries; 9a: determined, 9b: supposed.

Abb. 5: Schematischer Querschnitt durch das „kalte" Schneefeld Nr. 2 (Kar-Typ) und die umgebende Auftauzone in der nivalen Landschaft des Chekanowsky-Rückens. 1 bis 3 nival-äolische Ablagerungen: 1: geschichtetes Eis, 2: geschichteter Firn, 3: wechselnde Lagerung von Firn und grobkörnigem, geschmolzenem und wiedergefrorenem Schnee, 4: Grenze der Auftauzone, 5 und 6 oberflächiges kryogenes Eluvium: 5: Sandsteinschutt mit basalem oder konglomeratischem kryogenen Gefüge, 6: lockerer und krümmeliger Sandsteinschutt, 7: verschiedene Flecken aus „Chionoconit" (Silt mit Pflanzendetritus) auf der Firnoberfläche, 8: Moose, Flechten und andere Lithophyten in verschiedenen Flecken, 9: lithologische Grenzen: 9a: bestimmt, 9b: vermutet.

talus material from slopes. Similar situations were studied in three other positions, in slope kars of the Chekanovsky Ridge, the Kunga Ridge (Fig. 6) and on the Khaptagai Tas hills (Fig. 1e, 1g, 1b). This type of snow patch was named „kar type".

Another type of „cold" snow patches was studied on Bykovsky Peninsula (Fig. 1a). Snow patch No. 1 was located in a thermo-erosional ravine which cut the Ice Complex elevation (Yedoma) between 8-30 m a.s.l.. The boundary of the landscape concerned coincided with the slope edge where the surface of Yedoma is replaced by the slopes of the ravine (Fig. 7). It seems that up to the upper border the ravine was filled by snow and snow patch No. 1 was only a remain of niveo-eolian deposits, which were studied in summer 1998. A small brook divides the body of snow patch No. 1. Therefore, it was possible to study a section of a snow patch. The lower part consists of 1 m thick, transparent blue ice, which was frozen on the loamy bottom. Higher up in the studied section similar transparent ice includes 2-3 cm thick interlayers of milky ice.

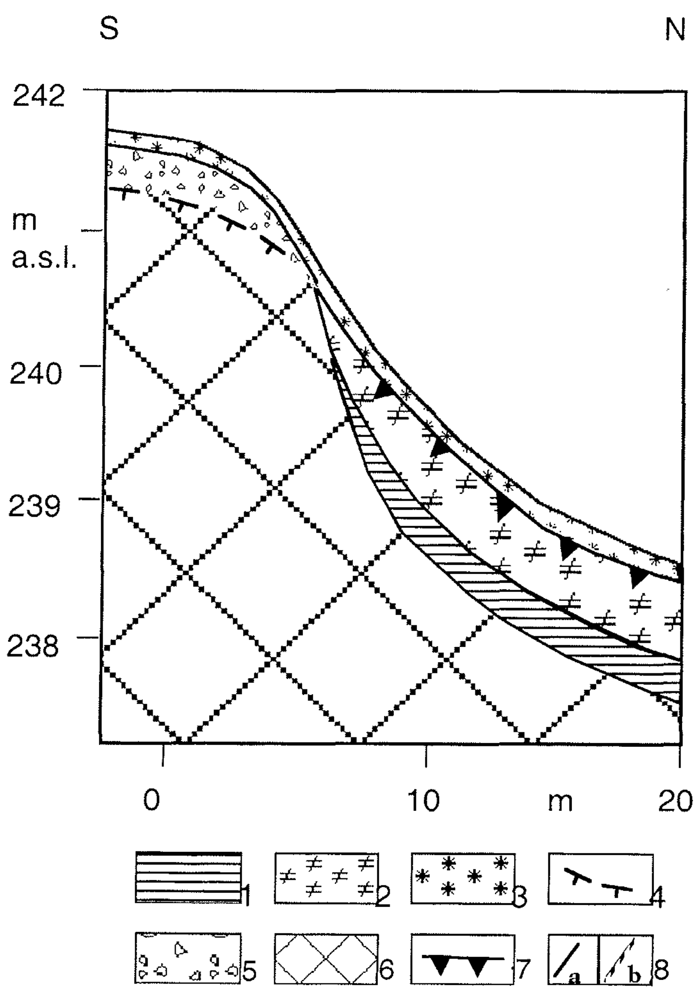

Fig. 6: Schematic profile of the upper part of the „cold" snow patch No. 6 (kar type) and the surrounded active layer in the nival landscape of Kunga Ridge. 1: stratified ice; 2: stratified firn; 3: clear snow; 4: boundary of the active layer; 5: thawed debris; 6: frozen debris; 7: several spots of „chionoconite" (silt with plant detritus) on firn surface; 8: lithologic boundaries: 8a: determined; 8b: supposed.

Abb. 6: Schematisches Profil vom oberen Teil des Schneefeldes Nr. 6 (Kar-Typ) und der umgebenden Auftauzone in der nivalen Landschaft des Kunga-Rückens. 1:geschichtetes Eis, 2: geschichteter Firn, 3: reiner Schnee, 4: Grenze der Auftauzone, 5: getautes Geröll, 6: gefrorenes Geröll, 7: verschiedene Flecken aus „Chionoconit" (Silt mit Pflanzendetritus) auf der Firnoberfläche, 8: lithologische Grenzen: 8a: bestimmt, 8b: vermutet.

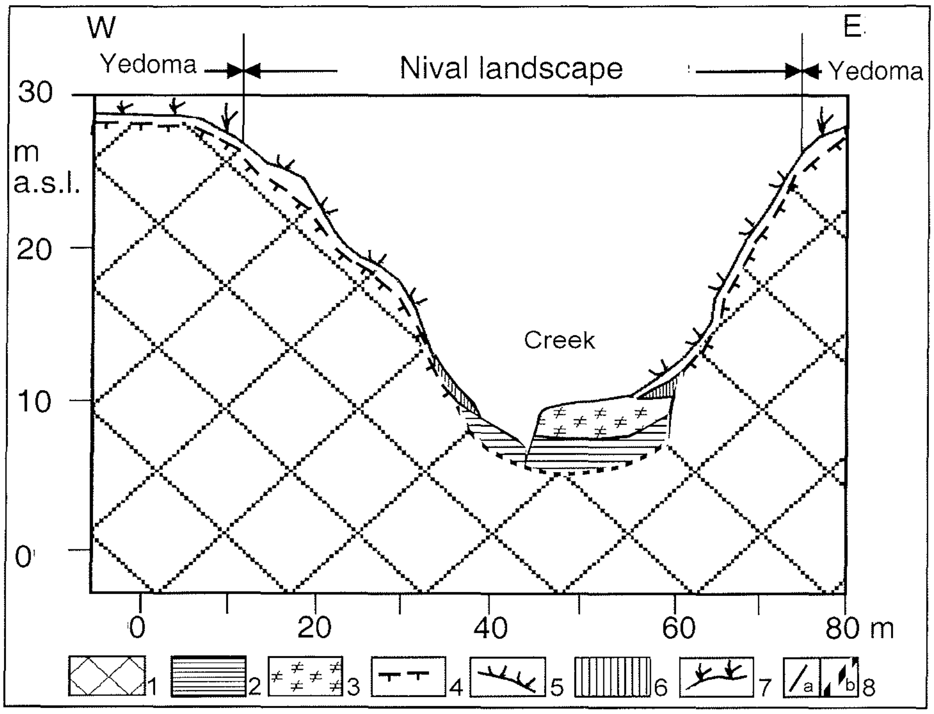

Fig. 7: Schematic profile of the „cold" snow patch No. 1 (ravine type) and the surrounding nival landscape at Bykovsky Peninsula. 1: Ice Complex; 2: stratified ice; 3: stratified firn; 4: boundary of the active layer; 5: silt with plant detritus from the surface of the active layer; 6: talus; 7: surface of the active layer with plant cover of Subarctic grass tundra; 8: lithologic boundaries: 8a: determined, 8b: supposed.

Abb. 7: Schematisches Profile des „kalten" Schneefeldes Nr. 1 (Ravinen-Typ) und der umgebenden nivalen Landschaft der Bykowsky-Halbinsel. 1: Eiskomplex, 2: geschichtetes Eis, 3: geschichteter Firn, 4: Grenze der Auftauzone, 5: silt mit Pflanzendetritus von der Oberfläche der Auftauzone, 6: Versturz, 7: Oberfläche der Auftauschicht mit Pflanzendecke der subarktischen Grastundra, 8: lithologische Grenzen: 8a: bestimmt, 8b: vermutet.

This packet of alternate bedding had a thickness of about 1 m and was followed by about 2 m of thick horizontal or cross-bedded firn. Small layers (0.1-0.2 mm) of „chionochonite" caused the stratification of the firn. The same matter was distributed in spots on the surface of snow patch No.1 as well as on the surface of the active layer on the slopes of the ravine (Fig. 7). The brook, which was fed by meltwater of the snow patch, flowed on the flat bottom of the ravine as several small muddy runnels. This water contained a lot of clastic and organic suspended detritus. The brook drained into the Laptev Sea across a big alluvial fan covered with grass. Similar nival landscapes were observed in other ravines as well as in narrow places of small river valleys of the studied region. We called this type of snow patch „ravine type".

One of the example for the structure of cryoplanation terraces is the area around the transversal snow patch No. 3 (Fig. 1e, Tab. 1) in the northwestern part of the Chekanovsky Ridge. The area is subdivided into three zones (Fig. 8). The zone of the nivation hollow with the snow patch lies on debris of sandstone and consists of ice mainly. „Chionoconite" spots covered its surface. The following area of laminar meltwater discharge is located hypsometrically more deeply. The zone of the cryoplanation terrace was covered and surrounded by herb and grass vegetation (Tab. 3). The upper part of the strongly wetted soil of the cryoplanation terrace consists of freshly

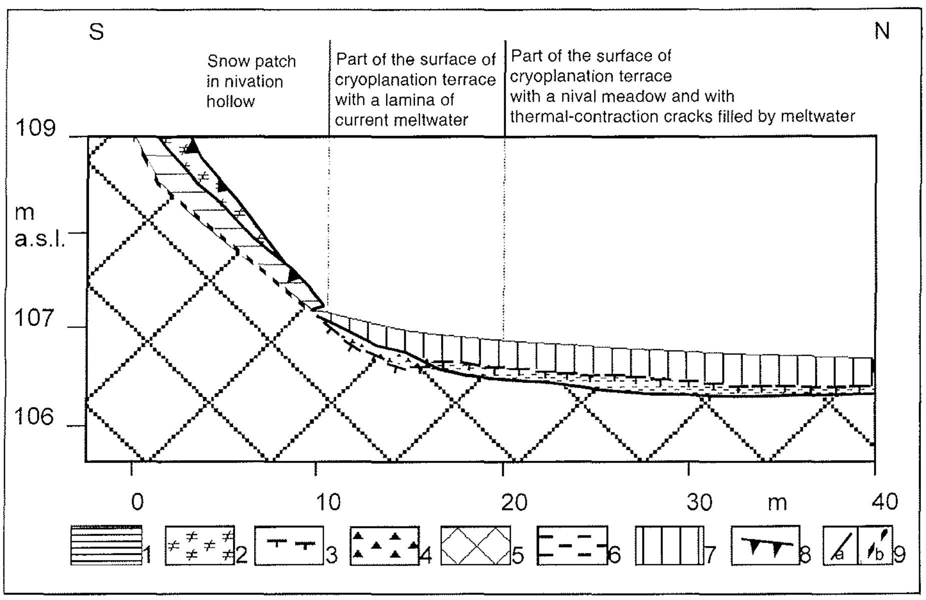

Fig. 8: Schematic profile of the lower part of the „cold" snow patch No. 3 (terrace type) and the surrounded active layer in the nival landscape of Chekanovsky Ridge. 1 and 2 niveo-aeolian deposits: 1: stratified ice; 2: stratified firn; 3: boundary of the active layer; 4 and 5: surfical cryogenic eluvium: 4: thawed debris; 5: frozen debris; 6 and 7: nival deposits („extranivities"): 6: frozen silt with debris, sandy lenses and ice inclusions; 7: thawed silt with sandy lenses and debris inclusions; 8: several spots of „chionoconite" (silt with plant detritus) on firn surface, 9: lithologic boundaries: 9a: determined, 9b: supposed.

Abb. 8: Schematisches Profil vom unteren Teil des „kalten" Schneefeldes Nr. 3 (Terrassen-Typ) und der umgebenden Auftauzone in der nivalen Landschaft des Chekanowsky-Rückens. 1 und 2: nival-äolische Ablagerungen: 1: geschichtetes Eis, 2: geschichteter Firn, 3: Grenze der Auftauzone, 4 und 5: oberflächiges kryogenes Eluvium: 4: getauter Schutt, 5: gefrorener Schutt, 6 und 7 nivale Ablagerungen: 6: gefrorener Silt mit Geröll, Sandlinsen und Eiseinschlüssen, 7: getauter Silt mit Sandlinsen und Geröllеinschlüssen, 8: verschiedene Flecken aus „Chionoconit" (Silt mit Pflanzendetritus) auf der Firnoberfläche, 9: lithologische Grenzen: 9a: bestimmt, 9b vermutet.

accumulated „chionoconite" and contains debris, gravels and lenses of sand. These wetted nival deposits near the snow patch, which are named „extranivities" contain ice inclusions and lay on icing debris with basal cryotexture below the active layer. The zone of the nival meadow directly bordered a bumpy surface on the area of the laminar discharge. There were frost cracks on this surface forming smaller (0.5-0.7 m) or larger polygons. The meltwater, running out slowly and in small volume from the snow patch, was completely kept in the microrelief of the distal part of the cryoplanation terrace. The „extranivities" of the nival meadow are deposited on weathered sandstone bedrock (eluvium). Snow patches in relation with cryoplanation terraces are called „terrace type".

The next type of nival landscapes with „cold" snow patches very often was found on marine terraces on the coast of the Laptev Sea (e.g. Bykovsky Peninsula) as well as on riversides of the Lena delta (e.g. Angardam Channel). The altitude of such sites was not higher than 4 m and the altitude of the bounding cliff was not higher than 10 m. The coastal cliffs are strongly and frequently structured by nivation hollows, which have shapes of peculiar wave-cut grooves. They are notched into frozen masses of disperse deposits as well as in strong weathered dense rocks with fissure ice. Snow patches located on sea or river cliffs are named „cliff type".

The vegetation of nival meadows

The determined plant association of nival meadows contains cryoxerophytes (*Dryas, Draba, Cassiope, Artemisia, Astragalus*) and cryophytes (*Salix*) as well as hydrophytes (*Eriophorum, Ranunculus*) and other indicators of moister conditions (*Oxyria, Vaccinium, Saxifraga hirculus*) (Tab. 3).

The flora of nival meadows is a sufficiently typical association of the Siberian nival landscape (TIKHOMIROV 1956). However, the determined flora of two nival meadows from Chekanovsky Ridge and Bol'shoy Lyakhovsky Island is not as diverse as EGOROVA (1985) described for the nival tundra and nival meadows, who had classified seven different floral zones in the mouth area of the Lena river. There are only a few species, which correspond with EGOROVA's (1985) determination list (*Arctophila fulva, Ranunculus nivalis, Draba* sp., *Saxifraga cernua, and Chrysoplenium alternifolium).* Nevertheless, the determined flora characterizes the plant association like that of nival meadows. A number of species corresponds to those of the Samoylov-Island (central Lena Delta) (ZHURBENKO pers. comm). Many plants of nival meadows are widely distributed in study areas of the Siberian Arctic (*Cassiope tretragona, Dryas punctata, Eriophorum, Oxyria, Polygonum viviparum,* Salix, Saxifraga). They have a wide ecological amplitude and are not only restricted to the locations of snow patch areas. Only a few species are characteristic for these habitats (*Saxifraga hyperborea, Ranunculus nivalis, Phleum commutatum*).

EGOROVA (1985) did not mention mosses and lichens shown in Table 4 and 5. However, both groups play an important role during the formation of nival landscapes. Firstly, the surface and the active layer could not dry-up below a cover of lichens and mosses. Secondly, they fix the fine-grained clastic matter, which was deposited around snow patches, and thirdly, the biogenic destruction of rock debris starts and continues below a cover of mosses and lichens. Some species of lichens, which are characteristical for special environments, could be identified. Three species of lichens indicate wet Arctic conditions (*Arctocetraria nigricascens, Stereocaulon rivulorum, and Cetrariella fastigiata).* One species is often associated with dry and exposed Arctic environments (*Ramalina almquistii*),

Species	Environmental (ecological) description
Artemisia sp.	cryoarid
Astragalus sp.	dry to mesic sites, drained sites; avoids moisture
Cassiope tetragona	typical for snow patch surroundings, prefers at least drained habitats
Draba sp.	mostly cryoxerophyte
Dryas punctata	cryoxerophyte, typically Arctic
Eeriophorum angustifolium	hydrophytes,; typical for snow patch surroundings in the Arctic
Eriophorum russeolum	hydrophytes
Novosieversia glacialis	wind swept, well drained sites
Oxyria digyna	typical Arctic cryophyte, also in nival meadows
Poaceae spec.	
Pedicularis sp.	cryophyte (needs insects)
Phleum commutatum	typical for snow patch surroundings
Polygonum viviparum	nical meadows, wide ecological amplitude
Ranunculus nivalis	nival meadows
Salix Subgen. *Chamaetia*	chryophyte, typical Arctic, different sites depending on species
Saxifraga cernua	euryoecious
Saxifraga hirculus	bogs of the tundra, on wet sites
Saxifrage hyperborea	nival meadows
Saxifraga nelsoniana	euryoecious
Saxifraga punctata	
Vaccinium vitis-idaea	prefers well drained habitats and subarctic tundra
Valeriana capitata	

Tab. 3: Plants of nival meadow in front of "cold" snow patch No. 3 (Fig. 7.), Mus Khaya Yuryage Creek, Chekanovsky Ridge.

Tab. 3: Pflanzen einer nivalen Wiese vor dem "kalten" Schneefeld Nr. 3 (Fig. 7), Mys Chaja Jujege-Bach, Chekanovsky-Rücken.

Species	Region	Sample No.	Description of environment
Alectoria nigricans (Ach.) Nyl.	Chekanovsky	F-29/2	large kar covered by weathering debris, on rocks
Arctocetraria nigricascens (Nyl.) Karnefeldt & A.Thell	Chekanovsky	F-20	wet / nival
Aspicilia sp.	Chekanovsky		epilithic
Bryocaulon divergens (Ach.) Karnefeldt	Chekanovsky	F-29/1	large kar covered by weathering debris, on rocks
Cetrarielly fastigiata (Nyl.) Karnefeldt & A.Thell	Chekanovsky	F-22	wet / nival
Cladina arbuscula (Wallr.) Hale & W.L.Culb	Chekanovsky	F-2	not specified
Cladonia amaurocraea (Florke) Schaer.	Chekanovsky	F-4	not specified
Dactylina arctica (Hook.) Nyl.	Chekanovsky	F-17	not specified
Flavocetraria cucullata (Bellardi) Karnefeldt & A.Thell	Chekanovsky / Bykovsky	F-26	large kar covered by weathering debris
Hypogymnia subobscura (Vain.) Poelt	Chekanovsky	F-23	not specified
Lecanora polytropa (Hoffm.) Rabenh.	Kunga Ridge	K6-1s	epilithic
Ochrolechia frigida (Sw.) Lynge	Chekanovsky	F-14	not specified
Ophioparma ventosa (L.) Norman var *lapponica* (Rasanen) R.Sant.	Chekanovsky	F-5	not specified
Peltigera leucophlebia (Nyl.) Gyeln.	Chekanovsky	F-7	not specified
Peltigera rufescens (Weiss) Humb.	Chekanovsky	F-16	not specified
Pertusaria coriacea (Th.Fr.) Th.Fr.	Chekanovsky	F-21/1	not specified
Psoroma hypnorum (Vahl) Gray	Chekanovsky	F-27/2	large kar covered by weathering debris
Ramalina almquistii Vain.	Chekanowsky	F-25	dry / exposed, on rock debris of nival kar
Rinodina turfacea (Wahlenb.) Korb.	Chekanovsky	F-21/2	not specified
Spherophorus globosus (Huds.) Vain	Chekanovsky	F-27/1	not specified
Stereocaulon rivulorum H.Magn.	Chekanovsky	F-19	wet / nival (on sandy soil)
Thamnolia vermicularis (Sw.) Schaer. var. *vermicularis*	Chekanovsky	F-8/1	not specified
Thamnolia vermicularis (Sw.) Schaer var. subuliformis (Ehrh.) Schaer.	Chekanovsky	F-8/2	not specified
Vulpicida tilesii (Ach.) J.-E.Mattson & M.J.Lai	Chekanovsky	F-1	Ca-rich

Tab. 4: Lichens around the studied "cold" snow patches of the Chekanovsky Ridge (identification by M. Zhurbenko).

Tab. 4: Flechten im Umfeld der untersuchten "kalten" Schneefelder des Chekanovxky-Rückens (Bestimmungen durch M. Zhurbenko).

Species	Region	Sample No.
Andrea rupestris Hedw.	Chekanovsky (shn 3)	Ch-2-m
Bryum sp.	Chekanovsky	M-6
cf. *Calliergon giganteum* (Schimp.) Kindb.	Chekanovsky	Shn 3/1
Dicranoweissia crispula (Hedw.) Lindb.	Kunga Ridge (shn 6)	K-6-m
Hylocomium splendens (Hedw.) Schimp. in B.S.G.	Chekanovsky / Kunga Ridge	M-4/2
Polytrichastrum alpinum (Hedw.) G.L.Sm.	Chekanovsky	Shn §/6 M-4/1
Polytrichum sp.	Kunga Ridge	K-6-mlg/2
Sanionia unicata (Hedw.) Loeske	Chekanovsky / Kunga Ridge	Shn 3/5, K-6-mlg/3
Sanionia paludicola Loeske et K.Muell.	Chekanovsky	Shn 3/4
Sarmentypnum sarmentosum (Wahlenb.)Tuom et Z.Kop.	Chekanovsky	Shn 3/7
Sphagnum aquarrosum Crome	Chekanovsky	Shn 3/2
Sphagnum warnstorfii Russ.	Chekanovsky	M-14
Sphagnum aongstroemii C.Hartm.	Chekanovsky	M-15

Tab. 5: Mosses around the studied "cold" snow patches of the Chekanovsky and Kunga Ridges (identification by E. Kuzmina).

Tab. 5: Moose im Umfeld der untersuchten "kalten" Schneefelder von Chekanovsky- und Kunga-Rücken (Bestimmung E. Kuzmina).

whereas the lichen *Vulpicida tilesii* is associated with calcium-rich Arctic environments. Some species seem to be typical for kars covered with weathering debris (*Alectoria nigricans, Bryocaulon divergens, Flavocetraria cucullata, and Psoroma hypnorum*). The environmental conditions could not be specified exactly for the other determined species of lichens. The eleven identified moss species (Tab. 5) are not very specific for the studied situation of snow patch areas, many of these species were observed in the central Lena delta as well (M. ZHURBENKO pers. comm.).

Analytical results

The content of clastic and plant detritus („chionoconite") of the studied snow patch samples varies between 0.6-12.3 g/l (Tab. 1) This indicates the importance of snow patches as a sediment source in nival landscapes. Most of the sediment-laden firn was found in transversal snow patches of cryoplanation terraces. The grain size distribution of the clastic material within and around snow patches (Tab. 6) partially differs between various locations. This indicates the activities of different processes during sedimentation. There are fine-grained silty deposits as well as coarse-grained sands. The modal values of the grain size vary between 0.01-0.3 mm. Grain-size frequency curves of the studied nival deposits are polymodal and show poorly sorted grain size distributions, whereas loess and loess-like sediments have a quite narrow grain size distribution (M^d = 0.02-0.06 mm) and are well sorted (REINECK & SINGH 1980). The same patterns like in recent nival deposits are evident in Late Pleistocene Ice Complex deposits (see SIEGERT et al. 2001). These Ice Complex deposits also differ in grain size distribution and grain size parameters between the studied locations and horizons but in general they show a polymodal distribution and are poorly sorted.

First hydrochemical analyses of deposited snow, firn and meltwater show different compositions (Tab. 7, Fig. 9). Different parent rocks could explain this. For example snow patch No. 1 studied on Bykovsky Peninsula contains the highest values of Ca^{2+} and hydrogen carbonate. This might have been caused by more or less carbonatic deposits of the surrounding Ice Complex formation (2-5 weight % $CaCO_3$, Schirrmeister et al. 2001b). However relatively small contents of Mg^{2+}, Na^+, K^+ and SO_4^{2-} and Cl^- could be connected with Mesozoic sandstones and slates, the bedrocks we found at the Chekanovsky and the Kunga Ridge. The major ion concentration of snow, firn and meltwater differ clearly from those of the precipitation from Tiksi and from Shalaurova-Station at Bol'shoy Lyakhovsky Island (Tab. 7). This is noticeable especially in a higher concentration of HCO_3^-, Ca^{2+} and $Na^+ + K^+$. Such a concentration could be caused by evaporation and interaction between snow, firn and meltwater with mineral detritus of snow patches. The relatively high content of SO_4^{2-} could be explained by the high content of organic matter in snow patches. Additionally, low contents of chloride and sodium are remarkable. That indicates a non-marine influence of the recent winter precipitation because of the ice-covered sea as

Location	Material	Sample	>1 mm	0.1-1 mm	0.01-0.1 mm	<0.01 mm	Median (mm)
Bol'shoy Lyakhovsky Island	hydromorphic soil of nival meadow at fine-grained sandstone	BL-3-99	6.2	7.4	46.8	39.6	-
Bol'shoy Lyakhovsky Island, Khaptagai Tas hill	freshly accumulated sandy silt between granite debris	KGT 1-2	0.3	35.6	40.2	23.9	0.042
		KGT 1-2	-	19.6	52.2	28.2	0.025
		KGT 1-3	2.1	47.9	41.8	8.2	0.100
Chekanovsky Ridge	freshly accumulated sandy silt near the boundary, above and beneath snow patches	Shn 2/2	1.2	39.6	43.2	16.0	0.075
		Shn 2/3	1.4	54.5	31.2	12.9	0.119
		Shn 4/2	0.2	40.3	43.6	15.7	0.074
		Shn 5/1	0.4	27.6	54.5	17.5	0.045
Bykovsky Peninsula	clastic material within firn of snow patches	SP 1	2.5	19.7	40.2	19.7	0.063
Chekanovsky Ridge	clastic material within firn of snow patches	SP 2	18.5	53.1	18.4	10.4	0.381
		SP 4	2.1	40.4	30.1	27.4	0.058
		SP 5	2.6	40.9	47.9	8.6	0.080
Kunga Ridge		SP 6	0	4.4	42.6	50.9	0.010
Bykovsky Peninsula	suspended matter from the muddy Meltwater stream of snow patch No. 1	MS-4	0	10.6	48	41.4	0.014

Tab. 6: Granulometric composition of modern nival deposits.

Tab. 6: Korngrößenzusammensetzung rezenter nivaler Ablagerungen.

	Sample	Locality	Date	pH	Eh (mV)	Ions (mg/l) Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	HCO_3^-	SO_4^{2-}	Cl^-
1	1-WC	Meltwater of shn 1, Bykovsky Peninsula	28.08.98	7.0	390	13.3	5.4	4.3	57.7	8.6	5.8
2	W-sp-1	firn of shn 1	28.08.98	6.7	-	13.7	4.5	2.6	58.4	7.4	1.8
3	W-sp-2	firn of shn 2, Chekanovsky Ridge	12.08.00	6.2	435	5	3.2	7.8	32.7	12.3	2.1
4	W-sp-4	firn of shn 4, Chekanovsky Ridge	13.08.00	6.8	420	3.7	2	8.1	22.6	11.9	2.8
5	W-sp-5	firn of shn 5, Chekanovsky Ridge	13.08.00	5.8	455	1.9	1.7	4.8	16.3	4.9	2.8
6	W-sp-6	firn of shn 6, Kunga Ridge	03.08.00	6.0	465	1	0.8	6	7.7	7.8	3
7	Tiksi-rain	Tiksi (GORDEEV et al. 1996)		-	-	1.2	1	1.2	3.2	2	3.2
8	Tiksi-snow	Tiksi (GORDEEV et al. 1996)		-	-	2	0.9	2.9	3.7	1.9	6.5
9	Shlaurova	Shlaurova (GORDEEV et al. 1996)		-	-	2.8	3.8	0.9	4.1	1.1	11
10	Lena river	Lena (GORDEEV et al. 1996)			-	16	4.4	11.7	52	12.3	17.1

Tab. 7: Hydrochemical analyses of firn and meltwater from different "cold" snow patches in comparison to precipitation and river water (GORDEEV et al. 1996).

Tab. 7: Hydrochemische Analysen von Firn und Schmelzwasser aus verschiedenen "kalten" Schneefeldern im Vergleich zu Niederschlagswasser und Flusswasser (GORDEEV et al. 1996).

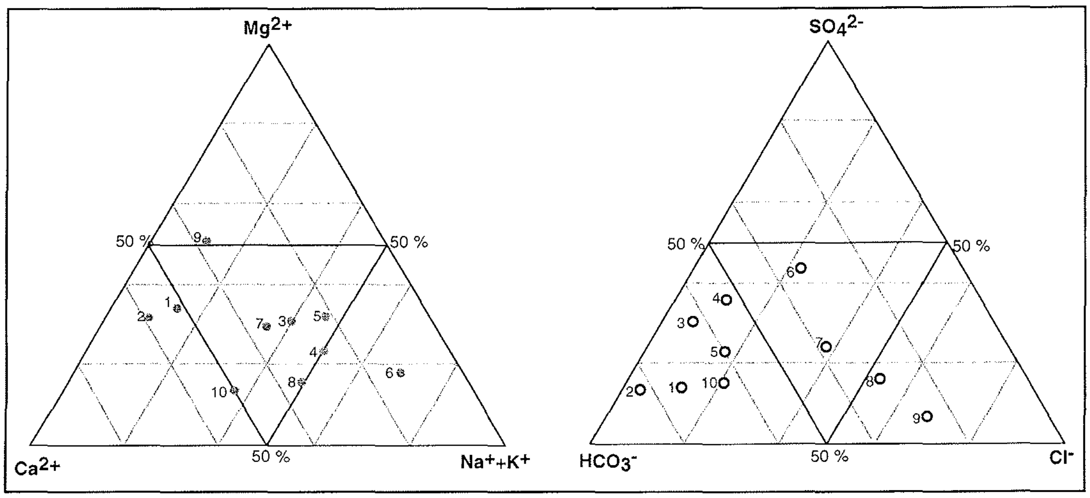

Fig. 9: Triangular diagrams of major-ion concentration of studied snow patches in comparison with precipitation and Lena River waters (for No. see Tab. 7).

Abb. 9: Dreiecksdiagramme der Hauptionenkonzentrationen der untersuchten Schneefelder im Vergleich zu Niederschlägen und Wasser der Lena (Nummerierung siehe Tab. 7).

well as the absence of sea-spray in these snow patches which are partly located at the coast of the Laptev Sea (shn 1).

DISCUSSION

We have classified the observed snow patches into four different types (Tab. 2). The longitudinal snow patches of a kar type were found on slopes of the mountains surrounding the Laptev Sea. In the study area such kars have extensions in diameter of some hundred meters to several kilometers. It seems to be possible that some of the largest kars are fossil. The kars are characterized by a wide upper part with a slope inclination of about 30° and a cone-like lower part, that ended in a small creek (Figs. 5 and 6). The snow patches of kar-type are formed when snow is blown from mountain valleys and then accumulates at the end of the valleys or in smaller branch-valleys. Small ice wedge polygons were observed in such a nival meadow. The longitudinal snow patches of the ravine type were formed in protected positions of relatively small, deep (10-15 m) and narrow thermokarst valleys (Fig. 7). The snow was blown from the surrounding tundra plain. Meltwater of this snow patch type also feeds small creeks, which flow into ravines. The transversal snow patches of the terrace type are smaller and they are formed when wind-blown snow accumulates on steps of cryoplanation terraces. Gradually nivation hollows develop on these steps and snow is better accumulated and preserved in such depressions. These transversal nivation hollows or nivation hollows (LEWIS 1939) go for predecessors of cryoplanation terraces (EMBLETON & KING 1975). The meltwater of the terrace type is widely running off into a bogy meadow in front of the snow patch (Fig. 8). The transversal snow patches of the cliff type were found very often on the coast of the Laptev Sea and on the main channels of the Lena delta (Tab. 2). These are remains of snow, which had been blown across the sea or river ice against the coastal cliffs in winter. The meltwater runoff is laterally wide across the shore into the sea. These types play an important role for coastal erosion processes and the accumulation near the coast.

Apparently, the concerned nival landscapes of slope kars, terraces, ravines and cliffs are the source for fine-grained nival silt and the mixture of clastic and plant detritus („chionoconite"). Parts of this matter attained with the meltwater of snow patches into lakes and to the inshore zone of the Laptev Sea. Other parts of the considered matter are restrained along the way of transport at the headwater region. They are part of bogy ravine deposits and of alluvial deposits as well as proluvial deposits of the Laptev Sea coastal zone.

Embryonic glaciation, in terms of „cold" snow patches does not appear every year in the same position in the study area. Additionally, such a snow patch as a single body exists only for a few months (seasonal snow patch) or some years (perennial snow patch). After that such a body disappears from the nivation hollow, whereas the nivation hollow continues to exist. Therefore, from the geological point of view the development of „cold" snow patches is a discontinuous process. At the same time the evolution of the nival landscape, which includes larger areas, like the concerned snow patches seems to be a continuous process. The long duration of this process results in the formation of slope kars, cryoplanation terraces and cryopediments as well as in the accumulation of deposits, which are dominant in the mountain forelands of the Laptev Sea coastal zone. On one hand they were named Ice Complex deposits (KATASONOV 1973, 1985, KONISHCHEV 1981) but on the other hand they were considered together with deposits near snow patches („extranivities") (KUNITSKY 1987, 1989, 1998). „Extranivities" could be explained as own deposits of the colluvial sequence (SHANTSER 1950) and they are a variation of cryolithogenic subaerial deposits (KATASONOV 1973), which were formed on slopes in nival landscapes. The accumulation of „extranivities" took place on cryoplanation terraces and is connected with meltwater streams of one or several snow patches in mainly flat, small runnels without outflow.

The landscapes with nival meadows and with „cold" snow patches are more representative for this territory of Arctic and Subarctic than landscapes with snow glaciers of the Chekanovsky Ridge (GALABALA 1997) and on Severnaya Zemlya Islands (BOL'SHIYANOV pers. comm.). The plant association of nival meadows contains plants of wet and of dry sites. Our field observations showed that such sites replace one another on a distance in some meters within the limits of the same nival meadow. The height difference between its dry sites and the adjacent wet sites mostly amount only half a meter. Already in the first year of the occurrence of recent „extranivities" herb and grass vegetation had been formed. This could explain the appearance of vertical fossil grass roots, which were often found in Late Pleistocene „extranivities" (Ice Complex deposits). The grass end herb roots of recent „extranivities" had no possibilities to rot because they were buried during the first stage of diagenesis of the „extranivities". This indicates a thin and very moist active layer during accumulation.

CONCLUSIONS

Nivation in connection with „cold" snow patches is a very complex combination of a number of processes. „Cold" snow patches lie on frozen ground. Therefore, there is no active layer beneath them and weathering does not take place. One of the most important processes is the combination of cryogenic and hydration weathering. The zone of cryohydration weathering is very active and dynamic, but relatively small around snow patches. Its position changes rapidly during summer. The zone is moving from borderline positions to central positions of the snow patch areas and, if a snow patch disappears, the ground of the area becomes visible. On one hand the formation of nival silt is a result of cryohydration weathering, on the other hand spots of eolian deposits are a second source for nival silt. Mosses and lichens occupy such spots of nival silt and then biochemical weathering takes place beneath these spots and the formation of fine-grained clastic material continues.

Other nivation processes are connected with activities of running meltwater, which leads to a certain phenomenon like the formation of pebble-shaped debris near the snow patch. These processes like rill wash, sheet wash and subsurface flow resulting in the accumulation of „extranivities", take place near the lower borderline of the snow patch. Additional transformation of 'extranivities' takes place by cryogenic actions (solifluction, congelifraction, cryoturbation) and noncryogenic processes (pedogenesis, desication, humification, biological activities).

Nival landscapes of cryoplanation terraces with „cold" snow patches were the area for the accumulation and freezing for important parts of Ice Complex deposits. These terrestrial deposits, large ice wedges and the enclosed layers, consist of cryogenic weathered rocks (eluvium) and contain buried fragments of hydromorphic cryosols (Fig. 10). Such formations are widely distributed in the plains in front of piedmont plains of the Laptev Sea for example along the Olenyek Channel west of the Lena-Delta (Fig 11, top). The formation of this horizon resulted from the accumulation of „extranivities" during a larger distribution of „cold" snow patches in Late Pleistocene time and thicker active layer in the piedmont plain of the Chekanovsky Ridge. The suggested higher frequency of embryonic glaciation could be a regional substitution for the Eurasian ice sheet in Northwestern Siberia up to the Taymyr Peninsula and the glaciation of Kharaulakh Mountain (GALABALA 1997). Our simplified suggestion of the Late Pleistocene situation near the Chekanovsky Ridge is shown in Figure 11, bottom. Because of sea level lowering during Late Pleistocene large and flat areas of the Laptev Sea shelf were situated in subaerial positions. The transport of clastic and organic matter took place through many discontinuous rivers, brooks and runnels fed by snow patch meltwater or sheet flood if some parts of the shelf-plains were flooded by meltwater. These deposits, supersaturated with water, had frozen in winter and were included into the permafrost horizon by and by after a sufficiently thick cover with newly accumulated matter. Soils were formed and peat could grow if no accumulation took place because of other meltwater runoff or stronger changes of environmental conditions. During the whole time large systems of ice wedge polygons were formed. The special feature composition and fabric of the upper horizons of the

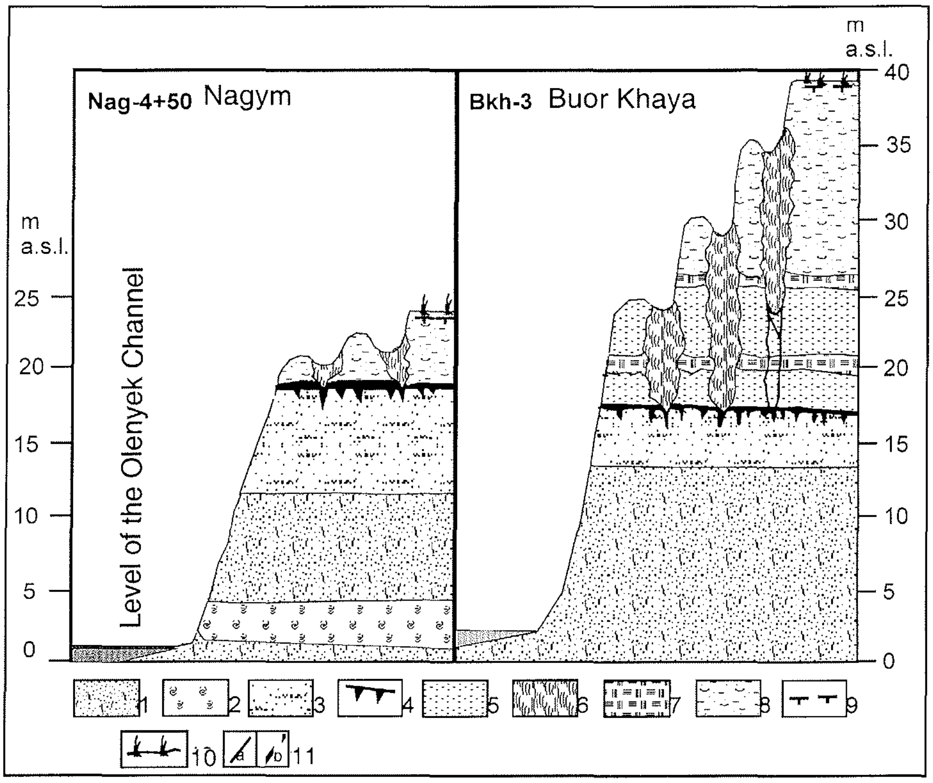

Fig. 10: Schematic Profile of Ice Complex and subjacent formations of the section Nagym and Buor Khaya on the northern riverside of the Olenyek Channel (western Lena Delta). 1 and 2 Formation of Quaternary cryolithogenic deposits with ice cement and slim ice wedges: 1: stratified sand with buried grass and shrub roots; 2: peaty sand layers; 3: sand layers with a few gravel lenses; 4: surfical cryogenic eluvium (fragments of buried hydromorphic paleosol); 5 through 8: Ice Complex deposits: 5: silt layers (aleurite) with fragments of hydromorphic paleosols; 6: ice wedges; 7: autochthonous peat (grass, moss); 8: silt with sandy interlayers, peat inclusions and bed-like cryostructure; 9: lower boundary of the active layer; 10-: ecent soil; 11: lithologic boundaries: 11a: determined, 11b: supposed.

Abb. 10: Schematisches Profil des Eiskomplexes und angrenzender Bildungen der Aufschlüsse Nagym und Buor Chaya am Nordufer des Olenjek-Kanals (westliches Lena-Delta). 1 und 2 zeigen Bildungen quartärer kryolithogener Ablagerungen mit Eiszement und schmalen Eiskeilen, 1: geschichteter Sand mit begrabenen Gras- und Strauchwurzeln, 2: torfige Sandschichten, Sandlagen mit einzelnen Kieslinsen, 4: oberflächiges kryogenes Eluvium (Reste von begrabenen hydromorphen Paläoböden), 5 bis 8 zeigt Eiskomplexablagerungen, 5: Siltschichten (Aleurit) mit Resten von begrabenen hydromorphen Paläoböden, 6: Eiskeile, 7: autochtone Torfe (Gras, Moos), 8: Silt mit sandigen Zwischenlagen, 9: untere Grenze der Auftauzone, 10: rezenter Boden, 11: lithologische Grenzen: 11a: bestimmt, 11b: vermutet.

cryolithozone permits to consider the important role those nivation and cryoplanation processes play for the formation of the Ice Complex. Snow patches are possibly more important for the genesis of Quaternary ice-rich permafrost deposits of Northern Siberia than presumed so far. A number of geocryological phenomena described in the Ice Complex are found again in the area of different snow patches.

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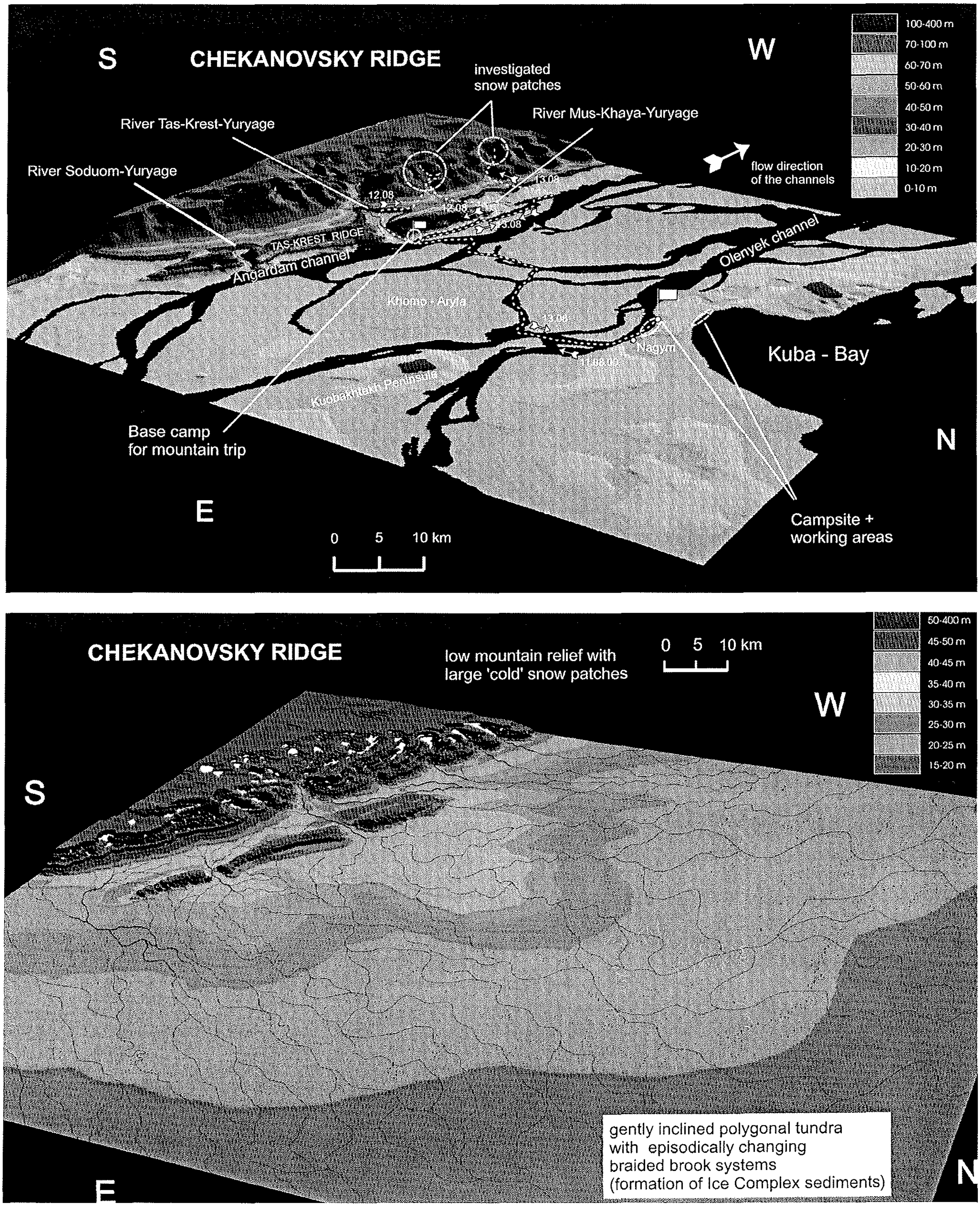

Fig. 11: Scheme of connection between snow patch areas and Ice Complex deposits (Chekanovsky Ridge – Olenyek Channel – Nagym); maps are based on the digital terrain model of the Lena Delta (ANTONOW et al. 1999). Top: Recent situation in the western Lena Delta with positions of study areas and expedition routes. Bottom: Supposed situation during accumulation of Ice Complex deposits in the foreland of the Chekanovsky Ridge.

Abb. 11: Schema der Beziehung zwischen Schneefeldgebieten und Eiskomplex-Ablagerungen (Chekanowsky-Rücken - Olenjek-Kanal - Nagym). Karten nach digitalen Geländemodell von ANTONOW et al. (1999). Oben: Heutige Situation im westlichen Lena-Delta mit den Positionen der Untersuchungsgebiete und Expeditionsrouten. Unten: Angenommene Situation während der Ablagerung der Eiskomplexsedimente im Vorland des Chekanowsky-Rückens.

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