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Reprint from

Land-Ocean Systems in the Siberian Arctic

Dynamics and History

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Springer

The Landscape and Geobotanical Characteristics of the Levinson-Lessing Lake Basin, Byrranga Mountains, Central Taimyr

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Received 30 June 1997 and accepted in revised form 26 January 1998

Abstract - A landscape and geobotanical map of the Levinson-Lessing Lake basin in the Byrranga mountains of the Taimyr peninsula is presented, accompanied by explanatory text. The lake basin has an area of about 500 km^2 and is situated on the border between the typical tundra and arctic tundra bioregional subzones. The mountainous character of this territory renders this border meaningless and it is most expedient to designate a special province in the geobotanical subdivision system: the Byrranga mountain tundra region.
The map was created at a 1:100.000 scale on the basis of aerial photographs and field investigations by the authors from 1993 to 1996. Thirty-four landscape units were identified, ranging from polygonal bog complexes and shrub communities in the valleys to cold alpine deserts. For each area probable geological genesis, relief characteristics, vegetation and soil types are described.

Introduction

During the years 1993-1996, a Russia-German cooperative project (AARI, AWI, IPO, MGU, ISSP, IFB, MLU) conducted investigations in the Levinson-Lessing Lake basin, Byrranga mountains, Central Taimyr. The lake and a large part of its basin are situated within the Taimyrsky State Biosphere Reserve. Reserve employees also worked in the region, but their research was mainly devoted to the biotic natural environments. Until now the region has received only scant attention from the research community. As a result of this series of studies, Levinson-Lessing Lake has become the most investigated area in the mountains of Central Taimyr. Extensive findings on the geology, hydrology, soils, vegetation and animals of the region have been collected and require integration (Report on Polar Research, No. 175, 1995; No. 211, 1996; No. 237, 1997).

The most convenient form of representation of this material is a complex landscape map of the lake basin territory. In the creation of the map presented here, special attention was given to vegetation, which is not only an indicator for, but also an important factor in determining landscape dynamics. The landscape-geobotanical map, in giving a general overview of the characteristics of the territory covered, can be applied for many purposes.

Materials and methods

The map was made following field survey route observations by M.A.Anisimov from 1993 until 1996 and by I.N.Pospelov during 1993 and 1996, on the basis of topographic maps (1:100,000) and from 1:50,000 scale aerial photographs. About 600 field descriptions in total were made during the project: about 400 are landscape descriptions and 200 are landscape-geobotanical descriptions. During primary analysis, some preliminary maps were created; in particular, the landscape map (Report AARI, 1995) and the permafrost features map (Chronicle of Nature, 1995).

In: Kassens, H., H.A. Bauch, I. Dmitrenko, H. Eicken, H.-W. Hubberten, M. Melles, J. Thiede and L. Timokhov (eds.) Land-Ocean Systems in the Siberian Arctic: Dynamics and History. Springer-Verlag, Berlin, 1999, 307-327.

Field descriptions comprised absolute elevation, ground composition, geological structure,relief, micro- and nanorelief and vegetation type. Soil characteristics were determined using basic soil trenches, which are described in each landscape unit. Dominant species were identified and plant cover (total and by species for dominants) was measured. A complete list of species is given in the landscape-geobotanical descriptions. In arctic landscapes the interrelation of all natural components is displayed in heaviest measure. Of central importance to all components is the permafrost and processes related to it, which create cryogenic relief forms. The complex landscape map therefore reflects the distribution of vegetation, soil and other ecosystem components more accurately and completely than individual thematic maps, constructed on the basis of hierarchical classifications of each component of the environment. These classifications frequently do not correlate with each other. Much experience has been amassed creating similar maps for the Taimyrsky Reserve territory (Pospelov, 1996), although the methods employed in their creation are constantly improving. The bases for the selection of territorial units are assumed to be geological structure and relief. The various forms of micro- and nanorelief, generally cryogenic in origin, are used to differentiate units and determine the spatial distribution of vegetation and soil types.

In the creation of the map we have consciously resisted the application of current Russian landscape taxonomy because it has no practical analogues abroad, where such units as "facia" - a minimal natural territorial complex - and "landscape" - a large taxonomic unit - are accepted. There exists a difference of opinions on the treatment of terms. So, in the territory of the Levinson-Lessing Lake basin, by using the different criteria (Isaczenco, 1965; Armand, 1975, Michailov, 1971), it was possible to allocate from one to four regional units to a landscape (described in the section on physico-geographical landscape characteristics). These cartographic units should not be understood on the basis of landscape-terminology (by Russian classification the majority of them have a rank of "uroczishje", sometimes treated as analogous to "stow"; Unsread, 1935). In the explanatory text, we define the term "unit" as some spatially and originally homogeneous territory. In the majority of cases it is possible to speak of their genetic complexity when, to all appearances, the geosystem was formed by spatially uniform processes. Sometimes, however, the structural elements of a unit are irregular, as with, for example, occasional rock outcrops on the background of a spotty tundral plain. A geologic-geomorphologic principle was applied as the basis for numbering landscape units. Watersheds, slopes, valleys, terraces and bogs are identified. Within these categories, landscape units are classified and numbered in order of: decrease in elevation, increase of the degree of ground patterning, decrease of the angle (for slopes), and stage of development and age of the relief forms (for terraces and bogs). Hence, we refer to all the units representing different landscape types in the following order: denudational (watersheds), transitional (slopes and valleys), accumulative-denudational (terraces) and accumulative (bogs). Attention was given to the geological structure and genesis of micro- and nanorelief for each unit. In the physico-geographical description of the lake basin, the analysis of the cryogenic relief forms and indicators for the developmental dynamics of cryomorphogenetic processes are given; as mentioned, this factor is determining for structures of geosystems. Communities were given names based on dominant species (for example, "herbaceous-dwarf shrub-moss tundra"); in each description, dominants and the most common species were indicated. In some cases indicator species were noted (for example, on limestone there were calciphilous species indicative of such). The names of vascular plants are given as per Arctic Flora USSR (1960-1987); the names of mosses as per Ignatov, Afonina (1992). In practically all units, the heterogeneity of the vegetative cover at the community level was too great to allow classification of vegetation for the entire unit as a whole phytocoenoses. In our opinion, neither of the existing approaches to classification of vegetation for the Arctic, especially Arctic/alpine regions, is acceptable. The vegetation is, in many cases, characterized not by developed communities, but by stable and unstable primitive plant aggregations.

The physico-geographical characteristics of the research area

The Levinson-Lessing Lake basin is situated in the central part of the Taimyr peninsula, within the limits of the Glavnaya Range in the Byrranga mountains. The centre of the territory is located at 74° 30′ N and has an area of about 500 km^2. The elevation ranges from 47 m a.s.l. at the lake surface up to 568 m. a.s.l. The average height of the mountains is about 300 m a.s.l. and mountains occupy not less than 80 % of the territory. To the north, the Krasnaja river enters the lake through a low-lying peatland plain, 5 km wide, influencedby ancient terraces and bedrock outcrops. The lake is drained by the short (less than 1 km) Protoczny stream, which flows into the Ledjanaja river and further on into Ledjanaja Bay of Taimyr Lake.

Geological structure and relief

The Byrranga mountains, running parallel to the northern coast of the Taimyr peninsula for more than 1000 km, arose during the Hercynian (Palaeozoic) orogeny and have, since then, undergone repeated tectonic dislocations, resulting in their current folded block structure. The most common bedrock types are auleurolites. Dolerite, gabbro-dolerite and diabase intrusions are also common, often in the form of weathered outcrops, and comprise the crests of ranges and ledges. There are a few limestone plateaus, hardly weathered as a consequence of the low mechanical durability of the bedrock. Traces of ancient karst are evident. Such deposits are more widely distributed outside the lake basin, especially in the Levly river region, and often adjoin coal slate outcrops. Tectonic dislocations are displayed through faulting, and are easily distinguished on space photographs. The largest of the breaks is the Levinson-Lessing Lake basin. This break is observed further southwards (Nedi Lake), and northwards (the valley of the Zamknutaya river). The second largest break is the valley of the Krasnaja river. It is almost rectilinear and runs parallel to the Glavnaja Range. Some small valleys (for example, the Wresanny stream) may also be related to tectonic structures.

In the Quaternary, the territory was exposed to glaciations. The question of what type of ice cover existed (ice sheet or alpine) and when the last glaciation occurred remains open. The discovery of buried glacial ice with terminal moraine material in the Zamknutaja river valley is a clear indication of glaciation. At modern scales of proluvial accumulation, alluvial fans of some water channels could not have been generated (with respect to their current size and capacity); hence, it is possible to assume that they were formed during deglaciation, when drainage was large enough to explain the depositions. The degree of entrenchment of small valleys, even those not affected by tectonic structures, is indicative of high speed deglaciation. On the other hand, significant moraine and fluvioglacial deposits were not found anywhere (with the exception of the afore-mentioned cases). Ancient terraced platforms are observed along the entire lakeshore. There are up to 13 levels, the most easily distinguished of which lie at an elevation of 100-120 m a.s.l. They usually resemble hills with flat tops, composed of rolled and sometimes calcified pebbles.

Outside the lake basin, a significant portion of the flat surface of these terraces was preserved in the Ledjanaja riverbed. This terrace fragment has a residual block structure (thermokarst with an ancient network of ice lodes), demonstrating that its formation preceded active permafrost processes. Proceeding from the foregoing, it is possible to rather confidently assert that the last glaciation of Central Byrranga was alpine or even exclusively niche glaciers, and that it was preceded by a significant marine transgression. Until now, the last glaciation was thought to have been covering or half-covering (reticulate) (Antropogen of Taimyr, 1982; Strelkov, 1965; Taimyr-Severnaja Zemlja region, 1970). Nevertheless, small niche-glaciers may have existed in the region not long ago; such a structure, similar to a niche glacier with a push-moraine, was found in the upper reaches of one of the Scalisty stream tributaries.

In postglacial time the lake was finally separated from an extensive shallow water reservoir. In the intermountain depression of the northern lakeshore, the large lacustrine-alluvial terrace was generated, on which peat accumulated; the accumulation rate, however, was very low and the current peat depth is not more than 0.5 m. Formation of the ice-lode and of polygonal microrelief occurred simultaneously. The presence of peat-palsa bogs, which cannot be generated under modern conditions in Central Taimyr, indicate a probably gradual drainage. Such bogs are described on the northern coast of Ledjanaja Bay and their azonality is emphasized by a lush dwarf bush (Betula nana) growth, which is currently dominant of more southern tundra. The low pebbly lake terraces drained last. Based on indirect attributes of the terraces, the drainage occurred against a background of climatic cooling: higher elevation polygonal networks are large. Of modern geomorphologic processes, alluvial, permafrost (more detailed description given below), erosional and deluvial (scree processes) are the most advanced. It is interesting that erosional processes in the cleft of the left hand tributary of the Mramornaja river are rather active, where the annual accumulation of rough sediments reaches 1 m in some places. The general relief in the region is middle mountainous (the term "middle mountainous" is used here to indicate altitudinal zonation). The range of relief features decreases with increasing distance from the lake basin. On the north-west lakeshore the relief amplitude attains 400 m, to the north-west of the basin, 100-150 m, and to the north, not more than 50 m.

The mountain structures usually have a table shape, with abrupt slopes and flat tops. At higher elevations the slopes are frequently terraced by nival altiplanation and structural terraces and are complicated by outcrops of dolerite and other intrusions resistant to weathering. The auleurolites are pelitisated to gravel and smaller-sized material. Downslope, profile development of cryogenic micro- and nanorelief is intensified. The valleys of the small mountain rivers usually have V-shaped or U-shaped transverse sections, sometimes canyon-shaped (Mramornaja river, Vodopadny stream). The corresponding rivers have no more than 2 fluvial levels: low and high flood-plain. In the majority of cases alluvial deposits are not differentiated. Deluvial accumulation occurs only on the periphery of the mountain lake kettles. At one location, significant displays of thaw slumping (gelifluction) are observed.

The large valleys and small valley mouths have 3-4 alluvial levels: usually low and high flood-plain, and terrace. The lake terraces were described earlier. In the bogs, thermokarst processes are very intense, and there are several thaw lakes, of which the largest is about 0.7 km^2.

Permafrost, cryomorphogenetic processes and cryogenic relief

The lake basin is in the zone of continuous permafrost and under rather severe conditions. The permafrost reaches to a depth of 500 m and a temperature of -13°C (Geocryologie of USSR, 1989). The depth of seasonal ground thaw ranges from 20-25 cm in peat up to 1 m in gravelly soil without vegetation. Under these conditions, cryogenic processes are the leading factor in determining the structure and functioning of geosystems. Practically all important cryogenic processes, except pingo formation, are displayed within the Levinson-Lessing Lake basin. It is most expedient to consider them together with consequent cryogenic relief forms. We do not adhere to any of the existing classification systems for cryogenic processes and forms; however, as a basis for their characterization, we use the genetic classification of B.I.Vtiyrin (1969), and the morphological classification system of A.L.Washburn (1979, 1988).

Only seldom does any cryogenic process occur alone. They generally occur in conjunction with non-cryogenic morphogenetic processes: aeolian, alluvial and other processes. The majority of cryomorphogenetic processes form dynamic series, in which non-cryogenic phenomena play determining or secondary roles. Many of the issues surrounding the nature of cryogenesis remain unclear; however, it is possible to define the general tendency of their development for a given region.

Almost all cryogenic processes develop only in fine grained soils. It is therefore of primary importance to consider cryogenic weathering for mountain regions. Together with other exogenic processes, cryogenic weathering results in the formation of cryoclastites and cryoclastopelites (Popov et al., 1985); that is, the monolithic bedrock is destroyed. Certainly, the most important factor is the seasonal freezing and thawing of the ground, though meteorological processes (precipitation, wind) play a role as well. As a result of the former process, boulder debris is formed. Further degradation occurs with spatial irregularity, depending on the durability of the bedrock, snow cover depth, intensity of aeolian processes and vegetation. Initial cryogenic forms are sorted soils (or patterned ground). At first, sorted areas form among coarse material (debris islands); stone pavements may also form among coarse materials. In the researched region, these forms were observed at the highest elevation study plots or on stable screes. As secondary weathering processes, cryogenic ground sorting results in stone polygons and in sorted stone stripes on the slopes. When the sorting locations are expanded and leveled, the influence of snow intensifies and gravel circles, circumscribed by coarse material, and gravelly hummocks with cracks between them, faintly pronounced in nanorelief, are formed. These processes improve the conditions for vegetative growth. The role of vegetation in nanorelief formation gradually increases. Plants act as thermal insulation and contribute to the accumulation of water. The vegetative cover has been repeatedly shown to be determining, or at least essential, in the formation of permafrost (Tyrtikov, 1979; Common permafrost science, 1974). Vegetation, and especially moss, promotes the accumulation of moisture in cracks and the formation of ice wedges in autumn and winter. In parallel with these processes, cryogenetic weathering continues, leading to the formation of silt-gravel and silt (fine-earth) soils (cryopelits; Popov et al., 1985). After the soil transformetion to loam, the role of snow and wind erosion is reduced (as these patterned soils are observed only in locations where snow cover depth is significant) and the role of ice-segregation in the thawing layer is increased. Cryoturbation in the centre of sorted circles gradually decreases, but is amplified on their periphery. The following evolutionary stages are (consistently): hummock-spotty, spotty-hummocky and hummocky tundra. Within the limits of the studied region, these features are most widely distributed at low elevations within the lake basin and on degraded fragments of lake terraces. Any subsequent ice-segregation activity results in thermokarst and gelifluction processes.

Examples of these processes are most distinct at low hypsometric levels. First, striped tundra is evident, which we name dellic. The term "dell", however, also has a general geological treatment including non-permafrost territories, and we try, therefore, to avoid it. The shallow (less than 1.2m), wet and flat stripes form drainage channels between their ridges and are one of the most widespread forms of microrelief in the lake basin. They represent one form of thermokarst activity, which is well developed on slopes with an ice-rich horizon. Nevertheless, it is possible to show that the dellic complexes are currently rather stable. Thaw slumping gelifluction was observed at only one location, but its genesis remains subject to examination. Thermokarst processes are distributed rather sporadically throughout the lake basin and occur only at a low hypsometric levels.

In the river valleys, cryogenic forms are rarely found, except in the intermountain depression of the Krasnaja river mouth. Here, on the lacustrine-alluvial terrace, various forms of polygonal bog complexes are found, from homogeneous and typical low-centered polygons to palsa bogs. The latter are relicts of a warmer epoch, as the formation of typical palsa bog complexes is now possible only in the southern part of Taimyr. The formation of such complexes requires considerably high rates of peat accumulation (Popov et al., 1985). Icing mounds are also found among the cryogenic forms in valleys. Three small icing mounds (up to 20 m in diameter and up to 1.5 m thick) were found in the main channel and in one bayou of the Krasnaja river around the mouth of Zamknutaja river. This phenomenon has not previously been observed in the Byrranga mountains. The displays of cryomorphogenetic processes on the lake terraces deserve special attention. The surface structure of the terrace exposures at 100-120 m a.s.l., described above, displays features of ancient permafrost. On the lower lake terrace, replacement of ice-lodes by ground lodes was evident. At the same time, however, these features were not visible on the smaller exposures of higher altitude terraces.

This leads to the conclusion that the cryomorphogenetic processes in the region developed following a basic pattern. In combination with non-cryogenic processes, the general ecosystem development can be regarded as a uniform, dynamic series, based on the general tendency of historical relief development. At different stages of this series, various factors prevail in determining the ecosystem: geomorphologic, cryogenic or biotic (vegetation).

Climatic conditions and hydrology

Peculiarities of the climate and hydrology of the region were preliminary reported severral times (Berichte zur Polarforschung, #175, 1995; #211, 1996). The region's climate is Arctic continental. The average air temperature in January is about -40 °C and in July ranges from 5 to 7 °C. In some years (for example, in 1993) summer temperature do not even exceed + 5 °C. Nevertheless, ground surface temperature under the influence of solar radiation can exceed + 30 °C on clear days (field observation by the authors). The annual precipitation reaches about 250 mm , with the maximum occurring in summer. A feature of the lake basin's microclimate are strong northern winds, passing here as arctic air masses move through the Glavnaja Range of the Byrranga mountains.

In addition to the main water reservoir, there are 5 lakes in intermountain kettles (Krasnoje, Nagornoje and 3 unnamed) and about 10 shallow thaw and bayou lakes in the depression of the Krasnaja river's alluvial plain. The largest rivers in the region are the Krasnaja (about 30 km length) and the Mramornaja. The density of the stream network is rather significant.

Vegetation

In existing schemes of geobotanical subdivision (Alexandrova, 1977; Czernov and Matveeva, 1979), the Byrranga mountains are treated as a border between typical (subarctic) and arctic tundra conditions and are not recognized as a special territorial unit. However, taking into account the mountainous character of the territory, as well as the sharp differences in its vegetation (in particular, in its community species compositions) compared to that of the surrounding tundra of the Taimyr plain, some evidence of altitude zonation and the specific character of the local flora, there is a strong basis for the recognition of this mountain massif as an independent geobotanical province (by analogy with the previously accepted Ural-Paichoi, Charaulach and other provinces of alpine tundra, Alexandrova, 1977) or as a geobotanical district (Andreev, Alexandrova, 1981). Additional support for this proposition is provided by the sheer variety of communities present in the Byrranga range, from cold mountain deserts to extrazonal dwarf birch brushwood on the southern macroslopes of mountains, and by the prevalence of specific alpine tundra flora and the significantly richer floristic composition in comparison with the Taimyr plain. Plant populations present in the range are significantly removed from their main area of distribution (Eremogone formosa, Papaver leucotrichum, Poa jordalii et al.), which serves as interesting material for the historical analysis of the floral development of this region. The investigation of the region's flora included 263 taxa of vascular plants and is rather typical of the Byrranga mountains. The circumpolar species of the cryophyte group (arctic, arctic-alpine, meta-arctic), a significant number, especially in alpine landscapes, of Siberian and East-Siberian cryophytes, form the basis of the investigation. The role of hypoarctic and boreal species was greater in the large valleys (for example, the Krasnaja river valley). The typical Arctic character of the flora is represented by the major role of the families Brassicaceae, Poaceae; genera Draba, Poa, Saxifraga, and, at the same time, typical alpine species are also well represented, through the families Asteraceae, Fabaceae, Rosaceae; generas Pedicularis, Papaver, Potentilla. Thus, on the basis of areal and taxonomic analysis, it is possible to identify the region as typical Siberian-Arctic/alpine flora.

Dwarf shrubs, herbs, mosses and lichens were observed within the area of investigation. The vegetation as a whole is subject to altitude zonation. However, the limits of the belts (zones) so varied with elevation that to give their sharp hypsometric significance is practically unrealistic. On slopes with different aspects and inclinations we found consecutive replacement of the same types of plant cover, but the extent of the belts and their limits with respect to elevation can be distinguished at a scale of 200 m and more. Hence, by distribution over an area of phytocoenotic units, connected with generically consistent surfaces, we can divide them into the background and the local elements of vegetation. The former is represented in communities with mosaic or complex vegetation, whereas the development of the latter is governed by external factors (geomorphologic, hydrothermal). On the map they are included in structural units as separate elements.

At the highest hypsometric levels, the background communities are cool mountain deserts, with sparse lichen-herb and lichen-moss-herb vegetative cover. These communities are formed in areas with low snow accumulation, combined with coarse residual deposits. They are replaced downwards on the profile by gravelly dry moss-forb and forb-moss tundra with solitary plant cushions, frequently without a continuous vegetative cover. Such communities are distinguished from deserts by a richer flora and greater cover (up to 30 %). Depending on drainage, either petrophilous forbs (*Papaver polare, Saxifraga sp. et al.)* or, on more humid, fine-grained sites, Deschampsia borealis, are dominant. A belt of dry herb-dwarf shrub-moss, mesic dwarf shrub-moss and dry herb-dwarf shrub tundra occurs on patterned grounds, from fine-grained-gravel to lower elevation loamy sites. Within this belt, clear sub-belts are identifiable, distinguished by the introduction of separate plant species. At the upper elevation limits of this belt, dwarf willow *(Salix polaris)* plays an essential role, at mid-elevations, the sedge *(Carex arctisibirica)* cover is also significant, and at lower elevations dryas *(Dryas punctata)* begins to dominate. Dryas is practically unique to this sub-belt, with clear altitudinal distribution limits. However, it occurs as the only dominant only on gravelly soils, whereas on sorted soils, it tends to be replaced by other species. Such a wide range of zonation mimics the zonal community distribution of the Taimyr plain: sedge-dwarf willow-moss in arctic tundra subzones and dryas-sedge-moss in subarctic subzones.

This unique complex of slope communities, which we considered to be a background for further distinctions between regions, was advanced on striped (dellic) slopes. As a rule, all of these communities were found below 300 m; on ridges, therefore, the vegetation was mesic herb-dryas-moss, and in drainage stripes it was moist sedge-moss and sedge-dwarf willow-moss.

Superimposed on this background vegetation, communities of polygonal bogs at all stages of development were found, with wet sedge-moss *(Carex concolor)* and moss-sedge depressions and moist herb-shrub-moss on the raised boundaries of polygons or palsas.

Fragments of background communities were sometimes also local elements of complex vegetation units. The most frequent example was moss-forb tundra on decimated auleurolites outcrops and on breaks in altiplanation terraces. The local communities of the territory were rather diverse, and the following were found to be most common. The nival and subnival communities were distributed in all altitude belts. Sparse moss-lichen vegetation found on the periphery of snow-beds with moist nival short herbs *(Phippsia algida, Saxifraga nivalis et al.)*, and mesic communities dominated by cassiope *(Cassiope tetragona)* were both consistent with the effects of decreased persistence of spring snow. The latter trailing dwarf shrub is very distinctive in that, although it never appeared as a dominant in the background communities, it abounded where thick snow covers are subject to rapid thawing. The cassiope-moss and moss-cassiope communities thus formed in slope niches, on terrace ledges and among boulder debris.

The communities found on limestones in various parts of the lake basin could also be included as background vegetation. They were common and comprise the dry sedge-forb-dryas *(Carex rupestris)* tundra, with a floristic composition enriched with calciphiles *(Lesquerella arctica, Eritrichium sericeum, Oxytropis putoranica, Carex redowskiana)*. The mesic communities of alpine meadows were found only on protected warm slopes in the lowest mountain belt. Only here grew the frequently plentiful alpine meadow plant species: *Delphinium middendorffii, Senecio tundricola, Arnica iljinii, Hedysarum arcticum* et al. Sometimes the vegetation had a dry, steppe character, with grasses dominating (*Poa glauca, Koeleria asiatica, Roegneria villosa et al.)*. Flood-plain mesic meadows dominated by *Oxytropis middendorffii, Astragalus tolmatczewii, A. umbellatus* et al. were also distributed locally. The remaining local communities will be described in the explanatory text for particular units.

Soils

The soils of various units were closely connected to the structure and grain size of the parent material, the cryogenic nanorelief, and the degree of development, structure and composition of the vegetation. Three types of soil forming processes were distinguished within the region. All soils have permafrost in parts of the first two meters, and are gelic subunits therefore. It should be noted that soils and soil processes of the area surveyed were reported formerly by the group of the authors participated in the Taimyr project in 1995-96 yrs. But the data obtained by Pfeiffer, Gundelwein, and others (Pfeiffer et al., 1996; Gundelwein et al., 1997) are coming from small key areas of the Levinson-Lessing Lake basin while the conclusions presented below are more general.

The turf forming process was observed mainly in alpine landscapes and sometimes on the flood-plain pebbles and dry terraces. It was associated with drained, well-thawed sites with a prevalence of herbs and dwarf shrubs. The soils formed there were rather rich in organic matte. Depending on the mechanical structure of the parent material, these soils were regosols (on gravely and fine earth-gravely surfaces), or Leptosols (from finer grained material). The names given here use the FAO-UNESCO soil nomenclature, (1990).

Dystri- and Gascari-gelic Rigosols in alpine desert and tundra regions were mostly primitive. The soil profile of Lithic Leptosol under dwarf shrub and herb-dwarf shrub tundra was a little more advanced. Gufri-gelic Regosols were the richest in soil organic matte; they had an advanced Histosols and were found in mountain meadows. At mountain spring fen and moist gravel dell locations, Dystri - or Umbri-gelic Regosol regosols were found. Leptosols were identified beneath similar tundra on loam and loamy clays: primitive Umbri-gelic or Molli-gelic Leptosols, in which humic contents were greater than 1 %. Stagni-gelic Leptosols were formed on barren loamy and loamy-gravelly spots. The turf soils on flood-plain places had converted to fluvisols of which haplic types are the most primitive. A little more humificated were the ochric fluvisols (underlying the grass-forb and dryas-forb communities of the flood plain). Under the influence of constant moistening and seasonal gleization, mollic-gleyic fluvisols developed on cotton grass growing mud banks. The gleying process occurs whereever soils are subject to long soil moisture conditions combined with a thin active layer, often beneath well developed moss beds. These gleysols are rather diverse in character, depending on the degree of moistesre regime, the degree of soil profile differentiation and the presence of humus horizon. At a low degree of gleyization and some humification of a profile (which usually occurs in spotty tundra on the drained borders of sorted circles) Gleysols develop to gelic-mollic. The most widely distributed Gleysols in the region were Umbri-gelic Gleysols, distinguished by the presence of a umbric or histic horizon.

They occurred in the mountain moss spotty tundra and hummock tundra, on ridges of dellic complexes and on lake terraces. Eutri-gelic Gleysols possessed the simplest profile - the gleyed horizon lay directly beneath the moss litter; they were usually found in soil complexes of spotty tundra, beneath moss hollows. In the presence of a thin peat horizon the Gleysols progress to Umbri-gelic. This generally occurred at weakly paludificated sites, in drainage stripes, on moist mossy tundra and on polygonal bogs in the early stages of development. If the peat is covered by a thin layer of humus, the Gleysols progressed to gelic-distric-humic tundra soils. The peat formation process may lead to Histosol formation with thick peat horizons. These were found only in flat palsas of bog complexes on terraces.

Landscape subdivision of the basin territory

The landscape structure of the region is, as a whole, rather monotonous. The greater part of the area tends to the typically middle-alpine landscape of the Glavnaja Range of the Byrranga mountains. The only exception to this is the extreme northern part of the basin (north of the Zamcnutaja river), which can be classified, under all existing schemes of subdivision, as part of the intermountain kettle of Ugolnaja river. Its relief has a flat, faintly hilly character, with substantial development of alluvial and kettle-bog complexes. Watershed vegetation here is similar to arctic herb-dwarf shrub-moss tundra. However, only 2 units in the lake basin conform to this landscape type and they are ecotonal.

At the same time, there are the larger geosystems, for which the application of a landscape type is open to question. There are the intermountain lake denression and mouth part of the Krasnaja river, but also small mountain ridges to the south-east of the basin. The former qualify for the rank of landscape based on such parameters as the specific character of bedrock composition, their genesis (alluvial and lacustrine-marine), mesorelief and vegetation. Their area is small, however, in comparison with the surrounding landscapes. Also, despite territorial integrity, their configuration is rather difficult, and the distribution of background units of the lowest rank is modest. The latter geosystem represents the same mountain massifs, but at the surface it is comprised of more weathered material and outcrops of bedrock are rare. It is isolated territorially from Glavnaja Range and on general appearance resembles the eastern part of a foothill ridge, Nedy, which is more likely to be considered at the rank of landscape type.

Explanatory text accompanying the landscape-geobotanical map of the Levinson-Lessing Lake basin (M 1:100.000)

Mountain watersheds

1 - Platforms of ancient flattened surfaces at elevations of more than 400 meters with striped patterned ground

Alternation of fine grained material with boulder debris from bedrock material more stable to weathering (dolerites, diabases). Patterned ground is widely distributed (debris islands, stone polygons, stone pits, and large spot-hummocks on flat, low-lying soils). These units retain only a slight snow cover during the winter, resulting in sparse vegetation represented by two variants: A) Higher elevations boulder debris with sparse (5-15 % cover) lichen aggregations (*Alectoria ochroleuca, Cetraria sp.),* soils are absent, and B) The tops and flat tops with

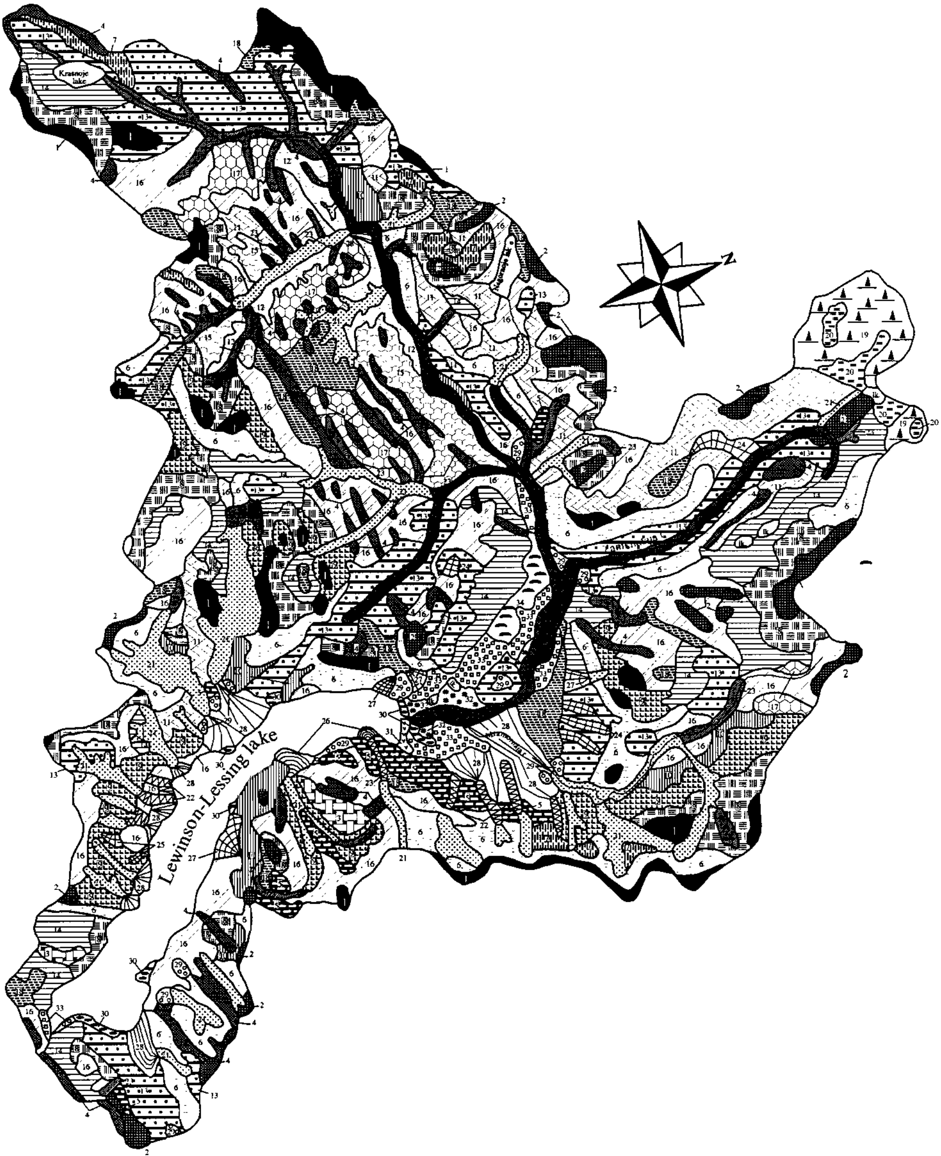

Figure 1: Landscape-geobotanic map of the Levinson-Lessing Lake Basin

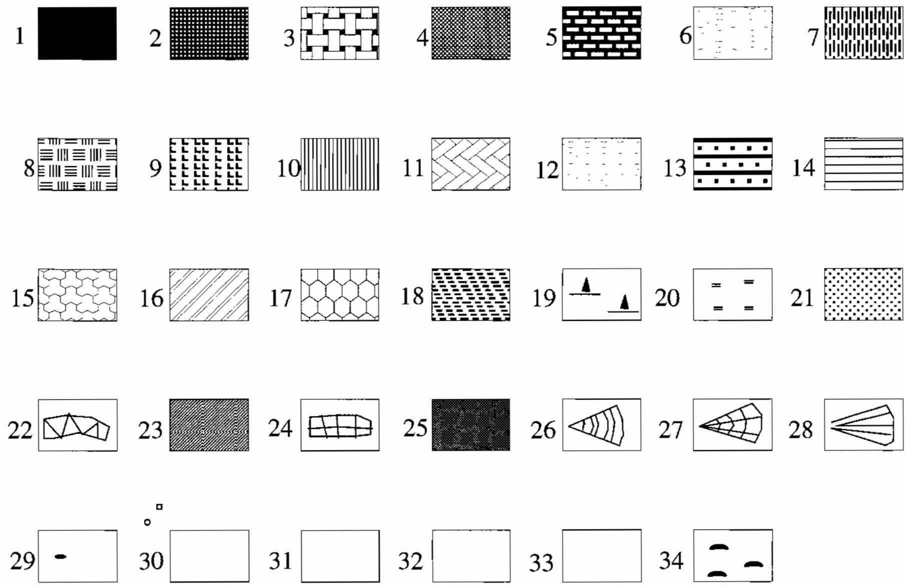

Figure 1: Explanations.

sparsely distributed herbs (Novosieversia glacialis, Poa abbreviata, Potentilla subvahliana, Luzula nivalis et al.) and moss-herb (mosses: Andreaea sp., Dicranoweisia crispula), cool mountain desert with 10-20 % cover on distric regosols.

2 - Terrace tops with boulder debris on the ledges and patterned ground (stone polygons, spots-hummocks) on the surfaces of steppes

These units are influenced by low (up to 5 m) cryoplanation terraces, and are composed of gravelly to boulder sized material. The vegetation is represented by 2 elements, depending on which form of micro- and mesorelief is present: A) Flat terrace surfaces: dry forb-moss (in moss layer: *Rhacomitrium spsp.; vascular: Novosieversia glacialis, Luzula spsp., Eritrichium villosum subsp. pulvinatum , Salix polaris et al.);* structural tundra with 10-30 % cover on the Dystri-gelic Regosols; B) Terraces slopes: boulder debris with fragmented mesic cassiope-moss vegetation on the Distri-gelic Regosols (*Cassiope tetragona, Draba pilosa, Saxifraga spinulosa* et al.; the dominant moss is *Hylocomium splendens var. obtusifolium.*), with about 50 % cover at low elevations. At high elevations, lichen aggregations similar to those of 1A are developed.

3 - Horizontal surfaces with remnants of auleurorolitic ridges and hummock nanorelief

These features are found only in the region north-east of the lakeshore and are probably associated with the proximity of large limestone outcrops. The 2 elements of vegetation (again, depending on which mesorelief elements are present): A) Ridges: dry moss-forb mountain tundra (*Papaver polare, Novosieversia glacialis, Saxifraga spsp.* et al.; the main moss is *Rhacomitrium lanuginosum*) with 10-20 % cover. B) Depressions between ridges: dry forb-dwarf shrub-moss spotty mountain tundra with 20-40 % cover (*Salix arctica, Dryas punctata, Carex rupestris, Papaver polare, Oxytropis nigrescens*; the forb and grasses are various; in the moss layer: *Hylocomium splendens var. Obtusifolium*). The soils are Dystri-gelic Regosols and Eutri-gelic Leptosols; in depressions the turf horizon is better developed.

4 - Structurally denudated mountain ridges with flat and inclined surfaces and patterned ground, which is defined by cryogenic weathering (rings of fine-grained soil) and boulder debris on the ledges of ridges

These features are composed mainly of dolerites and are distributed at all hypsometric levels. Their vegetation, however, varies depending on elevation. The boulder debris of the lower mountain belt (A) differs by having a rather specific petrophilous vegetation. The boulder slopes have a mesic herb-cassiope-moss vegetation with 40-60 % cover *(Cassiope tetragona, Saxifraga hyperborea, Dryopteris fragrans, Rhodiola rosea*; in moss layer *Hylocomium splendens var. obtusifolium dominates).* The soils are Regosols and have developed in the cracks between boulders. In protected locations, which receive more snow in winter, small mountain mesic short grass meadows with *Potentilla nivea subsp. mischkinii, Arnica iljinii, Saussurea tilesii* et al. on Eutri-gelic Regosols are found. For similar features of the upper mountain belt (B) (but also on heavily snowed portions of the lower belt) lichens alone, with 5-20 % cover, are found. On the western half of the central lake basin, the surfaces of the ridges are flat (C), with sparse (5-7 % cover) petrophilus forbs (*Novosieversia glacialis, Luzula nivalis, Saxifraga caespitosa* et al.) on Dystri-gelic Regosols.

5 - Prominent surfaces and plateaus, composed of limestones with rock outcrops and angles of inclination from 0 up to 10°

They have a very complicated relief. We consider them as a complex, consisting of 5 elements of relief mesoform, with specific calciphilous vegetation types. These relatively low (190-270 m a.s.l.) limestone mountains lie in the northern and north-eastern portion of the lake basin. The elements of the complex herein provided are usually grouped in one uniform ecological series: A) Rock outcrops with a very sparse (not more than 1-2 %) cover of crustaceous lichens and petrophilous forbs (*Papaver leucotrichum, Draba cinerea, D. macrocarpa et al.*) on Littic Loptosol. In rock cracks advanced Calcari-gelic Regosols develop. B) The structural mountain deserts with sparse lichens cover *(Thamnolia sp.)* and slightly greater vascular plant cover (*Braya purpurascens, Taraxacum phymatocarpum, Cardamine bellidifolia*). The cover is not more than 1 % and exposed locations are practically lifeless. There is no soil cover. C) Flatter and lower exposures than the previous landscape type, with patterned ground. These regions are occupied by dry willow-moss-forb tundra *(Salix arctica, Braya purpurascens, Poa arctica, Oxygraphis glacialis; in fragmented* moss layers, *Rhacomitrium lanuginosum dominated*). Cover is 1-10 % and the soils are Galcari-gelic Regosols. D) Stone-striped slopes with spotty-hummocks; herb-dryas tundra (*Dryas punctata, Carex rupestris, Astragalus tolmaczewii, Oxytropis putoranica, Eritrichium sericeum subsp.arctisibiricum et al.);* vegetative cover up to 30 %; the soils are Rendzi-gelic Leptosols. E) Feet of stone-striped slopes, moist, with moss-sedge and sedge-moss vegetation (*Carex redowskiana, C. atrofusca, Equisetum variegatum, Juncus castaneus; mosses*: *Tomentypnum nitens*, *Orthothecium chryseon*; cover up to 60 %) on Rendfi-gelic Leptosols. Moist nival short grass meadows with *Oxygraphis glacialis*, *Minuartia stricta*, *Stellaria crassipes* et al develop near snow fields.

Slopes

6 - Abrupt stony slopes with rock outcrops, boulders debris, screes, often complicated by ledges and by structural and cryoplanation terraces

As a rule, these slopes are rather extended and have 2 sharply pronounced altitude belts, though their height and limits vary. The vegetation of the bottom belts is represented by a combination of 3 elements: A) Boulder debris, between which grass-forb-dryas vegetation with 40-80 % cover develops (*Dryas punctata, Hierochloe alpina, Festuca auriculata, Astragalus alpinus, Potentilla uniflora* et al.) on fragmented Eutri-gelic Regosols. B) Alpine forb meadows on scree slopes with 60-80 % cover (grasses: *Poa glauca, P.arctica, Trisetum spicatum* et al.; forbs and legumes: *Hedysarum arcticum, Astragalus alpinus, Papaver pulvinatum, P.angustifolium, Delphinium middendorffii, Potentilla nivea subsp. mischkinii, Pedicularis amoena* et al.) growing on Eutri-gelic Regosols. C) Slope hollows with mesic herb-cassiope-moss vegetation of an almost continuous cover (*Cassiope tetragona, Carex vaginata, Saxifraga nivalis, Ledum decumbens*; mosses: *Hylocomium splendens var. obtusifolium*) growing on Eutri-gelic Leptosols. These 3 elements occur according to the distribution of snow during the winter and to the presence of turf on the slopes, as well as to the intensity of scree processes. The intensity of scree processes increases sharply upslope where the fourth element dominates: D) Screes with sparse grass-forb aggregations (*Arabis petraea s.l., Saxifraga spinulosa, Poa glauca* et al.); cover varies from 10-20 % at lower elevations up to 1-3 % higher up. The soils are found to be Regosols or not presented. The vegetation of similar slopes on the northern side of the Krasnaja river valley has some calciphilous species (*Oxytropis putoranica, Draba pohlei, Eremogone formosa),* despite a complete absence here of limestone bedrock at the surface.

7 - Altiplanation terraces with boulder debris on ledges and surface hummock nanorelief

These landscapes are indicated on the map only when they form large contiguous areas. This occurs only in the northwest portion of the basin. The vegetation types comprise 2 elements: A) Dry hummocky alpine tundra with terraced surfaces and forb-moss vegetation *(Papaver polare, Novosieversia glacialis, Potentilla uniflora* et al.; mosses, concentrated in cracks between hummocks, are *Hylocomium splendens var. obtusifolium, Tomentypnum nitens*); cover up to 30 %; the soils are the ochric leptosols. B) Boulder debris of ledges with mesic herb-lichen-moss vegetation (analogous to 2B), on Dystri-gelic Regosols, which occur as fragments between boulders.

8 - Slope surfaces with inclination 15-20°, complicated by numerous nivation hollows and boulder debris

These landscapes types are marked by a combination of frequent ledges with rock outcrops and of snow-fields. As a result of the scant snow cover on ledges (element A) the dry stony tundra is replaced by sparse (3-5 %) petrophilous forbs. The other elements are: B) Boulder debris with mesic herb- and herb-moss vegetation on the borders of ledges and on slopes (the dominant moss is *Hylocomium splendens var. obtusifolium*, 10-30 % cover) and C) Nivation hollows with moist herb-moss vegetation and with up to 70 % cover (*Phippsia algida, Saxifraga cernua; mosses: Oncophorus wahlenbergii, Bryum criophilum* et al.). The soils in A) are Dystri-gelic Regosols, in the others, Eutri-gelic Regosols.

9 - Stepped slopes with angle of inclination 10-20°

Their structure results from bedrocks with different weathering stabilities forming steps from 1 to 5 meters thick and is similar to that of the previously described region, in which such terraces were formed by nivation processes. The vegetation is classified into 3 elements: A) Bedrock outcrops with crustaceous lichens and sparse (3-5 %) petrophilous herbs (*Saxifraga caespitosa, S. spinulosa, Papaver polare, Hierochloe alpina*) on ochric regosols; B) The lowest portion of microslopes with dry-mesic dwarf shrub-moss and dwarf shrub mountain tundra (30-50 % cover). *Salix polaris* dominates at higher elevations, *Dryas punctata* dominates at lower elevations; the usual forbs are *Lloydia serotina, Arabis petraea s.l., Potentilla uniflora, Draba alpina* et al.; mosses: *Hylocomium splendens var. obtusifolium, Tomentypnum nitens*; the soils are Eutri-gelic Regosols; C) Moist depressions at the rear joints of the steps (spring fens) with practically continuous (cover 90-100%) herb-moss vegetation (*Lagotis minor, Carex arctisibirica, Juncus* biglumis, *Saxifraga cernua, Deschampsia borealis; the moss Bryum criophilum dominates*) on Gelic Regosols.

10 - Surfaces with inclination from 5 to 15°, with separate bedrock outliers and spotty hummocky alpine tundra

These regions share a similar genesis with the previous ones, but differ by an absence of moist places with fens. There are 2 vegetation elements: A) Bedrock outliers with crustaceous lichens and sparse forbs (about 10 % cover) on Dystri-gelic Regosols; and B) Slope surfaces with dry-mesic hummocky forb-moss mountain tundra (*Papaver polare, Myosotis asiatica, Draba alpina, D. macrocarpa, Saxifraga spsp.* et al., mosses: *Hylocomium splendens var. obtusifolium, Aulacomnium turgidum);* cover up to 40 % ; the soils are Dystri-gelic Leptosols.

11- Discontinuous surfaces with bedrock outcrops and irregular nanorelief

These outcrops of auleurolites are distinct from other landscape types only through their weak nanorelief development and vegetation. The latter comprises 2 elements: A) Primitive plant aggregations of petrophilous forbs and grasses (5-15 % cover) develop on the bedrock outcrops ; the soils are ochric regosols; B) -On main slope surfaces - mesic hummocky forb-dwarf willow-moss alpine tundra (*Salix polaris, Novosieversia glacialis, Deschampsia borealis, Luzula confusa; mosses: Hylocomium splendens var. obtusifolium, Aulacomnium turgidum, Tomentypnum nitens*) cover up to 70 %; the soils are Dystri-gelic Leptosols.

12 - Small-block sloped surfaces, slightly disjointed by deep erosion hollows

These structures are generally found on the side slopes of small mountain valleys. The deep erosion hollows are frequently associated with a change in bedrock composition. The vegetation comprises 2 elements: A) On positive mesorelief features: dry moss-forb spotty tundra (*Papaver polare, Saxifraga spinulosa, Myosotis asiatica* et al.) with 30-40 % cover; in the moss layer: Rhacomitrium lanuginosum and Hylocomium splendens var. obtusifolium dominate; the soils are Dystri-gelic Regosols; B) On negative mesorelief features: subnival, mesic herb-dwarf willow-moss, with an almost continuous cover (*Salix polaris, Saxifraga cernua, Cerastium regelii, Deschampsia spsp.*, the moss layer composed of *Sanionia uncinata*) on Eutri-gelic Regosols.

13 - Concave inclined slopes with striped nanorelief, complicated by bedrock outcrops and by outliers of terrace platforms

This area is characterized by a very complicated topography, with moisture levels varying from extremely dry to moderately moist; landscape elements (except for dellic drainage strips) occur at irregular intervals . Taken together, however, the elements form a massif defined by this landscape type. On the bedrock outliers (A), which are frequently used by predatory birds as nesting and feeding sites, one finds well-developed mesic herb meadow communities with 10-

30 % cover (*Bromopsis arctica, Hierochloe pauciflora, Erysimum pallasii* et al.) on Eutri-gelic Regosols. The outliers of the terrace platforms, (B), support dry-mesic forb-dryas alpine tundra (*Dryas punctata, Carex rupestris, Lloydia serotina, Astragalus alpinus* et al.) with a cover of about 30 %, on Dystri-gelic Regosols. Most of the area is occupied by stripe soil (dellic complexes). In the underdeveloped complexes, (C), spotty-striped tundra with mesic sedge-dwarf shrub-moss vegetation forms a 50 % cover; the dominants are *Carex arctisibirica, Salix polaris, Dryas punctata*; in the moss layer: *Aulacomnium turgidum, Tomentypnum nitens*) and the soils are Umbri-gelic and Molli-gelic Gleysols. In the developed complexes, 2 plant communities alternate at regular intervals: D) Mesic hummock-spotty herb-dwarf shrub-moss tundra with 30-50 % cover on the ridges of striped soil (*Carex arctisibirica, Arctagrostis latifolia, Dryas punctata, Salix polaris*; in the moss layer: *Hylocomium splendens var. obtusifolium*) on Umbri-gelic Gleysols; and E) Moist hummock sedge-moss communities in the troughs of the striped soil with continuous (100%) plant cover (*Carex concolor, Eriophorum polystachion*; the dominant moss is *Tomentypnum nitens*) on the Umbri-gelic Gleysols.

14 - Concave slopes (dellic complexes) with drainage channels of 0,3 to 1,2 m depth

These slopes are widely distributed and occupy a significant portion of the region. The drainage channels reach their maximum depth close to the lake. The vegetation comprises 3 regular and repeated elements: A) Mesic spotty sedge-dryas-moss tundra on ridges with 40-70 % cover (*Carex arctisibirica, Luzula confusa, Dryas punctata, Salix polaris*; the main moss is *Hylocomium splendens var. obtusifolium*) on Umbri-gelic Gleysols. The drainage channels of striped patterned ground support one of two type of vegetation, depending on structure and depth: B) Trough-like dells with wet sedge-moss vegetation (*Carex concolor, Eriophorum polystachion, Arctagrostis latifolia*, and sometimes bushes of *Salix reptans*; mosses: *Tomentypnum nitens*), on Umbri-gelic Gleysols ; C) V -shaped dells with wet graminoid vegetation (*Carex concolor, Eriophorum polystachion, Hierochloe pauciflora*) on Fibri-gelic Hystosols. Vegetative cover in the both types of dell is continuous.

15 - Spotty-striped slanting gravel surfaces with occasional rock streams

The vegetation in this region consists of two community types: A) Most surfaces have dry-mesic forb-moss spotty-hummocky alpine tundra with 30-40 % cover (*Papaver polare, Myosotis asiatica, Saxifraga spsp, Hylocomium splendens var. obtusifolium* dominated between hummocks). The soils are Lithic Leptosols; B) Rock streams with sparse (5-7 % cover) herb and primitive plant aggregations; the Distri-gelic Regosols are well-developed only between stones.

16 - Concave slopes with slight striped ground nanorelief in the initial stages of development of dell complexes

In this landscape type the ridges and troughs of patterned ground do not differ in vegetation. Both areas support mesic herb-dwarf shrub-moss and herb-moss communities (*Salix polaris, Luzula confusa, Equisetum variegatum, Draba pauciflora*; at lower altitudes: *Dryas punctata*; the common mosses are *Tomentypnum nitens* and *Orthothecium chryseon*); the soils are Umbri-gelic Gleysols; vegetative cover ranges from about 50 % on the ridges and up to 80 % in the almost flat dells.

17 - Striped horizontal surfaces with spotty, sometimes hummock-spotty nanorelief

This landscape type is common on the low (not more than 250 m a.s.l.) and flat watersheds and on their shallow slopes, where the ground has been subjected to pelitisation (soil material ranges from pelitized to clay loam). The vegetation consists of mesic cotton grass-dwarf willow-moss and sedge-dwarf shrub-moss communities (*Deschampsia borealis, Carex arctisib irica, Salix polaris, Alopecurus alpinus;* a well-developed moss layer of mostly *Tomentypnum nitens and Aulacomnium turgidum*); up to 80 % cover; the soil cover is a composite of Rentzi-gelic Leptosols regions bordered by Molli-gelic Gleysols surrounded by a background Distri-gelic Gleysol.

18 - Saturated surfaces at various hypsometric levels with angles of inclination close to 0°

Here the nanorelief is spotty and weakly striped and the vegetation is sedge-dwarf shrub-moss (*Carex arctisibirica, C.concolor, Salix polaris*, sometimes *S.reptans;* in the moss layer: *Tomentypnum nitens*); up to 90 % cover; the soils are a nanocomplex of Stagni-gelic Leptosol regions surrounded by Molli-gelic Gleysol borders, separated by Distri-gelic Gleysols.

19 - Watersheds on the northern macroslope of Byrranga Glavnaja Ridge, consisting of fine-grained material with occasional rock outcrops

The rudiments of striped patterned ground and thermokarst depressions are present as well. Generally speaking, they belong to another landscape: the intermountain kettles of the Ugolnaja river depression. The vegetation is close to that of the arctic tundra subzones (small role of dryas in community composition and its replacement by *Salix polaris*). The vegetation here comprises 3 elements: A) Weathered bedrock outcrops support sparse (3-5 % cover) forb-lichen vegetation between stones on a fragmented Distri Regosols; B) Mesic hummocky-spotty dwarf willow-sedge-moss tundra with 50-80 % cover (*Salix polaris, Carex arctisibirica*; in the moss layer: *Tomentypnum nitens, Ptilidium ciliare*) on Molli-gelic- and Umbri-gelic Gleysols; C) Thermokarst microdepressions and striped patterned ground with continuous wet sedge-moss vegetation (*Carex concolor, Eriophorum scheuchzeri, E.polistachyon*; mosses: *Tomentypnum nitens*) on Dysri-gelic Geysols.

20 - Polygonal surfaces on nearly horizontal slopes of the lower portions of watersheds

These features also occur in the previous landscape type. This palsa bog complex is generated through the natural draining of small lakes. The vegetation comprises 2 elements as a result of differences in microrelief: A) Palsa remnants with moist sedge-moss vegetation (*Carex arctisibirica, Luzula nivalis, Calamagrostis holmii*; moss layer consists of *Polytrichum strictum, Dicranum spsp*.,.); the soils are Dystri-gelic Gleysols; B) Flat depressions with wet moss-sedge-cotton grass vegetation (*Carex concolor, Eriophorum polistachyon, E.medium*; the sparse moss layer consists of *Meesia triquetra, Limprichtia revolvens*); the soils are Fibri-gelic Hystosols; the cover is continuous throughout the complex.

Valleys

21 - Deep V- shaped valleys of large mountain streams with abrupt scree slopes and with rock outcrops on the upper slopes

This is one of the most structurally complicated units. It includes almost all of the unit #6 units (the abrupt slopes). The elements of relief and vegetation vary even more here, because of the variety of exposures; the range of flora supported is much greater. The slope surfaces show evidence of the elements of ecological succession. The main elements are: A) Scree with sparse (cover < 5%) herbs (*Arabis petraea s.l., Cerastium beeringianum, Saxifraga spsp., Poa glauca* et al.) on Dystri-gelic Regosols and Dystri-gelic Regosols; B) Forb-dryas boulder debris (*Dryas punctata, Hierochloe alpina, Festuca auriculata, Astragalus alpinus, Potentilla uniflora* et al.) on fragmented Eutri-gelic Regosols; C) Mountain dry-mesic herbaceous meadows (*Poa glauca, Roegneria villosa., Astragalus alpinus, Senecio tundricola, S.resedifolius, Pedicularis verticillata* et al.) on Eutri-gelic Regosols; D) Niches on slopes with mesic herb-cassiope-moss (*Cassiope tetragona, Saxifraga cernua, S. nelsoniana; Hylocomium splendens var. obtusifolium*) communities, on the same soils. The vegetative cover corresponds exactly to similar communities of unit #6. The alluvial plains of each valley support a further 2 vegetative community types depending on the level of the flood-plain: E) Low altitude pebble banks with sparse (cover 1-3 %) forbs (*Chamaenerion latifolium, Arabis petraea*); soils are not presented; and H) High altitude pebble banks with herbaceous cover up to 40 % (*Oxytropis nigrescens, Papaver polare, Festuca brachyphylla, Luzula confusa* et al.) on Dystri Regosols.

22 - Flat-bottomed valleys of small mountain streams with scree or overgrown slopes

In these regions, wide flood plains are formed and the modern erosion and alluvial processes are still active. Generally, these landscape types occur on the limestone plateau on the north-east lakeshore. Because of this shore's favourable south-east aspect and the consequent fast thaw of even thick snow covers, the fragments of shrub communities observed here are almost unique in the region. The vegetation supported represents a series of ecological communities: A) Scree slopes with sparse (3-7 % cover) dry herbaceous (on limestones: herbaceous and lichen) vegetation: *Saxifraga oppositifolia, Braya purpurascens, Parrya nudicaulis* et al. on Dystric Regosols; B) Pebble banks with sparse forb short grass meadows (*Oxytropis middendorffii, O. nigrescens, Novosieversia glacialis* et al.; cover up to 30 %) growing on soils of fluvitierrestrial origin. C) Rare bushes of *Salix alaxensis* and *S.lanata*, with a layer of grasses, *Cardamine pratensis, Equisetum arvense, E.variegatum* et al.) on Eutric Fluvisols. The cover is either continuous or, in the willows-bushes, close to 30 %. Beneath the limestone slopes and near snow-fields there is usually wet nival turf with *Oxygraphis glacialis, Minuartia stricta, Cochlearia arctica* et al.

23 - U-shaped, nival, upper reaches of streams valleys with large snow accumulation and late thaw

The delay of snow thaw in this region can reach 2 months relative to the background surfaces. The slopes are composed of scree and are occupied (A) by primitive nival herbaceous aggregations (*Saxifraga cernua, S.nivalis*; in moss cushions: *Oncophorus wahlenberghii*) with irregular cover from 1 to 30-40 %; the soils are fragmented distric regosols. B) Lower slope reaches of pebbles at the altitude of alluvial deposits, with sparse vegetation consisting of a few herbs (10-15 % cover): *Cardamine bellidifolia, Arabis petraea, Papaver polare, Eritrichium villosum* et al. The soils are fragmented Eutric Fluvisols.

24 - Erosion valleys with overgrown slopes and with hummock-tussock nanorelief, on the northern macroslope of the lake basin

The vegetation of the valley bottoms is continuous, moist sedge-moss (*Carex arctisibirica, Lagotis minor,* Eriophorum callitrix; in the moss layer: *Tomentypnum nitens*) on moist Umbri-gelic Gleysols.

25 - Flood-plain of the Krasnaja river and its tributaries (large streams in the river delta).

This region is characterized by well-developed alluvial relief, but the limits between alluvial levels are rather variable; they are frequently expressed only in vegetation, which is again present as a series of ecologically distinct communities and includes the following elements: A) Low altitude pebble banks with solitary plants (*Thlaspi cochleariforme, Papaver polare, Leymus interior, Arabis petraea*), cover not more than 1 %, soils are absent.; B) Mid-altitude pebble banks with mesic herbaceous meadows, up to 30-50 % cover (*Oxytropis middendorffii, Astragalus tolmaczewii, A. alpinus, Pedicularis amoena, Festuca rubra subsp. arctica* et al.) on Dystric Fluvisols; C) High altitude sites with dry-mesic moss-herb-dryas short grass meadows (cover up to 90 %). They are present here as fragments only; the species composition is similar to that of the previous level, but here Dryas punctata dominates and there fragments of a moss layer (*Sanionia uncinata*); the soils are Fluvisols; D) High altitude locations with continuous mesic shrub-moss vegetation in fragments (*Salix reptans, S.lanata, Poa alpigena, Saxifraga nelsoniana* et al.; the continuous moss layer is almost only Tomentypnum nitens); the soils are the same; E) Moss-grass homogeneous bogs of the flood plain and terrace recesses (*Carex concolor, Eriophorum medium, E. polistachyon, Dupontia fisheri* et al.; in the fragmented mosslayer: Meesia triquetra, Limprichtia revolvens); the plant cover is continuous; the soils are Fibri-gelic Histosols. Mud banks with thickets of *Carex saxatilis subsp.laxa, C. maritima, Juncus castaneus* et al. occur occasionally; the cover here is not more 30 %; the soils are Mollic Fluvisols.

26- Gravelly alluvial fans with angles of inclination 10-20°, with hummocky nanorelief

The fans belong to ancient watercourses and there are no modern channels. They support mesic herb-dwarf shrub-moss tundra with up to 70 % cover *(Carex arctisibirica, C.misandra, Dryas punctata, Salix polaris, Salix arctica*; in the moss layer: *Hylocomium splendens var.obtusifolium).* The soils are Molli-gelic Gleysols.

27 - Fine grained alluvial fans with angles of inclination 3-8=83 and spotty-hummock nanorelief.

These fans often form part of the lakeshore and are frequently complicated by fragments of low lake terraces. This unit included 2 vegetation elements: A) The main surface with sedge-dwarf shrub-moss tundra, up to 80 % cover (*Carex arctisibirica, C. misandra, Dryas punctata, Salix polaris*; moss layer: *Tomentypnum nitens*); the soils of the hummocky regions are Molli-gelic Gleysols and between hummocks they are Umbri-gelic Gleysols. The presence of such species as *Oxytropis mertensiana*, *Eriophorum callitrix, Minuartia stricta* indicate a high level of nitrogen and available organic material in the soils; B) Channels with moist forb-dryas or dryas-forb meadows (*Dryas punctata, Poa alpigena, Carex tripartita, Gastrolychnis apetala, Artemisia tilesii* et al.) on Molli-gelic Leptosols with 20-40 % cover.

28 - Alluvial fans with angles of inclination of 0-5°, with pebbly banks and tundra between them

Such fans occur along the larger channels of small rivers. This landscape unit characterizes many of the older channels and indicates intense modern accumulation. Stone-loam spotty-hummocky tundra with small shallow thermocarst depressions and striped ground is found between the older channels. The vegetation forms 3 distinct elements: A) Pebbly sites proximal to channels with mesic forb-dryas vegetation *(Dryas punctata, Oxytropis middendorffii, O. arctica subsp. taimyrensis*, et al.) with about 50 % cover on Fluvisols; B) Mesic spotty-hummocky sedge-dwarf shrub-moss tundra *(Carex misandra, , Dryas punctata, Cassiope tetragona*, the moss layer is polydominant), 60-80 % cover, the soils surrounding spots are Molli-gelic Gleysols and in the depressions between borders they are Skeletic Cryosol; C) Thermokarst depressions with a continuous wet shrub-sedge-moss vegetation (*Salix reptans, Carex concolor, C. arctisibirica*; in the moss layer *Tomentypnum nitens* dominated), the soils are Fibri-gelic Histosols.

Terraces

29 - Fragments of marine accumulation marine terraces at 90-100 m a.s.l., with hummocks, and occasional large polygonal nanorelief

This region is part of the best preserved high altitude terraces, fragments of which can be found all along the shore, but are generally not marked on the map because of their small size. They usually occur as hills with flat or convex tops; in one case, however, in both the watersheds of the lake and of Ledjanaja Bay, the fragment occurs as a great residual block, hilly massif. The vegetation is classified into 3 elements: A) Forb hummocky dry communities of the terrace tops (*Carex rupestris, Potentilla uniflora, Oxytropis nigrescens, Hierochloe alpina* et al.) with 5-30 % cover on Geli-lithic Leptosols; B) Slopes with dry herb-dryas vegetation (composition of herbs is analogous, up to 60 % cover) on similar soils; C) Subnival mesic cassiope-moss tundra of snow covered slopes (*Cassiope tetragona, Carex vaginata, Taraxacum arcticum*; in the moss layer: Hylocomium splendens var.*obtusifolium*) with practically continuous plant cover on similar soils.

30 - Fragments of lacustrine accumulation terraces with large polygonal surface.

These terrace fragments are generally situated 3-5 m above the present lake level. Their surfaces are broken by cracks presumably as a result of ancient ground lodes. The surface of the polygons between the cracks are marked by hummocky nanorelief. The edges of the terraces are frequently marked by ice-shove ridges. The unit comprises 3 vegetation elements: A) Denudation-spotty terrace surface with the foliose lichens and sparse (cover not more 15 %) forb (*Papaver polare, Eritrichium villosum subsp.pulvinatum, Saxifraga oppositofolia* et al.) on Distri-gelic Regosols; B) Cracks with continuous mesic herb-cassiope-moss vegetation (*Cassiope tetragona, Carex misandra, Luzula nivalis, sometimes Vaccinium minus*; the moss *Rhacomitrium lanuginosum* dominated completely) on Dystric Leptosols; C) Ice-shove ridge and beach with herbaceous vegetation (*Papaver lapponicum, P.pulvinatum, Draba subcapitata, Chrysosplenium alternifolium* et al.).

31- Flooded low wet marshes of the lake.

This landscape unit occurs only once in the region, on the north-east lakeshore. The greater portion of its surface is under water for 2-3 weeks after the spring thaw and growth therefore begins late. The soil is composed of lake mud and mud-pebbles and shows a subtle polygonal microrelief, especially in areas somewhat raised. This unit consists of 3 elements, the vegetation of which form an ecological series: A) Low altitude mud and sandy-mud banks with sparse (cover 5-10 %) wet swamp vegetation (*Carex saxatilis sp. laxa, Eriophorum scheuchzeri, E. Polistachyon and Dupontia fisheri* on mollic-gleyic fluvisols; in the water: *Ranunculus gmelinii, Pleuropogon sabinii*); B) Higher level sedge tussocks (*Carex saxatilis ssp. laxa*), also with *Carex concolor, Eriophorum spsp.*, Pedicularis albolabiata; cover about 50%, the soils are the same; C) Highest level moist polygon-formed pebbly plots, covered beyond by mud, with sparse, frequently calciphilous, forbs (*Arabis petraea, Oxygraphis glacialis, Thlaspi cochleariforme, Braya purpurascens, Armeria maritima*) and solitary bushes of *Salix reptans*; cover 10-25 %, the soils are Dystri-gelic Leptosols.

Bogs

32 - Typical polygonal bogs on the northern shoreline region

The polygons are about 10 across and their borders reach a height of 0.5 m above the centers. The vegetation consists of 2 elements from the polygonal bog complex: A) -Wet moss-sedge communities of polygons (*Carex concolor, C. chordorrhiza*; in the fragmented moss layer:

Meesia triquetra, Aulacomnium palustre) on Fibri-gelic Histosols; B) Moist herb-moss communities of the polygon borders (*Carex arctisibirica*, sometimes *Astragalus umbellatus, Calamagrostis holmii*; the moss layer consists of *Tomentypnum nitens, Sphagnum spsp.*); the soils are Umbri-gelic Gleysols; the cover is continuous.

33 - Residual-polygonal bogs from the same location, but further from the lakeshore

These bogs are characterized by a significant development of thermokarst on the background flat-polygons and the low center polygon. The outliers of the elevated polygons occupy 5-25 % of the area. The vegetation is classified into 2 elements according to microrelief: A) Polygon outliers with moist shrub-herb-moss communities (*Salix reptans, S.pulchra, Carex arctisibirica, Luzula confusa, Senecio atropurpureus, Calamagrostis holmii*; the dense moss layer consists of *Polytrichum strictum, Dicranum elongatum, Aulacomnium palustre*). The soil is Umbri-gelic Gleysol; B) Thermokarst depressions with vegetation and soils analogous to polygons of unit 32; continuous plant cover.

34 - Palsa bog complexes

There is one large massif in the Krasnaja River mouth valley; it is probably a relict of an ancient warmer epoch. The cracks between palsas are frequently filled with water and the palsas reach 1,5 m In height. Denudation is evident on the palsas. The vegetation comprises 3 elements: A) Mesic shrub-herb-moss communities on palsas with 90-100 % cover (*Salix reptans, Cassiope tetragona, Carex arctisibirica, Luzula confusa, Senecio atropurpureus, Calamagrostis holmii*), the moss layer is thick (*Polytrichum strictum, Dicranum elongatum, Aulacomnium turgidum).* The soils are Umbri-gelic or Dystri-gelic Gleysols; B) Wet continuous sedge-cotton grass-moss communities in cracks (*Eriophorum polistachyon, E. medium, Carex concolor*, the hygrophilous moss Limprichtia revolvens) on Dystri-gelic Gleysols; C) Undergrowth of Arctophila fulva in water-filled cracks; the floating moss Calliergon giganteum is sometimes also found.

Acknowledgements

We thank all of the field group investigators from the AARI, AWI, IPÖ, MGU, ISSP, IfB, MLU expedition and members of the Taimyrsky reserve for their assistance in the field. We especially thank the expedition chief, Dr. D. Yu.Bolshijanov, and the Reserve chief, Yu. M. Karbainov, for the organization of field work. We gratefully acknowledge E.B. Pospelova for her review of the manuscript and for botanical consultation, M.V. Orlov for consultation on soil sciences and Prof. V.D. Vassiljevskaja for assistance in soil nomenclature.

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