# Russian-German Cooperation SYSTEM LAPTEV SEA 2000: The Expedition LENA 2000

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Edited by Volker Rachold and Mikhail N. Grigoriev

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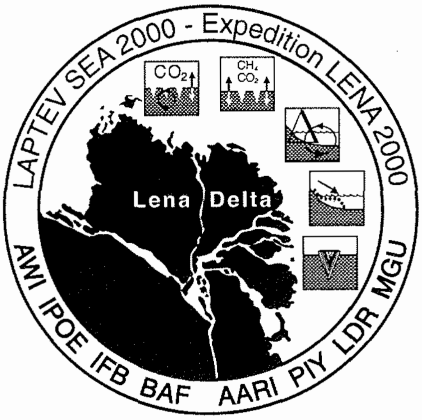
# The Expedition LENA 2000

*by the participants of the expedition*
*edited by Volker Rachold and Mikhail N. Grigoriev*



# Contents

# 1 Introduction

*(V. Rachold and M. N. Grigoriev)*

Our knowledge of the Arctic climate system has been significantly improved through multi-disciplinary investigations carried out in the Siberian Arctic during previous Russian-German projects, such as THE LAPTEV SEA SYSTEM (1994-1997) and TAYMYR (1994-1997). The results are presented in a collection of papers published by Kassens et al. (1999).

Detailed climatic reconstructions of the late Quaternary and important information concerning the complex modern system were obtained and form the basis for the prediction of future climate changes. The investigations documented that the closely coupled land-ocean system of the Laptev Sea with the East Siberian hinterland and its complex connections, such as the Lena Delta, represent a key region for understanding environmental changes. Our present knowledge indicates that environmental changes in this area not only affect the Arctic Ocean but also contribute to variations in the global system.

The Project SYSTEM LAPTEV SEA 2000 is based on these results but addresses completely new scientific problems as well. The following subjects are studied:

A. Seasonal variability of modern fluxes in permafrost areas
  - balance of greenhouse gases (carbon dioxide and methane) and process studies of the methane cycle
  - water and energy flux in permafrost soils
  - microbial communities and carbon dioxide flux in permafrost soils

B. Environmental reactions of the terrestrial-marine system of the Siberian Arctic during the last 100 years
  - marine environmental reactions and material balance
  - atmospheric input of radio-nuclides
  - sensibility of marine Arctic ecosystems

C. Land-ocean interactions and the influence on the sediment budget of the Laptev Sea
  - environmental and climatic history of the Lena Delta
  - particle transport in the delta-shelf system

D. Terrestrial system: short- and medium-term climatic trends in the Siberian Arctic
  - terrestrial climatic signals in ice-rich permafrost deposits

E. Marine system: long-term climatic trends in the Siberian Arctic
  - causes and consequences of short- and medium-term climatic trends in permafrost regions
  - acoustic signatures of submarine permafrost

Within the framework of the project SYSTEM LAPTEV SEA 2000 the first terrestrial expeditions to the Lena Delta and the Laptev Sea coastal region were performed during summer 1998 and spring/summer 1999 (Rachold and Grigoriev, 1999 and 2000). Based on the experiences and results of these expeditions, the third expedition LENA 2000 was carried out from July 28 to August 27, 2000. A multi-disciplinary, Russian-German team of 19 scientists worked in the Lena Delta and in the Laptev Sea coastal region (Figure 1-1).

The scientific program of the expedition covered the terrestrial research objectives of the project SYSTEM LAPTEV SEA 2000, i.e.:

A. Seasonal variability of modern fluxes in permafrost areas (➔ *Chapter 3: Modern Processes in Permafrost Affected Soils*)

C. Land-ocean interactions and the influence on the sediment budget of the Laptev Sea (➔ *Chapter 4: Coastal Processes in the Laptev Sea and the Environmental History of the Lena Delta*)

D. Terrestrial system: short- and medium-term climatic trends in the Siberian Arctic (➔ *Chapter 5: Late Quaternary and recent environmental situation around the Olenyok Channel (western Lena Delta) and on Bykovsky Peninsula*)

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Kassens, H., Bauch, H., Dmitrenko, I., Eicken, H., Hubberten, H.-W., Melles, M., Thiede, J. and Timokhov, L. (1999), Land-Ocean systems in the Siberian Arctic: dynamics and history. Springer, Berlin, 711pp.

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## Acknowledgments

The success of the expedition LENA 2000 would have not been possible without the support by several Russian, Yakutian, and German institutions and authorities. In particular, we would like to express our appreciation to the Tiksi Hydrobase and the Lena Delta Reserve, special thanks to D. Melnichenko and D. Gorokhov. The members of the expedition wish to thank the captains and crewmembers of the Vessels "Neptun" and "Sofron Danilov" and the staff of the biological station Samoylov.

The expedition was funded by the German and Russian Ministries of Science and Technology (BMBF-Verbundvorhaben SYSTEM LAPTEV-SEE 2000, LAPEX).

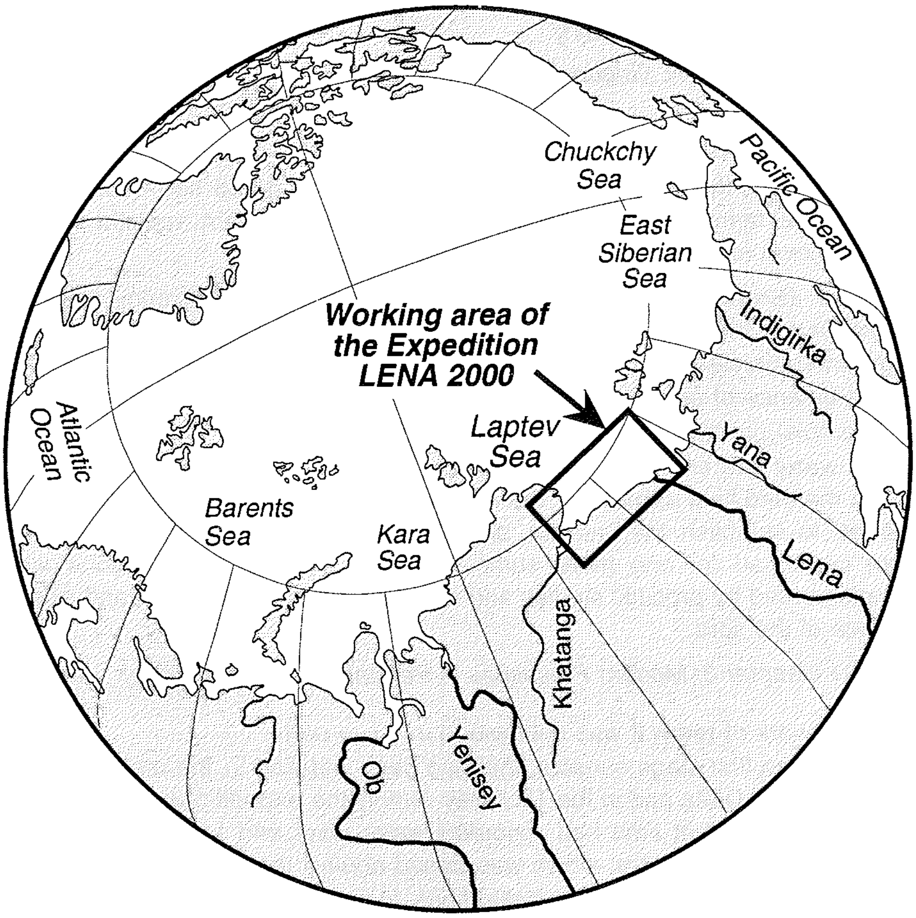

**Figure 1-1:** Map showing the location of the working area of the expedition LENA 2000.

# 2 Expedition Itinerary

*(V. Rachold and M. N. Grigoriev)*

## 2.1 Selection of working areas

With respect to the scientific program, the expedition group had been divided into several teams prior to the expedition. For each team specific working areas, shown in Figure 2-1, had been selected.

**Team 1 (Samoylov Island)** was based on the Island Samoylov in the central part of the Lena Delta. The team concentrated on modern processes of permafrost-affected soils, i. e.:

- the balance of greenhouse gasses ($CH_4$ and $CO_2$)
- microbial process studies regarding the $CH_4$ cycle
- the water and energy balance of permafrost soils.

Within the third field campaign, the measurements of gas emission, which are needed to establish the balance of greenhouse gasses in the Lena Delta, were continued for one more summer season. These investigations were complemented by process studies and measurements of the water and energy balance of the soils.

(➔ *Chapter 3: Modern Processes in Permafrost Affected Soils).*

The field work of **team 2** was subdivided into two parts:

- During the first stage sensors, that had been installed in the main channels of the Lena Delta and in the Tiksi Bay during the expeditions LENA 98 and 99 and since that time had recorded water level and temperatures, were retrieved by **Team 2 a**, which was based aboard the vessel **"Neptun"**.
- During the second stage investigations focussing on coastal erosion and sediment accumulation along the coastline of the Lena Delta and the western Laptev Sea sector have been carried out. **Team 2 b** used a marine tugboat (**"Sofron Danilov"**). The work program combined detailed geodetic measurements by a laser-theodolite, recording of bathymetric profiles, sampling of coastal sections and coastal marine sediments as well as measurements of water temperature. Key areas were located along the coastline of the active and in-active Lena Delta, the offshore islands and the western Laptev Sea.

(➔ *Chapter 4: Coastal Processes in the Laptev Sea and the Environmental History of the Lena Delta*)

**Team 3 (Olenyokskaya Channel)** focused on multi-disciplinary investigations of ice-rich permafrost deposits and their potential as climate archives. The objectives were:

- Investigations of Ice Complex deposits of the western part of the Lena River delta to compare it with Ice Complex deposits of the eastern part of the delta for understanding its origin and the evolution of the entire delta region during Late Pleistocene and Holocene.

- Study of sandy deposits below the Ice Complex along the Oleneksky Channel.
- Continuing the geomorphologic mapping of the delta and age determination of different terraces of the flood-plain.
- Investigations of nival processes in Chekanovsky Ridge to understand their role in relief construction and in the formation of the ice-complex.
- Investigations of all other types of Quaternary deposits in the lower part of Olenekskaya Channel.

Working areas have been the Bykovsky peninsula, Samoylov Island as well as outcrops along the Olenyokskaya Channel in the western Lena Delta.

> (→ *Chapter 5: Late Quaternary and recent environmental situation around the Olenyok Channel (western Lena Delta) and on Bykovsky Peninsula*)

**Team 4 (Gusinka)** carried out paleogeographical investigations north of the Olenyokskaya Channel in the western part of the Delta. Rubber boats were used for transportation and the participants lived in a field camp.

> (→ *Chapter 4: Coastal Processes in the Laptev Sea and the Environmental History of the Lena Delta*)

## 2.2 General logistics and transport

The general logistics of the LENA 2000 Expedition were jointly organized by the Permafrost Institute (Yakutsk), the Arctic and Antarctic Research Institute (St. Petersburg) and the Research Unit Potsdam of the Alfred Wegener Institute. Logistic operations in Tiksi (renting of busses, trucks, helicopters etc.) were organized by the Tiksi Hydrobase.

Timetable of the expedition:

| | |
|---|---|
| July 28 | Flight Berlin-Moscow |
| July 29 | Flight Moscow-Tiksi |
| July 30 | Preparation of fieldwork in Tiksi |
| July 31 | Ship transfer from Tiksi to the field |
| August 1-22 | Fieldwork of individual working groups |
| August 23 | Ship transfer back to Tiksi |
| August 24-25 | Preparation for departure in Tiksi |
| August 26 | Flight Tiksi-Moscow |
| August 27 | Flight Moscow-Berlin |

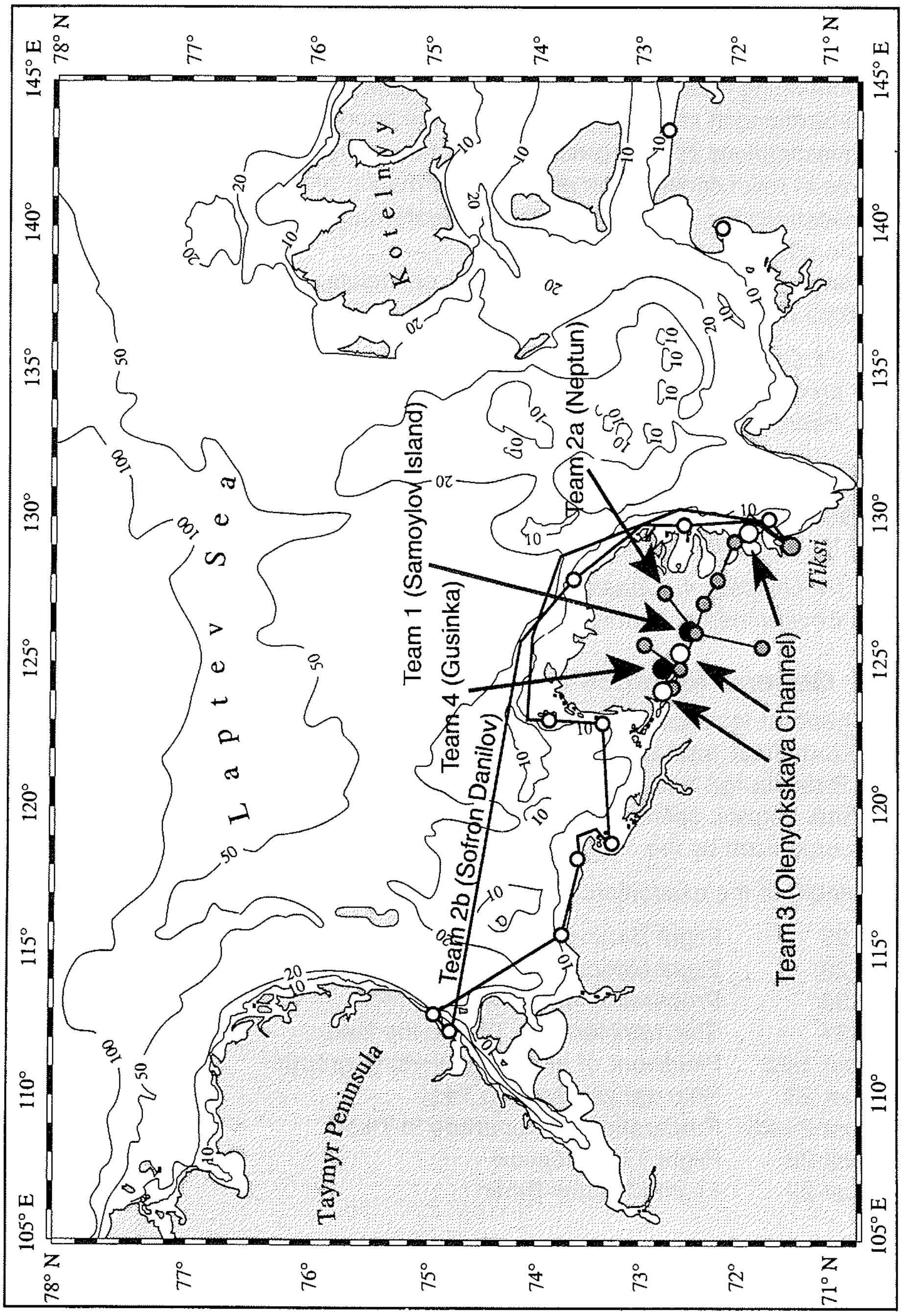

**Figure 2-1:** Location map of the expedition LENA 2000.

## 2.3 Timetables of individual working groups

### 2.3.1 Team 1 (Samoylov Island)

| | |
|---|---|
| July 31 | transfer Tiksi - Samoylov by ship |
| August 01 | arrival on Samoylov, first inspection of the investigation sites, set up of the laboratory |
| August 02 | installation and calibration of the gas chromatograph |
| August 02-21 | beginning of daily gas sampling for the analysis of $CH_4$ and $CO_2$ emission, daily soil monitoring at plot 3 (temperature, water table, permafrost table) |
| August 03 | data collection and check of automatic weather station at plot 3 |
| August 04 | each second day analysing of gas samples by gas chromatography, data collection and check of automatic soil station at plot 3 |
| August 05 | first excursion to Buor-Khaya: sampling of ice cores from ice complex and gas samples from a low-centre polygon for trace gas analysis |
| August 06 | excursion to Sardakh for ice core sampling |
| August 07 | water sampling from suction lysimeter at plot 3 and preparation for DOC analysis |
| August 08 | replacement of the net radiation sensor |
| August 09 | soil sampling, extraction of soil pore water and filtration for DOC analysis (polygon centre), sampling of ice cores from ice wedges of Samoylov |
| August 10 | installation of automatic station for redox potential measurements near plot 3 |
| August 11 | second excursion to Buor-Khaya for ice core sampling |
| August 11-20 | determination of in situ $CH_4$ production activity for the polygon border of plot 3 |
| August 12 | installation and start of $CH_4$ emission measurements from tundra lakes |
| August 13 | repair of the automatic soil station |
| August 14 | water sampling from suction lysimeter at plot 3 and preparation for DOC analysis, third excursion to Buor-Khaya for ice core sampling |
| August 15 | digging of a soil profile in the centre of the polygon and soil sampling |
| August 16 | digging of a soil profile in the border of the polygon and soil sampling, sampling of ice cores from ice wedges of Samoylov |
| August 17 | taking gas samples from the flood plain of Samoylov for trace gas analysis |
| August 18 | sampling of undisturbed soil cores from the polygon border near plot 3, fourth excursion to Buor-Khaya for ice core sampling |
| August 19 | soil sampling, extraction of soil pore water and filtration for DOC analysis (polygon border) |
| August 20 | last inspection and data collection of the automatic weather and soil stations |
| August 21 | deinstallation of automatic station for redox potential measurements and soil sampling, water sampling from suction lysimeter at plot 3 and preparation for DOC analysis |
| August 22 | deinstallation of several instruments, packing of samples and equippment |
| August 23 | return to Tiksi by ship |

### 2.3.2 Team 2a (Neptun)

| | |
|---|---|
| August 1 | Loading of "Neptun" and departure from Tiksi, recovery of sensor no.1 in Tiksi Bay, search for sensor no.2 near Cape Bykowsky without success |
| August 2 | Search for sensor no.3 near Nordenskiold station (no success), water sampling, cruise to Polar Station Sokol, search for sensor no.4 (no success) |
| August 3 | Sardakh Island: sampling for OSL dating, water sampling, search for sensor no.3 (no success), cruise to Samoylov Island, search for sensor no.5 (no success) |
| August 4 | search for sensor no.6 in Tumatskaya Channel (no success), cruise along Olenyok Channel to Nagym |
| August 5 | water sampling, search for sensor no.7 near Nagym (no success) |

| | |
|---|---|
| August 6 | cruise back along Olenyok Channel, search for sensor no. 8 near Gusinka (no success), cruise to Samoylov |
| August 7 | excursion to Sardakh Island with Team 1 (Samoylov) |
| August 8 | cruise to Tit-Ary, water sampling, search for last sensor (no. 9) without success |
| August 9 | cruise back to Tiksi |

### 2.3.3 Team 2b (Sofron Danilov)

| | |
|---|---|
| August 13 | loading of "Sofron Danilov" |
| August 14 | cruise to Samolyot Island |
| August 15 | bathymetric profiling and sediment sampling near Samolyot Island |
| August 16 | cruise to Olenyok Bay, storm |
| August 17 | storm, geodetic measurements in small, nameless bay near the mouth of Olenyok River |
| August 18-19 | bathymetric profiling, sediment sampling and geodetic measurements of 2 coastal sections between the mouths of Olenyok and Anabar rivers |
| August 19-22 | bathymetric profiling, sediment sampling and geodetic measurements of 2 coastal sections of Taymyr peninsula |
| August 21 | cruise back to the Lena Delta |
| August 22 | bathymetric profiling, sediment sampling of 2 section north-east off the Lena Delta (advancing Holocene delta), geodetic measurements on Muosktakh Island, cruise back to Tiksi |

### 2.3.4 Team 3 (Olenyokskaya Channel)

| | |
|---|---|
| July 31 -Aug 1 | transfer from Tiksi to the camp position near Nagym (western Lena delta) by RV Puteysky |
| August 2 | camp installation |
| August 3 | first overview trip to Kuba Bay |
| August 4 | second overview trip along the northern bank of Olenyok Channel |
| August 5 | installation of markers in distances of 100 m (2 km), determination of study positions |
| August 6-7 | geological and geocryological survey and sampling of the study point Nag 4+50 (sediments and ice wedges); screening of samples for insect analysis, sampling for paleontological studies (Expedition team from RV Neptun visited camp site while working in the Olenyok Channel on 6th August) |
| August 8 | expedition by motorboat along the studied bank, photo documentation, short trip to Khardang Island |
| August 9 | end of geological and geocryological survey and sampling (Nag 6+20, Nag 1+80) |
| August 10 | sampling of recent ice wedges, small ponds and soil horizons around the camp; separations and saving of sediment and ice samples |
| August 11-14 | field trip by motorboat to Chekanovsky Ridge; study of snow patches and nival landscapes |
| August 15 | dismantling of the camp |
| August 16 | transfer of the group from Nagym to the central Lena delta (Kurungnakh Island) by RV Neptun |
| August 17-19 | geological and geocryological survey and sampling (sediments and ice wedges) of the study points Buor Khaya (Bkh); screening of samples for insect analysis, sampling for paleontological studies |
| August 20 | transfer to Bykovsky Peninsula, supplementary sampling of ice wedges and permafrost deposits at the outcrop Mamontovy Khayata |
| August 21 | shipping back to Tiksi |
| August 22-23 | separations and saving of sediment and ice samples, preparation of all samples for the transport |

| | |
|---|---|
| August 24 | preparation of expedition equipment for shipment |

### 2.3.5 Team 4 (Gusinka)

| | |
|---|---|
| July 31 – August 01 | shipping from Tiksi to Samoylov Island and then to Gusinka (Kuogastakh-Aryta Island). Pollen trap station L-4 was set up on Samoylov Island. |
| August 02 | preparation of boats and motors and packing of equipment and foodstuffs for cruise to Dzhangylakh-Sis Island and Khardang-Sise Island. Pollen trap station L-5 was set up on Kuogastakh-Aryta Island. |
| August 03 | cruise from Gusinka (Kuogastakh-Aryta Island) to the northern part of Dzhangylakh –Sis Island by the Tyuerenkey-Tebyulege Channel and Arynskaya Channel by 2 motorboats. |
| August 04 | camp construction. Reconnaissance observations of the shore exposure in the northern part of Dzhangylakh –Sis Island. |
| August 05–12 | geologic and geomorphologic studies and sampling of permafrost section of shore exposure in the northern part of Dzhangylakh –Sis Island. |
| August 13 | reconnaissance route to the north-eastern part of Khardang Island by the Arynskaya Channel by motorboat and return back in field camp on Dzhangylakh –Sis Island. |
| August 14-15 | continuation of studies and sampling of the permafrost section of the shore exposure in the northern part of Dzhangylakh –Sis Island. |
| August 16 | stormy weather |
| August 17 | finish of studies and sampling of the permafrost section of the shore exposure in the northern part of Dzhangylakh –Sis Island |
| August 18 | dismantling camp on Dzhangylakh –Sis Island, cruise from Dzhangylakh –Sis Island to Mus-Khaya (the north-eastern part of Khardang Island) by the Arynskaya Channel by 2 motorboats. Camp construction on Mus-Khaya. |
| August 19–21 | geologic and geomorphologic studies of the north-eastern part of Khardang Island, sampling of permafrost section of the shore exposure in the north-eastern part of Khardang Island. |
| August 22 | dismantling camp, return to Gusinka (Kuogastakh-Aryta Island) by 2 motorboats. |
| August 23–24 | shipping back to Tiksi |

## 2.4 Appendix

**Table A2-1:** List of participants.

| Name | email | Institution | Team |
|---|---|---|---|
| Martin Antonow* | naturkundemuseum@stadt-chemnitz.de | (MNS) | 2a |
| Felix Are | but@peterlink.ru | (PSUMOC) | 2b |
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| Mikhail Grigoriev | grigoriev@mpi.ysn.ru | (PIY) | 2a, b |
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| Hans-Wolfgang Hubberten | hubbert@awi-potsdam.de | (AWI) | 2b |
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| Victor Kunitsky | kunitsky@mpi.ysn.ru | (PIY) | 3 |
| Sveta Kuzmina | skuz@orc.ru | (SIEE) | 3 |
| Tanya Kuznetsova | esin@sgm.ru | (MGU) | 3 |
| Anya Kurtshatova | kurtshatova@mpi.ysn.ru | (PIY) | 1 |
| Lena Pavlova | lpavlova@otto.nw.ru | (AARI) | 4 |
| Volker Rachold | vrachold@awi-potsdam.de | (AWI) | 2a, b |
| Sergey Rasumov | grigoriev@mpi.ysn.ru | (PIY) | 2b |
| Lutz Schirrmeister | lschirrmeister@awi-potsdam.de | (AWI) | 3 |
| Waldemar Schneider | wschneider@awi-potsdam.de | (AWI) | 2a, b |
| Günter Stoof | gstoof@awi-potsdam.de | (AWI) | 1 |
| Dirk Wagner | dwagner@awi-potsdam.de | (AWI) | 1 |

*former TU-BAF

**Table A2-2:** Participating institutions.

| | |
|---|---|
| **AARI** | Arctic and Antarctic<br>Research Institute<br>Bering St. 38<br>199397 St. Petersburg<br>Russia |
| **MGU** | Moscow State University<br>Faculty of Paleontology<br>119899 Moscow<br>Russia |
| **PIY** | Permafrost Institute<br>Russian Academy of<br>Science<br>677018 Yakutsk<br>Yakutia, Russia |
| **PSUMOC** | St. Petersburg State<br>University of Means of<br>Communications<br>9 Moskovskii<br>190031 St. Petersburg<br>Russia |
| **SIEE** | Severtsov Institute of<br>Ecology and Evolution<br>Russian Academy of<br>Sciences<br>33 Leninskiy Prospect<br>117071 Moscow<br>Russia |
| **AWI** | Alfred Wegener Institute<br>Research Unit Potsdam<br>PO Box 60 0149<br>D-14401 Potsdam<br>Germany |
| **MNS** | Museum for Natural Science<br>Theaterplatz 1<br>09111 Chemnitz<br>Germany |
| **TU-BAF** | Freiberg Academy of<br>Mining and Technology<br>Institute of Geology<br>Bernhard-von-Cotta-Str. 2<br>D-09596 Freiberg<br>Germany |

# 3 Modern processes in permafrost affected soils

*(D. Wagner, A. Kurchatova, G. Stoof)*

## 3.1 Introduction

Subarctic and arctic tundra located above 60° N covers a global area of 1.5 $10^9$ $km^2$ (Harris et al. 1993). They represent the biggest group of natural wetlands with about 26 % area. The reported methane emissions of wet tundra varied between 1 to 42 Tg $CH_4$ $a^{-1}$ (Christensen et al. 1995). Furthermore, about 14 % of the global organic carbon are stored in permafrost soils (Post et al. 1982). The importance of these regions is discussed regarding an expected climate warming. Especially, the carbon fixation in permafrost soils and the release of climate relevant trace gases like $CH_4$ and $CO_2$ due to the carbon decomposition are important for the global carbon budget.

The interdisciplinary soil and microbiological studies are focused on the seasonal variability of the modern carbon fluxes ($CH_4$, $CO_2$), the quantification of microbial processes as well as the thermal and hydrological dynamics of permafrost affected soils of the Lena Delta.

During the third Lena Delta Expedition in late summer 2000 the investigations of the methane and carbon dioxide emission from different polygon tundra sites and tundra lakes could be continued. The microbial methane production of permafrost soils was studied by additional field experiments. In order to obtain the estimation of the total carbon budget for the Lena Delta region, it was also necessary to take into account the methane emission from the ground ice. Therefore, the methane concentration of undisturbed ice samples from a number of ice wedges was analyzed. Additional soil, water and gas samples were taken for further microbial and geochemical analyses.

## 3.2 Methods and field experiments

The investigations of methane and carbon dioxide emission as well as process studies of methane fluxes were carried out on Samoylov, a representative island in the Lena Delta.

Daily measurements of trace gas emission ($CH_4$, $CO_2$), thaw depth and soil temperature were determined from August 2 to August 21, 2000 at a low center polygon site. Additional measurements of $CH_4$ and $CO_2$ release from the floodplain site on Samoylov and from polygon lakes as well as from a wet polygon tundra of Kurungakh island (N 72°19,49; E 126°13,37), were monitored. The used method and the main investigation sites were described previously (Pfeiffer et al. 1999).

The in situ $CH_4$ production was investigated considering the natural soil temperature gradient. Fresh soil material (20 g) from different layers of the polygon border was weight into 100-ml glass jars, closed gas tight with a srew cap with septum and flushed with $N_2$. The prepared soil samples were reinstalled in the same layers of the soil profile from which the samples had been taken. Gas samples were taken from the headspace with a gastight syringe and analyzed for the concentration of methane by gas chromatography in the field laboratory.

Dissolved organic carbon was extracted from soil samples of two vertical profiles (polygon center and border). Each 5 cm fresh soil material (9 g) was taken to a depth of 30 cm for the polygon center and to a depth of 40 cm for the polygon border. The samples from each layer were weight into glass flasks (50 ml) and mixed with 45 ml distilled water. The flasks were closed and shaken for 2 h in darkness. Afterwards the suspension was filtered (mesh 0.45 $\mu$m, Gelman Science) and the clear solution was inactivated by the addition of sodium azide.

An automatic station for longtime recording of redox potentials was installed along a transect of a low center polygon. The redox potential was determined in the top (5 cm soil depth) and bottom zone of the active layer (depth of electrodes depended on the permafrost table) in intervals of one hour at 14 measuring points. At the end of monitoring from each electrodes soil samples were taken for further analyses (e.g. organic carbon, microbial biomass, phospholipid analyses).

Microclimate and soil temperature were continuously logged using the automatic station at the low centered polygon site. A summary of instruments and methods was reported by Friedrich and Boike (1999).

A total number of 150 ice samples were taken from 12 ice wedges to determine the methane concentration of this potential methane source. The investigated sites are located on different geomorphological levels of the Lena Delta (Sardakh, Samoylov, Kurungakh islands; Table 3-1). It is well known, that the age of terrace levels depends on the altitude position in the Lena Delta. The highest ice complex terrace (Kurangakh Island) was formed during Late Pleistocene. The deposits of high flood plain (Sardakh Island) were dated about 3 ka. Samples were taken in 50 cm intervals along horizontal transects perpendicularly to ice wedge growth. In addition, from two sites 75 cm ice cores were taken horizontally from the central part of the ice wedges. Undisturbed ice samples with about 150 ml volume were transferred into plastic boxes (Nalgene) filled with concentrated NaCl solution and closed gastight. After ice melting the $CH_4$ concentration of the samples were analyzed by gas chromatography in the field laboratory. Additionally, ice samples were taken from the same sites for chemical and isotopic analyses.

**Table 3-1:** Description of the investigated ice wedges

| Location | Geomorphological level | Altitude* [m] | Stratigrafical genetic complex | Age | Ice wedge parameters Width [m] | Height [m] |
|---|---|---|---|---|---|---|
| Sardakh | high flood plain | 6-8 | alluvial complex | late Holocene | 2.0-2.5 | 3.0 |
| Samoylov | first terrace | 8-10 | alluvial complex | late Holocene | 2.75-3.0 | 3.0-5.0 |
| Kurungnakh | first terrace | 10-12 | Alas complex | middle Holocene | 3.0 | 5.0-8.0 |
| Kurungnakh | third terrace | 30-40 | ice complex | late Pleistocene | 10.0 | 15-20 |

* the altitude is given in meter about see level

$CH_4$ and $CO_2$ concentrations were determined with a Chrompack (GC 9003) gas chromatograph in the field laboratory. The detailed configuration was described previously (Wagner et al. 2000).

## 3.3 Preliminary results

In contrast to the vegetation period in 1999, which was unusually hot and dry, the summer 2000 was colder and a higher precipitation rate were typical. Therefore, the polygon center was still water-filled at the end of summer 2000. As a result the methane emission from the polygon center of wet tundra showed higher values between 51 and 89 mg $CH_4$ $d^{-1}$ $m^{-2}$, which was 2 to 4 times higher than in August 1999. The dryer polygon border had a relatively constant rate with an average of 4.2 mg $CH_4$ $d^{-1}$ $m^{-2}$ (Figure 3-1b).

Just like in the last year, the maximum thaw depth of the permafrost soil was reached in August 2000: The thaw depth of the center was in average 28 cm and the border had a depth of about 38 cm (Figure 3-1a).

The redox potential of the center and the bottom layer of the border decreased after the redox electrode installation and reached a constant rate of about -100 mV after 7 days. The redox potential of the top layer of the border, which was dry compared with the bottom layer, was relatively high with about +350 mV (Figure 3-1c).

The investigation of in situ activity of methanogenic archaea showed $CH_4$ production at the bottom of the active layer with temperatures of about 1 °C (Figure 3-2). The vertical profile of in situ $CH_4$ formation and soil temperature of the polygon border showed a $CH_4$ production rate between 0.18 and 1.01 nmol $CH_4$ $h^{-1}$ $g^{-1}$ (Figure 3-3). In contrast to the polygon center with the highest production rates in the top layer, the border showed only in the bottom layers $CH_4$ formation. The monitoring of redox potential indicated that only the bottom layer of the border provided $CH_4$ production whereas the positive Eh values of the top layer were outside the range of natural $CH_4$ producing environments.

The first results of the ice wedge sampling from different geomorphological levels of the Lena Delta are shown in the following table (Table 3-2).

**Table 3-2:** Summary of the ice wedge properties from different geomorphological levels of the Lena Delta.

| Terrain type | Sampling hight* | No. | $CH_4$ concentration [ppm] average | max. | min. | Coefficient of variability | $CH_4$ content [ml $dm^{-3}$] | Air volume [%] |
|---|---|---|---|---|---|---|---|---|
| Flood-plain | 4.5-5.0 | 8 | 300 | 445 | 82 | 0.5 | 0.04 | 12.5 |
| Fluvial terrace | 4.0-7.5 | 44 | 700 | 1886 | 91 | 0.7 | 0.06 | 8 |
| Alas | 6.5 | 10 | 2200 | 4350 | 600 | 0.5 | 0.15 | 7 |
| Interalas | 30-35 | 88 | 2200 | 4984 | 125 | 0.7 | 0.15 | 7 |

* the altitude is given in meter about see level

The average $CH_4$ concentration in undisturbed ice samples of different ice wedge generations varied significantly from 0.05 to 0.15 ml $dm^{-3}$ of ice. Small $CH_4$ concentrations were observed in ice wedges of the high flood plain with an average value of about 300 ppm $CH_4$. The highest values were obtained from ice wedges of the third terrace. The $CH_4$ concentration was more than 3000 ppm (maximum 4984 ppm $CH_4$). High values (about 2000 ppm $CH_4$) were also obtained from Alas deposits of the first terrace (Kurangakh Island). The average value of the $CH_4$ concentration was about 700 ppm on the first terrace of the Lena delta, Samoylov (Figure 3-4). The decreasing of $CH_4$ in young ice wedges in contrast to old ones can interpreted to the climatic change after the Holocene optimum.

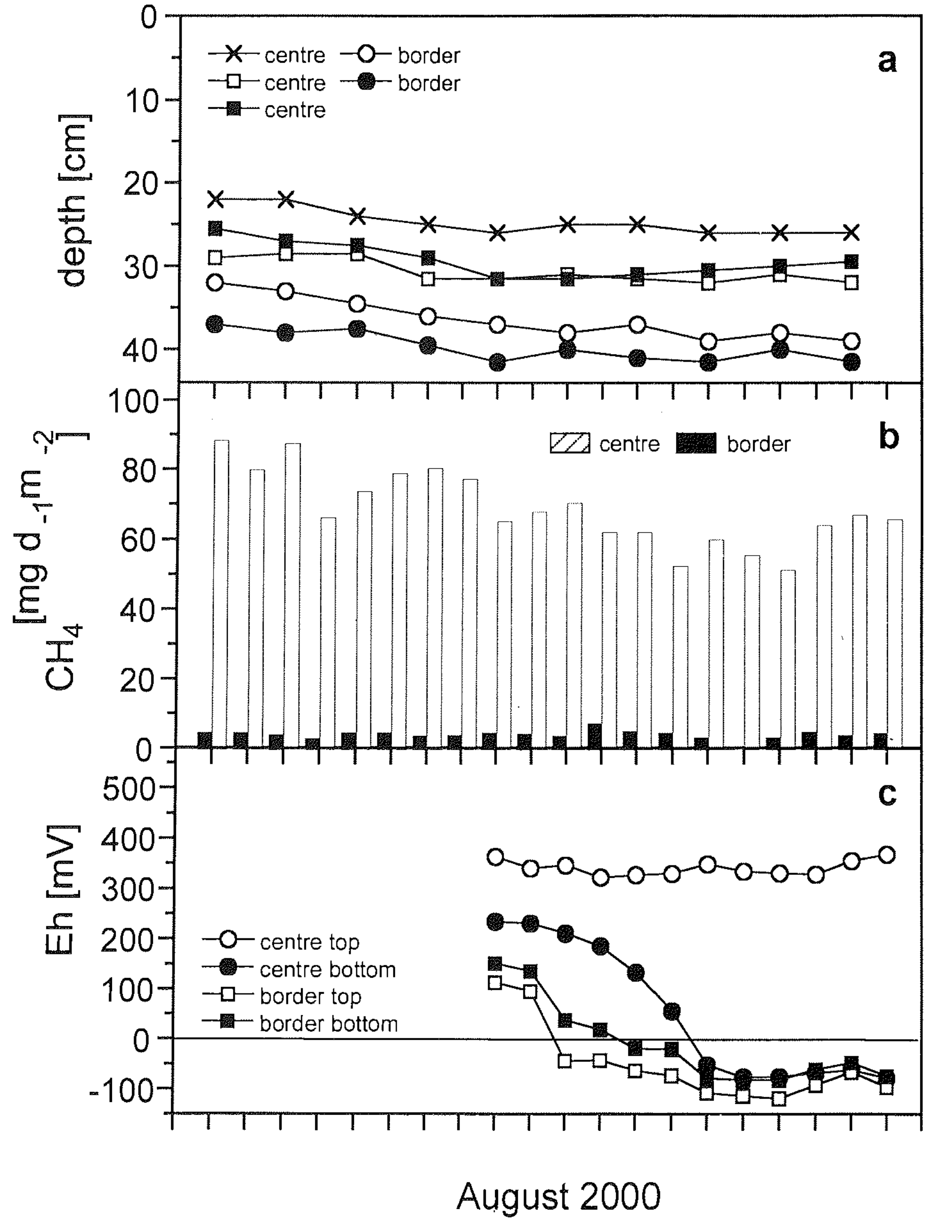

**Figure 3-1:** Thaw depth (a), $CH_4$ emission (b) and redox potential (c) of a low center polygon (center and border) in late summer August 2000.

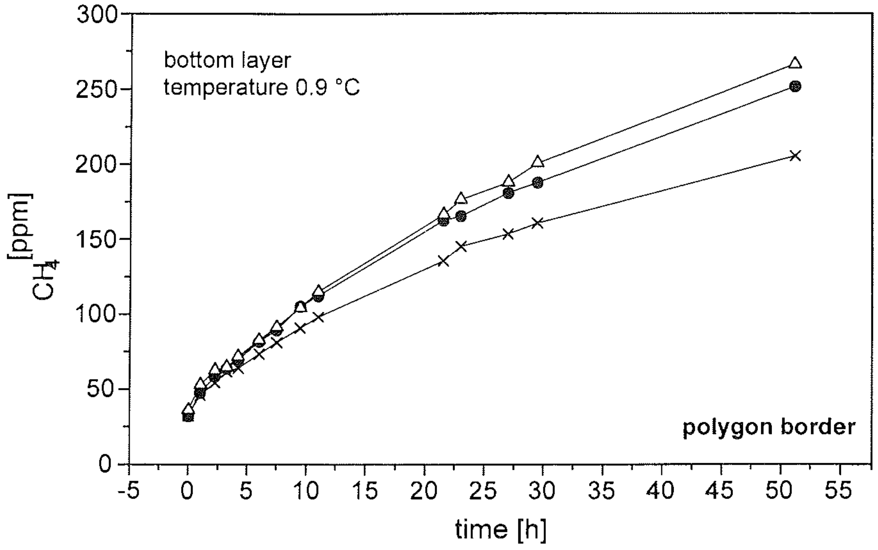

**Figure 3-2:** In situ methane production (3 replicates) of the bottom zone of the active layer for the polygon border (low temperature activity).

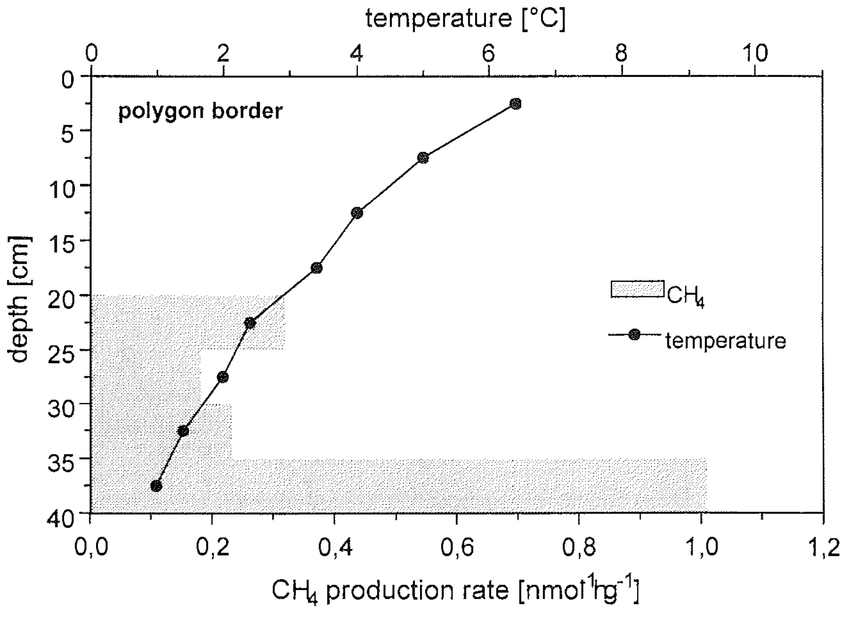

**Figure 3-3:** Vertical profile of in situ methane production and soil temperature for the polygon border.

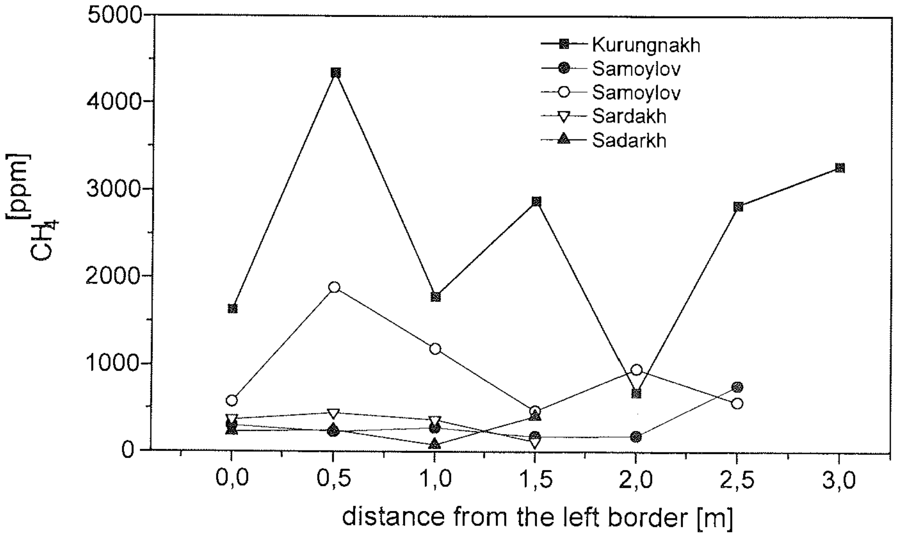

**Figure 3-4:** Methane concentration in the Holocene ice wedges.

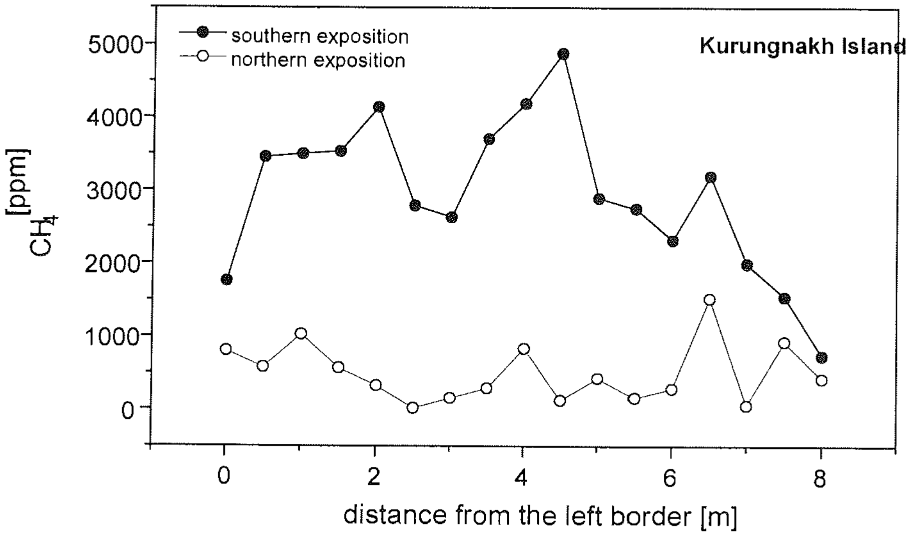

**Figure 3-5:** Methane concentration in the ice complex from Kurungnakh island.

The results of $CH_4$ determination have shown considerable variations of $CH_4$ in the same ice wedge and between ice wedges of the same generation (coefficient of variability was 0.5 to 0.7). The higher $CH_4$ concentration in the ice wedge in southern exposition compared to the wedge in northern exposition was probably caused not only by different conditions of formation but also by ice metamorphism in the active temperature layer (Figure 3-5).

## 3.4 Further investigations

The soil related investigations contribute to the understanding of the modern processes of the sensitive ecosystems. They lay the foundation to estimate the impact on possible global climate changes.

The studies will be continued with the fresh soil material and the water samples from the Lena 2000 Expedition. Especially the analyses of the organic carbon pools, the isotopic composition of methane gas samples and soil organic matter and the phospholipid fatty acid profiles are still in progress. Furthermore, the isolation and characterization of methanotrophic and methanogenic microorganisms which are adapted to the low in situ temperature is an time-consuming process, which have to go on in 2001.

The expected results represent the necessary database for further investigations like studies on permafrost associated gas hydrates or special research about the adaptation strategies and long-term survival of microorganisms in extreme habitats.

## 3.5. Comparative botanical recent-studies in the Lena Delta

*(F. Kienast, J. Tsherkasova)*

### 3.5.1. General introduction

Several times the vegetation of the Laptev shelf region was subject to radical environmental changes during the Late Quaternary. The recent vegetation complex[1] is a mirror for the arctic environment because the occurrence of any plant is linked with the availability of favourable living conditions. That means that every plant can only live within a certain tolerance range, which depends on the genetic adaptation of the species. Vice versa, the occurrence of a certain plant indicates the existence of certain environmental conditions, enduring for the plants lifetime (bioindication). This relationship is used in the reconstruction of the Laptev shelf region environment during the last glacial cycle by studying botanical macro remains. However, these results depend firstly on the reliability of the carpological determinations and secondly on the knowledge of the ecological requirements of identified taxa.

The main objective of the botanical part of the Laptev 2000 expedition was to improve both preconditions. The determination of fossil plants by means of their seeds and fruits is only feasible by comparing them with recent seeds. But a great number of seeds and fruits of arctic Siberian plants are not available in the collection of the Museum of Natural Sciences Berlin, which is used for comparisons. We therefore focussed on:

- the sampling of seeds and fruits from different sites especially of plants restricted to Siberia;
- the identification of different plant communities, characterized by certain species combinations, which indicate environmental conditions for each site;
- the comparison of different sites concerning both the botanical spectrum and the ecological parameters;
- the comparison of ecological requirements of the determined species with data from literature;
- the morphological and carpological comparison of closely related species.

Many arctic plants in particular tend to hybridize with close relatives. Most of the cold-adapted plants are very young in a phylogenetic sense (the Pleistocene did not begin earlier than 3,5 mio years ago) and the evolutionary process is still running. It is for instance impossible to determine the plants carpologically up to the species-level within the genera *Draba*, *Stellaria* and *Cerastium* and in the section *Scapiflora* of the genus *Papaver*.

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[1] Vegetation complex: entirety of a texture of plant communities in an area in which these constitutionally reflect the diversity of biological environmental effects. The distribution of plant communities is mosaic-like differentiated according to the sites conditions

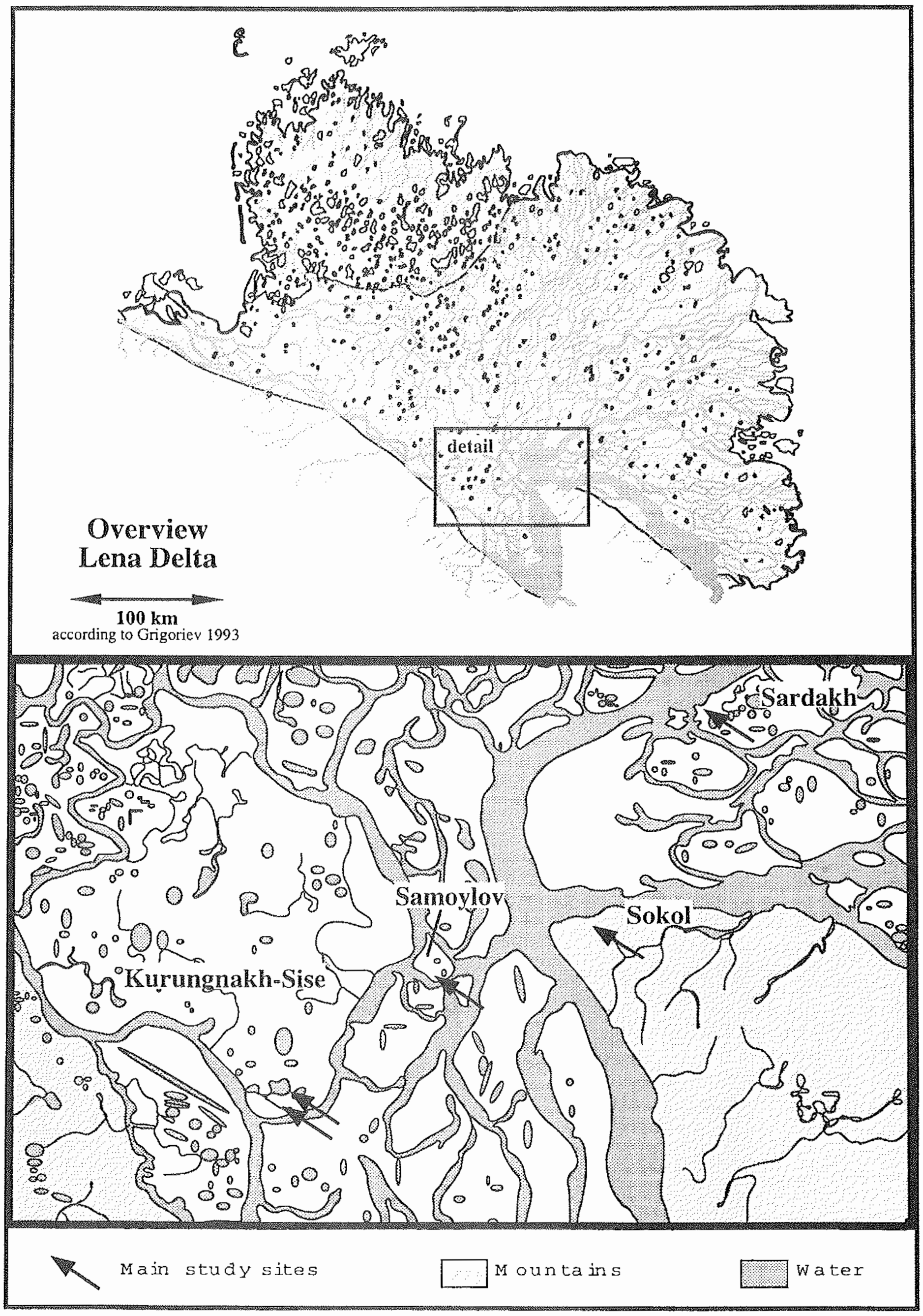
We focused on those taxa, which occur very often in fossil records and which indicate conditions typical for the Pleistocene, mainly occupants of dry habitats.

Plant-sociological descriptions were made only in Europe up to now. Many Siberian plant associations have no counterpart in Europe. That is why we limited the determination of plant communities to the level of classes, because the amount of plant sociological records, made during this expedition, is not sufficient for the specification of new (unknown) associations.

Unfortunately only a restricted amount of literature for the determination of Siberian plants was available. Without these keys we could not determine such important taxa like Poaceae, Cyperaceae or *Salix*. But we took specimen of these taxa from each study site. They are still waiting for their identifikation.

### 3.5.2. Study area

The main study area was situated in the central southeastern part of the Delta within the subarctic tundra zone along the Olenyok-channel (Figure 3-6). According to Aleksandrova (1980) the study area belongs to the East Siberian province of the subarctic tundras. Botanical records were made on the islands Samoylov, Kurungnakh-Sise, Sardakh-Aryta and Stalin, which belong to the Yana–Indigirka subprovince as well as on the headland Sokol belonging to the Kharaulakh subprovince of the East Siberian province of the subarctic tundras. Additionally a record was made in the surroundings of Tiksi.



according to Grigoriev 1993

**Figure 3-6:** The study area of the expedition Lena 2000 and the main study sites in detail.

### 3.5.2.1.Investigation site Samoylov

The only record on the island Samoylov (precise site description in Pfeiffer et al. 1999) was made on a coastal site in the SW very close to our encampment. The site was situated on the top of terrace 4. Alluvial permafrost (regosol) consisting of fine sand was very well drained. The site was quite windswept but the soil surface became well heated at sunshine.

Regardless of frequent anthropogenic disturbances (the ground was frequently trodden) the vegetation was very diverse even though the coverage was sparse. Depending on the degree of anthropogenic impact different successional stages were developed. Pioneer plants typical for dry, coarse substrates are compiled within the class Koelerio-Corynephoretea which is common in dry, steppe-like meadows:

*Artemisia borealis*
*Artemisia tillesii*
*Salix glauca*
*Rumex graminifolius*
*Rumex arcticus*
*Taraxacum macroceras*
*Astragalus subpolaris*
*Astragalus frigidus*
*Oxytropis adamsiana*
*Androsace septentrionalis*
*Castilleja pallida*
*Tanacetum bipinnatum*
*Sanguisorba officinalis*

**Figure 3-7:** Myosotis alpestris ssp. asiatica is characteristic for dry sites in the Arctic.

The arctic-alpine ruderal community Thlaspitea rotundifoliae is plant-sociologically closely related to the former one and contains the species:

*Papaver angustifolium*
*Armeria maritima*
*Minuartia arctica*
*Polemonium boreale*
*Polygonum viviparum*
*Parrya nudicaule*
*Luzula confusa*

By the species composition of the plant community Carici rupestris-Kobresietea the close relation of this special site to the Pleistocene tundrasteppe, which mainly consisted of Carici rupestris-Kobresietea is proved:

*Dryas punctata*
*Saussurea alpina*
*Myosotis alpestris ssp. asiatica*
*Lloyodia serotina*
*Hedysarum arcticum*

Some metres distant from the cliff the soil became slightly moist.

The following species lead over to the fen vegetation Scheuchzerio-Caricetea nigrae in moist places:

*Parnassia palustris ssp. neogaea*
*Pedicularis sceptrum-carolinum*
*Stellaria palustris*

### 3.5.2.2. Investigation site Kurungnakh-Sise/ Southend

The main study area during the expedition was the island Kurungnakh-Sise – a big island to the west of our encampment-site Samoylov (Figure 3-6), showing all types of habitats found within the Lena Delta.

Several vegetation records were mainly made in extrazonal sites such as shores of thermokarst lakes, mountain tundras and first of all dry banks at rivers and thermokarst valleys. These habitats were particularly interesting for us due to their increased species diversity and the high proportion of pioneer plants, which occurred more prevalent during the Pleistocene.

The first record on this Island was made along the shore of a thermokarst lake on August 3 (Figure 3-8). The main substrate was peat and the active layer was only about 25 centimetres thick. Because of the isolating effect of the organic layer only the uppermost 5 centimetres of the soil were heated. Various associations were recognized.

**Figure 3-8:** Riperian vegetation on a thermokarst lake on Kurungnakh Sise.

The first species combination contained riperian plants and mediated between Phragmitetea and Scheuchzerio-Caricetea:

*Hippuris vulgaris*
*Carex aquatilis ssp. stans*
*Polemonium acutiflorum*
*Stellaria palustris*
*Polygonum bistorta*
*Rumex arcticus*
*Poales indet.*
*Comarum palustre*
*Saxifraga hirculus*
*Eriophorum scheuchzeri*
*Saxifraga nelsoniana*

More distant from the shore-line the species composition gradually changes into Oxycocco-Sphagnetea and at dry places to Vaccinio-Juniperetea. We found:

*Rubus chamaemorus*
*Betula exilis*
*Vaccinium vitis idaea*
*Pyrola minor*
*Salix spec.*
*Polygonum viviparum*
*Draba juvenilis*
*Valeriana capitata*
*Saxifraga cernua*

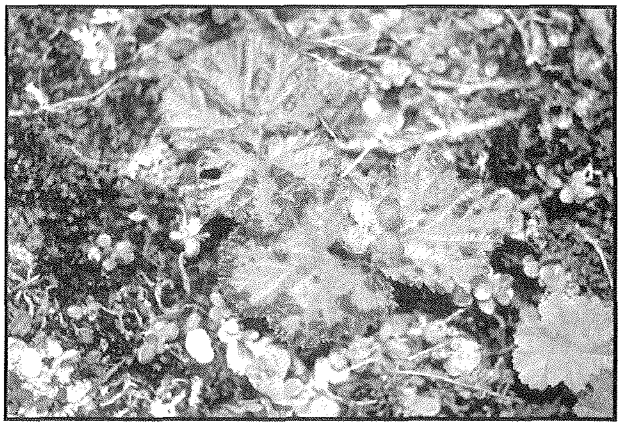


**Figure 3-9:** *Rubus chamaemorus* is a representative of the fen association Oxycocco-Sphagnetea. The small ovate leaves belong to *Vaccinium vitis-idaea.*

The other association was situated on a mound, up to two meters high, close to the northern shoreline of the lake. It seemed to be favoured by solar radiation (and thus heat supply) due to the reflection of the water surface. Furthermore, the site was well drained. Consequently the vegetation cover was very lush. The following species represent the association Ledo-Sphagnetum fusci within the class Oxycocco-Sphagnetea.

On the top of the mound the Dryado-Cassiopetum tetragonae of the class Carici rupestris-Kobresietea formed up.

**Oxycocco-Sphagnetea:**
*Betula exilis*
*Ledum palustre*
*Vaccinium vitis idaea*
*Rubus chamaemorus*
*Polygonum bistorta*
*Saxifraga nelsoniana*
*Pyrola minor*

**Dryado-Cassiopetum tetragonae**
*Dryas punctata*
*Cassiope tetragona*
*Saussurea alpina*
*Salix spec.*

At its eastern slope along a very steep thermoerosion valley the next record was made on August 5 (Figure 3-10). The substrate was fine sand. Because of the steepness the vegetation cover was strongly disturbed by soil erosion and solifluction. Depending on the varying steepness of the surface and its distance to the permafrost plate the moisture conditions ranged between well drained and wet. The slope was exposed to the southwest and strongly heated near the surface during sunny weather.

The vegetation consisted of xerophilous disturbance indicators and may be assigned to Thlaspitea rotundifolia.

*Draba hirta*
*Descurainia sophioides*
*Artemisia tillesii*
*Matricaria hookeri*
*Cerastium jenissejense*
*Cochlearia arctica*
*Gastrolychnis apetalum*
*Saxifraga cernua*
*Papaver polare*
*Stellaria spec.*

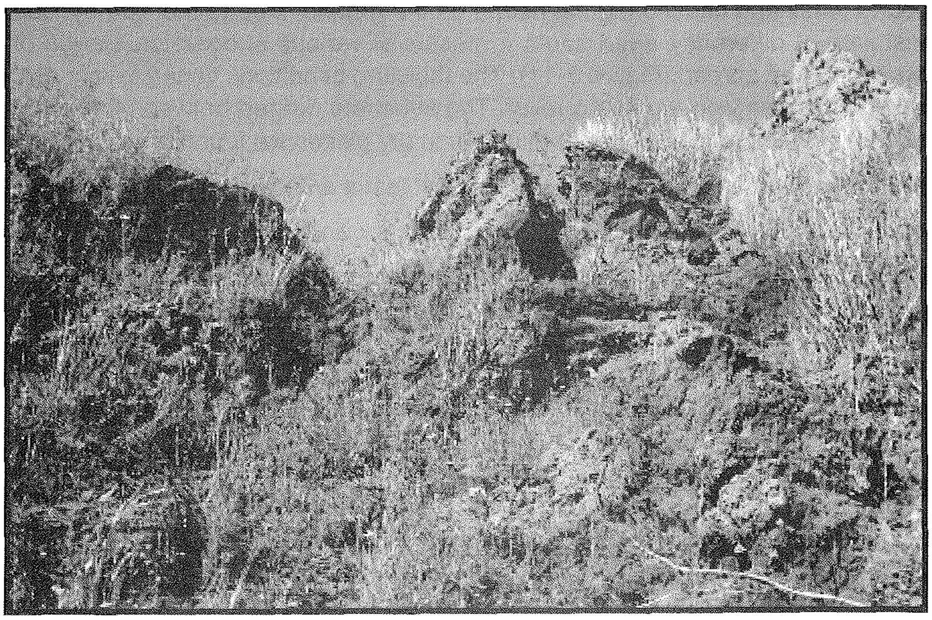


**Figure 3-10:** The steep slope of a thermoerosion valley studied in August 5.

*Senecio congestus* grew at unvegetated wet sites near melting water runoff in contrast to the plants mentioned above and is characteristic for floodplains.

Somewhat higher the slope was no longer steep and, thus, the vegetation became more closed. An older succession stage was developed. Wet conditions predominated.

The species composition ranged between Thlaspitea rotundifolia on dry sites represented by

*Cochlearia arctica*
*Cerastium regelii*
*Delphinium middendorfii*
*Myosotis alpestris*
*Saxifraga cernua*
*Polemonium boreale*
*Artemisia spec.*

and fen vegetation of Scheuchzerio-Caricetea and Oxycocco-Sphagnetea in the wet depression:

various *Salix*

*Saxifraga hieracifolia*

*Saxifraga hirculus*

*Eriophorum scheuchzeri*

*Betula exilis*

*Saxifraga nelsoniana*

*Chrysosplenium alternifolium*

*Caltha palustris*

August 11: A spotty tundra was investigated a few hundred meters off the former site. Soil pulp was squeezed out of frost cracks during refreezing of the ground in fall and caused big flat heaps on the ground. Due to the side by side existence of differently aged spots a mosaic of various succession stages of vegetation was spread (Figure 3-11). The moisture conditions varied from mesic to wet, depending on the micro-relief. The substrate ranged between fine sand and silt. Pioneer vegetation predominated. In dry places we found:

*Descurainia sophioides*

*Draba hirta*

*Stellaria peduncularis*

*Saxifraga cernua*

*Lychnis samojedorum*

*Stellaria amblyosepala*

*Cochlearia arctica*

*Stellaria ciliatosepala*

*Cerastium regelii*

*Myosotis alpestris ssp. asiatica*

*Rumex arcticus*

*Eutrema edwardsii*

Among the heaps the soil was moist. Following wetland plants covered these places.

*Eriophorum scheuchzeri*

*Stellaria humifusa*

*Carex stans (arctisibirica)*

*Senecio congestus*

August 14: The next investigated site was a dune-like steep slope, situated very close to the outflow of the thermoerosion valley into the Lena, described above. It consisted of sands and was exposed to the northwest. Its vegetation cover was very sparse due to soil erosion and lack of moisture (Figure 3-12). The species composition mediated between psammophilous pioneers such as

*Tanacetum bipinnatum*

*Equisetum arvense*

various *Poaceae*

*Delphinium middendorfii*

*Artemisia borealis*

and the arctic-alpine ruderal community Thlaspitea rotundifoliae

*Salix spec.*

*Stellaria edwardsii* *Papaver spec..*

*Polemonium boreale*

**Figure 3-11:** Spotty tundra on Kurungnakh. At the left side there is a soil heap surrounded by different successional stages.

Opposite this slope there was a site with quite similar environmental conditions. Nevertheless the appearance of the vegetation differed strongly. The only ecological contrast was the southward exposition of the slope.

*Dryas punctata* predominated absolutely whereas it was absent on the site described before. It covered more than 75% of the minimum area[2] (Figure 3-13). All other plants occurred solitary or in very small tufts.

Regardless its different appearance the ecological indication of the vegetation corresponded to the former site, because all species were either psammophilous pioneers of communities within Koelerio-Corynephoretea like

| | |
|---|---|
| *Artemisia spec.* | *Androsace septentrionalis* |
| *Lychnis villosula* | *Rumex acetosella* |
| *Saxifraga cespitosa* | *Rumex graminifolius* |

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[2] The minimum area contains the entire characteristic species combination of the association.

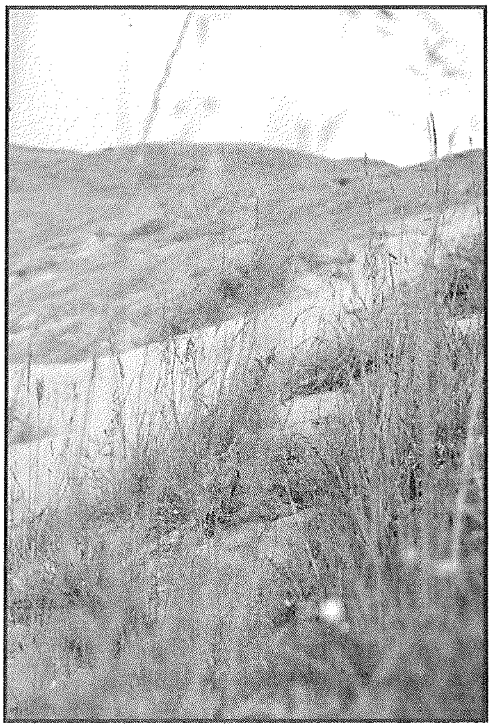

**Figure 3-12:** The dune-like slope, investigated in August 14. *Delphinium middendorfii* is situated in the centre of the image.

or representatives of Thlaspitea rotundifoliae and Carici rupestris-Kobresietea respectively, such as:

*Dryas punctata*

*Minuartia rubella*

*Lloydia serotina*

*Delphinium middendorfii*

*Polygonum viviparum*

*Salix spec.*

*Valeriana capitata*

*Cerastium regelii*

*Draba parvisiliquosa*

*Poaceae indet*

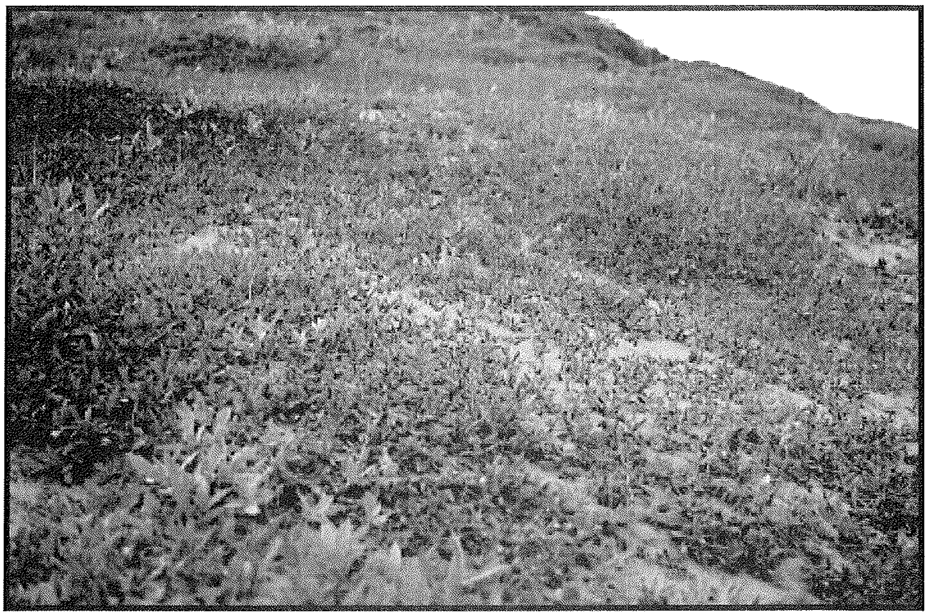

**Figure 3-13**: The dense cover of Dryas punctata on the southern exposed slope.

Another southern exposed slope not far from the site described admittedly before was recorded on August 19th (Figure 3-14).

It was a steep and thus well-drained bank of another thermoerosion channel with various substrates. The cover of vegetation decreased from top to bottom and consisted one more time of plant communities belonging to Koelerio-Corynephoretea as well as Thlaspitea rotundifoliae.

**Koelerio-Corynephoretea:**

*Androsace septentrionalis*

*Equisetum arvense*

*Artemisia spec.*

*Lychnis villosula*

*Delphinium middendorfii*

*Saxifraga hieracifolia*

*Polemonium boreale*

*Taraxacum macroceras*

various *Poaceae*

**Thlaspitea rotundifoliae:**

*Cerastium regelii*

*Draba hirta*

*Draba parvisiliquosa*

*Papaver angustifolium*

*Polygonum viviparum*

*Arabis petraea ssp. umbrosa*

*Stellaria crassifolia*

*Pedicularis spec.*

*Luzula confusa*

various *Salix*

**Figure 3-14:** The vegetation covering the top of the slope was recorded on August 19.

At the bottom of the slope the vegetation became patchy and the following pioneer plants became prevalent.

*Lychnis sibirica*
*Minuartia rubella*
*Myosotis alpestris*
*Lychnis villosula*
*Dryas punctata*
*Armeria maritima*

Within a short distance there was a similar plant association differing only in the older successional age of the vegetation. The sandy soil surface was more or less stabilized by the plant cover.

*Dryas punctata* was the absolutely predominating plant, covering more than 75% of the minimal area accompanied by *Salix* spec. (Figure 3-15). Thus the spectrum turned slightly to Carici rupestris-Kobresietea, even though Koelerio-Corynephoretea and Thlaspitea rotundifoliae were still prevalent.

*Salix spec.*
*Dryas punctata*
*Rumex graminifolius*
*Armeria maritima*
*Polygonum viviparum*
*Stellaria crassifolia*
various *Poaceae*
*Minuartia rubella*
*Pavaver angustifolium*
*Lychnis samojedorum*
*Draba hirta*
*Draba pilosa*
*Juncus castanaeus*
*Lloydia serotina*
*Pedicularis spec.*
*Equisetum arvense*
*Valeriana capitata*
*Dianthus repens*

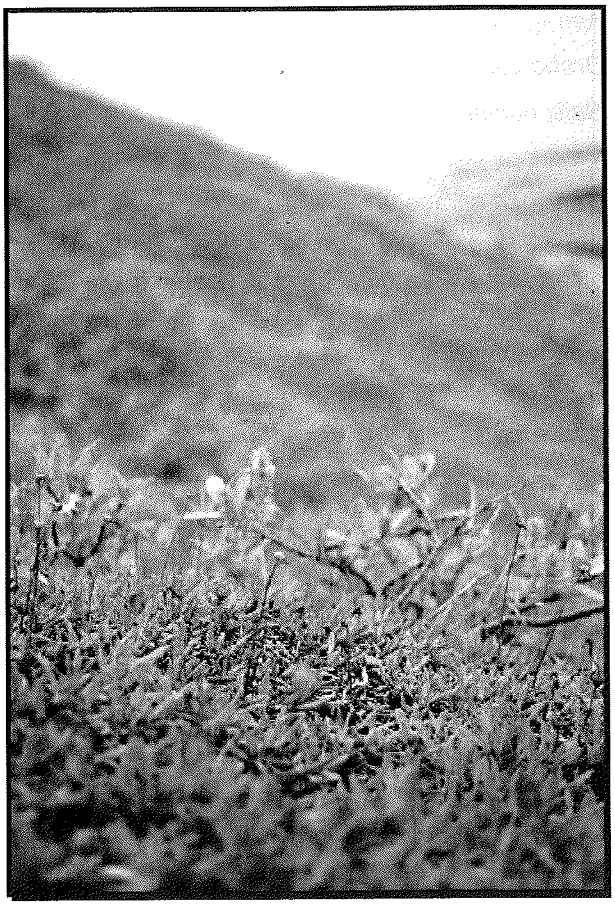

**Figure 3-15:** Carici rupestris-Kobresietea, often characterized by the predominance of *Dryas punctata,* is the climax stage of vegetational development on dry sites of the Arctic.

### 3.5.2.3. Investigation site Sardakh

At the top of a bluff at the NW coast of the island Sardakh-Aryta (72° 30' N, 127° 3' E) (location see Figure 3-6) a further plant sociological record was made (Figure 3-16). The investigated area was situated between 10 and 20 meters above the water level of the Lena.

The deposits above the bedrock were very thin and consisted of sand and rock debris. Accordingly the drainage conditions were very favourable. Thus the vegetation consisted again of Koelerio-Corynephoretea and Thlaspitea rotundifoliae:

| | |
|---|---|
| *Dryas punctata* | *Papaver* |
| *Saxifraga cernua* | *Artemisia subarctica* |

*Astragalus frigidus*
*Draba subcapitata*
*Salix nummularia*
*Valeriana capitata*
*Cassiope tetragona*
*Draba pauciflora*
*Polygonum viviparum*
*Myosotis alpestris ssp. asiatica*
*Armeria maritima*
*Oxyria digyna*

But its character was distinctly shifted into alpine, because the NW exposition effected adverse conditions concerning wind and solar radiation. Anyhow the species diversity was very high. The following plants were for instance alpine geoelements:

*Novosieversia glacialis*
*Minuartia arctica*
*Cardamine bellidifolia*
*Petasites glacialis*
*Minuartia macrocarpa*
*Saxifraga spinulosa*
*Lagotis glauca*
*Parrya nudicaule*

The plants:

*Saxifraga hirculus*
*Chrysosplenium alternifolium*
*Saxifraga nelsoniana*
*Polygonum bistorta*
*Saxifraga hieracifolia*

indicated moist conditions in wet depressions. The moisture conditions changed rapidly within short distances.

**Figure 3-16:** The character of vegetation on the top of the cliff at the coast of the island Sardakh is distinctly arctic-alpine.

### 3.5.2.4. Investigation site Sokol

The headland Sokol is the northernmost foothill of the Khara-Ulakh mountains- a promontory of the Verchoyansk mountain chain. Even though the altitude of the study area was not higher than about 60 meters above the Lena level the character of vegetation was distinctly arctic-alpine. The investigated windswept slope was exposed to northeast. The bedrock was only 10-20 cm covered by sediments.

At this site we met a real alpine-tundra (Figure 3-17) with the following species:

*Novosieversia glacialis*
*Oxytropis adamsiana*
*Rhododendron adamsii*
*Crepis spec.*
*Pedicularis hirsuta*
*Tofielda coccinea*
*Vaccinium uliginosum*
*Lychnis villosula*
*Oxytropis nigrescens*
*Cassiope tetragona*
*Dryas punctata*
*Polygonum viviparum*
*Pedicularis labradorica*
*Saxifraga opposotifolia*
*Pinguicola algida*
*Saussurea tillesii*

**Figure 3-17:** *Oxytropis nigrescens* grows exclusively in mountain tundras of NE-Siberia

### 3.5.2.5. Investigation site Peak Stalin

The study site mediated between the mountain slope of Sokol and the cliff of Sardakh concerning both the ecological factors and the species composition.

*Dryas punctata*
*Saussurea tillesii*
*Papaver czekanowskii*
*Myosotis alpestris*
*Saxifraga hirculus*
*Saxifraga spinulosa*
*Saxifraga hieracifolia*
*Oxytropis adamsiana*
*Valeriana capitata*
*Delphinium middendorfii*
*Minuartia arctica*
*Stellaria peduncularis*
*Salix nummularia*
*Papaver angustifolium*
*Polygonum viviparum*
*Saxifraga nelsoniana*
*Saxifraga cernua*
*Saxifraga platysepala*
*Astragalus spec.*
*Oxytropis nigrescens*
*Novosieversia glacialis*
*Crepis chrysantha*
*Ledum palustre ssp. decumbens*
*Draba alpina*

The site was characterized by a great number of species of *Saxifraga* among other mountain tundra representatives.

**Figure 3-18:** Mountain tundra on Peak Stalin. Above all *Dryas punctata* and *Oxytropis nigrescens* predominated in the cover among various *Saxifraga* species.

### 3.5.2.6. Investigation site gravel slope near Tiksi

A gravel stope, situated in the south of Tiksi, yielded a very interesting plant community. Due to the coarse substrate the site was very well drained and thus extremely dry. Because of its dark colour the gravel must have been very well heated by solar radiation. The vegetation cover was very patchy due to the gravel mining and the gradient-caused erosion. But the plant community contained some interesting thermophilous components (Figure 3-19).

*Cerastium jenissejense*
*Minuartia arctica*
*Stellaria edwardsii*
*Artemisia sericea*
*Androsace gorodkovii*
*Dryas punctata*
*Minuartia macrocarpa*
*Saxifraga spinulosa*
*Potentilla nivea*
*Rhodiola rhosea*
*Novosieversia glacialis*
*Lychnis sibirica*

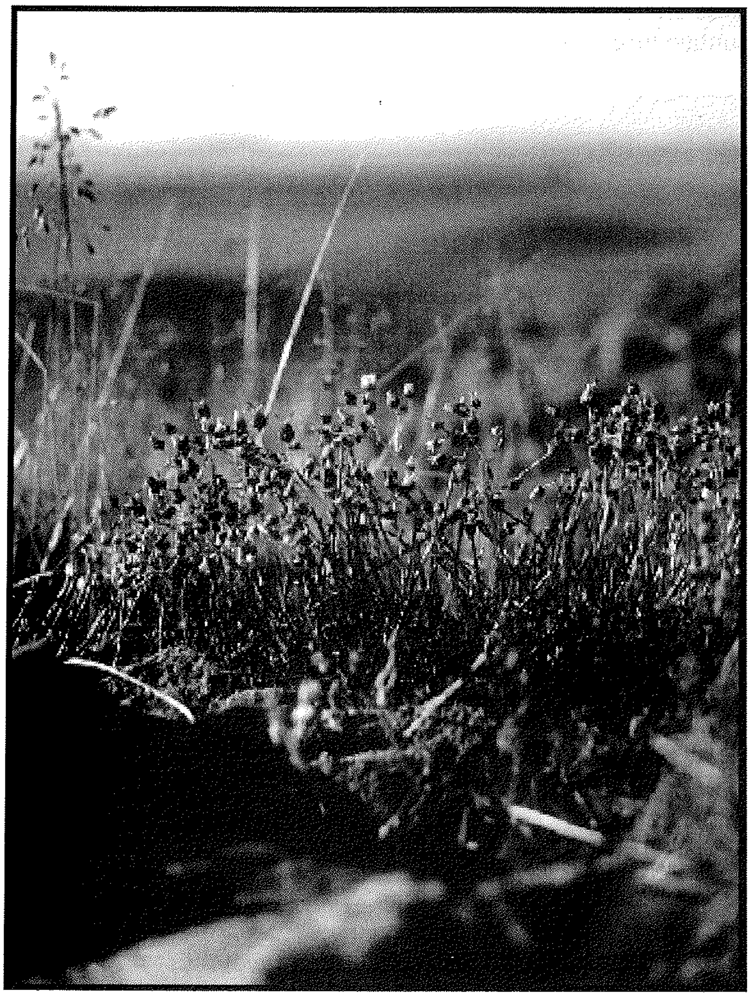

**Figure 3-19:** Saxifraga spinulosa had already finished its growing season at the gravel slope near Tiksi distinctly earlier than at the former investigated sites within the Delta.

It was very conspicuous that the seed maturation of the most plants was already finished. The plants seemed to be in better constitution than relatives living in the Lena Delta. These phenological particularities beside the occurrence of thermophilous plants point also to favourable living conditions at this site.

This plant community probably corresponds to the European Rhodiolo roseae-Saxifragetum cotyledonis or the Sedo-Saxifragetum, which covers detrital slopes.

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## 3.7 Appendix

**Table A3-1:** List of samples

| Numbers | Samples | Further Analyses |
|---|---|---|
| LD00 6488-6506 | water samples | geochemical[1] |
| LD00 6507-6511 | water samples | DOC* |
| LD00 6512-6519 | water samples | geochemical |
| LD00 6520-6525 | soil samples, soil extracts | geochemical, microbiological[2], DOC |
| LD00 6526-6537 | water samples | geochemical |
| LD00 6538 | gas sample | $^{13}C$ |
| LD00 6539-6544 | soil samples | geochemical, microbiological |
| LD00 6545-6552 | soil samples, soil extracts | geochemical, microbiological, DOC |
| LD00 6553-6569 | water samples | geochemical |
| LD00 6570-6574 | water samples | DOC |
| LD00 6575 | gas sample | $^{13}C$ |
| LD00 6576-6585 | soil samples | geochemical, microbiological |
| LD00 6586-6590 | soil samples | geochemical, microbiological |
| LD00 6591-6596 | soil samples | geochemical, microbiological |
| LD00 6597-6624 | soil samples | geochemical, microbiological |
| LD00 6525-6532 | water samples | geochemical |
| LD00 6633-6637 | water samples | DOC |
| LD00 6638-6652 | water samples | geochemical |
| LD00 6653-6679 | gas samples | $^{13}C$ |

[1] geochemical analyses: e.g. carbon and nitrogen, Fe and Mn, cations, pH

[2] microbiological analyses: e.g. potential $CH_4$ production activity, fluoreszence in situ hybridisation, phospholipid analysis, enrichment and characterization of microbes

*DOC = dissolved organic carbon

**Table A3-2:** List of collected seeds

| Family | Genus | Species | Origin |
|---|---|---|---|
| Asteraceae | Artemisia | borealis | Samoylov |
| | Artemisia | sericea | Tiksi gravel stope |
| | Petatitis | glacialis | Sardakh |
| | Saussurea | tillesii | Sokol |
| | Senecio | congestus | Kurungnakh |
| | Tanacetum | bipinnatum | Samoylov |
| Betulaceae | Betula | exilis | Kurungnakh |
| Boraginaceae | Myosotis | alpestris ssp. asiatica | Kurungnakh |
| Brassicaceae | Arabis | petrea ssp. umbrosa | Kurungnakh |
| | Cardamine | bellidifolia | Sardakh |
| | Coclearia | arctica | Kurungnakh |
| | Descurainia | sophioides | Kurungnakh |
| | Draba | alpina | Stalin |
| | Draba | hirta | Kurungnakh |
| | Draba | juvenilis | Kurungnakh |

**Table A3-2:** List of collected seeds (continued)

| Family | Genus | Species | Origin |
|---|---|---|---|
| | Draba | parvisiliquosa | Kurungnakh |
| | Draba | pauciflora | Sardakh |
| | Draba | pilosa | Kurungnakh |
| | Draba | subcapitata | Sardakh |
| | Eutrema | edwardsii | Kurungnakh |
| | Parrya | nudicaule | Samoylov |
| Caryophyllaceae | Cerastium | jenissejense | Tiksi gravel stope |
| | Cerastium | regelii | Kurungnakh |
| | Dianthus | repens | Kurungnakh |
| | Minuartia | arctica | Tiksi gravel stope |
| | Minuartia | arctica | Samoylov |
| | Minuartia | arctica | Sardakh |
| | Minuartia | macrocarpa | Sardakh |
| | Minuartia | macrocarpa | Tiksi gravel stope |
| | Minuartia | rubella | Kurungnakh |
| | Lychnis | samojedorum | Kurungnakh |
| | Lychnis | villosula | Kurungnakh |
| | Stellaria | ciliatosepala | Kurungnakh |
| | Stellaria | crassifolia | Kurungnakh |
| | Stellaria | edwardsii | Kurungnakh |
| | Stellaria | edwardsii | Tiksi gravel stope |
| | Stellaria | palustris | Kurungnakh |
| | Stellaria | peduncularis | Kurungnakh |
| Cyperaceae | Eriophorum | scheuchzeri | Kurungnakh |
| Ericaceae | Arctous | alpina | Stalin |
| | Cassiope | tetragona | Sardakh |
| | Rhododendron | adamsii | Sokol |
| | Vaccinium | uliginosum | Sokol |
| Fabaceae | Oxytropis | adamsiana | Stalin |
| | Oxytropis | nigrescens | Sokol |
| Juncaceae | Luzula | confusa | Samoylov |
| Lentibulariaceae | Pinguicola | algida | Sokol |
| Liliaceae | Lloydia | serotina | Kurungnakh |
| | Tofielda | coccinea | Sokol |
| Papaveraceae | Papaver | angustifolium | Stalin |
| | Papaver | czekanowskii | Stalin |
| Polemoniaceae | Polemonium | acutiflorum | Kurungnakh |
| | Polemonium | boreale | Kurungnakh |
| Polygonaceae | Oxyria | digyna | Sardakh |
| | Rumex | arcticus | Kurungnakh |
| Primulaceae | Androsace | gorodkovii | Tiksi gravel stope |
| | Androsace | septentrionalis | Kurungnakh |
| Ranunculaceae | Delphinium | middendorfii | Kurungnakh |

**Table A3-2:** List of collected seeds (continued)

| Family | Genus | Species | Origin |
|---|---|---|---|
| Ranunculaceae | Ranunculus | nivalis | Kurungnakh |
| | Ranunculus | pallasii var.minimus | Kurungnakh |
| | Ranunculus | turneri | Stalin |
| Rosaceae | Comarum | palustre | Kurungnakh |
| | Dryas | punctata | Kurungnakh |
| | Novosieversia | glacialis | Sardakh |
| | Potentilla | nivea | Tiksi gravel stope |
| | Rubus | chamaemorus | Kurungnakh |
| Salicaceae | Salix | nummularia | Sokol |
| Saxifragaceae | Chrysosplenium | alternifolium | Kurungnakh |
| | Rhodiola | rosea | Tiksi gravel stope |
| | Saxifraga | cernua | Kurungnakh |
| | Saxifraga | cespitosa | Kurungnakh |
| | Saxifraga | hieracifolia | Kurungnakh |
| | Saxifraga | hirculus | Samoylov |
| | Saxifraga | hyperborea | |
| | Saxifraga | nelsoniana | Kurungnakh |
| | Saxifraga | opposotifolia | Sokol |
| | Saxifraga | setigera | Stalin |
| | Saxifraga | spinulosa | Sokol |
| Scrophulariaceae | Lagotis | glauca | Sokol |
| | Pedicularis | hirsuta | Sokol |
| | Pedicularis | labradorica | Sokol |
| Valerianaceae | Valeriana | capitata | Kurungnakh |

# 4 Coastal Processes in the Laptev Sea and the Environmental History of the Lena Delta

## 4.1 Introduction

*(V. Rachold and M.N. Grigoriev)*

This chapter summarizes the field work of three individual working groups concentrating on coastal processes in the Laptev Sea, sedimentation processes in the Lena Delta and the sedimentation history of the Lena Delta.

The objective of the field work of **Team 2 a ("Neptun")** was to retrieve sensors that had been installed in the main channels of the Lena Delta and in the Tiksi Bay during the expeditions LENA 98 and 99 and since that time had recorded water level and temperatures.

> (➔ *Chapter 4.2: The measurement of water-level in the Lena Delta region: Preliminary results and frontiers of a multi-year study*)

The investigations of **Team 2 b ("Sofron Danilov")** focussed on coastal erosion and sediment accumulation along the coastline of the Lena Delta and the western Laptev Sea sector. The work program combined detailed geodetic measurements by a laser-theodolite, recording of bathymetric profiles, sampling of coastal sections and coastal marine sediments as well as measurements of water temperature.

> (➔ *Chapter 4.3: Coastal dynamics in the western Laptev Sea*)

**Team 4 ("Gusinka")** carried out paleogeographical investigations north of the Olenyokskaya Channel in the western part of the Delta.

> (➔ *Chapter 4.4: History of the relief formation of the western Lena Delta Sector in the late Pleistocene-Holocene*)

## 4.2. The measurement of water-level in the Lena Delta region: Preliminary results and frontiers of a multi-year study

*(M. Antonow)*

The Lena River drains large parts of the Siberian continent and discharges hugh amounts of particles, dissolved matter and fresh water, respectively. The manner in which the Lena River dumps the Spring meltwaters into the ice-covered Laptev Sea probably depends on the water depths in the very mouths of individual distributary channels and their ice-coverage. The Lena River can rise as much as 10 m above its normal level during break-up in June. A rising water-level might cause a rise in mean sea level in the coastal waters.

Tide gauges placed along several transects from inside the Lena River channels monitor water- and ice-level changes during several seasons of the year. This long-term monitoring (1998-2000) as well as the river break-up field study in 1996 should contribute some findings about Land/Sea interactions of this Russian Arctic environment. The investigations are limited by geographic and climatic conditions that offer striking disadvantages for the use of technical equipment.

The measurements were carried out using MINILOG-equipment by VEMCO Ltd. (Nova Scotia, Canada). The MINILOG-TD is a self-recording miniature data logger for temperature and pressure (water depth) at a user programmed time interval. This technology is described by Antonow et al. (1999).

### Sensor Deployments 1998-2000

A set of 9 individual sensors was moored along selected main channel transects. For detailed mooring positions and the in-situ water depths of the sensors see Rachold & Grigoriev (1999, p. 93) The TDR-sensors were moored at the river bottom and fixed by a 50 to 70 m long rope and ground weights of about 80 kg. The sample interval was 2 to 3 hours, which allowed a deployment time maximum of about three years. The minimum deployment depth of about 6 m should prevend an erosive destruction of the moored sensors by river ice during the break-up in Spring. Although, there was no doubt about the relocation of the mooring sites by significant landmarks, their GPS positions as well as the underwater landscape morphology, no one of these sensors was recovered during the Lena Delta 2000 expedition, unfortunately. The potential of transportation was much higher than the mooring construction and weights could resist. Incredible strong Lena river!

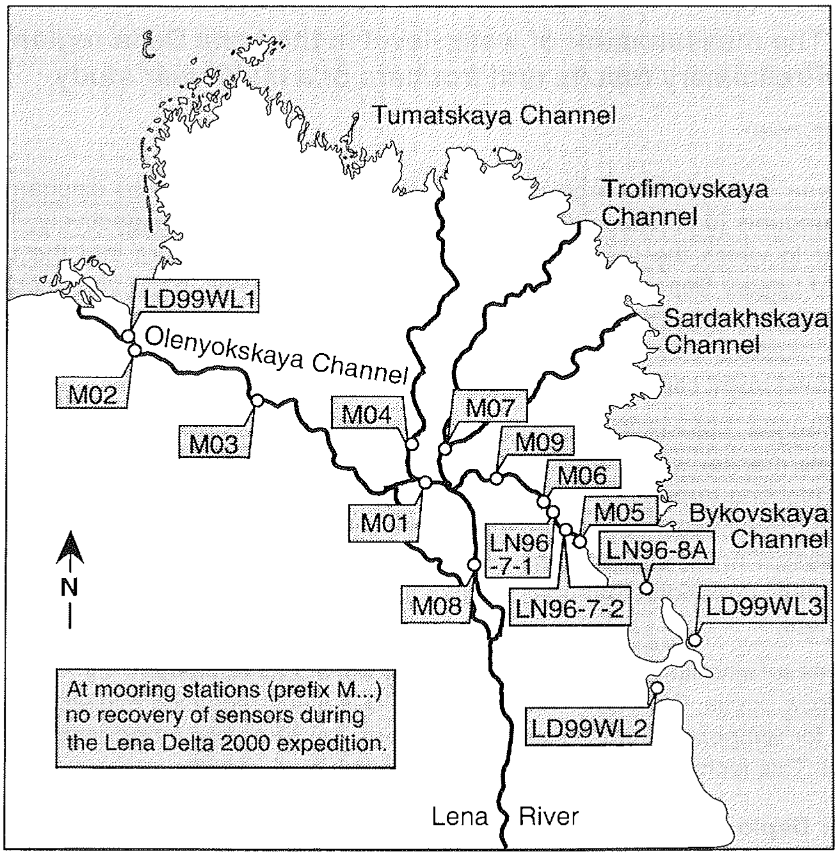
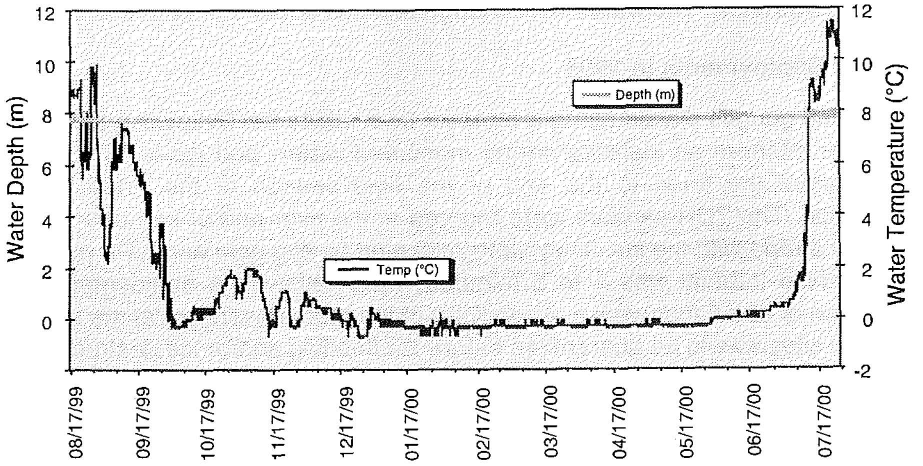


**Figure 4-1:** Geographic positions of all moored MINILOG-sensors from 1996-2000.

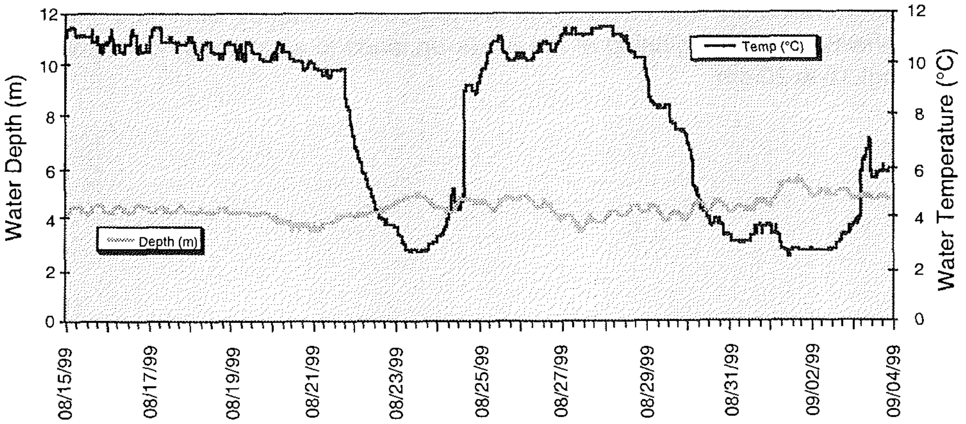
### Sensor Deployments in 1999

During August 1999 Pavlova et al. (2000) measured water-level oscillations of the Olenyokskaya channel (N 72°52.941', E 123°14.580'/ station LD99WL1). The 2-days-record was used for calibration of the gained Minilog data with absolute land marks. A tide influence of the Laptev Sea was documented by water level changes of about 40 cm in amplitude. Strong northerly and nortwesterly wind stress the sea waters that interact with the freshwater supply near the river mouth.

Beside this, one TDR-sensor (station LD99WL2) was moored in the Tiksi bay. Waldemar Schneider and colleagues fixed it on a submarine wrack of an ancient fisher boat south of the Tiksi port. The record represents a time period of nearly one year from August 1999 to July 2000. The data logger was deployed in a water depth of about 8 m with a measuring intervall of 2 hours. The tidal changes were only about 10 cm during the year. The change of temperature was much more significant. During autumn the shelf water cools down to zero but not below minus 1 degree of temperature during the winter time. At the beginning of June an abrupt water-level rise (up to 20 cm) is recorded due to the Lena river break-up. After this, the onset of thawing processes with coincident warm waters lead to a slightly increased water-level in the Tiksi bay region since the beginning of July.


71°38'N/128°57'E
Tiksi Bay/Station LD99WL2

The variation of water temperature and water-ice-level at station LD99WL2 (south of Tiksi port) from August 1999 to July 2000 (raw data).


71°52'N/129°23'E
Near Mamontovy Khayata/Station LD99WL3

The variation of water temperature and water-level at station LD99WL3 (off Bykovskaya peninsula) during August/Septmber 1999 (raw data).

**Figure 4-2:** The variation of water-level and temperatures.

A third Minilog sensor off the outcrop of Mamontovy Khayata near the Mamontovy Bulgunnyakh (Bykovskaya peninsula) revealed a 20-days-record during August and September of 2000. Moored in a water depth of more than 4 m the sensor detected tidal oscillations with a maximal amplitude of a half meter. The temperature curve exhibits negative excursions from values of 11 to 10 degrees down to about 3°C due to heavy summer storm events. Then, also an increase of the sea-level by catabatic winds is evident (see diagram of station LD99WL3). The water-level change reaches about 1.5 meters at all.

### Sensor Deployments in 1996

Three tide gauges placed along a transect from inside the Bykovskaya channel to as far offshore as logistics permit monitored water- and ice-level changes from before the flood to the end of the field season of the Transdrift IV expedition. The TDR-sensors were moored at the river and/or sea bottom and fixed by a rope with the ice. They were relocated by flag pole and GPS position. The sample interval was 4 to 5 minutes, which allowed a deployment time maximum of about four weeks. A recovery of the moored sensors at the still ice-covered sites was to be guaranteed before ice flooding and/or ice destruction.

During the measurment period the sensors recorded an increase of water level and ice level. Around May 25th, the onset of a Spring flood wave was recorded at station LN9607-1, where the Lena River originally was 3.70 m deep. Within the next six days the water- ice-level continued rising up to 5.20 m at this station. About 20 km downstream, at station LN9607-2, the water level significantly increased around June 1st. The recorded magnitude of river water level change is only about 1 m in the nearly 11 m deep riverbed. The easternmost station LN9608A was ice-covered (sea ice thickness 1.70 m) during the whole time of field work. Here, the Lena River break-up signal is superimposed on tidal fluctuations of the southern Laptev Sea. The impact of freshwater at the beginning of the break-up leads to an increase of sea-level of about 15 to 20 cm.

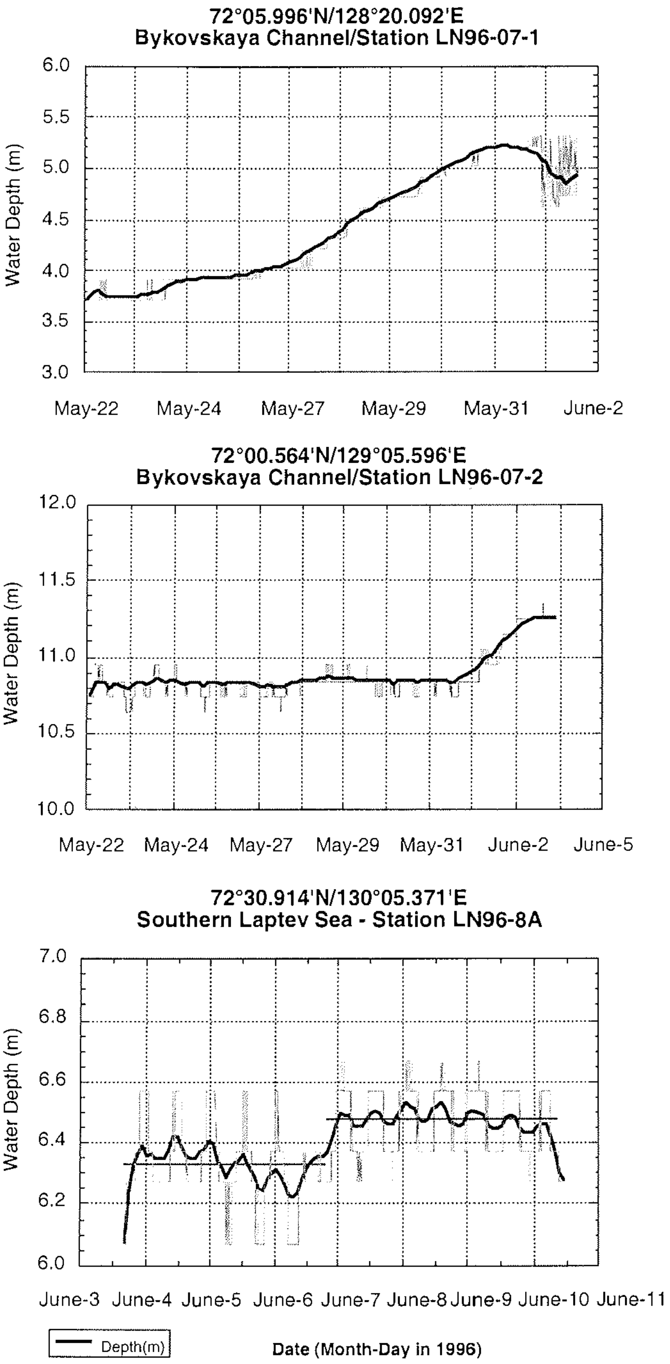


**Figure 4-3:** The variation of water-ice-level at the stations LN96-07-1, LN96-07-2, and LN96-8A during Spring Lena river break-up in 1996 (raw data).

## 4.3 Coastal dynamics in the western Laptev Sea

*(M. N. Grigoriev, V. Rachold, F. E. Are, H.-W. Hubberten, S.O. Rasumov and W. Schneider)*

### 4.3.1. Introduction

The main task of the expedition LENA 2000 studies was a quantitative assessment of primary parameters of coastal dynamics, i.e. land loss, land accretion and amount of coastal erosion products transferred to the sea. In 1999 the coastal team concentrated on coastal key sites around the Lena Delta and in the Eastern Laptev Sea (Rachold and Grigoriev, 2000). In 2000 the coastal part of the expedition LENA 2000 concentrated mainly on key sites located west of the Lena Delta (Figure 4-4).

The investigation of the Western Laptev Sea coastal region was a very important task for the coastal subprogram of the expedition LENA 2000 because so far coastal erosion processes in the Western Laptev Sea were studied insufficiently. The marine Tugboat "Sofron Danilov" was rented for conducting the coastal process studies (Figure 4-5). In 2000 the field observations were carried out on the following nine key sites:

- Station 1: Aerosiomka Island, low sand bank north-east off the Lena Delta, 0-0.5 m high coast (coastal processes observation)
- Station 2: Western Olenek Bay area, Quaternary Lowland, 8-15 m high coast (coastal processes and shoreface profile observation)
- Station 3: Terpiay-Tumsa Cape area, plain consisting of Late Pleistocene Ice Complex, 20-35 m high coast (coastal processes and shoreface profile observation)
- Station 4: Mamont Klyk Cape area, plain consisting of Late Pleistocene Ice Complex, 20-35 m high coast (coastal processes and shoreface profile observation)
- Station 5: Tsvetkov Cape area, bedrock coast consisting of Paleozoic rocks, 50-80 m high coast (coastal processes and shoreface profile observation)
- Station 6: Korotkaya River Mouth area, Quaternary pebble and Ice Complex Coast, 12-25 m high coast (coastal processes and shoreface profile observation)
- Station 8: Northeastern Lena Delta margin (shoreface profile observation)
- Station 9: Trofimovsky Channel Mouth (shoreface profile observation)
- Station 10: Muostakh Island, remnant of lowland consisting of Late Pleistocene Ice Complex in the Buor-Khaya Bay, 20 m high coast (coastal processes observation)

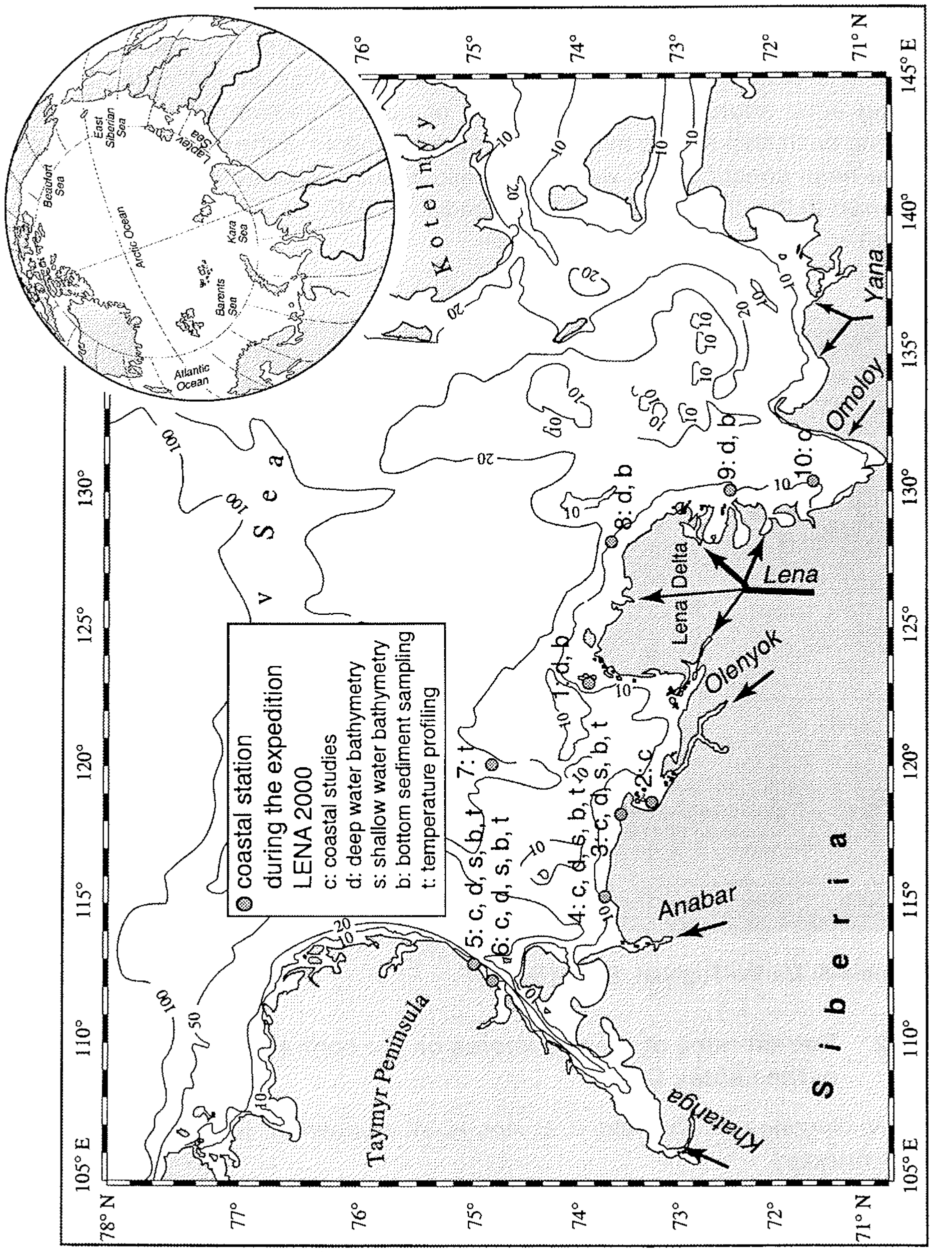


**Figure 4-4:** Coastal stations investigated during the expedition LENA 2000.

A geodetic survey of 16 km shorelines and cliff top edges has been carried out. Nine shoreface profiles of a total length of more than 50 km were measured using echo sounder. Ninety samples of bottom sediments were collected. During each ship station temperature measurements of the water column profile have been conducted as well. For details about the methodology the reader is referred to the cruise report of the expedition LENA 99 (Rachold and Grigoriev, 2000).

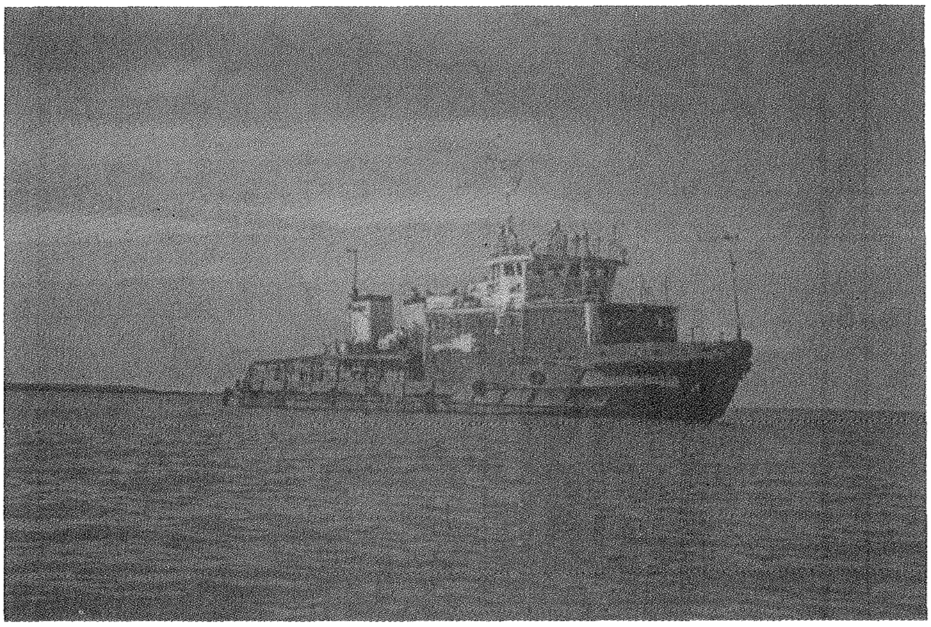


**Figure 4-5:** Marine Tugboat "Sofron Danilov".

### 4.3.2 Retreat rates of erosive shores on the central and western coasts of the Laptev Sea

*(M. N. Grigoriev, V. Rachold, F. E. Are, H.-W. Hubberten, S.O. Rasumov and W.Schneider)*

During field work a laser theodolite survey was the main method to determine the retreat rates of the coast. For that theodolite measurements were performed on land to obtain the modern horizontal and vertical position of the shores. On erosional shores the position of the cliff base and the cliff upper edge was measured. On accretional shores the subject of measurements was the shoreline. Characteristic terrestrial features, which could be identified on aerial photographs as well, such as sharp turns of small streams, small lakes, boundaries of different types of vegetation etc., served as natural marks. Measurements were carried out using a laser theodolite Elta 50 R. One example shows the result of the comparison between the coastal position on the old aerial photographs and the present-day coastal position (Figure 4-6).

The results of our laser theodolite survey carried out during the field season 2000 and the subsequent comparison with aerial photos taken between ca. 1950 and 1980 show that the average cliff top edge retreat rate for the long-term period is:

- Terpiay-Tumsa Cape: 1969-2000 - 5.1 m • year$^{-1}$
- Mamont Klyk Cape: 1969-2000 – 4.0 m • year$^{-1}$
- Northeastern coast of Muostakh Island: 1951-2000 –4.6 m • year$^{-1}$
- Northern Cape of Muostakh Island (cap edge retreat rate): 1951-2000 – 13.3 m • year$^{-1}$
- Western Olenek Bay area: 0.5 m • year$^{-1}$

Measurements of cliff base dynamics on two erosional key sites indicate that approximately the same long-term retreat rates at the selected sections of the coast can be observed:

- Terpiay-Tumsa Cape: 1969-2000 – 4.9 m • year$^{-1}$
- Mamont Klyk Cape: 1969-2000 – 4.4 m • year$^{-1}$

According to the results of our research during the expeditions LENA 1999 and LENA 2000 in the western, eastern and central sectors of the Laptev Sea we can evaluate the average shoreline and cliff top retreat rate for all Laptev Sea coastal sites, which consist of ice-rich sediments (Figure 4-7). This rate is approximately 2-2.5 m • year$^{-1}$. The shoreline retreat rate of small islands covered by ice-rich deposits is almost twice higher than that of continental sites or large islands. The maximum long-term rate of coastal erosion was observed on the Northern Cape of Muostakh Island (only for the edge of the cape): 660 m during 50 years or 13.3 m • year$^{-1}$. The obtained data on the average coastal retreat rate will allow us to estimate the volume of coastal mineral material entering the Laptev Sea shelf more precisely.

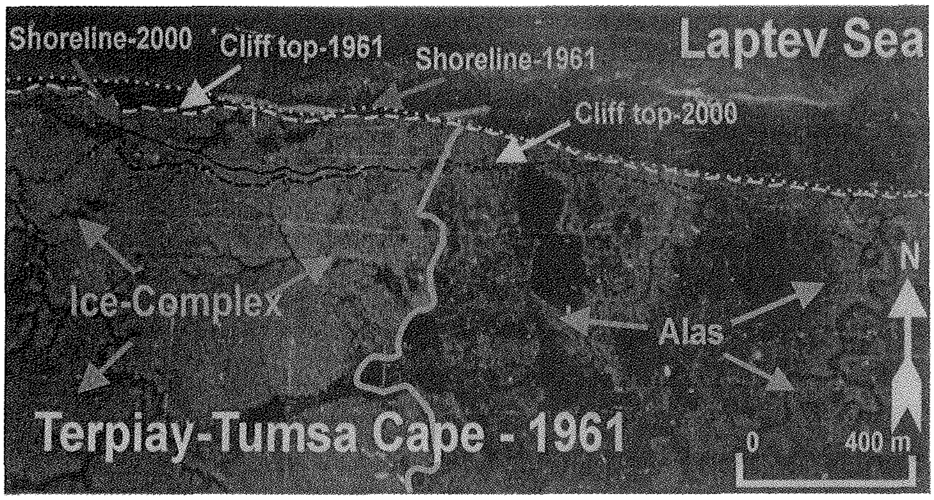


**Figure 4-6:** Arial photograph of Terpiay-Tumsa Cape (1961) and the modern position of the cliff top and shoreline.

**Figure 4-7:** Typical erosional shore of the Western Laptev coast consisting of fine-grained Late Pleistocene Ice Complex deposits: Mamont Klyk Cape, Olenek-Anabar coast.

The temperature measurements of sea-water vertical profiles show that temperatures below zero near sea bottom are a quite usual phenomenon even in the coastal zone. In August 2000 in the western part of shallow Laptev Sea shelf an extremely low bottom water temperature (up to –2.2°C) was observed at station 7 (Figure 4-8). This fact is very important for understanding the development of sub-sea permafrost along the near-shore shelf. The vast distribution of near bottom summer temperatures below zero indicates that sub-sea permafrost can be preserved on a shallow shelf for a long time. The temperature regime of water mainly depends on the local hydrometeorological conditions (see Appendix A4-2, A4-3).

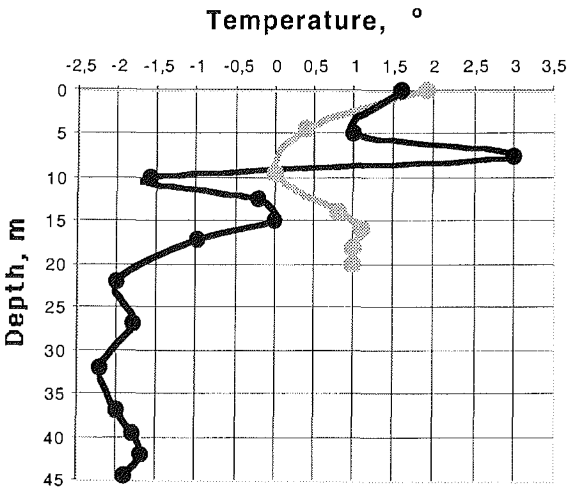


**Figure 4-8:** Water temperature profiles at station 6 (near Tsvetkov Cape, Taimyr Peninsula, gray symbols) and station 7 (east of Tsvetkov Cape, black symbols).

### 4.3.3 Shoreface profiles of the central and western Laptev Sea coast

*(F. E. Are, M. N. Grigoriev, V. Rachold, H.-W. Hubberten, S.O. Rasumov and W.Schneider)*

#### 4.3.3.1 Introduction

The shoreface may be defined broadly as the long shore stripe of the seabed affected by waves; this includes the area from the surf zone to the storm wave base isobath (Zenkovich, 1962; Reineck and Singh, 1990). The wave base may be calculated on the basis of meteorological and oceanographical data. Its position is usually well-defined geomorphologically in deep seas by the edge of an underwater accretion terrace. But accretion terraces are absent in shallow seas where possible (calculated) wave base exceeds water depth. In this situation it can be difficult to identify the lower boundary of the shoreface. According to Reineck and Singh (1990), it may be associated with the isobath where the comparatively steep slope of the shoreface changes into a rather gentle slope of the transition zone. However, in some coastal profiles the change of inclination is indistinguishable. Sometimes the boundary between the shoreface and the transition zone is indicated by a change in bottom sediment from sandy on the shoreface to silty in the transition zone.

There are several reasons to study shoreface morphology. One of them is connected with the assessment of coastal erosion sediment input to the sea, which is an important component of the marine sediment balance (Are, 1999). Eroded sediments are supplied to the sea both from the shoreface and the cliff, while the sediment amount coming from the shoreface sometimes exceeds that coming from the cliff. Thus, to evaluate sediment input of coastal erosion it is absolutely necessary to know the position of the shoreface lower (outer) boundary.

Another reason to study the shoreface is connected with the problem of coastal erosion modeling. The essential of coastal erosion is erosion of the shoreface. The destruction of the cliff is merely a consequence of shoreface erosion. Therefore, in modern mathematical models, shoreface dynamics is used as the base for calculating coastal changes (Thieler at al., 2000). The shoreface geometry is one of the major parts of these models. The basic notion of shoreface equilibrium profile suggested by Bruun (1954) is involved in all models considering erosion of coast composed of unconsolidated sediments. According to Bruun the form of the equilibrium profile is concave and to a first approximation may be described by the equation

$$\boldsymbol{h} = \boldsymbol{A} \cdot \boldsymbol{x}^{m}$$

where $\boldsymbol{h}$ is water depth, $\boldsymbol{x}$ – the distance from the shore, $\boldsymbol{A}$ – a sediment-scale parameter, increasing with the grain size, $\boldsymbol{m}$ – the coefficient of shoreface shape (Dean, 1997). The equation (1) shows that the form of the shoreface profile depends on bottom sediment grain size.

All existing models of coastal changes are based primarily on data from high-energy temperate latitude coasts and do not take into account the impact of permafrost. The influence of permafrost and complicated geocryological processes, occurring in the coastal zone of the sea, on the shoreface geometry and dynamics are entirely unexplored.

Very little is known about the shoreface of Arctic coasts in general. For instance, almost no information is available for the Laptev Sea. The southern part of this sea is shallow. Waves rework the sea floor everywhere up to several hundred kilometres from the shore. Obviously it is unreasonable to consider erosion of the sea floor at such distances from the coast as coastal erosion. In this situation the above notion of shoreface becomes meaningless. However, in order to calculate the volume of sediment supplied to the sea by coastal erosion it is necessary to define the boundary between erosion of pre-transgressive sediments (derived from downcutting) and reworking of modern marine materials.

Evidently, to improve our understanding of the shoreface along shallow Arctic coasts it is necessary to compile existing data on shoreface morphology, coastal geology, geocryology, and oceanography. But data available are very scarce and therefore extensive field investigations on representative key sections of the coast are needed. That is why in the frame of the Russian-German project “Laptev Sea 2000” pioneer investigations of Laptev Sea shoreface profiles started during the expedition LENA 99 in the western Laptev Sea have been continued in the eastern Laptev Sea during the expedition LENA 2000.

#### 4.3.3.2 Methods

The main part of the field work involved cross-shore bathymetrical profiling carried out by stationary echosounders on board “Sofron Danilov”. The real accuracy of the depth measurements was about 0.1 m. All profiles measured were drawn by echosounder strip-chart recorder with a vertical scale 1cm = 1 m. Navigation and distance measurements were conducted through the use of magnetic compass.

In the coastal shallows inaccessible for R/V (<3.5 m for “Sofron Danilov”) profiling was carried out from a motor boat using a hand-held echosounder with 0.1 m resolution. A precision laser theodolite Elta-36 was used for measurements of distances <1.5 km. But this technique is unusable on very wide coastal shallows, for example around the Lena Delta front, where the 2 m isobath lies as far as 18 km from the shore. In such areas the magnetic compass was used.

Besides field measurements extensive information was derived from navigation maps (scales 1:25 000 – 1:500 000), based on bathymetrical data, obtained at different times beginning from 1953. The maps were used mainly to reveal the changes in shoreface position and morphology during last decades, and also for preliminary study of the shoreface along the coast sections where the field measurements could not be carried out.

To compare measured profiles with the bathymetrical data taken from navigation maps it is absolutely necessary to take into account the sea level fluctuations which in the Laptev Sea coastal zone may exceed 2 m. For this purpose data of sea level monitoring on the polar stations Tiksi and Dunay were used. They measure the sea level deviation from the mean Baltic level every 3 hours. The maps are compiled relative to the Baltic level.

#### 4.3.3.3 Preliminary results

Examples of typical shoreface profiles are given in Figure 4-9 and 4-10 (Cape Tsvetko, station 5) and Figure 4-11 (Cape Terpyay-Tumsa, station 3. In general, it was observed that profiles off erosion shores have a concave form. This form poorly correlates with power functions, which is in disagreement with the generally accepted idea of the equilibrium shoreface profile form. The position of the shoreface lower boundary is determined by the level of lowland inundated during the last transgression (-5...-10 m) and may be easily recognized by the sharp decrease of the sea floor mean inclination for an order of magnitude. The mean shoreface inclination depends on sediment grain-size and ranges from 0.0022 to 0.033. The shoreface concave form did not change considerably during last 20-30 years which indicates that shore retreat did not slow dawn and proposes intensive coastal erosion in XXI century.

The underwater part of the Lena River delta extends into the sea as far as 35 km. Its upper part is formed by a shallow bench as wide as 18 km with 2-3 m depths on the outer edge. The delta evolution is irregular. Along with intensive advance into the sea (58 m/year), erosion is taking place in some sections. Comparison of measured profiles with old bathymetric data gives the opportunity to evaluate the changes of underwater delta parts during last decades. Thus the bathymetric survey of the sea bottom near the delta coast may be successfully used for quantitative evaluation of the sediment balance in the river-sea system.

Some sections of the Laptev Sea coast are composed of bedrock having comparatively low resistance against wave erosion. These sections may supply a considerable amount of sediments into the sea if the cliffs are sufficiently high, and therefore must be taken into account for the evaluation of the shore erosion input into the Laptev Sea sediment balance.

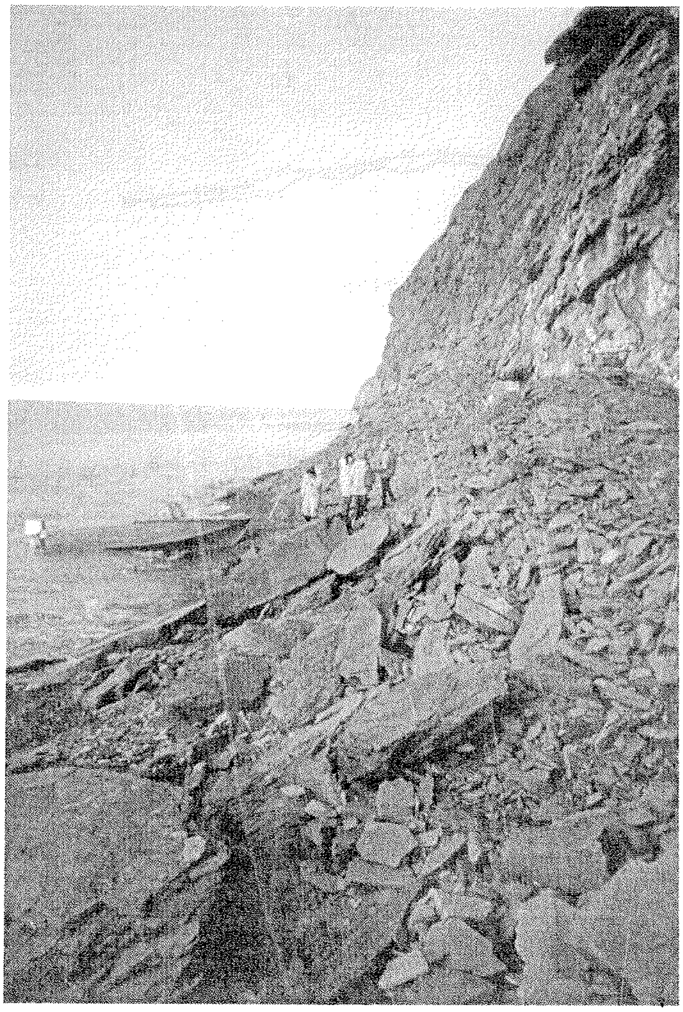


**Figure 4-9:** Cape Tsvetkova abrasion shore.

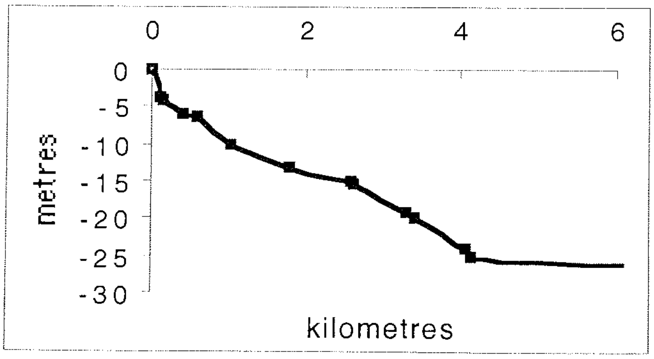


**Figure 4-10:** Cape Tsvetkova shoreface profile.

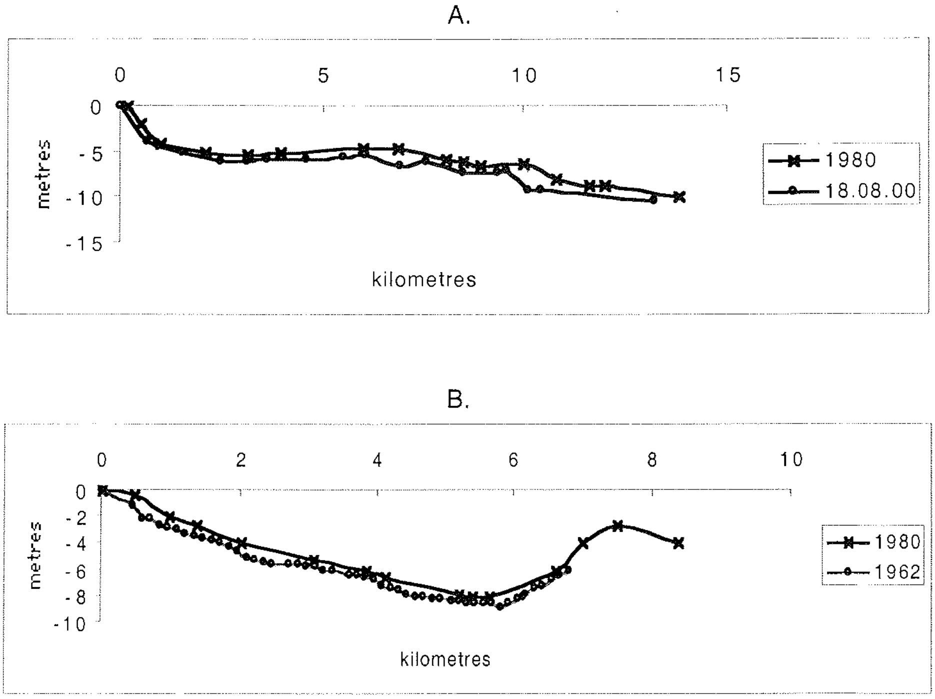


**Figure 4-11:** Erosion of (A.) and accretion on (B.) the sea floor near the Cape Terpyay-Tumsa, station 3.

## 4.4 History of the relief formation of the western Lena Delta Sector in the late Pleistocene-Holocene

*(E.Yu. Pavlova and M.V. Dorozhkina)*

### 4.4.1 Introduction

This study presents an analysis and generalization of data on the geological-geomorphologic Lena delta structure with the aim to reveal the main stages in the history of development of the western delta sector.

The area of the geological-geomorphologic studies undertaken during the "Lena-98" and "Lena-2000" expeditions (Pavlova and Dorozhkina, 1999, 2000) covered the western delta sector restricted by Bolshaya Tumatskaya branch from the east and the Olenyokskaya branch from the south.

The geological structure of the territory is mainly comprised of the sedimentary rocks of continental genesis represented by the Lower Paleozoic and Cenozoic deposits.

The terrigenous-carbonate Devonian rocks are observed in natural outcrops on Amerika-Khaya, Orto-Khaya and Kubalakh-Khaya islands being represented by dolomites, limestone, marl and basalt covers (Grigoriev, 1993).

The Cenozoic group within the western delta sector is represented by loose Pliocene-Quaternary deposits of different lithology (peat, silt, loam, sandy loam and sands).

In general, several geomorphologic levels of different height and age with a different spatial spreading are identified (Figure 4-12):

- low floodplain with a complex of modern channel features of the present age;
- high floodplain of late Holocene age;
- first above the floodplain accumulative terrace of early-middle Holocene age;
- second above the floodplain erosion terrace of late Pleistocene-Early Holocene age;
- third above the floodplain erosion terrace of late Pleistocene age;
- denudation relics worked out on the Paleozoic rock and pre-Pleistocene pebble-conglomerate rocks.

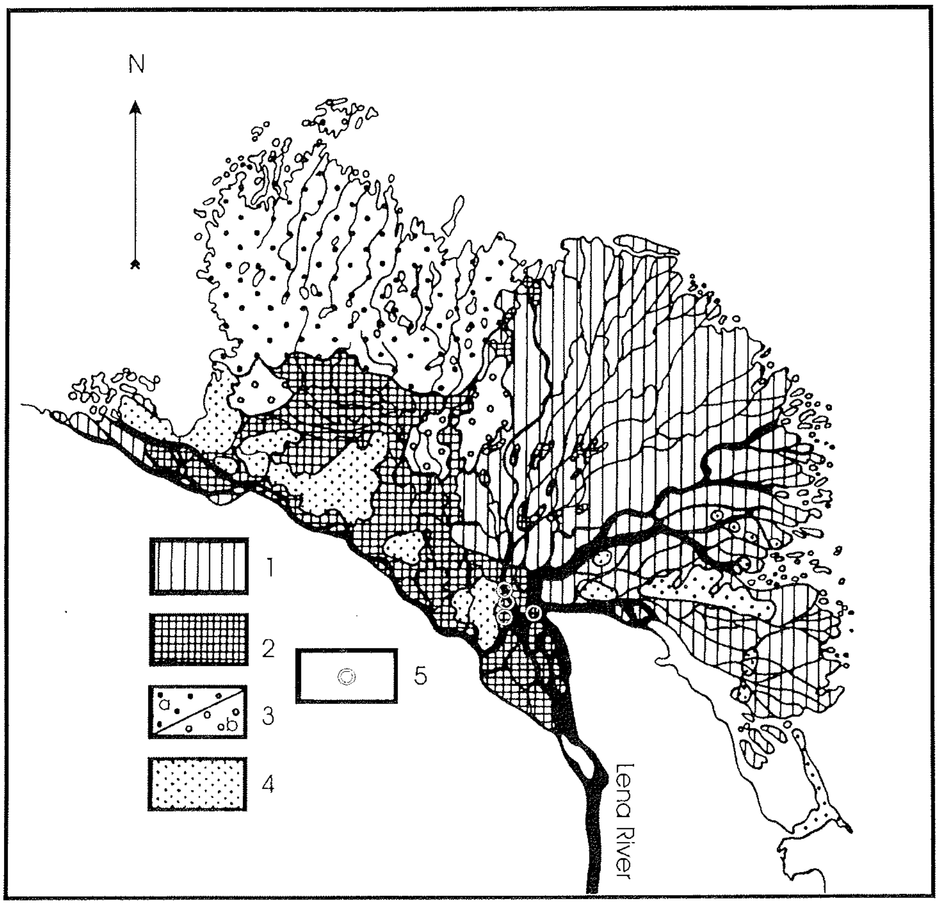


**Figure 4-12:** Geomorphologic scheme of the Lena delta. (1) - complex of the low floodplain with a complex of modern channel features of the present age and the high floodplain of the Late Holocene age; (2) - complex of the low and high floodplains and the first above the floodplain accumulative terrace of the Early-Middle Holocene age; (3) - second above the floodplain erosion terrace of the Late Pleistocene-Early Holocene age (a - main most pronounced second above the floodplain terrace; b - second terrace segments with the most significant denudation re-working of upper surface); (4) - third above the floodplain erosion terrace of the Late Pleistocene age; (5) - denudation relics worked out on the Paleozoic rock and pre-Pleistocene pebble-conglomerate rocks.

The subdivision of the Lena River delta into the western and eastern sectors is mainly made by the character of geomorphologic structure and plan distribution of Quaternary deposits of different age. The eastern sector is distinguished by a monotonic structure and a weak age differentiation of developed deposits. The low and high floodplain deposits of the modern and Late Holocene age outcrop to the surface here practically everywhere. Local outcrops of the ice complex deposits comprising the upper portion of the third above the floodplain erosion terrace of the Late Pleistocene age are noted. The western delta sector presents a more complicated feature in terms of geomorphology and geology. Two floodplain and three above the floodplain surfaces of the Late Pleistocene-modern age are expressed in the relief here. The deposits developed within the western delta sector are of the Pliocene-Quaternary age.

### 4.4.2 Geological-geomorphologic structure of the western sector of the Lena River delta – results and discussion.

The low floodplain and a complex of modern channel features are the most dynamic delta segments. Their formation at present is influenced by the changes in Lena water content (water runoff arriving to the apex), distribution of water runoff and sediment load by the delta arms, water runoff and sediment transformation along the length of the delta arms, marine factors, active processes of alluvial material accumulation and shore washout and thermoerosion.

The low floodplain is observed in segments of different width along the delta branches. The low floodplain surface has sparse vegetation and is annually flooded with water during the flood periods and frequent wind surges. Mort lakes are widespread within the low floodplain.

A complex of modern channel features is represented by channel bars comprised of alluvial wave-like laminated sands, near-channel shoals and alluvial islets whose surface is practically devoid of vegetation.

In general, the low floodplain height within the western delta sector decreases from the delta apex to its external margin. Along the Olenyokskya, Arynskaya, Malaya and Bolshaya Tumatskaya branches, the low floodplain is represented by segments 1.5 to 5 km wide, its height changing from 7-8 m in the head area of the branches to 1 m at their exit to the sea.

Along the small branches, the height of the low floodplain decreases from 6-4 m in the central part to 1-1.5 m towards the delta periphery with the width changing from first meters to 0.5 km.

The low floodplain deposits are represented by alluvial fine- and medium-grained sands with some extremely rare pebbles and sandy-silty-clayey alternating strata with plant macro-remains. At the boundary of the seaside and the subaerial delta, coastal-delta and coastal-marine sediments actively form being represented predominantly by strongly silty fine-grained sands.

The low floodplain and a complex of channel features actively forming at the present time, are of a modern age.

The high floodplain is developed everywhere throughout the entire length of the branches presenting a surface flooded with water during the flood periods only in some rare individual years. The high floodplain is characterized by widespread mort and thermokarst lakes. The height of the high floodplain surface at present is determined by the maximum water level values during the flood period.

The high floodplain along the Olenyokskaya and Malaya Tumatskaya branches is represented by segments of a different width (up to 2.5 km) jointed with the relics of the first above-the floodplain terrace. Along the Arynskaya and Bolshaya Tumatskaya branches, the high floodplain presents a complex of large delta islands.

The absolute marks of the high floodplain decrease from the delta apex to its marginal part. While in the vicinity of Stolb Island the high floodplain has 11 m marks, the height of its surface in the central delta area along the Malaya and Bolshaya Tumatskaya and small branches comprises only 6-8 m decreasing to 3-3.5 m towards the marginal delta area. Along the Olenyokskaya branch, the high floodplain decreases from 9-10 m in the upper portion (9 m on Samoilovsky Island) to 5-6 m in its middle reach and up to 3 m in the mouth area of the branch.

The high floodplain sediments are represented by laminated silty-sandy-peaty deposits that have a high ice content (up to 50%) with developed ice veins, ice interlayers and lenses and are characterized by schlieren and reticulate cryogenic texture.

Datings of the high floodplain deposits in the western delta sector are few. At present, there are the following radiocarbon datings from the high floodplain deposits: delta apex – Samoilovsky Island 2140±110 (IORAN-4101), 3700±260 (IORAN-4167) (Kuptsov, Lisitsin, 1996) and Olenyokskaya branch 3480±500 (Korotayev, 1984). The radiocarbon dating of the high floodplain deposits of the western delta sector based on 1998-1999 field studies of the authors revealed the following age: Dzheppiries-Tyubelege 2690±100 (LU-4193), 1320±80 (LU-4199), Olenyokskaya branch 2850±200 (LU-4414) and Arynskaya branch 3930±90 (LU-4413). The obtained datings suggest that the formation of the high floodplain occurred in the interval 3930±90 - 1320±80 yr BP, i.e. during the end of the Middle-Late Holocene.

The first above the floodplain terrace is spread in the southern part of the western delta sector along the Olenyokskaya branch, in the southern delta apex area and in local segments along the submeridional Malaya and Bolshaya Tumatskaya branches (see Figure 4-12). The first above the floodplain terrace presents Earth's surface segments comprised of alluvial deposits no longer under the river influence that are not flooded with water even during the high floods. Thermokarst lakes are predominantly developed at the terrace surface.

The first above the floodplain terrace has a height of 13-14 m in the southern delta apex area, its level decreasing along the Olenyokskaya branch from 13.2 m on Samoilovsky Island to 12.5 m at the southwestern tip of Kurungnakh-Sise Island to 11.5 m in the southern part of Byrrakan-Aryta Island and to 8-9 m in the vicinity of Nagym. The height of the first above the floodplain terrace along the Malaya and Bolshaya Tumatskaya branches decreases from 9.5-10 m in their upper portion to 3.5-4 m at the northern external delta margin (Skryabin-Aryta Island, Sagastyr Island).

Both along the large (Malaya and Bolshaya Tumatskaya) and small branches, which are shallow now, the near-channel ramparts 9-10 m high linearly elongated predominantly in the northern and northeastern direction are observed locally. They are comprised of fine- medium-grained oblique- and wavy laminated sands.

The deposits of the first above the floodplain terrace are similar in composition to the high floodplain sediments being represented by fine-grained sands, silty-sandy-peaty deposits and peat. The permafrost deposits of the first above the floodplain terrace are characterized by massive, lenticular, schlieren cryogenic textures. Ice veins are developed in the deposits.

Datings of alluvial deposits comprising the first above the floodplain terrace developed along the Olenyokskaya branch indicate the age of 5100±140 (LU-4411), 6530±160 (LU-4410) and 6870±230 (LU-4409) yr BP. For low part of the section of the deposits of the first above the floodplain terrace in the central delta area (Malaya Tumatskaya branch), a dating of 8570±160 (LU-4191) was obtained. Thus, the formation of alluvial deposits of the first above the floodplain terrace began as a minimum 8.5 kyr BP, i.e. in the Early Holocene, rather than 4.5 kyr BP according to Korotayev (1984, 1991). The formation of the first above floodplain terrace occurred during the Early-Middle Holocene.

The second above the floodplain cocle terrace presents a complex of large erosion relics with the absolute top marks of 13-29 m located exclusively in the western delta sector (Dunai, Arga-Muora-Sise, Turakh-Sise, Malyga-Sise and Dzheppiries-Sise Islands) (see Figure 4-12). The relics of the second above the floodplain terrace sharply differ from the other delta terrace levels by the lithology of deposits, geomorphologic look of the surface and character of the vegetation cover. A typical feature of relics is widespread numerous thermokarst lakes on their surface oriented northward, north-northeastward and north-northwestward. The relics of the second above the floodplain terrace are reworked to a different extent by the denudation processes. Relatively small Dunai, Malyga-Sise, Turakh-Sise and Dzheppiries-Sise islands located along the periphery of a large Arga-Muora-Sise massif are most reworked by denudation. In general, the surface of these islands presents alternating flat gently sloping isometrically-elongated in the submeridional direction sand ridges (with the absolute top surface marks of 10-17 m) with large basins. The basins are predominantly swampy being partly occupied by thermokarst lakes that are at the stage of draining and overgrowing. The relative elevations of sand ridges above the waterlines of overgrowing thermokarst lakes comprise between 6 to 12 m, on average.

The deposits of large relics of the second above the floodplain terrace are presented predominantly by monotonous quartz fine- and medium-grained sands with subhorizontal and oblique lamination. Permafrost deposits are characterized by the development of reticulate, lenticular and massive cryogenic textures. A wide development of seam ice is typical of sand deposits (Grigoriev, 1993).

The deposits of the second above the floodplain terrace were studied by many investigators (Strelkov, 1959; Gusev, 1953, 1959, 1960, 1961; Lungersgausen, 1961, 1966; Agapitov, 1962; Lomachenkov, 1966, 1971; Rusanov et al., 1967; Ivanov, 1970, 1971; Korolev, 1985, Grigoriev, 1985, 1988, 1993; Galabala, 1987, Schwamborn et al., 2000). Up to now, opinions about the origin of these deposits differ, however, most investigators treat their genesis as alluvial. Due to complexity of dating sand deposits practically devoid of organic matter, the determination of their age remained problematic. Sands of Arga-Muora-Sise Island by their position in the general stratigraphic section of the Lena delta were determined by different authors as Karginsk (Middle-Upper Quaternary) or as non-dissected Upper Quaternary (younger than Karginsk, but older than the modern ones).

The age and origin of the relief of sandy relics in the northwestern delta sector were also treated differently by different investigators. There is an opinion that the formation of the surface relief of the second terrace is connected with marine transgressions (Lomachenkov, 1966, 1971; Korotayev, 1984, 1991; Korotayev et al., 1990). Thus, Korotayev considers Arga-Muora-Sise Island a "marine Karginsk terrace" (p. 122, Korotayev et al., 1990). The formation of the second terrace was also related to the river runoff backwater from the ice shelf (Galabala, 1987). Gusev (Gusev, 1953, 1959, 1960 and 1961) suggested that the surface of Arga-Muora-Sise Island is a relic of the alluvial plain at the mountain foot. Grigoriev (1993) determined the time of formation of the second terrace as the Late Pleistocene-Early Holocene. As a result of dating and analysis of deposits from the shore sections and lacustrine deposits of Lake Nikolay-Kyuele (a complex of field surveys of the "Lena-98" and "Lena-99" expeditions (Schwamborn et al., 1999, 2000), we can unambiguously determine the genesis of sands comprising Arga-Muora-Sise Island as fluvial. The OSL and $^{14}C$ AMS datings obtained from the deposits of the second above the floodplain terrace (Schwamborn et al., 2000a) serve as evidence that the time of the onset of formation of the second above the floodplain terrace refers to the period not earlier than 12 kyr BP.

The onset of formation of thermokarst lakes of the sand relics of the second above-the-floodplain terrace belongs to the Middle Holocene. Lake Nikolay-Kyuele can serve as an example of such a lake with dating of the bottom portion of its lacustrine proper deposits revealing an age of 7090±40 BP. The deposits underlying the lacustrine sediments proper were dated as 12480±60 BP (Schwamborn et al., 2000a).

Thus, the formation of the second above the floodplain terrace belongs to the Late Pleistocene-Early Holocene.

The third above the floodplain cocle terrace within the western Lena delta sector presents large erosion relics (Ebe-Basyn-Sise, Khardang-Sise, Dzhangylakh-Sis and Kurungnakh-Sise Islands) with the absolute top marks of 30-66 m (see

Figure 4-12). A typical feature of the third above-the-floodplain level is the widespread ice complex deposits in the upper portion of the relics with fine-grained sands of the Bulukurskaya suite of the Late Pliocene-Middle Pleistocene age underlying them (Kunitsky, 1989).

The ice complex deposits present a composite stratified complex of sediments comprised of interbedding silt and sand loam with interlayers and lenses of fine-coarse-grained sands or peat. The main peculiarity of ice complex deposits is a widespread development of ice veins. The volumetric ice content of ice complex deposits is often greater than 50%. The deposits are characterized by the presence of bone remains of large mammals and rodents of the mammoth fauna complex.

A review of data of radiocarbon dating of ice complex deposits in the Lena delta and on the Bykovsky Peninsula undertaken by Grigoriev (Grigoriev, 1993) given the latest data (Schirrmeister et al., 1999; Siegert et al., 2000) indicate the Late Pleistocene, in most cases the Karginsk and Sartan age of these sediments.

The ice complex deposits of East Siberia were in general studied by many investigators (Popov, 1955; Katasonov, 1958, 1963, 1973; Romanovsky, 1958; Lavrushin, 1963; Alekseyev, 1970; Ravsky, 1972; Rosenbaum, 1973; Konishchev, 1975; Ivanov and Katasonov, 1978; Tomirdiaro, 1980; Tomirdiaro and Chernenky, 1987; Kunitsky, 1989; Gravis, 1996, 1997, etc.). The ice complex deposits in the Lena lower reaches and the delta with the results of laboratory studies are characterized by Kunitsky (1989).

Most investigators referred initially the main portion of ice complex deposits to alluvium with a subordinate participation of deposits of lacustrine, deluvial and biogenic genesis. The facies belonging of alluvial sediments remained an open problem. Some investigators considered that the ice complex deposits were represented by a floodplain facies of alluvium (Popov, 1955; Katasonov, 1958; Rosenbaum, 1973), while others were of the opinion that this was a channel alluvium facies (Lavrushin, 1963; Ravsky, 1972). The ice complex deposits were also defined as a polygenetic feature (Alekseyev, 1970), as a product of development of ancient alasy (Konishchev, 1975), as flood-glacial (Katasonov, 1963, 1973), delta (Ivanov an Katasonov, 1978) and eolian (Tomirdiaro, 1980; Tomirdiaro and Chernenky, 1987) deposits and as snow patch phenomena (Kunitsky, 1989). The alluvial-proluvial model of the formation of ice complex deposits based on the ideas of the changed erosion-accumulation activity of the water flows in the climatic rhythms of the Pleistocene and Holocene was proposed by Gravis (Gravis, 1996, 1997). The existence of so many different hypotheses shows that at present the problem of genesis of ice complex deposits remains unsolved.

The ice complex deposits are characterized by a fragmentary area development in the south of the western and eastern Lena delta sectors and a different thickness. The thickness of ice complex deposits in the eastern delta sector is 2-3-fold greater compared to the western sector (Figure 4-13) with the foot of the ice complex deposits decreasing from the absolute 11 to 20 m marks in the western part to –8 to –10 m in the eastern part. Thus, in the western delta area on Kyuryuelyakh-Sis Island the foot of ice complex deposits is observed at a height of 10-11 m above the sea level with the foot height comprising 20 m above the sea level on Kurungnakh-Sise Island and 19.5 m on Dzhangylakh-Sis Island. However, drilling in the eastern delta sector on the Bykovsky peninsula and Muostakh Island has outstripped the ice complex foot at a depth of 8-10 m below the sea level (Kunitsky, 1989; Grigoriev, 1993). A sharp drop of the level of the ice complex foot is observed east of the Malaya and Bolshaya Tumatskaya branches.

An analysis of the position of radiocarbon datings from the sections of deposits comprising the third above the floodplain terrace (available data at present at the disposal of the authors) for the western and eastern delta sectors on the plot revealed the western sector to be characterized by older datings (older than 25-30 kyr), whereas the eastern by predominantly younger datings (10-30 kyr) located at close hypsometric marks (Figure 4-14).

In general, the available data allow us to determine the age of the third above the floodplain erosion terrace as the Late Pleistocene.

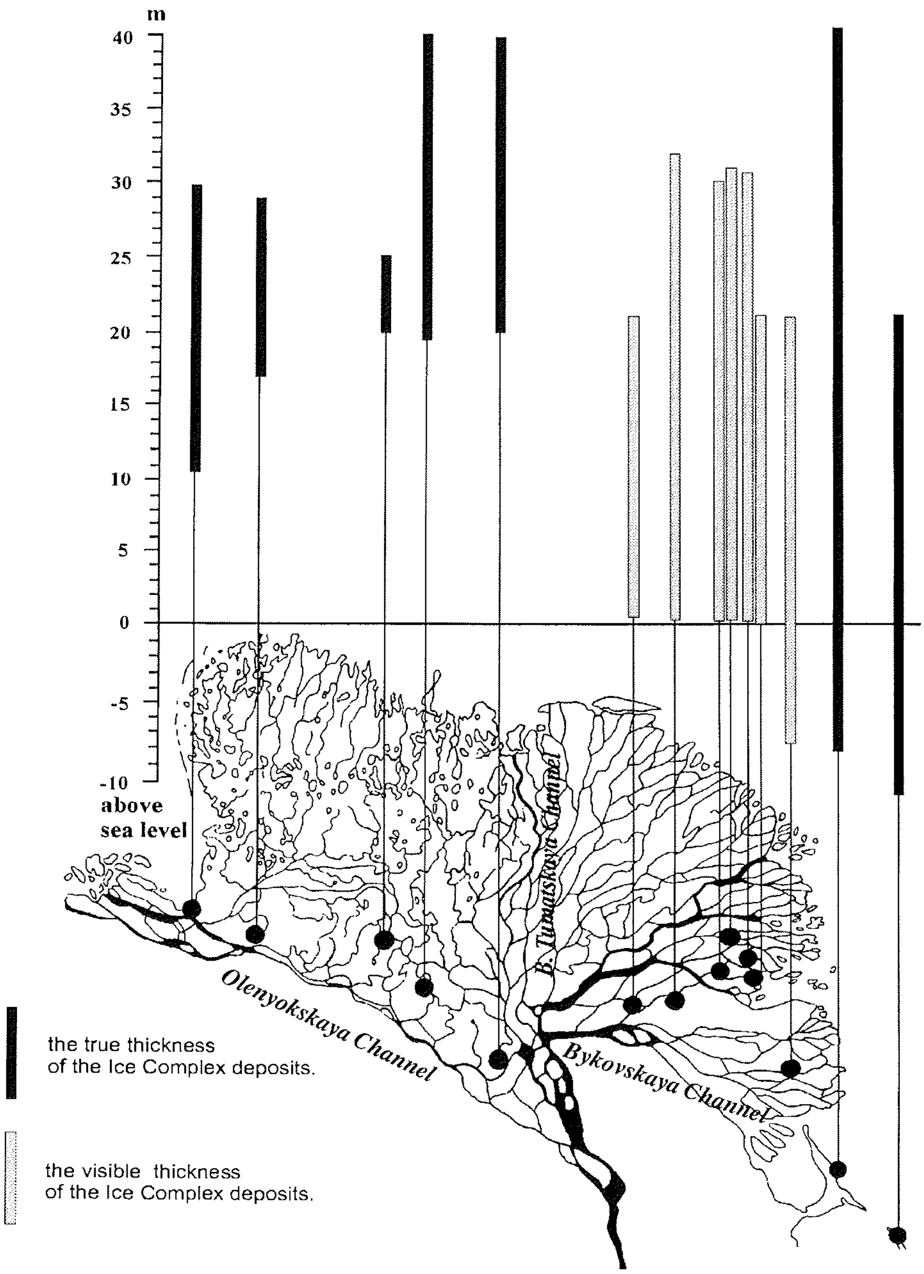


**Figure 4-13:** The thickness and position of the Ice Complex in the Lena Delta.

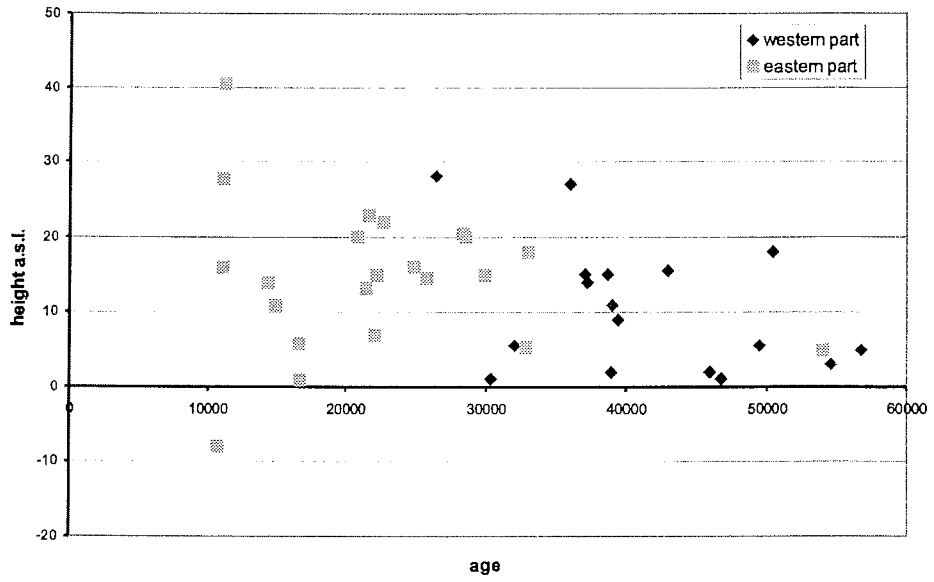


**Figure 4-14:** Plot of the position of radiocarbon datings from the sections of deposits comprising the third above the flood plain terrace for the western and eastern Lena Delta sectors.

### 4.4.3 History of the relief development in the western Lena delta sector – conclusions

The history of the relief development in the western Lena delta sector during the end of the Late Pleistocene-Holocene appears to be quite complicated and cannot be reconstructed apart from the history of development of the entire delta in general. An analysis of published data and the results of studies for the last 3 years allow us at present to outline the main development stages of the territory. The established typical features of the geological-geomorphologic structure of the region suggest the tectonic regime changes and the causes of modification of the Lena delta hydrographic network during the Late Pleistocene and the Holocene.

Late Pleistocene

The development of the territory occupied now by the Lena delta, was closely connected in the Late Pleistocene with the regressive-transgressive sea cycles (Romanovsky et al., 1997) that determined primarily the erosion basis and as a result the change of intensity of the accumulation-erosion processes on land.

During the period of a long sea regression during the Pleistocene, extensive shallow Laptev Sea shelf areas dried up to a depth of 100-140 m (Selivanov, 1996). Under the conditions of prevailing continental sedimentation the formation of Late Pleistocene syncryogenetic ice complex deposits occurred (Sher, 1997). At Sartan time, the coastline was located in 250-300 km north of the modern Lena delta coastline (Atlas). The main Lena runoff was in the northern and northwestern direction along the valleys coinciding with the modern Olenyokskaya and Bolshaya Tumatskaya branches. The fragments of these paleo-valleys are fixed at present on the Laptev Sea shelf. At this time the third above the floodplain erosion terrace formed within the modern delta territory due to intense entrenchment of the water flows. The plains of alluvial and lake genesis formed simultaneously in the western sector of the modern Lena delta (Gusev, 1961; Atlas).

End of the Late Pleistocene – Early Holocene

The relief formation at the end of the Late Pleistocene- Early Holocene occurred under the complicated paleogeographical conditions of the post-glacial sea transgression development and more active recent tectonic movements.

The first stage of the post-glacial transgression that began 18 kyr BP belongs to this period (Romanovsky et al., 1997). As noted by these authors, the most important features of the first transgression stage was a high rate of sea level rise, especially beginning from 13 kyr BP. Transgression, especially at the beginning was of an ingression character with mouth area of river paleo-valleys transforming to marine freshened bays. The average rate of the coastline displacement towards land comprised 40-60 m/year. By 11 kyr, the sea level raised to a 40 m isobath (Are, 1982).

At the end of the Late Pleistocene – Early Holocene, recent tectonic movements within the modern Lena delta become more active (Grigoriev, 1993; Pavlova and Dorozhkina, 2000, 2000a). The predominant stable arched block uplift of the western delta sector and a subsidence of the eastern sector caused a non-unidirectional development of the western and eastern delta sectors from the end of the Late Pleistocene. A divide zone of two delta areas that are characterized by a non-unidirectional tectonic regime has a submeridonal strike and passes between the Malaya and Bolshaya Tumatskaya branches. The non-unidirectional development of the western and eastern delta sectors is indicated by the decreased absolute marks of the foot of ice complex deposits from 11 to 20 m to –8 to –10 m, increased thickness of ice complex deposits and decreased top relic surfaces of the third above-the-floodplain terrace from 50-60 m to 20-35 m from west to east (see Figure 4-13). This fact is also confirmed by the analysis of distribution of radiocarbon datings of deposits comprising a cocle of the third above-the-floodplain terrace (see Figure 4-14). The difference in the tectonic regime of the western and eastern delta sectors resulted later in the formation of the entire terrace complex in the western delta sector whereas only two floodplain levels and relics of the third above the floodplain terrace were formed in the eastern sector.

The formation of the second above the floodplain erosion terrace belongs to the end of the Late Pleistocene – Early Holocene.

At the threshold of the Pleistocene – Holocene, thermokarst begins to develop in maritime lowlands of the northeastern Arctic due to climate warming (Kaplina, Lozhkin, 1979). The formation of alasy occurs in the Preboreal (Romanovsky et al., 1997).

Early Holocene – first half of the Middle Holocene

The formation of alluvial deposits of the first above the floodplain terrace in the Lena delta began as a minimum 8.5 kyr BP, i.e. in the Early Holocene rather than 4.5 kyr according to Korotayev (Korotayev, 1984, 1991). The formation of the first above the floodplain terrace occurred at the background of the second post-glacial transgression stage (Romanovsky et al., 1997) that began 8-7 kyr BP and was characterized by a slow level rise of the global ocean and climate warming. Stabilizing of the sea basin level belongs approximately to 6 kyr BP, which is in agreement with the Laptev Sea study data (Bauch et al., 1999).

The sea transgression and climate warming were the decisive factors of active thermal abrasion of sea shores. Lake thermokarst was widespread (Romanovsky et al., 1997). The formation of alasy basins confined to the surface of the third above the floodplain terrace continued.

The main Lena River runoff in the Early-Middle Holocene was along the Olenyokskaya branch in the northwestern direction and along the Malaya and Bolshaya Tumatskaya branches in the northern direction. This conclusion is based on the fact that a complete terrace complex is developed in the western delta sector while only two floodplain levels and the relics of the third above the floodplain terrace are observed in the eastern sector. Note that the first above the floodplain terrace of the Early-Middle Holocene age has only a fragmentary spreading along the Malaya and Bolshaya Tumatskaya branches that have a submeridional direction being more widespread along the Olenyokskaya branch in the southwestern delta area. The existence of a more intense northward runoff compared to the present time is indicated by the presence of near-channel ramparts belonging to the first above the floodplain terrace (see above) that have a northward and northeastward orientation. The orientation transformation of the near-channel ramparts from the northern to northeastern direction points to the changed distribution of the main runoff in the Lena delta governed by tectonic causes occurring at the next stage.

End of the Middle Holocene – Late Holocene

The formation of the high floodplain occurred during the end of the Middle Holocene – Late Holocene at a relative sea level close to a modern one (Are, 1982) or greater by not more than 1-3 m (Kaplin and Selivanov, 1999). The absence of a significant sea influence on the formation of delta deposits in the Late Holocene is confirmed by data of modern studies (Schwamborn, et. al., 2000a).

At this time the direction of the main runoff within the Lena delta changes to the north-east-eastward due to more active recent tectonic movements that began at the end of the Late Pleistocene-Early Holocene resulting in the arched block uplift of the western delta sector and a prevailing subsidence of the eastern sector. The main runoff was along the Trofimovsksya and Bykovskaya branches with decreasing runoff in the Olenyokskaya and Malaya and Bolshaya Tumatskaya branches. As a result of transformed main runoff, the most active accumulation of alluvial deposits begins from this time in the central area and in the northeastern delta sector. This is indicated by the prevailing development of the high floodplain of the Late Holocene age represented by extensive delta islands in the northeastern delta sector, and a restricted high floodplain development within the western delta sector.

During the second half of the Holocene, the river and ravine thermoerosion and thermokarst processes actively developed contributing to the general dissection of the delta relief. The formation of alasy continued and bulgunyakhi formed confined to the first above the floodplain terrace and the bottoms of alasy basins of the third above the floodplain terrace (Grigoriev, 1993).

### Modern stage

At the modern stage, the formation of low and high floodplains widespread by area within the Lena delta occurs. Their formation is closely connected with the hydrological regime of the delta being primarily due to the changed Lena water content, distribution of the water runoff and sediment load and intense spreading of the flood flow below the main delta branching node by arms. Within the external delta margin in the tidal influence zone where the final spreading of the water flow of the arms occurs at the shallow mouth seaside, the marine factors also influence the formation of the low floodplain relief.

The development of extensive areas throughout the entire northeastern delta sector annually flooded during the flood period is determined by the maximum water runoff and discharges of suspended sediment in the Trofimovskaya branch. The minimum of the water runoff and suspended sediment discharges in the Olenyokskaya and Tumatskaya branches (western delta sectors) governs a restricted by-area development of the low floodplain along the branches. The same tendency is preserved for the high floodplain.

At the current stage the fluvial processes that govern the creation of accumulation relief features of the floodplain levels along the branches and erosion (thermoerosion) destruction of shores play the main role in the formation of the Lena delta relief. The processes of thermoerosion due to the impact of temporary water flows are most active within the third above the floodplain terrace and account for the development of a complicated branched system of deeply entrenched ravines in the ice complex deposits with a high ice content. The processes of thermoerosion are spread to a lesser extent at the surface of the second above the floodplain terrace. Here, a leading role in the relief formation belongs to thermokarst, which generates numerous thermokarst lakes. The thermokarst processes are less typical of the floodplain levels and the first above the floodplain terrace where shallow thermokarst lakes form. The processes of frost heaving result in the formation of the heaving hills -

bulgunyakhi at the surface of the high floodplain and the third above the floodplain terrace. The processes forming a crack-polygonal micro-relief actively occur at practically all terrace levels except for the lowest near-channel and coastal-marine segments. The processes of eolian accumulation and deflation are most pronounced at the surface of sand relics of the second above the floodplain terrace and on the segments of near-channel shoals and islets not fixed by vegetation.

We note that the Lena delta is located within a seismically active zone to which the epicenters of earthquakes with a magnitude of up to M=3.5-6 (Imayev et al., 1996) are confined. In general, a zone of concentrated epicenters of earthquakes within the delta extends west northwestward along the northern slopes of the Chekanovsky and Kharaulakh Ranges. In the opinion of the authors, two main areas of concentration of the epicenters of earthquakes within the Lena delta can be defined. The first is confined to the western delta sector with a maximum concentration of earthquakes in Olenyoksky Bay and the second includes the southeastern part of the delta with the adjoining Buor-Khaia Bay. The confining of the Lena delta to a seismically active zone is evidence of the continuing recent tectonic movements at the modern stage of the territory development.

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## 4.6 Appendix

**Table A4-1:** List of coastal stations.

| no. | date | location | c | d | s | b | t |
|---|---|---|---|---|---|---|---|
| 1 | 15 Aug | Aerosiomka Island |  | x |  | x |  |
| 2 | 17 Aug | Western Olenek Bay area | x |  |  |  |  |
| 3 | 18 Aug | Terpiay-Tumsa Cape area, Olenyek-Anabar coast | x | x | x | x | x |
| 4 | 19 Aug | Mamont Klyk Cape area, Olenyek-Anabar coast | x | x | x | x | x |
| 5 | 20 Aug | Tsvetkov Cape area, Taymyr Peninsula | x | x | x | x | x |
| 6 | 20 Aug | Korotkaya River Mouth area, Taymyr Peninsula | x | x | x | x | x |
| 7 | 21 Aug | central Laptev Sea |  |  |  |  | x |
| 8 | 22 Aug | NW off Lena Delta |  | x |  | x |  |
| 9 | 22 Aug | W off Lena Delta (Trofimovkaya Channel) |  | x |  | x |  |
| 10 | 22 Aug | Muostakh Island | x |  |  |  |  |

***Station no. LD00-C...**

**c:** coastal studies
**d:** deep water bathymetry
**s:** shallow water bathymetry
**b:** bottom sediment sampling
**t:** temperature measurements

**Table A4-2:** Hydrometeorological characteristics along the western Laptev Sea coast (air temperature – Ta, bottom water temperature – Tb).

| St. | Date | Time | Latitude, N ° ' | Altitude, E ° ' | Wind direction | Wind speed, m/sec | Wave height, m | Wave length, m | Ta, °C | Depth, M | Tb, °C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-a | 15. 08 | 13:40 | 73 58.11 | 123 07.94 | NE | 12 | 0.5 | 8 | 3.5 | 4.0 | 3.2 |
| 1-b | 15. 08 | 15:30 | 73 58.12 | 122 54.35 | NE | 14 | 0.8-1.3 | 12-20 | 4.5 | 10.0 | 2.1 |
| 2-a | 15. 08 | 19:20 | 73 28.67 | 120 52.49 | NE | 15 | 1.2 | 12-22 | 3.6 | 17.0 | 0.4 |
| 2-b | 16. 08 | 13:20 | 73 15.85 | 118 36.35 | N | 12 | 0.5-0.7 | 7-12 | 6.2 | 4.0 | 6.4 |
| 3-a | 18. 08 | 21:00 | 73 34.26 | 118 24.04 | N | 5 - 7 | 0.2-0.4 | 5-8 | 1.8 | 4.0 | 4.8 |
| 3-b | 18. 08 | 23:40 | 73 40.96 | 118 26.37 | N | 5 - 7 | 0.4 | 20 | 0.9 | 10.3 | 3.3 |
| 4-a | 19. 08 | 14:30 | 73 37.33 | 117 12.27 | NE | 2 - 3 | 0.1 | 2 | 4.1 | 3.6 | 4.1 |
| 4-b | 19. 08 | 18:00 | 73 45.78 | 117 12.88 | N | 3 - 4 | 0.3 | 3-5 | 2.8 | 10.2 | 2.2 |
| 5-a | 20. 08 | 09:10 | 74 56.53 | 112 47.27 | N | 3 - 5 | 0.3 | 3-5 | 1.8 | 9.0 | 0.6 |
| 5-b | 20. 08 | 12:00 | 74 57.71 | 112 57.49 | NE | 5 - 7 | 0.4-0.5 | 10-15 | 1.4 | 20.2 | 1.0 |
| 6-a | 20. 08 | 18:20 | 74 52.84 | 112 16.74 | E | 3 - 5 | 0.3 | 10 | 1.7 | 5.5 | 1.2 |
| 6-b | 20. 08 | 20:00 | 74 52.30 | 112 17.97 | SE | 2 - 4 | 0.2 | 10 | 1.8 | 10.0 | 0.6 |
| 7 | 21. 08 | 01:00 | 74 44.26 | 114 28.18 | SE | 2 - 3 | 0.1-0.2 | 15 | 2.7 | 44.5 | - 1.9 |
| 8 | 22. 08 | 01:10 | 73 30.69 | 129 05.66 | SE | 5 - 7 | 0.7 | 12 | 2.7 | 15.0 | - 0.9 |
| 9 | 22. 08 | 09:15 | 73 04.60 | 130 12.45 | SE | 7 - 9 | 1.0 | 10-15 | 3.6 | 20.0 | - 1.1 |
| 10 | 22. 08 | 20:00 | 71 36.32 | 129 51.36 | ESE | 3 - 4 | 0.2-0.3 | 5-7 | 5.6 | 5.0 | 7.3 |

**Table A4-3:** Water temperature (°C) along the western Laptev Sea coast.

| Horizon, m | Stations | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1a | 1b | 2a | 2b | 3a | 3b | 4a | 4b | 5a | 5b | 6a | 6b | 7 | 8 | 9 | 10 |
| 0 | 3.3 | 2.0 | 5.1 | 6.4 | 4.9 | 1.1 | 4.2 | 2.3 | 1.9 | 1.9 | 3.0 | 2.7 | 1.6 | 2.7 | 3.6 | 7.3 |
| 2 | 3.2 | | | 6.4 | 4.9 | | 4.1 | | 0.4 | | | | | | | |
| 3 | | | 5.1 | | | | 4.1 | | | | 1.8 | | | | 4.1 | 7.3 |
| 4 | 3.2 | 1.8 | | 6.4 | 4.8 | 3.1 | | 2.0 | 0.6 | | | 0.6 | | 4.4 | | |
| 5 | | | | | | | | | | 0.4 | 1.2 | | 1.0 | | | 7.3 |
| 6 | | 2.2 | | | | 3.1 | | 2.3 | | | | 0.9 | | | | |
| 7 | | | 4.7 | | | | | | 0.6 | | | | | | 2.0 | |
| 8 | | 3.0 | | | | 3.3 | | 2.2 | | | | 2.8 | 3.0 | | | |
| 9 | | | | | | | | | 0.6 | | | | | -0.9 | | |
| 10 | | 2.1 | | | | 3.3 | | 2.2 | | 0.0 | | 0.6 | -1.6 | | | |
| 11 | | | 4.7 | | | | | | | | | | | -0.9 | | |
| 13 | | | 5.0 | | | | | | | | | | -0.2 | -0.9 | -1.3 | |
| 14 | | | | | | | | | | 0.8 | | | | | | |
| 15 | | | 4.2 | | | | | | | | | | 0.0 | -0.9 | -1.0 | |
| 16 | | | | | | | | | | 1.1 | | | | | | |
| 17 | | | 0.4 | | | | | | | | | | -1.0 | | -1.1 | |
| 18 | | | | | | | | | | 1.0 | | | | | | |
| 20 | | | | | | | | | | 1.0 | | | | | -1.1 | |
| 22 | | | | | | | | | | | | | -2.0 | | | |
| 27 | | | | | | | | | | | | | -1.8 | | | |
| 32 | | | | | | | | | | | | | -2.2 | | | |
| 37 | | | | | | | | | | | | | -2.0 | | | |
| 40 | | | | | | | | | | | | | -1.8 | | | |
| 42 | | | | | | | | | | | | | -1.7 | | | |
| 44 | | | | | | | | | | | | | -1.9 | | | |

# 5 Late Quaternary and recent environmental situation around the Olenyok Channel (western Lena Delta) and on Bykovsky Peninsula

## 5.1 Objectives and tasks

*(L. Schirrmeister)*

The fieldwork of a group of 6 scientists was mainly focused on supplementary multi-disciplinary studies of Quaternary deposits in two positions on the northern bank of the Olenyok Channel, western Lena Delta and one position on the Bykovsky Peninsula (Figure 5-1). All these activities were connected with former studies at the Olenyok Channel (Schwamborn 1999, Pavlova & Dorozhkina, 2000) and on the Bykovsky Peninsula (Siegert et al. 1999, Sher et al. 2000) in the frame of the expeditions "Lena Delta 98" and "Lena Delta 99". The main objective was the geocryological survey of Late Pleistocene Ice Complex deposits in the western Lena Delta for comparison with similar deposits studied during former expeditions and the supplementary studies of the sandy horizons, lying below the Ice Complex deposits. Additionally, we studied recent nival processes in connection with perennial snow patches in the mountains of the Chekanovsky Ridge, south of the Olenyok Channel.

The methods of geological and geocryological survey and the sampling and preparations of sediments, ice wedges and fossils were the same as described in former expedition reports (Siegert et al. 1999, Schirrmeister et al. 2000).

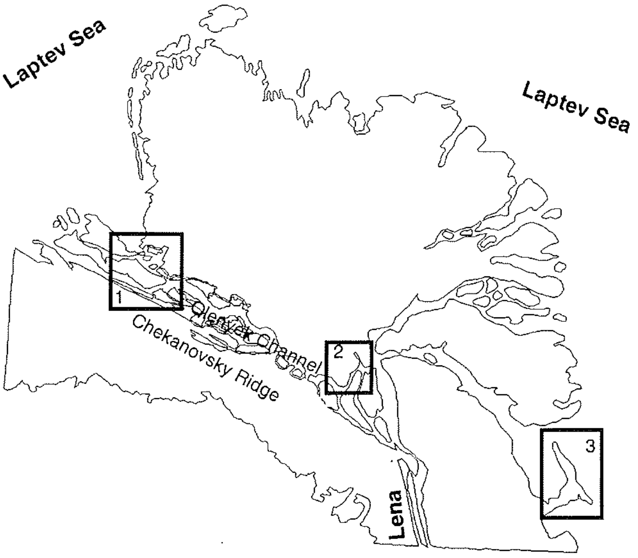


**Figure 5-1:** Map of the Lena-Delta with locations of the study areas 1-Nagym, 2-Buor Khaya, 3-Bykovsky Peninsula.

## 5.2 Geological and geomorphological situation of the Olenyok-Channel area

*(V.V. Kunitsky, L. Schirrmeister)*

The about 200 km long Olenyok-Channel is the only channel of the Lena Delta draining to the West. To the south this river is bounded by the mountains of the Chekanovsky Ridge and to the north by the 30-40 m Late Pleistocene third terrace of the Lena Delta. (Figure 5-2). The Chekanovsky Ridge is described as a system of narrow asymmetrical anticlines, which are divided off by broad trough-like synclinals (Mikulenko 1996). This system consists generally of a sequence of overthrusted imbricate synclines. The tectonic dislocation continues to the north below the Lena Delta as a system of small grabens and horsts (Mikulenko 1996). Quaternary tectonical activities might be responsible for the special geomorphological and geological structure of the Lena Delta region (Are & Reimnitz 2000).

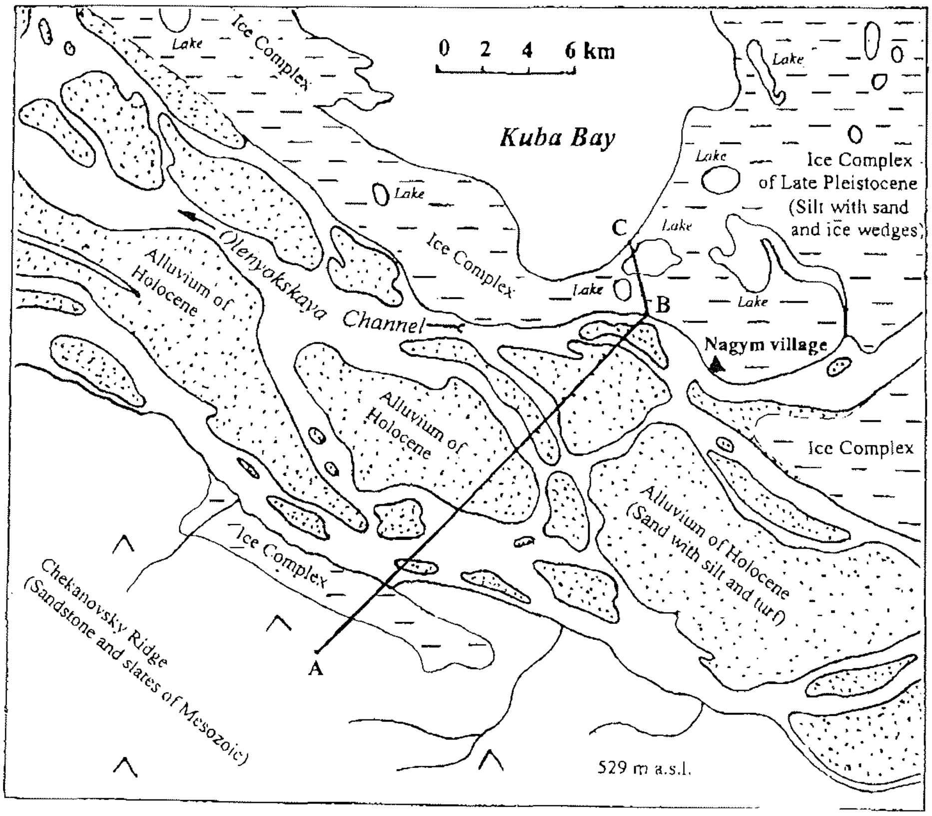


**Figure 5-2:** Schematic geomorphologic map of the study area between Kuba Bay and Chekanovsky Ridge.

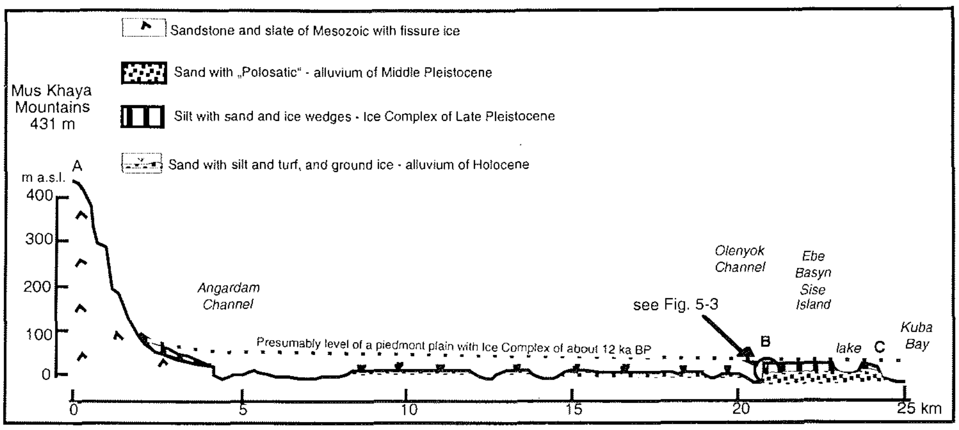


**Figure 5-3:** Schematic geocryologic profile across the Olenyok Channel on the line A-B-C (see Figure 5-2).

The geological situation along the Olenyok Channel is characterized by the appearance of two different sediment sequences, which follow one another. The lower Bulukursky Suite is described as aluvial-eolian sandy deposits with gravels (Lungersgauzen 1961). The peaty, ice-rich Kobakh Suite (Lungersgauzen 1961) discordantly covers the Bulukursky Suite (Figures 5-3/4).

After Vereshchagin (1982) the Kobakh Suite consists of an alternation of peat and black silts and contains large ice wedges. Fossils of the Mammoth Fauna and brackish diatoms have been proved in this sequence. Galabala (1987) has compared the sands of Bulukursky Suite with sandy deposits on the northern situated Arga Island because of sedimentological and cryolithological similarities. The 30 to 40 m high cliffs along the whole northern riverside of the Olenyok Channel mainly consist of these two sequences. This steep coast alternates with a gentle coastal part in Holocene thermokarst depressions (alases). Single hills of pingos have been observed in such alases. Additionally, several small thermoerosional valleys cut the northern riverside of the Olenyok Channel. Numerous sandy islands with peat covers of floodplain and the first terrace above the floodplain (Pavlova & Dorozhkina 2000) are situated between the Chekanovsky Ridge to the south and the Islands Ebe Basyn Sise, Khardang Sise, Djangylakh Sise and Kurungnakh Sise.

Lungersgauzen (1961), Kunitsky (1989) and Grigoryev (1993) described some sections on the Olenyok Channel. In the frame of the Russian-German cooperation "System Laptev Sea 2000" new sedimentological investigations and age determinations were carried out by Schwamborn (1999) and new geomorphological mapping by Pavlova and Dorozhkina (2000).

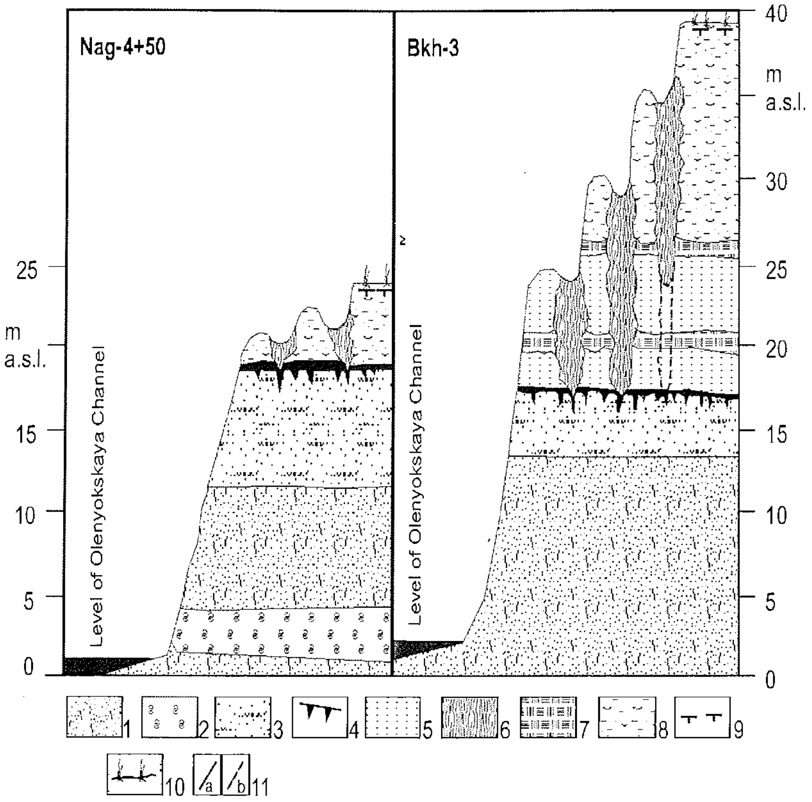


**Figure 5-4:** Schematic Profile of Ice Complex and subjacent formations of the section Nagym and Buor Kyaha on the northern riverside of the Olenyok Channel (Lena Delta).

1-2 Formation of Quaternary cryolithogenic deposits with ice cement and slim ice wedges (Bulukursky Suite): 1 stratified sand with buried grass and shrub roots, 2 peaty sand layers, 3-sand layers with a few of gravel lenses 4 surfical cryogenic eluvium (fragments of buried hydromorphic paleosol)
5-8 Ice Complex deposits (Kobakh Suite): 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 recent soil, 11 lithologic boundaries: a determined, b supposed

## 5.3 Study area of the western Olenyok Channel - Nagym

### 5.3.1 Geological-cryolithological survey

*(L. Schirrmeister, V. Kunitsky, G. Grosse, T. Kuznetsova)*

The first study location was the northern riverside of the Olenyok Channel west of the Lena Delta between the campsite (N 72°52'44", E 123°12'3") and the small settlement Nagym (N 72°52'46", E 123°19'20") (Figure 5-5). The geological survey was carried out about 4.5 km along the riverside (Figures A5-1). The cliff was studied geocryologically and sedimentologically more detailed in a distance of about 400 to 600 m from the camp valley. Like in former expeditions we tried to combine a whole profile by means of several subprofiles.

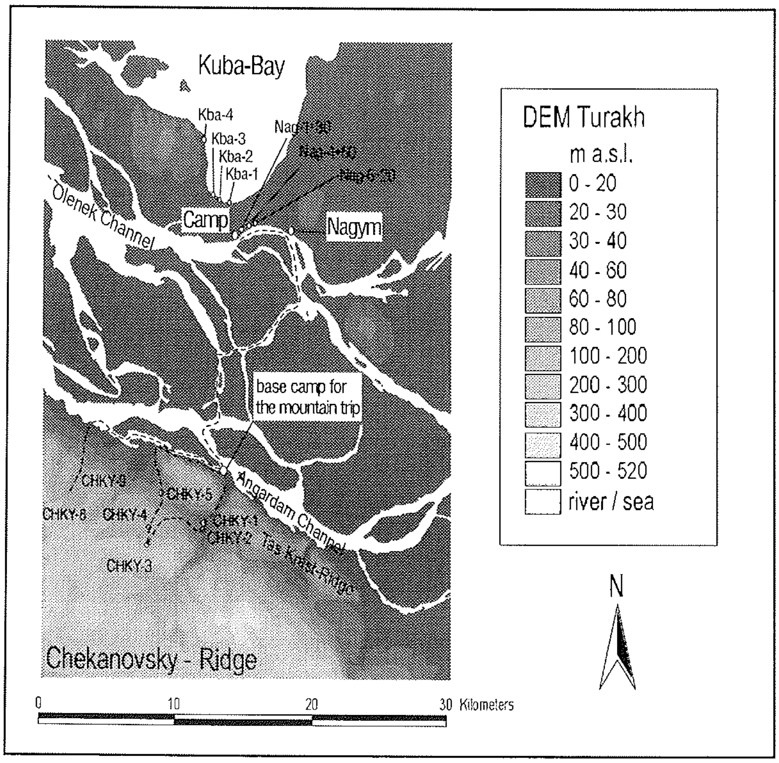


**Figure 5-5:** The study area in the western Lena Delta, near the settlement of Nagym; based on the digital elevation model (DEM) of the Lena Delta (Antonow et al. 1999).

At first numerous markers were established in distances of 100 m as simple orientations on the shore. The exact appellation of the single profile consists of the number of the nearest marker and the distance of the study point to this marker. The altitude of study points and characteristic locations was surveyed by tape measurements. Sediments were sampled by hammer; hatchet and spade for ice content determination in the camp as well as later sedimentological and micropaleontological analysis and radiocarbon age determination (Table A 5-2). In the camp sediment samples were separated for pollen analysis. Sampling of ice wedges was carried out by chain saw. At first we had sawed two horizontal wedge-shaped cuts and than, in a distance of 10 to 15 cm, vertical cuts in order to obtain sequences of single ice samples. Ice samples were thawed in the field laboratory and separated for isotope and hydrochemical studies (Table A5-3).

The main emphasis was laid on the study of the boundary between the lower sandy deposits and the Ice Complex as well as the Ice complex deposits themselves.

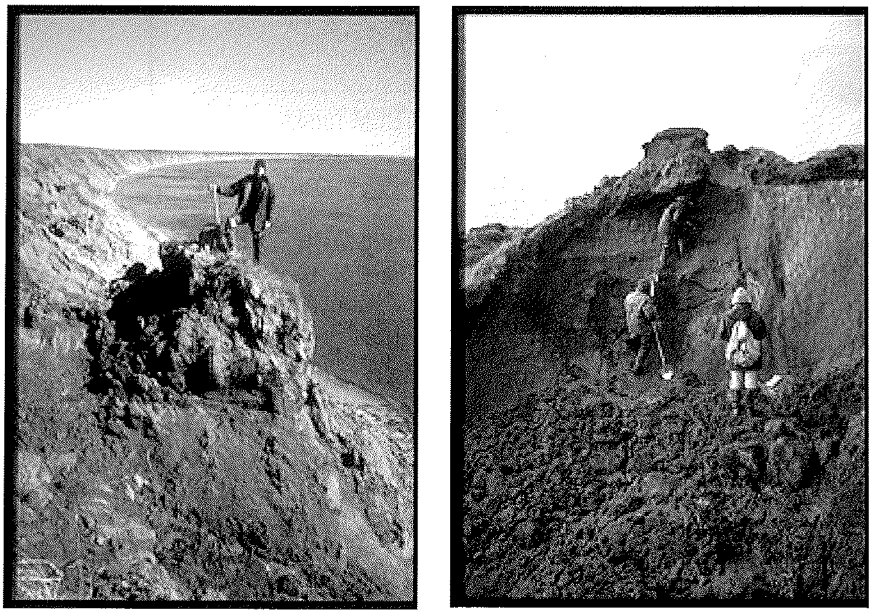


**Figure 5-6:** Thermokarst mound with peaty paleosol (right picture) and the contact of ice wedges and permafrost deposits with deformation of sandy sediments (left picture) near the settlement of Nagym.

The sandy deposits of about 10 to 15 m thickness are subdivided into two parts (Figure 5-7). The fine- to middle-grained lower horizon contains layers of plant remains and peaty sand. The content of plant remains decreases downward. One sample for IR-OSL-age determination was taken near the river level. The upper horizon of the sandy deposit consists of fine-grained silty sand with some interlayers of middle-grained sand and gravels. This horizon contains layers with shrub roots, but generally it contains less organic material. The ice content of the sand deposits is low (about 20 %) and the cryostructure is massive. We have observed a few very small ice wedges about 10 cm wide and some fissures filled with ice. Ice wedges were only formed in organic-rich sands.

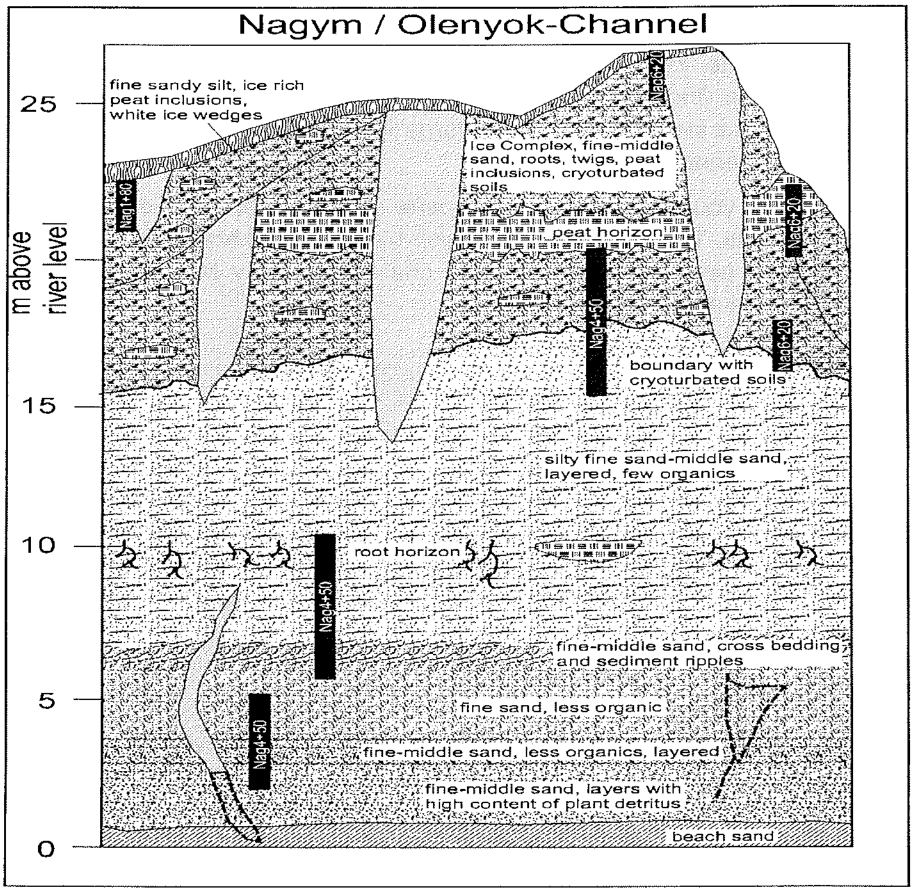


**Figure 5-7:** Normal profile of the studied permafrost deposits at the northern riverside of the Olenyok Channel near Nagym and the position of studied subprofiles.

The ice-rich silty sands of the Ice Complex deposits with peat inclusions, larger peat lenses and paleosols cover the lower sands. At the sharp boundary of these two different units a brownish-grey cryoturbated peaty paleosol is formed. This paleosol was found in different subprofiles at about 15 m above the river. The horizon below and above the boundary was sampled for IR-OSL age determination. The Ice Complex deposits are rich in plant detritus as well as twigs and grass roots and consist predominantly of fine to middle grained sand. Ice bands of about 2 to 5 cm thickness characterize the cryotexture and lens-like reticulation of ice in the sediment interlayers. The gravimetric ice content is about 30-80 %. The ice wedges of the Ice Complex reach some meters and have a width of 0.5 to 0.7 m even in lower sands. The roots of the deep ice wedges consist of vertical alternations of 1 cm small strips of ice and sediment (polosatiks). On top of the sections these ice wedges are 3 to 5 meters in width. The ice wedges are vertically stripped and contain numerous gas bubbles.

Near the top of the outcrop we have studied some large deformations of permafrost deposits. Yellow coarse-grained sand seems to underlie typical Ice Complex deposits (Figure 5-6, right). These might be deformed sands from below, which were steeply upturned at large ice wedges or sands, that have filled erosional channels on the surface.

Small profiles of younger, probably Holocene deposits were studied near the top of the sections. They consist of brownish-black cryoturbated silty sand with numerous small peat inclusions and are characterized by smaller white ice wedges (1 m wide and 3 m long).

### 5.3.2 Paleontological study

*(T. Kuznetsova, S. Kuzmina)*

Paleontological studies of the Pleistocene deposits at the Olenyok Channel included research and collecting of large and small fossil mammals, fossil and modern insects. Previous researchers had found some mammal bones in this area (Pavlova et all. 2000) and samples of fossil insects, but during our expedition fossil mammals and insects at the Olenyok Channel were sampled systematically for the first time.

Collection of mammal fossils

As in 1998, 1999 on Bykovsky Peninsula and Bol'shoy Lyakhovsky Island all of the found bones and their fragments were registered in order to obtain statistics of species composition as complete as possible. During our work in 2000 in the western part of the Olenyok Channel at the Nagym exposure we collected only 31 bones and bone fragments of large mammals (Table A5-4). They were collected from an about 4 km long segment of the northern coast of the Channel. Unfortunately, not one bone was found strictly *in situ*. Most of the material has been collected within the exposures. These bones belong to group "b" (found in mudflow, in the outcrop) - 25 specimens. We had not known their initial position in the outcrop, but the interval of their stratigraphic position could be reconstructed. Another 6 bones were collected on the shore and compose the group "d". Three samples of group "b" we sent to the Radiocarbon Laboratory of the Geological Institute RAS for conventional $^{14}$C dating.

Remains of small fossil animals were screened from the lower part of the Nagym section - the „Bulukursky Suite". The screening was performed by the sieve with 1 mm mesh. All four samples were collected from "Bulukursky Suite". Three samples (R1, R3, and R4) were taken from the highest part of the "Bulukursky" deposits. There is yellow-grey sand with rock debris, rubble and plant remains in the Ice Complex-"Bulukursky" boundary (Figures A5-1.1, Table A5-5). Sample R2 was collected from grey sand with seams of plant detritus

3.5m below the boundary. More than 450 kg were screened but the collected assemblage of small mammal fossil is not rich and varied. Screening residual of sample R1 contained several specimens of *Gastropod* (sample M1) (Figure A4-1.1).

### Collection of screened samples for fossil insects

The Lena Delta is a rather interesting region for paleoentomological research, because it is situated between two paleogeographic areas. East of the Lena Delta xerotic tundra-steppe Pleistocene insect complexes were found and west of the Lena Delta xerotic or mesic tundra ones. Besides, one of the refuge of tundra-steppe biota is situated there (one of such areas is located in the Lena Delta at the Belaya Skala, Tit-Ary Island). There were only several small samples from Olenyok Channel collected before our expedition.

From the Nagym exposure 8 samples were screened for insect fossils, 5 of them are from sands of “Bulukursky Suite” and 3 - from the deposits of Ice Complex (Table A5-5). All samples were screened by the hand sieve with 0.5 mm.

Sands of “Bulukursky Suite” contain a few plant detritus seams and lenses, which could contain insect remains. Layers with allochthonous peat and stems of Equisetum did not contain a lot of remains of fossil insects. On the other hand layers of well-sorted sand also did not contain any fossil insects. We selected sand seams with plant detritus and screened 100-200 kg from each sample.

From the Ice Complex only 3 samples were collected, because the Ice Complex deposits were not of great thickness. Samples were collected from layers of silt or sand with plant detritus. In this case the sample size for insect fossils was almost 60 kg (Table A5-5).

## 5.4 Study area of the Eastern Olenyok-Channel - Kurungnakh Island (Buor Khaya)

### 5.4.1 Geological-cryological survey

*(L. Schirrmeister, V. Kunitsky, G. Grosse, T. Kuznetsova)*

The second study location was situated in the central Lena Delta at the eastern bank of Kurungnakh Island (Figure 5-8). Four different sites were studied in a distance of about 2.5 km in the location Buor Khaya between N 72°20'00" E 126°17'16" and N 72°21'02" E 126°19'16". The expedition group was accommodated on the small vessel "Neptun" in front of the study section.

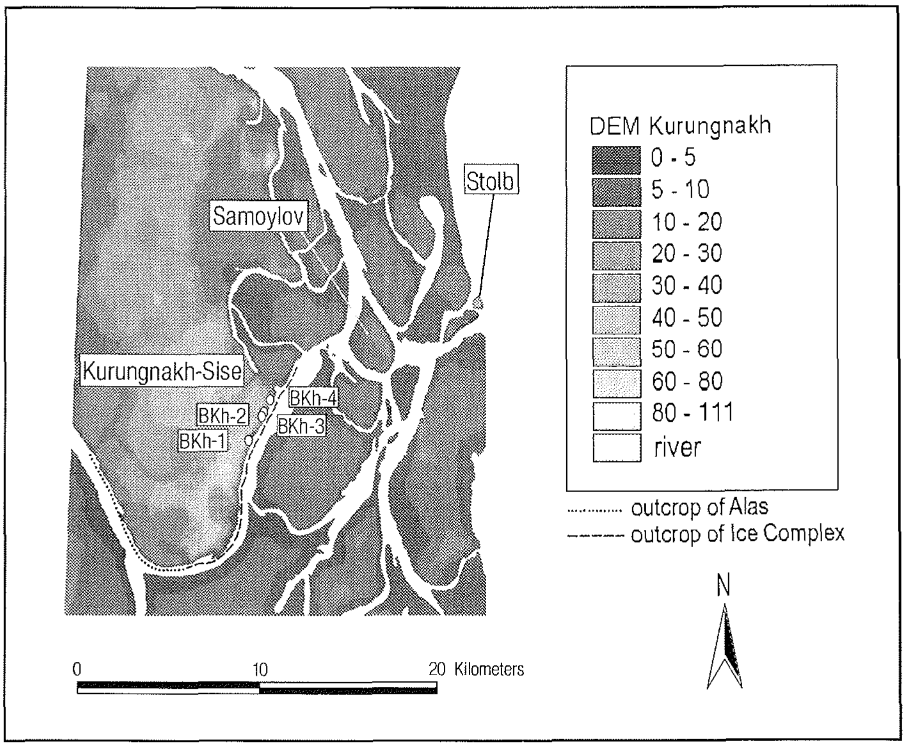


**Figure 5-8:** The study area in the central Lena Delta near Samoylov Island; based on the digital elevation model of the Lena Delta (Antonow et al. 1999).

Here generally the same situation was found like in the location Nagym (Figure 5-9, Figure A5-1-2). In the first position (Bkh 1) organic-free fine layered middle-grained sands of about 20 m thickness were covered by Ice Complex deposits. These sands with massive cryostructure contain only a few small ice wedges. The roots or ends of large ice wedges penetrate from the Ice Complex deposits into the lower sand unit (Figure 5-10). Small channel cast of about 0.3 m width filled with fine laminate organic detritus occurred repeatedly in the uppermost sand horizon. We were not able to study more detailed the boundary between these two deposits in this position because of the steep wall (Figure 5-10).

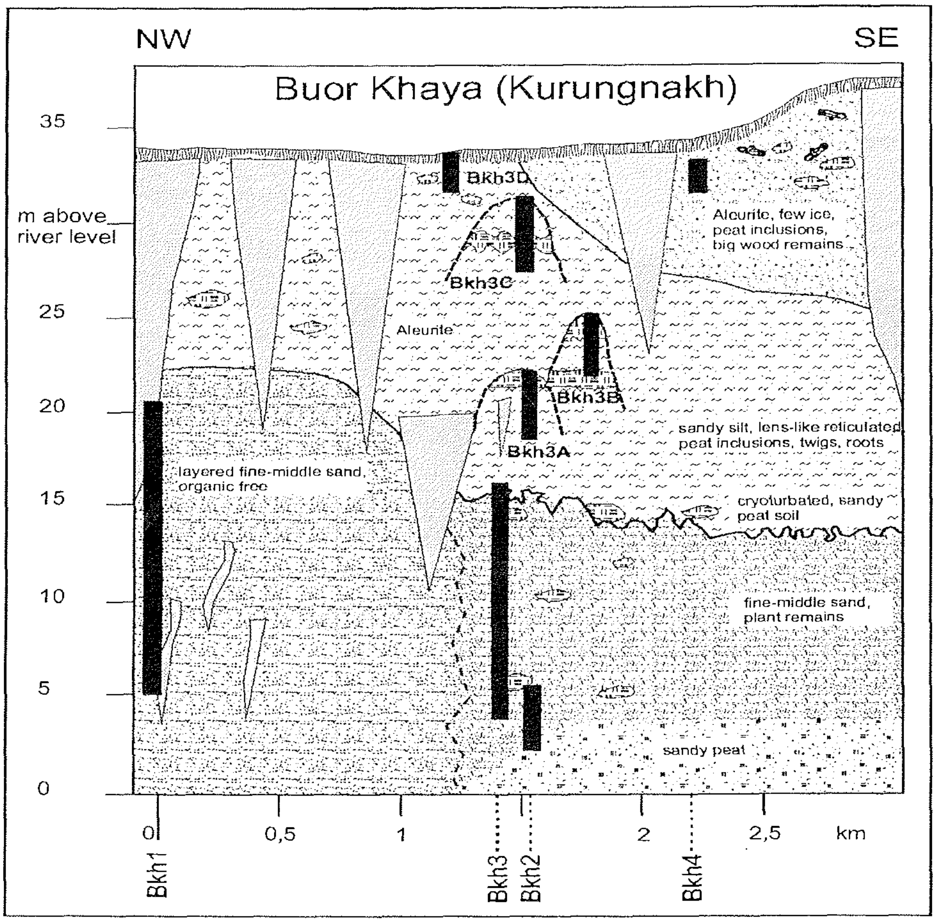


**Figure 5-9:** Normal profile of the studied permafrost deposits of Kurungnakh Island in the central Lena Delta at Olenyok Channel.

A combined profile from the river level up to the top of the cliff was studied at the points Bkh 3 and Bkh 3. A layered sandy peat horizon of about 3 m was covered by fine laminated sands of about 10 to 12 m thickness containing twigs with barks and vertical autochthonous roots. The sandy peats were sampled for U/Th age determination. At the boundary between the sandy unit and the Ice Complex cross-bedded channel casts of about 0.5 m width were visible. Additionally, a strong cryoturbated 1 m thick silty-sandy paleosol with an involution layer and peat inclusions was formed there. Below and above the boundary samples were taken for IR-OSL-age determination. The lower part of the Ice Complex contains several horizons of moss peat of about 0.5 to 0.7 m thickness, which could be studied in several neighboring thermokarst mounds. The sediment interlayers consist of grey silty sand and contain numerous vertical grass roots and small twigs. 1 to 2 cm thick ice bands and lens-like reticulation of ice characterized the cryostructure. Beside of large ice wedges (about 20 m long and 5 to 7 m wide) we observed single small ice wedges in a few thermokarst mounds. Peaty paleo-cryosols appeared in the upper part of the Ice Complex but not such thick peat horizons or lenses like in the lower part.

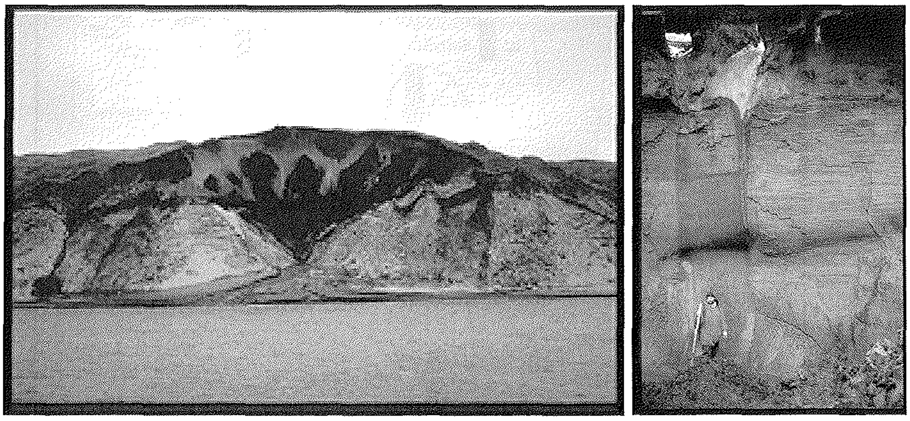


**Figure 5-10:** Ice Complex deposits cover the lower sand unit at the section Buor Khaya (Khardang Island).

Organic-rich Holocene Alas deposits situated some hundred meters to the east (Bkh 4) contain large remains of birch and alder. These sediments consist of alternated cryoturbated middle-grained sands and silty sands (aleurite) and contain numerous plant remains and peat inclusions. We have to note that these certainly Holocene sediments contain large ice wedges of about 3 to 5 m width like in the Ice Complex deposits described before. In general, it looks like Ice Complex deposits but with larger trunks and boughs. The according ice wedge polygons (diameter 15-20 m) were visible on the surface above the cliff. One of the ice wedges was sampled for stable isotope analysis.

### 5.4.2 Paleontological study

*(T. Kuznetsova, S. Kuzmina)*

Collection of mammal fossils

Although we worked a much shorter time at the Buor Khaya outcrop Kurungnakh Island (East of the Olenyok Channel) and a much shorter time than at Nagym outcrop, we collected a more representative collection. With help of all our team members we collected 81 bones and bone fragments. Strictly *in situ* in frozen silt of the Ice Complex we found one bone – *radius* of horse with copulas and bone marrow inside. It was sent to the Radiocarbon Laboratory of the Geological Institute RAS for conventional $^{14}C$ dating.

Most of the material we collected at the Buor Khaya exposure was divided into two groups - 32 bones belong to group "b" and 22 bones compose group "c". Bones of group "b" were found in the thermo-erosional cirques of the exposure. We know the altitude of these founds (the level of minimum altitude of their original position) and can define the area where the bones come from. Among this group there are several bones of leg *Mammuthus primigenius* (Bkh O-68 – Bkh O-90) which belong to one individual (Table A5-4). Group "c" includes bones, which were also collected at the exposure but in debris. We are unable to define their initial position on the cliff. Fourth group ("d") includes bones from the shore. From the shore and sandbank we also collected bones, which were, we believe, transported by ice-flow from distant parts of this outcrop or from other exposures of the eastern part of Olenyok Channel. Such bones (6 specimens) were selected in the separate group "e". As time was limited the screening of small mammal fossils was not carried out on Kurungnakh Island. In Moscow we sent several samples of big bones from different groups to the Radiocarbon Laboratory of the Geological Institute RAS for conventional $^{14}C$ dating. On the whole, the preliminary list of vertebrate taxa identified at the Olenyok Channel collection contain 10 species of mammals.

**Table 5-1**: Preliminary list of vertebrate taxa identified at the Olenyok Channel collection (Nagym and Buor Khaya exposures).

- Class MAMMALIA-mammals
  - Order Lagomorpha
    - *Lepus sp.* (hare)
    - *Lepus tanaiticus Gur.* (Pleistocene hare)
  - Order Rodentia
    - *Microtinae gen.* (Voles and lemmings)
- Order Carnivora
  - Family Felidae
    - *Panthera spelaea (Gold.)* (Pleistocene "lion")
- Order Proboscidea
  - *Mammuthus primigenius (Blum.)* (woolly mammoth)
- Order Perissodactyla
  - Family Equidae
    - *Equus sp.* (horse)
    - *Equus caballus L.* (Pleistocene horse)
- Order Artiodactyla
  - Family Cervidae
    - *Rangifer tarandus (L.)* (reindeer)
  - Family Bovidae
    - *Ovibos moschatus Zimm.* (muskox)
    - *Bison priscus (Boj.)* (Pleistocene bison)
- Mammalia gen.*

*Mammalia gen. – non-identifiable fragments of bones of large mammals.

All determined species are typical for the Pleistocene deposits of the Arctic region and the composition of the mammalian bone collection also is very typical.

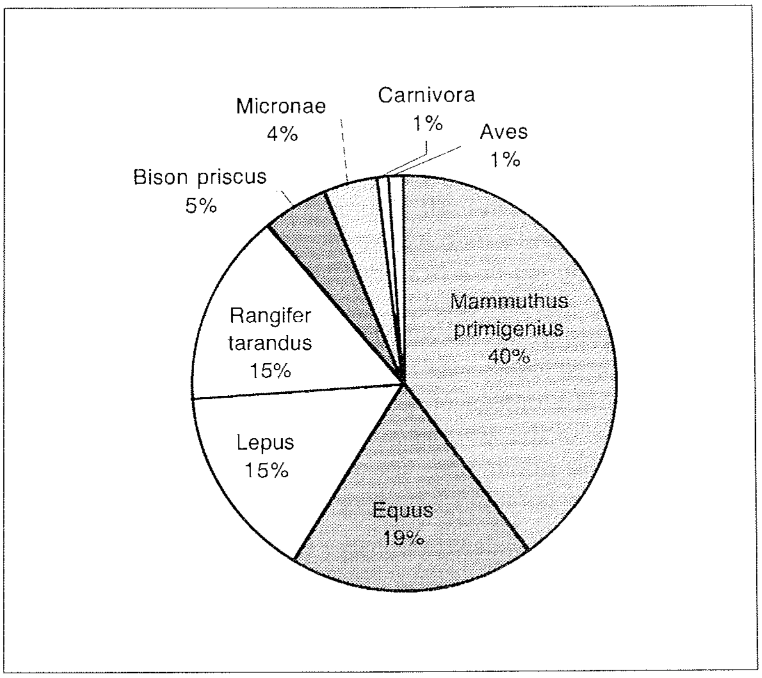


**Figure 5-11:** Composition of the mammal bone collection from the Olenyok Channel.

Collection of screened samples for fossil insects

Because of limited time, on Kurungnakh Island only Holocene deposits were sampled. There are 4 samples, 3 of which (Bkh–B1, -B2, -B3) were screened from the high flood plain section of the Lena River. It is located 0.5 km off the main Buor Khaya section. Plant remains from the Bkh-B-2 were sent to be radiocarbon dated. One sample (Bkh–B4) was screened from silt with abundant wood shrubs and parts of tree stems. These deposits form the Holocene part of the Buor Khaya exposure (? alas complex). The sample (BKh-B4) amount was 160 kg. The biggest parts of these samples consist of shrub stems and parts of wood. This material was sent to Yakutsk for radiocarbon-dating as well (Table A5-5).

## 5.5 Geomorphologic map of the Olenyok Channel mouth in the Lena River delta

*(D.Yu. Bolshianov)*

A geomorphological map of the Olenyok Channel mouth has been constructed on the basis of the 2000 field studies (Figure 5-11). The studies include a geomorphologic survey and an investigation into loose deposits comprising the terraces. The terrace levels differing in age and genesis were identified using the following criteria:

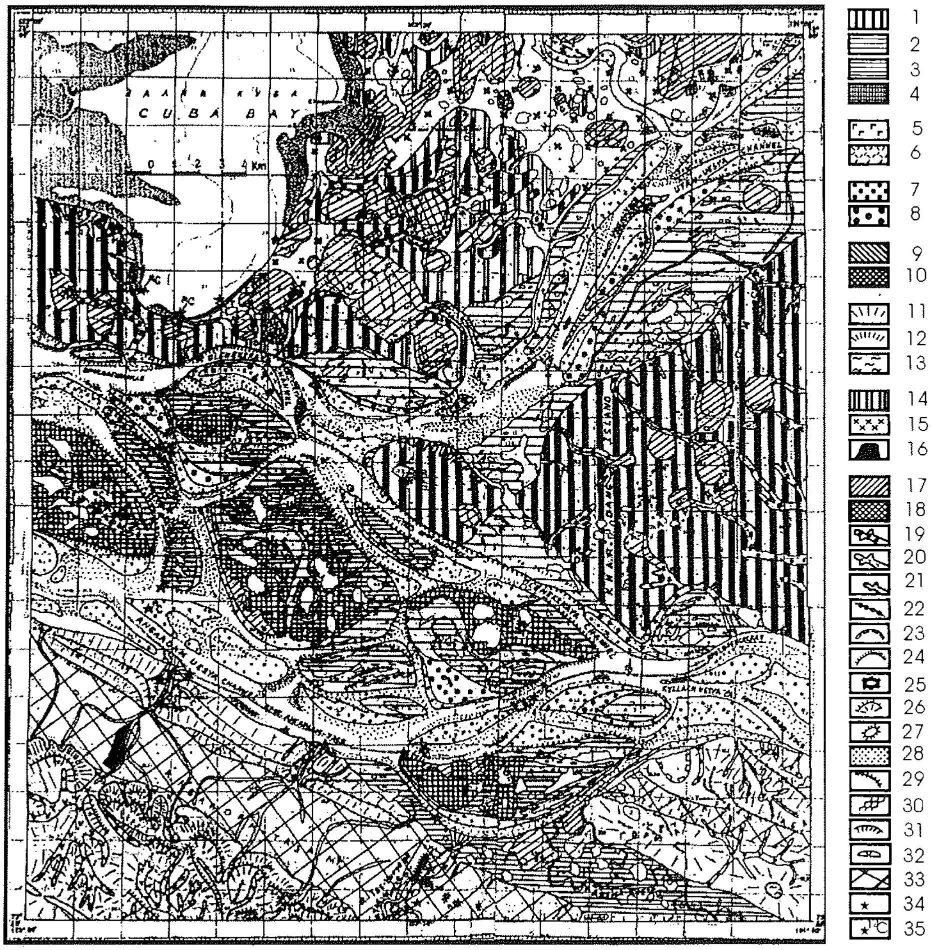
- Geological structure;
- Development of permafrost processes;
- Presence of the ancient channel network components and the absolute height above the sea level.

For this purpose, the direct field observations and interpretation of aerial photographs were performed.

In general, the structure of the massif of islands in the channel mouth is determined by denudation of estuary-alluvial deposits accumulated during the Holocene. A different time of accretion of these sediments indicates several estuary-made cycles occurring in the place of the modern channel and erosion washout stages following them. The accretion conditions occurred at the increased level stand of the receiving basin (Laptev Sea) with the washout stage being manifested at the decreased erosion basis. At the heights of 2-4 and 8-12 m the marine terrace mapped in Kuba Bay also indicates the sea level rise in the Holocene.

The current river regime determines the structure of alluvial long shore ridges and islets joining the old delta islands. This type of accumulation bodies comprised of sands differs significantly from the main massif of islands by the sedimentation conditions, the deposits of which were accreted under the conditions of weak flow estuaries. The active thermokarst processes that occur continuously during the Holocene change to a great extent the appearance of the delta islands.

The alluvial-marine terrace of a height of 30 m detected in the piedmont area of the Angardam-Tasa mountains (the Tas-Yuryage river mouth) reveals that in the Late Pleistocene, the Laptev Sea level fluctuation had a large significance for the formation of the Lena River delta. The precise determination of the age of the events described will be specified after the radiocarbon analysis of the sediment samples collected from different terraces.



**Accumulative Relief**

*Alluvial-estuarine surfaces:* 1-Late Pleistocene alluvial-estuarine terrace 20-50 m high consists of sand at the base with a mantle of icy silt (ice complex deposits); 2-Late Holocene alluvial-estuarine terrace 4-5 m high; 3-Late Holocene alluvial-estuarine terrace 5-6 m high; 4-Late Holocene alluvial-estuarine terrace 6-8 m high

*Marine surfaces:* 5-Late Holocene marine terrace 2-4 m high; 6- Modern wood beach

*Alluvial surfaces:* 7- Modern flood plain terrace < 3 m high; 8-Modern flood plain terrace 3-5 m high

**Denudated Relief**

*Marine surfaces:* 9-Late Pleistocene - Holocene abrasional terrace 8-12 m high; 10-Late Pleistocene abrasional terrace 25-30 m high

*Surfaces of complex denudation:* 11-Slopes with steepness less than 15°; 12-Slopes with steepness more than 15°; 13-Flat surface of watershed (terrace of unknown genesis)

*Accumulative - denudation Relief:* 14-Denudated surface of Late Pleistocene alluvial-estuarine terrace 10 - 20 m high; 15-Denudated surface of the terrace 7-10 m high consists of ice complex sediments; 16-Late Pleistocene alluvial-marine terrace 25-30 m high

**Forms of Relief and other conventional signs**

17-Alassy; 18-Different age alassy superimposed each other; 19-Late Pleistocene-Holocene thermokarst-erosion valley; 20-Pleistocene erosion valley, wide and V-shaped; 21-Holocene-modern erosion valley; 22-Crest of ridge; 23-Circus niche; 24-Terrace's escarp; 25-Pingo; 26-Cuesta with a steep northern slope in accordance with a monoclinal dip to the south of Triassic and Cretaceous rocks; 27-Erosion remnant; 28-Shoal; 29-Channel bank; 30-Beach accumulation rumpart; 31-Piedmont train; 32-Alluvial cone; 33-Valleys subsidented by zones of faults; 34-Investigation Points; 35-Points of sampling for Radiocarbon determination of age.

**Figure 5-11:** Geomorphologic map of the Olenyok Channel mouth in the Lena Delta.

## 5.6 Recent environmental studies

*(G. Grosse)*

During the expedition "Lena-Delta 2000" the Olenyok-Team carried out several studies regarding the recent environment.

**Measurements of the river water level oscillations** were carried out in the river Olenyok in front of the campsite (N 72°52'44" / E 123°12'03") near Nagym. During the Lena-Delta 1999 expedition Pavlova & Dorozhkina (2000) used the same location for hour-wise water level measurements within 48 hours. This year's measurements were executed episodically but consequently during the whole time of our stay. We got a total number of 105 single measurements of the water level within the period 2nd August to 16th August (about 320 hours of measurement) (Figure 5-12). Within those 13 days a maximum amplitude of 70cm was observed. Changes of more than 50cm sometimes occurred within less than 8 hours. This might have been a source for errors too, because the range between two single measurement points is sometimes more than 8 hours. Reasons for a non-periodical oscillation of the river water level could be wind-induced water level changes in a regional style from the sea into the wide river mouth, respectively in a more local style around the studied location.

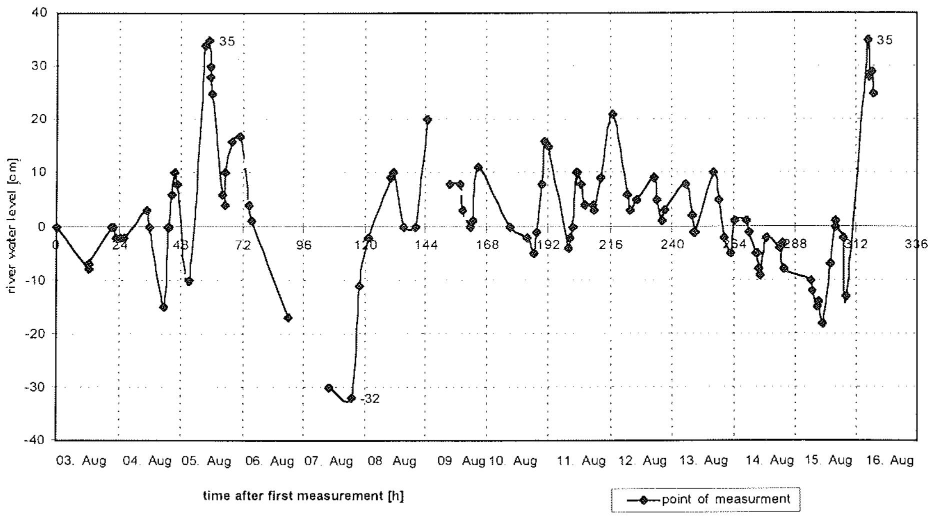


**Figure 5-12:** Water level oscillation of the Olenyok Channel near. Nagym from 02.08.00 (11 p.m.) to 16.08.00 (12 a.m.).

The **air temperature** was episodically monitored by a digital weather station 2m above the surface in front of our camp near Nagym during the same time. Altogether 43 temperature measurements were collected (Figure 5-13). On 4th August ($7^{30}$ p.m.) the maximum air temperature was 24°C and a minimum air temperature of 1°C on 9th August ($0^{00}$ a.m.). A strong decreasing average temperature from 3rd August to 15th August is obvious.

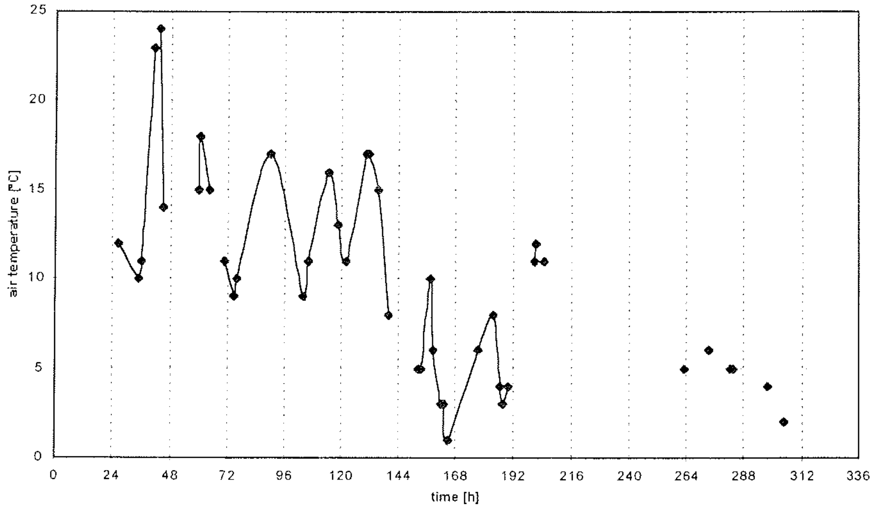


**Figure 5-13:** Measurements of temperatures from 04.08.00 to 15.08.00.

## Observations of recent phenomenon in a permafrost environment

### Zonation of recent beaches

On a one-day trip our team investigated a coastal area of the Kuba Bay situated some kilometers north of our campsite. The shallow bay (6 m in the deepest parts) is very strongly affected by the low tides of the Laptev Sea and wind induced water level changes. Therefore, some beach areas have a special zonation according to the material sorting (Figure 5-14). The studied coastal line is approximately 5km in length and is situated in the most southern part of the bay.

The average width of the beach was 10-20 m at high tide and 80-100 m at low tide. A coastal cliff of up to 8m in height borders the polygonal tundra in the hinterland from the beach area. Remarkable are some large pieces of drift wood discovered in polygonal melt water ponds near the cliff approximately 3 m above the beach level (similar to observations made at Mamontovy Khayata outcrop, Bykovsky Peninsula). Additionally, the melt water of these polygonal structures was tested for salinity and it was found salty. Several meltwater runoffs, ravines and dry valleys separate the cliff. The permafrost formations exposed at this cliff consisted mainly of sandy to silty deposits with variable ice content.

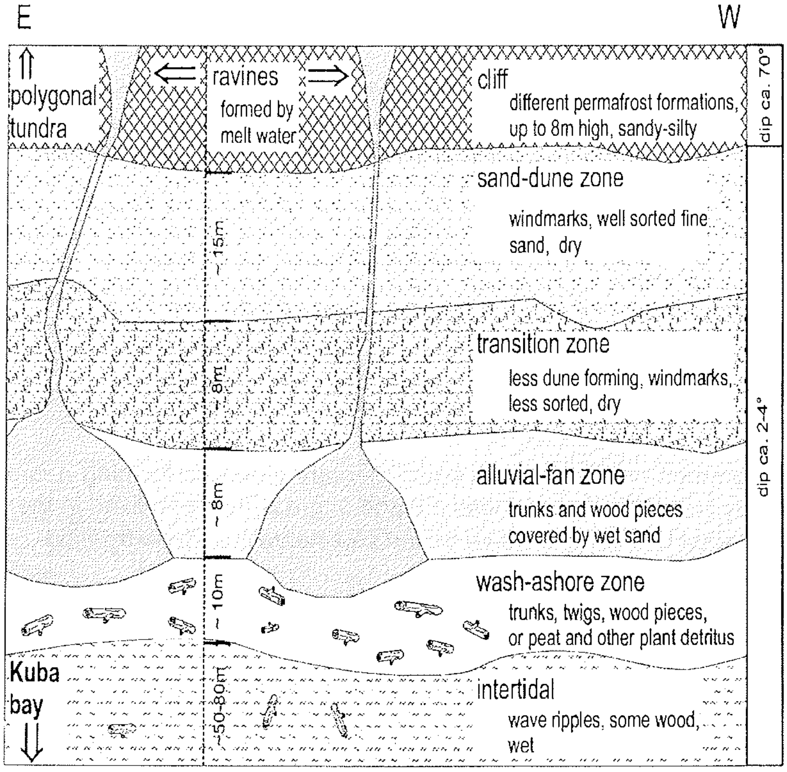


**Figure 5-14:** Different zones of recent deposits at the beach of the Kuba Bay.

Wide parts of the cliff are affected by shore-parallel aeolian activities. An approximately 15m wide part with dunes of very fine-grained dry sand and wind ripples has formed in front of the cliff. Clear wind markings point to unique wind directions from E to W. The next zone is an episodically seawater influenced area with a compact sandy surface and lots of wind markings. The surface has a very gentle dip between 2-4°. Thereafter a wet zone with alluvial fans produced from the ravines has been formed 20-25 m in front of the cliff. The material transported by the ravines overburdens organic matter like wood trunks, wood pieces and twigs. The wood itself is drift material that has been carried by the large streams from the Siberian taiga hinterland. The characteristic reddish color of the water from ravines in this part originates from the humic acids of organic matter leaching iron out of the sediment. The following zone consists of wood, which was washed ashore in huge amounts. The wood in this area is not covered by sediment. At some places peat was the dominating organic washed-ashore material. Remarkable is the zonation within the wood zone. At least two high stands were determined by us. They consisted of huge wood trunks (several meters in length and some dm in width) whereas the material between these two high stands consisted of fine wood pieces (less than 10 cm). The close intertidal of 50-80m width consisted of wet sandy mud with wave ripples and single wood pieces.

Other observations

In the lowest parts of the beach we found many small gaseous bubbles (~1cm ∅) in the muddy surface. Gas production ($CH_4$) from rotting organic matter in the wet sediment could be a possible explanation for this phenomenon.

In several wind exposed places (cliff at Kuba Bay, cliff at campsite) horizons with polished gravel (<1cm ∅) were found. The gravel mainly consisted of quartz, feldspar and sandstone. The origin of the gravel is still not clear but it seems plausible that it originates from the wind eroded sedimentary section above. Various mechanisms of transport and deposition of small stones in a milieu of generally fine-grained sediments can explain the observations. Transport within river ice in winter and spring could be a reason as well as transport within drift wood trunks in summer.

Beyond common wind markings a sedimentary structure forming a circle was found in dry sand. The reason was a blade of grass that was fixed in the ground and was forced to a circular move on the sedimentary surface by wind.

## 5.7 Observations of nival landscapes and processes at the Chekanovsky Ridge

*(V.V. Kunitsky, L. Schirrmeister, G. Grosse)*

Field observations around the Laptev Sea show the importance of nival processes for the relief formation and hydrological and sedimentological processes in this area. 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. The study area is located in the northwestern part of the Chekanovsky Ridge. The studies took place during a small three-days expedition by motorboat (Figure 5-15).

Several snow patches were comprehensively studied (Table 5-2) in order to obtain data on the structure, occurring processes, newly formed deposits and the vegetation connected with this landscape. Excavations were made from snow patches in order to study vertical profiles and to sample snow and firn. The measurement of the snow patch extension was carried out by tape. Plants, mosses and lichens were sampled from nival meadows and rock debris near snow patches. The bodies of snow patches lie criss-cross on the slopes of the study areas in different morphological positions. Horizontal snow patches, which are located parallel to the isohypse are distinguished from transversal snow patches crossing the isohypses of the slopes.

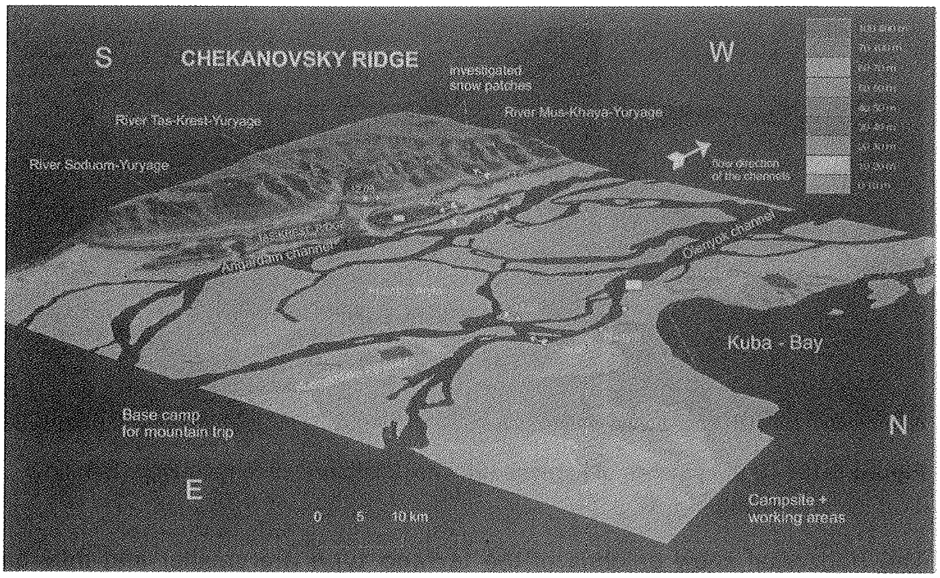


**Figure 5-15:** Recent situations in the western Lena Delta with study areas and expedition routes. The maps based on the digital elevation model of the Lena Delta (Antonow et al. 1999).

**Table 5-2:** Positions and sizes of the studied "cold" snow patches in the Chekanovsky Ridge.

| snow patch No | Latitude | Longitude | Location | Altitude (lower border) [m a.s.l.] | width [m] | Length [m] | Thickness [m] |
|---|---|---|---|---|---|---|---|
| 2 | 73°43'40" | 123°00'13" | nival hollow on a kar-slope | 240 | 25 | 50 | >1.5 |
| 3 | 72°44'12" | 123°00'25" | nival hollow on the rim of a cryoplanation terrace | 107 | 20 | 30 | >0.5 |
| 4 | 72°44'30" | 122°51'40" | nival hollow on a kar-slope | 155 | 70 | 130 | >1.5 |
| 5 | 72°45'00" | 122°54'50" | nival hollow on the upper rim of a cryoplanation terrace | 122 | 10 | 30 | >0.5 |

The transversal snow patches of a **kar-type** were found on nival kars on slopes of the Chekanovsky Ridge mountains (Figure 5-16, left). Such kars have extensions of some hundred meters in diameter in the study area. The nival 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. The snow patches of kar-type are formed when snow is blown from mountain valleys and than accumulates at the end of the valleys or in smaller branch-valleys. Those snow patches consist of alternating horizons of ice, firn and snow, covered by a 1 cm thick dark layers of plant and mineral detritus.

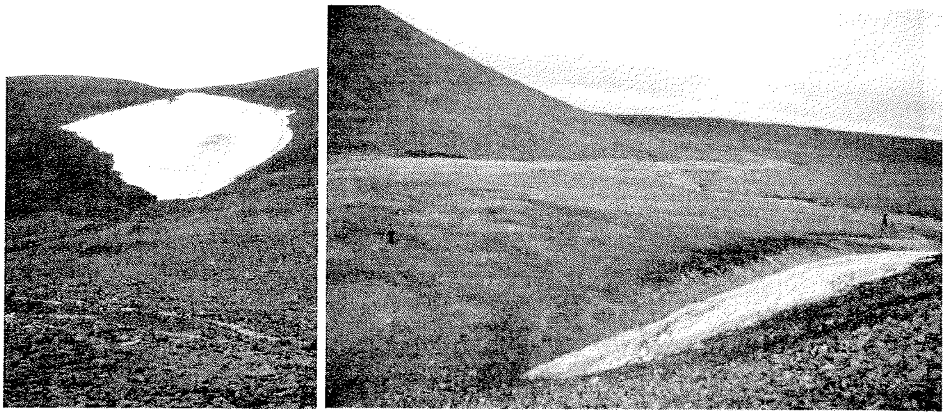


**Figure 5-16:** Snow patches of kar-type (Shn no. 2 left) and of terrace-type (Shn no.3 right).

The horizontal snow patches of the **terrace type** are smaller and they are formed when wind-blown snow accumulates on steps of cryoplanation terraces. Gradually nival niches develop on these steps and snow is better accumulated and preserved in such depressions. One example is the area around the horizontal snow patch No. 3 (Figure 5-16, right).

The area is subdivided into three zones. The zone of the nival hollow with the snow patch lay on debris of sandstone and consisted mainly of ice. Plant and mineral detritus covered these snow patches too. A zone of laminar meltwater discharge lay hypsometrically deeper. The zone of the cryoplanation terrace was covered and surrounded by herbs and grass vegetation. The determined plant association 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). A difference in the elevation of half a meter to distances of several meters is sufficient for such various habitats. The upper part of the strongly wet soil of the cryoplanation terrace consists of freshly accumulated plant and mineral detritus, rock debris, gravels and lenses of sand. These wetted nival deposits near the snow patch contain ice inclusions and lie on icing debris with basal cryotexture below the active layer. The zone of the nival meadow directly bordered a bumpy surface in the area of the laminar discharge. There were frost cracks in this meadow forming smaller (0.5 to 0.7 m) or bigger polygons (Figure 5-16 right). 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). Meltwater of this snow patch type also feeds small creeks, which flow into ravines.

The nival landscapes of slope kars and cryoplanation terraces are sources for fine-grained nival silt and the mixture of clastic and plant detritus. 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 in 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. The plant association of nival meadows indicates favourable conditions for vegetation near snow patches.

## 5.8 Supplement studies at the section "Mamontovy Khayata", Bykovsky Peninsula

*(L. Schirrmeister, T. Kuznetsova)*

The last day of field trip was focused on supplement sampling of ice wedges and permafrost deposits on the best studied Late Quaternary location of the Laptev Sea Region, the Bykovsky Peninsula (Figure 5-17). Although the profiles of "Mamontovy Khayata" (Figure 5-18) are investigated quite detailed during the last two expeditions "Lena Delta 98" and "Lena-Delta 99" (Siegert et al. 1999, Sher et al. 2000) and many results are already published (Meyer et al. 2000, Schirrmeister et al. 2000) there are still some open questions. Some of them should be answered with help of additional samples.

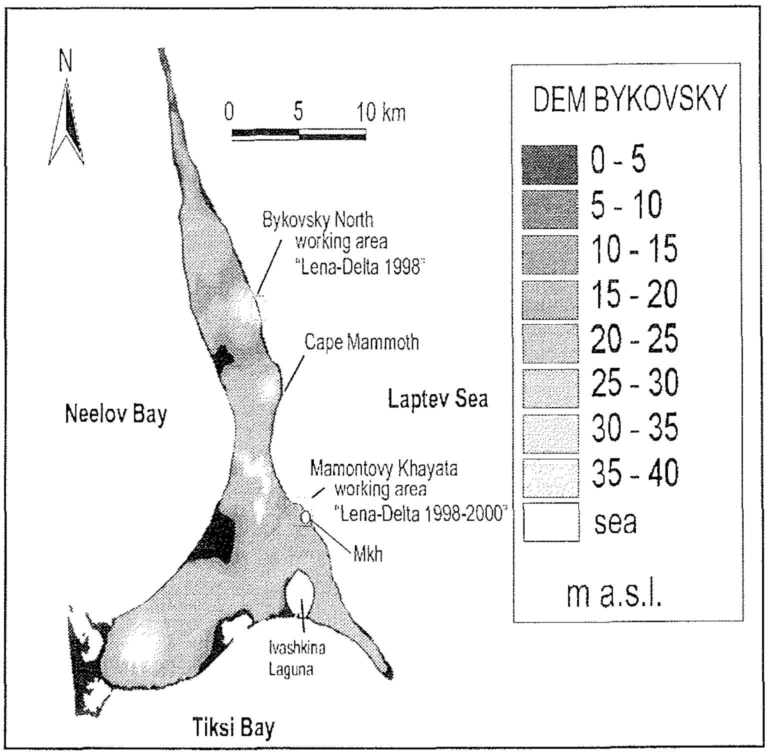


**Figure 5- 17:** The study area of the Bykovsky Peninsula based on the digital elevation model /DEM) of the Lena Delta (Antonow et al. 1999).

At first we have sampled a large ice wedge of the Ice Complex in the altitude of 30-32 m a.s.l. (MKh-00). During former field studies we had no possibilities to work there because of bad outcrop conditions. By chain saw we cut a long step of about 5 m length into the ice wedge 10 m below the surface between two thermokarst mounds. A sequence of 35 samples was taken also by motor saw in distances of 10 to 15 cm. This way we got a horizontal profile of a presumably Late Weichselian (Sartanian) ice wedge, which was missing up to now.

The coastal erosion of the Laptev Sea has formed good outcrops near the sea level and therefore we were able to sample a profile of the perhaps lowest and oldest Ice Complex deposits. These permafrost deposits contain ice-rich silty sands with single small twigs and vertical grass roots. They characterize typical ice-banded and lens-like reticulated cryostructures. The ice belts are bent upward at the contact to about 3 m wide ice wedges. Both, ice wedges and deposits were sampled (MKh-00-10).

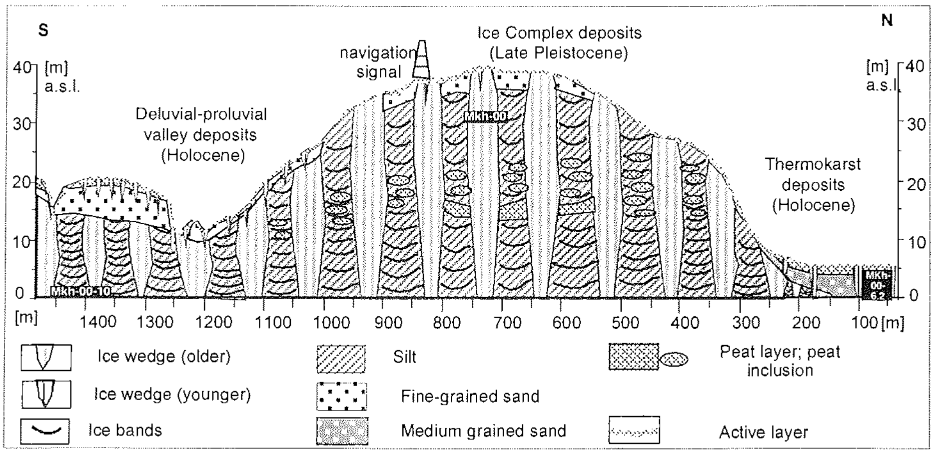


**Figure 5-18:** Scheme of the section Mamontovy Khayata with the new sampling positions.

A profile of alas deposits was sampled in the same position, which had been studied two years ago. This second profile could be helpful to clarify questions of age determination and the character of slope sediments at the border of a thermokarst depression. These deposits consist of ripple- to cross-laminated fine-grained sands with twigs and peat inclusions covered by cryoturbated peaty soil (MKh-00-6.2.).

At the Mamontovy Khayata 90 bones of fossil mammals were collected from the exposure, shore and bar. They supplement our paleontological collection of the previous years. At the outcrop Mkh-3 we found several fragments of a skull and lower jaw of a large Pleistocene horse (from one individual) (Table A5-4).

Two samples were screened for insect fossils. Mkh-2000-B1 was sampled 33 m a.s.l., from sandy silt with plant detritus, 1.2 m below a peat layer. From this sample we obtained rich fossil insect assemblages. It supplemented the data of the distribution of insect complexes in this part of Bykovsky Peninsula. The second sample MKh-2000-B2 was screened from baydzherakh B1 in "Baydzherakh City" (Figure 5-22b in Sher et al. 2000) 33.5 m a.s.l. It is from a Holocene upper layer of grey silt under the thick peat layer, which was found in all baydzherakhs of "Baydzherakh City". Preliminary studies of fossil insects confirm the Holocene age of these deposits.

## 5.9 References

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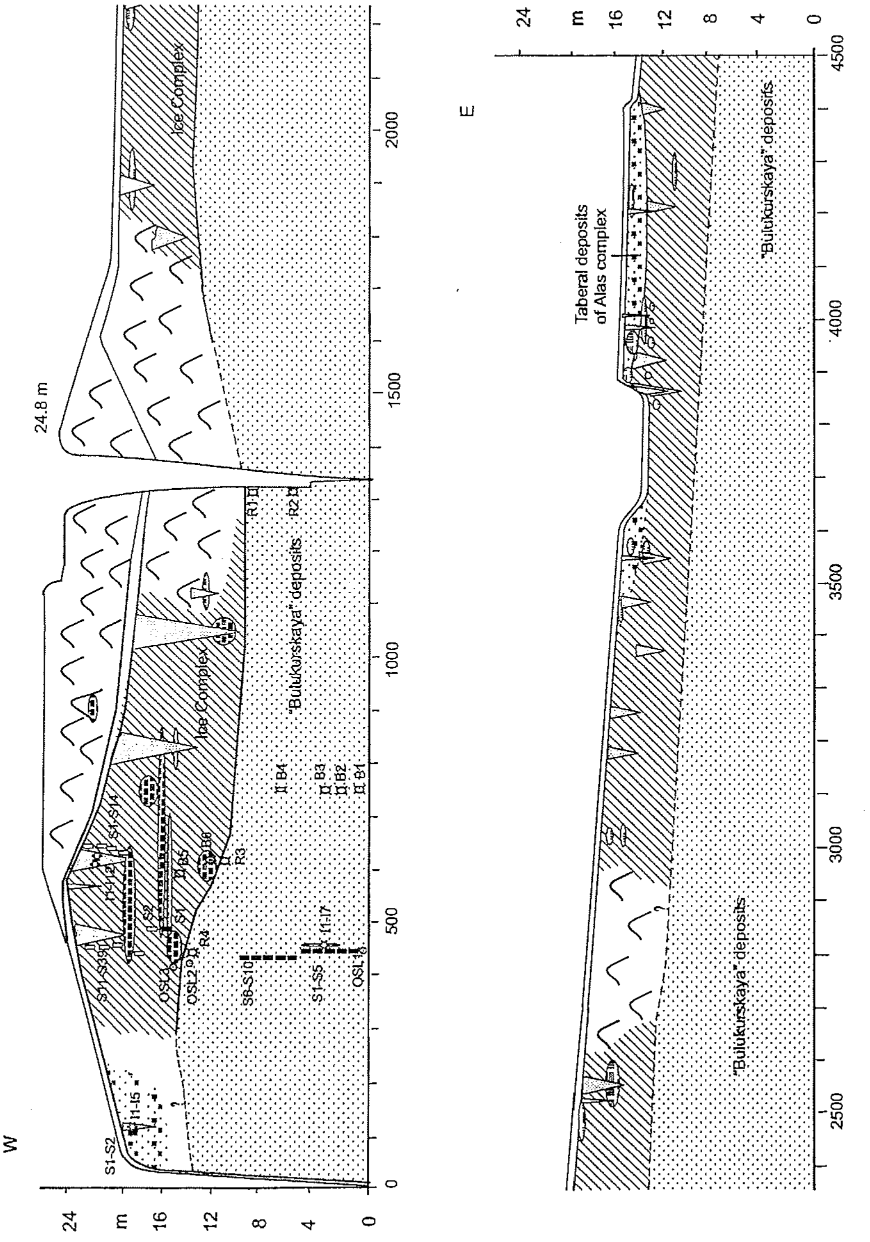
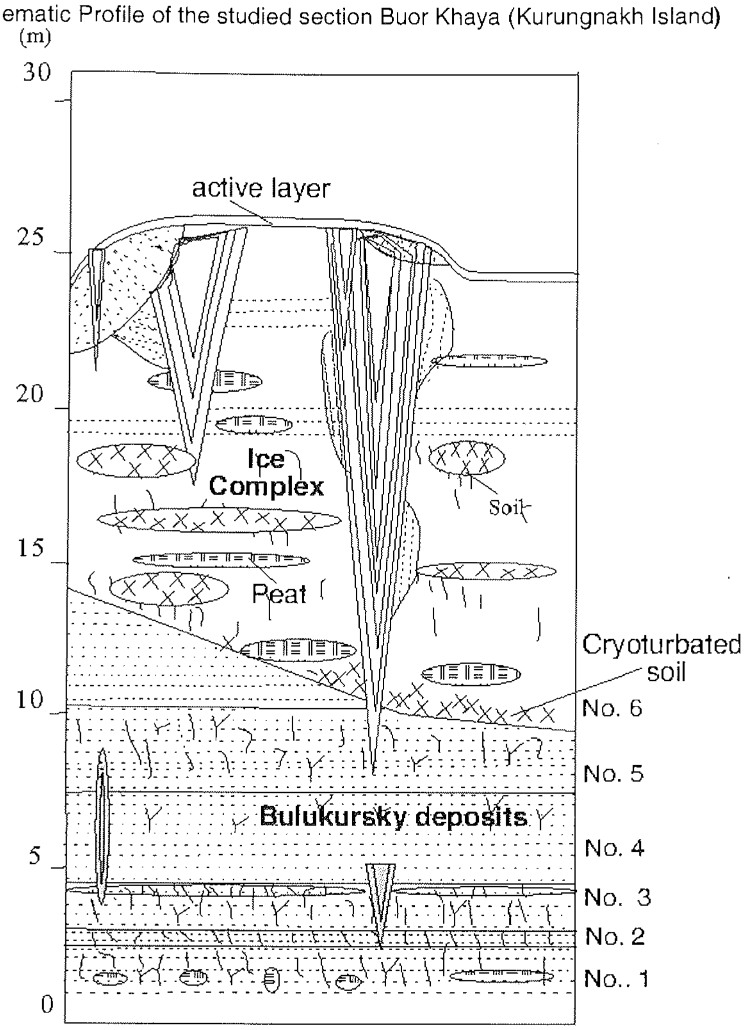
## 5.10 Appendix

**A5-1:** Profile maps (created by Tanya Kuznetsova

**A5-1-1:** Schematic Profile of the studied section near Nagym (Olenyok Channel)



**A5-1-2:** Schematic Profile of the studied section Buor Khaya (Kurungnakh Island)



Bulukursky Suite (1m a s. l)

**Layer 1.** Grey sands fine- to middle-grained, badly graded with thin layers of brown sand. In the layer there are plants remains: twigs of bushes, thread-like rootlets, lower part of the layer contains a lot of Equisetum stems and allochthonous peat. Thickness – 1.6 m

**Layer 2.** Sand middle-grained, with think layers gray and brown sand, it divides into two varieties: sand layers with plant remains and layers of well-graded sand. First ones form vertical slope, second – niche. All organic remains are allochthonous. Thickness – 0.5 m

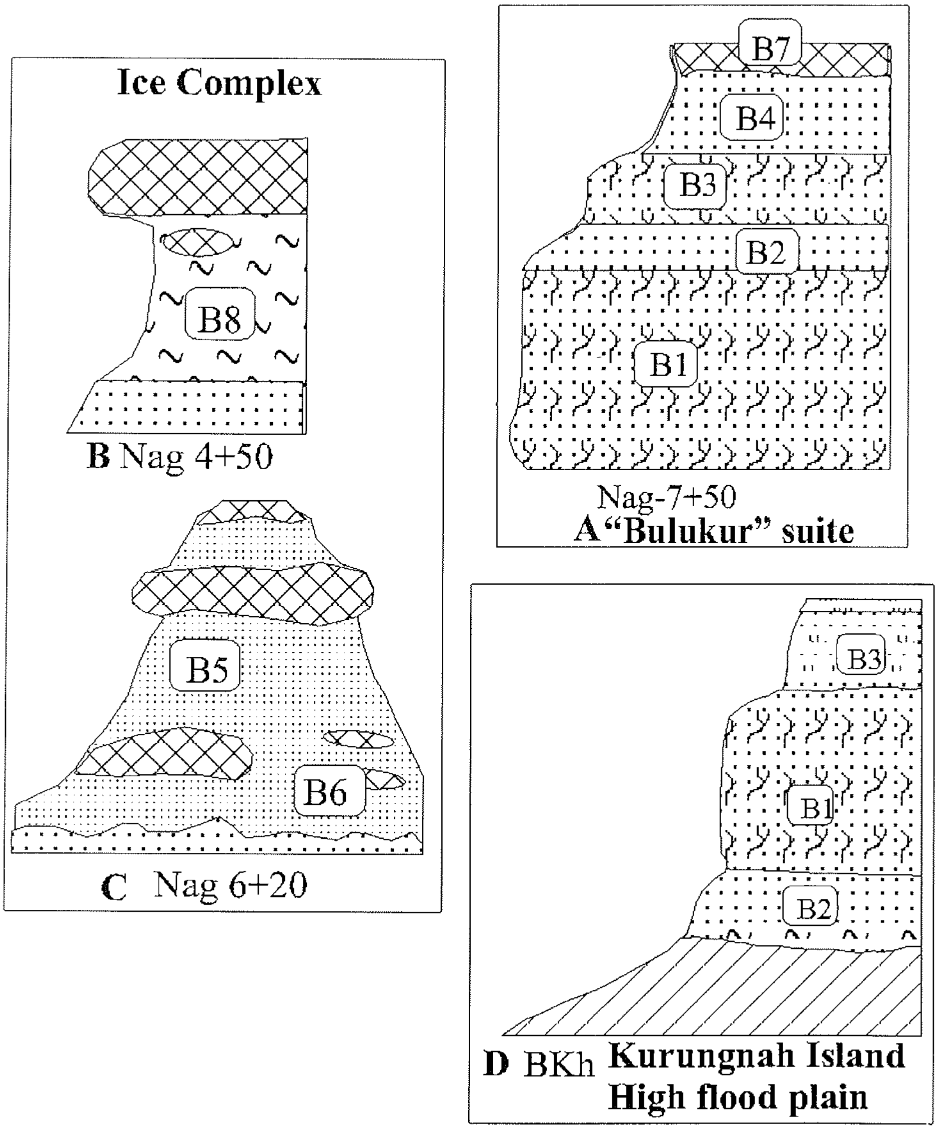
**Layer 3.** Sand middle-grained with numerous twigs of bushes, grass roots, and peat. Thickness – 1.5 m

**Layer 4.** Brown sand, middle-grained, well-graded, with thin dark layers. Layers are horizontal, but there are slanting. Organic remains are very few. Thickness – 3m.

**Layer 5.** Grey sand middle-grained, with thin dark layers. Layer includes a lot of grass roots, woody twigs and other plant detritus. Distribution of plant remains in the layer isn't order. Thickness – 2.8 m.

**Layer 6.** Sand middle-grained, well-graded with one thin dark layer in upper part and with isolated plant remains. Thickness – 1.6m.

**Figure A5-1.3.:** Studied subprofiles for insect analysis



**A5-2:** List, positions and description of sediment samples

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | Cryo-structures | AMS | Ice cont. | pollen | OSL | absolute ice content, [weight %] | Carb. content | coordinates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Western Olenyok Channel, section Nagym** | | | | | | | | | | | | |
| 1 | Nag 4+50-S-0 | 0,7 | 450 | grey fine-sand, strong rooted | | | | x | Nag OSL-1 | | | N 72°52'49"<br>E 123°12'43" |
| 2 | Nag 4+50-S-1 | 1,5 | 450 | peaty detritus, moss, roots | | | | x | | | | |
| 3 | Nag 4+50-S-2 | 1,6 | 450 | grey fine-sand with plant remains | | | x | x | | 27 | - | |
| 4 | Nag 4+50-S-3 | 1,4 | 450 | sand layer | | | | x | | | | |
| 5 | Nag 4+50-S-4 | 3 | 450 | alternation of sand layers and plant detritus layers, (flaser bedding), roots | | x | x | x | | 20 | - | |
| 6 | Nag 4+50-S-5 | 4 | 450 | lamination of fine and middle grained sands, graded bedding, light grey | | x | x | x | | 20 | - | |
| 7 | Nag 4+50-S-6 | 6,8 | 450 | silty grey fine-sand, light-grey, single layers of roots | | x | x | x | | 19 | - | |
| 8 | Nag 4+50-S-7 | 7 | 450 | black layer, 1-2 cm thickness, plant detritus or heavy mineral | | | | x | | | | |
| 9 | Nag 4+50-S-8 | 7,4 | 450 | light middle-grained sand, cross bedding | | | | x | | | | |
| 10 | Nag 4+50-S-9 | 9 | 450 | Fs-ms, light to dark grey, roots | | x | x | x | | 22 | - | |
| 11 | Nag 4+50-S-10 | 10 | 450 | root system, vertical | | | x | x | | 21 | - | |
| 12 | Nag 4+50-S-11 | 18,2 | 450 | fine-sand, brownish no-bedded, free of organic, iron (impregnated), soil horizon ?, single gravels | | | x | x | Nag OSL-2 | 18 | - | |
| 13 | Nag 4+50-S-12 | 18,7 | 450 | sandy ice complex deposits, paleosol, peat inclusions, wood remains (twigs) | | x | x | x | Nag OSL-3 | 36 | (+) | |
| 14 | Nag 4+50-S-13 | 19,3 | 450 | peaty layer within sand | | x | x | x | | 42 | (+) | |
| 15 | Nag 4+50-S-14 | 20,4 | 450 | paleosol, cryoturbated, sandy peaty, grey-green to brown, small ms-layers | fine banded ice schlieres | x | x | x | | 40 | - | |
| 16 | Nag 4+50-S-15 | 20,7 | 450 | middle to coarse-grained sand, weakly bedded, grey-green, only small plant remains, without peat inclusions | banded | | x | x | | 22 | - | |
| 17 | Nag 4+50-S-16 | 21,2 | 450 | paleosol | | x | x | x | | 30 | - | |
| 18 | Nag 4+50-S-17 | 21,5 | 450 | fine to middle grained sand, grey-green, small twigs | finely distributed | | x | x | | 19 | - | |
| 19 | Nag 4+50-S-18 | 22,2 | 450 | fine grained sand, twigs, roots | banded | | | x | | 38 | (+) | |
| 20 | Nag 4+50-S-19 | 22,6 | 450 | moss peat, light-brown | | | x | x | | 79 | (+) | |

A5-2: continuation

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | Cryo-structures | AMS | Ice cont. | pollen | OSL | absolute ice content, [weight %] | Carb. content | coordinates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Nag 4+80-S-1 | 16 | 480 | weak bedded Fs-ms, grey-brown, without roots | | | x | x | | 20 | - | |
| 22 | Nag 4+80-S-2 | 17,2 | 480 | gravel layer, organic-riche | | | | x | | | | |
| 23 | Nag 4+50-C-Horizont | | | | | | | | | | | |
| 24 | Nag 4+50-B-Horizont | | | | | | | | | | | |
| 25 | Nag 6+20-S-1 | 20 | 620 | silty fine-sand to middle sand, grey-brown, organic-riche (twigs, roots) | | | | x | | 33 | - | N 72°52'53"<br>E 123°12'59" |
| 26 | Nag 6+20-S-2 | 20,6 | 620 | silty fine-sand to middle sand, grey-brown, organic-riche (twigs, roots), paleosol | weakly banded, fine-distributed | x | | x | | 35 | - | |
| 27 | Nag 6+20-S-3 | 21,1 | 620 | brownish-grey fine to middle grained sand, single twigs | | | | x | | 33 | (+) | |
| 28 | Nag 6+20-S-4 | 21,5 | 620 | brownish-grey fine to middle grained sand, single twigs | | | | x | | 40 | (+) | |
| 29 | Nag 6+20-S-5 | 22 | 620 | brownish-grey fine to middle grained sand, single twigs | | | | x | | 80 | | |
| 30 | Nag 6+20-S-6 | 24 | 620 | sand above the ice wedge, younger? | | | | x | | 23 | + | |
| 31 | Nag 6+20-S-7 | 16 | 620 | yellowish-grey, bedded, sand | | | | x | | | | |
| 32 | Nag 6+20-S-8 | 16,3 | 620 | sand, iron impregnated?, Go-horizon ? | | | | x | | | | |
| 33 | Nag 6+20-S-9 | 16,4 | 620 | sand, grey, Ge-horizon | | | | x | | | | |
| 34 | Nag 6+20-S-10 | 16,5 | 620 | Peat-sand-alternations, Ah-horizon? | | | | x | | | | |
| 35 | Nag 6+20-S-11 | 27 | 620 | middle to coarse grained sand, gravels, yellowish, without bedding | finely distributed | | | x | | 16 | | |
| 36 | Nag 6+20-S-12 | 26,5 | 620 | silt (aleurite), dark grey | banded, | | | x | | 46 | + | |
| 37 | Nag 6+20-S-13 | 27,5 | 620 | silt (aleurite), dark grey | fine lens-like | | | x | | 41 | (+) | |
| 38 | Nag 6+20-S-14 | 28 | 620 | moss peat ?, dark-brown | reticulated | | | x | | 65 | - | |
| 39 | Nag 1+80-S-1 | 21 | 180 | silt (aleurite), grey-brown, peat inclusions | ice rich | | | x | | 48 | | N 72°52'45" |
| 40 | Nag 1+80-S-2 | 22 | 180 | silt (aleurite), grey-brown, peat inclusions | ice rich | | | x | | | | E 123°12'22" |

**A5-2:** continuation

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | cryostructures | AMS | Ice cont. | pollen | OSL | absolute ice content, [weight %] | coordinates |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **central Lena Delta, section Buor Khaya** | | | | | | | | | | | |
| 41 | Bkh 1-S-1 | 5 | | light-brownish/ grey-brown, finely laminated silty fine-sand to middle sand; 1-2 mm thick, without gravels and plants | distributed | | x | x | | 17 | N 72°20'00"<br>E 126°17'16" |
| 42 | Bkh 1-S-2 | 7 | | light-brownish/ grey-brown, finely laminated silty fine-sand to middle sand; 1-2 mm thick, without gravels and plants | distributed | | | x | | | |
| 43 | Bkh 1-S-3 | 9 | | silty sand .., see above | distributed, polosatic | | x | x | | 17 | |
| 44 | Bkh 1-S-4 | 12 | | silty sand .., see above | | | x | x | | 17 | |
| 45 | Bkh 1-S-5 | 20 | | sand | | | | | | | |
| 46 | Bkh 1-S-6 | 20,1 | | organic filling of a small channel (20 cm) | | | | x | | | |
| 47 | Bkh 1-I-1s | 9 | | sediment within the polosatic-ice | | | | | | | |
| 48 | Bkh 2-S-1 | 3,0-3,1 | 1,53 km to Bkh 1 | sandy peat | | | | | | | N 72°20'43"<br>E 126°18'40" |
| 49 | Bkh 2-S-2 | 3,4-3,5 | | sandy peat | | | | | | | |
| 50 | Bkh 2-S-3 | 3,9-4,0 | | sandy peat | | | | | | | |
| 51 | Bkh 2-S-4 | 4,4-4,5 | | peaty sand | | | | | | | |
| 52 | Bkh 2-S-5 | 4,9-5,0 | | alternation of silty fine-sand (black-brown) with middle sand (yellowish) | | | | | | | |
| 53 | Bkh 2-S-6 | 5,1 | | peat inclusion | | | | | | 59 | |
| 54 | Bkh 2-U/Th-1 | 3,6-3,8 | | sandy peat | | | x | | | 43 | |
| 55 | Bkh 2-U/Th-2 | 3,6-3,8 | | sandy peat | | | x | | | | |
| 56 | Bkh 3-S-1 | 4 | 1,42 km to Bkh 1 | fine-sand with twigs and other plant remains | | | | x | | | N 72°20'40"<br>E 126°18'33" |
| 57 | Bkh 3-S-2 | 7 | | fine-sand with twigs and other plant remains | | x | | x | | | |

**A5-2:** continuation

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | cryostructures | AMS | pollen | OSL | coordinates |
|---|---|---|---|---|---|---|---|---|---|
| 58 | Bkh 3-S-3 | 15 |  | light grey-brown middle- to fine-sand with *(cross bedded)* |  |  | x | Bkh-OSL-1 |  |
| 59 | Bkh 3-S-4 | 15,2 |  | silty fine-sand, grey, organic-riche layer |  |  | x |  |  |
| 60 | Bkh 3-S-5 | 15,3 |  | cryoturbated sand below the lower ice complex boundary |  |  | x |  |  |
| 61 | Bkh 3-S-6 | 15,4 |  | peat inclusion of the transition zone between sands and Ice Complex |  |  | x |  |  |
| 62 | Bkh 3-S-7 | 15,45 |  | cryoturbated silt-sand-alternation |  |  | x |  |  |
| 63 | Bkh 3-S-8 | 15,5 |  | peaty sand, black-brown |  |  | x |  |  |
| 64 | Bkh 3-S-9 | 15,7 |  | peaty sand/sandy peat |  |  | x |  |  |
| 65 | Bkh 3-S-10 | 15,9 |  | peat inclusion |  |  | x |  |  |
| 66 | Bkh 3-S-11 | 18 | Bkh 3-A | grey-black silty sand (aleurite), organic-rich, vertical grass roots Ice Complex | lens-like reticulated, banded |  |  |  |  |
| 67 | Bkh 3-S-12 | 19 | Bkh 3-A | see above |  |  |  |  |  |
| 68 | Bkh 3-S-13 | 20 | Bkh 3-A | see above | ice band 2 cm thick |  |  |  |  |
| 69 | Bkh 3-S-14 | 21 | Bkh 3-A | moss peat (drabanacladus + equisetum), lower part of a peat horizon |  |  |  | 20,8 Bkh 3-OSL 2 |  |
| 70 | Bkh 3-S-15 | 21,5 | Bkh 3-A | peat, middle part of a peat horizon | lens-like reticulated, banded |  |  |  |  |
| 71 | Bkh 3-S-16 | 22 | Bkh 3-A | peat, upper part of a peat horizon |  |  |  |  |  |
| 72 | Bkh 3-S-17 | 22,2 | Bkh 3-A | grey-black silty sand (aleurite), organic-rich |  |  |  |  |  |
| 73 | Bkh 3-S-18 | 23 | Bkh 3-B | silty fine-sand with peat inclusion, twigs, roots | lens-like reticulated, banded |  |  |  |  |
| 74 | Bkh 3-S-19 | 24 | Bkh 3-B | peat lower part of the peat layer |  |  |  |  |  |
| 75 | Bkh 3-S-20 | 24,5 | Bkh 3-B | moss peat upper part of the peat layer |  |  |  |  |  |
| 76 | Bkh 3-S-21 | 25 | Bkh 3-B | silty fine-sand with peat inclusion, twigs, roots |  |  |  |  |  |
| 77 | Bkh 3-S-22 | 27,5 | Bkh 3-C | silty fine-sand with peat inclusion, twigs, roots | lens-like reticulated, banded |  |  |  |  |
| 78 | Bkh 3-S-23 | 28,5 | Bkh 3-C | cryoturbated peat |  |  |  |  |  |
| 79 | Bkh 3-S-24 | 29,5 | Bkh 3-C | sandy silt, yellowish to green-grey |  |  |  |  |  |
| 80 | Bkh 3-S-25 | 31 | Bkh 3-C | sandy silt, yellowish to green-grey |  |  |  |  |  |
| 81 | Bkh 3-S-26 | 32 | Bkh 3-C | sandy silt, yellowish to green-grey |  |  |  |  |  |
| 82 | Bkh 3-S-27 | 34 | wall below | peat inclusion |  |  |  |  |  |
| 83 | Bkh 3-S-28 | 33 | surface | silty sand (aleurite) |  |  |  |  |  |
| 84 | Bkh 3-S-29 | 35 |  | silty sand (aleurite) + peat inclusion |  |  |  |  |  |

**A5-2:** continuation

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | Cryo structures | AMS | pollen | OSL | Carb. content | coordinates |
|---|---|---|---|---|---|---|---|---|---|---|
| 85 | Bkh 3-Boden-A | 35,95-36 | | grey, silty sand (aleurite) | | | | | | |
| 86 | Bkh 3-Boden-B | 35,8-35,95 | | | | | | | | |
| 87 | Bkh 3-Boden-C | 35,75-35,8 | | brown, peaty | | | | | | |
| 88 | Bkh 4-S-1 | 32 | 2,2 km to Bkh 1 | middle- to fine-sand, yellow-green to green-grey | | | | x | | N 72°21'02"<br>E 126°19'16" |
| 89 | Bkh 4-S-2 | 32,5 | | silty sand, grey, (aleurite) | ice-poor | | | x | | |
| 90 | Bkh 4-S-3 | 33 | | peat inclusion | | | | x | | |
| 91 | Bkh 4-S-4 | 33,5 | | silty sand, grey, (aleurite) | ice-rich, lens-like reticulated | | | x | | |
| 92 | Bkh 4-S-5 | 34 | | silty sand, grey, (aleurite) with peat inclusions and large wood remains | | | | x | | |

## Additional recent and Holocene samples

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | Cryo structures | AMS | pollen | OSL | Carb. content | coordinates |
|---|---|---|---|---|---|---|---|---|---|---|
| 93 | Nag R1-S-1 | 21 | | sediment of a small thermokarst pool | | | x | | | N 72°53'05"<br>E 123°11'41" |
| 94 | Nag R1-S-2 | 21 | | sediment of a high centered polygon; 3 m beneath the thermokarst pool | | | x | | | |
| 95 | Nag R4-S-1 | | | sediment from polygon center pool | | | x | | | N 72°53'14"<br>E 123°10'00" |
| 96 | Nag R4-S-2 | | | sediment from polygon rim | | | x | | | |
| 97 | Shn 2/1 | 250 | valley of Mys Khaya Yuryage | surface deposits of snow patch no.2 , plant detritus | | | | | | N 72°43'40"<br>E 123°00'13" |
| 98 | Shn 2/2 | 230 | | surface deposits below the snow patch, silt (aleurite) | | | | | | |
| 99 | Shn 2/3 | 280 | | surface deposits above the snow patch, silt (aleurite) | | | | | | |
| 100 | Shn 4/1 | 200 | | surface deposits of snow patch no.4 , plant detritus | | | | | | N 72°45'08"<br>E 122°49'25" |
| 101 | Shn 4/2 | 240 | | surface deposits above snow patch, silt (aleurite) | | | | | | |

**A5-2:** continuation

| no | sample | Height [m a.s.l.] | Distance [m] | sample description | cryostructures | AMS | pollen | OSL | coordinates |
|---|---|---|---|---|---|---|---|---|---|
| 102 | Shn 5/1 | 125 | | surface deposits of snow patch no. 5, plant detritus | | | | | N 72°45'34" |
| 103 | Shn 5/2 | 130 | | surface deposits above the snow patch, silt (aleurite) | | | | | E 122°50'47" |
| 104 | Camp 1 | | | Gravels at the surface, blown-out by wind; above the camp | | | | | |
| 105 | Mys 1 | 60 | | Holocene slope deposit; alder root on the creek Mys Khaya Yuryage (Chekanovsky Ridge) | | | | | N 72°45'14"<br>E 123°02'12" |
| 105 | Bkh 4 Holz alder | 32-34 | | | | | | | |
| 107 | Bkh 4 Holz- birch | 32-34 | | | | | | | |

## Bykovsky Peninsula section Mamontovy Khayata

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 108 | Mkh 00-S-1 | 30 | below the navigation signal | sandy silt (aleurite)with grass roots | banded, lens-like reticulated | | x | | N 71° 47' 07"<br>E 129°25'10" |
| 109 | Mkh 00-10-S-1 | 0,2 | 300 m | silty sand (aleurite) with single small twigs and vertical grass roots | ice-rich, | | x | | |
| 110 | Mkh 00-10-S-2 | 0,7 | south of | see above | banded, | | x | | |
| 111 | Mkh 00-10-S-3 | 1,2 | the thermo- | see above | lens-like | | x | | |
| 112 | Mkh 00-10-S-4 | 1,5 | channel | see above | reticulated | | x | | |
| 113 | Mkh 00-10-S-5 | 1,7 | | see above | | | x | | |
| 114 | Mkh 00-6.2-S-0 | 1,95 | Alas, | sand | ice-rich, | | x | | |
| 115 | Mkh 00-6.2-S-1 | 2 | Bykovsky | grey, fine-sand, twigs, peat inclusion | lens-like | | x | | |
| 116 | Mkh 00-6.2-S-2 | 2,5 | | grey, fine-sand, ripple layers | reticulated | | x | | |
| 117 | Mkh 00-6.2-S-3 | 3 | | sand | and broken | | x | | |
| 118 | Mkh 00-6.2-S-4 | 3,7 | | cryoturbated peat soil | | | x | | |
| 119 | Mkh 00-6.2-S-5 | 4,3 | | silty fine-sand | | | x | | |
| 120 | Mkh 00-6.2-S-6 | 4,8 | | silty fine-sand | | | x | | |
| 121 | Mkh 00-6.2-B-horizon | 3,5 | | grey sand with small peat inclusions | | | | | |
| 122 | Mkh 00-6.2-C-horizon | 3,45 | | yellow sand | | | | | |

**A5-3:** List of ice and water samples

| altitude | sample | $d^{18}O$ | $\delta D$ | Kations | Anions | additional samples | remarks |
|---|---|---|---|---|---|---|---|
| | | | | | | Be | |
| 5.40 m | Nag4+50-I-1 | x | x | x | x | | Nagym |
| above | Nag4+50-I-2 | x | x | | | | N 72°52'49" |
| the river | Nag4+50-I-3 | x | x | x | x | | E 123°12'43" |
| | Nag4+50-I-4 | x | x | | | | |
| 5.70 m | Nag4+50-I-5 | x | x | x | x | Nag4+50Be1 | small ice wedge in |
| | Nag4+50-I-6 | x | x | | | Nag4+50Be1 | lower sands |
| | Nag4+50-I-7 | x | x | x | x | | |
| 2 m | Nag4+50-I-8 | x | x | | | | filling of a joint |
| | Nag4+50-I-9 | x | x | x | x | | |
| 18 m above | Nag4+50-I-10 | x | x | | | | |
| river level | Nag4+50-I-11 | x | x | | | | |
| | Nag4+50-I-12 | x | x | x | x | | |
| | Nag4+50-I-13 | x | x | | | | root of a large ice wedge |
| | Nag4+50-I-14 | x | x | | | | of the Ice Complex |
| | Nag4+50-I-15 | x | x | x | x | | which is ending within |
| | Nag4+50-I-16 | x | x | | | | lower sands |
| | Nag4+50-I-17 | x | x | | | | |
| | Nag4+50-I-18 | x | x | | | | |
| | Nag4+50-I-19 | x | x | | | | |
| | Nag4+50-I-20 | x | x | | | | |
| | Nag4+50-I-21 | x | x | | | | |
| | Nag4+50-I-22 | x | x | x | x | | |
| | Nag4+50-I-23 | x | x | x | x | | |
| 24.5 m | Nag6+20-I-1 | x | x | | | | N 72°52'53" |
| | Nag6+20-I-2 | x | x | | | | E 123°12'59" |
| | Nag6+20-I-3 | x | x | | | | |
| | Nag6+20-I-4 | x | x | | | | |
| | Nag6+20-I-5 | x | x | | | | |
| | Nag6+20-I-6 | x | x | | | | upper part of a large |
| | Nag6+20-I-7 | x | x | | | | ice wedge of the Ice |
| | Nag6+20-I-8 | x | x | x | x | Nag6-20Be2 | Complex |
| | Nag6+20-I-9 | x | x | | | Nag6-20Be2 | 1 m below surface |
| | Nag6+20-I-10 | x | x | | | | |
| | Nag6+20-I-11 | x | x | | | | |
| | Nag6+20-I-12 | x | x | x | x | | |
| 21.0 m | Nag1+80-I-1 | x | x | x | x | | N 72°52'45" |
| | Nag1+80-I-2 | x | x | x | x | | E 123°12'22" |
| | Nag1+80-I-3 | x | x | x | x | | |
| | Nag1+80-I-4 | x | x | x | x | | Holocene ice wedge |
| | Nag1+80-I-5 | x | x | x | x | | |
| | | | | | | **$d^{18}O + d^{13}C$** | recent |
| | Nag R1-H | x | | | | x x | small thermokarst pool |
| | Nag R2-H | x | | | | x x | large thermokarst lake NW of the camp |
| | Nag R3-H | x | x | | | x x | head of recent ice wedge |
| | Nag R4-H | x | | | | x x | pool of low centred polygon |
| | Nag R5-H | x | x | x | x | x x | small creek above the camp |

**A5-3:** continuation

| altitude | sample | $\delta^{18}O$ | δD | Kations | Anions | additional samples | remarks |
|---|---|---|---|---|---|---|---|
| 250 m a.s.l. | | | | | | $^{3}H$ | |
| **depth** [cm] 5 | Shn2-I-1 | x | x | x | x | x | snow patch of the |
| 30 | Shn2-I-2 | x | x | | | x | Chekanovsky Ridge |
| 60 | Shn2-I-3 | x | x | | | x | N 72°43'40" |
| 90 | Shn2-I-4 | x | x | | | x | E 123°00'13" |
| 130 | Shn2-I-5 | x | x | x | x | x | |
| 155 m a.s.l. | | | | | | | |
| **depth** [cm] 10 | Shn4-I-1 | x | x | x | x | x | |
| 20 | Shn4-I-2 | x | x | | | x | |
| 30 | Shn4-I-3 | x | x | | | x | snow patch of the |
| 40 | Shn4-I-4 | x | x | | | x | Chekanovsky Ridge |
| 50 | Shn4-I-5 | x | x | | | x | |
| 60 | Shn4-I-6 | x | x | | | x | N 72° 45'08" |
| 70 | Shn4-I-7 | x | x | | | x | E 122°49'25" |
| 90 | Shn4-I-8 | x | x | | | x | |
| 100 | Shn4-I-9 | x | x | x | x | x | |
| | | | | | | | Buor Khaya |
| | | | | | | | N 72°20'00" |
| | | | | | | | E 126°17'16" |
| 9 m | Bkh1-I-1 | x | x | | | | polozatik; lower sands |
| 9.5 m | Bkh1-I-2 | x | x | | | | polozatik |
| 20 m above | Bkh1-I-3 | x | x | | | | root of a large ice wedge, right |
| the river | Bkh1-I-4 | x | x | | | | root of a large ice wedge, left |
| 3 m | Bkh3-I-1 | x | x | | | | small ice wedge within |
| 4 m | Bkh3-I-2 | x | x | | | | lower sands |
| 15 m | Bkh3-I-3 | x | x | | | | root of large ice wedge |
| | Bkh3-I-4 | x | x | | | | near the boundary of |
| | Bkh3-I-5 | x | x | | | | lower sands/ Ice Complex |
| | Bkh3-I-6 | x | x | | | | |
| 36.5 m above | Bkh4-I-1 | x | x | | | | large ice wedge |
| the river | Bkh4-I-2 | x | x | x | x | | between Holocene |
| | Bkh4-I-3 | x | x | | | | deposits; |
| | Bkh4-I-4 | x | x | x | x | | 1.5 m below surface |
| | Bkh4-I-5 | x | x | | | | |
| | Bkh4-I-6 | x | x | x | x | | |
| | Bkh4-I-7 | x | x | | | | |

**A5-3:** continuation

| altitude | sample | $\delta^{18}O$ | $\delta D$ | Kations | Anions | additional samples | remarks |
|---|---|---|---|---|---|---|---|
| | **Bykovsky Peninsula, section Mamontovy Khayata** | | | | | | |
| 30 m a.s.l. | MKh00-I-1 | x | x | | | | |
| | MKh00-I-2 | x | x | x | x | | |
| | MKh00-I-3 | x | x | | | | Large ice wedge of the Ice Complex |
| | MKh00-I-4 | x | x | | | | |
| | MKh00-I-5 | x | x | x | x | | |
| | MKh00-I-6 | x | x | | | | |
| | MKh00-I-7 | x | x | | | | |
| | MKh00-I-8 | x | x | x | x | | |
| | MKh00-I-9 | x | x | | | | |
| | MKh00-I-10 | x | x | | | | |
| | MKh00-I-11 | x | x | x | x | | |
| | MKh00-I-12 | x | x | | | | |
| | MKh00-I-13 | x | x | | | | |
| | MKh00-I-14 | x | x | x | x | | |
| | MKh00-I-15 | x | x | x | x | | |
| | MKh00-I-16 | x | x | | | | |
| | MKh00-I-17 | x | x | x | x | | |
| | MKh00-I-18 | x | x | | | | |
| | MKh00-I-19 | x | x | | | | |
| | MKh00-I-20 | x | x | x | x | | |
| | MKh00-I-21 | x | x | | | | |
| | MKh00-I-22 | x | x | | | | |
| | MKh00-I-23 | x | x | x | x | | |
| | MKh00-I-24 | x | x | | | | |
| | MKh00-I-25 | x | x | | | | |
| | MKh00-I-26 | x | x | x | x | | |
| | MKh00-I-27 | x | x | | | | |
| | MKh00-I-28 | x | x | | | | |
| | MKh00-I-29 | x | x | x | x | | |
| | MKh00-I-30 | x | x | | | | |
| | MKh00-I-31 | x | x | | | | |
| | MKh00-I-32 | x | x | | | | |
| | MKh00-I-33 | x | x | x | x | | |
| | MKh00-I-34 | x | x | x | x | | |
| | MKh00-I-35 | x | x | | | | |
| | Mkh00-10-I-1 | | | | | | |
| 1.5 m a.s.l. | Mkh00-10-I-2 | x | x | | | | |
| | Mkh00-10-I-3 | x | x | | | | lower level of the Ice Complex |
| | Mkh00-10-I-4 | x | x | | | | |
| | Mkh00-10-I-5 | x | x | | | | |
| | Mkh00-10-I-6 | x | x | | | | |
| | Mkh00-10-I-7 | x | x | | | | |
| | Mkh00-10-I-8 | x | x | | | | |
| | Mkh00-10-I-9 | x | x | | | | |
| | Mkh00-10-I-10 | x | x | | | | |
| | Mkh00-10-I-11 | x | x | | | | |
| | Mkh00-10-I-12 | x | x | | | | |
| | Mkh00-10-I-13 | x | x | | | | |
| | Mkh00-10-I-14 | x | x | | | | |
| | Mkh00-10-I-15 | x | x | | | | |
| | Mkh00-10-I-16 | x | x | | | | |
| | Mkh00-10-I-17 | x | x | | | | |
| | Mkh00-10-I-18 | x | x | | | | |

## A5-4: List of bone samples

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| | **Nagym** | | | | | | |
| 1 | Nag - O1 | Lepus sp. | humerus | distal fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 2 | Nag - O2 | Lepus sp. | tibia | distal fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 3 | Nag - O3 | Lepus sp. | metapodia | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 4 | Nag - O4 | Mammuthus primigenius | tusk | small fragments (5 pieces) | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 5 | Nag - O5 | Large mammal | cranium | fragments (2 pieces) | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 6 | Nag - O6 | Large mammal | costa | fragments | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 7 | Nag - O7 | Large mammal | bone | fragments | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 8 | Nag - O8 | Eguus sp. | mandible (left stem) with dp2 - dp4 | | b | N 8+80m, in scree, latitude 11m | juv. |
| 9 | Nag - O9 | Mammuthus primigenius | humerus | distal fragment, sample cut out | b | N 4+80m, altitude 19m (on 1m below the tundra surface) | C14, juv. |
| 10 | Nag - O10 | Equus caballus | mandible (left stem) with dp3 - M3 | | d | shore | |
| 11 | Nag - O11 | Mammuthus primigenius | pelvis | fragment | d | shore | C14 |
| 12 | Nag - O12 | Large mammal | limb bone | fragment | d | shore | |
| 13 | Nag - O13 | Large mammal | costa | fragment | d | shore | Trashed |
| 14 | Nag - O14 | Equus caballus | metapodia | fragment, distal articulation part | d | shore | juv. |
| 15 | Nag - O15 | Lepus sp. | tibia | proximal fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | juv. |
| 16 | Nag - O16 | Large mammal | vertebra | fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | juv. |
| 17 | Nag - O17 | Bison priscus ? | maxilla with premolar tooth | fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 18 | Nag - O18 | Large mammal | small bone of carpale | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 19 | Nag - O19 | Carnivora? | phalanx | proximal fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 20 | Nag - O20 | Lepus sp. ? | phalanx I | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 21 | Nag - O21 | Lepus sp. | calcaneus | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 22 | Nag - O22 | Lepus sp. | metapodia | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 23 | Nag - O23 | Microtinae | tooth | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 24 | Nag - O24 | Microtinae | incisor | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 25 | Nag - O25 | Microtinae | tibia | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 26 | Nag - O26 | Microtinae | limb bone? | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 27 | Nag - O27 | Mammal | tooth | | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | |
| 28 | Nag - O28 | Large mammal | incisor | fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 29 | Nag - O29 | Large mammal | limb bone | fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 30 | Nag - O30 | Lepus sp. | limb bone | fragment | b | N 13+30m, "Bulukurskaya" deposit, interval 2 - 10m | Trashed |
| 31 | Nag - O31 | Lepus sp. | humerus | distal fragment | d | shore | |
| **Kurungnah island, Buor- Khaya** | | | | | | | |
| 32 | Bkh - O32 | Mammuthus primigenius | antebrahium (radius + ulna) | proximal fragment (2 pieces) | b | the exposure, altitude 20m | C14 |
| 33 | Bkh - O33 | Equus sp. | femur | damaged | c | the exposure | |
| 34 | Bkh - O34 | Equus sp. | metatarsale III | | c | the exposure, lower part of Ice Complex | recent?, samples 34, 35 from the same specimen |
| 35 | Bkh - O35 | Equus sp. | phalax I | | c | the exposure, lower part of Ice Complex | |
| 36 | Bkh - O36 | Mammuthus primigenius | costa | fragment | c | the exposure, lower part of Ice Complex | C14 |
| 37 | Bkh - O37 | Equus sp. | metapodia II or IV | | c | the exposure, lower part of Ice Complex | |
| 38 | Bkh - O38 | Rangifer tarandus | phalanx | | b | the exposure, altitude 20m | |
| 39 | Bkh - O39 | Bison priscus | metacarpale III | | e | shore, ice transposition | |
| 40 | Bkh - O40 | Mammuthus primigenius | lower molar tooth (M3) | fragment | d | shore | |
| 41 | Bkh - O41 | Equus sp. | pelvis | fragment | d | shore | |
| 42 | Bkh - O42 | Equus sp. | humerus | damaged | c | the exposure, upper part of Ice Complex | |
| 43 | Bkh - O43 | Equus sp. | metacarpale III + IV | | c | the exposure | |
| 44 | Bkh - O44 | Bison priscus | pelvis | fragment | c | the exposure | |
| 45 | Bkh - O45 | Rangifer tarandus | ulna | fragment | e | shore, ice transposition | |
| 46 | Bkh - O46 | Rangifer tarandus | antler | fragment | e | shore, ice transposition | |
| 47 | Bkh - O47 | Equus sp. | radius | proximal fragment | e | shore, ice transposition | |
| 48 | Bkh - O48 | Large mammal | cranium | fragment | e | shore, ice transposition | |
| 49 | Bkh - O49 | Large mammal | costa | fragment | e | shore, ice transposition | trashed |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 50 | Bkh - O50 | Rangifer tarandus | antler | fragment | d | shore | |
| 51 | Bkh - O51 | Rangifer tarandus | thorax vertebra | | d | shore | ?recent |
| 52 | Bkh - O52 | Equus sp. | pelvis | fragment | c | the exposure | |
| 53 | Bkh - O53 | Rangifer tarandus | femur | distal fragment | c | the exposure | ?recent |
| 54 | Bkh - O54 | Rangifer tarandus | antebrahium (radius + ulna) | proximal fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | ?recent |
| 55 | Bkh - O55 | Rangifer tarandus | limb bone | fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | trashed |
| 56 | Bkh - O56 | Large mammal | limb bone | fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | |
| 57 | Bkh - O57 | Mammuthus primigenius | costa | | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | juv. |
| 58 | Bkh - O58 | Rangifer tarandus | costa | fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | trashed |
| 59 | Bkh - O59 | Rangifer tarandus | costa | fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | trashed |
| 60 | Bkh - O60 | Rangifer tarandus | costa | fragment | b | the exposure BKh-3, 23-24m, middle part of Ice Complex | trashed |
| 61 | Bkh - O61 | Mammuthus primigenius | costa | fragment | c | the exposure | trashed |
| 62 | Bkh - O62 | Large mammal | costa | fragment | c | the exposure | trashed |
| 63 | Bkh - O63 | Rangifer tarandus | radius | fragment | c | the exposure | trashed |
| 64 | Bkh - O64 | Rangifer tarandus | metapodia | distal fragment | d | shore | ?recent |
| 65 | Bkh - O65 | Equus sp. | radius (with marrow and copulas) | | a | in situ, the exposure, altitude 20m | |
| 66 | Bkh - O66 | Mammuthus primigenius | upper milk tooth (P4 or M1) | | d | shore | |
| 67 | Bkh - O67 | Mammuthus primigenius | femur | fragment, sample cut out | d | shore | C14 |
| 68 | Bkh - O68 | Mammuthus primigenius | vertebra | processus spinosus | b | the exposure, altitude 32 - 35m | C14, samples from 68 to 90 from the same specimen |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 69 | Bkh - O69 | Mammuthus primigenius | lumbar vertebra | damaged | b | the exposure, altitude 32 - 35m | C14 |
| 70 | Bkh - O70 | Mammuthus primigenius | costa |  | b | the exposure, altitude 32 - 35m | C14 |
| 71 | Bkh - O71 | Mammuthus primigenius | costa | fragment | b | the exposure, altitude 32 - 35m | juv., C14 |
| 72 | Bkh - O72 | Mammuthus primigenius | first costa | fragment | b | the exposure, altitude 32 - 35m | C14 |
| 73 | Bkh - O73 | Mammuthus primigenius | costa | fragment | b | the exposure, altitude 32 - 35m | C14 |
| 74 | Bkh - O74 | Mammuthus primigenius | costa |  | b | the exposure, altitude 32 - 35m | C14 |
| 75 | Bkh - O75 | Mammuthus primigenius | costa | fragment | b | the exposure, altitude 32 - 35m | C14 |
| 76 | Bkh - O76 | Mammuthus primigenius | costa | fragment (2 pieces) | b | the exposure, altitude 32 - 35m |  |
| 77 | Bkh - O77 | Mammuthus primigenius | metatarsale III |  | b | the exposure, altitude 32 - 35m | samples |
| 78 | Bkh - O78 | Mammuthus primigenius | metatarsale II |  | b | the exposure, altitude 32 - 35m | from |
| 79 | Bkh - O79 | Mammuthus primigenius | metatarsale IV |  | b | the exposure, altitude 32 - 35m | 77 to 87 |
| 80 | Bkh - O80 | Mammuthus primigenius | metacarpale I |  | b | the exposure, altitude 32 - 35m | from the |
| 81 | Bkh - O81 | Mammuthus primigenius | metacarpale I |  | b | the exposure, altitude 32 - 35m | same |
| 82 | Bkh - O82 | Mammuthus primigenius | os centrale |  | b | the exposure, altitude 32 - 35m | specimen |
| 83 | Bkh - O83 | Mammuthus primigenius | os centrale |  | b | the exposure, altitude 32 - 35m |  |
| 84 | Bkh - O84 | Mammuthus primigenius | os tarsale 3 |  | b | the exposure, altitude 32 - 35m |  |
| 85 | Bkh - O85 | Mammuthus primigenius | os carpale 3 |  | b | the exposure, altitude 32 - 35m |  |
| 86 | Bkh - O86 | Mammuthus primigenius | astrogalus |  | b | the exposure, altitude 32 - 35m |  |
| 87 | Bkh - O87 | Mammuthus primigenius | phalanx I |  | b | the exposure, altitude 32 - 35m |  |
| 88 | Bkh - O88 | Mammuthus primigenius | lumbar vertebra | damaged | b | the exposure, altitude 32 - 35m |  |
| 89 | Bkh - O89 | Mammuthus primigenius | vertebra | fragment | b | the exposure, altitude 32 - 35m |  |
| 90 | Bkh - O90 | Mammuthus primigenius | bone | fragment | b | the exposure, altitude 32 - 35m |  |
| 91 | Bkh - O91 | Mammuthus primigenius | costa | fragment | c | the exposure | trashed |
| 92 | Bkh - O92 | Large mammal | limb bone | fragment | d | shore | C14 |
| 93 | Bkh - O93 | Lepus sp. | mandible (right stem) | fragment | d | shore |  |
| 94 | Bkh - O94 | Lepus sp. | mandible (right stem) | fragment | d | shore |  |
| 95 | Bkh - O95 | Lepus sp. | tibia | distal fragment (2 pieces) | c | the exposure |  |
| 96 | Bkh - O96 | Lepus sp. ? | cranium | fragment | c | the exposure |  |
| 97 | Bkh - O97 | Lepus sp. | femur | fragment | c | the exposure |  |
| 98 | Bkh - O98 | Large mammal | tooth | fragment | c | the exposure |  |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 99 | Bkh - O99 | Mammuthus primigenius | phalanx II | | c | the exposure | |
| 100 | Bkh - O100 | Mammuthus primigenius | pelvis | fragment, sample cut out | c | the exposure | C14 |
| 101 | Bkh - O101 | Large mammal | limb bone | fragment | d | shore | trashed |
| 102 | Bkh - O102 | Lepus sp. | limb bone | fragment | d | shore | trashed |
| 103 | Bkh - O103 | Large mammal | pelvis | fragment | c | the exposure | |
| 104 | Bkh - O104 | Bison priscus? | pelvis | fragment | c | the exposure | |
| 105 | Bkh - O105 | Mammuthus primigenius | tibia | fragment, diaphys | d | shore | juv. |
| 106 | Bkh - O106 | Rangifer tarandus | antler | fragment | d | shore | |
| 107 | Bkh - O107 | Rangifer tarandus | antler | fragment | d | shore | |
| 108 | Bkh - O108 | Mammuthus primigenius | mandible | fragment | d | shore | |
| 109 | Bkh - O109 | Mammuthus primigenius | os carpale 4+5 | | d | shore | |
| 110 | Bkh - O110 | Mammuthus primigenius | vertebra | fragment, processus spinosus | d | shore | |
| 111 | Bkh - O111 | Bison priscus or Ovibos sp. | lumbar vertebra | | d | shore | |
| 112 | Bkh - O112 | Equus sp. | tibia | fragment, proximal articulation part | d | shore | |

## Mamontovy Khayata

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 113 | MKh 00 - O113 | Equus sp. | maxilla (incisor part and upper second premolar (P2), (2 pieces) | fragment | b | MKh 3, 1m from the surface of the exposure (near 12 a.s.l.) | samples 113, 132, 133 from the same specimen |
| 114 | MKh 00 - O114 | Lepus sp. | cranium with upper teeth | | d | shore and bar | |
| 115. | MKh 00 - O115 | Lepus sp. | mandible (left stem) | | d | shore and bar | |
| 116 | MKh 00 - O116 | Lepus sp. | lumbar vertebra | | d | shore and bar | |
| 117 | MKh 00 - O117 | Artiodactyla | lower tooth | fragment | d | shore and bar | |
| 118 | MKh 00 - O118 | Rangifer tarandus | upper premolar tooth | | d | shore and bar | |
| 119 | MKh 00 - O119 | Mammuthus primigenius | costa | fragment | d | shore and bar | trashed |
| 120 | MKh 00 - O120 | Mammuthus primigenius | costa | | d | shore and bar | trashed |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 121 | MKh 00 - 0121 | Mammuthus primigenius | tusk | fragment | d | shore and bar | trashed |
| 122 | MKh 00 - 0122 | Large mammal | costa | fragment | d | shore and bar | trashed |
| 123 | MKh 00 - 0123 | Large mammal | costa | fragment | d | shore and bar | trashed |
| 124 | MKh 00 - 0124 | Large mammal | costa | fragment | c | the exposure | trashed |
| 125 | MKh 00 - 0125 | Mammuthus primigenius | tusk | fragment | c | the exposure | trashed |
| 126 | MKh 00 - 0126 | Mammuthus primigenius | tusk | fragment | c | the exposure | trashed |
| 127 | MKh 00 - 0127 | Mammuthus primigenius | costa | fragment | c | the exposure | trashed |
| 128 | MKh 00 - 0128 | Lepus sp. | tibia | fragment | c | the exposure | |
| 129 | MKh 00 - 0129 | Lepus sp. | tibia | fragment | c | the exposure | |
| 130 | MKh 00 - 0130 | Lepus sp. | scapula | fragment | c | the exposure | |
| 131 | MKh 00 - 0131 | Aves | humerus | | c | the exposure | |
| 132 | MKh 00 - 0132 | Equus sp. | mandible (incisor part and second premolar (P2) | fragment | b | MKh 3, 1m from the surface of the exposure (near 12 a.s.l.) | samples 113, 132, 133 from the same specimen |
| 133 | MKh 00 - 0133 | Equus sp. | mandible | fragment | b | MKh 3, 1m from the surface of the exposure (near 12 a.s.l.) | |
| 134 | MKh 00 - 0134 | Rangifer tarandus | shed antler | fragment | b | MKh 3, 1m from the surface of the exposure (near 12 a.s.l.) | |
| 135 | MKh 00 - 0135 | Equus sp. | cervical vertebra | fragment | c | the exposure | |
| 136 | MKh 00 - 0136 | Rangifer tarandus | humerus | proximal fragment | c | the exposure | |
| 137 | MKh 00 - 0137 | Rangifer tarandus | lumbar vertebra | | c | the exposure | |
| 138 | MKh 00 - 0138 | Bison priscus | phalanx I | | c | the exposure | |
| 139 | MKh 00 - 0139 | Bison priscus ? | tibia | proximal fragment | c | the exposure | |
| 140 | MKh 00 - 0140 | Equus sp. | pelvis | sample damaged | c | the exposure | |
| 141 | MKh 00 - 0141 | Equus sp. | pelvis | sample damaged | c | the exposure | |
| 142 | MKh 00 - 0142 | Equus sp. | humerus | distal fragment | c | the exposure | |
| 143 | MKh 00 - 0143 | Rangifer tarandus | scapula | fragment | c | the exposure | |
| 144 | MKh 00 - 0144 | Rangifer tarandus | humerus | distal fragment | c | the exposure | |
| 145 | MKh 00 - 0145 | Rangifer tarandus | humerus | distal fragment | c | the exposure | recent |

A5-4: continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 146 | MKh 00 - O146 | Mammuthus primigenius | os carpale 4+5 | | c | the exposure | |
| 147 | MKh 00 - O147 | Mammuthus primigenius | limb bone | fragment, sample cut out | c | the exposure | C14 |
| 148 | MKh 00 - O148 | Mammuthus primigenius | tusk | fragment | b | the exposure, altitude near 28m, under the reper 4.10 | C14 |
| 149 | MKh 00 - O149 | Mammuthus primigenius | tusk | fragment (2 pieces) | b | the exposure, altitude near 28m, under the reper 4.10 | C14 |
| 150 | MKh 00 - O150 | Mammuthus primigenius | tusk | fragment | d | shore and bar | trashed |
| 151 | MKh 00 - O151 | Mammuthus primigenius | tusk | fragment | d | shore and bar | trashed |
| 152 | MKh 00 - O152 | Mammuthus primigenius | tusk | fragment | d | shore and bar | trashed |
| 153 | MKh 00 - O153 | Mammuthus primigenius | premolar tooth | fragment | d | shore and bar | at Luts |
| 154 | MKh 00 - O154 | Rangifer tarandus | limb bone | fragment | d | shore and bar | trashed |
| 155 | MKh 00 - O155 | Rangifer tarandus | limb bone | fragment | d | shore and bar | trashed |
| 156 | MKh 00 - O156 | Mammuthus primigenius | tusk | fragment | d | shore and bar | trashed |
| 157 | MKh 00 - O157 | Mammuthus primigenius | tooth | fragment | d | shore and bar | trashed |
| 158 | MKh 00 - O158 | Mammuthus primigenius | tooth (heavily worn) | fragment | d | shore and bar | trashed |
| 159 | MKh 00 - O159 | Lepus sp. | femur | proximal fragment | d | shore and bar | |
| 160 | MKh 00 - O160 | Lepus sp. | femur | distal fragment | d | shore and bar | |
| 161 | MKh 00 - O161 | Lepus sp. | tibia | | d | shore and bar | |
| 162 | MKh 00 - O162 | Lepus sp. | lumbar vertebra | | d | shore and bar | |
| 163 | MKh 00 - O163 | Equus sp. | lower tooth | fragment | d | shore and bar | |
| 164 | MKh 00 - O164 | Equus sp. | upper tooth | fragment | d | shore and bar | |
| 165 | MKh 00 - O165 | Rangifer tarandus | upper premolar tooth | | d | shore and bar | |
| 166 | MKh 00 - O166 | Artiodactyla | upper tooth | fragment | d | shore and bar | |
| 167 | MKh 00 - O167 | Large mammal | cranium (occipitalia part) | fragment | d | shore and bar | |
| 168 | MKh 00 - O168 | Equus sp. | tooth | fragment | d | shore and bar | trashed |
| 169 | MKh 00 - O169 | Bison priscus | humerus | | d | shore and bar | |
| 170 | MKh 00 - O170 | Bison priscus | radius | | d | shore and bar | |
| 171 | MKh 00 - O171 | Equus sp. | metatarsale III | | d | shore and bar | |
| 172 | MKh 00 - O172 | Equus sp. | scapula | fragment | d | shore and bar | |
| 173 | MKh 00 - O173 | Bison priscus ? | astrogalus | | d | shore and bar | |

**A5-4:** continuation

| No. | No. samples | Taxon | Skeleton element | Preservation | Loc. Type | Locality | Notes |
|---|---|---|---|---|---|---|---|
| 174 | MKh 00 - O174 | Mammuthus primigenius | metapodia | sample damaged (without distal articulation part) | d | shore and bar | |
| 175 | MKh 00 - O175 | Mammuthus primigenius | limb bone | fragment | d | shore and bar | trashed |
| 176 | MKh 00 - O176 | Mammuthus primigenius | lower tooth | fragment | d | shore and bar | |
| 177 | MKh 00 - O177 | Mammuthus primigenius | lower tooth | fragment | d | shore and bar | |
| 178 | MKh 00 - O178 | Mammuthus primigenius | limb bone | fragment | d | shore and bar | C14 |
| 179 | MKh 00 - O179 | Large mammal | bone | fragment | d | shore and bar | |
| 180 | MKh 00 - O180 | Large mammal | limb bone | fragment | d | shore and bar | trashed |
| 181 | MKh 00 - O181 | Bison priscus | sesamoidea phalanx I ? | | d | shore and bar | |
| 182 | MKh 00 - O182 | Rangifer tarandus | phalanx I | sample damaged | d | shore and bar | |
| 183 | MKh 00 - O183 | Mammuthus primigenius | limb bone | fragment | d | shore and bar | trashed |
| 184 | MKh 00 - O184 | Mammuthus primigenius | vertebra, processus spinosus | fragment | d | shore and bar | trashed |
| 185 | MKh 00 - O185 | Equus sp. | calcaneum | | d | shore and bar | |
| 186 | MKh 00 - O186 | Rangifer tarandus | metatarsale | distal fragment | d | shore and bar | juv. |
| 187 | MKh 00 - O187 | Rangifer tarandus ? | femur | proximal fragment | d | shore and bar | |
| 188 | MKh 00 - O188 | Equus sp. | os cuneiforme | | d | shore and bar | |
| 189 | MKh 00 - O189 | Equus sp. | os cuneiforme | | d | shore and bar | |
| 190 | MKh 00 - O190 | Bison priscus | phalanx II | fragment | d | shore and bar | |
| 191 | MKh 00 - O191 | Mammuthus primigenius | tibia | fragment | d | shore and bar | juv. |
| 192 | MKh 00 - O192 | Mammuthus primigenius | costa | fragment | d | shore and bar | trashed |
| 193 | MKh 00 - O193 | Rangifer tarandus | scapula | fragment | d | shore and bar | |
| 194 | MKh 00 - O194 | Mammuthus primigenius ? | ?cervical vertebra | fragment | d | shore and bar | |
| 195 | MKh 00 - O195 | Mammuthus primigenius | phalanx I | | d | shore and bar | |
| 196 | MKh 00 - O196 | Bison priscus | phalanx III | sample damaged | d | shore and bar | |
| 197 | MKh 00 - O197 | Mammuthus primigenius | ?scapula | fragment | d | shore and bar | trashed |
| 198 | MKh 00 - O198 | Mammuthus primigenius | ? femur | fragment | d | shore and bar | juv. |
| 199 | MKh 00 - O199 | Mammuthus primigenius | limb bone | fragment | d | shore and bar | juv. |
| 200 | MKh 00 - O200 | Large mammal | limb bone | fragment | d | shore and bar | |
| 201 | MKh 00 - O201 | Ovibos sp.? | patella | | d | shore and bar | |
| 202 | MKh 00 - O202 | Rangifer tarandus | metapodia | fragment, without distal articulation part | d | shore and bar | |

**A5 5:** List of screened samples for small fossil (insects and rodent) from the sediment of the Olenyok Channel, Kurungnakh Island, and Bykovsky Peninsula

| Sample No. | Horizontal position | Altitude (m., a.s.l.) | Sediment discription |
|---|---|---|---|
| **1. Nagym, "Bulukur" deposits** | | | |
| B-1 | Nag-7+50 | 1.0 | sand with plant remains ( ) and seams of silt and plant detritus |
| B-2 | Nag-7+50 | 3.2 | sand with plant remains ( ) |
| B-3 | Nag-7+50 | 4.6 | sand with few plant detritus and roots of small shrubs |
| R-2 | Nag-13+30 | 6.6 | grey sand with seams of plant detritus |
| B-4 | Nag-7+50 | 7.6 | sand with plant detritus |
| R-1 | Nag-13+30 | 10.0 | yellow-grey sand with rock debris and rubble |
| B-7 | Nag-7+50 | 11.5 | Sand with few plant detritus |
| R-3 | Nag-6+20 | 12.7 | yellow-grey sand with rock debris and rubble |
| R-4 | Nag-4+50 | 14.2 | yellow-grey sand with plant remains |
| **2. Nagym, Ice complex deposits (yedoma)** | | | |
| B-6 | Nag-6+20 | 13.4 | grey silty sand with plant detritus and peat inclusions |
| B-5 | Nag-6+20 | 15.6 | grey silty sand with plant detritus and lenses of yellow gross-grained sand |
| B-8 | Nag-4+50 | 21 | grey silt |
| **3. Byor-Khaya, Holocene alas deposits** | | | |
| B-4 | BKh | ? | silt with twigs of large shrubs and part of big trees |
| **3. Byor-Khaya, Holocene high flood plain deposits** | | | |
| B-2 | BKh | 3.4 | grey silty sand with plant detritus and lenses of yellow gross-grained sand |
| B-1 | BKh | 4.9 | grey silty sand with seams of silt and plant remains ( ) |
| B-3 | BKh | 6 | yellow sand with seams of silt and plant detritus |
| **4. Bykovsky Peninsula, Mamontovy Khayata Exposure** | | | |
| 2000-B-1 | MKh | 33 | grey silt |
| 2000-B-2 | MKh | 33.5 | grey silt |

**Table A5-6:** Plants of studied periglacial landscapes (identified by G. Grosse and F. Kienast)

| family | genus | species | study area |
|---|---|---|---|
| *Asteraceae* | *Crepis* | *chrysanta* | Nagym |
| *Asteraceae* | *Dendranthema* | *mongolicum* (Ling) | Nagym |
| *Asteraceae* | *Petasites* | *frigidus* | |
| *Asteraceae* | *Saussurea* | *tilesii* | Nagym |
| *Boraginaceae* | *Myosotis* | *alpestris* | Nagym |
| *Campanulaceae* | *Campanula* | *rotundifolia* | Nagym |
| *Caryophyllacea* | *Cerastium* | *maximum* | Nagym |
| *Caryophyllacea* | *Minuartia* | *arctica* | Nagym |
| *Caryophyllacea* | *Stellaria* | *peduncularis* (Bunge) | Nagym |
| *Caryophyllacea* | *Stellaria* | *edwardsii* (?) | |
| *Caryophyllacea* | *Stellaria* | sp. | Nagym |
| *Compositae* | *Artemisia* | sp. | Chekanovsky |
| *Compositae* | *Senecio* | *congestus* | Nagym |
| *Compositae* | *Senecio* | *resedifolius* (Less.) | Nagym |
| *Compositae* | *Tanacetum* | *bipinatum* | Nagym |
| *Cruciferae* | *Cardamine* | *pratensis* (L.) | Nagym |
| *Cruciferae* | *Draba* | sp. | |
| *Cyperaceae* | *Eriophorum* | *angustifolium* | |
| *Cyperaceae* | *Eriophorum* | *Scheuchzeri* | Nagym |
| *Equisetaceae* | *Equisetum* | *arvense* | Nagym |
| *Ericaceae* | *Arctous* | *alpina* | |
| *Ericaceae* | *Cassiope* | *tetragona* | |
| *Fabaceae* | *Astragalus* | *umbellatus frigides* | Nagym |
| *Fabaceae* | *Hedysarum* | *hedysaroides* | Nagym |
| *Fabaceae* | *Oxytropis* | *adamsiana* | Nagym |
| *Onagraceae* | *Chanemerion* | *latifolium* (L.) | Chekanovsky |
| *Onagraceae* | *Chanemerion* | *angustifolium* (L.) | Buor-Khaya |
| *Papaveraceae* | *Papaver* | *angustifolium* | Nagym |
| *Plumbaginaceae* | *Armeria* | *maritima* | Nagym |
| *Polemoniceae* | *Polemonium* | *arcutiflorus* | |
| *Polygonaceae* | *Polygonum* | *viviparum* | Nagym |
| *Polygonaceae* | *Rumex* | *arcticus* (Tr.) | Chekanovsky |
| *Pyrolaceae* | *Pyrola* | *rotundifolia* | |
| *Ranunculaceae* | *Caltha* | *arctica* | Nagym |
| *Ranunculaceae* | *Delphinium* | *chamissonis* | Nagym |
| *Rosaceae* | *Dryas* | *punctata* | Nagym |
| *Rosaceae* | *Rubus* | *chamaemorus* | |
| *Rosaceae* | *Novosieversia* | *glacialis* | |
| *Rosaceae* | *Potentilla* | *hyparctica* ssp. *hyparctica* | |
| *Salicaceae* | *Salix* | sp. | Nagym |
| *Saxifragaceae* | *Chrysosplenium* | *alternifolium* (L.) | Nagym |
| *Saxifragaceae* | *Saxifraga* | *foliolosa* | Chekanovsky |
| *Saxifragaceae* | *Saxifraga* | *hirculus* | Nagym |
| *Scrophulariaceae* | *Lagotis* | *glauca* (Gearth) | Nagym |
| *Scrophulariaceae* | *Lagotis* | *minor* | |
| *Scrophulariaceae* | *Pedicularis* | sp. | Nagym |
| *Valerianaceae* | *Valeriana* | *capitata* (Pallex) | Nagym |

**A5-7:** Species list of mosses in the studied periglacial landscape (identification by Elena Kuzmina, St. Petersburg)

| genus | species | study area | sample No. |
|---|---|---|---|
| *Amblystegium* | *sarinum* (Hedw.) Lindb. | Nagym | M-12/3 |
| *Andrea* | *rupestris* Hedw. | Chekanovsky | Ch-2-ms |
| *Aulacomnium* | *turgidum* (Wahlenb.) Schwaegr. | Nagym | M-5/2 |
| *Aulacomnium* | *turgidum* (Wahlenb.) Schwaegr. | Nagym | M-10 |
| *Aulacomnium* | *palustre* (Hedw.) Schwaegr. | Nagym | M-13 |
| *Aulacomnium* | *turgidum* (Wahlenb.) Schwaegr. | Nagym | M-16/1 |
| *Bryum* | sp. | Chekanovsky | M-6 |
| *Calliergon* | *giganteum* (Schimp.) Kindb. | Chekanovsky, nival meadow Shn 3 | Shn3/1 |
| *Campylium* | *stellatum* (Hedw.) C.Jens. | | M-2/3 |
| *Cinclidium* | *latifolium* Lindb. | | M-2/1 . |
| *Dicranoweissia* | *crispula* (Hedw.) Lindb. | Kunga Ridge | K-6-m |
| *Distichium* | *capillaceum* (Hedw.) Bruch et Schimp. in B.S.G. | Nagym | M-9/2 |
| *Ditrichum* | *flexicaule* (Schwaegr.) Hampe | Nagym | M-9/1 |
| *Hylocomium* | *splendens* (Hedw.) Schimp. in B.S.G. | | M-3 |
| *Hylocomium* | *splendens* (Hedw.) Schimp. in B.S.G. | Chekanovsky | M-4/2 |
| *Hylocomium* | *splendens* (Hedw.) Schimp. in B.S.G. | Kunga Ridge | K-6-mlg/2 |
| *Hypnum* | *hamilosum* Schimp. in B.S.G. | Nagym | M-1 |
| *Limprichtia* | sp. Loeske | | M-2/2 |
| *Limprichtia* | sp. | Nagym | M-16/2 |
| *Meesia* | *triquetra* (Richter) Aongstr. | Nagym | M-7 |
| *Pohlia* | *cruda* (Hedw.) Lindb. | Nagym | M-12/2 |
| *Polytrichastrum* | *alpinum* ssp. *fragile* (Bryhn) Long | Chekanovsky | M-4/1 |
| *Polytrichastrum* | *alpinum* (Hedw.) G.L.Sm. | Chekanovsky, nival meadow Shn 3 | Shn3/6 |
| *Polytrichum* | *strictum* Brid. | Nagym | M-5/1 |
| *Polytrichum* | *juniperinum* (Hedw.) | Nagym | M-12/1 |
| *Polytrichum* | sp. | Kunga Ridge | K-6-mlg/3 |
| *Sanionia* | *uncinata* (Hedw.) Loeske | Kunga Ridge | K-6-mlg/1 |
| *Sanionia* | *uncinata* (Hedw.) Loeske | Chekanovsky, nival meadow Shn 3 | Shn3/3 |
| *Sanionia* | *paludicola* Loeske et K.Muell. | Chekanovsky, nival meadow Shn 3 | Shn3/4 |
| *Sanionia* | *uncinata* (Hedw.) Loeske | Chekanovsky, nival meadow Shn 3 | Shn3/5 |
| *Sarmentypnum* | sarmentosum (Wahlenb.) Tuom. et. T.Kop. | Chekanovsky, nival meadow Shn 3 | Shn3/7 |
| *Sphagnum* | *obtusum* Warnst. | Nagym | M-11 |
| *Sphagnum* | *warnstorfii* Russ. | Chekanovsky | M-14 |
| *Sphagnum* | *aongstroemii* C.Hartm. | Chekanovsky | M-15 |
| *Sphagnum* | *squarrosum* Crome | Chekanovsky, nival meadow Shn 3 | Shn3/2 |
| *Tomentypnum* | *nitens* (Hedw.) Loeske | | M-8 |

**A5-8:** List of lichens from different studied nival and periglacial landscapes (identification by Mikhael Zhurbenko, St. Petersburg)

| genus | species | study area | Sample No. | environment |
|---|---|---|---|---|
| *Alectoria* | *nigricans* (Ach.) Nyl. | Chekanovsky | F-29/2 | |
| *Alectoria* | *ochroleuca* (Hoffm.) A.Massal. | Bykovsky | F-34 | |
| *Arctocetraria* | *nigricascens* (Nyl.) Kärnefelt & A.Thell | Chekanovsky | F-20 | wet / nival |
| *Asahinea* | *chrysantha* (Tuck.) C.F.Culb. & W.L.Culb. | Bykovsky | F-32/1 | |
| *Bryocaulon* | *divergens* (Ach.) Kärnefelt | Chekanovsky | F-29/1 | |
| *Cetraria* | *islandica* (L.) Ach. | Nagym | F-12 | |
| *Cetrariella* | *fastigiata* (Nyl.) Kärnefelt & A.Thell | Chekanovsky | F-22 | wet / nival |
| *Cladina* | *arbuscula* (Wallr.) Hale & W.L.Culb. | Chekanovsky | F-2 | |
| *Cladina* | *arbuscula* (Wallr.) Hale & W.L.Culb. | Nagym | F-11 | |
| *Cladonia* | *amaurocraea* (Florke) Schaer. | Chekanovsky | F-4 | |
| *Cladonia* | *subfurcata* (Nyl.) Arnold | Nagym | F-6 | |
| *Cladonia* | *gracilis* (L.) Willd. | Nagym | F-18 | |
| *Cladonia* | *amaurocraea* (Florke) Schaer. | Nagym | F-28 | |
| *Cladonia* | *gracilis* (L.) Willd. | Nagym | F-35 | |
| *Dactylina* | *arctica (Hook.) Nyl.* | Chekanovsky | F-17 | |
| *Dactylina* | *arctica* (Hook.) Nyl. | Nagym | F-24 | |
| *Flavocetraria* | *cucullata* (Bellardi) Kärnefelt et A.Thell | Bykovsky/Chekanovsky | F-26 | |
| *Hypogymnia* | *subobscura* (Vain.) Poelt | Chekanovsky | F-23 | |
| *Lopadium* | *pezizoideum* (Ach.) Korb. | Bykovsky | F-31/2 | |
| *Melanelia* | *infumata* (Nyl.) Essl. | Bykovsky | F-33 | on lignum (wood) |
| *Ochrolechia* | *frigida* (Sw.) Lynge | Chekanovsky | F-14 | |
| *Ophioparma* | ventosa (L.) *Norman* var. *lapponica* (Räsänen) R.Sant. | Chekanovsky | F-5 | |
| *Parmelia* | *omphalodes* (L.) Ach. | Bykovsky | F-30 | on stone |
| *Parmelia* | *saxatilis* (L.) Ach. | Bykovsky | F-31/1 | |
| *Parmelia* | *omphalodes* | Bykovsky | F-32/2 | |
| *Peltigera* | *rufescens* (Weiss) Humb. | Chekanovsky | F-3 | |
| *Peltigera* | *leucophlebia* (Nyl.) Gyeln. | Chekanovsky | F-7 | |
| *Peltigera* | *leucophlebia* (Nyl.) Gyeln. | Nagym | F-9/1 | |
| *Peltigera* | sp. | Nagym | F-9/2 | (glossy, sterile) |
| *Peltigera* | *rufescens* (Weiss) Humb. | Chekanovsky | F-16 | |
| *Pertusaria* | *coriacea* (Th.Fr.) Th.Fr. | Chekanovsky | F-15 | |
| *Pertusaria* | *coriacea* (Th.Fr.) Th.Fr. | Chekanovsky | F-21/1 | |
| *Psoroma* | *hypnorum* (Vahl) Gray | Chekanovsky | F-27/2 | |
| *Ramalina* | almquistii Vain. | Chekanovsky | F-25 | dry / exposed |
| *Rinodina* | *turfacea* (Wahlenb.) Korb. | Chekanovsky | F-21/2 | |
| *Spherophorus* | *globosus* (Huds.) Vain. | Chekanovsky | F-27/1 | |
| *Stereocaulon* | *alpinum* Laurer ex Funck | Nagym | F-13 | |
| *Stereocaulon* | *rivulorum* H.Magn. (on sandy soil) | Chekanovsky | F-19 | wet / nival |
| *Thamnolia* | *vermicularis* (Sw.) Schaer. var. *vermicularis* | Chekanovsky | F-8/1 | |
| *Thamnolia* | *vermicularis* (Sw.) Schaer. var. *subuliformis* (Ehrh.) Schaer. | Chekanovsky | F-8/2 | |
| *Thamnolia* | *vermicularis* (Sw.) Schaer. var. *subuliformis* (Ehrh.) Schaer. | Chekanovsky | F-10 | |
| *Vulpicida* | *tilesii* (Ach.) J.-E.Mattsson & M.J.Lai | Chekanovsky | F-1 | Ca-rich |
| *Cetrariella* | *delisei* | - | - | nival |
| *Lecidea* | *ramulosa* | - | - | nival |
| *Bryonora* | spp. | - | - | nival |

**A5-8:** continuation

| genus | species | study area | Sample No. | environment |
|---|---|---|---|---|
| Rhizocarpon | *geographicum* (L.) DC. | Chekanovsky | CHKY-F24 | nival, on rock |
| *Aspicilia* | sp. | Chekanovsky | CHKY-F25 | nival, on rock |
| *Lecanora* | *marginata* (Schaer.) Hertel & Rambold | Chekanovsky | CHKY-F26 | nival, on rock |
| *Tephromela* | *atra* (Huds.) Hafellner | Chekanovsky | CHKY-F27 | nival, on rock |
| *Lecanora* | *polytropa* (Hoffm.) Rabenh. | Chekanovsky | CHKY-F30 | nival, on rock |
| *Lecidea* | *confluens* (Weber) Ach. | Chekanovsky | CHKY-F33 | nival, on rock |
| *Lecidea* | *lapicida* (Ach.) Ach. | Chekanovsky | CHKY-F34 | nival, on rock |

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