Paleoenvironmental and Paleoclimatic Records from Permafrost Deposits in the Arctic Region of Northern Siberia

Lutz SCHIRRMEISTER[1], Christine SIEGERT[1], Hanno MEYER[1], Alexander DEREVYAGIN[2], Frank KIENAST[1], Andrei ANDREEV[1], Victor KUNITSKY[3], Vladimir TUMSKOY[2] and Piet GROOTES[4]

[1] *Alfred-Wegener Institute for Polar and Marine Research, PF 600149, 14401 Potsdam, Germany*
[2] *Moscow State University, Faculty of Geology, 119899 Moscow, Russia*
[3] *Permafrost Institute Russian Academy of Sciences, 677018 Yakutsk, Yakutia, Russia*
[4] *Leibniz-Laboratory, Christian-Albrecht-University, Max-Eyth-Strasse 11, 24098 Kiel, Germany*

ABSTRACT. Extremely ice-rich permafrost deposits with large ice wedges, called Ice Complex, are widely distributed in the Arctic region of Northeast Siberia. They present excellent archives for the reconstruction of Late Quaternary paleoenvironmental conditions in non-glaciated areas. In 1998 and 1999 Russian and German scientists worked together on Bykovsky Peninsula south-east of the Lena Delta in order to investigate the Ice Complex and their associated formations. Complex cryolithological and sedimentological studies, radiocarbon age determinations, stable isotope and hydrochemical studies of ground ice, investigations of mammal and insect fossils, palynological and carpological studies were made. Radiocarbon data have been obtained from the entire exposed sequence covering approximately the last sixty thousand years. The Ice Complex was formed in a wet, poorly drained polygonal tundra landscape with bogs and small waters within the polygons. Obtained results indicate that the investigated Ice Complex sequence was formed during two cooler and more arid stages of the Late Pleistocene with uniform environmental conditions and a stage with variable environmental conditions with more intensive soil formation caused probable by a distinct climate amelioration. A strong break is evidenced for the Pleistocene/Holocene transition. These Late Pleistocene changes in environmental conditions were not as strong as those occurring during the Pleistocene/Holocene transition.

KEY WORDS: permafrost, North-East Siberia, paleoenvironment, age determinations, Late Pleistocene, sedimentology.

Introduction

Ice-rich permafrost sequences of up to 40 m and more thickness with large ice wedges are widely distributed in Northern Yakutia, especially in the coastal lowland and on the New Siberian Islands. These deposits, called Ice Complex, were formed under terrestrial conditions during Late Pleistocene. The sediments turned into permafrost almost synchronously with their accumulation (Romanovsky, 1993). Therefore, numerous paleontological, paleobotanical, geochemical and sedimentological records are very well conserved in ground ice and perennially frozen sediment. These excellent archives were studied by Russian-German teams on the East Coast of the Bykovsky Peninsula southeast of the Lena Delta (Fig. 1).

The aim of these studies is the reconstruction of the Late Quaternary environmental conditions in the Laptev Sea region by using different records, which frozen in permafrost. The genesis of Ice Complex deposits is still under discussion. For the studied area the lithogenetic conceptions vary from glacier dammed basin sediments (Grosswald, 1998) and acolian Arctic

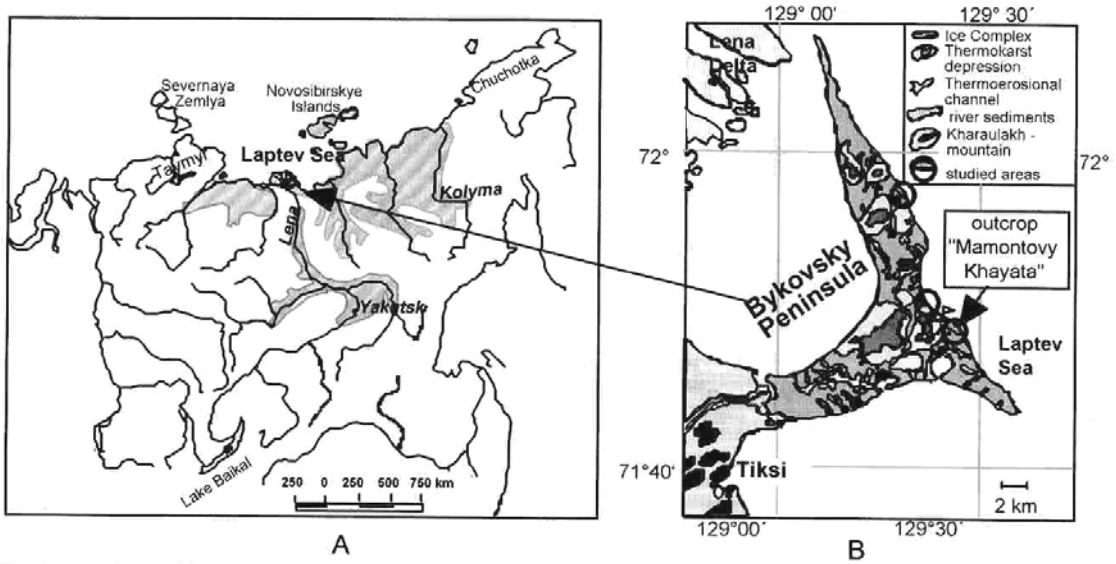

Fig. 1. (A) Areas with Ice Complex of great thickness on various relief elements in Northern Siberia (after Romanovsky, 1993); (B) position and geomorphological features of the study area - the Bykovsky Peninsula.

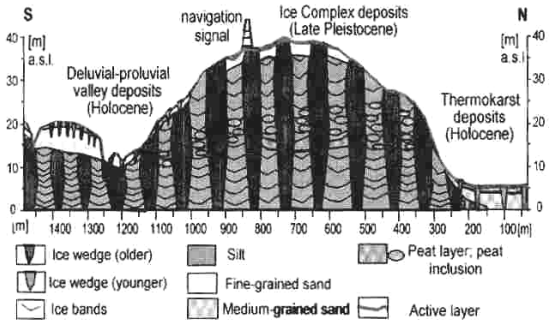

Fig. 2. Schematic profile of the main studied outcrop - the coastal cliff "Mamontovy Khayata".

loess (Tomirdiaro et al., 1984) to flood plain and proluvial slope sediments (Slagoda, 1991), nival deposits (Kunitsky, 1989) and Lena delta sediments (Sone, 1994; Nagaoka, 1994).

Methods and material studied

The results which are presented in this paper include the study of permafrost sequences by cryolithological and sedimentological methods (cryo-structure, gravimetric ice content, grain size analysis, TOC content, C/N ratio, $\delta^{13}C$ of TOC, mass specific magnetic susceptibility) and the radiocarbon age determination (AMS, conventional). These results are supported by paleontological studies of mammals and insects, paleobotanical studies (pollen, seeds) and stable isotope investigations of ground ice ($\delta^{18}O$, δD).

The main study object - the Ice Complex in the coastal outcrop "Mamontovy Khayata" consists predominantly of ice-rich fine-grained silty sandy deposits. The Ice complex is covered by deposits formed during the Holocene by thermokarst and thermal erosion. The Ice Complex sequence is subdivided into three units (Fig. 2). However, the middle part is characterized by strong peatification and the presence of numerous peaty paleosols whereas the lower and the upper parts contain less peaty material and other plant fossils and they are only slightly influenced by soil formation. The top the Ice Complex is covered by a single sandy horizon.

In general the studied deposits contain large amounts of ground ice in the form of massive polygonal ice wedges and have segregated ice in the sediment. The ice content of the intrapolygonal sediment blocks varies between 80 and 180% (ice content in relation to dry weight of the sediment). Paleosol horizons enriched in organic matter are characterized by smaller ice contents than mineral interlayers and sediment horizons slightly influenced by soil formation. The observed thick-banded and lens-like reticulated cryostructure is typical for sediments formed in poorly drained landscapes with near-surface position of the permafrost table (Katasonov, 1975; French, 1996).

Results and analyses

Radiocarbon age determinations of about 80 samples show a closed age sequence covering about last 60 ka, including Middle Weichselian, Late Weichselian and Holocene periods

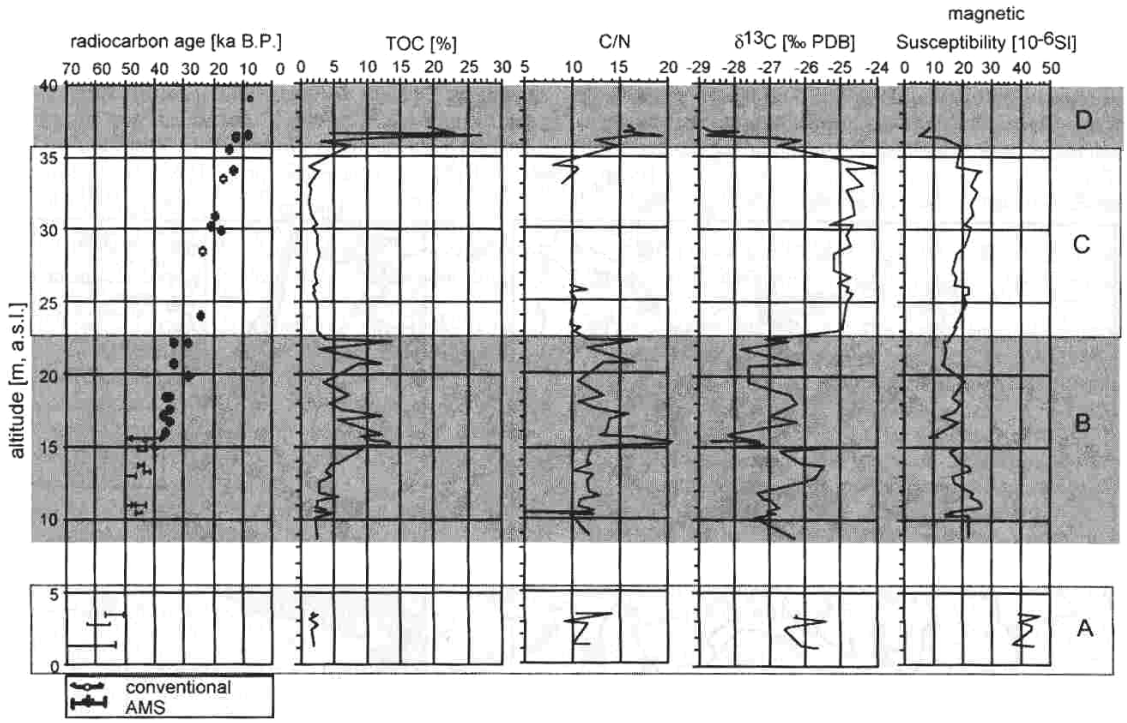

Fig. 3. Results of radiocarbon age determinations and selected sedimentological studies of the permafrost sequences at the outcrop "Mamontovy Khayata" (the different stages A-D are explained in the text).

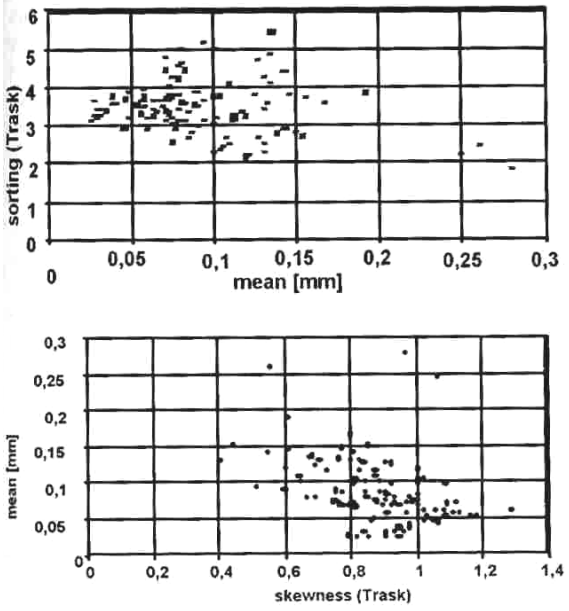

Fig. 4. Relationships of grain size parameters in Ice Complex deposits and the Holocene cover.

(Fig. 3). The obtained results of sedimentological studies allow to distinguish clearly between three different units in the Ice Complex deposits (A, B, C) and a cover horizon (D) at the top.

The variation of TOC content, C/N ratio and $\delta^{13}C$ values of bulk organic matter seems to be connected with differences in intensity and character of soil formation and peat accumulation. Variations in the magnetic susceptibility and grain size distribution reflect different sediment sources as well as changes in the transport conditions. There are two stages with relatively low variations of the environmental conditions (A = about 60–52 ka, C = 28–12 ka) and two stages with obviously instable conditions (B = about 48–28 ka, D = since about 12 ka).

Grain size analyses indicate that the Ice Complex deposits and their Holocene cover are composed of badly sorted sandy silt to silty sand. The distribution of the grain size parameters mean, sorting and skewness don not show clearly any orientation or groups of data (Fig. 4). That means that the general accumulation does not change very strong but there is a large spectrum of fine-grained silty sands. Only some samples from the uppermost Holocene cover have a real sandy grain size distribution.

Entomological (Kuzmina et al., 1999) and palynological studies yielded comparable trends in variations of the environmental conditions during the examined Late Pleistocene period. At the same time, the continuous high quantity of alga spores and ostracodan shells in numerous samples of the Ice Complex deposits indicates that their accumulation has occurred in a wet polygonal landscape with small shallow waters in low-centered polygons. But the entomological and carpological results indicate a mosaik-like construction of the tundra landscape with dominating more dry stepp-like conditions. This contrast has to solve by further studies.

A diverse mammal fauna of grazers, dominated by mammoth, bison, and reindeer, inhabited the study area until the end of the Late Pleistocene (the last currently available date on mammoth bones is 14.3 ka). Their forage resource, mosaic Arctic grassland, started to decline with the rapid environmental change at the end of the Pleistocene (Kuzmina et al., 1999). This change is also reflected by stable isotope analyses on ice wedges ($\delta^{18}O$, δD) showing a shift towards heavier isotopic composition from Late Pleistocene to the Holocene indicating a warming trend (Meyer, 2000).

Discussion and conclusions

The continuous accumulation of Ice Complex deposits, which contain various fossils of plants, insects and mammals indicate that the Laptev Sea region was not covered by an ice sheet during the Late Pleistocene as assumed by Grosswald (1998). Although up to now not all records can be explained by special paleoenvironmental conditions we try a first reconstruction.

More arid conditions marked the earliest period of the accumulation, while the middle part was formed during a period (48–28 ka) in which the climate seems to be more humid and instable. Peaty soils, partially cryoturbated were formed and peat beds were accumulated during this period. The upper part of the Ice Complex succession, including the LGM, was formed during a cold, more arid stage. A rapid climate and environment change at the Late Pleistocene - Early Holocene transition is proved by stable isotope data of ice wedges for the study area. It was probably caused by a change in atmospheric circulation and fast retreat of the stable ice cover of the Arctic Ocean and the beginning of the inundation of the recent shelf by the Holocene marine transgression. Such significant changes in the environmental conditions had never occurred during the entire Late Pleistocene in the non-glaciated area of the NE-Siberian Arctic.

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Paleoenvironmental Changes in the Lagoon of Mayotte Associated with the Holocene Transgression

Jens ZINKE[1], Johannes Jozef G. REIJMER[1], Wolf-Christian DULLO[1] and Bernard A. THOMASSIN[2]

[1] *GEOMAR, Research Center for Marine Geosciences, Wischhofstrasse 1-3, Geb. 4, Kiel, D-24148, Germany.*

[2] *Centre d'Océanologie de Marseille (CNRS UA 41), Station marine d'Endoume, rue de la Batterie-des-Lions, 13007 Marseille, France.*

ABSTRACT. The volcanic island of Mayotte (12°50'S, 45°10'E) belongs to the Comoro archipelago located in the SW Indian Ocean (Northern Mocambique Channel). It is surrounded by an almost continuous ribbon barrier reef system which encircles a large lagoon of 1500 km² with a maximum water depth of 80 m. The objective of this study is to determine paleoenvironmental changes associated with the Holocene transgression. The physical (grain size), mineralogical (aragonite, calcite) and geochemical (carbonate, organic carbon and terrigenous content) sedimentary parameters show significant changes during the Holocene transgression. Rising sea level interacted with the complex morphology of the lagoon floor and produced different sedimentary environments at different times with varying water depths. The transgressive and highstand systems tract are characterised by their specific mineralogy, geochemistry, grain size distribution and magnetic susceptibility. Local processes like climatic variations (monsoonal precipitation, solar insolation, shift of the Intertropical Convergence Zone) or volcanism influenced the sedimentary processes during specific time intervals. Higher precipitation during the early Holocene (11–9 ka BP) caused by an intensified NE-monsoon enhanced runoff of terrigenous sediments into the lagoon. A mid-Holocene period (6–4 ka BP) of major volcanic activity on the eastern Petite Terre volcano disturbed the carbonate production in the neighbouring lagoons for a few hundred years. Maximum carbonate concentrations are found between 4–1 ka BP and coincide with a time of maximum solar insolation. A dramatic change in carbonate production occurred after 1 ka BP. This is probably linked to the ultimate stillstand in sea level rise at this time and anthropogenic input, which caused progradation of terrigenous sediments. Anthropogenic changes overprint the natural changes in the geochemistry and mineralogy of the lagoonal sediments after the first human settlement on the island around 1.2–0.8 ka BP.

KEY WORDS: Holocene, lagoonal sedimentation, geochemistry, mineralogy, grain size, SW Indian Ocean.

Introduction

The present study documents the evolution of the sedimentary sequences in the lagoon of Mayotte during the Holocene transgression. We will focus on the role of sea level, lagoonal topography and climate dynamics for the facies development. Finally, we will answer the questions when and how anthropogenic input occurred.

Methods and results

10 gravity cores were examined derived from various settings within the lagoon of Mayotte. Bulk sediment samples were taken every 10 cm. All samples were oven-dried at 50 °C and subsamples (~ 0.5 g) ground by hand for four minutes in an agate mortar.

Calcium carbonate, organic carbon and terrigenous contents were determined by LECO-analysis. X-ray diffraction was performed to quantify the abundance of carbonate minerals in the samples. The program Mac Diff 3.1.5 was used to determine the amount of calcite and aragonite within the sediment, by measurement of peak area. The relative weight percentages of calcite and aragonite where than calibrated with an in-house calibration curve (Andresen, 2000). X-ray fluorescence (XRF) were performed to determine the amount of major and minor elements within specific facies realms in the individual cores.

For grain size analysis the bulk sediment samples were at first wet-sieved for a devision into coarse (> 63 µm) and fine