8 Paleoecological and permafrost studies of Ice Complex in the Laptev Sea area (Bykovsky Peninsula)

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8.1 Introduction, objectives and logistics

Multidisciplinary research of the Late Pleistocene Ice Complex in the Lena Delta (Bykovsky Peninsula, Mamontovy Khayata Cliff) under the Russian-German project "Laptev Sea System 2000" in 1998-99 provided the most detailed, continuous and well dated record of the past environment of the Laptev Shelf Land during the last 50 ka (Schirrmeister et al., 2002). An important component of that study was a unique succession of fossil insect assemblages, which allowed recognizing the trends and stages in the development of landscape and climate in the Late Pleistocene and Early Holocene (Kuzmina, 2001). It was for the first time revealed that the early Karginian and late Sartanian environment had much in common, as the corresponding insect assemblages included a large number of steppe species. That implied a relatively warm and arid tundra-steppe environment that existed under extremely continental climate with summers warmer than today, especially during the latter interval. The late Karginian (35-25 ka) and especially early Sartanian (corresponding to the LGM) were marked by lower summer temperature, but retained essential aridity (Sher et al., 2001).

The previously obtained record, however, included some gaps, and required a finer sampling resolution, especially during the critical periods of environmental changes. Among those periods were the transition from the Last Glacial Maximum (LGM) to the "warm" stage in the Late Sartanian (previously estimated as about 18,000 ^{14}C years BP), the beginning of the LGM, and the Pleistocene/Holocene transition. Also, an additional characteristics of faunas of the LGM itself (first time discovered in 1999 and based on three samples only) was vitally important. There were also some gaps in the ice wedge sampling for ^{18}O isotope analysis, which was important to estimate past winter temperature. The earlier obtained geocryological description of the upper part of the Ice Complex sediment was not sufficient enough. Some important geological and permafrost problems, raised by the previous research, remained unsolved. In particular, such questions were insufficiently understood as the observed cyclic character of the Ice Complex deposits, the origin of "paleosol" horizons, the nature of stratified units in the section (sedimentary or purely cryological ?), and the processes, which occurred during the termination of the Ice Complex accumulation and beginning of the early Holocene thermokarst outburst. Finally, it was important to find more mammal bones *in situ* in permafrost, both for the dating purposes, and for various analyses, such as the oxygen isotope and DNA studies currently in progress.

With all those aims and tasks, a Russian team continued the study of Mamontovy Khayata in 2001. The Bykovsky expedition team was organized by the Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences (SIEE RAS) as a part of the research project "Mammoth evolution and environmental changes in northern Eurasia" supported by the Russian Foundation for Basic Research (RFBR grants 01-04-48930 and 01-04-63073). As the planned investigation was directly related to the previous Russian-German work at this site, it was agreed that the Bykovsky team, though logistically and financially independent, would be considered under the umbrella of the Russian-German program "Laptev Sea System 2000".

Besides its leader, representing the organizing institution, the Bykovsky team included four scientists and students from the Paleontological Institute of the Russian Academy of Sciences (PIN RAS), and the Departments of Geocryology and Paleontology of the Moscow State University, all of them being for that period associates of the SIEE RAS. Essential logistic and financial support was rendered by the partner expedition of the Institute of Fundamental Problems of Biology RAS (Pushchino), led by Dr. David Gilichinsky and managed by Victor Sorokovikov. We highly appreciate this support, without which the Bykovsky team work would be hardly possible. We also thank the Lena Delta Reserve, and Mr. Ivan Vorobyov and Dr. Alexander Gukov in particular, for their permanent assistance, and our German colleagues (AWI-Potsdam) for lending some very useful working equipment.

8.2 Methods and field measurements

In the general investigation of the section, we followed the same method, which was successfully used in 1999: the tracing of continuous section through a "chain" of closely positioned baydzherakhs, with some overlap at their tops and bottoms. In 2001, we were able to build such a "chain" from the very top of the section (39 m above sea level, a.s.l.), at its almost highest point, to the depth of about 22 m (Fig. 8-1), which earlier yielded ^{14}C dates around 35-36 ka (below this level, the radiocarbon dates show some dispersion, and individual layers can be dated with some approximation only). Instrumental survey helped to reconstruct the earlier landmarks, most of which were not preserved since 1998-99, and to correlate with the previous altitude/depth estimates. During the 2001 summer, the thawing of the cliff was quite active, so we had to repeat the depth survey several times and to reconstruct the markers (which were drilled-in sticks along the ice wedges).

The main problem of sampling for macrofossil screening (to obtain insect, plant, bone and other fossils larger than 0.5 mm mesh) was common for the study of permafrost sediments. To obtain a representative number of fossils, which can be used for statistical analysis, a large volume of sediment is required (more than 50 kg). Earlier, such samples were taken from a thawed crust of a layer to be sampled, still preserved in its original place. Normally, to get the necessary volume at once is impossible, even if we are able to take the thawed sediment

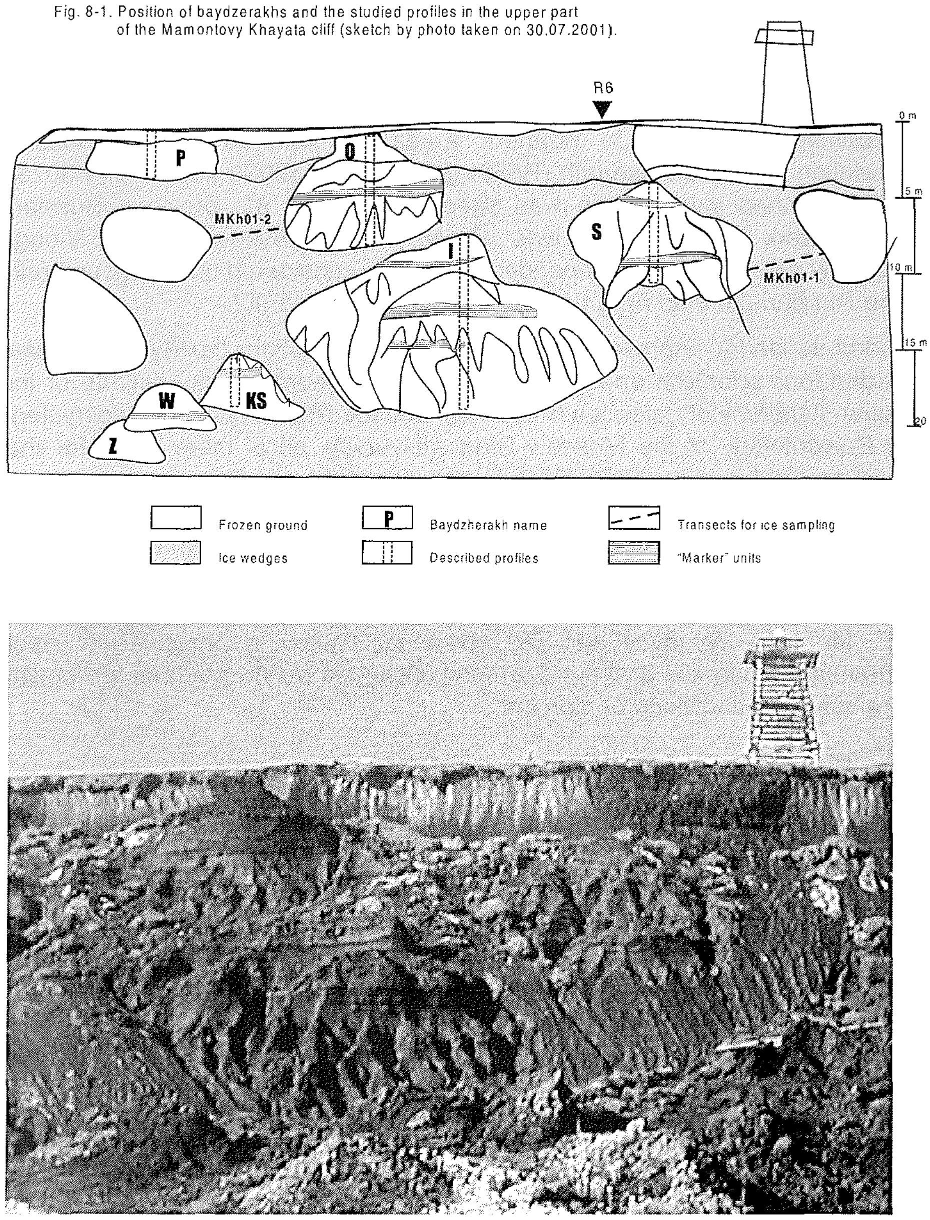

Figure 8-1: Position of baydzherakhs and the studied profiles in the upper part of the Mamontovy Khayata cliff (sketch by photo taken on 30.07.2001).

from 2-3 m strike of the same layer. Besides the need to come back to the same layer several times for the collecting its newly thawed portion, such a technique has a number of other disadvantages. Some cryolithological varieties do not form such a crust during the thaw, but turn into liquid mud immediately after melting; being confined in sampling to the thawed spots, you often cannot take the sample exactly in the place, where you need it for stratigraphy, etc. That means that large-volume samples should be taken from frozen, undisturbed sediment, which would allow more precise stratigraphic control and minimize possible contamination. We tried several techniques to take such samples, including the chain-saw, chisel and hammer, etc, but none of the instruments was effective. Finally, we came to the usage of a big axe, with which we tried to make a few grooves on a frozen surface, deep enough to eventually chop off a more or less large block of frozen rock (20-30 cm). By this primitive technique it was possible to take one or two samples during the whole day, but some of them turned still insufficient after melting (because of high ice content), and needed additional sediment to be taken later.

Thus, for the first time, most samples were taken not from the thawed sediment on the slope, but chopped from permafrost. In total, 23 samples were taken and screened for fossil insects, mostly from the upper part of the section (Fig. 8-2, Table A8-1, A8-2, A8-3). At the same time, 35 general sediment samples (for pollen, ^{14}C dating, etc.) were taken (also chopped from permafrost).

For oxygen isotope analysis, ice samples were taken from several ice wedge transects, following the instructions, given by Dr. H. Meyer (AWI-Potsdam). We used a chain saw to cut a transverse step across the ice wedge, and to cut sample blocks every 10 cm from the step. The ice blocks were finally separated by chisel and hammer and put in the pre-labeled zip-bags. After melting under normal temperature and precipitation of most of the sediment, a part of water was poured into sealable sampling bottles. The rest of the sample, after stirring up, was filtered through the 0,5 mm mesh, and the residual dried and put in plastic bags for further study. In total, 110 ice/water samples were taken from 5 transects (see details in the next section).

In course of the cryolithological description of the section, frozen samples were taken to define full moisture content by standard technique (weighing-drying-weighing).

8.3 Preliminary results

The geological and geocryological investigation in the top part of the MKh section in 2001 agrees quite well with the observations made in 1999. Although we worked in 2001 only a little aside from the 1999 profiles, we definitely observed different baydzherakhs (bdzkhs), as the rate of thermo-denudation and retreat of the top part of the cliff is very high. Only bdzkh "S" probably represented the remains (the lower part) of the '99's bdzkh "E".

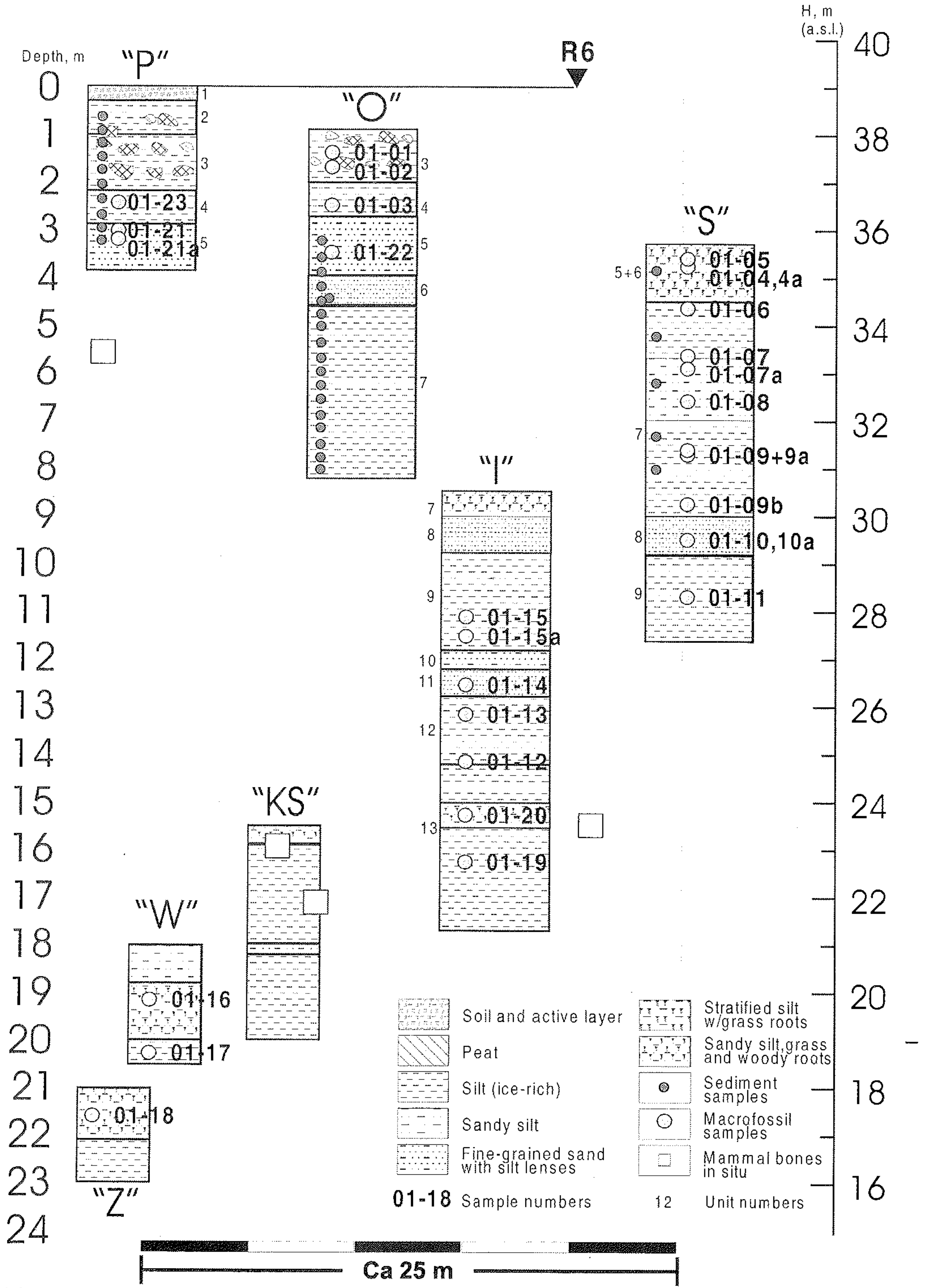

Figure 8-2: Mamontovy Khayata Exposure. Areas, profiles and sampling in 2001

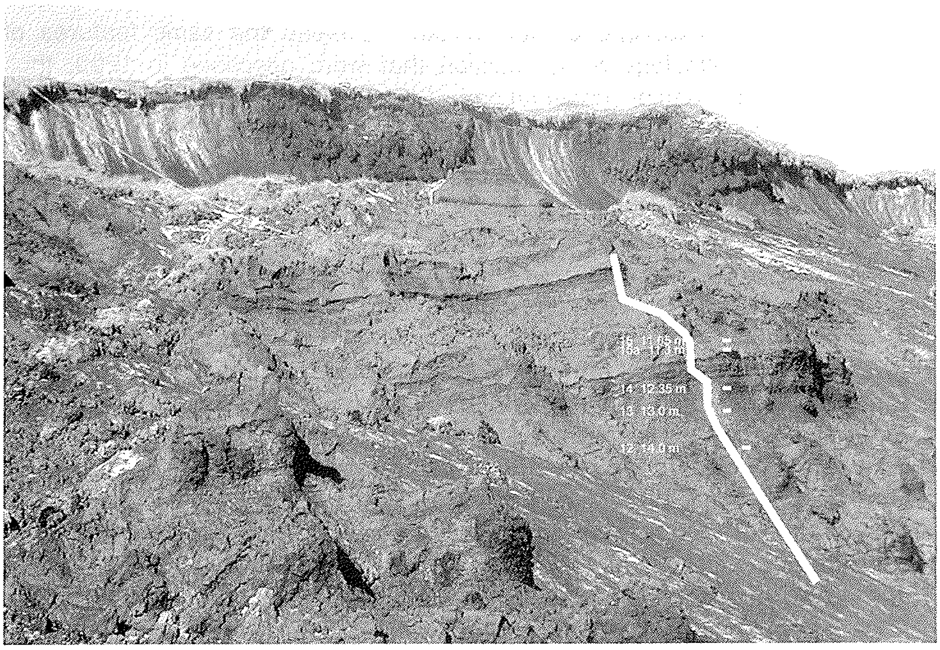

Figure 8-3: Mamontovy Khayata, 30.07.2001. Side view of baydzherakh "I". Two "marker" units are well visible because of their stratified appearance and steep part in the profile. Behind it – then still preserved - dome of bdzkh "S" with its upper "marker" unit.

Figure 8-4: Mamontovy Khayata, 03.08.2001. The lower "steep" part of baydzherakh "I" with the "marker" unit 11 at 12,2-12,8 m depth.

Nevertheless, the exposure of new bdzkhs revealed the same features of geology and cryolithology of the section that were described in 1999, thus corroborating our earlier observations (Sher et al., 2000). The following regularities were noticed in 1999 and confirmed in 2000:

There are a few levels of baydzherakhs in the upper half of the MKh cliff, and they all have essentially the same construction, reflecting the cyclic character of cryogenic sedimentation. This construction gives similar appearance to most of the baydzherakhs which is explained by the fact that the pattern of exposing and further denudation of each of them is predefined with the same sequence of cryolithological units with peculiar properties. The most noticeable unit (B) forms very steep or vertical step on the bdzkh's seaside front; it has generally darker color and a stratified appearance, and includes abundant grass roots (Fig. 8-3, 8-4). In 1999, we provisionally labeled it as "paleosol", but we were not able to get any strong confirmation either of the soil origin of this unit, or of lithological nature of its stratification. On the contrary, it was concluded that the visually observed stratification was caused mostly by intercalation of horizontal layers with different cryogenic structure (see Unit 6 in "O", Unit 8 in "S", Unit 12 in "I", Table A8.1). Although neither lithological base of this cryogenic stratification, nor the soil origin of this unit cannot be excluded, we prefer now to use more prudent term "the marker unit". The latter is always underlain by silt layer (A) with generally higher ice content, without visible stratification, and forming radiating "ridges" below the "marker unit", i.e. in the lower part of the bdzkh. The "ridges" are formed by exposed frozen sediment, while along the "valleys" between them mud flows creep down. This feature gives the baydzerakhs in the upper part of the MKh cliff their peculiar "octopus"-like appearance (Fig. 8-5, 8-6). The unit (C) above the "marker", forming the upper part of a more or less steep step, normally is enriched with sand particles (sandy silt or silty sand) and sometimes demonstrates horizontal lens-like -wavy lamination. All three units include more or less abundant organic material – grass roots, woody roots and twigs, sometimes peaty spots, but its distribution is uneven, and may have some regularities. For instance, although the grass roots are present in all types of layers, the units of the B-type are most rich for grass roots, which form long furcating systems. Woody roots are common both for the type A and C units, but their maximum concentration was more often observed in C. So, each bdzkh basically includes one cycle of these three units (from the bottom): A, B, and C, about 4-5 m in total thickness. Some of them, however, may cover two cycles (as "S" and "I" in our case) and provide a continuous section 7-10 m long (measured by vertical).

Interesting observations were made on the units of A-type. It turned out that the "ridges" have a slightly different cryostructure from the "valleys" separating them, or they may even have a slightly different lithology. That shows, that the "ridges" and "valleys" are not just random erosional features, but their shape is somehow predefined by their structure. This observation has even raised the suggestion that the ridges include some "xenoliths" of the sediment from the layers above, that was melted, dropped or slid down, and then was refrozen.

That is, however, hardly possible to happen in the second half of summer, when thawing and denudation are very fast, the frozen surfaces are "refreshed" every day by loosing several centimeters of frozen ground, and the appearance of some bdzkhs can be hardly recognized after a week. Unfortunately, this phenomenon could not been fully understood, as it requires special subtle studies.

Very informative were the observations on the dynamics of the bdzkh development in course of the cliff denudation, especially in the upper level. Originally, they appear on the upper wall of the cliff as shallow synclinal troughs (up to 2 m deep) in the middle of long ice walls. They all include the Holocene "peat hummock" unit, and look like the insertions into the Pleistocene polygonal system from the top of the Yedoma (Fig. 8-7). With time, however; they gradually come forward from the ice wall, broaden at the base (due to fast melting of ice beneath them). Now they look as very broad trapezoid-shaped baydzerakhs, still mainly attached to the Yedoma surface, with relatively narrow ice wedges between them. Since that time, the process of their separation from the Yedoma starts: for a week or two they look like the capes, still attached to the main surface and covered with tundra sod. The adjoining ice wedges melt very fast, and the more the bdzkh protrudes from the wall, the faster denudation on its sides goes, so at this stage it acquires a typical conic shape and starts to look much narrower than the adjoining ice wedges. By the end of this stage (even before the complete separation from the Yedoma), the bydzkh commonly already has a sub-vertical step in the middle (Unit B) and the "ridges" at the bottom (Unit A) are becoming more and more clear. When the bydzkh finally looses the connection with the Yedoma surface (a longitudinal ice wedge appears between it and the Yedoma), its denudation goes still faster, as it is now exposed from the back side as well. At the same time, more and more frozen sediments are getting exposed at the bottom, and the base of the now "octopus"-like bdzkh becomes very broad, much broader than the adjoining ice wedges. Behind it, the latitudinal ice wedge now forms the upper part of the cliff, and the latter now looks as a continuous ice wall, giving the erroneous impression of extremely wide ice wedges, while a few meters down they look normal (narrower than the bdzkhs are).

Due to the essential similarity of the 2001 exposure appearance to the 1999 one, we were able to provide a provisional correlation with the earlier described units, and thus to estimate preliminarily the age of the new units and the observed sedimentation cycles from the earlier dating. The top level of bdzkhs – "P" and "O" – correlate with "H" and "E" of 1999. They include the Early Holocene "peat hummock" unit, which is dated around 8000 y BP, and the Pleistocene sequence from about 18 to 12 ka. Bdzkh "S" also belonged to that level, but its upper part has already been destroyed, and the increment at its bottom incorporated the sediments of the earlier cycle. Its studied part correlates with the downward extension of "E" (with the date of 19340 y BP) and with the bdzkh "V" of the second level that was dated from 23800 to 20600 y BP. Bdzkh "I" of the second level also covers at least two cycles: one is the

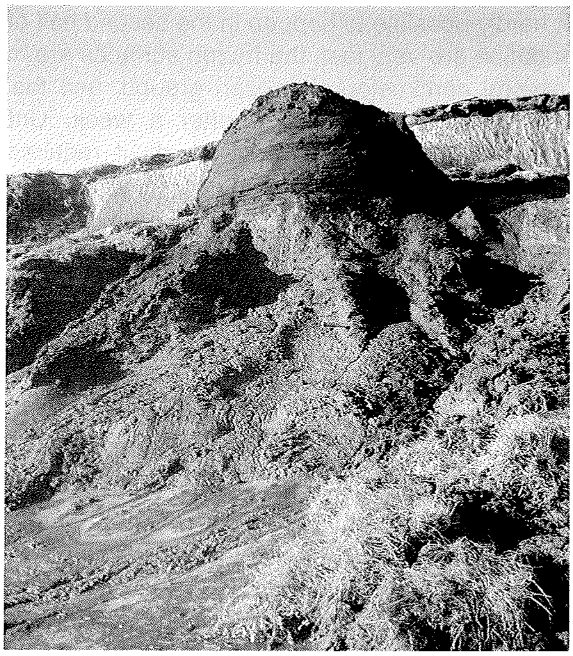

Figure 8-5: Mamontovy Khayata, 24.08.2001. View of baydzherakh "O" in the top level of bdzhks. The "marker" unit at the bottom of the steep part and the "ridges" further down, built by ice silt, suggest the "octopus"-like appearance.

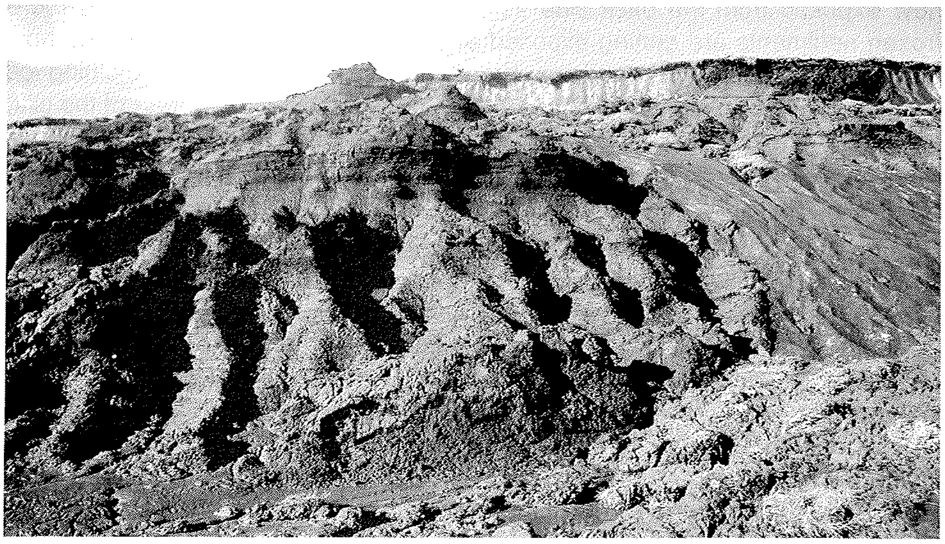

Figure 8-6: Mamontovy Khayata, 30.07.2001. View of baydzherakh "I" from the sea side. The same "marker" unit as in Fig. 8-4.

same as the lower in "S" and as "V", the other correlates with the '99 bdzkh "L" and possibly "M" (26-24 ka). An insufficiently studied bdzkh "KS" possibly correlates with "F" (28110 y BP), while the lowermost bdzkhs "W" and "Z" are built with the sediment that most likely was formed within the span of 30-35 ka.

Following the program of our field work, we sampled with greater detail the top of the section and the interval, approximately covering the time span between 20 and 12 ka (taking both macrofossil and sediment samples) (Fig. 8-2, Table A8-1). Samples for screening were also taken with about 1 m interval in the middle part of the cliff (ca 28 to 20 ka). Three samples were also taken from remarkable "twig horizons" in bdzkhs "W" and "Z".

The main conclusion of the preliminary analysis of the 2001 insect assemblages is that the new sampling confirms the earlier recognized pattern of environmental change (Sher et al., 2001), which is a good indication of the high reliability of the method, and adds some additional details to it. The late Karginian insect assemblages, in line with the previous results, indicate a relatively cold and dry climate with low summer temperature. They are usually dominated by xerophilous tundra species, such as ground beetles *Curtonotus alpinus, Pterostichus (Lyperopherus) sublaevis,* weevils *Mesotrichapion wrangelianum, Hemitrichapion tschernovi,* and *Sitona borealis*; very important is the share of arctic insects (weevil *Isochnus arcticus*).

Fully confirmed is the earlier suggested recognition of two different climatic intervals within the Sartanian stage: the earlier, with the sharp dominance of the arctic weevil *Isochnus arcticus,* indicating a very cold environment, and the later, characterized by typical tundra-steppe conditions (evidenced by the presence of steppe species and dominated by the pill-beetle *Morychus viridis*). However, the beginning of the late Sartanian "warm" interval should most likely be shifted to a later time (from previously suggested 18 ka to about 14 ka). A very short-termed episode of warmer summers was found inside the "cold" Sartanian interval (corresponding to the Last Glacial Maximum). The section interval from which this anomalous sample comes requires further study.

The Early Holocene insect assemblages are sharply different from the late Sartanian ones. In 2001, we traced the boundary between the Pleistocene and Holocene deposits in the Mamontovy Khayata main section to a greater detail. It runs at the depth about 2 m. The gray silt member below it, like the Sartanian sands further down, turned out to be dominated by *Morychus viridis* and to include fossils of meadow-steppe (*Coniocleonus cinerascens, C. astragali)* and steppe (*Stephanocleonus eruditus*) species, thus portraying a typical tundra-steppe environment. The brownish-gray silt with peat inclusions above 2 m is dominated by the mesic tundra ground beetles *Pterostichus (Cryobius) brevicornis* and includes thermophilic species, such as the ground beetles *Blethisa catenaria, Diacheila polita, Elaphrus sp., Trichocellus mannerheimi*, the carrion beetle *Blitophaga opaca*, the rove beetle *Philonthus sp.*, the leaf beetles *Chrysomela blaisdelli*, the ant *Camponotus herculeanus.* The assemblage indicates an environment similar to the modern southern shrub tundra or foresttundra, and a climate warmer than the present one. Such a striking change in faunal composition confirms the existence of a break in sedimentation, earlier suggested by radiocarbon dating as 3-4 thousand years long. Our previous statement on the smooth transition between the Pleistocene and Holocene beetle fauna should be abandoned as it was based on a single sample B-4, which was taken in 1998 at the boundary between the Pleistocene and Holocene and most likely included fossils from both above and below it.

In the previous sampling for the oxygen isotopes of ice wedges there was a gap between about 18 and 12 ka (Schirrmeister et al., 2002). We were supposed to sample additional ice wedge transects, corresponding to this interval (approx. 9 to 4 m depth). Most of the ice wedges in this interval, however, were too wide, and in fact represented crossing wedges of various directions, so it was not possible to select a normal cross-section of one ice wedge. Finally, we managed to make the transect of one well-exposed ice wedge between the bdzkh “S” and the next to NW at the depth of about 10 m (Transect MKh01-1), and the other between the bdzkh “O” and the next to SE at the depth of 7 m (Transect MKh01-2, Table A8-4, A8-5) (Fig. 8-1).

Trying to understand the geological features of the very top of the Ice Complex section (e.g., why the early Holocene “peat-hummock” layer seems to be rather deeply inserted into the big ice wedges obviously of the Pleistocene age), we made some observations over the ice wedges in this interval. Although the time limitation did not allow us to do any special study of these wedges, we could suppose that there were at least two generations of ice wedges, younger than big (Pleistocene) ice wedges (Type 1). The first (Type 2) had the bodies almost completely inside the big wedges, but their tops protruded a little (ca 20-30 cm) above the upper edge of the big wedge, so that their "shoulders" were clearly related to a younger sediment layer than immediately overlying the big ice wedge. At the same time, they did not seem modern (growing). The second generation (Type C) were the modern and growing ice wedges of smaller size, with clear shoots (stocks) reaching the bottom of the active layer. The best examples of the second were found inside the peat "sinclines", which, as we know, had mostly early Holocene age. The third kind (Type 4 ?) were the wedges, up to 1.5 m width at the top, narrowing downwards, but then broadening and entering the continuous ice wall. They are probably related to the type B, but their upper parts are not within the Pleistocene wedges, but within the ground blocks (later forming baydzerakhs). Besides all that, the upper edge of the big wedges (Type 1) shows many small shoots, intruding the overlying sediment, but hardly reaching the bottom of active layer. So we made two transects and sampled across one ice wedge of Type 4 – at its narrow waist (Transect MKh01-3a), and the broader lower part (Transect MKh01-3b), and one transect of a modern wedge of Type C (Transect MKh01-4) (Table A8.4, A8-5). All the samples are currently being analyzed by Dr. Hanno Meyer in AWI-Potsdam.

An almost permanent search for *in situ* fossil bones of mammals was not very successful. However, two bones of horses were found in the baydzherakhs of

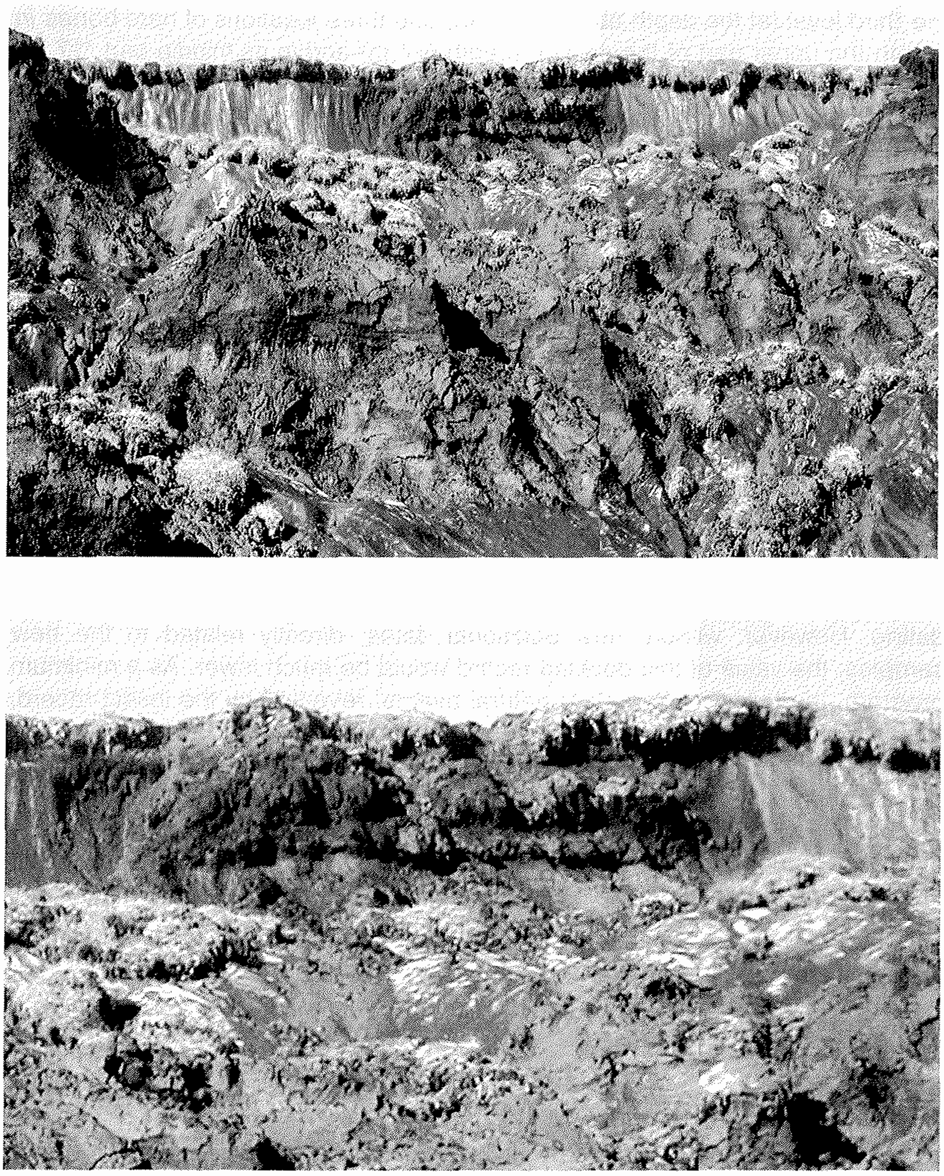

Figure 8-7a,b: Mamontovy Khayata, 30.07.2001. Initial stage of exposing of a baydzherakh of the top level. Currently only the Early Holocene "peat hummock" unit is visible. In a few weeks this ground block will separate from the upper wall as the baydzherakh "P", and soon after will look as "O".

the third level (at the depth about 15-17 m) and three locations of hare bones *in situ* in the upper part of the section (depth 5-7 m) and in its middle part (17 m) (Fig. 8-2). Some samples of these *in situ* bones were kept frozen for further DNA and isotope analyses. Collecting of fossil mammals on the shore and bars (both of Mamontovy Khayata and the Came Mamont) yielded some interesting specimens of mammoth, musk-ox and some other mammals (Table A8-6).

One more result of the summer work was our participation in the description and collection of an Early Holocene moose carcass in the SW part of the general Mamontovy Khayata area, initiated and carried out by the Lena Delta Reserve scientists (Sher et al, in press).

8.4 Further investigations

We believe that the results of our field work will contribute to a better understanding of some questions of the Late Pleistocene and Early Holocene environment. So far, a good progress has been reached in the study of fossil insect assemblages from the new samples, which offer a higher resolution of the record of insect fauna and other natural conditions. As mentioned above, we can estimate an approximate age of fossil assemblages from the previous dating. However, without new additional dates, directly related to the new samples, the value of this detailed record would be much lower. As a minimum program, the following important natural events, revealed by the insect record, require precise dating: the last steppe-like fauna and the earliest Holocene sediment above it (after the break); the transition from the "cold" faunas of the LGM to the first fauna, enriched with steppe components in the Late Sartanian; the beginning of the LGM-correlated cold stage. No funds for the dating are available in our institutions, so we must apply to the Laptev Sea System program or other sources to look for funding for 8-10 AMS dates.

Of the other materials obtained in the course of our field work, only ice isotope samples are currently in work. The future of the other materials, collected in 2001, such as the samples for pollen and other analyses, should be discussed with our German colleagues.

8.5 References

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