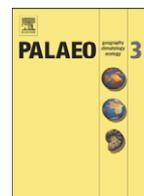




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Testate amoebae record from the Laptev Sea coast and its implication for the reconstruction of Late Pleistocene and Holocene environments in the Arctic Siberia

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ABSTRACT

Our study aims to look for testate amoebae (TA) in the surface and fossil sediments from the Cape Mamontov Klyk (73°60'–73°63' N, 116°88'–117°18' E), southern coast of the Laptev Sea, ca 150 km west of the Lena Delta and to discuss the potential of TA analysis for Glacial/Interglacial environmental reconstructions in Arctic Siberia. The radiocarbon age determination suggests that the studied sediments accumulated between ca 45,000 ¹⁴C yr BP and present. A total of 98 TA taxa were identified in the 10 recent surface and 59 fossil samples. Results of taxonomical identification and ecological analysis of TA in the modern and fossil samples suggest that major changes in the soil moisture conditions took place. Our results show that soil-living taxa dominated the testate TA assemblages at the study sites during the past 45,000 years. The environmental conditions of the study area were most favourable (relatively warm and humid) during the Kargin Interstadial (ca 45,000–25,000 ¹⁴C yr BP). An opposite situation is reconstructed for the Sartan Stadial (ca. 25,000–15,000 ¹⁴C yr BP). During the Kargin Interstadial, optimum conditions occurred between ca 44,000 and 40,000 ¹⁴C yr BP characterised by highest TA abundances and taxa diversity. This initial optimal phase was followed by the interval with drier and colder conditions about 40,000–30,000 ¹⁴C yr BP. The sediments dated between ca. 24,000 and 18,000 ¹⁴C yr BP show low TA abundances and diversity, in agreement with the much colder and drier environments during the maximum phase of the last glacial. The onset of the Holocene is indicated by a broad representation of obligate hydrophilic taxa, especially from genus *Diffflugia*, suggesting wet and relatively warm conditions. By comparison with other environmental proxies used in the studied sections as well as from the neighbouring arctic regions our results suggest that TA analysis can provide valuable information, contributing to the better understanding of the Late Quaternary climate and environments in Arctic Siberia.

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1. Introduction

The Arctic is more sensitive to climate change than most other parts of our planet (ACIA, 2004). Here effects of the current warming can obviously be seen from the present destruction of terrestrial and sub-sea permafrost surfaces as well as the reduction of the sea-ice cover. There are also many indications of various palaeoenvironmental changes in lowland regions of Northeast Siberia during the Late Quaternary that are available from multi proxy studies of permafrost records (e.g. Andreev et al., 2002b; Schirrmeister et al., 2002a). Northern Eurasia has long been known as an important region for understanding the magnitude of climatic and environmental changes during the Late Quaternary and their consequences for other high-

latitude regions (e.g. Velichko, 1984; Khotinskiy, 1984; Hubberten et al., 2004; Lozhkin et al., 2007; Kienast et al., 2008). This area has been lagged behind other regions in terms of high-resolution palaeoclimatic studies. Therefore comprehensive multidisciplinary and high-resolution palaeoecological studies are necessary in order to understand the complex environmental changes that took place in the Arctic periglacial environments in the past.

Permafrost sequences exposed around the Laptev Sea coast have proven to represent informative archives of Late Quaternary environmental and climate dynamics. One of the best preserved sequences on the Laptev Sea coastal region has been studied using a multi-proxy approach at Bykovsky Peninsula (e.g. Schirrmeister et al., 2002a,b; Meyer et al., 2002; Andreev et al., 2002b; Bobrov et al., 2004; Kienast et al., 2005; Sher et al., 2005). Environmental changes from the Middle to the Late Weichselian and into the Holocene have been reconstructed through multidisciplinary studies. The two clearest results of these studies are (i) the continuous existence of a treeless grass/herb-dominated vegetation

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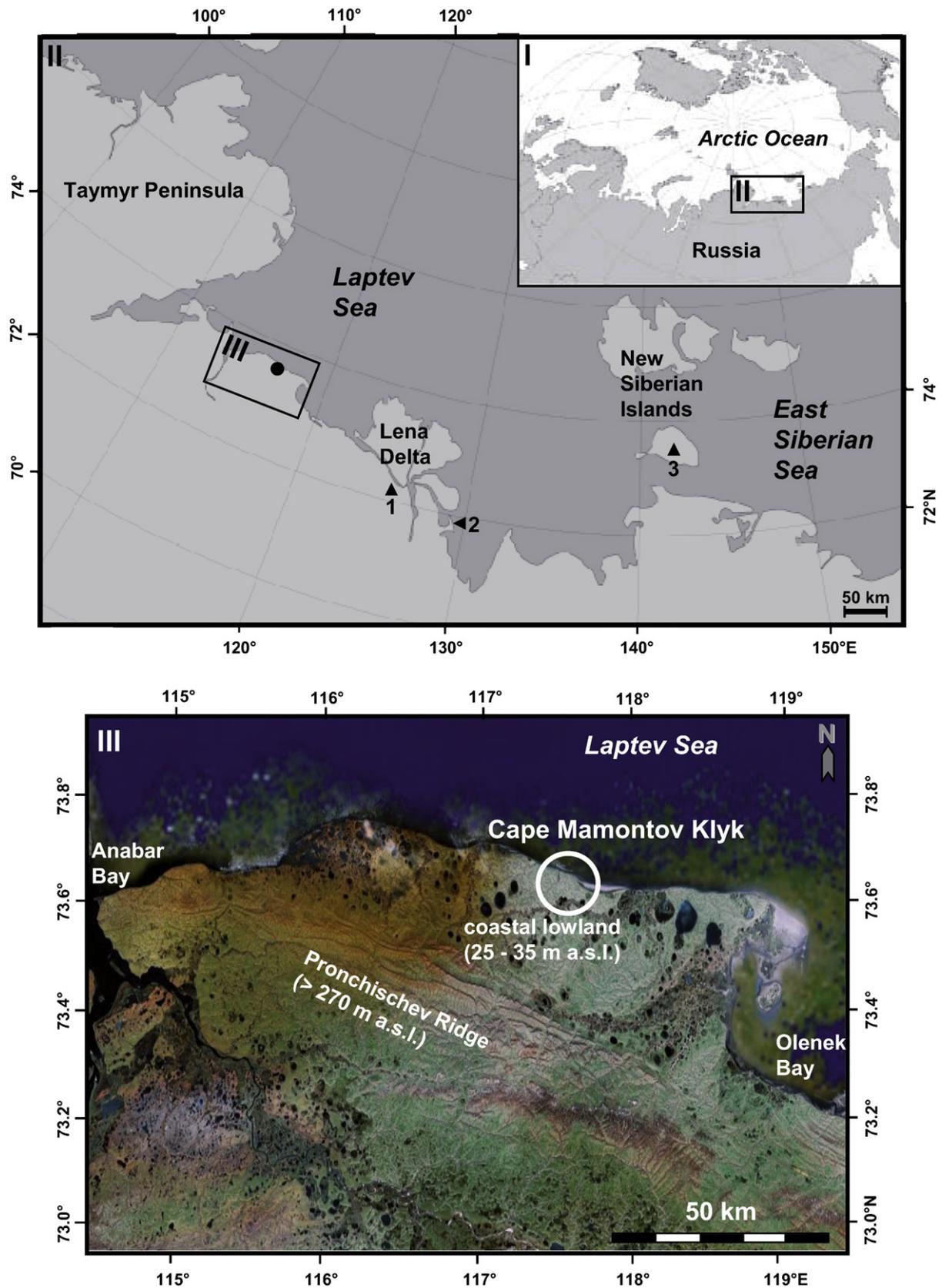


Fig. 1. Map of the Arctic (I) and Laptev Sea region (II) showing the location of the studied section at Cape Mamontov Klyk (III); 1 – Olenek channel; 2 – Bykovsky Peninsula; 3 – Bol'shoi Lyakhovskiy Island; source for III: GoogleEarth software.

(Andreev et al., 2002b), and (ii) very cold winters, attested by the continuous growth of thick ice wedges and by their stable-isotope composition (Meyer et al., 2002; Hubberten et al., 2004).

Recent studies in the Arctic regions show a complex response of the environmental system to major climatic fluctuations during the Late Pleistocene and Holocene. In such situations it is difficult, if at all

possible, to find a single proxy which provides complete information about the palaeoenvironment at local to regional scale. It is therefore important to find complementary records and proxies for multi-disciplinary investigation of Late Quaternary sediments in the Arctic.

Testate amoebae (Cercozoa & Amoebozoa; hereafter TA) are small single-celled organisms (7–450 µm) with a distinct organic shell (*testa*) and well-defined ecological preferences. They are distributed worldwide in freshwater environments, in peat bogs, and mosses, but they are also frequent in soils, especially in soils with a high organic content. The empty shell remains intact after the death of the amoebae and allows precise taxonomic identification; in most cases to species level (Beyens and Meisterfeld, 2001). An important advantage for palaeoecological investigations is the short generation time, which makes TA sensitive indicators of short-lived environmental changes. This provides a basis for reconstruction of past environments and climates. The occurrence of the fragile shells in fossil sequences also reflects non-disturbed sediment accumulation without reworking. Beyens and Chardez (1987) reported that the moisture content determines the structure of TA communities. Therefore fossil TA assemblages can be used to detect changes in local hydrological conditions. TA have been widely studied in peat bogs (e.g. Schönborn, 1962; Tolonen, 1986), in particular in *Sphagnum*-moss habitats (e.g. Charman, 2001; Gilbert et al., 2003; Schnitchen et al., 2003; Mitchell et al., 2004; Lamentowicz and Mitchell, 2005), and in lakes (Ogden and Hedley, 1980). Most of the former studies have been done in Europe. In the Arctic terrestrial moss habitats were studied for TA in Greenland (Beyens et al., 1992; Trappeniers et al., 2002), Spitsbergen (Beyens et al., 1986), Canada (Beyens et al., 1990) and Alaska (Beyens and Chardez, 1995). Smith (e.g. 1992, 1996) and Wilkinson (e.g. 1990, 1994) performed several case studies focusing on distribution and ecology of terrestrial TA in the Antarctic soil environments.

Studies from aquatic environments have shown that TA are good palaeoenvironmental indicators in freshwater environments. For example Medioli and Scott (1988) noted that TA require a certain minimum water temperature (6 °C) at some time during the year to reproduce successfully. McCarthy et al. (1995) compared palaeotemperatures and precipitation amounts derived from pollen data with the TA assemblages from the same sediment. Patterson et al. (1985) found that the division between two major TA assemblages in some small lakes appears to be a function of seasonal temperatures. Dallimore et al. (2000) studied TA communities in lakes of the Canadian Arctic in order to correlate modern TA assemblages to varying environmental variables (e.g. summer lake temperature, water conductivity) and in turn, to relate this information to past assemblages from core material. In East Siberia the TA analysis of lacustrine sediments of the Last Interglacial and the Holocene has been reported from Bol'shoy Lyakhovsky Island in the Laptev Sea (Andreev et al., 2004a,b; Andreev et al., in press), from Bykovsky Peninsula, east of the Lena Delta (Bobrov et al., 2004), and from the Olenek Channel, the westernmost outlet of the Lena Delta (Schirmer et al., 2003) where differences between Late Pleistocene and Holocene environmental conditions as well as during Late Pleistocene climate fluctuations are convincingly reflected by TA records.

2. Study area

The study area, Cape Mamontov Klyk (73°60'–73°63'N, 116°88'–117°18'E; Fig. 1), is located at the Laptev Sea coast between the Anabar Bay and the Olenek Bay, about 30 km to the north of the Pronchishchev Ridge (about 270 m a.s.l.). The coastal lowland is a gently inclined plain ca 25–35 m a.s.l. in elevation. Wide flat watersheds with gentle slopes and shallow valleys characterize the

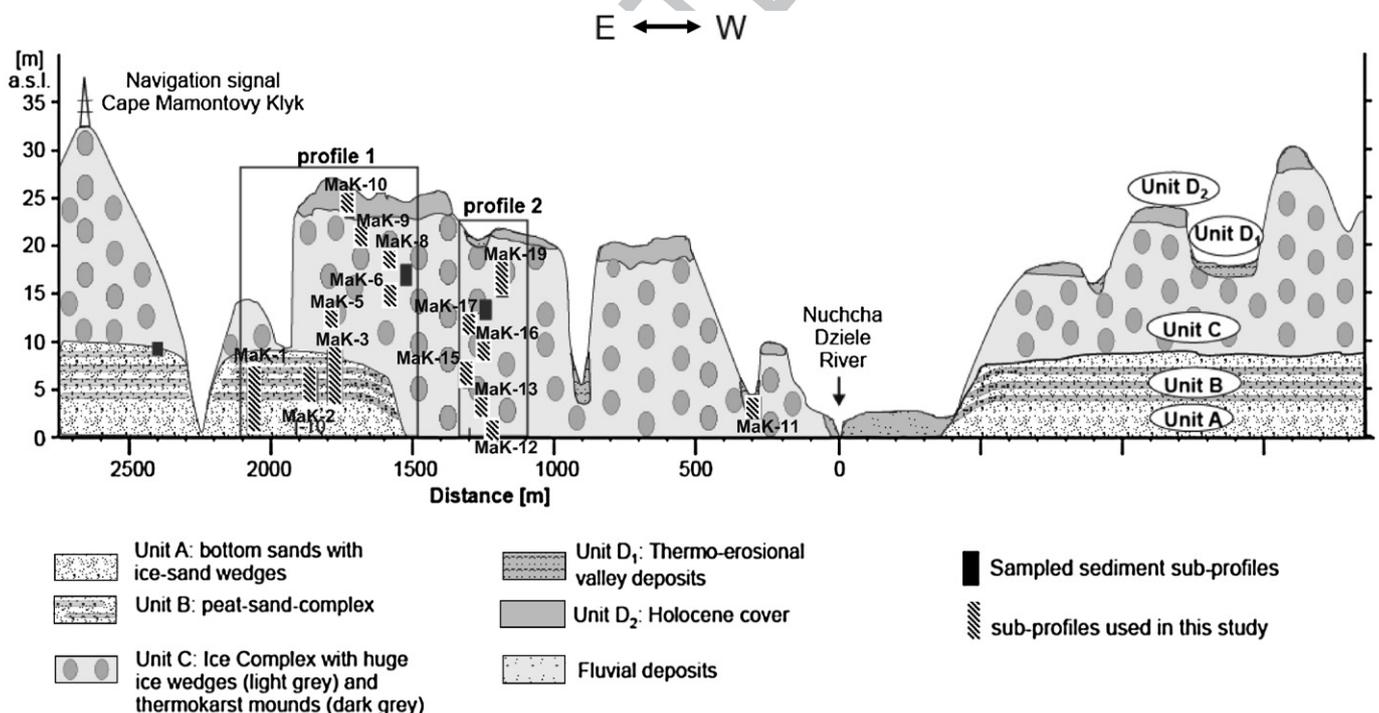


Fig. 2. Stratigraphic scheme of the main studied site of Cape Mamontov Klyk with position of investigated sections. Explanations for geomorphological terms used in this study: thermo-erosional valley: dendritic u-shaped valleys with flat floor, very moist, often with surface water and little ponds, dense grass/sedge vegetation; width about 50 m; thermokarst depression: deep ground subsidence area due to permafrost melting often with large extent (100 m to several km), dominated by wet tundra vegetation (mosses, grass), lakes may occur in the depressions; thermokarst mounds: intra-polygon sediment blocks surrounding the perimeter of ice wedges that have melted; Yedoma: frozen sequences of organic and mineral soils containing large amounts of ground ice, erosional relicts of Late Pleistocene surface; Alas: steep-sided depression formed by the melting of permafrost, it may contain a lake.

Table 1
Selected geochemical characteristics, radiocarbon ages, and short lithological description of analysed samples; samples marked with * containing no testate amoebae shells

| Sample | Profile/unit 1/transition | Height (m a.s.l.) | pH | TOC (wt.%) | C/N | Radiocarbon age (^{14}C yr BP) | Lithology | |
|--------|---------------------------|-------------------|-------|------------|-------|--|-------------------|--|
| t1.4 | MaK-1-9* | A to B | 4.30 | – | 0.29 | 0.68 | >44,520 | Fine-sand silt, grass roots |
| t1.5 | MaK-1-12 | 1/B | 5.30 | – | 11.10 | 24.48 | 40,410+1230/-1070 | Peaty palaeosol |
| t1.6 | MaK-1-13 | 1/B | 5.50 | 7.4 | 1.76 | 8.14 | – | Silty interlayer |
| t1.7 | MaK-1-14 | 1/B | 5.70 | – | 3.18 | 11.17 | – | Peaty palaeosol, peat inclusion |
| t1.8 | MaK-2-1* | 1/A | 6.20 | 7.3 | 0.21 | 2.34 | >37,100 | Sand, organic free |
| t1.9 | MaK-2-3 | 1/B | 7.40 | 6.5 | 15.30 | 24.96 | – | Peaty palaeosol, cryoturbated, peat inclusion |
| t1.10 | MaK-2-4 | 1/B | 7.80 | 6.6 | 3.02 | 10.46 | – | Fine sand silt, interlayer, plant remains |
| t1.11 | MaK-2-5 | 1/B | 8.10 | – | 2.82 | 10.00 | – | – |
| t1.12 | MaK-2-6 | 1/B | 8.30 | 6.0 | 9.90 | 18.65 | 42,260+1860/-1510 | Peaty palaeosol, cryoturbated, peat inclusion |
| t1.13 | MaK-2-7* | 1/B | 8.70 | 7.9 | 0.98 | 7.37 | – | Fine sand silt, interlayer, plant remains, net-like structures |
| t1.14 | MaK-2-8 | 1/B | 9.20 | 7.4 | 0.83 | 5.35 | – | Fine sand to silt |
| t1.15 | MaK-2-9 | 1/B | 9.80 | 6.8 | 13.50 | 15.48 | 44,310+1260/-1090 | Peaty palaeosol, cryoturbated, peat inclusion |
| t1.16 | MaK-3-1* | 1/B | 4.90 | – | 1.20 | 6.57 | – | Fine sand, peat inclusions |
| t1.17 | MaK-3-3* | 1/B | 5.90 | – | 1.96 | 9.78 | – | Reworked, refrozen slope material?, peat inclusion |
| t1.18 | MaK-3-5 | 1/B | 6.90 | 7.0 | 4.07 | 11.82 | – | Palaeosol, fine-sand silt, small, discontinuous peat inclusion |
| t1.19 | MaK-3-7 | 1/B | 7.00 | 6.7 | 4.86 | 10.00 | 43,510+1010/-900 | Peaty palaeosol, see MaK 3-5 |
| t1.20 | MaK-3-10 | 1/B | 8.40 | 7.2 | 2.56 | 6.56 | – | Palaeosol, plant remains |
| t1.21 | MaK-3-12* | 1/B | 9.40 | 7.3 | 0.81 | 2.95 | – | Palaeosol, plant remains |
| t1.22 | MaK-3-14 | 1/B | 10.30 | 7.6 | 2.72 | 6.67 | 43,620+1700/-1400 | Peaty palaeosol, peat inclusions |
| t1.23 | MaK-3-16 | 1/B | 12.40 | 6.7 | 3.55 | 8.58 | – | Peaty palaeosol, peat inclusions |
| t1.24 | MaK-3-17 | 1/B | 13.20 | – | 3.62 | 8.91 | 31,250+1080/-950 | Peaty palaeosol, peat inclusions |
| t1.25 | MaK-5-3 | 1/C | 14.30 | 6.7 | 3.37 | 8.08 | 24,600+170/-160 | Palaeosol, peat inclusion, wood remains (twigs, roots) |
| t1.26 | MaK-5-4* | 1/C | 14.60 | 6.6 | 1.97 | 5.80 | – | Silty sand, grass roots, weakly laminated, sand laminae |
| t1.27 | MaK-6-4* | 1/C | 16.00 | – | 2.02 | 6.27 | 20,640±90 | Sandy silt, vertical grass roots |
| t1.28 | MaK-8-3 | 1/C | 15.80 | – | 2.07 | 7.32 | – | Peaty palaeosol, peat inclusion, wood remains |
| t1.29 | MaK-8-4* | 1/C | 16.30 | 6.7 | 4.93 | 12.41 | – | Peaty palaeosol, peat inclusion, wood remains |
| t1.30 | MaK-9-3 | 1/C | 20.90 | 6.7 | 4.06 | 10.84 | – | Fine-sand silt, wood remains |
| t1.31 | MaK-9-4 | 1/C | 21.40 | 6.4 | 3.53 | 9.54 | – | Fine-sand silt, wood remains |
| t1.32 | MaK-9-5 | 1/C | 21.90 | – | 4.90 | 13.41 | 16,510±60 | Fine-sand silt, wood remains |
| t1.33 | MaK-10-5 | 1/D | 24.30 | 6.7 | 21.80 | 16.53 | 9480±40 | Cryoturbated palaeosol, peat inclusion |
| t1.34 | MaK-10-7 | 1/D | 24.90 | – | 11.10 | 15.25 | – | Peaty palaeosol, peat inclusion |
| t1.35 | MaK-10-8 | 1/D | 25.20 | 7.2 | 7.89 | 13.81 | 9510±45 | Cryoturbated palaeosol, peat inclusion |
| t1.36 | MaK-10-10* | 1/D | 25.75 | 6.6 | 10.54 | 14.58 | – | Palaeosol, peat inclusion |
| t1.37 | MaK-10-11 | 1/D | 26.00 | – | 16.10 | 14.69 | 2785±30 | Palaeosol, peat inclusion |
| t1.38 | MaK-11-2* | sub-profile | 2.50 | – | 3.50 | 10.58 | 11,060±45 | Sandy silt, plant remains |
| t1.39 | MaK-11-6 | sub-profile | 4.20 | – | 2.13 | 10.31 | 2075±30 | Silty fine sand, laminated, grass roots |
| t1.40 | MaK-11-7 | sub-profile | 4.90 | 5.5 | 1.99 | 9.57 | – | Peaty palaeosol, peat inclusions |
| t1.41 | MaK-11-8* | sub-profile | 5.20 | – | 3.81 | 11.57 | – | Peaty soil, peat inclusions |
| t1.42 | MaK-11-9 | sub-profile | 5.50 | 5.8 | 6.41 | 12.85 | – | Peat inclusion |
| t1.43 | MaK-11-10 | sub-profile | 5.80 | – | 6.55 | 12.82 | – | Fine sand to silt |
| t1.44 | MaK-11-11 | sub-profile | 6.00 | – | 7.48 | 14.07 | – | Transition layer, soil |
| t1.45 | MaK-12-1 | 2/C | 0.50 | 6.6 | 6.13 | 10.89 | 27,220+310/-300 | Peaty palaeosol, peat inclusion |
| t1.46 | MaK-12-2 | 2/C | 0.75 | – | 8.22 | 13.44 | – | Peaty palaeosol, peat inclusion |
| t1.47 | MaK-12-4 | 2/C | 1.00 | 6.6 | 8.52 | 15.58 | – | Peaty palaeosol, peat inclusion |
| t1.48 | MaK-12-5 | 2/C | 1.25 | 6.3 | 5.58 | 13.08 | – | Cryoturbated palaeosol, peat inclusion |
| t1.49 | MaK-13-7 | 2/C | 4.30 | 7.4 | 3.34 | 9.30 | 24,150±120 | Fine-sand silt, few organic, wood remains |
| t1.50 | MaK-14-4 | sub-profile | 1.40 | 5.6 | 14.15 | 11.73 | 1480±20 | Alas deposit, interbedding peaty layers (2-4 cm) |
| t1.51 | MaK-14-5 | sub-profile | 1.70 | – | 3.47 | 11.01 | – | Alas deposit, sand-peat interbedding |
| t1.52 | MaK-14-6 | sub-profile | 2.00 | 5.3 | 3.57 | 11.54 | – | Alas deposit, sand-peat interbedding |
| t1.53 | MaK-14-7* | sub-profile | 2.30 | – | 6.18 | 15.82 | – | Alas deposit, sand-peat interbedding, more peaty |
| t1.54 | MaK-14-8 | sub-profile | 2.60 | 5.5 | 4.88 | 14.34 | 3720±30 | Alas deposit, peaty soil |
| t1.55 | MaK-14-9* | sub-profile | 2.90 | – | 4.20 | 14.11 | – | Alas deposit, cryoturbated peat soil, peat inclusion |
| t1.56 | MaK-15-5* | 2/C | 6.60 | – | 2.26 | 9.31 | 21,890±90 | Fine-sand to silt, wood (twigs, roots) |
| t1.57 | MaK-16-5* | 2/C | 9.30 | – | 1.81 | 9.06 | 20,180±80 | Fine-sand to silt, wood (twigs, roots) |
| t1.58 | MaK-17-3 | 2/C | 11.50 | – | 2.49 | 10.24 | 18,920±70 | Peaty palaeosol, wood remains |
| t1.59 | MaK-17-7* | 2/C | 13.60 | 7.0 | 2.06 | 9.46 | 17,700+70/-60 | Palaeosol |
| t1.60 | MaK-19-3* | 2/C | 15.30 | – | 1.41 | 7.17 | 16,350±90 | Sand, few wood remains, finely distributed plant remains |
| t1.61 | MaK-19-4 | 2/C | 15.60 | 7.5 | 5.06 | 13.37 | – | Palaeosol, many wood remains, organic-rich spots |
| t1.62 | MaK-19-7* | 2/C | 17.10 | 7.5 | 2.61 | 11.32 | 14,545±50 | Sandy silt |

relief. The coastal lowland is drained to the sea by several small streams. The studied section (Fig. 2) is located at the lowland's cliff (10 to 25 m a.s.l.) formed by frozen deposits and ice wedges. The section extends, from the Nuchcha Dziele River mouth ca 2.2 km eastwards close to the navigation signal of Cape Mamontov Klyk.

The continental Arctic climate of this region is characterized by long cold winters and short cool summers. The mean annual air temperature is about -14 °C. The mean January temperature is about -22 °C and the mean July temperature 5 to 6 °C. Mean annual precipitation is 230–270 mm with 75% of it falling as rain during the summer months. In general, the snow cover stays from the end of September to the end of June. The snow cover is thin but locally reaches up to 50 cm. The study

area belongs to the zone of continuous permafrost reaching 400–600 m (Yershov, 1989). The mean annual ground temperature is about -11 to -12 °C. The active layer varies in depth from 20 to 50 cm in July.

This area belongs to the northern tundra vegetation zone (Atlas Arktiki, 1985). The CAVM Team (2003) classifies it further to the nontussock-sedge, dwarf-shrub, moss tundra characterized by hemi prostrate and dwarf shrubs (<40 cm high) and a well-developed moss layer (5–20 cm thick). Prostrate and hemi prostrate dwarf shrubs include *Betula exilis*, *Salix arctica*, *S. polaris*, *S. reticulata*, and *Dryas*. Among other common taxa are sedges (*Carex arctisibirica*, *C. bigelowii*, and *Eriophorum*), grasses (e.g. *Arctagrostis latifolia*, *Poa arctica*), forbs (e.g. *Silene*, *Sagina nivalis*, *Senecio frigidus*, *Saxifraga oppositifolia*,

Table 2
List of testate amoebae taxa in Late Pleistocene and Holocene deposits and their habitat preference (after Chardez, 1965)

| Species | Frequency (%) | | | Ecology |
|--|---------------|----------|-----------------|---------|
| | Pleistocene | Holocene | Surface samples | |
| <i>Arcella arenaria</i> v. <i>compressa</i> Chardez | 10.3 | 18.2 | 0.97 | M |
| <i>A. artocrea</i> Leidy | | 9.1 | 0.19 | Sh |
| <i>A. c.f. crenulata</i> Deflandre | 3.4 | | | ShM |
| <i>A. discoidea</i> v. <i>scutelliformis</i> Playfair | 6.9 | | | W |
| <i>A. rotunda</i> v. <i>aplanata</i> Deflandre | | | 0.39 | ShM |
| <i>A. sp.</i> | 3.4 | | | – |
| <i>Bullinularia gracilis</i> Thomas | 3.4 | | | MS |
| <i>B. indica</i> Penard | | 0.6 | | MS |
| <i>Trigonopyxis arcuata</i> (Leidy) Penard | 10.3 | | | MS |
| <i>T. minuta</i> Schönborn & Peschke | 3.4 | | | S |
| <i>Centropyxis aculeata</i> (Ehrenberg) Stein | 3.4 | | | W |
| <i>C. aculeata</i> f. A | 3.4 | | | W |
| <i>C. aerophila</i> Deflandre | 86.2 | 63.6 | 5.41 | M |
| <i>C. aerophila</i> v. <i>minuta</i> Chardez | 86.2 | 72.7 | 0.58 | WMS |
| <i>C. aerophila</i> v. <i>sphagnicola</i> Deflandre | 41.4 | 45.5 | | ShM |
| <i>C. cassis</i> (Wallich) Deflandre | 3.4 | 27.3 | 0.19 | ShMS |
| <i>C. constricta</i> (Ehrenberg) Penard | 51.7 | 18.2 | 6.76 | MS |
| <i>C. constricta</i> v. <i>minima</i> Declouire | 79.3 | 63.6 | 12.16 | MS |
| <i>C. discoidea</i> (Penard) Deflandre | 3.4 | | | W |
| <i>C. gibba</i> Deflandre | 3.4 | | | ShM |
| <i>C. orbicularis</i> Deflandre | 20.7 | 18.2 | 0.19 | WShM |
| <i>C. plagiostoma</i> Bonnet, Thomas | 86.2 | 45.5 | 0.39 | S |
| <i>C. plagiostoma</i> f. A major | 37.9 | | 0.58 | S |
| <i>C. plagiostoma</i> f. B minor | 48.3 | 54.5 | 3.86 | S |
| <i>C. plagiostoma</i> Bonnet, Thomas v. <i>oblonga</i> Chardez | | 9.1 | | S |
| <i>C. plagiostoma</i> v. <i>terricola</i> Bonnet, Thomas | 3.4 | 54.5 | | S |
| <i>C. platystoma</i> (Penard) Deflandre | 6.9 | 27.3 | 0.19 | WMS |
| <i>C. pontigulasiformis</i> Beyens, Chardez & and De Bock | | | 0.19 | WM |
| <i>C. sylvatica</i> (Deflandre) Thomas | 86.2 | 72.7 | 4.05 | S |
| <i>C. sylvatica</i> v. <i>globulosa</i> Bonnet | 3.4 | | | S |
| <i>C. sylvatica</i> v. <i>microstoma</i> Bonnet | 37.9 | 9.1 | | S |
| <i>C. sylvatica</i> v. <i>minor</i> Bonnet, Thomas | 86.2 | 63.6 | 0.39 | ShS |
| <i>C. sp. 1</i> | 3.4 | | | – |
| <i>C. sp. 2</i> | | 9.1 | | – |
| <i>Cyclopyxis arcelloides</i> Penard | 3.4 | | | WShM |
| <i>C. eurystoma</i> Deflandre | 44.8 | 36.4 | 1.16 | S |
| <i>C. eurystoma</i> v. <i>parvula</i> Bonnet, Thomas | 72.4 | 81.8 | 11.39 | S |
| <i>C. kahli</i> Deflandre | 67.2 | 18.2 | | WShS |
| <i>C. c.f. kahli</i> Deflandre f. A (minor) | 6.9 | | | WShS |
| <i>C. sp.</i> | 6.9 | | | – |
| <i>Plagiopyxis bathystoma</i> Bonnet | 10.3 | | | S |
| <i>P. callida</i> Penard | 20.7 | 9.1 | | WShMS |
| <i>P. declivis</i> Thomas | 3.4 | | | ShS |
| <i>P. minuta</i> Bonnet | 3.4 | | 0.39 | MS |
| <i>P. penardi</i> Thomas | 31.0 | 36.4 | | WS |
| <i>Heleopera petricola</i> Leidy | 20.7 | | | WSh |
| <i>H. petricola</i> v. <i>amethystea</i> Penard | 6.9 | | | WSh |
| <i>H. petricola</i> v. <i>humicola</i> Bonnet & Thomas | 3.4 | | | S |
| <i>H. sphagni</i> Leidy | 3.4 | | | WM |
| <i>Nebela bigibbosa</i> Penard | | 0.19 | | WShM |
| <i>N. collaris</i> (Ehrenberg) Leidy | 3.4 | 18.2 | | ShM |
| <i>N. lageniformis</i> Penard | 3.4 | | 0.39 | ShM |
| <i>N. parvula</i> Cash | 6.9 | | | ShM |
| <i>N. penardiana</i> Deflandre | | 9.1 | | W |
| <i>N. tincta</i> (Leidy) Awerintzew | 3.4 | 9.1 | 9.85 | ShM |
| <i>N. tincta</i> f. <i>stenostoma</i> Jung | | | 0.58 | ShMS |
| <i>N. sp.</i> | 6.9 | | | – |
| <i>Argynnia</i> sp. | 31.0 | 18.2 | | WSh |
| <i>Argynnia</i> sp. f. A (minor) | 3.4 | | | WSh |
| <i>Schoenbormia humicola</i> (Schönborn) Declouire | | | 5.02 | S |
| <i>Sch. viscicola</i> Schönborn | | | 0.39 | S |
| <i>Diffugia bryophila</i> (Penard) Jung | 3.4 | | | ShM |
| <i>D. cratera</i> Leidy | 3.4 | 18.2 | | W |

Table 2 (continued)

| Species | Frequency (%) | | | Ecology |
|---|---------------|----------|-----------------|---------|
| | Pleistocene | Holocene | Surface samples | |
| <i>D. difficilis</i> Thomas | | 18.2 | | W |
| <i>D. globulus</i> Wallich | 37.9 | 36.4 | 1.93 | WSh |
| <i>D. lucida</i> Penard | 20.7 | 9.1 | | WSh |
| <i>D. mammilaris</i> Penard | 6.9 | | | W |
| <i>D. microstoma</i> (Thomas) | 3.4 | | | W |
| <i>D. minuta</i> Rampi | 10.3 | 9.1 | | Sh |
| <i>D. oblonga</i> Ehrenberg | | 9.1 | | W |
| <i>D. oblonga</i> v. <i>longicollis</i> Gassowsky | | 9.1 | | W |
| <i>D. penardi</i> Hopkinson | 6.9 | 9.1 | | W |
| <i>D. pristin</i> Penard | 6.9 | | | W |
| <i>D. c.f. pyriformis</i> Perty | 3.4 | | | W |
| <i>D. sp. 1</i> | 3.4 | | | – |
| <i>D. sp. 2</i> | 3.4 | | | – |
| <i>Phryganella acropodia</i> (Hert. & Less.) Hopkinson | 55.2 | 27.3 | 0.97 | WMS |
| <i>Ph. acropodia</i> c.f. v. <i>australica</i> Playfair | 13.8 | 45.5 | | W |
| <i>Ph. hemisphaerica</i> Penard | | 9.1 | | WShM |
| <i>Paraquadrula irregularis</i> Archer | 3.4 | | | M |
| <i>Assulina muscorum</i> Greef | | | 2.90 | M |
| <i>Valkanovia delicatula</i> (Valkanov) | | | 0.39 | ShM |
| <i>Euglypha ciliata</i> (Ehrenberg) Wailes | | | 0.19 | WShM |
| <i>E. ciliata</i> f. <i>glabra</i> Wailes | | | 9.46 | WShMS |
| <i>E. cuspidata</i> Bonnet | | | 0.39 | S |
| <i>E. dolioliformis</i> Bonnet | | | 0.19 | MS |
| <i>E. laevis</i> (Ehrenberg) Perty | | | 5.41 | WShMS |
| <i>E. strigosa</i> f. <i>glabra</i> Wailes | | | 2.32 | ShMS |
| <i>Corythion dubium</i> Taranek | | | 0.77 | WShM |
| <i>Trinema enchelys</i> (Ehrenberg) Leidy | | | 0.58 | WShM |
| <i>T. lineare</i> (Ehrenberg) Leidy | | | 6.56 | WShMS |
| <i>T. penardi</i> Thomas-Chardez | | | 1.93 | MS |
| <i>Pseudodiffugia c.f. gracilis</i> Schlumberger | 3.4 | 27.3 | | W |
| <i>P. gracilis</i> v. <i>terricola</i> Bonnet & Thomas | 6.9 | 9.1 | | S |
| Testacea sp. 1 | 10.3 | 9.1 | | – |
| Testacea sp. 2 | | | | – |
| Testacea sp. 3 | | | 0.19 | – |
| N. species | 68 | 42 | 40 | |

S – soil, Sh – *Sphagnum*, M – other mosses, W – water.

Pedicularis lanata), mosses and liverworts (*Tomenthypnum nitens*, 154
Hylocomnium splendens, *Aulacomnium turgidum*), and lichens (*Tham-* 155
nolia, *Peltigera*, *Cladonia*). 156

3. Data and analytical methods 157

3.1. Sediments and chronology 158

Two large vertical composite profiles were studied at the coastal 159
cliff consisting mostly of frozen sediments accumulated in polygonal 160
centres of ice wedge polygon systems (Fig. 2). The sub-profiles are 161
mostly exposed in so-called thermokarst mounds between large ice 162
wedges. Additionally, deposits from a thermo-erosional valley and 163
from a thermokarst depression were collected. After cleaning the 164
profile wall the soil morphology of the sections were described in the 165
field. Then about 0.5–1 kg of frozen sediment was collected with a 166
hammer or a small axe and stored in sealed plastic bags for multiproxy 167
analysis, including TA analysis, and radiocarbon dating. 168

In the laboratory the content of total organic carbon (TOC) and 169
total nitrogen (TN) were measured with a CNS elementary analyser 170
(Elementar vario EL III). pH measurements of the filtrated water 171
extract were done with a pH-meter (WTW multilab 540) in the 172
laboratory. Organic material from 32 samples was extracted for 173
Accelerated Mass Spectrometry (AMS) dating at the Leibniz Labora- 174
tory (Nadeau et al., 1997, 1998). For TA analysis we tried to select dated 175
samples. The age estimation of non-dated sediment samples was done 176

Table 3
List of summarised testate amoebae taxa

| Ecological preference/ habitat | TA groups | TA taxa | | |
|--------------------------------------|---|---|-------------------------------|---|
| Eurybiotic soil | <i>Centropyxis plagiostoma</i> group (5 taxa) | <i>C. plagiostoma</i> | | |
| | | <i>C. plagiostoma</i> f. A major | | |
| | | <i>C. plagiostoma</i> f. B minor | | |
| | | <i>C. plagiostoma</i> v. <i>oblonga</i> | | |
| | | <i>C. plagiostoma</i> v. <i>terricola</i> | | |
| | <i>Plagiopyxis</i> group (3 taxa) | <i>P. callida</i> | | |
| | | <i>P. minuta</i> | | |
| | | <i>P. penardi</i> | | |
| | | Sphagnophilic and moss | <i>Arcella</i> group (4 taxa) | <i>Arcella arenaria</i> v. <i>compressa</i> |
| | | | | <i>A. artocrea</i> |
| <i>A. c.f. crenulata</i> | | | | |
| <i>A. rotunda</i> v. <i>aplanata</i> | | | | |
| <i>Heleopera petricola</i> | | | | |
| <i>Heleopera</i> group (3 taxa) | <i>H. petricola</i> v. <i>amethystea</i> | | | |
| | <i>H. sphagni</i> | | | |
| | <i>Nebela</i> group (5 taxa) | | <i>N. collaris</i> | |
| | | | <i>N. lageniformis</i> | |
| | | | <i>N. parvula</i> | |
| <i>N. penardiana</i> | | | | |
| <i>N. tincta</i> | | | | |
| <i>Diffflugia</i> group 2 (4 taxa) | <i>Diffflugia bryophila</i> | | | |
| | <i>D. globulus</i> | | | |
| | <i>D. lucida</i> | | | |
| | <i>D. minuta</i> | | | |
| Aquatic | <i>Diffflugia</i> group 1 (8 taxa) | <i>D. cratera</i> | | |
| | | <i>D. difficilis</i> | | |
| | | <i>D. mammilaris</i> | | |
| | | <i>D. microstoma</i> | | |
| | | <i>D. oblonga</i> | | |
| | | <i>D. oblonga</i> v. <i>longicollis</i> | | |
| | | <i>D. penardi</i> | | |
| | | <i>D. pristin</i> | | |
| | | <i>D. c.f. pyriformis</i> | | |

Taxa with similar ecological preferences were grouped into three ecological groups. (see also Fig. 3.)

using a simple altitude–age correlation according to Schirrmeister et al. (in press).

In order to compare fossil and modern TA assemblages we collected ten modern surface soil samples (ca 500 g) from different permafrost formations and habitats in the study area. Detailed sedimentological and geomorphological descriptions as well as results of more comprehensive palaeoecological and geochronological investigations of the studied sections are presented in separate papers (Schirrmeister et al., 2004, in press). Here we focus on the additional data sets, which are relevant to the TA study.

3.2. TA analysis

Three grams of each representative and carefully mixed fossil or modern surface sample were prepared for TA analysis. The samples were first suspended in distilled water and passed through a 500 µm meshed sieve to remove large masking organic and mineral particles. The next day a drop of suspension mixed with a drop of glycerine was added on a glass slide. The samples were counted under light microscope at magnifications 100–400×. On the average, five slides were examined for each sample. If possible a minimum of 150 TA shells were counted for each sample. We stopped counting if no shells were found in the first two slides.

The TA identification followed Chardez (1967), Ogden and Hedley (1980), Ogden (1983), Ellison and Ogden (1987), Gel'tser et al. (1985, 1995). For ecological interpretation of TA assemblages we followed Chardez (1965), former arctic studies (Beyens et al., 1990, 1995; Dallimore et al., 2000, Andreev et al., 2004a; Bobrov et al., 2004), as well as our own field observations. TA analysis described here was done in the laboratory of the Soil Science Faculty at Moscow State University.

The TILIA, TILIAGRAPH, and TGView computer programs were used for calculation of taxa percentages and graphing the data (Grimm, 1993, 2004). The sum of all TA taxa counted in each sample was taken as 100%. Photographs were done with the light microscope Axioskop Zeiss 40 and a digital camera (inteq). Scanning electron microscope observations were done using the microscope Jeol GSM 6060A.

4. Results

4.1. Description of the general profile

The studied sequences were subdivided into several units (A to D, Fig. 2) according to geochronological and sedimentological data. Results of sediment analyses, which are used for the interpretation of TA records, are presented in Table 1. The lowest unit A consists of yellowish-grey, weakly bedded fine-grained sand without visible plant remains (lower part of MaK-1). A transition layer of about one meter thickness, which contains numerous *in situ* grass roots, covers the organic-free sands. The sand is considered as fluvial deposit, and the transition layer reflects shallow facies conditions of a flood plain. The subsequent unit B (upper part of MaK-1, MaK-2 and MaK-3) consists of an alternation of four cryoturbated peaty horizons and of weakly laminated, dark-grey silty to fine sandy interbeds. The peaty horizons mostly consist of brown coloured moss peat. The sandy interbeds contain numerous plant remains like grass roots and twig fragments. The sediments of unit B are most probably formed by alternating processes of alluviation in the flood plain. Both units contain separate ice wedges and are additionally penetrated by ice wedges coming from the overlying unit C. The transition to unit C is gradual without a sharp boundary. Unit C represents the Ice Complex deposits with their typical huge ice wedges reaching from about 25 m a.s.l. down below the present sea level. Unit C is composed of many palaeosol layers with peat inclusions and numerous twig fragments. This unit is subdivided into two subunits. The lower horizon of about 0 to 2 m a.s.l. consists of cryoturbated peat soils with silty to fine sandy interbeds (MaK-12). The main part of unit C is formed by several weakly developed palaeosol horizons and silty to fine sandy interbeds with *in situ* grass roots and fragments of shrub twigs (MaK-5 to MaK-9 and MaK-13 to MaK-19). In places, unit C is covered by a 2 m thick sequence of peat soils representing the filling of small thermokarst ponds, which have developed on the surface of the Ice Complex formation (Yedoma). They were often observed as peat spots irregularly distributed on the Yedoma surface. These uppermost deposits (MaK-10) were assigned to the Holocene (unit D). Additionally unit D includes deposits of thermo-erosional valleys (sub-profile MaK-11) and of a thermokarst depression, 8 km west of the Nuchcha Dziele River mouth (sub-profile MaK-14).

4.2. TA analysis of fossil samples

In total, 59 samples from Late Quaternary deposits were studied. TA were found in 40 samples of unit B, C and D. A total of 97 species, varieties, and morphological forms of TA (Table 2) belonging to different ecological groups were identified (Table 3). The sand deposits of unit A did not contain visible plant remains and organic material at all. No TA shells could be found in these sediments. The number of taxa found per sample varied from 1 to 32. The number of TA shells counted in one sample varied from 1 to 356. In the fossil TA diagram (Fig. 3) the samples were ordered following the age–height model. According to the chrono-stratigraphic information for Siberia and results of the radiocarbon AMS-dating the diagram was divided into three zones – Kargin Interstadial (MIS 3, Middle Weichselian), Sartan Stadial (MIS 2, Late Weichselian), and Holocene (MIS 1) (Kind, 1974; Hubberten et al., 2004; Svendsen et al., 2004).

Kargin Interstadial sediments dated to between 44,310 and 26,400 ¹⁴C yr BP. In sediments dated to 44,310–40,000 ¹⁴C yr BP the highest

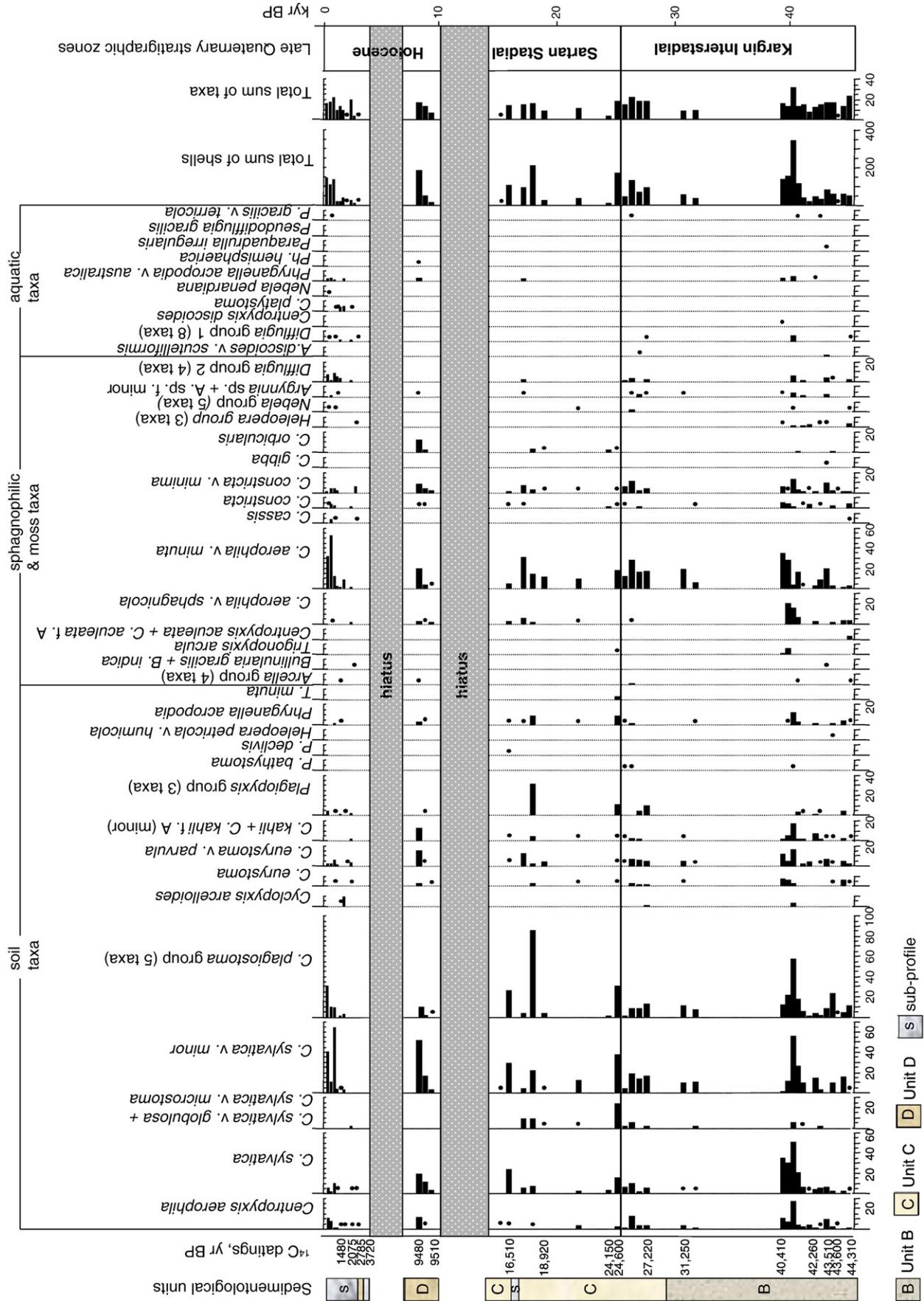


Fig. 3. Testate amoebae diagram of fossil samples from Cape Mamontov Klyk; absolute numbers.

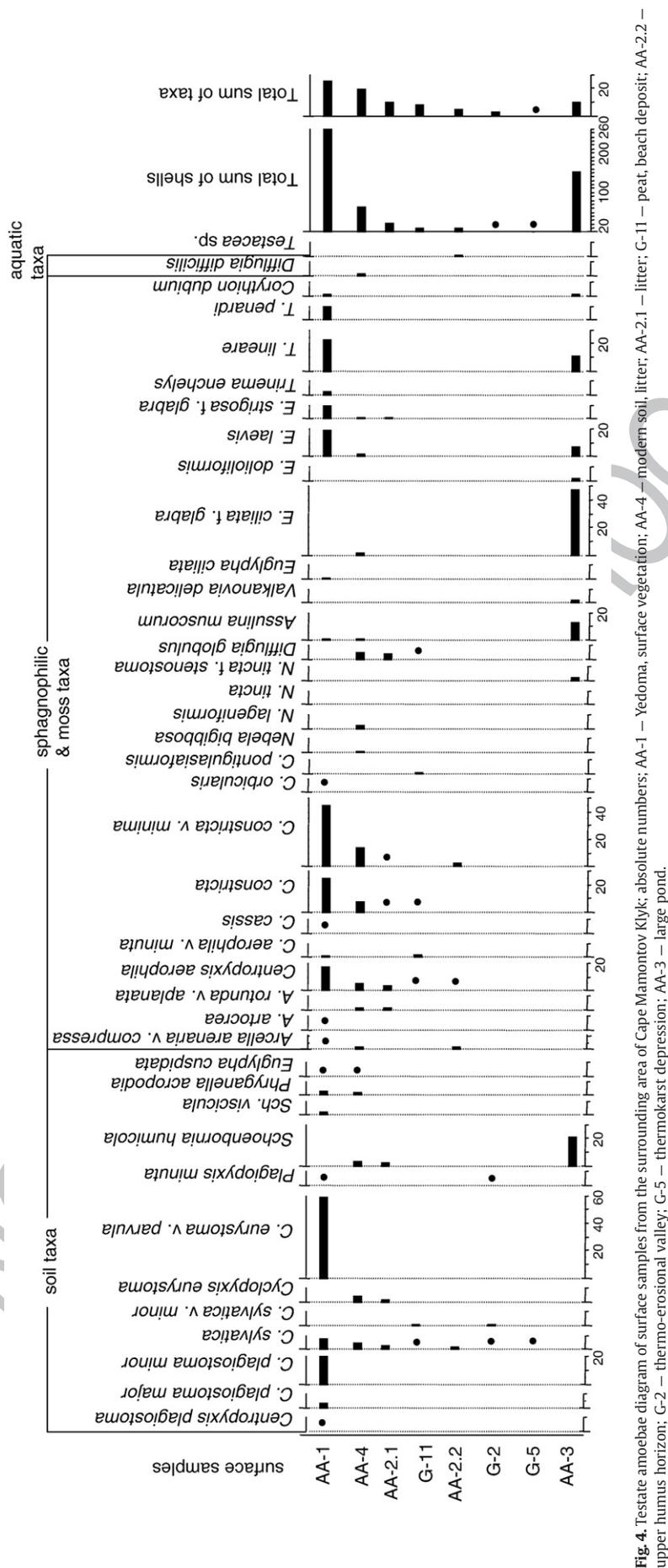


Fig. 4. Testate amoebae diagram of surface samples from the surrounding area of Cape Mamontov Klyk; absolute numbers: AA-1 – Yedoma, surface vegetation; AA-4 – modern soil, litter; AA-2.1 – litter; G-11 – peat, beach deposit; AA-2.2 – upper humus horizon; G-2 – thermo-erosional valley; G-5 – thermokarst depression; AA-3 – large pond.

t4.1 **Table 4**

t4.2 List of studied samples containing testate amoebae shells and palaeoecological interpretation of testate amoebae assemblages (correlated ages were estimated according to age-

t4.3 height correlations of Schirmer et al., in press)

| t4.3 | Sample ID, height, m a.s.l. | Type of sediment | Age, ¹⁴ C yr BP correlated ages | TA assemblages with palaeoecological interpretation |
|-------|-----------------------------|---|--|---|
| t4.4 | Unit B | | | |
| t4.5 | Peat-sand-complex deposits | | | |
| t4.6 | MaK-1-14, 5.7 | Peaty palaeosol, cryoturbated, peat inclusion | 40,800 | 32 species and varieties. Highest species diversity (10 hydrobiotic <i>Diffflugia</i> taxa) within studies samples including modern ones. Presence of sphagnobiotic <i>Heleopera</i> , <i>Nebela</i> and <i>Argygnia</i> sp. indicates boggy habitat conditions with permanent or temporal open water bodies. Numerous ostracod shells also indicate the existence of aquatic habitats. The climate was rather warm and wet. |
| t4.7 | MaK-1-13, 5.5 | Silty interlayer | 40,600 | 13 taxa. Presence of <i>Trigonopyxis arcuata</i> , characteristic for bogs with low water table (Woodland et al., 1998; Tolonen et al., 1992) reflects soil with well-developed humus litter. |
| t4.8 | MaK-1-12, 5.3 | Peaty palaeosol | 40,410 + 1230/ – 1070 | 15 species and varieties. Mainly eurybiotic <i>Centropyxis aerophila</i> and <i>C. sylvatica</i> . Sphagnobiotic <i>Trigonopyxis arcuata</i> , <i>Heleopera petricola</i> , <i>Argygnia</i> sp. f. A (<i>minor</i>) and calceophilic <i>Centropyxis</i> taxa indicating meso-oligotrophic peatland conditions. |
| t4.9 | MaK-2-3, 7.4 | Peaty palaeosol, cryoturbated, peat inclusion | 41,600 | 17 species, varieties and forms including hydrophilic <i>Diffflugia</i> , sphagnobiotic species from <i>Heleopera</i> and <i>Argygnia</i> . 2 species from the hydrophilic <i>Arcella discoides</i> v. <i>scutelliformis</i> . First find of <i>Paraquadrula irregularis</i> in Late Pleistocene sediments. Increasing soil moisture. |
| t4.10 | MaK-2-4, 7.8 | Fine sand silt, plant remains | 41,900 | 15 taxa. Sphagnobiotic/hydrophilic <i>Heleopera petricola</i> v. <i>amethystea</i> and hydrophilic <i>Diffflugia</i> sp. 1 and sp. 2, indicating increasing moisture. |
| t4.11 | MaK-2-5, 8.1 | Palaeosol | 42,100 | 12 species, varieties and forms from soil-eurybiotic <i>Centropyxis</i> , <i>Cyclopyxis</i> , <i>Plagiopyxis</i> , and <i>Phryganella</i> , partly represented by smaller forms (<i>minor</i> , <i>minuta</i> , <i>minima</i>). Soil environment. |
| t4.12 | MaK-2-6, 8.3 | Peaty palaeosol, peat inclusion | 42,260 + 1860/ – 1510 | 8 taxa. Mostly soil and eurybiotic species, like <i>Centropyxis aerophila</i> , <i>Cyclopyxis eurystoma</i> v. <i>parvula</i> . Single find of <i>Centropyxis plagiostoma</i> . Sphagnophilic <i>Heleopera petricola</i> and <i>H. sphagni</i> indicating peatland development. Hydrophilic taxa are absent. Sediment formation under more dry conditions, than in the previous sample. |
| t4.13 | MaK-2-8, 9.2 | Fine sand to silt | 43,000 | 15 taxa including calceophilic <i>C. plagiostoma</i> and <i>Cyclopyxis kahli</i> , sphagnophilic <i>Heleopera petricola</i> and <i>Argygnia</i> sp., hydrophilic <i>Diffflugia globulus</i> . Rather wet meso-oligotrophic peatland conditions. |
| t4.14 | MaK-2-9, 9.8 | Peaty palaeosol, peat inclusion | 44,310 + 1260/ – 1090 | 24 taxa including genera <i>Centropyxis</i> (50%), <i>Arcella</i> , <i>Cyclopyxis</i> , <i>Heleopera</i> , <i>Nebela</i> , <i>Diffflugia</i> , <i>Pseudodiffflugia</i> , and <i>Phryganella</i> . Aquatic <i>Centropyxis aculeata</i> and <i>C. cassis</i> as well as hydrophilic <i>Diffflugia</i> (<i>D. globulus</i> , <i>D. lucida</i> , <i>D. penardi</i>) are indicating wet habitat conditions. Calceophilic <i>Centropyxis plagiostoma</i> and <i>Cyclopyxis kahli</i> suggests pH close to neutral. Sphagnobiotic <i>Arcella</i> and <i>Nebela</i> species suggest an oligotrophic environment typical for bogs with a high water table. |
| t4.15 | MaK-3-5, 6.9 | Palaeosol, fine- sand silt, small, discontinuous peat inclusion | 43,700 | 12 taxa. Dominated by eurybiotic and soil taxa (including <i>Plagiopyxis</i>). Species diversity decreased only half of previous level. No hydrophilic species. Rather dry soil conditions. |
| t4.16 | MaK-3-7, 7.0 | Palaeosol, fine- sand silt, small, discontinuous peat inclusion | 43,510 + 1010/ – 900 | 17 taxa (mostly <i>Centropyxis</i> and <i>Cyclopyxis</i> taxa). Hydrophilic <i>Diffflugia globulus</i> and sphagnobiotic <i>Heleopera petricola</i> v. <i>humicola</i> reflecting more humid conditions compared to MaK-3-5. |
| t4.17 | MaK-3-10, 8.4 | Palaeosol | 43,550 | 13 taxa. Predominantly soil and eurybiotic species from <i>Centropyxis</i> , <i>Cyclopyxis</i> , <i>Plagiopyxis</i> , and <i>Phryganella</i> mostly represented by smaller forms like <i>minor</i> , <i>minuta</i> , <i>minima</i> . High decrease of species diversity and disappearance of numerous genera (in detail hydro- and sphagnobiotic taxa). Sedimentation under soil conditions. |
| t4.18 | MaK-3-14, 10.3 | Peaty palaeosol, peat inclusions | 43,620 + 1700/ – 1400 | 3 taxa. Soil-eurybiotic <i>Centropyxis aerophila</i> , <i>C. constricta</i> v. <i>minima</i> , <i>C. plagiostoma</i> f. <i>minor</i> . Unfavourable conditions for TA, probably too dry. |
| t4.19 | MaK-3-16, 12.4 | Peaty palaeosol, peat inclusions | 32,700 | 10 soil-eurybiotic taxa from <i>Centropyxis</i> , <i>Cyclopyxis</i> , and <i>Phryganella</i> . <i>Centropyxis</i> and <i>Cyclopyxis</i> taxa mostly represented by f. <i>minor</i> , <i>minuta</i> , <i>minima</i> reflecting dry soil conditions. |
| t4.20 | MaK-3-17, 13.2 | Peaty palaeosol, peat inclusions | 31,250 + 1080/ – 950 | 9 taxa. Species composition is similar to MaK 3-16. However, the presence of hydrophilic and sphagnobiotic <i>Argygnia</i> sp. indicates wetter habitat conditions. |
| t4.21 | Unit C | | | |
| t4.22 | Ice Complex sediments | | | |
| t4.23 | Profile 1 | | | |
| t4.24 | MaK-5-3, 14.3 | Palaeosol, peat inclusion | 24,600 + 170/ – 160 | 21 taxa. Presence of sphagnobiotic <i>Trigonopyxis arcuata</i> and <i>T. minuta</i> , inhabitants of a coarse-humus litter, as well as soil taxa <i>Plagiopyxis callida</i> , <i>P. minuta</i> , and <i>P. penardi</i> . |
| t4.25 | MaK-8-3, 15.8 | Peaty palaeosol, peat inclusion | 22,000 | 11 species and forms. Predominantly soil taxa from genera <i>Centropyxis</i> , <i>Cyclopyxis</i> , <i>Plagiopyxis</i> , and <i>Phryganella</i> . Presence of sphagnobiotic <i>Nebela parvula</i> reflects short flooding. Absence of calceophilic taxa indicates acidic pH of soil solution. |
| t4.26 | MaK-9-3, 20.9 | Fine-sand silt | 18,000 | 16 taxa of soil-eurybiotic <i>Centropyxis</i> , <i>Cyclopyxis</i> , <i>Plagiopyxis</i> , and <i>Phryganella</i> . Dominance of calceophilic <i>C. plagiostoma</i> (43.5%) point to nearly neutral pH soil solution. |
| t4.27 | MaK-9-4, 21.4 | Fine-sand silt | 17,600 | 15 taxa. Species composition similar to that in MaK 9-3, but soil-living <i>Plagiopyxis</i> is replaced by hydrophilic <i>Diffflugia globulus</i> and <i>D. lucida</i> . Presence of hydro-sphagnobiotic <i>Argygnia</i> sp. indicating increasing habitat moisture. |
| t4.28 | MaK-9-5, 21.9 | Fine-sand silt | 16,510 ± 60 | 17 taxa from the soil-eurybiotic group, mainly (63.5%) represented by small sized forms. Soil formation under unfavourable conditions – lower temperatures and decreasing moisture. |
| t4.29 | Unit D ₂ | | | |
| t4.30 | Holocene cover | | | |
| t4.31 | MaK-10-5, 24.3 | Cryoturbated palaeosol, peat inclusion | 9480 ± 40 | 17 species and varieties reflecting meso-oligotrophic peatland conditions. <i>Arcella arenaria</i> v. <i>compressa</i> , <i>Argygnia</i> sp., and <i>Phryganella hemisphaerica</i> are indicating active processes of paludification. |
| t4.32 | MaK-10-7, 24.9 | Peaty palaeosol, peat inclusion | 9500 | 13 taxa reflecting soil formation under dry conditions. |
| t4.33 | MaK-10-8, 25.2 | Cryoturbated palaeosol, peat inclusion | 9510 ± 45 | 7 taxa reflecting the same environmental conditions like in MaK 10-7. |
| t4.34 | MaK-10-11, 26.0 | Palaeosol, peat inclusion | 2785 ± 30 | 4 taxa. <i>Centropyxis cassis</i> and <i>Heleopera sphagni</i> indicating peatland habitat conditions. |

(continued on next page)

Table 4 (continued)

| Sample ID, height, m a.s.l. | Type of sediment | Age, ¹⁴ C yr BP correlated ages | TA assemblages with palaeoecological interpretation |
|-------------------------------------|---|--|--|
| Unit C | | | |
| Profile 2 | | | |
| MaK-12-1, 0.5 | Peaty palaeosol, peat inclusions | 27,220+310/-300 | 19 species and intraspecific taxa. Mostly soil-eurybiontic species. Hydrophilic <i>Diffflugia globulus</i> and <i>D. pristis</i> c.f., and single find of sphagnobiotic <i>Argygnia</i> sp. reflect rather wet conditions. <i>Centropyxis plagiostoma</i> represented by different morphological types point to meso-oligotrophic water regime of the habitat. Numerous diatom shells also reflect wet habitat conditions. |
| MaK-12-2, 0.75 | Peaty palaeosol, peat inclusions | 27,000 | 19 taxa. Species composition is similar to MaK 12-1, but hydrophilic <i>Diffflugia</i> are replaced by aquatic and sphagnobiotic <i>Arcella</i> . Numerous diatom and ostracod shells support the assumption of moist bog conditions. |
| MaK-12-4, 1.0 | Peaty palaeosol, peat inclusions | 26,800 | 23 taxa. Sphagnobiotic <i>Arcella</i> , <i>Nebela</i> and <i>Diffflugia</i> indicate meso-oligotrophic peatland conditions. Dominance of <i>Centropyxis</i> taxa and especially <i>C. plagiostoma</i> confirms this interpretation. |
| MaK-12-5, 1.25 | Cryo-turbated palaeosol, peat inclusion | 26,400 | 15 taxa. Species composition resembles that in MaK 12-4. Meso-oligotrophic peatland conditions. |
| MaK-13-7, 4.3 | Fine-sand silt | 24,150±120 | 4 <i>Centropyxis</i> taxa. Presence of morphological f. <i>major</i> of calcophilic <i>Centropyxis plagiostoma</i> previously found under higher moisture conditions (Bobrov et al., 2004) point to wet soil environments. |
| MaK-17-3, 11.5 | Peaty palaeosol | 18,920±70 | 8 species and varieties from <i>Centropyxis</i> and <i>Cyclopyxis</i> represented by f. <i>minor</i> , <i>minuta</i> , <i>minima</i> , <i>microstoma</i> , which probably indicate unfavourable climatic conditions, e.g. lower temperatures (Smith, 1988) and/or climate deterioration accompanying with dehumidification (Bobrov et al., 1999), resulting in a reduction of shell size. Presence of <i>Cyclopyxis eurystoma</i> v. <i>parvula</i> (small sized variety) also confirms unfavourable habitat conditions. |
| MaK-19-4, 15.6 | Palaeosol, organic rich spots | 16,000 | 2 taxa. Soil-eurybiontic <i>Centropyxis aerophila</i> v. <i>minor</i> and <i>C. sylvatica</i> v. <i>minor</i> indicates a period of unfavourable environmental conditions. |
| Unit D ₃ | | | |
| Deposits in thermokarst depressions | | | |
| MaK-14-4, 1.4 | Alas deposit, interbedding, peaty layers | 1480±20 | 9 taxa. Dominance of <i>Diffflugia globulus</i> (25%) indicating marshy environmental conditions. Absence of calcophilic taxa reflecting slightly acidic pH. |
| MaK-14-5, 1.7 | Alas deposit, sand-peat interbedding | | 14 taxa including some hydrobiontic (<i>Diffflugia cratera</i> , <i>D. globulus</i> , <i>D. minuta</i>) and hydro-sphagnobiotic (<i>Cyclopyxis arcelloides</i>). Wet <i>Sphagnum</i> -peatland environment, probably with periodically open water bodies. Numerous diatom and ostracod shells confirm the existence of open water bodies. Soil taxa <i>Plagiopyxis callida</i> and <i>P. penardi</i> suggest seasonal changes in water table. |
| MaK-14-6, 2.0 | Alas deposit, sand-peat interbedding | | 17 taxa. Species composition indicates meso-oligotrophic peatland conditions. Presence of soil species <i>Plagiopyxis penardi</i> and xerophilic moss-soil inhabitant <i>Bullinularia indica</i> , as well as ostracod shells, indicate fluctuations in the seasonal water regime, interchange with a period of water supply and drying. Similar combination of hydrophilic and xerophilic species is rather characteristic for sediments in the Arctic region (Bobrov et al., 2004). |
| MaK-14-8, 2.6 | Alas deposit, peaty soil | 3720±30 | Single find of aquatic <i>Diffflugia cratera</i> reflect a lacustrine stage of sedimentation. |
| Unit D ₁ | | | |
| Thermo-erosional valley deposits | | | |
| MaK-11-6,4.2 | Laminated silty fine sand | 2075±30 | Single find of soil-eurybiontic <i>Cyclopyxis eurystoma</i> v. <i>parvula</i> . |
| MaK-11-7, 4.9 | Peaty palaeosol, peat inclusions | | 9 taxa including hydro-sphagnobiotic <i>Centropyxis platystoma</i> , <i>Cyclopyxis arcelloides</i> , and <i>Pseudodiffflugia gracilis</i> indicating an active stage of paludification. |
| MaK-11-9, 5.5 | Peat inclusion | | 22 taxa. Aquatic <i>Diffflugia globulus</i> , <i>D. minuta</i> , <i>D. oblonga</i> , <i>D. sp.</i> , hydro-sphagnobiotic <i>Centropyxis platystoma</i> , and sphagnobiotic <i>Nebela collaris</i> indicate wet peatland stage with near-surface water table. Numerous diatom shells confirm the existence of very wet habitats. |
| MaK-11-10, 5.8 | Fine sand to silt | | 18 taxa including <i>Centropyxis cassis</i> , <i>Heleopera petricola</i> , <i>Pseudodiffflugia gracilis</i> characteristic for drier habitat conditions than in MaK 11-9. Youngest find of sphagnobiotic <i>Argygnia</i> sp., previously found only in Ice Complex sediments in the Laptev Sea region. |
| MaK-11-11, 6.0 | Soil transition layer | | 17 soil-eurybiontic, sphagnobiotic taxa (like <i>Nebela collaris</i> , <i>N. penardiana</i>), and hydrophilic (like <i>Diffflugia globulus</i> , <i>D. penardi</i> and <i>D. sp.</i>) indicate wetter conditions than in MaK 11-10. Numerous diatom shells and tardigrada eggs confirm this interpretation. |
| Modern surface samples | | | |
| MaK-AA-1 | Modern vegetation on dry Yedoma top | Recent | 22 taxa, mostly soil-eurybiontic. Presence of few hygro- and hydrophilic taxa (like <i>Arcella artocrea</i> , <i>A. arenaria</i> v. <i>compressa</i> , <i>Centropyxis cassis</i>) may reflect seasonal fluctuations in the hydrological regime. |
| MaK-AA-2 | Large temporary polygon 22 cm deep pond on Yedoma top | | |
| MaK-AA-2.1 | Litter | Recent | 10 taxa. Hydrophilic <i>Diffflugia globulus</i> and <i>Arcella arenaria</i> v. <i>compressa</i> indicate wet habitats in the local environment. |
| MaK-AA-2.2 | Upper humus horizon | Recent | 5 taxa. Litter indicating and hydrophilic taxa absent. |
| MaK-AA-3 | Large pond (<50 cm deep) on the bottom of a thermo-erosional valley | Recent | 10 taxa. Dominance (29%) of sphagnobiotic <i>Nebela tinctoria</i> reflects marshy habitats. |
| MaK-AA-4 | Modern soil with litter | Recent | 18 taxa. Hydrophilic and sphagnobiotic <i>Diffflugia difficilis</i> , <i>Nebela biggibosa</i> , <i>N. lageniformis</i> , and <i>N. tinctoria</i> confirm wet habitat conditions. |
| MaK-G-2 | Thermokarst mound on the slope of a thermo-erosional valley | Recent | Poorly preserved amoebae shells. 3 soil-eurybiontic taxa. |
| MaK-G-5 | Very moist bottom of a thermokarst depression | Recent | Single find of <i>Centropyxis sylvatica</i> . |
| MaK-G-11 | Peaty detritus from beach | Recent | Single hydrophilic <i>Diffflugia globulus</i> and hydrophilic <i>Centropyxis platystoma</i> . |

amounts in TA sums (150–356 shells per sample) and taxa diversity (15–32 taxa per sample) for the whole studied units are noted, especially for hydrophilic *Diffugia* taxa (10). Dominant taxa are soil eurybiotic and moss-living *Centropyxis*. During the period between ca 40,000 and 33,000 ¹⁴C yr BP TA shells were absent in the studied samples. After 32,700 ¹⁴C yr BP TA abundance and diversity slowly increases to 150 shells per sample and 20 taxa per sample and remain stable until the end of the interstadial. Dominant taxa are still soil-living TA and hydrophilic taxa are rarely found.

Sartan Stadial sediments are dated to 24,600–16,000 ¹⁴C yr BP. At the beginning of this zone TA abundance slightly increases (almost 200 shells per sample) while TA diversity remained constant (20 taxa per sample). Dominant taxa are from soil eurybiotic genera *Centropyxis* and *Plagiopyxis*. Hydrophilic taxa are absent until ca 17,600 ¹⁴C yr BP. In one sample (ca 18,000 ¹⁴C yr BP) the number of calcophilic *Centropyxis plagiostoma* group sharply increases (up to 43.5%). Sediments accumulated during the *Sartan Stadial* are generally characterized by the absence of hydrobiont taxa.

Holocene sediments are dated to between 9510 and 500 ¹⁴C yr BP. In the lowermost two samples dated to ca 9000 ¹⁴C yr BP TA abundance is very low (50 shells), but increases up to 200 at 7400 ¹⁴C yr BP. After that a sedimentary hiatus is noted between ca 7400 and 3720 ¹⁴C yr BP (Schirrmeister et al., in press). Within the TA palaeocoenoses the number of hygro-hydrophilic and sphagnophilic taxa strongly increase (up to 40%) towards present times. However, dominant taxa are belonging to the soil- and moss living *Centropyxis* genus.

4.3. TA analysis of modern surface samples

No TA shells were found in two modern samples. One sample (MaK-G-1) was taken from the beach of a marine terrace where frequent flooding and poor or no available organic substrate makes it an unfavourable habitat for TA. The other sample (MaK-G-8) was taken from a thermokarst depression with sparse vegetation and very dry soil which also makes it impossible for TA communities to establish and survive, because TA require a certain minimum amount of water for their activity. In total 40 species, subspecies, and forms were identified in the other eight surface samples. The results are compiled in a diagram (Fig. 4). Sample AA-1 was taken from the surface vegetation of a Yedoma hill. In this sample we counted the highest number of TA shells (259). Taxa diversity was the highest (25), too. We also counted a high number of shells in sample AA-3, which was taken from a large pond (<50 cm depth) on the floor of a thermo-erosional valley. Sphagnophilic and moss taxa dominate this TA spectrum. In the other six surface samples, taken from different habitats, TA abundance was rather low (<100 shells per sample). The TA communities of modern habitats include representatives of all ecological groups found in the fossil samples. Main differences of the studied surface samples from the fossil ones are (1) significantly smaller number of sphagno-, hygro- and hydrobiont taxa from genera *Arcella*, *Bullinularia*, *Trigonopyxis*, *Heleopera*, *Nebela*, *Argynnia*, *Diffugia*; (2) rare finds of soil-living taxa from genus *Plagiopyxis*; (3) frequent finds of *Sphagnum*-moss taxa from genera *Valkanovia*, *Assulina*, *Euglypha* and *Trinema* in modern TA communities. Similarities are in dominant taxa from soil-living genera *Centropyxis*.

5. Interpretation and discussion

The TA assemblages and their palaeoecological interpretations, as well as radiocarbon and correlated ages are presented according to the sample height in Table 4. The sand deposits of unit A do not contain any TA shells. This is most likely caused by the fluvial origin of these sediments. TA communities could not develop in this environment and/or TA shells were mechanically damaged and destroyed by the fluvial processes. This unit is also almost free of pollen and plant

macro fossils (Schirrmeister et al., in press). Running water tends to remove lightweight sediment fractions, including TA shells, pollen, and plant macrofossils.

TA assemblages of the Kargin Interstadial zone (unit B) reflect environments with well drained soils. High abundance and diversity of TA in these samples indicate favourable environmental conditions and possibly also a diversity of microhabitats allowing species with diverse ecological requirements to develop. Especially the high taxa diversity of hydrophilic genus *Diffugia* indicates the existence of small, shallow water bodies in either low-centred ice wedge polygons or in small thermokarst depressions that could warm during the summer season prior ca 40,000 ¹⁴C yr BP. This conclusion is supported by the high contents of green algae colonies of *Botryococcus* and *Pediastrum* recorded in the microscopic analysis of these sediments as well as by the plant macrofossil record, demonstrating that wetland plants such as sedges and cotton grass dominated the macrofossil assemblages (Schirrmeister et al., in press). Dominant TA taxa include the soil eurybiotic *Centropyxis* and among them frequent moss-living taxa such as *Heleopera petricola*, *H. sphagni*, and *Argynnia* species. *Arcella* species and *Centropyxis aerophila* reflecting wet moss-tundra habitats, rather similar to the modern vegetation in the study area. Based on the TA data, the climate at ca 40,000 ¹⁴C yr BP can be described as moderately warm and humid. In the sample dated to 43,600 ¹⁴C yr BP the abundance of TA is strongly decreased suggesting a change to colder and drier habitat conditions. The variations of habitat conditions reconstructed by TA assemblages demonstrate slight environmental changes during the Kargin Interstadial. After ca 40,000 ¹⁴C yr BP TA taxa completely disappeared suggesting unfavourable environmental conditions induced by repeated flooding and soil erosion caused by fluvial activity, respectively. The drastic decrease in hydrophilic taxa persisting until ca 32,700 ¹⁴C yr BP may also be interpreted as an indication of a general climatic deterioration. From ca 32,700 ¹⁴C yr BP to 27,220 ¹⁴C yr BP low TA shell concentration indicate a cooling period and the transition to the *Sartan Stadial* interval. Soil eurybiotic taxa dominate the TA assemblages, but sphagnobiotic taxa from genera *Centropyxis* and *Argynnia* are also frequent. This together with the abundance of calcophilic *Centropyxis plagiostoma* indicates the presence of meso-oligotrophic peatland conditions. The deposits of this peat-sand alternating complex (unit B) demonstrate the highest variations in the organic carbon contents. TOC contents vary from 0.2% to 15.3% and the C/N ratios of the studied sediments vary from 1.2 to 24.9 (Table 1). Environmental conditions must have changed drastically during the formation of unit B sequence. Sediment accumulation occurred in swampy and water-logged areas, most likely situated in the floodplain environments near the river channel. Periods of soil formation with stable surface conditions were interrupted by periods or short events of increased sediment accumulation pointing to unstable surface conditions. Thus, changes of water level, bog and soil stages can be reconstructed for the period of the Kargin Interstadial by the TA analysis.

Prior to the transition to the *Sartan Stadial* TA abundance as well as taxa diversity of soil- and moss-living taxa increased before 24,150 ¹⁴C yr BP reflecting recurring stable environmental conditions. The strong decrease in TA abundance and diversity and the complete disappearance of hydrophilic taxa reflect climate deterioration between 24,150 ¹⁴C yr BP and 18,000 ¹⁴C yr BP (Last Glacial Maximum/LGM). Hubberten et al. (2004) found out that most of the *Sartan Stadial* (24,000–15,000 ¹⁴C yr BP) was characterized by the lowest levels of xerophilic insects and a dominance of Arctic tundra taxa. They inferred from palaeobotanical data that the LGM was marked by high aridity and relatively low summer temperatures compared to the previous Interstadial. TA assemblages are reflecting a period of rather stable environmental conditions, less favourable than in unit B sediments. Decreasing C/N ratios reflect relatively dry well aerated conditions in the unfrozen active layer zone with enhanced decomposition of the organic material. The decreasing TOC content and low

Table 5
Relative frequency (min, max, average) and standard deviation of five different forms and varieties of *Centropyxis plagiostoma* in Late Pleistocene ($n=27$) and Holocene ($n=13$; except surface samples) deposits

| Taxa | Pleistocene/Holocene min (%) | Max (%) | Average (%) | SD (%) |
|---|------------------------------|-------------|-------------|------------|
| <i>Centropyxis plagiostoma</i> | 0/0 | 45.50/14.10 | 13.31/2.76 | 12.43/4.12 |
| <i>C. plagiostoma</i> f. <i>major</i> | 0/0 | 10.00/0 | 1.04/0 | 2.13/0 |
| <i>C. plagiostoma</i> f. <i>minor</i> | 0/0 | 11.11/7.50 | 1.92/1.98 | 3.15/2.68 |
| <i>C. plagiostoma</i> v. <i>oblonga</i> | 0/0 | 0/0.89 | 0/0 | 0/0 |
| <i>C. plagiostoma</i> v. <i>terricola</i> | 0/0 | 2.04/0.70 | 0.08/0 | 0.39/0 |

C/N ratios reflect the reduction of the number of nutrition rich habitats (mainly bogs). Many taxa, especially soil eurybiotic *Centropyxis* and *Cyclopyxis*, are represented by small sized forms and varieties (*minor*, *minuta*, *minima*, *microstoma*) probably indicating unfavourable climatic conditions, e.g. lower temperatures (Smith, 1988) and/or colder and drier climate (Bobrov et al., 1999), resulting in a reduction of shell size. The presence of *Cyclopyxis eurystoma* v. *par-*

vula, small sized variety, reflects unfavourable habitat conditions during this period, too. Pollen and macrofossil data indicate that open tundra- and steppe-like associations dominated the area during the Sartan Stadial (Andreev et al., 2002a,b; Kienast, 2002; Schirrmeister et al., in press). It can be therefore assumed a very continental, winter-cold and yearly dry climate for this period. After ca 16,000 ^{14}C yr BP, at the end of the Late Pleistocene, a hiatus in the sediments is noted.

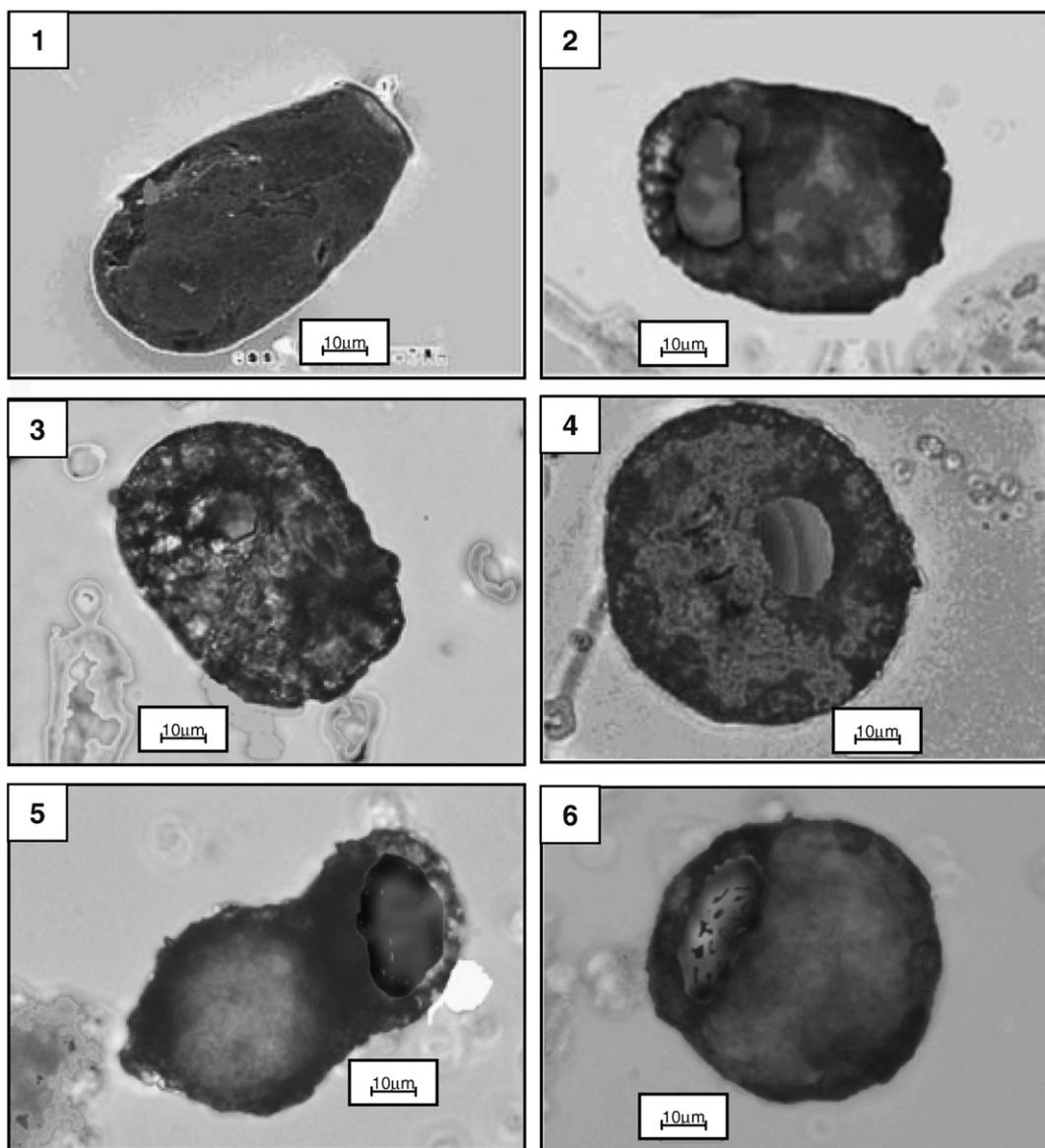


Fig. 5. Some characteristic testate amoebae taxa in surface samples, and Late Quaternary sediments from Cape Mamontov Klyk: 1 – *Nebela bigibbosa*, 2 – *Centropyxis aerophila*, 3 – *C. plagiostoma* v. *oblonga*, 4 – *C. plagiostoma*, 5 – *C. platystoma*, 6 – *C. sylvatica*.

Probably the result of a short period of warmer climate conditions (Allerød) and permafrost thawing enabled the establishment favourable habitats and thus aquatic TA palaeocoenoses.

The increase of the calceophilic *Centropyxis plagiostoma* and *Plagiopyxis* group taxa reflect higher nutrient supply between 18,000 and 16,000 ¹⁴C yr BP. The favourable habitat conditions for calceophilic TA taxa are also confirmed by the pH measurements showing rather alkaline values (Table 1). *C. plagiostoma* is present in more than 75% of the samples, but it was found only in samples with relatively high TA abundance and high TA diversity. *C. plagiostoma* is a well-defined stenobiotic species whose polymorphism was already mentioned in permafrost deposits from the Bykovsky Peninsula (Bobrov et al., 2004). They distinguished between forms *major*, *typica*, and *minor* in the samples. It was concluded that *f. typica* occurred more frequently in the Holocene habitats, which were wetter than the Pleistocene ones. Whereas *f. minor* and *major* were more frequent in the Pleistocene habitats, probably because of the greater diversity of ecological niches during the Late Pleistocene due to a greater biotope differentiation as compared with the Holocene. In our analysis we distinguished between *f. major*, *typica*, and *minor* but also between varieties *terricola* and *oblonga* (Tables 2 and 5). In this study *C. plagiostoma f. minor* and *f. typica* were frequent in Holocene samples, whereas *f. major* was exclusively found in Late Pleistocene (Kargin Interstadial and Sartan Stadial) samples. We conclude that the forms *typica* and *major* correspond to the forms that Bobrov et al. (2004) found on Bykovsky Peninsula. In contrast to this we found *f. minor* in Holocene samples in higher abundances as they did on Bykovsky. It can be explained by an overall high abundance of small-sized TA forms in the whole MaK-sequences and may be interpreted as an adaptation to the specific permafrost habitats around the study site of Cape Mamontov Klyk.

Slight increases in TOC (up to 8%) contents and C/N ratios (14) during the Holocene sediments reflect a general shift in environmental conditions. Around 9500 ¹⁴C yr BP environmental conditions were more favourable and TA communities established in the study area. The relatively high amount of *Alnus fruticosa*, *Betula sect. Nanae* and *Salix* pollen as well as plant macrofossils point to higher temperatures and increasing humidity than before, too (shrub-tundra vegetation) (Andreev et al., 2004b; Schirrmeister et al., in press). Samples are characterized by high TOC contents (up to 21.8%) and C/N ratios (around 13) indicating favourable plant growth and nutrient supply for TA after the hiatus between 9480±40 and 3720±30 ¹⁴C yr BP, probably caused by thermo-erosion. During the Late Holocene TA abundance slowly increased towards modern values reflecting favourable conditions that allow TA to spread and become abundant in all distinguished habitats. Especially the number of hydrophilic taxa is increased until present times. Schirrmeister et al. (2003) described that after 7700 ¹⁴C yr BP the local soil environment at the Olenek Channel (Lena Delta) was much wetter than during the previous Late Glacial period indicated by the presence of hydrophilic and sphagnophilic taxa. A single find of aquatic *Diffflugia cratera* shell may reflect a lacustrine stage of sedimentation. Only vascular plant remains, belonging to *Salix*, *Luzula* and *Juncus* were identified among the moss remains in the macrofossil record. These plants indicate continuously wet conditions in the study area (Schirrmeister et al., in press).

TA taxa diversity is about 30% higher in the Kargin Interstadial samples than in Holocene ones. This was also shown by Bobrov et al. (2004) from Ice Complex sediments from Bykovsky Peninsula, where the maximum diversity was recorded for the Kargin Interstadial (54,000–33,000 ¹⁴C yr BP) too. The pronounced cold/dry periods during the last 45,000 ¹⁴C yr BP are characterized by the lack of hydrophilic TA taxa. This is consistent with Bobrov et al. (2004) study on Bykovsky Peninsula and finds of Schirrmeister et al. (2003) at the Olenek Channel. It can be assumed that the minimum temperature required for successful reproduction is higher for TA taxa living in aquatic environments than for those living in soils.

Beyens et al. (1992) found a higher number of TA taxa in soils with a high content of organic matter. This can be explained by the hypothesis that higher organic content results in more food resources for the TA. However, Trappeniers et al. (2002) reported that the observation of higher diversity together with a higher organic content could not be consistently proved. Our study does not show direct correlations either. The loss of an important soil TA *Phryganella acropodia* already described in Beyens et al. (1990) for the Canadian Arctic (Devon Island) could be observed in our study too, where only in 19 of the 40 samples this taxa was found.

TA analyses show that different sedimentation processes and different habitats result in different species composition. The genus *Centropyxis* (Fig. 3) dominated in all types of sediments. Beyens et al. (1992) has already drawn attention to the shift in faunistic composition within the water-dwelling TA communities. In the arctic water bodies the genus *Diffflugia* is replaced by the genus *Centropyxis*.

Special interest is given to findings of rare TA species in Late Pleistocene Ice Complex and Holocene sediments. Shells of *Argygnia* sp. were found in 10 Late Pleistocene samples (9 in Kargin Interstadial samples, 1 in Sartan Stadial sample) and in 2 Holocene samples. Today, only two species of the 15 known species, *A. dentistoma* and *A. vitrea* have cosmopolitan distribution (Ogden and Hedley, 1980). Other species are restricted to specific regions in Canada, Eurasia, Australia and the Antarctic (Deflandre, 1936; Meisterfeld, 1998). Almost all *Argygnia* species inhabit *Sphagnum*-bogs and acidic hummocks within the forest zone. No species of this genus, except *A. dentistoma*, have been found in the present-day Arctic biotopes (Beyens and Chardez, 1995). This fact provides an additional evidence of a unique soil environment that existed in northeastern Siberia during the Kargin Interstadial. It is also interesting to notice the findings of the sphagnophilic *Nebela bigibbosa* (syn. *Porosia bigibbosa*; Fig. 5) in the surface sample AA-4 (litter). Our study presents the most northern find of this species for the Eurasian mainland. Todorov (2001) pointed out that *Nebela bigibbosa* is not a typical inhabitant of *Sphagnum*-mosses but is closely related to the litter soil layer. So far this species was only identified in Late Pleistocene sediments from Bykovsky Peninsula (Bobrov et al., 2004). Another rare species *Paraquadrulla irregularis*, typical for mesotrophic peatlands (Opravilova and Hajek, 2006), was identified in fluvial sediment samples (MaK 2-3, Kargin Interstadial). Until today the find of *P. irregularis* in Late Quaternary sediments is unique.

A striking feature in the Pleistocene TA communities is the absence of the filose genera *Trinema*, *Euglypha* and *Corythion*. These were frequently found in the modern surface samples and are also known to be sometimes dominant genera in Arctic habitats (e.g. Beyens et al., 1992; Trappeniers et al., 2002). The absence of these taxa in the Late Pleistocene samples could mainly be explained by taphonomical problems; composition difficulties and bad preservation could cause the absence of filose genera in the studied Late Quaternary sediments. Further investigation in this particular region and comparison of fossil samples with reliable surface samples can probably answer this question.

Located at the Laptev Sea coast, the study area today is subject to and effectively changed by strong coastal erosion. This study has shown that complex relationships between TA and different environmental factors can be detected. Climate change could be the main cause of environmental change and thus habitat variations. In permafrost landscapes thermokarst processes have also to be taken into account when interpreting the TA changes through the time.

6. Conclusions

Our study represents one of the first attempts to use TA from permafrost regions of Eurasia as indicators of environmental changes at local and regional scales. During the last 45,000 ¹⁴C yr the composition of TA communities in permafrost sequences shifted along with changes in habitat and climate conditions. The recorded TA

fauna from the studied high arctic locality show highest abundances and taxa diversity in fossil samples dated to 44,000–40,000 ¹⁴C yr BP (during the Kargin Interstadial). Low TA abundances were recorded during the period between 24,000 and 18,000 ¹⁴C yr BP (Sartan Stadial). Our study confirm that TA are valuable as complementary palaeoenvironmental proxies for the Arctic regions and can thus provide more detailed information for environmental changes in the study area and their causes. The low number of surface samples analysed so far prevents from quantitative interpretations of the fossil samples. Further work will focus on detailed analysis of recent surface samples from the Arctic Siberia collected in summer 2007 to get reliable information of arctic micro-habitats and to quantify observed changes in the fossil TA records.

7. Uncited references

Bobrov, 1995
Schwamborn et al., 2002

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