Journal of Paleolimnology (2005) 34: 363–376
DOI 10.1007/s10933-005-5801-y

Freshwater ostracodes in Quaternary permafrost deposits in the Siberian Arctic

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Received 1 August 2004; accepted in revised form 26 March 2005

Key words: Freshwater ostracodes, Late Quaternary, Paleoenvironments, Permafrost, Siberian Arctic

Abstract

Ostracode analysis was carried out on samples from ice-rich permafrost deposits obtained on the Bykovsky Peninsula (Laptev Sea). A composite profile was investigated that covers most of a 38-m thick permafrost sequence and corresponds to the last ca. 60 kyr of the Late Quaternary. The ostracode assemblages are similar to those known from European Quaternary lake deposits during cold stages. The ostracode habitats were small, shallow, cold, oligotrophic pools located in low centred ice wedge polygons or in small thermokarst depressions. In total, 15 taxa, representing 7 genera, were identified from 65 samples. The studied section is subdivided into six ostracode zones that correspond to Late Quaternary climatic and environmental stadial-interstadial variations established by other paleoenvironmental proxies: (1) cold and dry Zyrianian stadial (58 – 53 kyr BP); (2) warm and dry Karginian interstadial (48 – 34 kyr BP); (3) transition from the Karginian interstadial to the cold and dry Sartanian stadial (34 – 21 kyr BP); (4) transition from the Sartanian stadial to the warm and dry Late Pleistocene period, the Allerød (21 – 14 kyr BP); (5) transition from the Allerød to the warm and wet Middle Holocene (14 – 7 kyr BP); and (6) cool and wet Late Holocene (ca. 3 kyr BP). The abundance and diversity of the ostracodes will be used as an additional bioindicator for paleoenvironmental reconstructions of the Siberian Arctic.

Introduction

Fossil freshwater ostracodes have been used as bioindicators for the reconstruction of Late Quaternary environments in Europe for about 60 years (e.g., Triebel 1941; Lüttig 1955, 1959; Kempf 1967; Diebel 1968; Diebel and Pietrzeniuk 1969, 1975, 1978a, b; Fuhrmann and Pietrzeniuk 1990a, b; Meisch 2000; Schwalb 2003). Ostracodes have also been used as paleoindicators in many other regions, such as North America (e.g., Curry and Delorme 2003) and Africa (e.g., Park et al. 2003), as well as in other regions. Whereas fossil and modern ostracode fauna and their ecology in Europe are relatively well known due to numerous investigations, there are only a few records concerning freshwater ostracodes in Siberia, particularly from periglacial permafrost regions. Recent ostracodes were summarised by Bronshtein (1947) and Kurashov (1995) for the area covering the former USSR. The occurrence of Arctic freshwater ostracodes is only briefly mentioned. In addition, recent freshwater ostracodes from Siberia are described for Lake Baikal (Mazepova 2001), Central Yakutia (Pietrzeniuk 1977), and Arctic Siberia (Alm 1914; Neale 1969). Only a few freshwater ostracodes studies have been published for the Arctic regions of Alaska (e.g., Swain 1963)

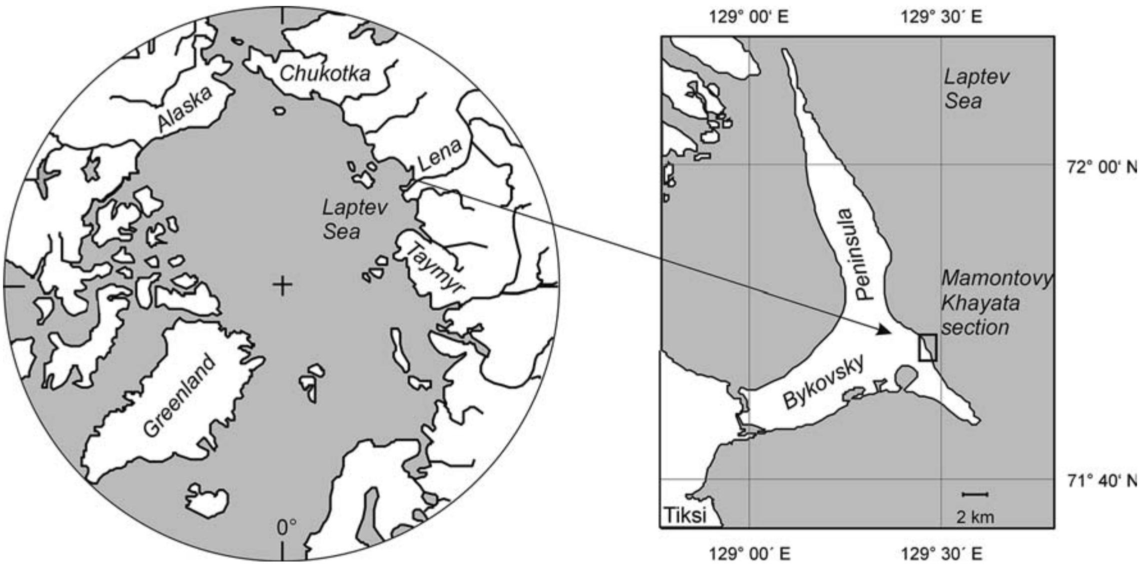

Figure 1. Location of the Mamontovy Khayata study section.

and Canada (e.g., Delorme 1970; Delorme et al. 1977). Detailed studies of fossil ostracodes occurring in permafrost deposits are lacking.

A diverse ostracode fauna was observed during multidisciplinary investigations of Late Pleistocene, ice-rich Arctic permafrost sequences on the Bykovsky Peninsula, Russia (Figure 1). The occurrence of ostracode valves in these permafrost sequences was previously mentioned by Kunitsky (1989) and Slagoda (1993 unpublished thesis). However, up to now, detailed taxonomic and quantitative analysis of these freshwater Arctic ostracodes has not been carried out. The aim of this paper is to describe freshwater ostracodes as bioindicators within a paleoenvironmental permafrost archive. This study was carried out in a geochronologically, sedimentologically and paleoecologically well-studied permafrost sequence located at Mamontovy Khayata ('Mammoth hill'), on the Bykovsky Peninsula. In the future, freshwater ostracode studies in periglacial environments will be supported by studies of the modern Arctic assemblages, as well as by stable isotope studies on ostracode valves.

Study area and geological background

The permafrost sequence in this study is an exposure located on the east coast of the Bykovsky Peninsula (71°40′–72° N and 129°–129°30′ E) in the southern Laptev Sea (Figure 1). Initial paleoecological studies were carried out at the beginning of the 19th century when the first complete mammoth carcass was recovered (Adams 1807). Subsequently, the Mamontovy Khayata profile has become one of the most extensively paleoecologically studied permafrost sequences in the Siberian Arctic. Geomorphological, geocryological, and sedimentological studies were conducted by Kunitsky (1989), Slagoda (1993 unpublished thesis), and Grigoryev (1993). Mamontovy Khayata was also mentioned in reviews of Ice Complex deposits in Siberia by Tomirdiaro and Chernenky (1987), and Fartyshev (1993).

Under the framework of the Russian–German science cooperation 'SYSTEM LAPTEV SEA', the Bykovsky Peninsula has been studied by expeditions every year since 1998. The results include several publications concerning geocryology, sedimentology, and geochronology (Schirrmeister et al. 2002a; Siegert et al. 2002), stable isotope ratio and hydrochemistry of ground ice (Meyer et al. 2000, 2002), and bioindicators such as fossil pollen (Andreev et al. 2002), plant macrofossil remains (Kienast et al. 2005), and rhizopods (Bobrov et al. 2004). A comprehensive paleoenvironmental reconstruction is presented in Schirrmeister et al. (2002b).

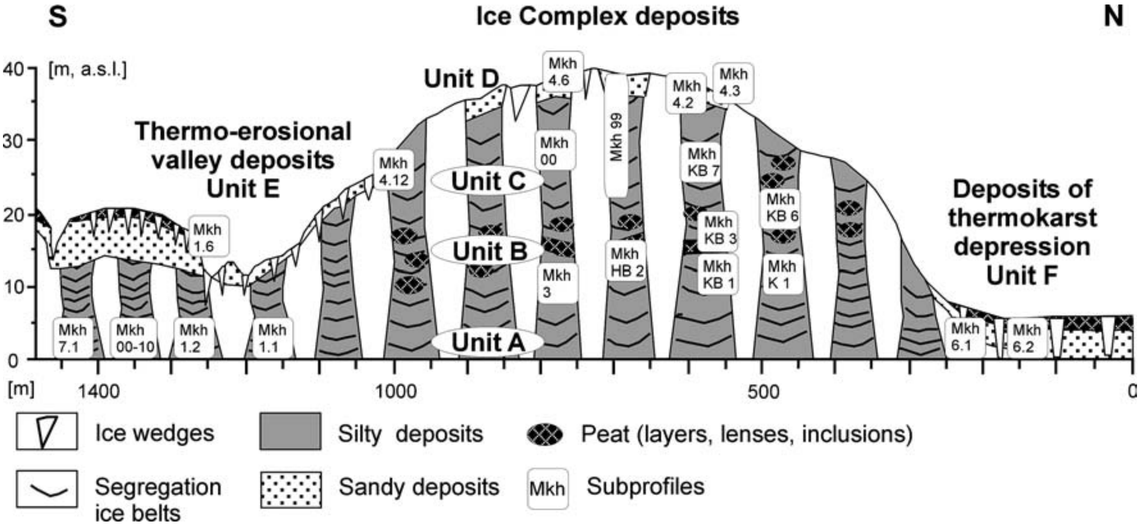

Figure 2. Schematic profile of the study section on the east coast of Bykovsky Peninsula with subdivided cryolithological units (A–F) and the position of the analysed subprofiles.

The ice-rich permafrost sequence of Mamontovy Khayata covers the last ca. 60 kyr of the Quaternary. The profile was divided into four units (A, B, C, D), which include the Late Pleistocene Ice Complex units and its overlying Holocene cover (Figure 2). This division is based on changes in biogeochemical parameters, such as total organic carbon content (TOC), carbon/nitrogen ratio (C/N), isotope values of organic carbon ($\delta^{13}C_{org}$) and carbonate content, as well as cryolithological and grain size parameters, and mass-specific magnetic susceptibility (Schirrmeister et al. 2002a). The units reflect several stages of the Late Quaternary landscape history in the Laptev Sea region.

Ice Complex deposits were formed on the accumulation plains of the dry Siberian shelf areas during the Late Pleistocene. These Arctic accumulation plains were characterised by widely distributed ice wedge polygon systems. The studied coastal outcrops are dominated by giant ice wedges reaching approximately 40 m long and 5 – 6 m wide, which were formed continuously and syngenetically during periods of sedimentation on these plains.

The studied permafrost sequence consists of numerous cryoturbated peaty cryosol horizons with silty to fine-grained sandy interbeds, which are mostly supersaturated with ice. Numerous well-preserved micro- and macro-fossils are found in the frozen deposits. Thus, the syngenetically formed permafrost sequences are excellent terrestrial paleoenvironmental archives. Most of the samples belong to the Ice Complex deposits (units A–C) and their Holocene cover (unit D). Two additional deposit types (Figure 2) were classified as thermo-erosional valley deposits (unit E) and thermokarst depression deposits (unit F). Both were formed during the Late Holocene, when thawing of ground ice reduced the extent of Ice Complex deposits due to thermo-erosional and thermokarst processes. This resulted in a strong transformation of the Arctic landscape by changing the hydrological regime, as well sediment accumulation conditions.

Materials and methods

Frozen samples weighing approximately 0.5 kg each were collected from several overlapping thermokarst mound subprofiles (Figure 2). Thermokarst mounds represent intra-polygon sediment blocks that surround the perimeter of ice wedges that have melted (Figure 3). A composite profile was studied covering most of the 38-m thick permafrost sequence. Ostracode valves were obtained from the deposits of the Ice Complex (units A–C), the Holocene cover (unit D), and the thermokarst depression (unit F). The thermo-erosional valley deposits (unit E) generally lacked ostracodes.

Figure 3. Photograph of some analysed subprofiles on thermokarst mounds showing the structure and composition of the exposed permafrost deposits.

Samples were freeze-dried, wet sieved through a 0.250-mm mesh screen, and then air-dried. About 0.2 kg of each sample was used for ostracode analysis. If less material was available, the numbers of valves counted were normalised to a 0.2 kg sediment weight. Ostracode valves were analysed under a binocular microscope (Zeiss SV 11) and their structure was studied by light microscopy, as well as by scanning electron microscopy (Phillips CM 20 ATEM). Broken fragments of valves were also used for ostracode analysis if they could be identified. The species identification was based on Diebel and Pietrzeniuk (1969, 1975, 1978b) and Pietrzeniuk 1977), as well as on the reference collection of ostracodes at the Museum of Natural History in Berlin, Germany.

The age control of the Mamontovy Khayata section was provided by 70 radiocarbon AMS-dates and 20 conventional radiocarbon dates. The geochronological results are presented in detail by Schirrmeister et al. (2002a). The age–height correlation of *in-situ* organic remains is in good agreement. This age model takes into account the rising uncertainties of older radiocarbon AMS-dates. Nevertheless, the high accuracy of the dates provided by Leibniz Laboratory Kiel, Germany (Nadeau et al. 1997, 1998) and the corresponding geological observations allow an estimation of the chronology back to 60 kyr BP. Therefore, continuous accumulation during the last 60 kyr BP is assumed for the Ice Complex units (units A–C) and its younger cover (unit D). Additionally, the thermo-erosional valley deposits (unit E) were dated between 2 and 1 kyr BP. The sediments of the thermokarst depression (unit F) accumulated at about 3 kyr BP.

Results and interpretations

Ostracode valves occurred in the silty, fine-grained sandy Ice Complex deposits and its Holocene cover, as well as in the sandy sediments of the thermokarst depression (Figure 2, Plates 1 – 3). Peaty permafrost deposits from all sections generally lacked ostracode valves because of the acidic environment present during peat accumulation (Figure 2). The thermokarst deposit profile (unit F) includes a 0.1-m thick layer of eroded Ice Complex material dated to 13,560 ± 80 yr BP, which do not correspond with the Holocene sequence dated between 2910 ± 30 yr BP and 2925 ± 30 yr BP. This layer is a result of slope processes depositing material within the thermokarst deposits, and consequently will have to be considered separately (Figure 5).

In general, the ostracode taxa presented in this paper are similar to Late Pleistocene assemblages from the Lena Delta (Pietrzeniuk 1986 unpublished report), as well as to a modern assemblage from Central Yakutia (Pietrzeniuk 1977). There are no evident distinctions between ostracode assemblages identified in the deposits of the thermokarst depression and the Ice Complex. However, the exact number of taxa is different. In total, 15 taxa were identified and counted. Fourteen taxa were found in the Ice Complex sequence, while 11 taxa were observed in the Ice Complex material layer within the thermokarst depression deposits, and 9 taxa within the true thermokarst depression deposits. The study section can be subdivided into six ostracode zones based on the ostracode distribution in the profile (Table 1, Figures 4 and 5). These zones correspond to the profile zones established using sedimentological, geochemical, and paleoecological proxies (Schirrmeister et al. 2002b).

Ostracode zone I (58–53 kyr BP, 1.3–3.4 m, a.s.l.)

Six of the eight samples in ostracode zone I contained ostracodes with up to 300 valves per sample. Ostracodes were not found in two of the zone's samples. Six taxa are present in this zone, with juvenile *Candoninae* and *Limnocytherina sanctipatricii* being the most abundant taxa (Figure 4). According to Meisch (2000), *Limnocytherina sanctipatricii* (Plate 3; 9–12) are found from the shallow littoral to the profundal zone in lakes, as well as in permanent small water bodies. They have been reported in fossil records in Europe ranging from the Pleistocene to recent times. Their habitats range from oligotrophic, cold waters to brackish waters with up to 3‰ salinity in the Baltic Sea (Frenzel 1991). Their presence in this zone suggests arid climatic conditions with higher evaporation rates than the present. The low species diversity and abundance of the identified assemblage reflect unfavourable (cold and dry) life conditions for ostracodes. Ostracode zone I corresponds to unit A of the sedimentological data (Zyrianian stadial), which is, according to grain size distributions, considered to be a shallow, fluvial environment with graded bedding (Siegert et al. 2002). The pollen data suggest an open treeless landscape with scarce vegetation cover, dominated by cold and dry summers (Andreev et al. 2002). Strong climatic conditions are also reported by the analysis of plant macrofossils, which are represented primarily by the remains of kryoxerophytic pioneer plants (Kienast et al. 2005). The permafrost sequence between 3.4 and 8.8 m, a.s.l. was buried by modern deposits that were deposited by coastal erosion and, therefore, could not be studied.

Ostracode zone II (48–34 kyr BP, 8.8–22.0 m, a.s.l.)

Zone II is characterised by the profile's highest valve abundance and diversity (Figure 4). Altogether 20 samples from this zone were studied. Two samples did not contain any ostracodes. The faunal association of zone II is characterised by the dominance of juvenile *Candoninae* and *Ilyocypris lacustris*. The arctic summers were probably too short to complete their life cycle and allow sufficient growth for the *Candoninae* to develop into their adult stage. Six species of the genera *Candona* and *Fabaeformiscandona* were identified. Only one valve of *Candona* cf. *acutula* was found in single sample (Plate 2; 1), suggesting that it may have been misidentified. *Candona acutula* has previously been found in Holocene lake sediments (Porter et al. 1999) and currently occurs in shallow water with abundant vegetation in Canada (Delorme 1970). *Candona* cf. *combibo* was identified in five samples (Plate 1; 1). The ecological characteristics of *Candona combibo* are not well understood. Fossil records of *Candona combibo* are reported in Russia from the Middle Pliocene to the Middle Pleistocene periods (Kaz'mina 1975).

Candona harmsworthi were found in eight samples of zone II with up to 16 valves being found in a single sample (Plate 1; 5–6). *Candona harmsworthi* has been found in the modern Arctic environments of Novaya Zemlya and Franz-Josef-Land (Neale 1969) and as cold stage fossils in both Europe and northern Siberia (Lena Delta) (Pietrzeniuk 1986 unpublished report). Only female *C. harmsworthi* valves have been found. Males are not known.

Candona muelleri ssp. *jakutica* was present in eight samples, with up to 14 female and male valves being found in a single sample (Plate 1; 2–4). This species was first described by Pietrzeniuk (1977) in thermokarst lakes from Central Yakutia, as subspecies of *Candona muelleri*. It has been

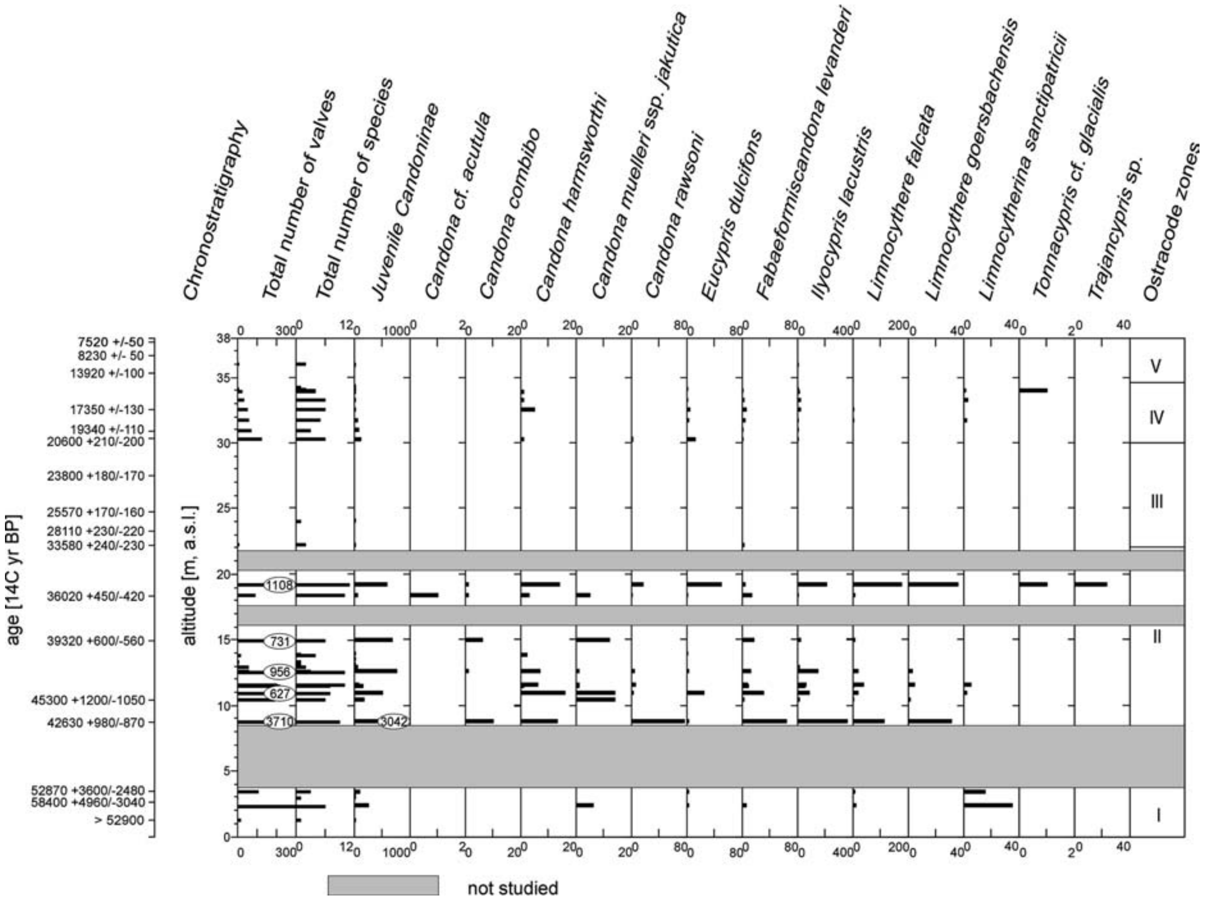

Figure 4. Chronostratigraphy, and stratigraphic variation in two ostracode indices (total numbers of valves and species) as well as in number of each ostracode species of the Ice Complex sequence and the Holocene cover (units A–D). Counts are based on 0.2 kg sediment.

frequently recorded and the records point to a wide general distribution in Siberia (Meisch 2000). Further findings of *Candona muelleri* ssp. *jakutica* are reported for Late Pleistocene thermokarst deposits in Central Yakutia (Pietrzeniuk 1984 unpublished report). *Candona muelleri* is Holarctic and oligothermophilic (Meisch 2000), and has been observed in Europe in sediments ranging from Pleistocene cold stage deposits up to recent times (Fuhrmann et al. 1997).

A high abundance of female and male *Candona rawsoni* was recorded in only one sample at 8.8 m, a.s.l. (Plate 1; 7 – 10). *Candona rawsoni* occurs in cold, oligotrophic lakes, and small temporary water bodies (Delorme 1969). Smith (1997) describes the species as eurytopic (tolerant to a wide range of physical and chemical conditions). Fossil records are reported for both cold and warm Pleistocene stages in Middle Europe (Diebel and Pietrzeniuk 1975, 1978a, b), through the Holocene to recent times in North America (Delorme 1968, 1970; Smith 1997) and Siberia (Bronshtein 1947; Pietrzeniuk 1983 unpublished report).

The highest abundance of *Fabaeformiscandona levanderi* was found in the lower part of zone II (Plate 2; 3 – 4). *F. levanderi* has been observed in the littoral and profundal zones of lakes, even those with a higher salinity (1 – 6‰). It has been described as oligothermophilic, likely titanoeuryplastic (occurring in different calcium-ranges from 0 mg/l up to > 72 mg/l), oligorheophilic, (Hiller 1972), and mesohalophilic (Meisch 2000). Its presence in the fossil record ranges from the Lower Pleistocene to recent times with a Holarctic distribution (Meisch 2000).

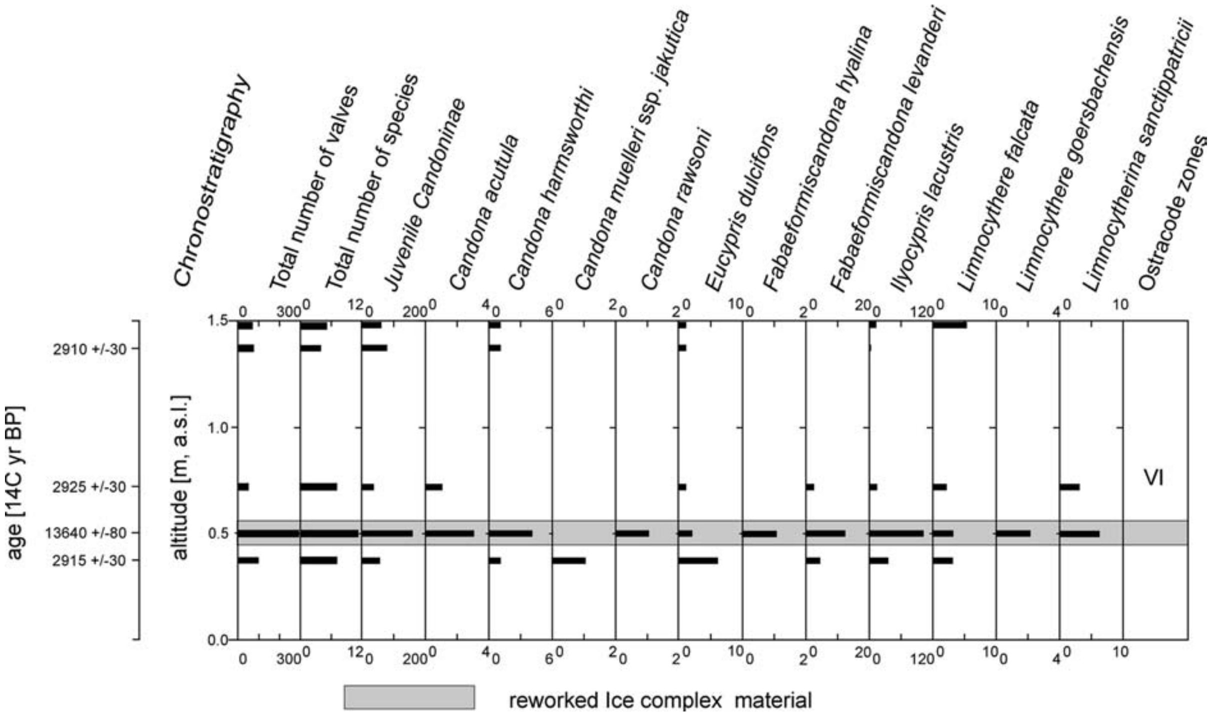

Figure 5. Chronostratigraphy, and stratigraphic variation in two ostracode indices (total numbers of valves and species) as well as in number of each ostracode species of the thermokarst depression (unit F). Counts are based on 0.2 kg sediment.

The species *Ilyocypris lacustris* (Plate 2; 7–8) occurs in most samples of ostracode zone II. It is has been reported in Pleistocene cold stage sediments in Germany (Diebel and Pietrzeniuk 1969) and in Central Yakutia (Pietrzeniuk 1983, 1985 unpublished reports), and has recently been reported in Europe in Switzerland and in Lake Constance (Meisch 2000). Its ecology and life history are unknown.

Eucypris dulcifons (Plate 2; 5–6), *Limnocythere falcata* (Plate 3; 1–4), and *Limnocythere goersbachensis* (Plate 3; 5–8) are numerous in two samples within ostracode zone II, as well as being less frequently found in other samples. *Limnocythere falcata* valves were found up to 0.85 mm in length (Plate 3; 1–2). The environmental preferences of these species are not known. Fossil records are reported from Pleistocene cold stages in Europe (Fuhrmann et al. 1997; Diebel and Pietrzeniuk 1969, 1975, 1978) and Northern Yakutia (Pietrzeniuk 1986 unpublished report), as well as from Holocene lake sediments in north-west China (Mischke 2001).

Broken fragments of *Tonnacypris* cf. *glacialis* were found in only two samples (Plate 2; 11). *Tonnacypris glacialis* inhabits Arctic freshwaters and is also found as a Pleistocene cold stage fossil in Europe (Griffith et al. 1998). *Tonnacypris glacialis* is characterised as a Holarctic, circumpolar species, which occurs at mean summer temperatures of 5.9 (±3.2) °C (Griffith et al. 1998). Valves of the genus *Trajancypris* sp. (Plate 2; 9–10) were mostly juvenile and similar to those of *Trajancypris clavata* and *Trajancypris laevis*. Adults were only represented as broken fragments. Both species have been found as fossils spanning from Pleistocene to recent times (Meisch 2000).

Ostracode zone II presents the most favourable environmental conditions for ostracodes preferring a stable shallow water environment. This is reflected in the high diversity of the ostracode fauna and high abundances of several species. The ostracode assemblages are characterised by the occurrence of Arctic species (e.g., *Candona harmsworthi* and *Tonnacypris glacialis*), typical cold stage species (e.g., *Eucypris dulcifons*, *Limnocythere falcata* and *Limnocythere goersbachensis*),

Table 1. Ostracode zones of the Mamontovy Khayata sequence.

Ostracode zones	Unit	Altitude (m, a.s.l.)	^{14}C Age (kyr BP)	Number of samples	Number of valves Mean (min. – max.)	Number of taxa
Zone VI	F	0.4 – 1.5	ca. 3	4	77 (54 – 103)	3 – 7
Zone V	D	34.5 – 37.6	14 – 7	10	< 1 (0 – 7)	0 – 2
Zone IV	C	30.0 – 34.5	21 – 14	11	32 (0 – 124)	0 – 6
Zone III	C	22.0 – 30.0	34 – 21	13	< 1 (0 – 9)	0 – 2
Zone II	B	8.8 – 22.0	48 – 34	20	410 (0 – 3710)	0 – 11
Zone I	A	1.3 – 3.5	58 – 53	6	71 (0 – 298)	0 – 6

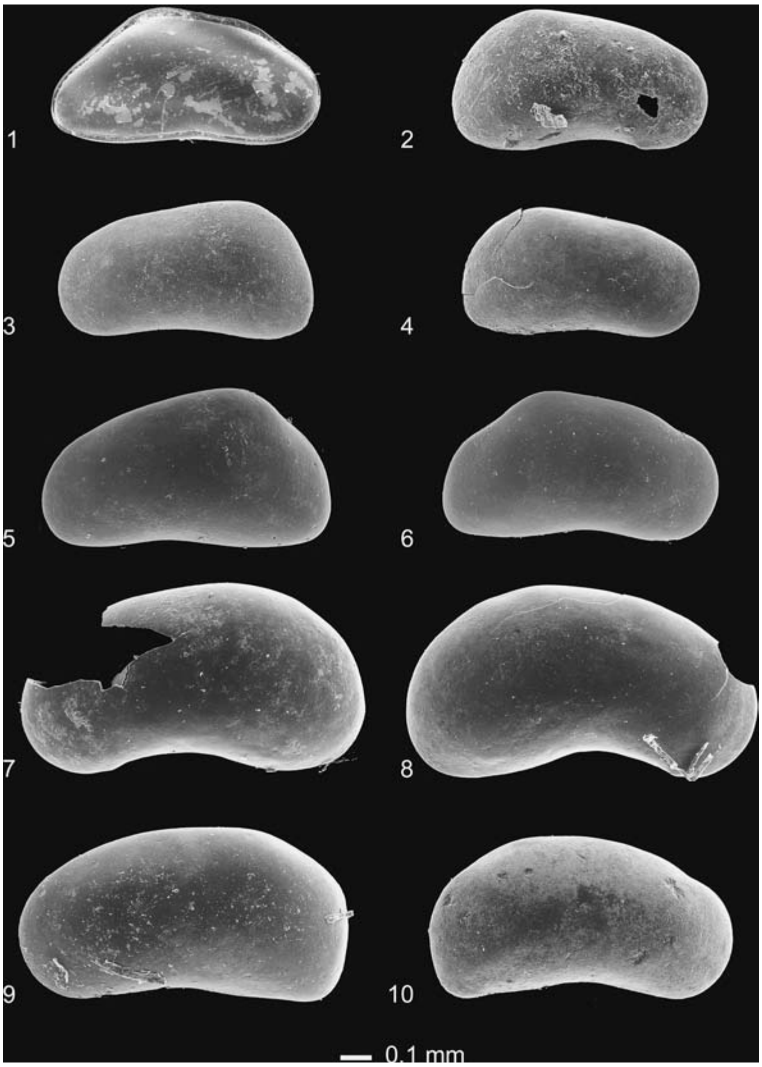

Plate 1. Species of the genus *Candona*. *Candona* cf. *combibo*: (1) female, carapace; *Candona muelleri* ssp. *jakutica*: (2) male, RV; (3) female, LV; (4) female, RV; *Candona harmworthi*: (5) female, LV; (6) female, RV; *Candona rawsoni*: (7) male, LV; (8) male, RV; (9) female, LV; (10) female, RV.

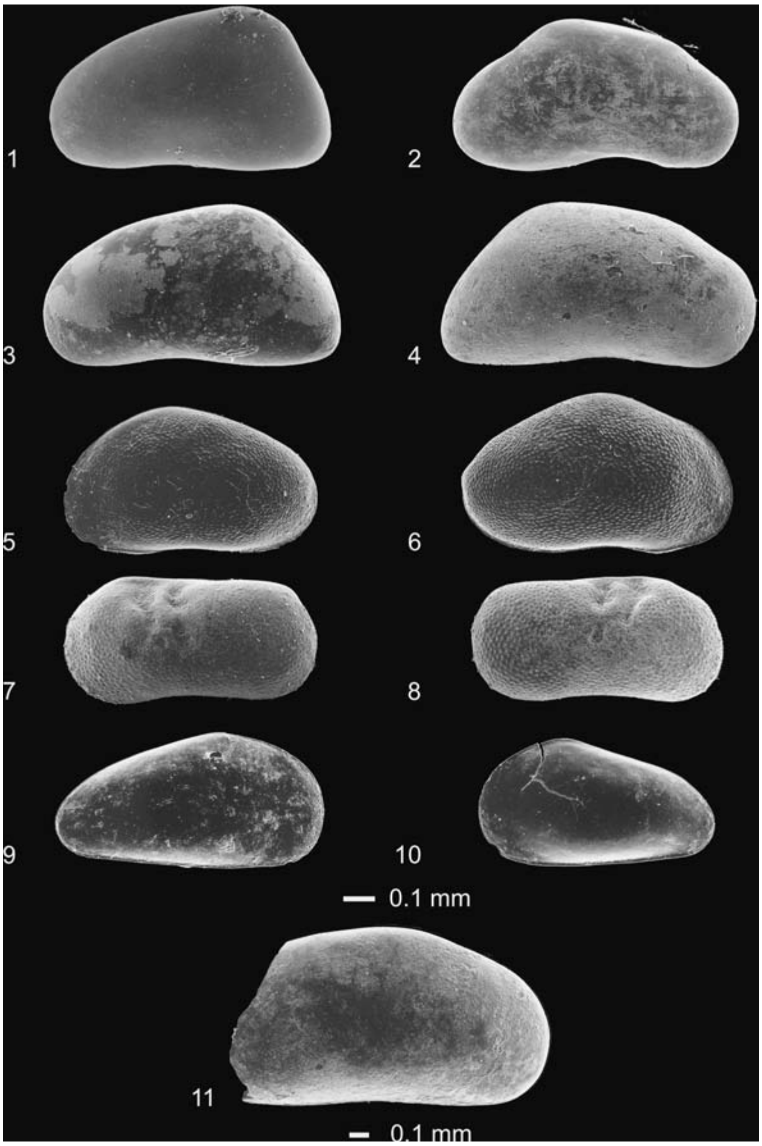

Plate 2. Species and taxa of the genera *Candona*, *Fabaeformiscandona*, *Eucypris*, *Ilyocypris*, *Trajancypris* and *Tonnacypris*. *Candona* cf. *acutula*: (1) female, LV; *Candona* sp. *hyalina*: (2) male, RV; *Fabaeformiscandona levanderi*: (3) female, LV; (4) female, RV; *Eucypris dulcifons*: (5) female, LV; (6) female, RV; *Ilyocypris lacustris*: (7) female, LV; (8) female, RV; *Trajancypris*sp. juv.: (9) LV; (10) RV; *Tonnacypris* cf. *glacialis*: (11) LV.

and cosmopolitans with a preference for cold conditions (e.g., *Candona rawsoni* and *Fabaeformiscandona levanderi*). According to paleoecological and geochronological data, zone II belongs to the Karginian interstadial (unit B). The pollen record of this period is represented by the shrubby vegetation of steppe-like and tundra environments that correspond to dry and relative warm summers (Andreev et al. 2002). In addition, the frequent occurrence of kryoxerophytic pioneer and tundra bog plants, as well as hydrophytes is reported by plant macro fossil remains (Kienast et al. 2005).

Ostracode zone III (34–21 kyr BP, 22.0–30.0 m, a.s.l.)

In zone III, only 2 of the 13 samples yielded a total of 9 juvenile *Candoninae* and *Fabaeformiscandona levanderi* valves (Figure 4). The lack of ostracodes

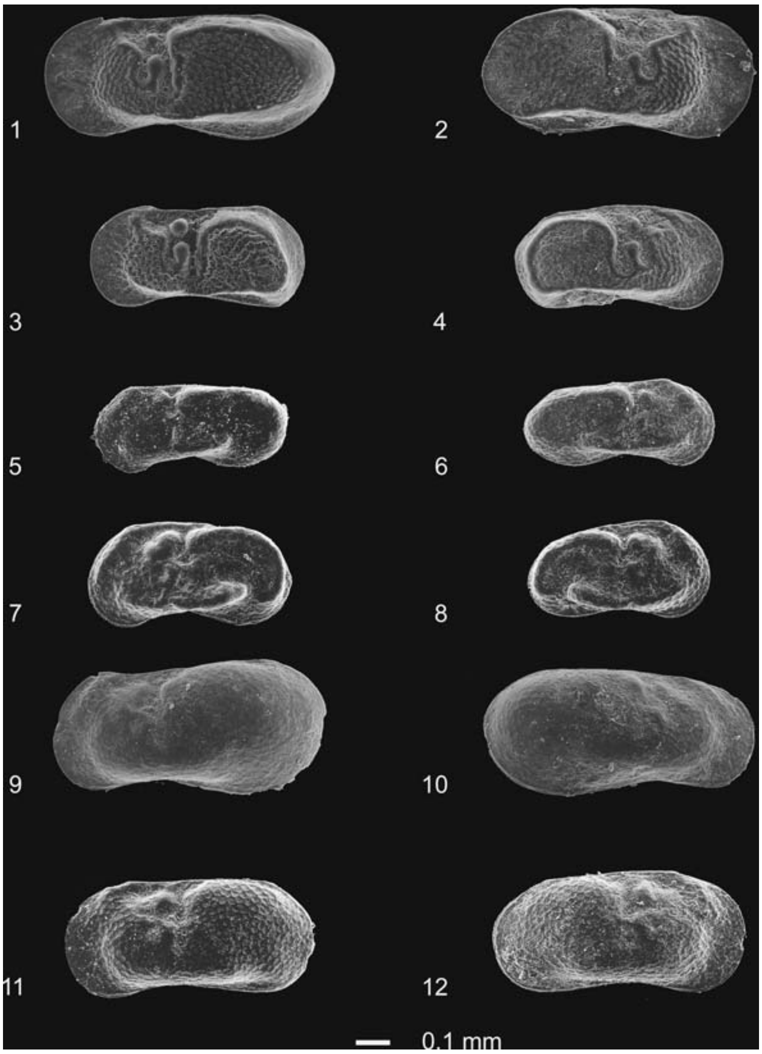

Plate 3. Species of the genera *Limnocythere* and *Limnocytherina*. *Limnocythere falcata*: (1) female LV; (2) female RV; (3) female LV; (4) female RV; *Limnocythere goersbachensis*: (5) male LV; (6) male RV; (7) female LV; (8) female RV; *Limnocytherina sanctipatricii*: (9) male, LV; (10) male, RV; (11) female, LV; (12) female, RV.

in zone III suggests extremely unfavourable life conditions and corresponds to the transition to the coldest and driest period known as the Sartanian stadial (unit C). Because of the dry conditions, polygon ponds were not continuously formed and habitats for ostracodes therefore did not exist. This climatic and environmental situation is supported by testate amoebae data that note the absence of hydrophillic, hygrophillic, and sphagnophillic species (Bobrov et al. 2004) as well as by paleobotanical data which contain a large number of xerophytes and species characteristic to a scarce steppe-like environment (Andreev et al. 2002; Kienast et al. 2005).

Ostracode zone IV (21–14 kyr BP, 30.0–34.5 m, a.s.l.)

Zone IV contains ostracode valves in 10 out of 12 studied samples, but not as many valves as in zone I (Figure 4). The ostracode species richness per sample ranges up to six taxa. The *Candoninae* group of this zone includes juvenile *Candoninae*, *Candona harmsworthi*, and *Fabaeformiscandona levanderi*. In addition, a few valves of *Eucypris dulcifons*, *Limnocytherina sanctipatricii*, and *Ilyocypris lacustris*, as well as one fragment of *Tonnacypris* cf. *glacialis*, were found. Zone IV indicates a warming trend at the end of the Sartanian stadial (unit C), which improved the life conditions for ostracodes. However, the zone IV assemblages are dominated by *Candona harmsworthi* and *Eucypris dulcifons*, which still imply cold conditions. In this period, the effective moisture gradually increased, and consequently the hydrological conditions allowed for the formation of small polygon ponds. This interpretation of climate amelioration at the end of the Sartanian stadial (~15 kyr BP) is supported by several paleoecological indicators including pollen (Andreev et al. 2002), testate amoebae (Bobrov et al. 2004), and insect records (Schirrmeister et al. 2000b). These data suggest an increase of herb communities, wet and warm soil conditions, and the occurrence of tundra-steppe insects.

Ostracode zone V (14–7 kyr BP, 34.5–37.6 m, a.s.l.)

Only 1 of the 10 samples in zone V contained ostracodes, yielding three valves of juvenile *Candoninae* and four valves of *Ilyocypris lacustris* (Figure 4). The sediment in this zone consists mainly of peat, which is not a favourable environment for ostracodes and the preservation of their carbonatic valves. Zone V corresponds to the Holocene optimum (unit D) when climatic conditions were at both their warmest and wettest climate according to the data of pollen (Andreev et al. 2002) and macrofossil plant remains (Kienast et al. 2005).

Ostracode zone VI (about 3 kyr BP, 0.4–1.5 m, a.s.l.)

Ostracodes from the Late Holocene sandy deposits of the thermokarst depression were delineated as ostracode zone VI (unit F). The species assemblage and diversity seem to be quite similar to those of zone IV (Figure 5). The ostracode data suggest cool and wet climatic conditions, as well as the stable persistence of ostracode habitats. The occurrence of the species *Eucypris dulcifons* and *Limnocythere falcata* in Late Holocene deposits, mostly known from

Table 2. Characteristics and stratigraphy of the Ostracode zones in the Mamontovy Khayata section.

Ostracode zones (^{14}C kyr BP)	Units	Ecological characteristics	Typical species	Stratigraphy
Zone VI (ca. 3)	F	Low diversity and abundances	*C. harmsworthi*	Late Holocene
		Cool and wet conditions	*E. dulcifons*	
		Stable shallow water environment	*L. falcata*	
			I. lacustris	Middle Holocene
Zone V (14–7)	D	Lack of ostracodes	*I. lacustris*	
		Warm and wet conditions		
		Stable peat environment		Allerød
Zone IV (21–14)	C	Low diversity and abundances	*C. harmsworthi*	
		Climate amelioration	*E. dulcifons*	Sartanian stadial
		Unstable shallow water environment	*L. sanctipatricii*	
			I. lacustris	
Zone III (34–21)	C	Lack of ostracodes	*F. levanderi*	
		Coldest and driest conditions		
		Unstable shallow water environment		
Zone II (48–34)	B	High diversity and abundances	*C. harmsworthi*	
		Warm and dry conditions	*C. muelleri-jakutica*	Karginian interstadial
		Stable shallow water environment	*C. rawsoni*	
			F. levanderi	
			L. falcata	
			L. goersbachensis	
			I. lacustris	Zyrianian stadial
Zone I (58–53)	A	Low diversity and abundances	*F. levanderi*	
		Cold and dry conditions	*E. dulcifons*	
		Shallow, fluvial environment	*L. falcata*	
			L. sanctipatricii	

Pleistocene cold stage deposits in Europe (Diebel and Pietrzeniuk 1969, 1975, 1978b; Fuhrmann et al. 1997) are noteworthy. Zone VI reflects the recent conditions of the Arctic tundra (Andreev et al. 2002).

Conclusions

Ostracode valves from permafrost deposits on the Bykovsky Peninsula reflect the existence of stable aquatic habitats in the Siberian Arctic coastal lowlands during different paleoecological periods of the Late Quaternary (Table 2). Their occurrence in permafrost deposits depends mainly on climatic changes such as the stadial-interstadial variations of the Late Quaternary. During the Zyrianian stadial (58 – 53 kyr BP), the Karginian interstadial (48 – 34 kyr BP), the end of the Sartanian stadial (21 – 14 kyr BP), and the Late Holocene (about 3 kyr BP), the climatic and environmental conditions allowed for the formation of polygon ponds and thermokarst lakes that were inhabited by ostracodes. Whereas, during most of the Sartanian stadial (34 – 21 kyr BP) the climatic conditions for were too cold and dry to ensure the persistence of stable ostracode habitats. The lack of ostracodes in the Early and Middle Holocene is likely caused by the poor preservation conditions of the acidic peaty sediments of this time period, even if the existence of ponds and lakes can be assumed.

Ostracode-bearing samples are characterised by a dominance of *Ilyocypris lacustris* and juvenile *Candoninae*. Other taxa occur in substantially less numbers. Some general ecological conditions could be concluded despite the wide ecological spectrum that characterise the identified ostracode taxa.

The ostracode zones correspond with the zones established by sedimentological, geochemical, and other paleoecological proxies (Schirrmeister et al. 2002b). The profile was subdivided into six ostracode zones representing stadial-interstadial variations in Late Quaternary climate change: (1) cold and dry Zyrianian stadial (58 – 53 kyr BP); (2) warm and dry Karginian interstadial (48 – 34 kyr BP); (3) transition from the Karginian interstadial to the cold and dry Sartanian stadial (34– 21 kyr BP); (4) transition from the Sartanian stadial to the warm and dry Allerød (Late Pleistocene) period; (5) transition from the Allerød to the warm and wet Middle Holocene (14 – 7 kyr BP); and (6) cool and wet Late Holocene (ca. 3 kyr BP). The ostracode data suggest that the main habitats were small, shallow, cold, oligotrophic pools located in either low-centred ice wedge polygons or in small thermokarst depressions that warmed during the summer season. The presence of *Fabaeformiscandona levanderi* and *Limnocytherina sanctipatricii* suggest arid climatic conditions with higher evaporation rates than the present. Our study shows that ostracode fauna preserved in permafrost deposits provides considerable potential for paleoenvironmental reconstructions in aquatic habitats of the Siberian Arctic.

Acknowledgements

This study was conducted under the auspices of the Russian–German science cooperation ''LAPTEV SEA 2000'', which was mainly supported by the German Ministry of Science (BMBF). The authors thank A. Sher for providing the subprofiles sampled in 1999, the laboratory team of the Alfred Wegener Institute for Polar and Marine Research (AWI) in Potsdam for general assistance during preparation works. We also thank our colleagues, especially A. Andreev, H. Meyer, C. Siegert, H. Henschel from AWI Potsdam and F. Viehberg from the University of Greifswald (Germany), for critical comments and discussions. Furthermore, we thank our colleagues at the Museum of Natural History, Berlin, for undertaking the SEM photography.

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