Thermokarst Lakes in Central Yakutia (Siberia) as Habitats of Freshwater Ostracods and Archives of Palaeoclimate

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Abstract

Thermokarst lake deposits are useful archives of climatic and environmental changes in the past, and can contain palaeo-bioindicators such as pollen, plant macro-fossils, diatoms, chironomids, and ostracods. Nevertheless, such studies from permafrost regions including thermokarst lake deposits are still rare. We studied late Holocene ostracods from an excavation of deposits of the Alas Myuryu in Central Yakutia. In order to apply modern data to fossil records, we also studied the present-day relationships between the environmental setting and the geochemical properties of ostracods in six thermokarst lakes of the same region. The fossil ostracod record reflects lake-level fluctuations in the composition and stable isotope data ($\delta^{18}O$, $\delta^{13}C$) of both species. The modern ostracod communities of thermokarst lakes in Central Yakutia are broadly similar to those of Holocene age. Geochemical stable isotopes studies in both modern host water and ostracod calcite are a prerequisite for further interpretation of the fossil records.

Keywords: Central Yakutia; Holocene; ostracods; thermokarst lakes.

Introduction

Thermokarst is a common phenomenon of the cryolithozone generally caused by extensive melting processes of ground ice in the underlying permafrost. Widespread thermokarst processes have been climatically driven and intensified during warm periods in the Quaternary, especially since the Holocene (e.g., Katasonov 1979). They are responsible for the formation of numerous depressions in the landscape surface (alases), which are often occupied by thermokarst lakes. These landscape forms are typical for Central Yakutia (e.g., Soloviev 1973). The deposits of thermokarst lakes frequently contain fossil remains of bioindicators, e.g., freshwater ostracods, which can be used for palaeoenvironmental reconstructions. Cyclic water level changes in the lakes are related to regional climatic variations (e.g., Nemchinov 1958).

Freshwater ostracods are crustaceans, usually less than 3 mm long, with a bi-valved carapace made of low-magnesium calcite. Changes in climatic and hydrological parameters influence the diversity of freshwater ostracods as well as the geochemical composition of ostracod calcite. In general, several geochemical properties of the calcareous shells of ostracods contain environmental information about the water chemistry and stable isotope composition of the host water at the time of shell formation (e.g., Griffiths & Holmes 2000). In particular, $\delta^{18}O$ and $\delta^{13}C$ records of ostracod calcite provide a highly localized and temporally restricted reflection of the isotopic composition of water, making them useful tools in palaeolimnology (Griffiths & Holmes 2000). The $\delta^{18}O$ of carbonates serves as proxy for temperature of the water, the isotopic composition of which is also influenced by precipitation, drainage basin hydrology, and the precipitation/evaporation ratio (P/E) (Kelts & Talbot 1990). The $\delta^{13}C$ of carbonates reflects changes in the isotopic ratio of the total dissolved inorganic carbon (TDIC) (Griffiths & Holmes 2000). Changes in $\delta^{13}C$ are attributed to changes in aquatic productivity within a lake, CO_2 exchange rates between atmosphere and water TDIC, as well as to the photosynthesis/respiration ratio within the lake (Leng & Marshall 2004).

In this respect, we present here the first combined study of modern and late Holocene ostracod assemblages from Central Yakutia. The first description of ostracods from this area was given by Pietrzeniuk (1977). Further regional studies were carried out on freshwater ostracods of the North Yakutian Lena River Delta, Laptev Sea (Wetterich 2007). In addition, Arctic freshwater ostracod associations were palaeoecologically analyzed in late Quaternary permafrost sequences from Bykovsky Peninsula, Laptev Sea (Wetterich et al. 2005).

Study Area

The studied lakes are situated on the Lena-Amga interfluve and around Yakutsk in Central Yakutia, in East Siberia (Fig. 1). The region belongs to the southern foreland of the Verkhoyansk Mountain Range. The fieldwork on an excavation of the late Holocene deposits of the Alas Myuryu (62°43′N, 131°08′E) was performed in summer

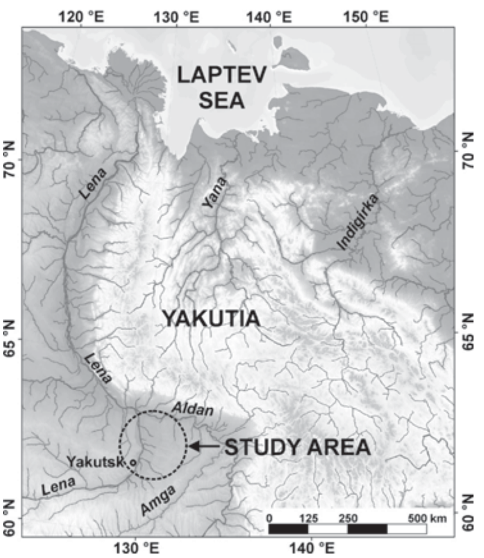

Figure 1. Schematic map of Russia showing the study site on the Lena-Amga interfluve in Central Yakutia (East Siberia). Map compiled by G. Grosse (UAF) using data from GLOBE Task Team (1999).

1997. Six modern thermokarst lakes (between 61°32′N and 62°19′N, 129°32′E and 132°12′E) were sampled in summer 2005 under the auspices of the Russian-German expedition “Central Yakutia 2005” (Wetterich et al. 2007).

Central Yakutia is characterized by a strong continental climate with low annual precipitation (222 mm) and a high temperature gradient over the year (mean temperature in January -37.6°C and in July 19.3°C) and a mean annual air temperature of -8.7°C (Meteorological station Yakutsk; RIHMI-World Data Centre: http://www.meteo.ru).

Materials and Methods

The late Holocene ostracod assemblages of the Alas Myuryu were recovered from a 1.4-m-deep excavation of lake deposits at the desiccated margin of the lake. The sediment samples were freeze-dried, wet sieved through a 0.250 mm mesh size, and then air-dried. About 200 g of each sediment sample was sieved for further ostracod analysis.

Living ostracods were caught at the lake bottoms in the littoral zone of six thermokarst lakes using a plankton net and an exhaustor (Viehberg 2002) in July and August 2005. The ostracods were preserved in 70% alcohol and afterwards counted and identified under a binocular microscope by soft body and valve characteristics.

The stable isotope analyses of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) were performed at the isotope laboratories of the Alfred Wegener Institute (AWI, Potsdam and Bremerhaven, Germany) and the GeoForschungsZentrum (GFZ, Research Centre for Geosciences, Potsdam, Germany).

For $\delta^{18}O$ and $\delta^{13}C$ analyses on fossil and modern valves of adult ostracods we used mass spectrometers (Finnigan MAT 251 at AWI and MAT 253 at GFZ) directly coupled to automated carbonate preparation devices (Kiel II and IV, respectively). Only clean valves of adult specimens were used. Particles adhered to valves were removed with a fine brush under microscope. To ensure enough material for isotope analysis (50–100 mg $CaCO_3$), multi-valve samples of single species have been created. The reproducibility as determined by standard measurements is better than ±0.08% (1σ) for $\delta^{18}O$ and ±0.06% (1σ) for $\delta^{13}C$.

The rain and lake water samples for $\delta^{18}O$ and δD were analyzed by equilibration technique (Meyer et al. 2000) using a mass spectrometer (Finnigan MAT Delta-S at AWI). The water samples for $\delta^{13}C$ analysis on TDIC were preserved by adding HgCl until analysis using a mass spectrometer (Finnigan MAT 252 at AWI). The reproducibility of these data derived from standard measurements is better than ±0.1‰ (1 σ).

The values are expressed in delta per mille notation (δ, ‰) relative to the Vienna Standard Mean Ocean Water (VSMOW) for water isotopes ($\delta^{18}O$, δD) and relative to the Vienna Pee Dee Belemnite standard (VPDB) for $\delta^{13}C$ on TDIC and carbonate isotopes.

The dating of organic matter and calcareous valves from seven samples (Table 1) was undertaken at the Leibniz Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel (Germany) using radiocarbon Accelerator Mass Spectrometry (AMS).

Results and Interpretation

Fossil ostracods

The late Holocene ostracod assemblage consists of 22 species (Fig. 2). The most abundant species during the periods recovered are *Candona candida*, *Fabaeformiscandona rawsoni*, *Ilyocypris lacustris*, and *Limnocythere inopinata*. According to the modern ecological requirements of these species, some facts can be concluded for the living conditions of the fossil assemblage. Most of the species show a great adaptation to changes in both temperature and salinity regime, and are mostly typical for shallow water. The tolerance to temperature ranges from cold stenotherm to warm stenotherm with a great part of thermoeuryplastic (temperature tolerant) species. Furthermore, concerning changes in salinity, most of the species have oligo- to mesohaline ranges; i.e., 0.5 to 18‰ total salt content in the host waters (Meisch 2000). In general, the habitat of the fossil ostracods was a shallow-water environment with significant changes in temperature and salinity, which are linked to lake-level changes. Three periods of different lake conditions are distinguishable (Fig. 2). However, the geochronology of the fossil record from the excavation at the lake margin of the Alas Myuryu does not yield age relations for periods B and C. Whereas period A is well-defined by three dates between about 4300 to 1500 yr BP, period B lacks direct dates, and period A was only dated in its upper part with about 300 yr BP. Furthermore, the lower part of period A is complicated by two rejected ages, which are most likely caused by re-deposition during lake-level changes after sedimentation. Therefore, geochronological interpretation of the fossil data is weak and needs further dates. Nevertheless, late Holocene variations of the lake stages are reflected in taxonomical and geochemical data of the periods A to C (Fig. 2).

Period A (about 4300 to 1500 yr BP) is characterized by moderate water level fluctuations, which are also reflected in the changes in ostracod abundance and diversity. The $\delta^{18}O$ data of *F. rawsoni* with relative ^{18}O-depleted values between about -11 to -8‰ are most likely a sign of a higher P/E due to lower evaporation that caused a generally higher lake level. The shifting $\delta^{13}C$ values of *F. rawsoni* between about -2 to 1.5‰ indicate variable aquatic productivity during period A.

The following period B (after about 1500 yr BP) shows a short-time distinct decrease (at a depth of 58–63 cm) in the abundance of all species which appeared before. That was apparently caused by drying up of the water body. The appearance of *Plesiocypridopsis newtoni* shortly before and during period B (Fig. 2) points to higher salinity, since this species tolerates and even prefers brackish conditions (Meisch 2000). The $\delta^{18}O$ data of *F. rawsoni* reflect drastic changes in the isotopic composition of the lake with shifts between about -12 and -9‰ in a very short time. Afterwards, during a gradual flooding the species composition changed again.

In period C (about 300 yr BP) the species *F. acuminata*, *F. hyaline,* and *F. lepnevae* became common, and moderate lake-level fluctuations took place. In accordance with the $\delta^{18}O$ data of *F. rawsoni*, with relative ^{18}O-enriched values between about -9 to -6‰, the P/E ratio was lower (E>P) and that generally suggests higher evaporation and/or lower precipitation, resulting in a generally lower lake-level compared to period A. The $\delta^{13}C$ values of *F. rawsoni* between about -4 to -1‰ are relatively ^{13}C-depleted and can imply a general lowering in aquatic productivity compared to period A.

Modern ostracods

In six thermokarst lakes of Central Yakutia we observed 15 ostracod species (Fig. 3). In total, up to 250 adult specimens per lake were caught. The highest diversity per lake includes six species. The most abundant species from the fossil assemblages were found, but they are rare in the modern dataset. The dominant modern species are *Candona weltneri* in combination with *C. muelleri jakutica* and/or *F. rawsoni* (Fig. 3).

The studied lakes are shallow, without visible in- or outflows, and mainly fed by precipitation and meltwater from

Table 1. AMS dates of deposits of the Alas Myuryu. Rejected ages in brackets.

Lab No.	Sample No.	Depth [cm]	Material	uncal. Ages [yr BP]	cal. Ages* [yr BP] Max	cal. Ages* [yr BP] Min
KIA20827	J-97-6/161	10-15	Ostracods	275 ± 25	285	330
KIA8180	J-97-6/164	19-21	Reed leafs	285 ± 30	349	456
KIA8179	J-97-6/156	35-40	Grass and moss	(1935 ± 30)	(1820)	(1949)
KIA20828	J-97-6/156	35-40	Ostracods	(2100 ± 30)	(1995)	(2146)
KIA20829	J-97-6/147	75-80	Gastropods	1505 ± 30	1329	1417
KIA8178	J-97-6/141	105-110	Plant detritus	1945 ± 30	1823	1950
KIA20830	J-97-6/138	120-125	Gastropods	4280 ± 30	4822	4880

* Calibrated ages were calculated using the software "CALIB 5.0." Calibration data set: intcal04.14c (Stuiver & Reimer 1993, Reimer et al. 2004).

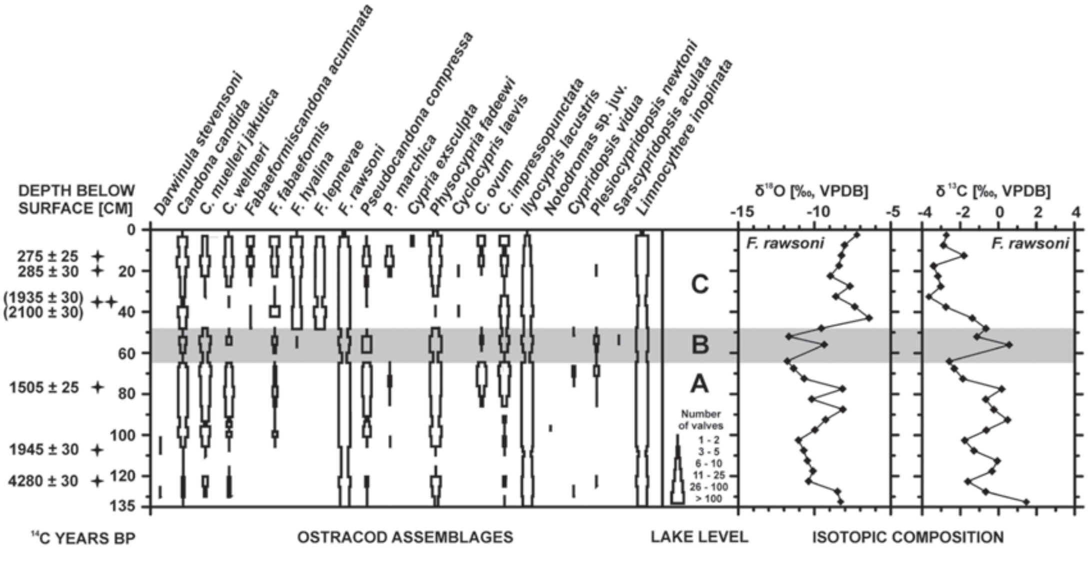

Figure 2. Ostracod assemblages and isotopic composition of ostracod valves from late Holocene lake deposits of the Alas Myuryu: A - Period of moderate lake-level fluctuations; B - Period of drastic lake-level fluctuations; C - Period of moderate lake-level fluctuations. Rejected AMS dates from deposited material are marked in brackets. Width of bars indicates ostracod number (see key).

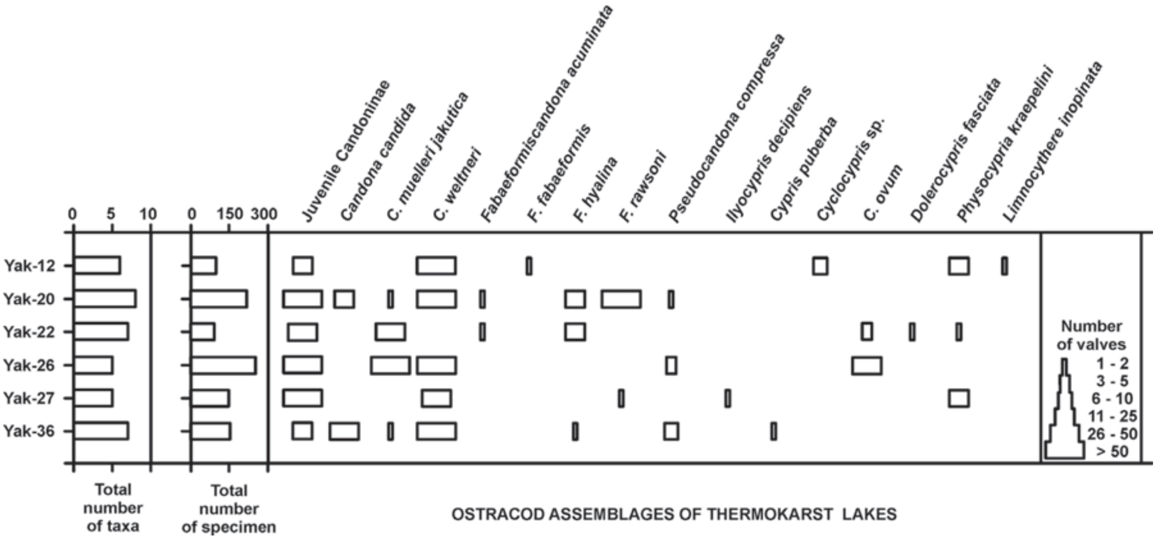

Figure 3. Modern ostracod assemblages from six thermokarst lakes on the Lena-Amga interfluve. Width of bars indicates ostracod number (see key).

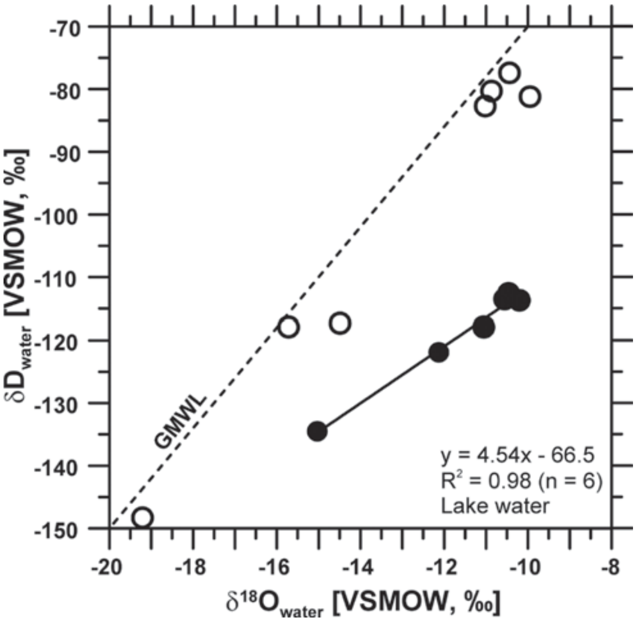

Figure 4. Isotopic composition of rain water (open circles) from Yakutsk in August 2005 and the studied lakes (filled circles) on the Lena-Amga interfluve.

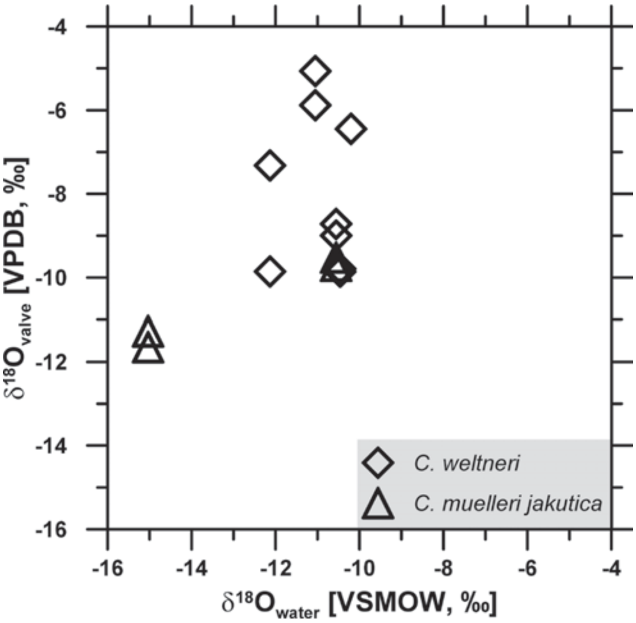

Figure 5. Stable isotope composition of $\delta^{18}O$ in ostracod calcite and host waters for female and male specimen of adult *C. weltneri* and *C. muelleri jakutica*.

the underlying permafrost. The high temperature variation in the surface lake waters during the fieldwork ranged from 12°C up to 26°C, and the ionic content expressed as electrical conductivity reached from 0.36 to 0.92 mS/cm.

The results of oxygen and hydrogen isotope analyses of the lake waters are shown in a $\delta^{18}O$ - δD plot (Fig. 4) with respect to the Global Meteoric Water Line (GMWL), which correlates fresh surface waters on a global scale (Craig 1961). Furthermore, in Figure 4 the stable isotope data of seven rainwater samples from August 2005 taken in Yakutsk are presented. Lake water samples are shifted below the GMWL, and this deviation reflects evaporation in the studied water bodies, as indicated by a slope of 4.54 (R^2 = 0.98; shown in Fig. 4).

The geochemical analyses of ostracod calcite ($\delta^{18}O$, $\delta^{13}C$) were performed on valves of the most common species, *C. weltneri* and *C. muelleri jakutica*. The $\delta^{18}O$ of host waters varies between about -15 to -10‰, whereas the $\delta^{18}O$ of ostracod calcite is generally shifted to ^{18}O-enriched values and ranges between about -12 to -5‰ (Fig. 5). The shift between $\delta^{18}O$ in host waters and ostracod calcite includes metabolic (vital) and temperature effects. Vital offsets on the isotopic composition of several species of Candoninae of up to 3‰ were already proposed by other studies, (Xia et al. 1997, von Grafenstein et al. 1999, Keatings et al. 2002, Wetterich et al. 2007). The temperature-dependence of $\delta^{18}O$ fractionation is reflected by the variation of the shift within a species, where increased temperatures correspond to smaller

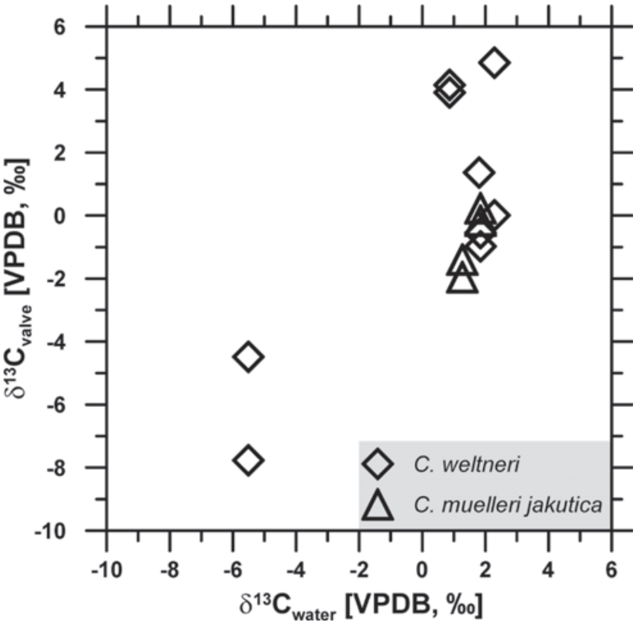

Figure 6. Stable isotope composition of $\delta^{13}C$ in ostracod calcite and ambient waters for female and male specimen of adult *C. weltneri* and *C. muelleri jakutica*.

shifts (e.g., Leng & Marshall 2004). The observed variation in the shift can be explained by different temperatures of the host water at the time of calcification.

The $\delta^{13}C$ of the studied host waters TDIC shows two different ranges at about -5.5‰ and between 1 to 2.5‰. The corresponding $\delta^{13}C$ data on ostracod calcite show considerable scatter from about -8 to -4‰ and -2 to 5‰, respectively. The scatter in $\delta^{13}C$ indicates the influence of complex abiotic and biotic effects at different times of shell secretion on $\delta^{13}C$ fractionation, as is expected in natural waters.

Discussion

For the late Holocene, Wolfe et al. (2000) detected a similar pattern of cellulose-inferred lake water $\delta^{18}O$ in a North Yakutian lake sediment record. They found most ^{18}O-depleted values between 2000 and 500 yr BP due to probably cooler conditions and less influence of evaporation. After 500 yr BP, the data change to relative ^{18}O-enriched values, as it is also recorded in the $\delta^{18}O$ record of ostracod calcite in period C, indicating a warming trend with higher evaporation.

The observed modern ostracod assemblages from Central Yakutian thermokarst lakes are characterized by species with preferences for lower water temperatures and lower salinities (e.g., *C. candida*, *C. muelleri jakutica*, *C. welterni*, *F. hyalina*, *F. rawsoni*). The most common species, *C. weltneri,* is described as cold stenothermal to oligothermophilic and oligohalophilic (Meisch 2000). Other species are tolerant to changes in temperature and salinity. In comparison to Arctic ostracod assemblages (Wetterich et al. 2007) from North Yakutia (Lena River Delta, Laptev Sea), the Central Yakutian fauna generally lacks strictly cold-adapted species such as *F. harmsworthi*, *F. pedata*, and *Tonnacypris glacialis*. Nevertheless, other species, such as *C. candida*, *C. muelleri jakutica,* and *F. hyaline,* are common in both regions. The $\delta^{18}O$ record of ostracods from North and Central Yakutia shows differences. The $\delta^{18}O$ in valves of Arctic ostracods is relatively more ^{18}O-depleted and ranges between about -20 to -13‰ (Wetterich et al. 2007), whereas the $\delta^{18}O$ of the Central Yakutian ostracods ranges between about -12 to -5‰. This general tendency in the $\delta^{18}O$ records reflects the general lower temperatures and lower evaporation in the north with higher P/E rations as compared to Central Yakutia.

Comparing the Central Yakutian $\delta^{13}C$ records of modern and late Holocene ostracods, we observe a reversed pattern, in which the fossil data are relatively more ^{13}C-depleted (mostly lighter than 0‰) than the modern ones (mostly heavier than 0‰). That may imply generally higher aquatic productivity today as compared to the late Holocene, since plants preferentially fix $^{12}CO_2$ during photosynthesis thereby leaving TDIC enriched in ^{13}C (Griffiths & Holmes 2000). The generally lower range in ostracod $\delta^{13}C$ between -2 to -11‰ from modern North Yakutian ponds (Wetterich et al. 2007) as compared to Central Yakutia may point to dominance of organic matter decay in the northern waters, since these microbiological processes release ^{13}C-depleted CO_2 and lower $^{13}C/^{12}C$ ratios in TDIC (Griffiths & Holmes 2000).

Conclusions

Periodic short- and mid-term climate variability leads to significant changes in hydrological conditions; e.g., to drastic water-level changes in thermokarst lakes of Central Yakutia, as it was first described by Nemichov (1958). A drying-up period of the thermokarst lake within Alas Myuryu in the late Holocene was observed in both taxonomical and geochemical properties of fossil freshwater ostracods. The uncertain geochronology of the record presented here renders unclear the relationship between lake changes as reflected by ostracod data and the Holocene environmental history. Nevertheless, freshwater ostracods are useful indicators for reconstruction of aquatic conditions in the past.

The modern ostracod assemblage reflects today's environmental conditions that are characterized by moderate lake-level variations due to evaporative effects during the summer season. The high variability in the modern $\delta^{18}O$ and $\delta^{13}C$ data of ostracod calcite underscores the need for further studies in this context.

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