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Evaporation effects as reflected in freshwaters and ostracod calcite from modern environments in Central and Northeast Yakutia (East Siberia, Russia)

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Abstract

Taxonomical and geochemical investigations on freshwater ostracods from 15 waters in Central and Northeast (NE) Yakutia have been undertaken in order to estimate their potential usefulness in palaeoenvironmental reconstructions based on regional fossil records. Higher variability in environmental factors such as pH, electrical conductivity, and ionic content was observed in thermokarst-affected lakes in Central Yakutia than in NE Yakutia lakes. Species diversity of freshwater ostracods reached up to eight taxa per lake, mostly dominated by *Candona weltneri* HARTWIG 1899, in Central Yakutia, whereas in NE Yakutian waters the diversity was lower and *Candona muelleri jakutica* PIETRZENIUK 1977 or *Fabaeformiscandona inaequivalvis* (SARS 1898) had highest frequencies. Coupled analyses of stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and element ratios (Sr/Ca, Mg/Ca) were performed on both host waters and ostracod calcite, aiming to estimate the modern relationships. Correlations between host waters and ostracod calcite of single species were found for $\delta^{18}O$, $\delta^{13}C$, and Sr/Ca and Mg/Ca ratios. The relationships between $\delta^{18}O$, Mg/Ca and Sr/Ca ratios, and electrical conductivity (salinity) as an expression of solute concentrations in the waters mainly controlled by evaporation are more complicated but evident, and may be useful in future interpretation of geochemical data from fossil Siberian ostracods.

Introduction

Knowing the physico-chemical properties of lake water is a prerequisite for understanding relationships between environmental conditions and the significance of bioindicators such as freshwater ostracods for interpreting fossil records in palaeoenvironmental reconstructions. Therefore, we studied relevant environmental parameters controlling ostracod diversity and the geochemical properties of their shells in order to apply modern reference data in future studies of fossil assemblages.

The most characteristic feature of micro-crustacean ostracods is a bi-valved carapace made of low-magnesium calcite. Changes in environmental parameters alter the composition of freshwater ostracod assemblages and the geochemical composition of ostracod calcite that precipitates from the host water at the time of shell secretion (e.g. Griffiths & Holmes, 2000). In particular, stable isotopes of oxygen and carbon ($\delta^{18}O$, $\delta^{13}C$) as well as molar element ratios of strontium and magnesium to calcium (Sr/Ca, Mg/Ca) in ostracod calcite provide a highly localised and temporally restricted reflection of the host water composition (Griffiths & Holmes, 2000).

In East Siberia, two palaeo-archives have mainly been used for reconstructions of palaeoclimatic changes: lake sediments (e.g. Katamura et al., 2006; Lozkhin et al., 2007) and permafrost deposits (e.g. Hubberten et al., 2004). The scientific interest in palaeoclimatic and palaeoenvironmental reconstructions from East Siberian records is based on current understanding that permafrost is a climate-driven phenomenon and Arctic regions are sensitive to the ongoing climate change. In this context, the Siberian Arctic is experiencing a large impact from global warming (ACIA, 2005; IPCC, 2007). The permafrost system reacts to warming with intensified thermokarst processes which lead to changes in matter and energy cycles, and also influence relief and hydrology in the Arctic. Understanding past environmental history can enable us to explain and estimate future environmental dynamics in Arctic permafrost areas.

Remains of fossil freshwater ostracods have been obtained from Siberian lacustrine sediments and used as proxy for climatic and hydrological conditions during the Late Quaternary (Wetterich et al., 2005; Wetterich et al., in press). However, modern and fossil Siberian freshwater ostracods have seldom been studied. The first description of modern ostracods from Yakutia was given by Pietrzeniuk (1977). More recent data on ostracod occurrence in Siberia was summarised by Semenova (2005). The first geochemical studies on shells of Yakutian freshwater ostracods were carried out on samples from waters located on islands in the Lena River Delta, Laptev Sea (Wetterich et al., 2008a).

In this paper we present taxonomical and geochemical data on ostracods and their habitats from two study regions in East Siberia in order to apply modern analogues to fossil records. Further studies of East Siberian fossil ostracod assemblages and their palaeoecological interpretation will benefit from the modern reference data offered here since the understanding of fossil records is impossible without knowledge of recent relationships and processes. Therefore, we focus our research on climate-relevant parameters such as evaporation, solute concentration, and temperature regime in lakes as they are reflected in geochemical composition of both host waters and ostracod calcite.

Study area

Our limnological study in East Siberia includes two regions: (1) Central Yakutia (61° N to 62° N and 129° E to 132° E) at the Lena River, and (2) NE Yakutia (66° N and 143° E) at the mouth of the Moma River where it flows into the Indigirka River (Fig. 1). The study regions belong to the boreal coniferous forest zone (taiga) and to the zone of continuous permafrost. The permafrost thickness in both regions reaches up to 500 m (Geocryological Map, 1991).

The climatic conditions are strongly continental, with high annual temperature amplitudes (Gavrilova, 1998). The mean annual air temperatures are -10.4 °C in Yakutsk ($T_{January}$ -41.7 °C; T_{July} +18.1 °C) and -15.3 °C in Khonuu ($T_{January}$ -46.3 °C; T_{July} +13.9 °C) (Rivas-Martínez, 2007). The mean precipitation averages about 250 mm in both regions (Rivas-Martínez, 2007). About 75-85 % of the annual precipitation occurs from April to October, and evaporation exceeds precipitation during the summer (Gavrilova, 1973). The moisture deficit amounts to more than 220 mm per year in both study regions due to approximately twofold higher potential evapotranspiration than real precipitation (Gavrilova, 1969; Rivas-Martínez, 2007).

Thermokarst, an important landscape-forming feature of the permafrost zone, is mainly caused by extensive melting of ground ice in the underlying formerly permanently-frozen loose sediments (van Everdingen, 1998). Widespread thermokarst processes form numerous depressions in the landscape surface (Alases), which are often occupied by thermokarst lakes. This thermokarst landscape is typical of Central Yakutia (e.g. Soloviev, 1973). Due to the continental climate conditions, the lakes of Central Yakutia are especially likely to experience changing water levels and desiccation (e.g. Nemchinov, 1958; Bosikov, 2005; Pestryakova, 2005). Water level changes and depth in thermokarst lakes are also controlled by geomorphological features (e.g. Bosikov, 2005). Solute concentrations in these waters are influenced by the ionic composition of thawed ground ice from the underlying permafrost (e.g. Lopez et al., 2007), but the main source of such waters is precipitation. Thermokarst lakes are sensitive to any variations in climate, vegetation, or anthropogenic influence (e.g. Kumke et al., 2007; Pestryakova et al., 2007). Except of river branches where periodic flooding may alter the isotope and ionic composition all other studied waters are mainly feed by precipitation since visible inflows and outflows have not been observed. In summer, commonly the upper 0.5 to 2.0 m of the ground is unfrozen. The thickness of the so-called active layer mainly depends on substrate, exposition and vegetation covers and controls the melt water flow above the permafrost table within the seasonal thawed ground.

Material and methods

All presented samples and data were obtained in frame of a joint Russian-German Expedition to Yakutia in summer 2005. A total of 56 lakes and other waters was sampled for several limnological purposes during the fieldwork in two study regions. Here, we present the limnological data from all sampled lakes and focus on ostracod data from 15 sites where enough ostracod material could be obtained for further taxonomical and geochemical analyses.

Field work

In July 2005, fieldwork was performed in Central Yakutia; 12 sites around Yakutsk and 27 sites on the Lena-Amga interfluve east of Yakutsk were sampled (Fig. 1). The studied waters, including thermokarst lakes in different development stages, lakes in thermo-erosion depressions, one Tukulan (dune) lake and old branches of the Lena River (Tab. 1), are situated on denudation plains and different flood plain levels (terraces) of the Lena River. The classification of thermokarst lakes comprises after Solov'ev (1959) the stages: Dyuedya (initial thermokarst), Tyympy (first stage of Alas development) and mature Alas Lake. In August 2005, 17 sites in total were sampled in NE Yakutia near the Khonuu settlement (Fig. 1) on the flood plain and the lower terraces of the Indigirka and the Moma rivers. Kerdyugen ponds (ponds in areas of burned forests) as well as lakes in lowland depressions and anthropogenic water basins were studied (Tab. 1).

Studies of water chemistry and physics in lakes were undertaken in order to describe recent environmental variables affecting life conditions for ostracods. For hydrochemical analyses conducted while still in the field and afterwards in the laboratory, lake water was sampled from each site in Central Yakutia in the lake centre at 0.5 to 1 m water depth using an inflatable dinghy. Because we did not have a dinghy in NE Yakutia, the lake water was sampled at the lake margin at a water depth of 0.5 to 1 m.

Total hardness, alkalinity, and acidity were determined using titrimetric test kits (Macherey-Nagel, Visocolor series). We quantified pH, temperature, oxygen concentration, and electrical conductivity (EC) using a handheld multi-parameter instrument (WTW 340i) equipped with appropriate sensors (pH: SenTix 41; Oxygen: CellOx 325; EC and temperature: Tetracon 325). In August, due to technical problems with the oxygen sensor these measurements were continued using a titrimetric test kit (Aquamerck, Oxygen Test). These field measurements were performed on water samples directly after sampling. Our investigations included measuring water depth using an echo sounder (Tab. 1). Continuous measurements of water temperature, EC, and water level fluctuations (HM-500 series, Hi-net) were performed from May to September 2005 at the Japanese-Russian research station Neleger, west of Yakutsk (62° 05’ N, 129° 45’ E) in an Alas lake (2 m deep) at a water depth of ca. 0.4 m using a datalogger (Campbell, CR10X).

Water analyses

Water samples were analysed for stable isotopes and hydrochemistry at the Alfred Wegener Institute (Potsdam and Bremerhaven, Germany).

The lake water samples for $\delta^{18}O$ determination were stored cool and afterwards analysed by an equilibration technique (Meyer et al., 2000) using a mass-spectrometer (Finnigan MAT Delta-S). The water samples intended for analysis of $\delta^{13}C$ in total dissolved inorganic carbon (TDIC) were preserved by adding $HgCl_2$ until analysis; carbon was extracted from lake water with 100 % phosphoric acid in an automatic preparation line (Finnigan Gasbench I) coupled online with the mass-spectrometer (Finnigan MAT 252). The reproducibility of these data derived from standard measurements is better than ±0.1‰ (1σ). The stable isotope water data are expressed in delta per mil 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 (VPDB) standard for $\delta^{13}C$ in TDIC.

Water samples for ion analysis were passed through a cellulose-acetate filter (pore size 0.45 µm) in the field. Afterwards, samples for element (cation) analyses were acidified with HNO_3, whereas samples for anion analysis and residue samples were stored cool. Upon return to the laboratory, the element content of the water was analysed by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES, Perkin-Elmer Optima 3000 XL), while the anion content was determined by Ion Chromatography (IC, Dionex DX-320). The bi-carbonate concentrations of the waters were calculated from the alkalinity measurements in the field. To ensure the reliability of the analytical methods, the ion balance of each sample was calculated, resulting in deviations of better than ± 10 % for most samples. Poor charge balances were obtained in single samples, that are likely caused by underestimated bi-carbonate concentrations. Molar ratios in the water were calculated from the concentrations of magnesium, strontium, and calcium as Mg/Ca and Sr/Ca ($* 10^{-3}$).

Ostracod analyses

Living ostracods were captured from the upper five centimetres of the lake margin sediment in about 0.5 to 1 m water depth using an exhaustor system (Viehberg, 2002), and were preserved in 70 % alcohol. This method allows representative and qualitative sampling of living specimens, enables further preparation of the soft body needed for taxonomical work, and preserves the undamaged valves needed for geochemical analyses of ostracod calcite. In samples with sufficient numbers of living ostracods, the most common species were prepared for element (Mg, Sr, Ca) and stable isotope ($\delta^{18}O$, $\delta^{13}C$) analyses.

The species were identified under a binocular microscope (Zeiss SV 10) by the soft body and valve characteristics described in Bronshtein (1947), Pietrzeniuk (1977), and Meisch (2000), and following the taxonomic nomenclature given by Meisch (2000). The total number of caught and identified individuals per lake reaches more than 100 in most lakes except of Yak-31 (69 individuals) Yak-22 (92 individuals) and Yak-12 (99 individuals). Maximal number of ostracods was caught in Yak-49 (911 individuals). From the total numbers of individuals per lake percentage data of species frequencies were calculated as shown in Figure 7. Scanning Electron Microscopy (SEM, Zeiss Digital Scanning Microscope 962) with x40, x80, or x100 magnification, depending on valve sizes, was used at the GeoForschungsZentrum (Potsdam, Germany) for imaging valves of the most common ostracod species.

Altogether, 34 samples of modern ostracods from 15 water bodies were analysed for $\delta^{18}O$ and $\delta^{13}C$ stable isotopes and for Mg/Ca and Sr/Ca ratios. In order to create sufficient material (ca. 50 µg) for isotope analyses we compiled two to four valves of one species and sex for mostly two samples per lake (Tab. 3). In total, 112 valves were used for isotope analyses. The analyses on element content (Sr, Mg, Ca) of ostracod calcite were carried out on mostly two single-valve samples from one species and sex per lake (Tab. 3). In total, 34 valves were used for element analyses. The analytical work on ostracod valves was performed at the GeoForschungsZentrum laboratories. Following Keatings et al. (2006a) the ostracod valves were manually cleaned by removing the soft body under the binocular microscope, and then washed in distilled water and air-dried. Only clean valves of adult specimens were used for analysis. Particles adhering to valves were removed with a fine brush. The prepared valves were dissolved with 103% phosphoric acid and analysed for $\delta^{18}O$ and $\delta^{13}C$ by a mass-spectrometer (Finnigan MAT 253) directly coupled to an automated carbonate preparation device (Kiel IV). The reproducibility as determined by standard measurements is better than ±0.06% (1σ) for $\delta^{18}O$ and ±0.04% (1σ) for $\delta^{13}C$. The stable isotope ostracod calcite ($\delta^{18}O$, $\delta^{13}C$) data are expressed in delta per mil notation (δ, ‰) relative to VPDB.

For analysis of Ca, Mg, and Sr we used an ICP-OES (Varian Vista-MPX) at the GeoForschungsZentrum. The single valve samples were placed in a reaction vial, dissolved in 30 ml of 20% HNO_3 (Baker Ultrex), and 3 ml of distilled water were added. The ICP-OES was calibrated with three multi-element standards prepared from mono-element standard solutions for ICP (Alfa Aesar Specpure 1,000 µg/l). Standard solution 1 contained 1 ppm Ca, 0.02 ppm Mg, and 0.01 ppm Sr. Concentrations in standard solutions 2 and 3 were two and three times higher, respectively. For samples with calcium concentrations more than 3 ppm standard solutions of 2, 4, and 6 ppm Ca were used. Three determinations were made from each sample to check machine precision. Contaminant (blank) concentrations in the solvent acid were analysed for each batch of 10 samples to determine detection limits of the measurements. The detection limits in solution (3σ above background in µg/l (ppb), e.g. Doerfel, 1966) are 0.55 for Ca (wavelength 422.673 nm), 0.11 for Mg (279.553 nm), and 0.01 for Sr (407.771 nm). The results for Mg, Sr, and Ca are expressed as µg/g (ppm) in calcite following Chivas et al. (1986). From these results, molar ratios in ostracod calcite were calculated as Mg/Ca ($* 10^{-2}$) and Sr/Ca ($* 10^{-3}$).

Results

Physico-chemical characteristics of the lakes and ponds

Results of limnological investigations and observations during the fieldwork and afterwards in the laboratory are summarised in Table 1 and 2.

The studied lakes are shallow with maximal depths of about 4 m. Lake area varies from 2 x 5 m to 30 x 1000 m. The pH ranges from 6.6 to 10.2 in mostly slightly alkaline to alkaline waters in Central Yakutia and from 6.0 to 9.1 in mostly neutral waters in NE Yakutia. Electrical conductivity differs between the regions, with generally higher values in Central

Yakutia (0.10 to 5.71 mS/cm) than in NE Yakutian waters (0.03 to 0.93 mS/cm). The water temperature varies from 8.0 to 26.3 °C at different times and sites of sampling.

The data obtained at the Neleger Site from continuous monitoring of water temperature, EC, and lake level fluctuations in one Alas lake reflect clear trends during summer 2005 (Fig. 2). The water temperature record is characterised by high daily amplitudes of up to 11 °C with mean temperatures of 9.8 °C in May, 19.1 °C in June, 19.2 °C in the second half of July (data from 03 to 21 July 2005 are lacking), 14.9 °C in August and 9.6 °C in September. Electrical conductivity increases continuously from the beginning of May until the end of June, rising fourfold from 0.1 to 0.4 mS/cm, and likely stays at the upper end of this range during July and August; the highest value (0.5 mS/cm) is reached in the second half of September (Fig. 2). The measured lake level fluctuations are consistent with the changes in conductivity; they decrease from May to June and remain fairly stable from July to September (Fig. 2). Lake levels briefly increased after larger rainfall events (Fig. 2); in total, 217 mm precipitation was measured during the monitoring period.

As shown in Figure 3, the ionic composition of Central Yakutian lakes is dominated by Mg or Na + K and HCO_3. In contrast, lakes studied in NE Yakutia are dominated by Ca and HCO_3.

The results of oxygen and hydrogen isotope analyses of the lake waters are presented in a $\delta^{18}O$-δD plot (Fig. 4) with respect to the Global Meteoric Water Line (GMWL) that correlates fresh surface waters on a global scale (Craig, 1961). The studied lakes are mainly fed by precipitation. The isotope values of seven August 2005 rain water samples from Yakutsk are given in Figure 4. Whereas the local rain water samples are close to the GMWL, samples from the studied lakes are shifted to lower values. The $\delta^{18}O$ values from Central Yakutian lake samples range between about -15.7 to -5.5 ‰, differing from NE Yakutian lakes with values between about -21.3 to -12.2 ‰ (Fig. 5). The $\delta^{13}C$ data from both regions show a similar and considerable scatter, and range between about -11.2 to +11.0 ‰ (Fig. 5). We did not detect a correlation between $\delta^{18}O$ and $\delta^{13}C$.

Ostracod taxonomy and environmental ranges

Among the 18 ostracod taxa observed, 16 taxa were identified to the species level, one taxon (*Cyclocypris* sp.) to the genus level, and one taxon is represented by a single undetermined juvenile Candoninae. SEM images of the most common species are presented in Figure 6.

Most of the adult specimens belong to species of the subfamily Candoninae including the genera *Candona*, *Fabaeformiscandona*, and *Pseudocandona* (Fig. 7). With up to eight taxa per lake, the number of species is generally higher in Central Yakutian lakes than in NE Yakutia. In our Central Yakutian collection the dominant species in most samples is *Candona weltneri* HARTWIG 1899, but *Candona candida* (O.F. MÜLLER 1776), *Candona muelleri jakutica* PIETRZENIUK 1977, and *Fabaeformiscandona rawsoni* (TRESSLER 1957) are most common in single lakes (Fig. 7). NE Yakutia lakes are dominated by *C. muelleri jakutica* PIETRZENIUK 1977 or *F. inaquivalvis* (SARS 1898) except for two lakes, where *F. acuminata* (FISCHER 1851) or *Physocypria kraepelini* G.W. MÜLLER 1903 are most abundant. *F. inaquivalvis* was first described as *Candona inaequivalvis* by Sars (1898) from the environs of Verkhoyansk in Yakutia and also listed by Semenova (2005) as a rare species in East Siberia. Other species such as *Pseudocandona compressa* (KOCH 1838), *F. fabaeformis* (FISCHER 1851), *F. hyalina* (BRADY & ROBERTSON 1870), *Limnocythere inopinata* (BAIRD 1843), and *Cyclocypris ovum* (JURINE 1820) are recorded as common in Central Yakutia by Pietrzeniuk (1977), but are found in lower quantities in our data set.

In Figure 8 the ecological ranges of the species that occur in three or more lakes are shown according to environmental parameters measured at the sampling time and site. The broadest ranges in most of the presented parameters were found for the species *C. candida* (at 5 sites) and *C. weltneri* (at 8 sites), which are common in our collection. *F. inaequivalvis* (at 3 sites) was found exclusively in NE Yakutia, within relatively small ranges in most of the measured environmental parameters; its rarity underscores the differentiation in the environmental setting (e.g. pH, ionic content) between study regions.

Stable isotopes in host waters and ostracod calcite

Analyses of the stable isotope content were performed on valves of the most common species and their host waters (Tab. 3). The $\delta^{18}O$ values vary between about -18.5 ‰ to -10 ‰ in lake water where either *C. candida* or *C. muelleri jakutica* were abundant; the $\delta^{18}O$ values of the valves of both species taken together ranges from -16 ‰ to -9 ‰ (Fig. 9a). A positive correlation between the $\delta^{18}O$ of six lakes and of *C. muelleri jakutica* valves was found ($R^2 = 0.76$, n = 12; Fig. 9a). The species *F. inaequivalvis* (typical for NE Yakutia) shows small variations in valve $\delta^{18}O$ from -14 to -12 ‰, corresponding to host waters from -17 to -15 ‰ (Fig. 9b). Whereas the $\delta^{18}O$ values range from about -12 to -10 ‰ in host waters where *C. weltneri* (typical for Central Yakutia) occurs, the $\delta^{18}O$ range in valves of this species was about 6 ‰, from -11 to -5 ‰ (Fig. 9b).

The relationship between the $\delta^{13}C$ in host waters and in ostracod valves is illustrated in Figure 10. The overall variation in water $\delta^{13}C$ amounts to more than 9 ‰, ranging between about -7 and +2 ‰ (Fig. 10). The $\delta^{13}C$ in valves of *C. muelleri jakutica* co-varies with values between about -6 and 0 ‰ ($R^2 = 0.82$, n = 12; Fig. 10a). The variation of $\delta^{13}C$ in valves of *C. candida* and *F. inaequivalvis* are within the same range, whereas *C. weltneri* values are widely scattered between about -8 and +5 ‰ (Fig. 10a, b). Nevertheless, the *C. weltneri* data also seem to show the same trend; higher $\delta^{13}C$ values in ostracod calcite correspond to higher $\delta^{13}C$ values in host waters.

Element ratios in host waters and ostracod calcite

The element ratios in host waters and in the ostracod calcite of several species are listed in Table 3. The Sr/Ca of host waters in both study regions ranges from about 2 to 6.5 ($*10^{-3}$), corresponding to Sr/Ca ratios in calcite of *C. muelleri jakutica*, which varies from about 0.7 to 1.8 ($*10^{-3}$) (R^2 = 0.92, n = 12; Fig. 11a). The Sr/Ca of the other studied species *F. inaequivalvis* and *C. weltneri* are within the range mentioned above, whereas Sr/Ca ratios in *C. candida* reach about 2.3 ($*10^{-3}$) (Fig. 11a, b). The Sr/Ca ratios in seven lakes and in *C. weltneri* valves is correlated (R^2 = 0.74, n = 12; Fig. 11b). A positive correlation between the Sr/Ca in host waters and ostracod calcite is obvious for all species.

The Mg/Ca of host waters shows a wide range between about 0.4 and 7 (Fig. 12 a, b). The species *C. candida*, *F. inaequivalvis*, and *C. muelleri jakutica* are found in waters with low Mg/Ca ratios of about 2 or less. Only *C. weltneri* also inhabits waters with Mg/Ca of about 5 to 7 (Fig. 12b). For this species, we found a correlation of Mg/Ca in water to Mg/Ca in ostracod calcite (R^2 = 0.66, n = 12; Fig. 12b).

Discussion

Physico-chemical characteristics of the lakes and ponds

In comparison to NE Yakutian lakes the studied Central Yakutian lakes are characterised by higher pH (slightly alkaline to alkaline), higher electrical conductivity (up to 5.71 mS/cm), and an ionic composition dominated by Mg or Na + K and HCO_3, not by Ca and HCO_3 as in NE Yakutian waters (Fig. 3). Central Yakutian limnological features reported by Kumke et al. (2007) include alkaline conditions with mean pH 8.5 and mean electrical conductivities of 0.5 mS/cm with maxima of up to 3.6 mS/cm in Yakutsk environments. From these data, it is obvious that physico-chemical characteristics of Central Yakutian lakes are strongly influenced by the climatic setting (i.e. high continentality) resulting in strong evaporation and a negative moisture balance. Therefore, decreasing water levels in lakes are common and, as a consequence, the enrichment of soluble salts at different stages of lake development (e.g. Pestryakova et al., 2007). Limnological records from North Yakutia report neutral pH values and generally low EC of maximum 0.25 mS/cm in lakes and ponds in the headwaters region and in the delta of the Lena River (Duff et al., 1999; Wetterich et al., 2008a). The NE Yakutian data show higher ionic contents than in the North, with EC up to 0.93 mS/cm; Central Yakutian data show EC up to 5.71 mS/cm, reflecting increasing continentality from the North to the South.

Seasonal changes in water properties are obvious in the record of evaporation-relevant parameters (temperature, EC, lake level fluctuations) from data of an Alas lake in Central Yakutia at the Neleger site (Fig. 2). Increasing EC and decreasing water level point to a major influence of evaporation during the summer. In addition, the ongoing thawing of deeper ground layers with higher ionic contents below and around the lake during the summer (Lopez et al., 2007) likely explains the increase in EC from 0.4 to 0.5 mS/cm in the second half of September. Although monitoring data over several years is lacking, it is assumable that the lake level will rise again and the EC will decline again during the next spring due to winter precipitation and snow melt.

The influence of evaporation on lake waters is reflected in stable oxygen-hydrogen isotope compositions which show distinct local evaporation effects on lake waters, evidenced by the Local Evaporation Lines (LELs) with low slopes of 4.99 ($n = 39$, $R^2 = 0.95$) for Central Yakutian lakes and 4.09 ($n = 17$, $R^2 = 0.98$) for NE Yakutian lakes (Fig. 4). The initial precipitation source for both regions shows a similar isotope signature as indicated by similar slopes and very narrow points of intersection with the GMWL (Fig. 4). The small differences in LELs can be explained by varying local conditions such as low recharge rates, repeating precipitation-evaporation cycles, and generally shallower water bodies in the mountainous region of NE Yakutia. The lower summer mean temperature in NE Yakutia is reflected by generally lower $\delta^{18}O$ values in lake water between about -21.3 to -12.2 ‰ as compared Central Yakutian lake water data which are higher than -15 ‰ (Fig. 4).

Ostracod taxonomy, biogeography, and environmental ranges

Ostracod species compositions differ between the two study regions, most likely because of differences in the environmental parameters that affect ostracod habitats (Fig. 7). Higher diversity in environmental conditions, and accordingly in species, was recorded in Central Yakutian waters where, in total, 15 species were found. The dominating species *Candona weltneri* has only been recorded once in a NE Yakutian lake. Other common Central Yakutian species are *Cyclocypris ovum*, *Candona candida* and *C. muelleri jakutica*. The later seems to be widely distributed and was already recorded from several in modern environments of North Yakutia, in the Lena River Delta (Wetterich et al., 2008a) and in Central Yakutia (Pietrzeniuk, 1977). Fossil records of *C. muelleri jakutica* are known from Central Yakutia (Wetterich et al., in press) and also from North Yakutia, Lena River Delta (Wetterich et al., 2008b) and Bykovsky Peninsula (Wetterich et al., 2005).

Most species such as *C. compressa*, *Fabaeformiscandona acuminata*, *F. fabaeformis*, *F. rawsoni*, *Limnocythere inopinata*, *Cypris pubera*, *Ilyocypris decipens*, and *Dolerocypris fasciata* are very rare, with one or two records and low frequencies in the studied waters (Fig. 7). Except for *F. acuminata* all species are already described for the region by Pietrzeniuk (1977), who counted 24 species in Central Yakutia. The higher number of Central Yakutian species recorded by Pietrzeniuk (1977) is most likely caused by additional sampling of sediments in order to expand the live-caught collection. Most species which have not been found in 2005 are represented in the dataset of Pietrzeniuk (1977) by valves (*Pseudocandona sucki*, *P. hartwigi*, *Cyprois marginata*, *Plesiocypridopsis newtoni*, *Paralimnocythere cf. diebeli*) or by rare, sometimes juvenile, individuals (*Cypria exsculpta*, *Cypridopsis vidua*, *Bradleystrandesia reticulata*, *Notodromas monarcha*). Generally, we believe that every careful ostracod sampling in the low studied waters of Yakutia would expand the total species number.

Nine species were found in NE Yakutia; *C. muelleri jakutica* and *F. inaequivalvis* occur at the highest frequencies. The latter species, previously known as *Candona inaequivalvis* SARS 1898, should be re-described as belonging to the genus *Fabaeformiscandona*. This genus, defined by Krstić (1972), did not originally include *F. inaequivalvis*, but the structure of the externo-distal seta (γ-seta) of the penultimate segment of the mandibular palp (which is smooth, not pulmose), and a carapace longer than 0.6 mm with the carapace width/length ratio (W/L) less than 0.4 confirm this attribution. This determination should be confirmed by further detailed taxonomical studies.

An ostracod community studied in lakes and ponds in North Yakutia (Lena River Delta, Laptev Sea) was clearly dominated by the typical Arctic species *F. harmsworthi* and *F. pedata* (Wetterich et al., 2008a). In addition, *C. candida* and *C. muelleri jakutica*, known from more southern regions of Yakutia (Pietrzeniuk, 1977), occurred there. Obviously, both species are adapted to the harsh conditions of the Siberian Arctic.

The observed modern ostracod assemblages are dominated by species preferring, in general, lower water temperatures and low ionic content (e.g. *C. candida*, *C. muelleri jakutica*, *C. welterni*). *C. weltneri*, the most common species in Central Yakutia, is described as cold stenothermal to oligothermophilic and oligohalophilic (Meisch, 2000). However, a broad spectrum of species was observed with different adaptations to temperature and salinity, ranging from cold stenothermal (e.g. *F. hyalina*) to mesothermophilic (e.g. *P. compressa*, *D. fasciata*), and from oligohalophilic (e.g. *F. acuminata*) to mesohalophilic (e.g. *C. ovum*). Therefore, care should be taken when interpreting the temperature and salinity environments of fossil ostracod assemblages.

The observed environmental gradients (Fig. 8) do not determine the overall distribution of the ostracods species since species distribution surely depends on more environmental parameters than observed in course of the here presented study. Especially, detailed sampling of ostracods in different water depths, lake zones and types as well as estimations of parameters such as the presence and type of the aquatic vegetation, the substrate type, the turbidity of the water and the duration of the ice-free period in relation to the length of the life cycle are required to study in detail at monitoring sites for better understanding of the complex environmental dependencies of species distribution. In this context, our record is more focused on stable isotope and hydrochemical properties of the sampled lakes in comparison to the geochemical properties in ostracod calcite. Actually, detailed discussion on modern ostracod species distribution and their environmental habitat parameters in Yakutia is impossible since data sets needed for these purposes are lacking except of the already mentioned publications of Pietrzeniuk (1977) and Wetterich et al. (2008a). However, within the Yakutian data set, *C. candida*, *C. muelleri jakutica*, *C. weltneri*, and *C. ovum* are the most common species, probably suggesting higher tolerance to solute composition in lakes within the observed ranges (Fig. 8). In contrast, *F. inaequivalvis* was only found in very narrow ranges of pH and electrical conductivity in NE Yakutian waters.

Stable isotopes in ostracod calcite

The relationship between the isotopic composition of ostracod calcite (δ^{18}O, δ^{13}C) and of host waters has already been examined in numerous laboratory and field studies (e.g. Xia et al., 1997a; Keatings et al., 2002, 2006). The δ^{18}O of lake water is affected by environmental factors, such as the isotope composition of the input water (precipitation, groundwater), the climate-driven precipitation to evaporation (P/E) ratio, and the hydrochemical properties and temperature of the lake water (e.g. Leng and Marshall, 2004). Commonly, δ^{18}O and δ^{13}C records of ostracod calcite are thought to provide a restricted reflection of the isotopic composition of water and TDIC at the time of shell secretion, making them helpful proxies in palaeolimnology (Griffiths & Holmes, 2000). However, the δ^{18}O and δ^{13}C composition of ostracod calcite is influenced by interspecific and intraspecific variations, caused by species-dependent metabolic effects on isotope fractionation (vital effects) and preferences for different microhabitats, as well as by the timing of shell calcification in different seasons and at different temperatures (e.g. Heaton et al., 1995; von Grafenstein et al., 1999). Temperature-independent vital effects (in comparison to anorganic calcite precipitated in equilibrium to the isotopic composition of the water) for species of Candoninae from different field and laboratory collections were estimated to be +2.2 ‰ (von Grafenstein et al., 1999) and +2.5 to +3 ‰ for *C. candida* (Keatings et al., 2002), 1.5 to 2 ‰ for *C. subtriangulata* (Dettman et al., 1995), about +2 ‰ for *F. rawsoni* (Xia et al. 1997a), and 1.4 ‰ for *F. pedata* (Wetterich et al., 2008a).

In our study, the species *C. muelleri jakutica* was observed at six localities in numbers sufficient for stable isotope analyses, and over great ranges of about 8 ‰ for water δ^{18}O. The corresponding stable isotope values of this species' ostracod calcite show good correlations (Fig. 9). Similar results were obtained from the species *F. pedata* common in lakes and ponds in the North Yakutian Lena Delta (Wetterich et al., 2008a), where the stable oxygen isotopes in host waters and ostracod calcite were also well correlated. The lack of such correlation in other species (*C. candida*, *C. weltneri*, *F. inaequivalvis*) is likely because they are less frequent and they occurred in more restricted stable isotope ranges during our fieldwork. The vertical stack of δ^{18}O values in calcite of *C. weltneri* probably reflects different isotope compositions in host waters at the time of calcification and at the sampling time. Monitoring of ostracod development and seasonal changes in water properties at selected sites is needed for detection of such relationships.

Compared to Arctic Siberian ostracod δ^{18}O records ranging from -18 to -11 ‰ (Wetterich et al., 2008a), the data presented here show more evaporation influence by more positive (heavier) values ranging from about -15 to -9 ‰ (Fig. 9). This general tendency in the δ^{18}O records of ostracod calcite reflects cooler conditions and lower evaporation (higher P/E ratios) in the North as compared to the South, and is consistent with southwards-decreasing continentality as estimated by the stable isotope record of the host waters. Furthermore, the influence of evaporation is obvious when comparing $\delta^{18}O$ of waters or ostracod calcite and electrical conductivity as an expression of ionic concentration (salinity).

Even though Central Yakutia and NE Yakutia are geographically and hydrologically different regions, they may be used to illustrate the Rayleigh distillation process during evaporation of lakes. We found a logarithmic correlation (R^2 = 0.69, n = 55; Fig. 13a) between $\delta^{18}O$ of lake water and EC when both regions are plotted in one diagram. The observed relationship is controlled by Rayleigh distillation processes, wherein light isotopes evaporate faster than heavy ones leading to nonequilibrium enrichment of the residual water (Clark & Fritz, 1997). Depending upon relative humidity this relation leads to an asymptotic increase in $\delta^{18}O$ values under high evaporation conditions to a steady-state value which is strongly influenced by the salinity of the residual water (e.g. Gat, 1979, 1981). As shown in Figure 13a a steady-state value of about -6 ‰ is reached in evaporated residual waters at conductivities of about 4 mS/cm and more. However, this interpretation is likely based on only few data, but may be a reliable explanation of the scatter observed. The correlation between $\delta^{18}O$ of ostracod calcite and conductivity is weak (R^2 = 0.39, n = 34; Fig. 13b) and more data and sampling of time-series during the ice-free season are required to assess this relationship. Nevertheless, it seems that these first results should be taken into account for interpreting stable isotope data from fossil ostracods of East Siberia, where lakes occurred during the Quaternary past under high continental conditions and climate-driven lake level changes up to desiccation took place (Bosikov, 2005).

The $\delta^{13}C$ composition of TDIC in waters is controlled by fractionation during several carbon cycles; the most important influences are the isotopic composition of inflows, CO_2 exchange between air and lake water, and photosynthesis/respiration of aquatic plants (Leng & Marshall, 2004). The last two controls are characterised by high seasonal and even daily variability; thus it is more difficult to interpret these data since periodic sampling during the open-water season is required to register carbon cycle dynamics. The $\delta^{13}C$ records from both host waters and ostracod calcite reflect a positive trend over great ranges of about 9 ‰ for $\delta^{13}C$ in waters and about 14 ‰ for $\delta^{13}C$ in ostracod calcite (Fig. 10). For *C. muelleri jakutica* from six lakes we found a correlation between $\delta^{13}C$ in host waters and valves ($R^2 = 0.82$, $n = 12$; Fig. 10a). However, as explained above any interpretation of this relationship is complicated.

Element ratios in ostracod calcite

The relationship between element ratios (Sr/Ca, Mg/Ca) in host waters and in ostracod calcite has been investigated in (palaeo-) limnological studies (e.g. Palacios-Fest & Dettman, 2001; Palacios-Fest et al., 2002; Xia et al., 1997b). The partitioning is usually expressed as the species-dependent coefficient *D*(M):

$$D(M) = (M/Ca)_{valve} / (M/Ca)_{water} \quad (1)$$

where M can either be Mg or Sr, and M/Ca ratios are molar ratios (e.g. Chivas et al., 1986). The strong dependency on temperature of Mg uptake into the valves at the time of valve secretion must also be taken into account (Engstrom & Nelson, 1991; De Deckker et al., 1999). Furthermore, Xia et al. (1997b) showed in field experiments that the uptake of both Sr and Mg is influenced by Mg/Ca ratios of the host water whereas physiological costs of calcification becomes substantial at in high Mg/Ca waters.

Both proxies have been used to indicate changes in salinity due to evaporation leading to increasing Sr/Ca and/or Mg/Ca ratios in both host water and ostracod calcite (e.g. Chivas et al., 1993; Xia et al., 1997c; Ingram et al., 1998). However, the correlation between M/Ca of host water and measured EC as an expression of ionic concentration (salinity) is not clear, as has been shown by several authors in studies of modern environments. Engstrom & Nelson (1991) explained the weakness of the correlation between salinity and the Sr/Ca ratio of Devils Lake, North Dakota, USA by postulating continuous Sr removal via mineral precipitation of both calcite and inorganic aragonite. Keatings et al. (2006b) suggested that the lacking of correlation between water salinity and M/Ca ratios in the arid Faiyum Depression, Egypt was caused by regional characteristics of groundwater input and precipitation/dissolution of evaporative minerals.

In the Yakutian dataset, correlations between Sr/Ca ratios in waters and valves are obvious for the most common species *C. muelleri jakutica* ($R^2 = 0.92$, n = 12; Fig. 11a) and *C. weltneri* ($R^2 = 0.74$, n = 12; Fig. 11b) over a Sr/Ca range from about 2 to 6.5 ($*10^{-3}$) in host waters. It has to be mentioned that the data base is actually poor since the ostracod calcite analyses for *C. muelleri jakutica* were performed on two single-valve samples per lake and only six lakes were taken into account. For the same approach ostracod calcite of *C. weltneri* from seven lakes was measured. Two single-valve samples could be applied to five lakes and one single-valve samples each to two lakes.

According to equation (1), average partition coefficients were calculated for live-caught *C. muelleri jakutica* with $D(\mathrm{Sr}) = 0.32 \pm 0.03$ (1σ) and *C. weltneri* with $D(\mathrm{Sr}) = 0.38 \pm 0.05$ (1σ). Similar results from field collections were obtained for *Fabaeformiscandona pedata* from Arctic Siberia ($D(\mathrm{Sr}) = 0.33 \pm 0.06$ (1σ); Wetterich et al., 2008a) and for *Fabaeformiscandona rawsoni* in laboratory cultures ($D(\mathrm{Sr}) = 0.406$; Engstrom & Nelson, 1991).

A clear correlation of lake water Sr/Ca ratio to conductivity has not been obtained especially because the Sr/Ca ratios in waters at low conductivities below 0.5 mS/cm are highly variable ranging from about 1.8 to 7.6 ($*10^{-3}$) (Fig. 14a). However, higher conductivities in the waters where ostracods have been caught lead to higher Sr/Ca ratios in ostracod calcite, though the relation between host water and ostracod calcite data (Fig. 14b) suffers by time lag between sampling and calcification, and a general poor data base of mostly two single-valve samples per lake.

The Mg/Ca ratios in the studied Yakutian waters and in ostracod calcite are correlated for *C. weltneri* ($R^2 = 0.66$, n = 12; Fig. 12b) over an Mg/Ca range in waters between 0.4 and 7; the other species studied occurred in restricted ranges with low Mg/Ca ratios of about 2 or less. The uptake of Mg by ostracods and the resulting Mg/Ca ratios of ostracod calcite are controlled by temperature (Engstrom & Nelson, 1991; De Deckker et al., 1999). However, the temperature effect is small in comparison to the dependence on Mg/Ca of water at higher ranges. For the species *C. candida*, *C. muelleri jakutica* and *F. inaequivalvis* that were found in a narrow (and low) range of Mg/Ca waters, temperature effect became relatively large, and consequently no correlation between Mg/Ca of water and Mg/Ca of ostracod calcite is seen (Fig. 12a). For *C. weltneri*, the range of Mg/Ca of water was large enough that a positive trend became apparent (Fig. 12b), but with a large scatter that is caused by different sampling time in relation to the time of calcification which leads in our data based on mostly two single-valve samples per lake to clear shifts in ostracod calcite chemistry from individual lakes. This effect is clearly seen in *C. weltneri* data from lakes Yak-12, Yak-20 and Yak-27 (Tab. 3) and should be avoided in future studies by applying more measurements on ostracod calcite per lake in order to improve the data base for more robust statistic evidence of the data obtained. However, our results give a first base on geochemical properties of Yakutian ostracods in relation to their host waters.

The partition coefficient *D*(Mg) has not been calculated, since the temperature dependence of Mg uptake cannot be quantified in our dataset based on field collections. Due to generally higher ionic concentrations (i.e. electrical conductivities) as compared to Arctic environments in the Lena Delta (Wetterich et al., 2008a), Mg/Ca records of both waters and ostracod calcite reflect increasing salinity by increasing ratios under low Mg/Ca conditions in the host waters. As compared to EC, Mg/Ca ratios in waters show covariance ($R^2 = 0.81$, n = 55; Fig. 15a), but the conductivity gradient is mostly covered by values below 2.5 mS/cm. The Mg/Ca ratio in *Candona* species in relation to Mg/Ca ratios in host waters shows a different scatter (Fig. 15b). The relatively low Mg/Ca values in the Na + K and HCO_3 dominated waters Yak-31 with 1.43 mS/cm and Yak-33 with 0.85 mS/cm are probably caused by different hydrological setting. Both waters are exposed on the floodplain of the Lena River in Central Yakutia and the river water control on the hydrochemical setting might explain the probably different relationship in Mg uptake into ostracod calcite. However, these assumptions are currently based on two single-valve samples from two old branches and surely need additional sampling of such waters.

Conclusions

Siberian freshwater ostracods and their geochemical properties have so far been poorly studied; this paper presents adequate data for further expansion of the data base as prerequisite for the use of ostracods in palaeoenvironmental reconstruction from East Siberian records. The following conclusions can be drawn from this paper:

(1) The species *C. muelleri jakutica* seems to be common in East Siberia in modern habitats and also in fossil records. Due to its distribution over significant environmental gradients, this species should be subjected to further studies on geochemistry and palaeoenvironments since the species was already recorded in Quaternary lake sediments, and permafrost deposits.

(2) The stable isotope ratios ($\delta^{18}O$, $\delta^{13}C$) and the element ratios (Sr/Ca, Mg/Ca) in ostracod calcite are correlated to the composition of host lake waters, if the studied species were found in higher frequencies and over significant ranges in the respective environmental proxies. Thus, geochemical proxies of ostracod calcite can provide environmental information for further studies of fossil assemblages in East Siberia.

(3) The relation between electrical conductivity as evaporation proxy and geochemical properties of ostracod calcite ($\delta^{18}O$, $\delta^{13}C$, Sr/Ca, Mg/Ca) is not apparent due do the general low database and several controls on the uptake of the respective isotopes and elements into ostracod calcite such as temperature effects and physiological costs which could not been quantified in the presented field study.

(4) Synchronic sampling of waters and ostracods at calcification time in course of monitoring approaches would be desirable for better understanding of complex biomineralisation processes and biogeochemical cycles in lakes.

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Figure captions

Figure 1: Location of the two study regions in Central and Northeast Yakutia in East Siberia. Map compiled by G. Grosse (UAF) using data from Hastings et al. (1999)

Figure 2: Continuous temperature and conductivity measurements in an Alas lake at the Japanese-Russian research station Neleger from May 2 until September 27, 2005. Note lacking data due to technical problems in the first half of July 2005.

Figure 3: Ionic composition of lake and pond waters in Yakutia. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 4: Isotopic composition of natural Yakutian waters; plot shows oxygen and hydrogen isotopes in lake water and summer 2005 precipitation. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols. Precipitation data are given by black symbols. Regional evaporation effects on the waters are expressed as Local Evaporation Lines (LELs).

Figure 5: Isotopic composition of natural Yakutian waters; plot shows oxygen and carbon isotopes in lake water in summer 2005. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 6: SEM images of Yakutian ostracod valves (LV - left valve, RV - right valve). *Dolerocypris fasciata*: (1) female RV; *Candona candida*: (2) female LV, (3) female RV; *C. muelleri-jakutica*: (4) female LV, (5) female RV, (6) male LV, (7) male RV; *C. weltneri*: (8) female LV, (9) female RV, (10) male LV, (11) male RV; *Fabaeformiscandona acuminata*: (12) female LV, (13) female RV, (14) male LV, (15) male RV; *F. fabaeformis*: (16) female LV, (17) female RV, (18) male LV, (19) male RV; *F. hyalina*: (20) female LV, (21) female RV, (22) male LV, (23) male RV; *F. inaequivalvis*: (24) female LV, (25) female RV, (26) male LV, (27) male RV; *F. rawsoni*: (28) female LV, (29) female RV, (30) male LV, (31) male RV; *Physocypria kraepelini*: (32) female LV, (33) female RV, (34) male LV, (35) male RV; *Cyclocypris ovum*: (36) female LV, (37) female RV, (38) male LV, (39) male RV; *Cypris pubera*: (40) postero-ventral RV margin, (41) antero-ventral RV margin, (42) female LV, (43) female RV. Note varying scales: 0.5 mm scale for number 1-41 and 1 mm scale for number 42-43.

Figure 7: Ostracod taxa and specimens (in absolute numbers) as well as species frequency (in percentage) in waters of Northeast and Central Yakutia (highlighted in grey). Frequencies of single species < 5 % are marked by a cross. Note varying scales. The data are arranged by increasing electrical conductivities for each region.

Figure 8: Ranges of environmental parameters of ostracod habitats for most current taxa found in the studied lakes. Horizontal lines connect the minimum and the maximum, and the

vertical line connects the mean values. Species include *Candona candida* (n = 5), *C. muelleri jakutica* (n = 10), *C. weltneri* (n = 8), *Fabaeformiscandona acuminata* (n = 3), *F. hyalina* (n = 3), *F. inaequivalvis* (n = 3), *Cyclocypris ovum* (n = 8), *Dolerocypris fasciata* (n = 3), and *Physocypria kraepelini* (n = 4). Note varying scales.

Figure 9: Stable oxygen isotopes in host waters and ostracod calcite of: (a) *C. candida* (squares) and *C. muelleri jakutica* (circles); (b) *F. inaequivalvis* (triangles) and *C. weltneri* (diamonds). Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 10: Stable carbon isotopes in host waters and ostracod calcite of (a) *C. candida* (squares) and *C. muelleri jakutica* (circles), and (b) *F. inaequivalvis* (triangles) and *C. weltneri* (diamonds). Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 11: Molar strontium/calcium (Sr/Ca) ratios in host waters and ostracod calcite of (a) *C. candida* (squares) and *C. muelleri jakutica* (circles), and (b) *F. inaequivalvis* (triangles) and *C. weltneri* (diamonds). Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

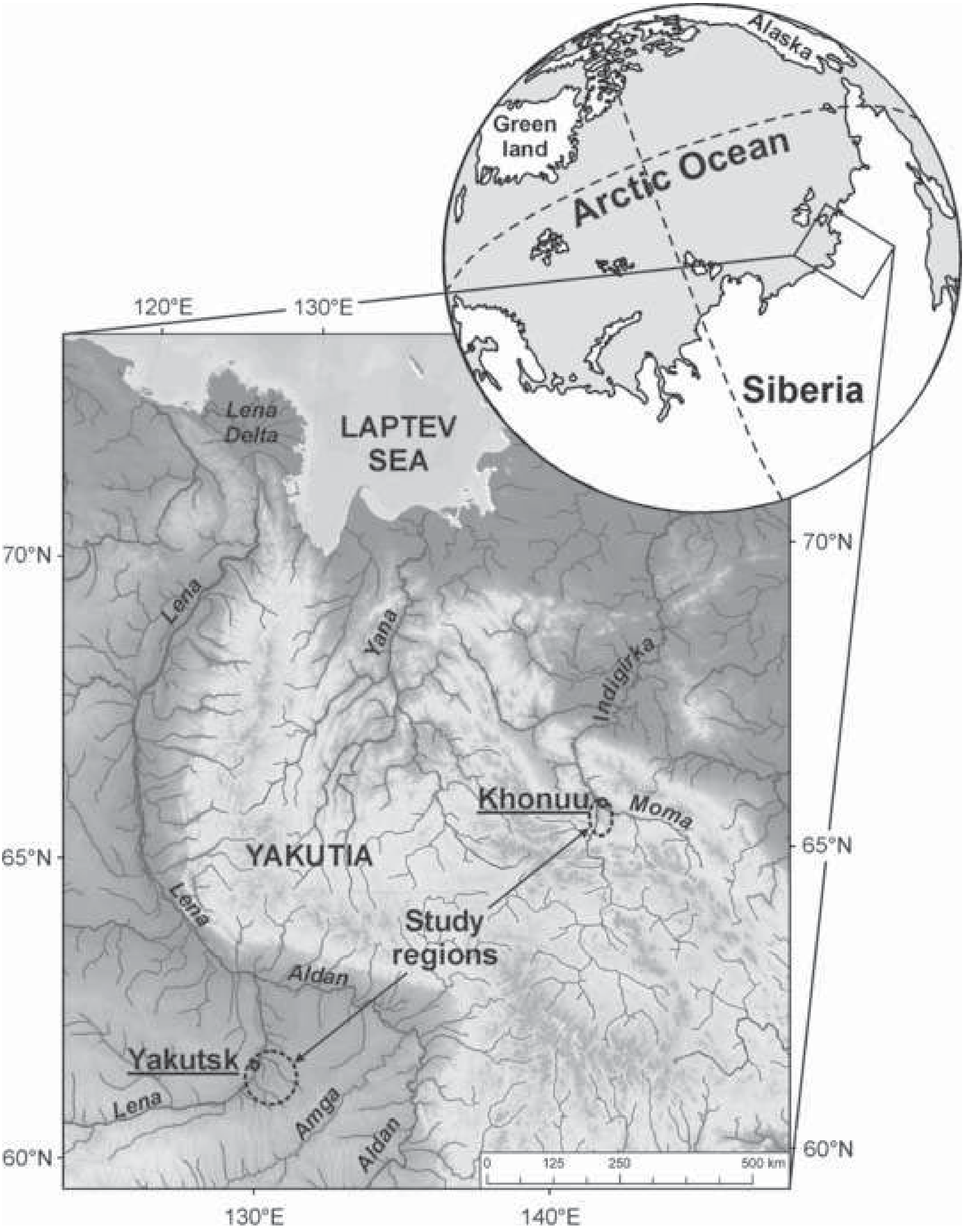
Figure 12: Molar magnesium/calcium (Mg/Ca) ratios in host waters and ostracod calcite of (a) *C. candida* (squares) and *C. muelleri jakutica* (circles), and (b) *F. inaequivalvis* (triangles) and *C. weltneri* (diamonds). Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols. Note varying scales in Figure 12a and 12b.

Figure 13: Plot of electrical conductivity and oxygen stable isotopes in (a) host waters and (b) ostracod calcite. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 14: Plot of electrical conductivity and molar strontium/calcium (Sr/Ca) ratios in (a) host waters and (b) ostracod calcite. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Figure 15: Plot of electrical conductivity and molar magnesium/calcium (Mg/Ca) ratios in (a) host waters and (b) ostracod calcite. Data from Central Yakutia are shown by grey symbols and those from NE Yakutia by white symbols.

Fig. 1 revised



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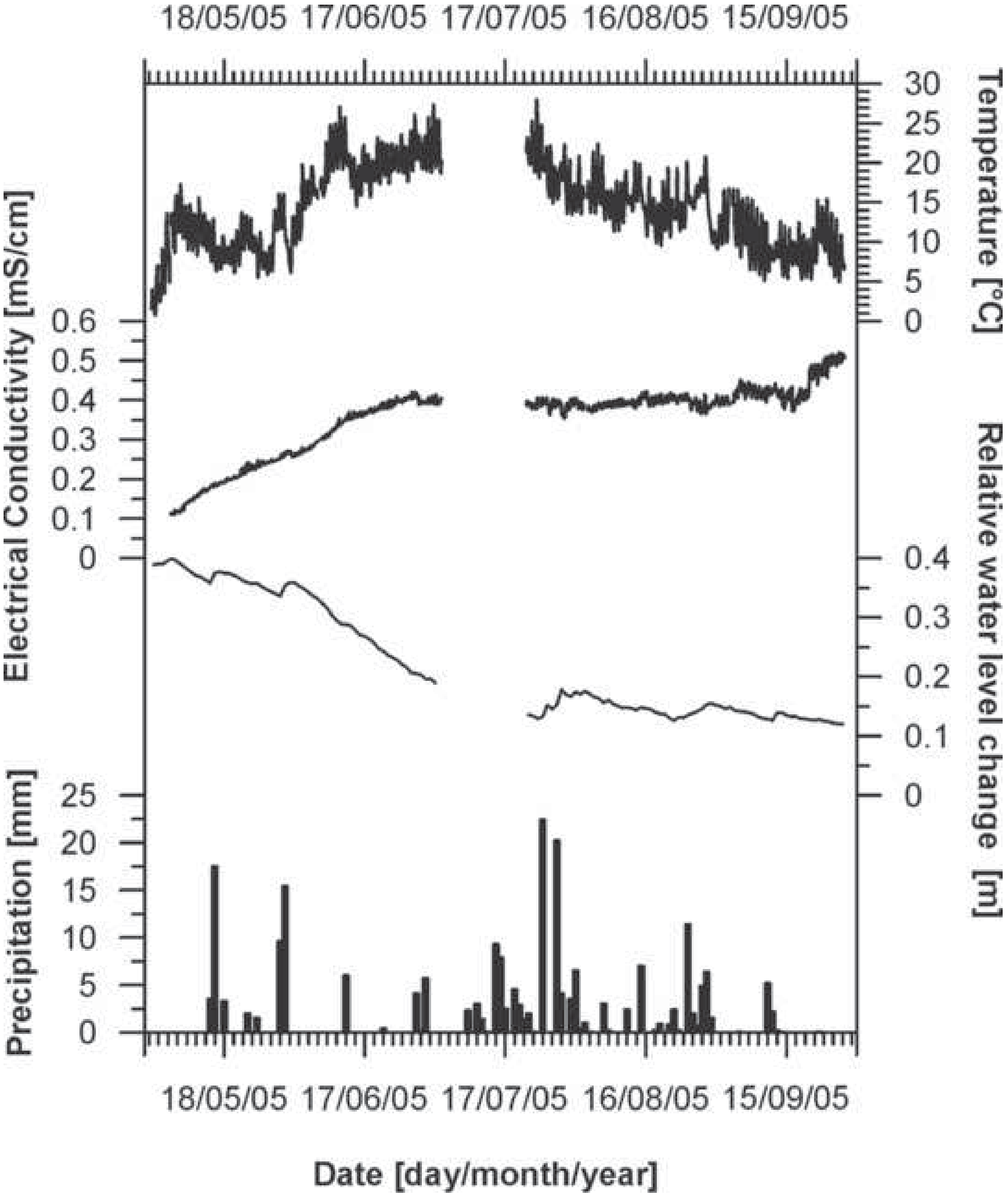

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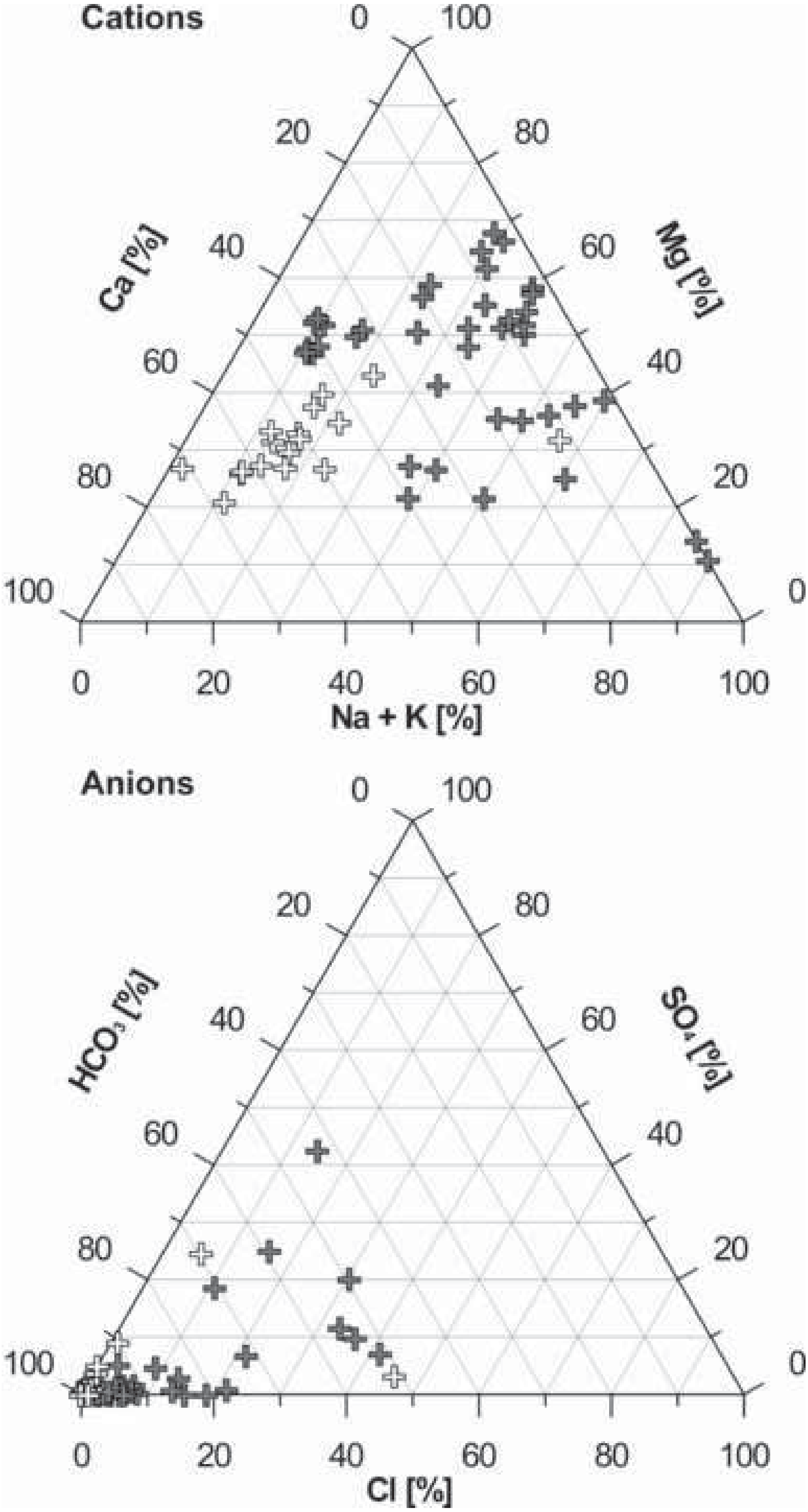

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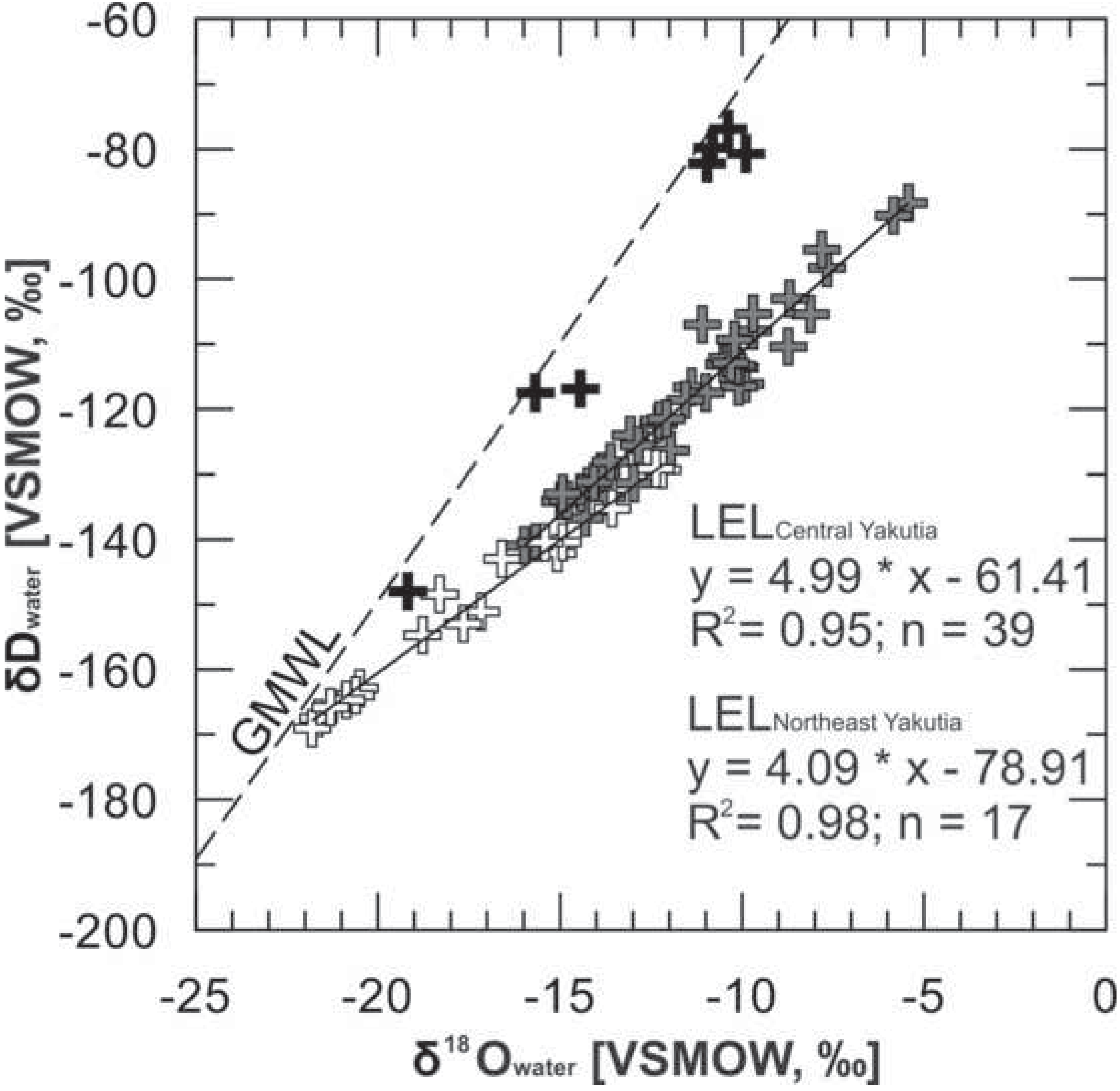

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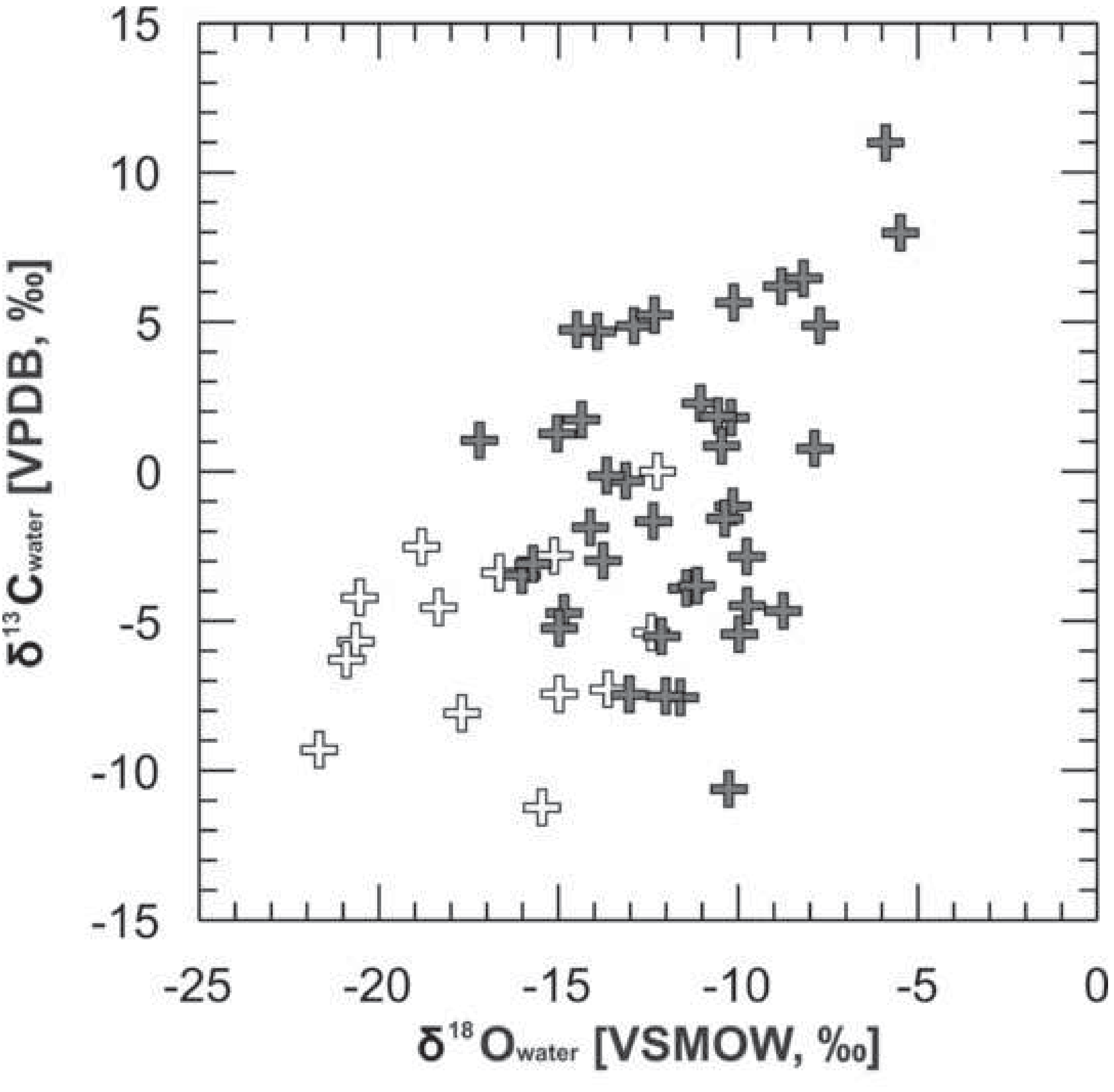


Fig. 6 revised

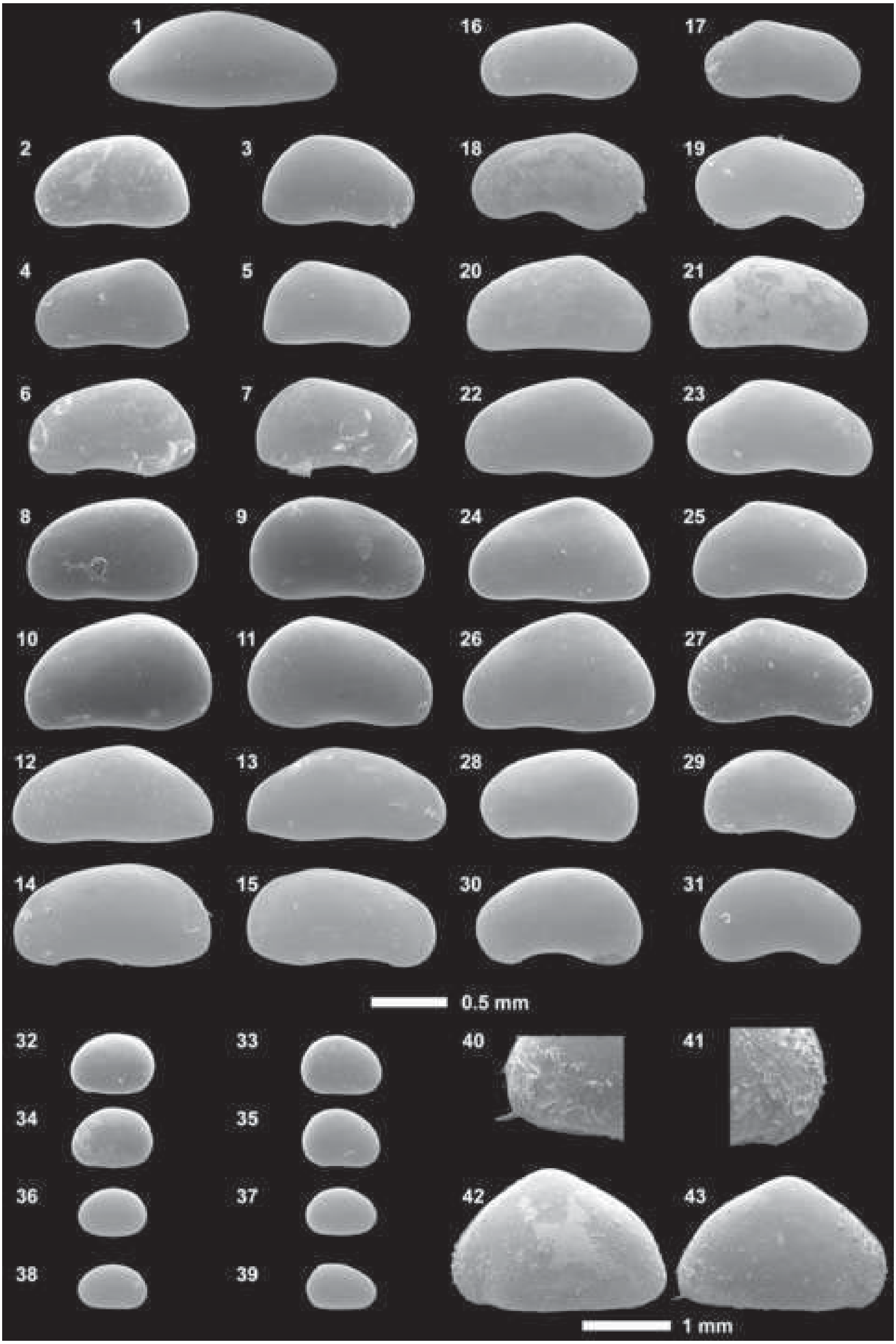


Fig. 7 revised

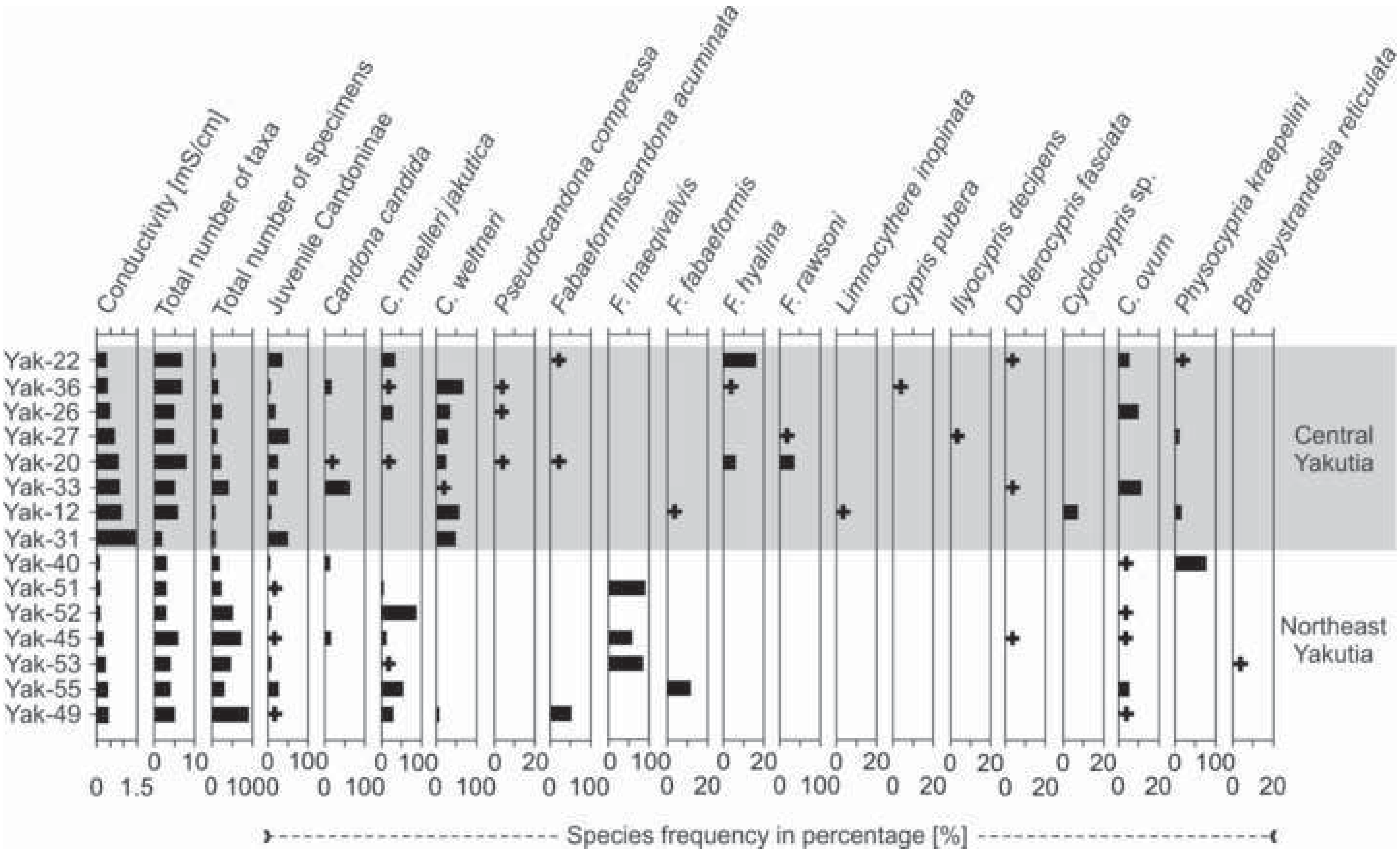


Fig. 8 revised

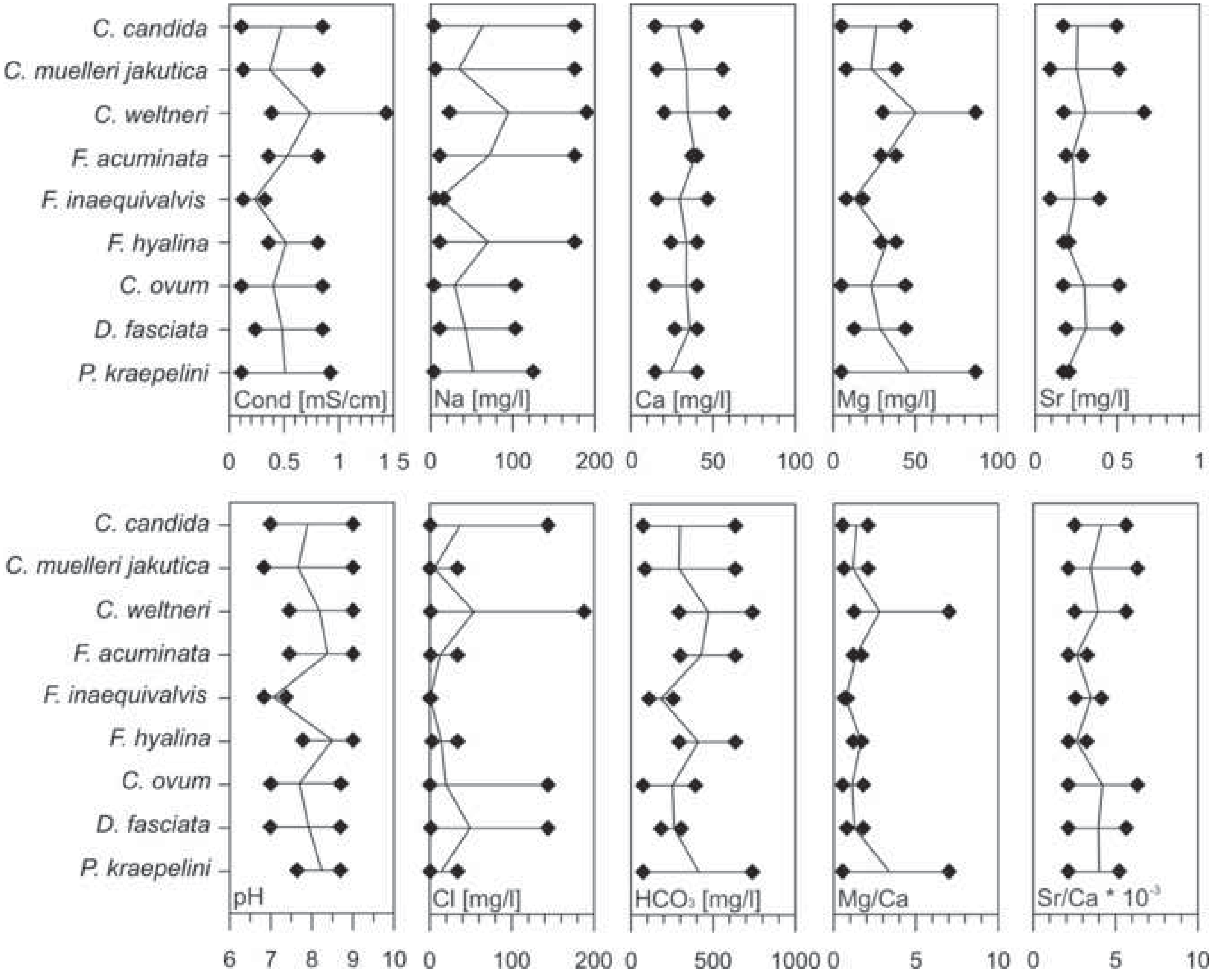
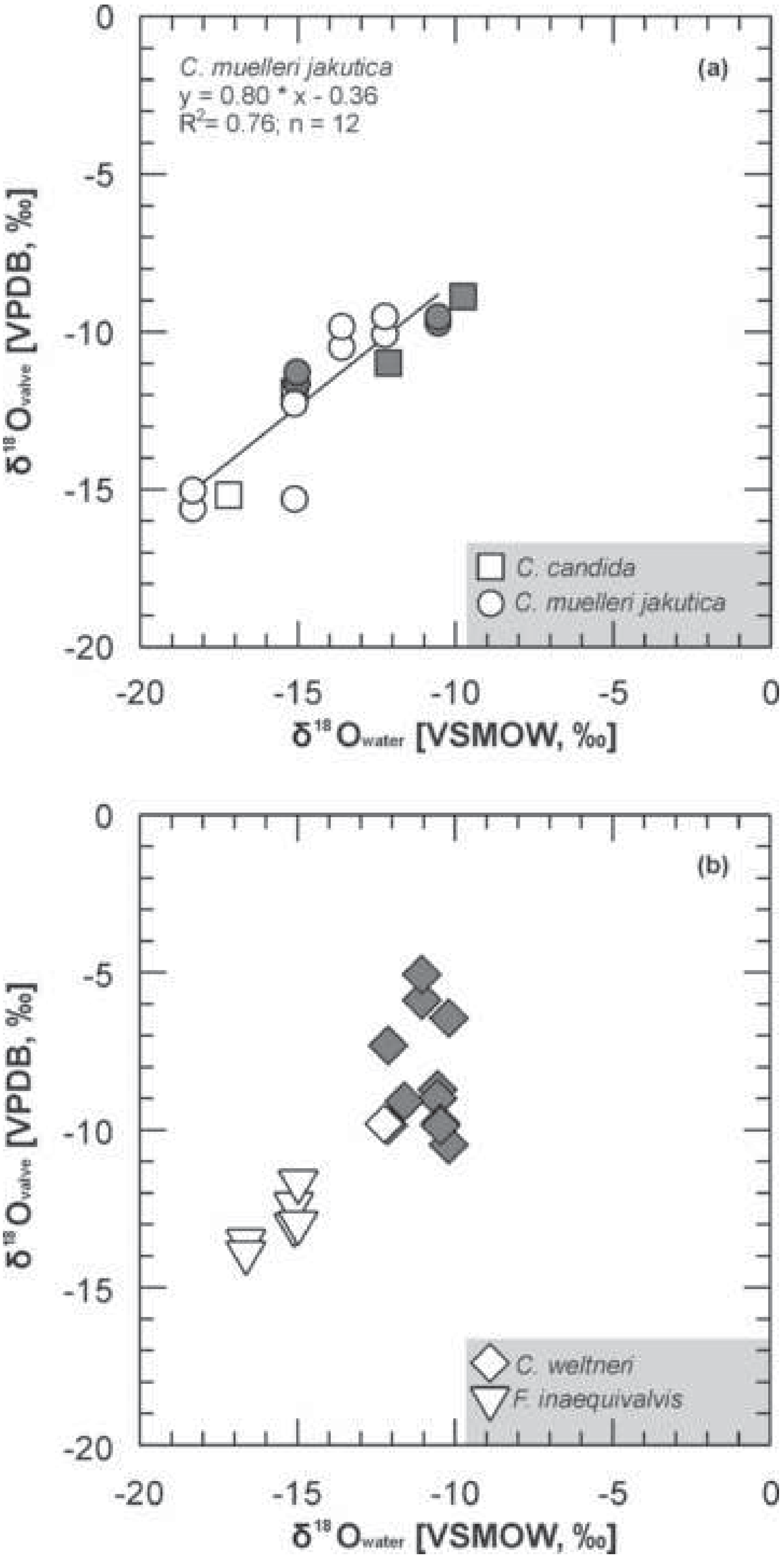


Fig. 9 revised



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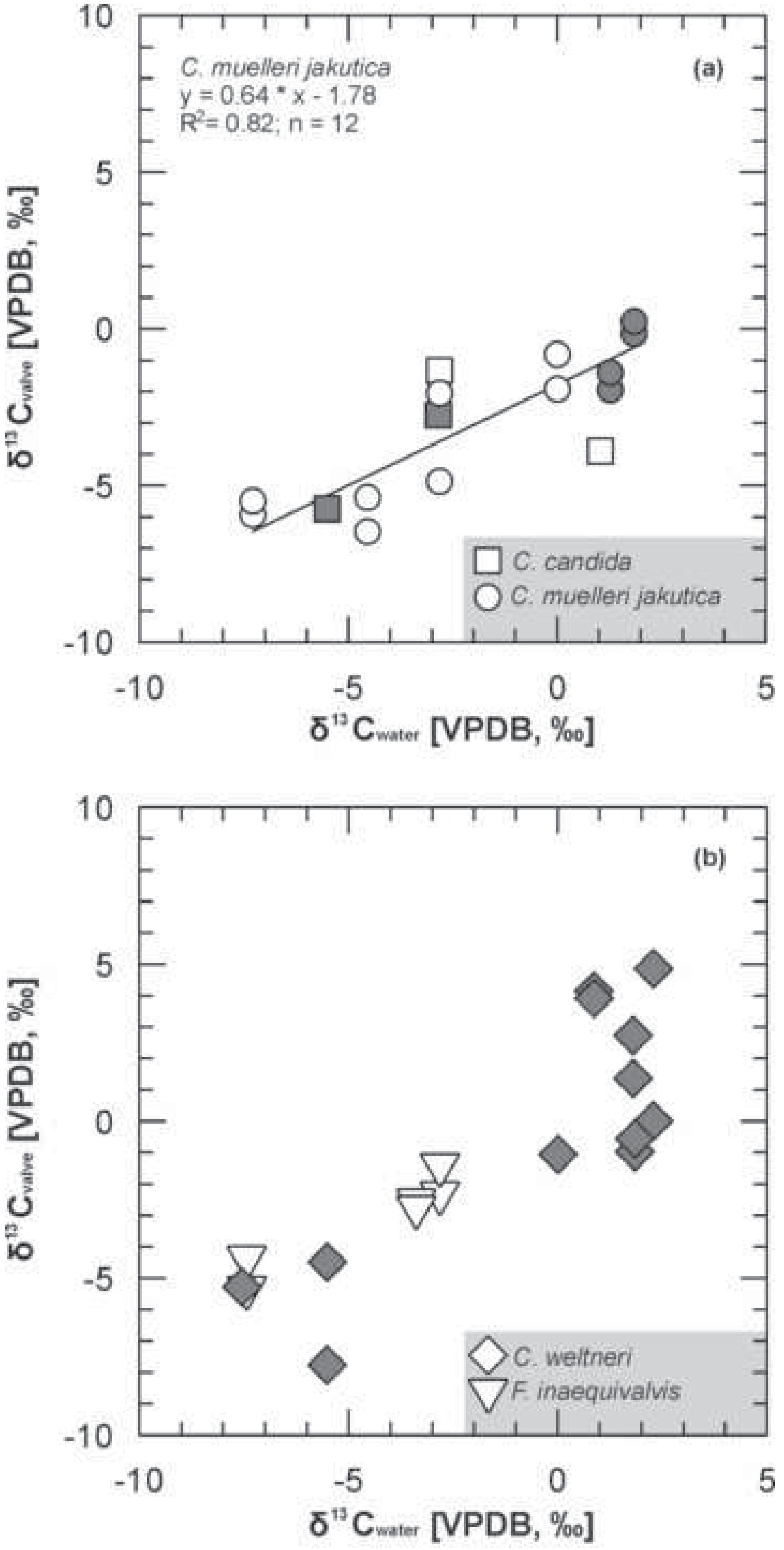

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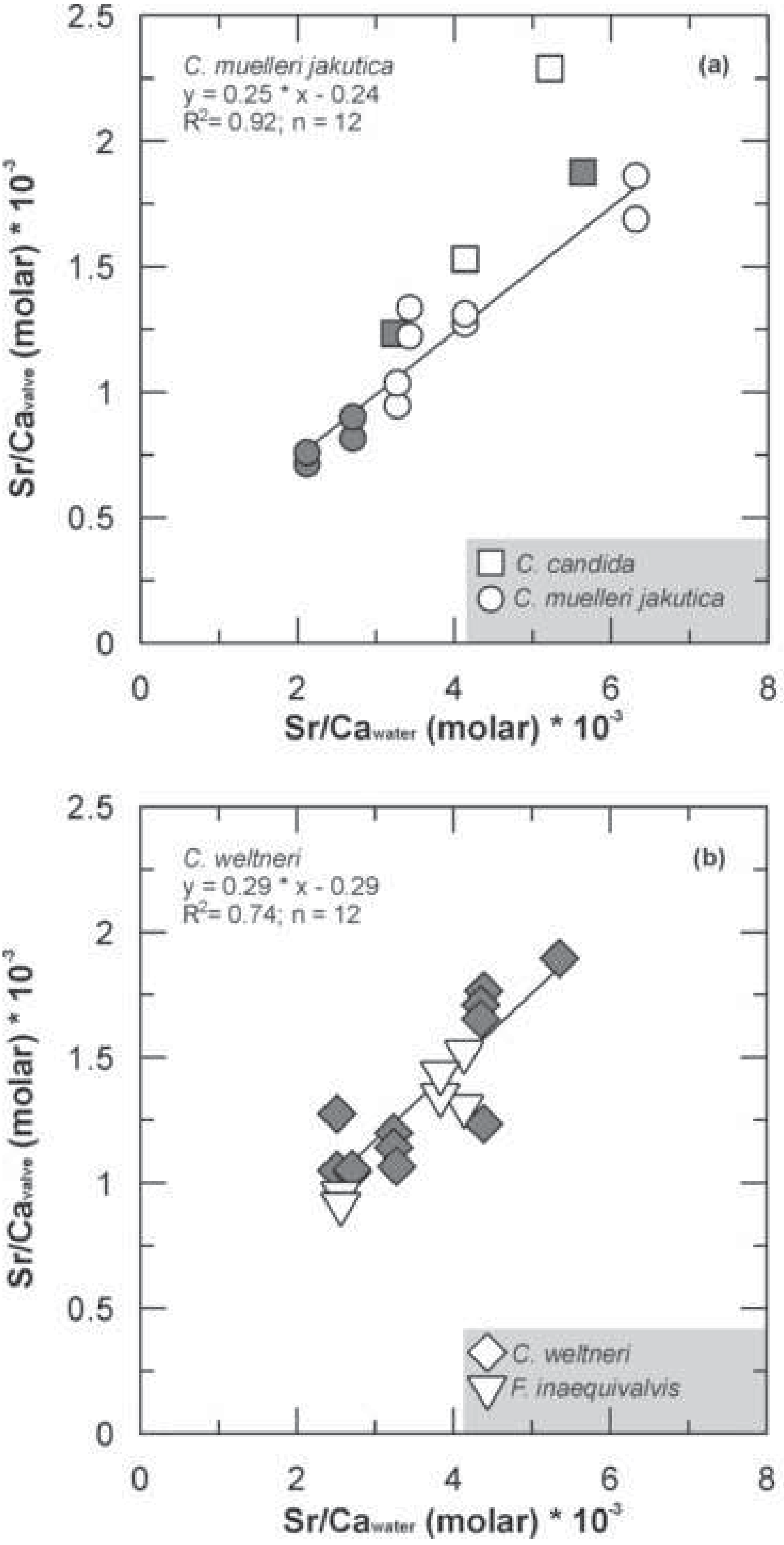
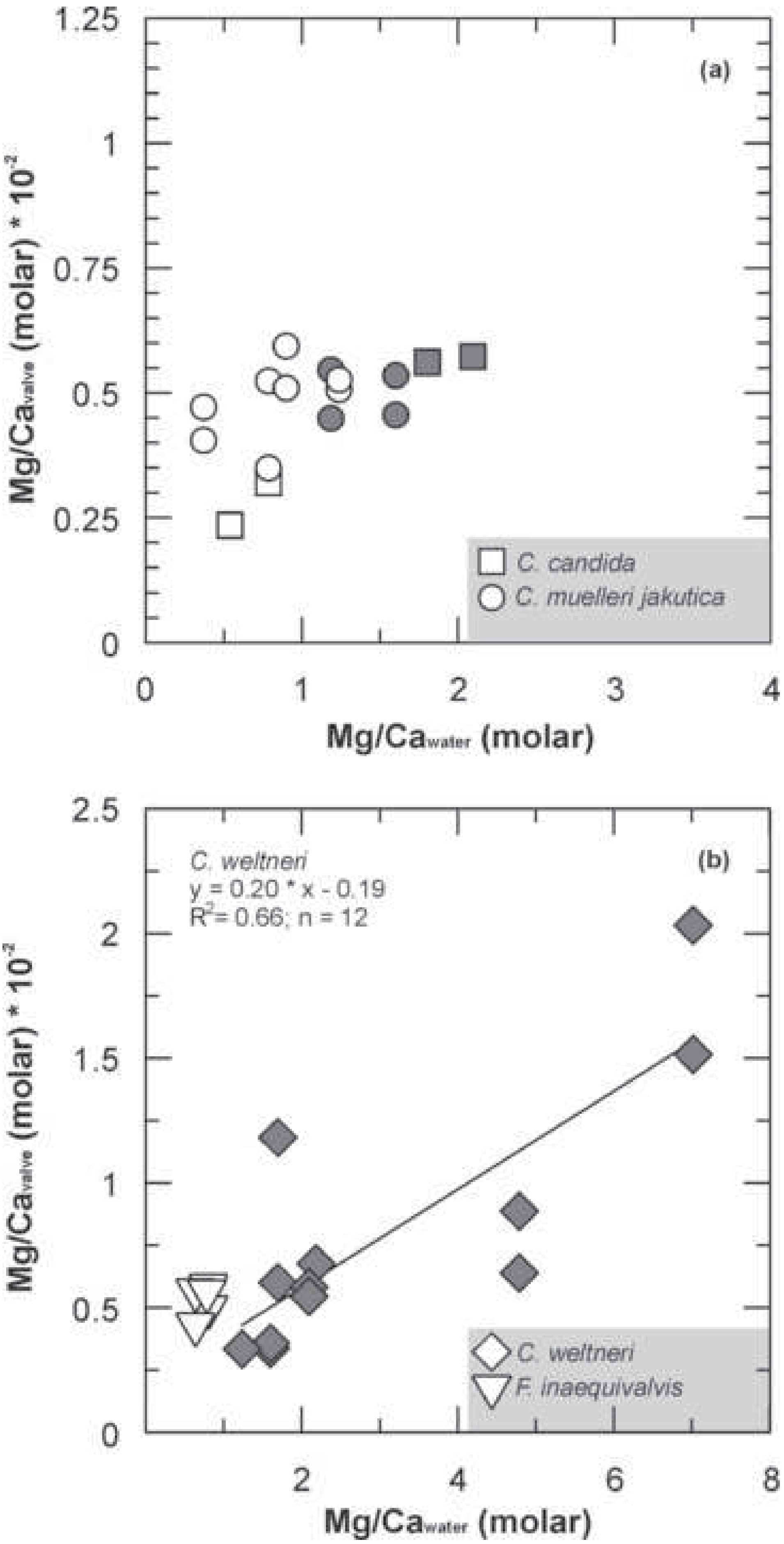


Fig. 12 revised



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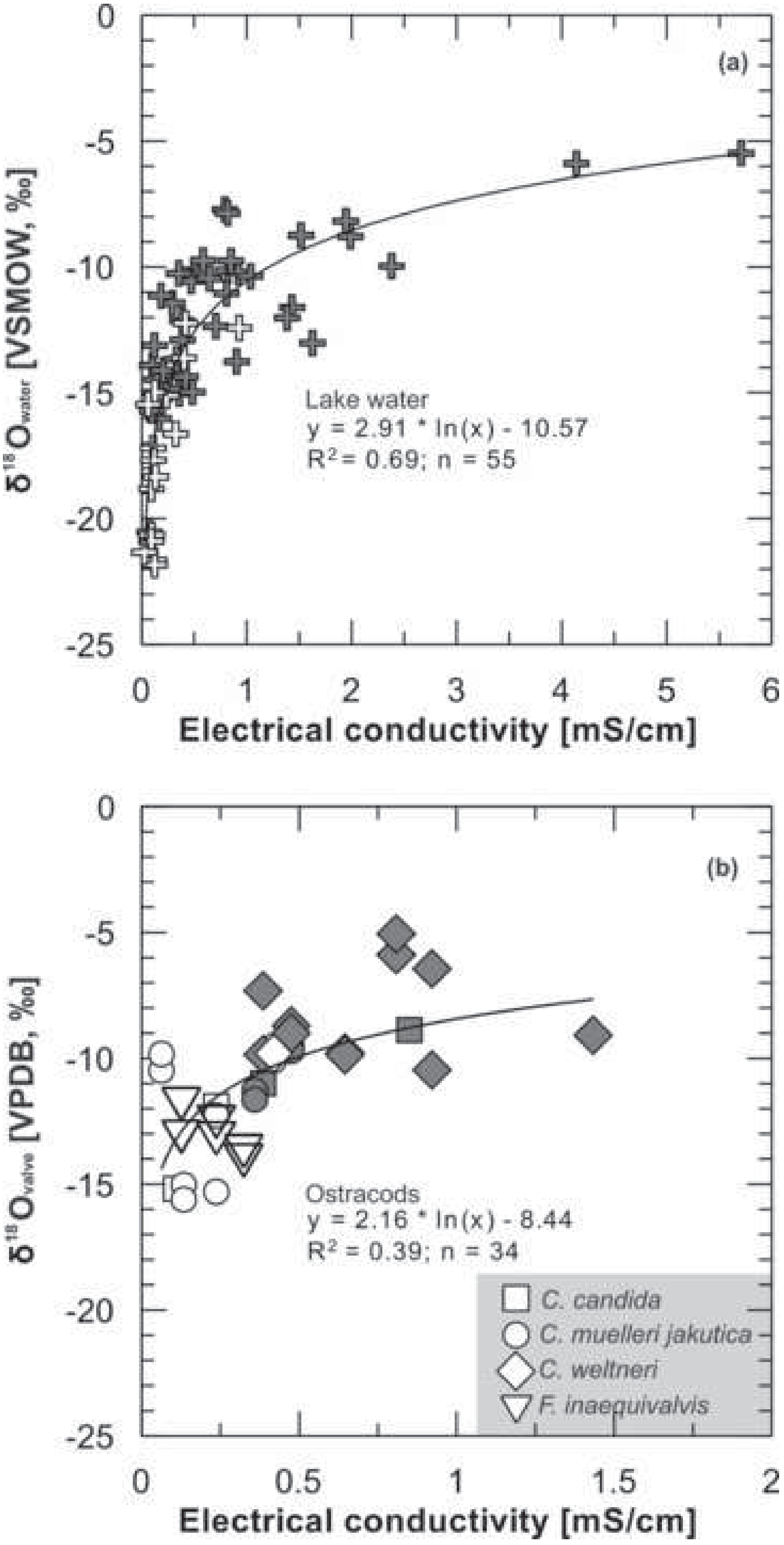

Fig. 14 revised

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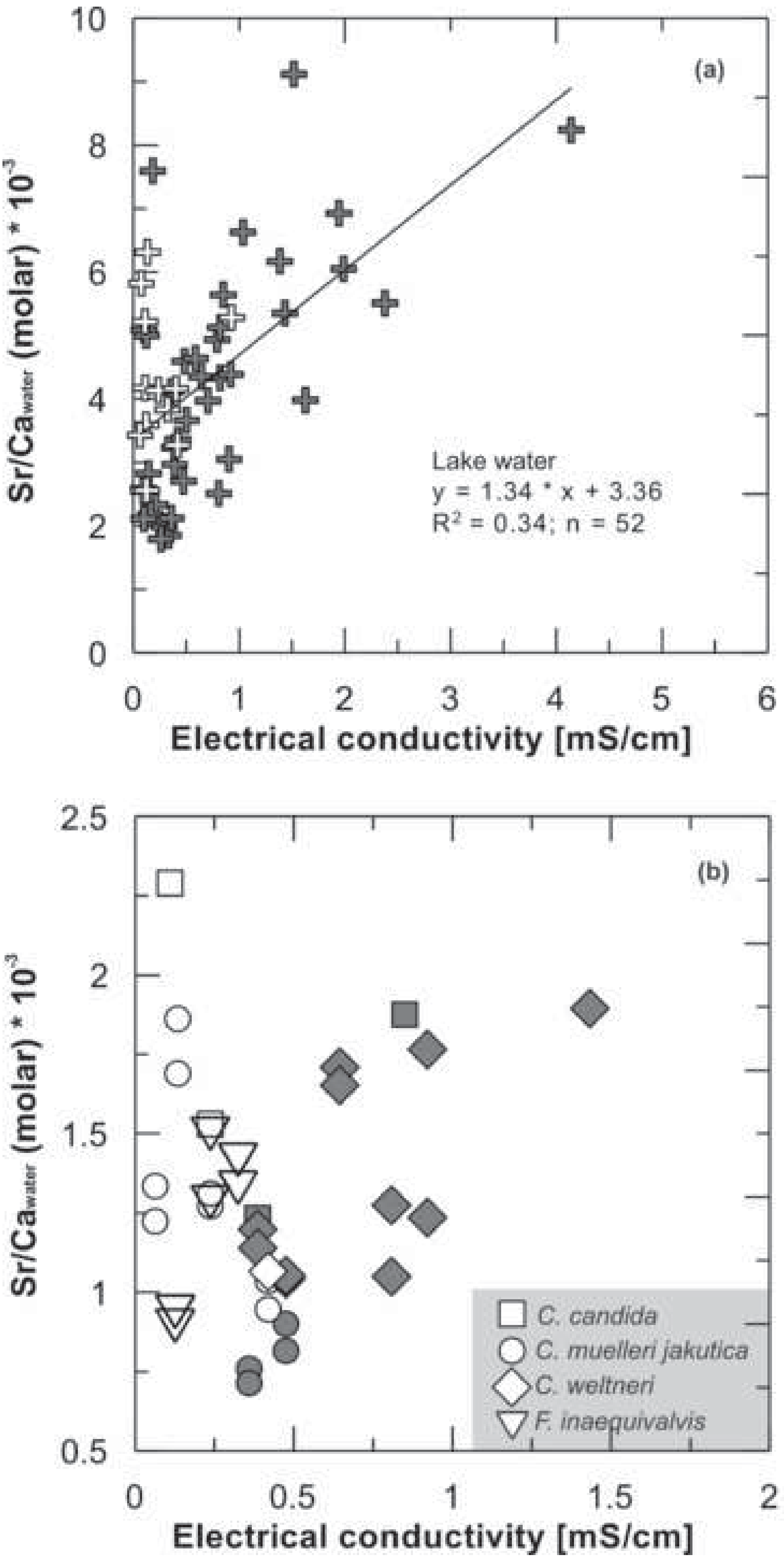
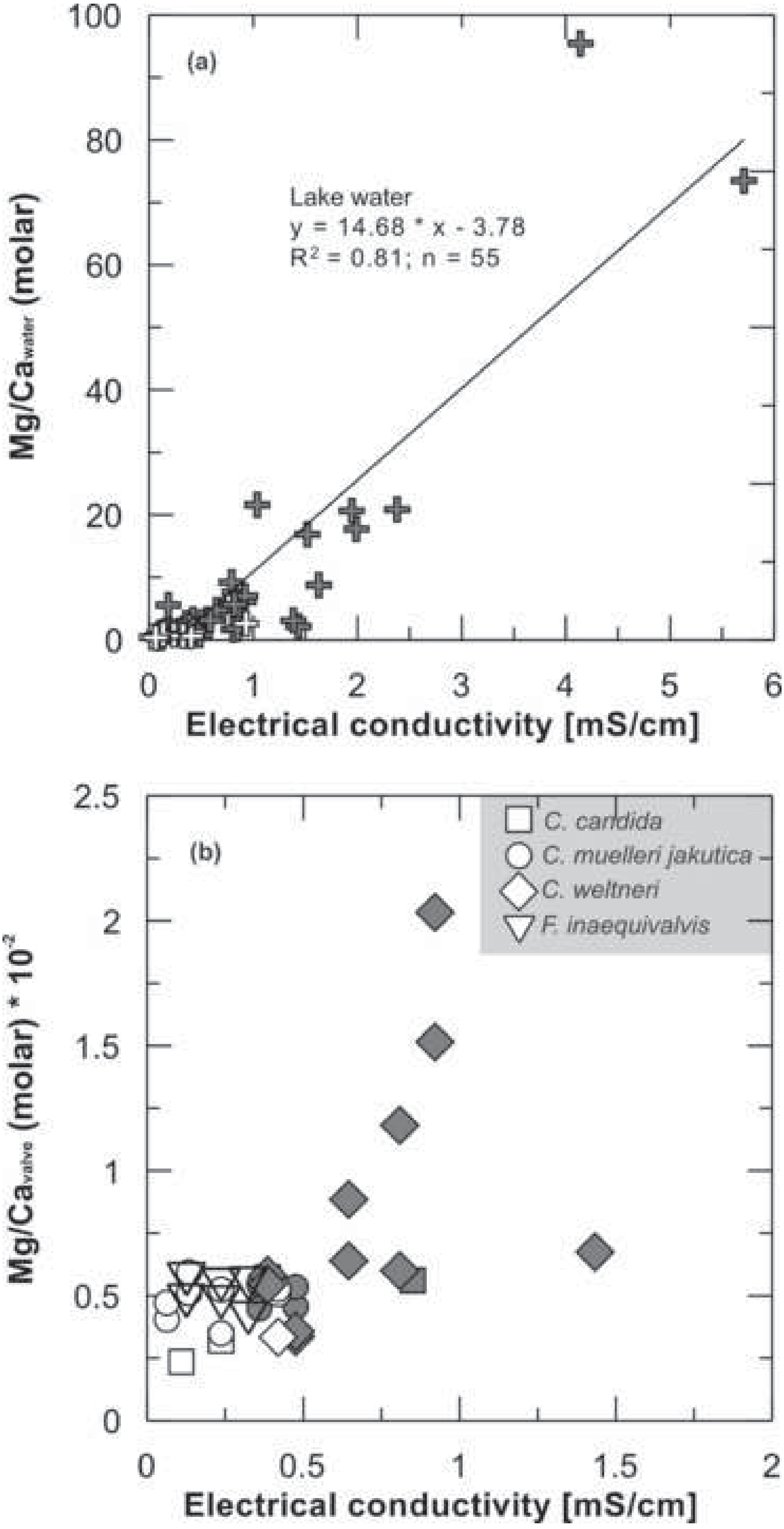


Fig. 15 revised



Tab. 1 revised

Table 1: Location, type, and general characteristics of the studied lakes and ponds.

Lake №	Date*	Region**	Latitude °N	Longitude °E	Elevation [m, a.s.l.]	Lake type***	Size [m x m]	Depth [m]
Yak-01	10.07.05	Lena	61°45'39,6"	130°28'15,6"	213	D	20 x 30	1.8
Yak-02	10.07.05	Lena	61°45'36,0"	130°28'19,2"	213	D	60 x 100	3.5
Yak-03	10.07.05	Lena	61°45'39,6"	130°28'26,4"	233	D	80 x 80	4.6
Yak-04	11.07.05	Lena	61°45'54,0"	130°27'55,9"	209	Alas	40 x 250	1.8
Yak-05	11.07.05	Lena	61°46'11,1"	130°28'07,4"	215	T	100 x 300	4.6
Yak-06	13.07.05	Lena	62°06'13,3"	130°13'21,6"	130	L-D	300 x 400	1.3
Yak-07	13.07.05	Lena	62°01'00,1"	130°03'57,1"	138	L-D	400 x 700	1.0
Yak-08	15.07.05	Yakutsk	62°03'60,5"	129°03'23,4"	228	Alas	400 x 800	1.5
Yak-09	15.07.05	Yakutsk	62°03'28,9"	129°03'13,9"	228	Alas	200 x 300	2.2
Yak-10	17.07.05	Lena	61°42'11,4"	129°22'11,1"	160	Alas	80 x 150	5.2
Yak-11	17.07.05	Lena	61°36'50,4"	130°42'12,6"	182	Alas	200 x 350	5.2
Yak-12	17.07.05	Lena	61°37'06,6"	130°42'28,1"	172	Alas	no data	3.0
Yak-13	18.07.05	Lena	61°33'26,0"	130°32'48,3"	219	Th-E	200 x 600	3.9
Yak-14	18.07.05	Lena	61°34'06,0"	130°33'59,2"	203	Th-E	100 x 300	1.9
Yak-15	18.07.05	Lena	61°34'20,7"	130°36'42,7"	198	Th-E	80 x 300	1.6
Yak-16	19.07.05	Lena	61°24'13,4"	130°33'10,8"	224	Alas	150 x 400	1.5
Yak-17	19.07.05	Lena	61°33'09,3"	130°51'34,0"	234	Alas	40 x 350	1.6
Yak-18	20.07.05	Lena	61°33' 01,5"	130°53'11,7"	211	Th-E	no data	1.5
Yak-19	20.07.05	Lena	61°24'26,0"	131°07'01,7"	250	Alas	50 x 150	1.3
Yak-20	20.07.05	Lena	61°32'45,3"	130°54'18,9"	230	Th-E	400 x 800	2.0
Yak-21	22.07.05	Lena	62°00'11,3"	131°49'06,1"	208	Th-E	100 x 200	1.9
Yak-22	22.07.05	Lena	62°00'23,7"	131°43'10,0"	207	Th-E	100 x 200	1.7
Yak-23	22.07.05	Lena	62°07'54,2"	131°13'24,9"	169	Th-E	150 x 350	2.3
Yak-24	23.07.05	Lena	61°58'05,7"	132°14'49,7"	182	Alas	200 x 300	3.2
Yak-25	23.07.05	Lena	61°48'05,9"	132°04'58,8"	198	Alas	300 x 500	2.0
Yak-26	24.07.05	Lena	61°54'09,9"	132°12'22,1"	187	Alas	150 x 150	1.7
Yak-27	24.07.05	Lena	61°53'24,2"	132°09'51,3"	200	Alas	200 x 350	2.0
Yak-28	24.07.05	Lena	61°56'23,9"	132°09'55,8"	171	T	150 x 200	4.7
Yak-29	24.07.05	Lena	61°56'46,5"	132°08'39,2"	207	Alas	150 x 200	1.4
Yak-30	26.07.05	Yakutsk	61°57’60,9"	129°24’51,2"	200	Tukulan	300 x 500	4.0
Yak-31	31.07.05	Yakutsk	62°00'11,7"	129°35'57,8"	102	R-B	20 x 30	no data
Yak-32	31.07.05	Yakutsk	62°00'13,7"	129°35'58,8"	104	R-B	20 x 100	no data
Yak-33	02.08.05	Yakutsk	61°50'57,8"	129°34'10,2"	111	R-B	30 x 300	no data
Yak-34	03.08.05	Yakutsk	62°18'22,8"	129°54'29,0"	96	R-B	200 x 500	no data
Yak-35	04.08.05	Yakutsk	62°19'00,7"	129°30'20,3"	182	Alas	40 x 50	no data
Yak-36	05.08.05	Yakutsk	62°19'03,7"	129°32'58,2"	217	Alas	20 x 30	no data
Yak-37	05.08.05	Yakutsk	62°18'35,7"	129°31'18,9"	218	Alas	40 x 50	no data
Yak-38	06.08.05	Yakutsk	62°20'02,2"	129°34'50,1"	200	D	30 x 200	no data
Yak-39	06.08.05	Yakutsk	62°19'39,2"	129°33'43,2"	210	Alas	100 x 100	no data
Yak-40	09.08.05	Moma	66°20'57,7"	143°23'42,9"	220	L-D	200 x 300	no data
Yak-41	09.08.05	Moma	66°20'57,4"	143°23'37,1"	223	L-D	10 x 100	no data
Yak-42	10.08.05	Moma	66°28'33,7"	143°15'01,9"	210	K	20 x 30	no data
Yak-43	13.08.05	Moma	66°31'05,2"	143°45'26,0"	768	L-D	300 x 500	no data
Yak-44	15.08.05	Moma	66°27'22,6"	143°15'27,3"	205	A	30 x 300	no data
Yak-45	15.08.05	Moma	66°26'57,8"	143°16'00,0"	203	A	10 x 30	no data
Yak-46	16.08.05	Moma	66°16'34,2"	143°18'49,1"	220	R-B	20 x 1100	no data
Yak-47	16.08.05	Moma	66°17'11,2"	143°18'48,4"	224	R-B	30 x 1000	no data
Yak-48	17.08.05	Moma	66°00'54,4"	143°12'40,4"	270	R-B	30 x 250	no data
Yak-49	18.08.05	Moma	66°11'44,9"	143°20'49,5"	240	L-D	5 x 10	no data
Yak-50	18.08.05	Moma	66°13'18,2"	143°23'13,5"	235	L-D	2 x 5	1.0
Yak-51	19.08.05	Moma	66°14'44,2"	143°19'18,2"	222	L-D	10 x 20	1.0
Yak-52	20.08.05	Moma	66°26'22,2"	143°17'20,1"	217	L-D	5 x 5	0.5

Yak-53	20.08.05	Moma	66°26'46,4"	143°16'24,4"	203	L-D	10 x 20	1.0
Yak-54	21.08.05	Moma	66°29'14,3"	143°13'23,8"	203	L-D	10 x 30	1.0
Yak-55	21.08.05	Moma	66°28'19,8"	143°15'21,2"	211	K	5 x 10	1.0
Yak-56	21.08.05	Moma	66°27'23,1"	143°14'05,4"	199	A	10 x 200	1.0

*day/month/year

**Lena – Lena-Amga interfluve, Central Yakutia; Yakutsk – near Yakutsk, Central Yakutia; Moma – near Khonnu, NE Yakutia

***Alas – Lake in an Alas depression; D – Dyuedya; T – Tyympy; Th-E – Lake in a thermokarst valley; R-B – River branch on the floodplain; Tukulan – Dune lake; L-D – Lake in a lowland depression; A – Anthropogenic (man-made reservoir); K – Kerdyugen

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Table 2: Hydrochemical and stable isotope characteristics of the studied lakes and ponds.

Lake	EC*	pH	O_2	T_{water}	Ca	HCO_3	Na	Cl	Mg	Sr	K	SO_4	$\delta^{18}O$	δD	$\delta^{13}C$
№	[mS/cm]		[mg/l]	[°C]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[mg/l]	[‰]	[‰]	[‰]
Detection limit					0.10		0.20	0.10	0.10	0.02	0.20	0.10	VSMOW	VSMOW	VPDP
Yak-01	1.63	8.54	3.88	24.3	33.56	561.36	147.09	109.60	178.72	0.29	3.88	436.80	-13.02	-131.7	-7.45
Yak-02	2.38	9.11	9.50	26.3	24.11	1269.15	267.42	199.00	305.26	0.29	4.03	424.20	-9.97	-116.5	-5.43
Yak-03	0.82	8.71	6.50	26.1	18.64	561.36	81.08	33.82	86.23	0.18	1.26	23.98	-10.14	-116.9	-1.17
Yak-04	0.91	8.08	7.63	24.2	17.67	475.93	100.28	83.13	65.47	0.12	7.45	35.39	-13.76	-133.8	-2.98
Yak-05	1.99	9.05	9.13	24.4	26.5	1598.65	227.81	147.55	285.44	0.35	4.47	43.53	-8.79	-110.9	6.19
Yak-06	5.71	9.96	5.70	18.7	2.17	3794.51	1481.44	408.50	96.71	< 0.02	158.27	0.52	-5.48	-88.7	7.98
Yak-07	4.14	9.91	14.50	21.0	1.58	2581.52	1040.92	350.80	91.64	0.03	68.25	< 0.10	-5.89	-90.7	11.00
Yak-08	0.10	7.54	7.50	20.5	11.61	48.81	11.37	1.32	3.75	0.13	2.74	< 0.10	-13.91	-130.0	4.68
Yak-09	0.12	7.31	6.14	19.5	10.0	73.22	18.62	2.59	4.54	0.11	3.03	0.94	-13.12	-124.4	-0.31
Yak-10	0.42	8.78	9.76	21.8	20.8	347.80	24.1	8.56	41.10	0.15	12.49	0.19	-14.36	-137.1	1.73
Yak-11	0.50	8.64	7.60	21.9	32.51	439.32	41.12	5.75	54.85	0.26	3.87	0.33	-10.12	-114.0	5.65
Yak-12	0.92	8.42	8.46	21.4	20.35	738.31	124.85	33.77	86.63	0.20	11.13	10.34	-10.20	-113.7	1.80
Yak-13	0.14	8.46	12.00	21.7	14.33	122.03	3.46	0.37	11.90	0.09	2.32	2.48	-14.48	-133.2	4.74
Yak-14	0.21	6.86	9.18	24.6	22.17	170.85	5.46	< 0.10	18.02	0.11	1.30	2.87	-14.12	-131.5	-1.87
Yak-15	0.16	7.55	5.75	22.9	16.74	140.34	3.95	< 0.10	14.12	0.08	1.53	2.25	-16.02	-141.3	-3.47
Yak-16	0.29	10.24	19.90	21.3	25.39	256.27	12.37	4.24	22.63	0.11	3.93	< 0.10	-11.44	-117.0	-3.90
Yak-17	0.10	6.60	2.40	20.2	10.83	73.22	1.80	0.11	7.32	0.05	2.94	0.13	-15.71	-140.8	-3.09
Yak-18	0.39	8.57	13.70	21.5	36.25	335.59	20.26	1.46	34.62	0.24	3.63	0.30	-12.90	-125.9	4.87
Yak-19	0.71	8.02	1.00	22.9	21.39	573.56	83.24	19.83	60.50	0.19	4.53	5.18	-12.36	-122.6	-1.66
Yak-20	0.81	9.00	13.30	22.6	37.16	634.58	175.36	33.80	38.23	0.20	5.35	1.49	-11.05	-117.9	2.29
Yak-21	0.33	8.19	7.40	20.0	37.71	274.58	8.79	0.96	25.82	0.15	3.81	0.54	-13.66	-128.4	-0.15
Yak-22	0.36	8.69	22.20	20.8	40.31	298.98	11.09	2.98	28.99	0.19	4.73	2.78	-15.03	-134.5	1.27
Yak-23	0.26	9.20	15.70	22.8	34.50	262.37	8.20	0.58	22.88	0.14	3.01	1.10	-14.84	-134.3	-4.73
Yak-24	0.79	8.58	38.00	21.7	17.18	842.03	129.12	38.37	96.13	0.19	13.05	5.04	-7.72	-98.7	4.89
Yak-25	0.82	8.75	n.a.	22.0	23.50	683.39	107.94	28.36	80.93	0.26	9.22	2.44	-7.86	-95.9	0.77
Yak-26	0.48	8.16	13.50	21.5	35.89	390.51	50.21	5.95	34.84	0.21	6.61	0.60	-10.56	-113.5	1.85
Yak-27	0.65	8.20	14.30	22.0	21.66	536.95	65.92	19.19	62.91	0.21	11.81	0.24	-10.46	-112.6	0.87
Yak-28	1.95	8.60	17.30	23.8	18.10	1659.66	288.97	151.35	226.77	0.27	4.09	11.20	-8.18	-105.9	6.46
Yak-29	1.04	8.93	14.20	22.0	4.91	683.39	180.11	110.36	64.36	0.07	17.95	6.01	-10.37	-113.3	-1.58

Yak-30	n.a	n.a	n.a	n.a.	8.29	61.02	8.11	1.18	3.67	0.13	2.13	2.70	-12.33	-122.1	5.24
Yak-31	1.43	8.38	5.90	20.5	56.63	524.75	189.96	187.90	74.99	0.66	18.18	168.30	-11.61	-119.0	-7.55
Yak-32	1.39	8.09	6.80	20.2	39.02	561.36	197.36	196.90	73.59	0.53	15.08	93.19	-12.02	-126.7	-7.51
Yak-33	0.85	8.09	5.50	20.5	40.19	305.09	103.22	143.70	43.93	0.50	7.66	33.12	-9.76	-108.4	-2.84
Yak-34	0.49	9.05	6.80	18.5	39.23	183.05	52.75	72.29	18.80	0.39	3.81	26.41	-14.98	-133.3	-5.23
Yak-35	0.36	9.19	4.50	18.7	16.84	274.58	28.37	7.96	27.49	0.15	16.30	2.77	-10.26	-109.8	-10.62
Yak-36	0.39	7.78	2.40	16.4	24.37	292.88	22.94	5.65	30.93	0.17	12.20	1.03	-12.13	-121.9	-5.51
Yak-37	1.52	9.12	2.40	22.7	15.22	976.27	202.39	87.84	155.88	0.30	7.01	203.40	-8.75	-103.5	-4.65
Yak-38	0.59	7.58	1.50	15.0	26.17	414.92	56.77	9.88	50.61	0.27	9.35	1.95	-9.74	-105.8	-4.48
Yak-39	0.18	7.04	5.00	16.1	3.39	122.03	24.11	4.92	11.45	0.06	14.20	< 0.10	-11.14	-107.4	-3.82
Yak-40	0.11	7.64	4.70	17.2	14.86	73.22	4.04	0.51	4.87	0.17	2.24	5.83	-17.20	-151.4	1.04
Yak-41	0.11	6.85	5.80	17.1	15.08	85.42	3.83	< 0.10	5.13	0.14	0.71	0.54	-17.69	-153.3	-8.08
Yak-42	0.12	7.21	5.40	13.7	18.14	97.63	4.45	< 0.10	5.02	0.14	0.67	0.11	-21.66	-167.8	-9.30
Yak-43	0.12	6.00	5.80	11.4	1.17	2.44	0.64	0.12	0.37	< 0.02	< 0.20	0.68	-21.84	-169.4	n.a.
Yak-44	0.08	7.27	4.90	14.6	11.25	61.02	2.48	0.18	4.10	0.14	0.75	< 0.10	-20.53	-163.2	-4.22
Yak-45	0.24	6.99	1.90	12.6	26.76	183.05	12.34	1.15	12.76	0.24	5.19	1.44	-15.11	-142.4	-2.82
Yak-46	0.10	6.81	7.50	14.8	15.41	73.22	3.07	0.16	3.80	0.09	0.27	0.46	-20.64	-164.3	-5.67
Yak-47	0.09	6.89	7.40	14.4	14.86	85.42	2.98	0.12	3.73	0.08	0.26	0.53	-20.89	-165.0	-6.29
Yak-48	0.03	6.48	5.70	14.2	3.62	14.79	1.32	< 0.10	1.04	< 0.02	< 0.20	< 0.10	-21.33	-166.1	n.a.
Yak-49	0.42	7.45	4.00	13.2	40.16	341.70	27.21	1.08	30.15	0.29	5.93	10.51	-12.24	-129.7	0.00
Yak-50	0.10	7.03	5.70	11.7	16.65	61.02	3.24	< 0.10	3.05	0.09	< 0.20	2.53	-18.81	-155.0	-2.52
Yak-51	0.13	6.83	4.70	10.4	16.03	109.83	5.91	0.16	7.83	0.09	1.30	< 0.10	-14.98	-140.8	-7.44
Yak-52	0.13	7.09	5.30	14.2	16.11	85.42	5.80	0.12	8.79	0.22	2.28	0.10	-18.34	-148.8	-4.54
Yak-53	0.32	7.37	6.90	14.3	46.71	256.27	16.00	0.30	18.11	0.39	2.61	0.12	-16.64	-143.3	-3.38
Yak-54	0.06	6.08	5.50	8.0	12.03	35.23	0.43	< 0.10	2.71	0.09	< 0.20	< 0.10	-15.46	-140.8	-11.23
Yak-55	0.40	7.30	4.70	16.4	55.91	335.59	17.69	2.10	21.02	0.51	6.89	< 0.10	-13.62	-135.6	-7.29
Yak-56	0.93	9.08	6.20	18.9	26.96	329.49	119.49	171.30	42.71	0.31	44.97	16.46	-12.42	-129.5	-5.38

Table 3: Stable isotopes ($\delta^{18}O$, $\delta^{13}C$) and element ratios (Mg/Ca, Sr/Ca) of host waters and ostracod calcite. The species identification follows the key: species (candida → *C. candida*, inaequi → *F. inaequivalvis*, jakutica → *C. muelleri jakutica*, weltneri → *C. weltneri*) and sex (f → female or m → male)

Lake №	**Species**	**$\delta^{18}O$ [‰] VSMOW water**	**$\delta^{18}O$ [‰] VPDP valve**	**$\delta^{13}C$ [‰] VPDP water**	**$\delta^{13}C$ [‰] VPDP valve**	**Mg/Ca molar water**	**Mg/Ca (* 10^{-2}) molar valve**	**Sr/Ca (* 10^{-3}) molar water**	**Sr/Ca (* 10^{-3}) molar valve**
Yak-12	welterni_f	-10.20	-10.47	1.80	2.73	7.02	1.52	4.39	1.77
Yak-12	welterni_m	-10.20	-6.45	1.80	1.37	7.02	2.03	4.39	1.24
Yak-20	welterni_f	-11.05	-5.88	2.29	0.01	1.70	0.60	2.51	1.05
Yak-20	welterni_m	-11.05	-5.07	2.29	4.85	1.70	1.18	2.51	1.28
Yak-22	jakutica_f	-15.03	-11.27	1.27	-1.95	1.19	0.45	2.12	0.76
Yak-22	jakutica_m	-15.03	-11.64	1.27	-1.39	1.19	0.55	2.12	0.71
Yak-26	jakutica_f	-10.56	-9.52	1.85	-0.15	1.60	0.46	2.71	0.82
Yak-26	jakutica_m	-10.56	-9.72	1.85	0.24	1.60	0.53	2.71	0.90
Yak-26	welterni_f	-10.56	-8.72	1.85	-0.97	1.60	0.34	2.71	1.04
Yak-26	welterni_m	-10.56	-9.00	1.85	-0.56	1.60	0.36	2.71	1.05
Yak-27	welterni_f	-10.46	-9.79	0.87	4.15	4.79	0.89	4.35	1.71
Yak-27	welterni_m	-10.46	-9.86	0.87	3.91	4.79	0.64	4.35	1.65
Yak-31	welterni_m	-11.61	-9.09	-7.55	-5.28	2.18	0.67	5.35	1.90
Yak-33	candida_f	-9.76	-8.88	-2.84	-2.75	1.80	0.56	5.64	1.88
Yak-36	candida_f	-12.13	-10.99	-5.51	-5.75	2.09	0.57	3.24	1.23
Yak-36	welterni_f	-12.13	-7.32	-5.51	-7.77	2.09	0.58	3.24	1.20
Yak-36	welterni_m	-12.13	-9.86	-5.51	-4.49	2.09	0.55	3.24	1.14
Yak-40	candida_f	-17.20	-15.19	1.04	-3.90	0.54	0.24	5.22	2.29
Yak-45	candida_f	-15.11	-11.91	-2.82	-1.33	0.79	0.32	4.14	1.53
Yak-45	inaequi_f	-15.11	-13.18	-2.82	-2.45	0.79	0.47	4.14	1.29
Yak-45	inaequi_m	-15.11	-12.51	-2.82	-1.56	0.79	0.55	4.14	1.50
Yak-45	jakutica_f	-15.11	-15.30	-2.82	-4.87	0.79	0.52	4.14	1.27
Yak-45	jakutica_m	-15.11	-12.27	-2.82	-2.05	0.79	0.35	4.14	1.31
Yak-49	jakutica_f	-12.24	-9.51	0.00	-0.81	1.24	0.51	3.27	1.04
Yak-49	jakutica_m	-12.24	-10.08	0.00	-1.92	1.24	0.53	3.27	0.95
Yak-49	welterni_f	-12.24	-9.80	0.00	-1.06	1.24	0.33	3.27	1.07
Yak-51	inaequi_f	-14.98	-11.81	-7.44	-4.51	0.81	0.57	2.56	0.94
Yak-51	inaequi_m	-14.98	-13.11	-7.44	-5.47	0.81	0.48	2.56	0.90
Yak-52	jakutica_f	-18.34	-15.03	-4.54	-6.47	0.90	0.51	6.32	1.69
Yak-52	jakutica_m	-18.34	-15.61	-4.54	-5.38	0.90	0.59	6.32	1.86
Yak-53	inaequi_f	-16.64	-13.68	-3.38	-2.69	0.64	0.41	3.83	1.33
Yak-53	inaequi_m	-16.64	-14.05	-3.38	-2.91	0.64	0.55	3.83	1.42
Yak-55	jakutica_f	-13.62	-10.48	-7.29	-5.94	0.37	0.41	3.43	1.34
Yak-55	jakutica_m	-13.62	-9.83	-7.29	-5.49	0.37	0.47	3.43	1.22