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Mineral Composition of the Sediments of Lake Malye Chany as an Indicator of Holocene Climate Changes (Southern West Siberia)

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Abstract—We present results of research into the mineral composition of the Holocene sediments of Lake Malye Chany of the Chany lake system located in the Baraba steppe and comprising three lakes: Bol'shie Chany, Malye Chany, and Yarkul', connected by channels. The sediments were studied by XRD, IR and Raman spectroscopy, laser granulometry, analysis of stable ^{18}O and ^{13}C isotopes, elemental analysis (XRF), etc. Mineral analysis has revealed predominant quartz, feldspars, and carbonates and subordinate gypsum, bassanite, pyrite, mica, chlorite, and kaolinite. Mathematical modeling of the XRD spectra of carbonates, using Pearson VII function, made it possible to identify the carbonate phases and determine their quantitative proportions. The obtained high-resolution carbonate record providing information about the stratigraphic distribution of carbonates in the dated section was compared with the available lithological, geochemical, and isotope data. Based on these data, we have reconstructed five stages of the Holocene evolution of the Malye Chany basin. It is shown that the proportions of minerals in the section vary in accordance with the lake level fluctuations in the alternating periods of the Holocene regional arid and humid climate. We compared the mineral compositions of the bottom sediments of Lake Malye Chany and Yarkovsky Pool of Lake Bol'shie Chany. The revealed mineral assemblages reflect the local specifics of the lake system and the influence of natural and climatic factors on the inland sedimentation processes.

Keywords: bottom sediments, carbonates, XRD analysis, stable ^{18}O and ^{13}C isotopes, Holocene, paleoclimate, Lake Malye Chany, West Siberia

INTRODUCTION

At present numerous comprehensive investigations of the bottom sediments of shallow lakes are carried out in different climatic zones of the Siberian region (Bezrukova et al., 2008; Shichi et al., 2009; Tarasov et al., 2009; Bezrukova et al., 2010; Ptitsyn et al., 2010, 2014; Bazarova, 2011; Krivonogov et al., 2012a,b; Solotchina et al., 2012, 2014, 2017; Solotchina and Solotchin, 2014; Dar'in et al., 2015; Leonova et al., 2018; Rusanov and Teterina, 2018; Strakhovenko et al., 2018). Nevertheless, there are a number of issues that can be solved only by studying a much larger number of objects and obtaining higher-resolution records.

The most widely used methods for study of lacustrine sediments are palynological and diatom analyses, analysis of stable oxygen and carbon isotopes, and geochemical analysis (distribution of major and trace elements throughout the section, separation of tracers, etc.). Each of these methods, however, has limitations and thus cannot provide detailed and complete paleoclimatic reconstructions. In this paper, we focus on research into the mineral composition of bottom sediments, its temporal changes, and comparison of the obtained results with data of other methods.

The object of our study was Lake Chany (Fig. 1) located in the central area of the Baraba steppe (54º30′–55º09′ N, 76º48′–78º12′ E). This is the largest closed mineralized water basin in West Siberia, with a water plane of 1840 km^2 (Ermolaev and Vizer, 2010). It is more correct to consider Chany a system of lakes: It comprises Bol'shie Chany, Malye Chany, and Yarkul'. The Kargat and Chulym Rivers flow into Lake Malye Chany, providing 45% of its water budget (Savkin et al., 2006). The ion composition of the lake water and its mineralization are presented in Table 1.

The lake shores are covered with abundant aquatic plants: cattail, pondweed, reed, and bulrush (Ermolaev and Vizer, 2010). The modern vegetation in the study area corresponds to a forest–steppe zone, with a predominance of steppe meadows and meadow steppes with aspen–birch groves (Korolyuk and Kipriyanova, 2005). The climate in the Chany area is continental, with a short frost-free season (Smirnova and Shnitnikov, 1982).

In recent years, the scientific interest in the lake has increased, but mostly hydrological, hydrochemical, and hydrobiological studies are carried out. In particular, the re-

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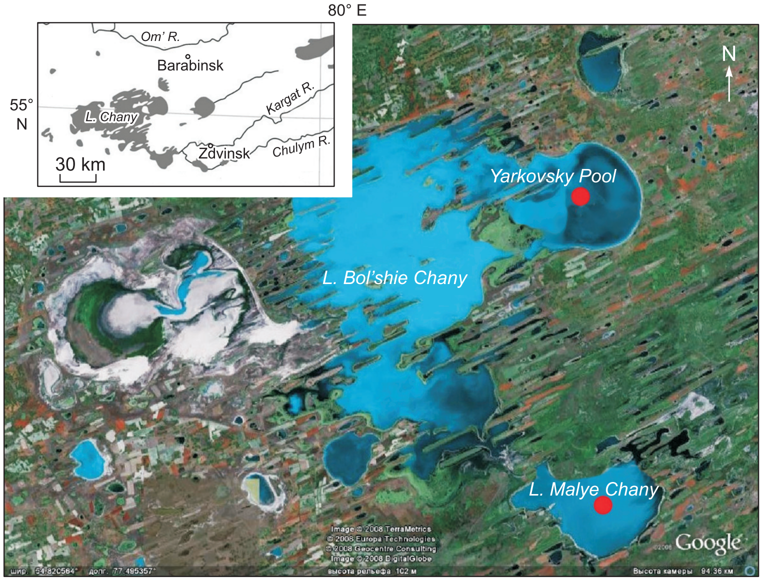

Fig. 1. Satellite image of Lake Chany (Baraba steppe, southern West Siberia) with the points of drilling into the Malye Chany and Yarkovsky Pool sediments. Inset shows the geographic location of Lake Chany.

searchers examine the lake water balance and geochemical parameters of the water (Savkin et al., 2005, 2006), the behavior of carbon, oxygen, sulfur, and nitrogen isotopes in it (Doi et al., 2004; Mizota et al., 2009), seasonal flora and fauna variations (Shikano et al., 2006; Vasiliev and Veen, 2015), and composition and structure of zoobenthos (Kipriyanova et al., 2007; Bezmaternykh et al., 2011).

The available literature presents general viewpoints of the structure and age of the lacustrine sediments (Krivonogov et al., 2013), results of their palynological study (Zhilich et al., 2016), and data on ostracod associations (Khazin et al., 2016). The aim of this research is to study the mineral composition of the bottom sediments of Lake Malye Chany and to establish the relationship between the distribution of minerals throughout the sediment section and the Holocene environmental and climatic changes.

MATERIALS AND METHODS

A 360 cm long core was extracted in the central zone of Lake Malye Chany in 2008 (Fig. 1). It was sampled with a 6 cm step; a total of 45 samples were analyzed. The sediment section consists of two parts: lower, coarse-grained sandy, and upper, fine-grained, rich in organic matter and containing mollusk shells (Fig. 2).

Analyses of the bottom sediments were carried out by XRD and IR spectroscopy at the Analytical Center for Multi-Elemental and Isotope Research SB RAS, Novosibirsk. X-ray studies of their mineral composition were performed on an ARL X'TRA (CuK_α radiation) diffractometer. For phase analysis, the samples were scanned in the interval from 2º to 65º (2Θ) with a 0.05º step and a counting time of 3 s at each point. For modeling the XRD profiles of sediment carbonates, scans were performed from 28º to 32º (2Θ) with the same step and a counting time of 15 s at each point. The contents of carbonates, quartz, and feldspars in the samples were determined by IR spectroscopy, using calibration plots constructed with standard synthetic mixtures of pure components (Stolpovskaya et al., 2006; Solotchina, 2009). Infrared spectra were recorded on a VERTEX 70 FT IR spectrometer. The samples were prepared by pressing tablets with KBr. Granulometric analysis of the terrigenous

Table 1. Seasonal changes in the ionic composition of the water (eq. %) of Lake Chany in 1977 (Smirnova and Shnitnikov, 1982; Vasiliev and Veen, 2015)

Pool	month	Mineralization, ppm	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Lake Malye Chany	III	4.9	–	25.5	16.1	58.4	3.2	44.8	52.0	
	V	1.0	–	29.2	21.0	49.8	13.9	36.1	48.4	1.6
	VII	0.8	6.4	27.0	8.3	58.3	16.5	37.2	44.3	2.0
	IX	1.1	–	27.7	21.7	50.6	12.4	43.1	42.6	1.9
Yarkovsky	III	8.0	4.0	13.9	8.9	73.2	0.8	33.5	65.7	
	V	6.6	4.1	11.5	17.4	67.0	0.7	32.8	65.6	0.9
	VII	7.1	5.0	10.8	12.2	72.2	0.7	32.8	65.6	0.9
	IX	7.1	5.2	12.8	11.2	70.8	0.7	34.7	63.7	0.9

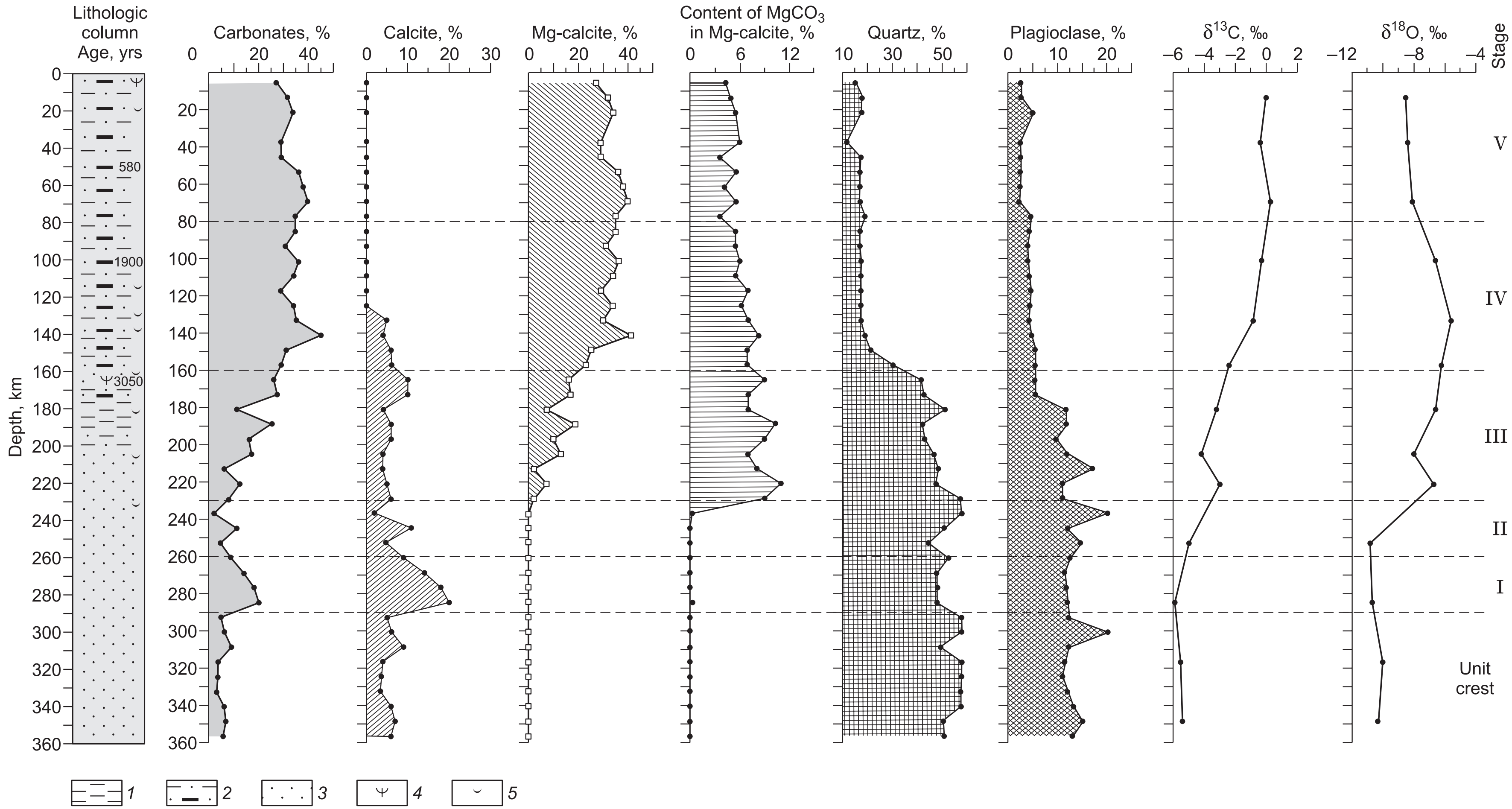

Fig. 2. Lithologic column of the Holocene sedimentary section of Lake Malye Chany, age model, and distribution of carbonate minerals, quartz, plagioclase, and stable isotopes ($\delta^{18}O$ and $\delta^{13}C$). *1*, silt; *2*, sand–silty sapropelic sediment; *3*, sand; *4*, plant detritus; *5*, mollusk shells.

component of sediments was carried out on an Analysette 22 MicroTec laser particle sizer with a preliminary dissolution of carbonates. Analysis for stable ^{18}O and ^{13}C isotopes in carbonates was performed on a Finnigan MAT 253 mass spectrometer, using the Continuous Flow method and GasBench II sample preparation device (NBS-18 and NBS-19 standards). The chemical composition of the samples was determined on an ARL-9900-XP XRF spectrometer. The AMS ^{14}C dating of the sediments was made on their total organic carbon (TOC) and total inorganic carbon (TIC) at the Korean Institute of Geoscience and Mineral Resources (KIGAM), Daejeon, and at the "Cenozoic Geochronology" Center of Common Use, Novosibirsk. The obtained dates were calibrated using the Calib ver. 7.1 software (Reimer et al., 2013).

RESULTS

Lithology. The bottom sediments of Lake Malye Chany are 300 cm thick. They are brownish-gray argillaceous sand in the lower section and gray sapropelic loam passing into clay sapropel in the upper section (Fig. 2).

Granulometric analysis of the terrigenous component of the bottom sediments showed an upsection increase in the content of the fine fraction, whereas the content of psammitic material significantly decreases from 55% at a depth of 268–270 cm to 20% at a depth of 140–142 cm. From bottom to top of the section, the arithmetic mean diameter of particles decreases from 51.7 to 29.7 μm, and the median diameter decreases from 61.2 to 25.6 μm. Figure 3 presents the results of analysis of two samples with contrasting granulometric compositions, one of which (depth 140 cm) depicts the distribution of particles in the upper section of the sediments, and the other (depth 270 cm), in the lower section.

Mineral composition of the lacustrine sediments. Quartz, feldspars, and carbonates are predominant minerals in the Malye Chany sediments, and gypsum, bassanite, pyrite, mica, chlorite, and kaolinite are subordinate (Fig. 4).

Carbonates amount to 20–50% of the mineral component of the sediments in the upper part of the core (depth <180 cm) and are much scarcer in the lower part, where their content shows drastic fluctuations from 2 to 20% (Fig. 2). Carbonate minerals in the sediments were studied in detail by mathematical modeling of their complex XRD profiles. To identify the carbonate phase, we decomposed their complex XRD profiles into individual peaks by Pearson VII function in the angle interval 28–32° (2Θ CuK_{α}) (Fig. 5). Carbonate minerals in the studied core are calcite $CaCO_3$, Mg-calcites (Ca, Mg)CO_3 (with $MgCO_3$ = 4–11 mol.%), and aragonite. Following the classification by Veizer (1983) and Deelman (2011), we divided Mg-calcites into low-Mg calcites with $MgCO_3$ < 5 mol.%, intermediate-Mg calcites with $MgCO_3$ = 5–17 mol.%, and high-Mg calcites with $MgCO_3 \leq$ 43 mol.% (Solotchina et al., 2012, 2014; Solotchina and Solotchin, 2014). The content of $MgCO_3$ in each phase was determined from the d_{104} vs. $MgCO_3$ content (mol.%) calibration plots (Goldsmith and Graf, 1958; Deelman, 2011). Aragonite was found in trace contents in the middle section of the sediments; its weak major analytical reflex (*hkl* = 111) is observed in the range from 165 to 100 cm in the diffraction patterns of some samples. The diffraction pattern of shell fragments sampled under a binocular has distinct peaks of aragonite.

High contents of quartz (up to 60%) and feldspars (up to 20%) are revealed in the depth ranges from 360 to 160 cm

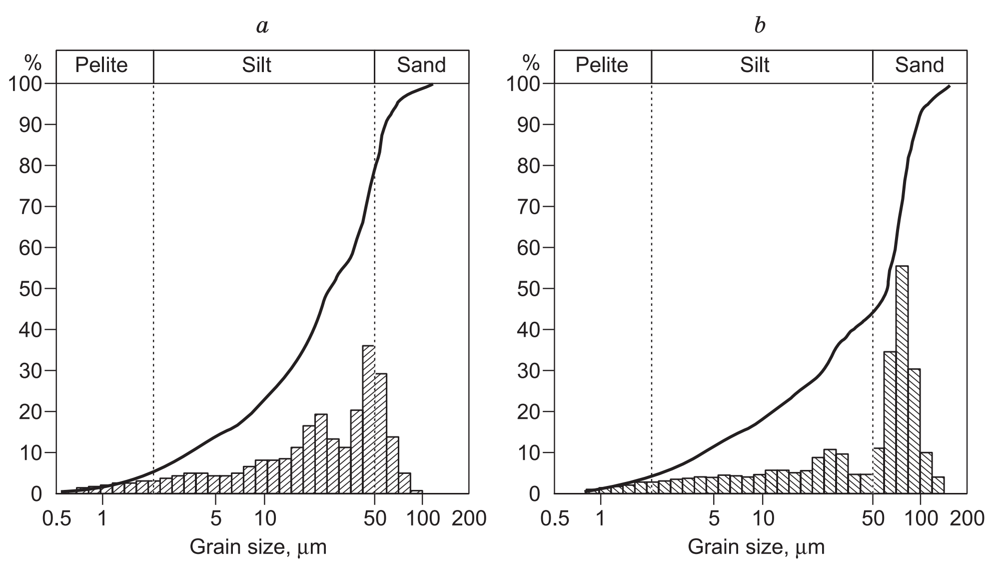

Fig. 3. Results of granulometric analysis of sediment samples from the Malye Chany section. Left—depth 140 cm (stage III), arid climate, shallow lake; right—depth 270 cm (stage I), climate humidification, watering of the lake basin. Carbonates were preliminarily dissolved. The histogram shows the statistical distribution of particles, and the cumulative curve depicts the granulometric composition. The horizontal axis marks the diameter of particles in logarithmic units.

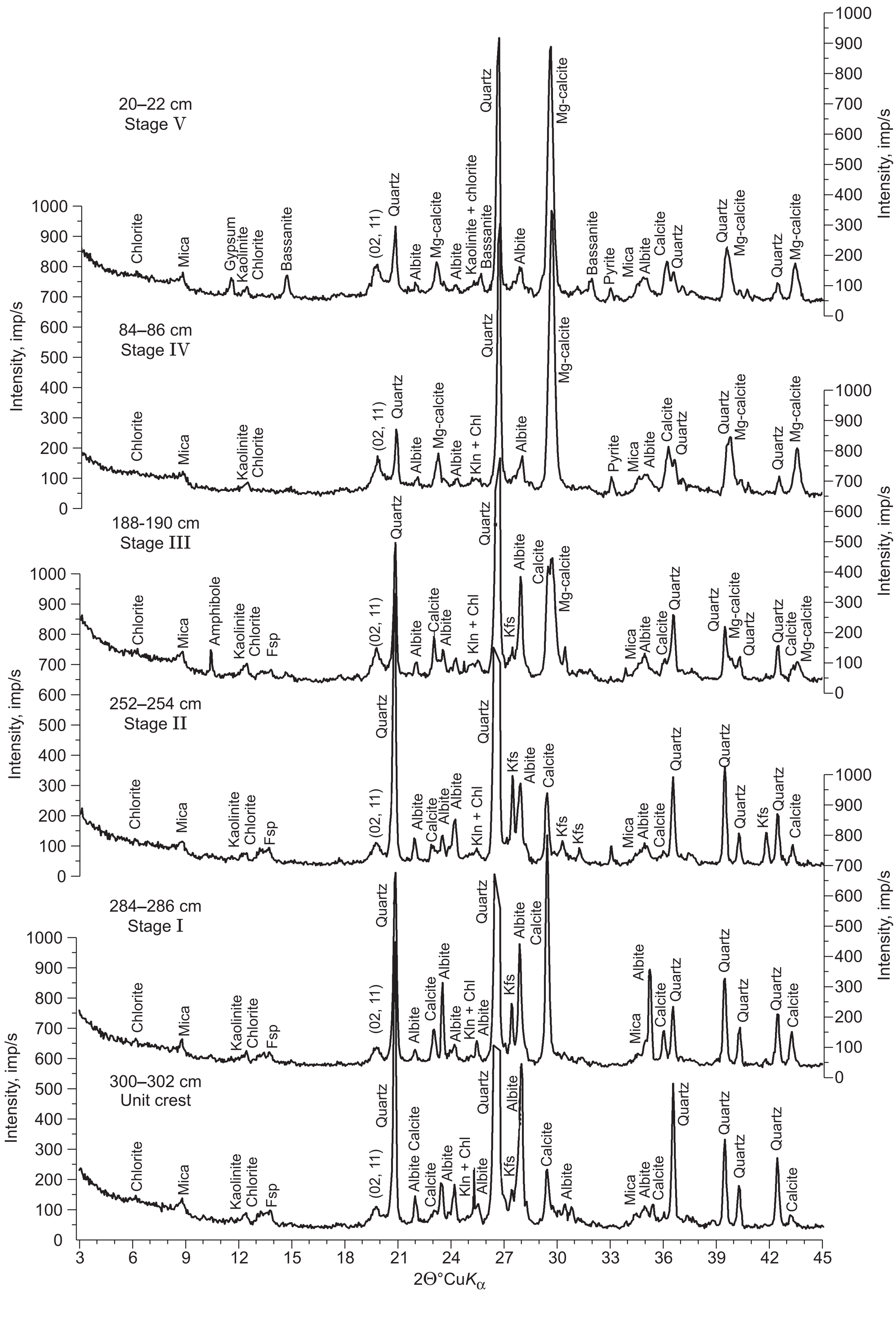

Fig. 4. General XRD spectra of the Malye Chany sediment samples, depicting the recognized lake evolution stages. Changes in the composition of terrigenous and carbonate components with a decrease in depth are clearly observed.

Table 2. Parameters of model XRD profiles of carbonates in the sediments of Lake Malye Chany (see Fig. 5)

Depth, cm	Carbonates	Line no.	2Θ°CuK_α	*d*, Å	Content of	
					$MgCO_3$, mol.%	phase, %
60–62	Mg-calcite	1	29.56	3.023	4	47
188–190	Calcite	1	29.45	3.034	0	4
	Mg-calcite	2	29.73	3.006	10	13

and from 360 to 180 cm, respectively. Upsection, the contents of these minerals decrease nearly twice (Fig. 2).

Feldspars were detected in the samples from their most intense peaks in the angle range 27.50º–28.00º (2Θ) in the X-ray diffraction patterns. These are K-feldspar (microcline) and plagioclase (albite). The diffraction patterns clearly show the presence of these minerals in the lower section (Fig. 4). Upsection, the intensity of their peaks decreases, and the half-width of the peaks increases, which makes it difficult to identify feldspar varieties.

The X-ray patterns of all studied samples show the presence of kaolinite (peaks at 7Å, *hkl* = 001 and 3.5Å, *hkl* = 002). The presence of chlorite in the sediments makes it difficult to identify kaolinite by XRD because of the superposition of its major analytical peaks (001) and (002) on the peaks of chlorite (002) and (004). Therefore, we additionally performed an IR spectroscopy analysis, which reliably identified kaolinite from its band at 3700 cm^{-1} (Fig. 6, inset). The content of kaolinite does not vary in the section and is ~3% of the mineral component of the sediments.

Mica is present in all studied samples; its content slightly varies throughout the section and does not exceed 10% of the mineral component of the sediments. Mica was identified from the reflex *hkl* = 001 in the angle interval 8º–9º (2Θ). Broad low-intensity peaks indicate a low crystallinity of mica. No shift of the mica peak or change in its shape occurs under ethylene glycol saturation of the sample, which indicates the absence of smectite interlayers.

The samples from the upper part of the core (180–0 cm) are richer in organic matter and contain pyrite (FeS_2), gypsum ($CaSO_4 \cdot 2H_2O$), and bassanite ($CaSO_4 \cdot 0.5H_2O$). Pyrite is found in all studied samples from the depth range 180–0 cm, whereas gypsum is present in the ranges 180–115 cm and 55–0 cm, and bassanite, within 50–20 cm. Electron microscope images of the sample from a depth of 20–22 cm show distinct white flat crystals (Fig. 7, photo). According to data of Raman spectroscopy, these plates are bassanite. The Raman spectrum (Fig. 7) has its major bands ν_1 at 1015 cm^{-1}, symmetric bands of SO_4 tetrahedra (ν_2) at 424 and 487 cm^{-1}, and weak bands at 1128 cm^{-1} (ν_3) and at 628 and 667 cm^{-1} (ν_4). Bassanite seems to replace gypsum, as follows from the small gray gypsum spots inside the white plates. The Raman spectrum clearly shows the bands of SO_4 tetrahedra at 1006 cm^{-1} (ν_1), 413 cm^{-1} (ν_2), and 1133 cm^{-1} (ν_3), bands at 622 and 671 cm^{-1} (ν_4), and the band of H_2O at 3404 cm^{-1}.

Stable isotopes. Analysis of stable oxygen and carbon isotopes in the Malye Chany carbonates showed that all

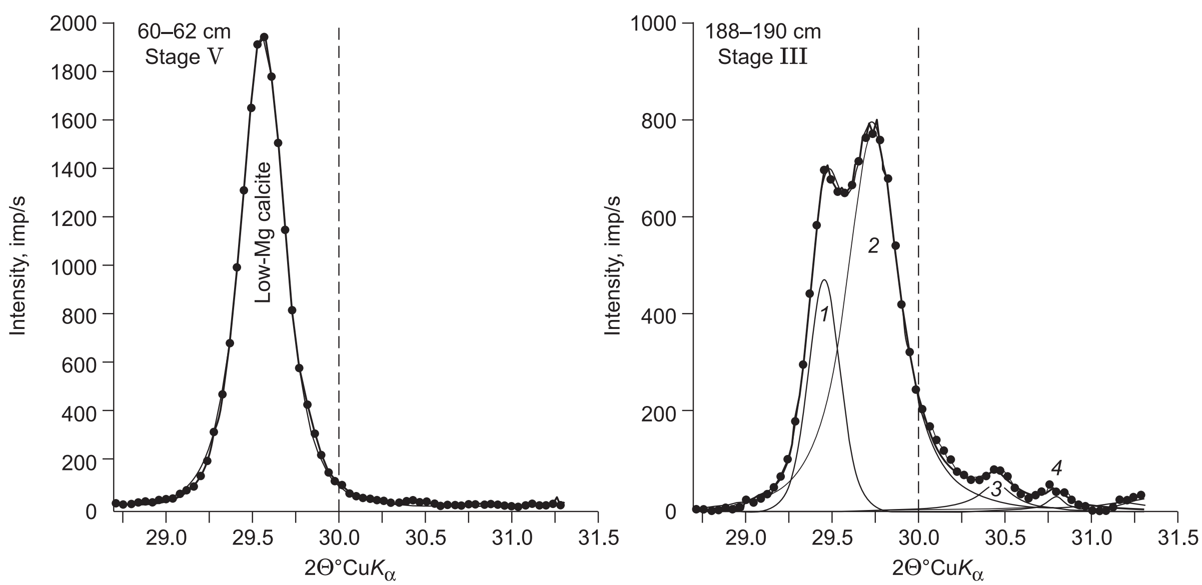

Fig. 5. Results of modeling of experimental XRD profiles of calcite–dolomite carbonates. The overall model profiles (solid line) are in accord with the experimental ones (points). The diffraction peaks of the individual phases are described by the Pearson VII function. The total carbonate content in the sample is taken as 100%. *1*, calcite; *2*, intermediate Mg-calcite; *3*, *4*, feldspar.

samples, except for two in the upper section, are characterized by only negative values of $\delta^{18}O$ and $\delta^{13}C$. The $\delta^{18}O$ and $\delta^{13}C$ trends synchronously change upsection; only in the upper 10 cm thick layer do the values of $\delta^{18}O$ increase and the values of $\delta^{13}C$ remain the same (Fig. 2). In general, the negative $\delta^{18}O$ values point to an inflow of fresh water enriched in the light oxygen isotope. The lowest $\delta^{18}O$ value (–10.8‰) is established in the depth range 230–260 cm, which indicates a high stand of the lake level. The highest $\delta^{18}O$ value (–5.6‰) is determined at a depth of 140–130 cm. The lake was shallow, evaporation dominated over water inflow, which led to the enrichment of the surface waters with the heavy oxygen isotope. In the upper section (100–0 cm), the values of $\delta^{18}O$ vary insignificantly, from –8.1 to –8.5‰. The minor variation might be due to the scarce number of experimental points.

Negative low values of $\delta^{13}C$ (–6‰) indicate that dissolved inorganic carbon deposited in the form of carbonates was from the sources of light carbon isotope. The increase in $\delta^{13}C$ to 0‰ in the upper section points to enrichment of the lake waters with ^{13}C, apparently as a result of absorption of ^{12}C during photosynthesis in the shallow lake.

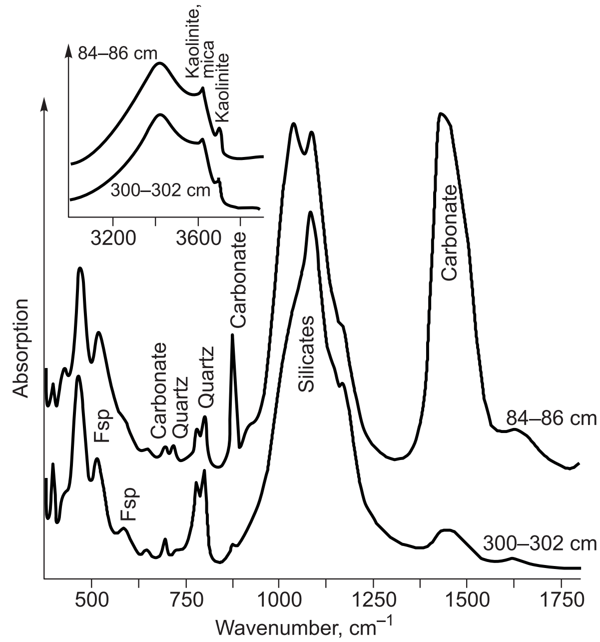

Fig. 6. General IR spectra of the Malye Chany sediments from depths of 300–302 cm (crest unit) and 84–86 cm (stage IV). The inset shows the range from 3200 to 3800 cm^{-1}, in which the clear spectral bands of kaolinite are observed.

Geochemical indicators. During the studies performed at the Siberian Synchrotron and Terahertz Radiation Center, Novosibirsk, SR XFA spectra were recorded and the contents of elements (K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, Ge, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, As, Pb, Th, and U) in the lacustrine sediments were calculated. The distributions of some elements and some ratios of indicator elements throughout the sedimentary section are shown in Fig. 8. Quantitative analysis was made by the external-standard method.

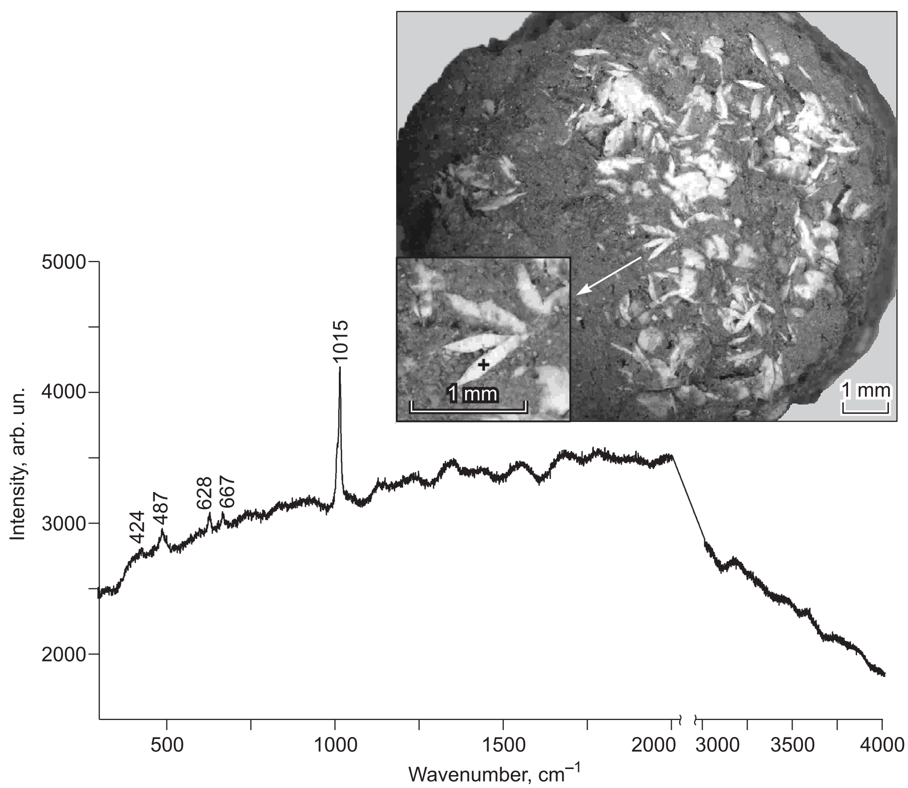

Fig. 7. Representative Raman spectrum of bassanite $CaSO_4 \cdot 0.5H_2O$. Photograph (reflected light) of bassanite crystals in the sediment groundmass (sample from a depth of 20–22 cm). The inset shows a magnified site with a focal laser point.

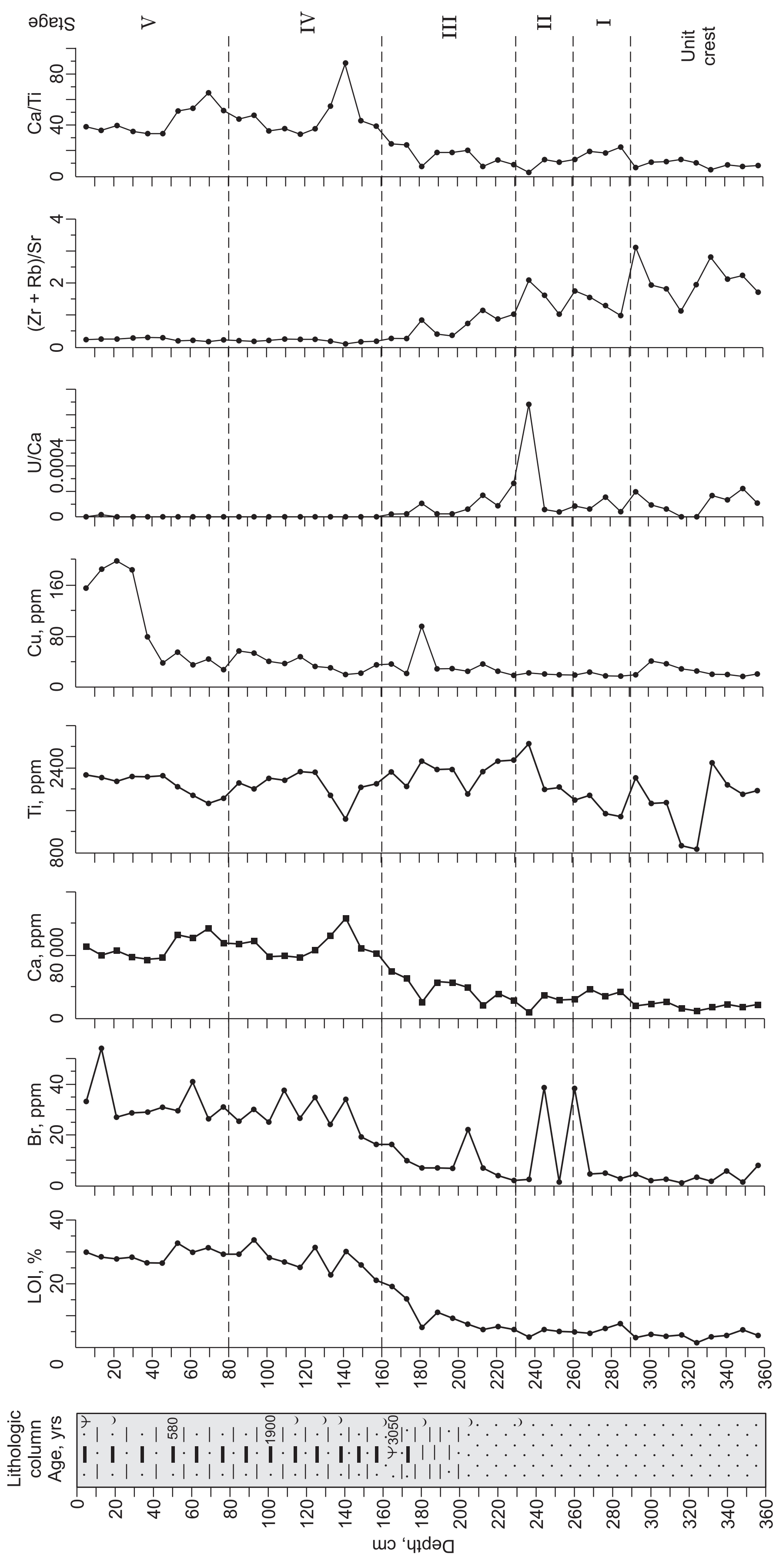

Fig. 8. Distributions of indicator elements ratios and individual elements throughout the Malye Chany sedimentary section. The legend for the lithologic column follows Fig. 2.

The obtained data were statistically processed with the Cluster computer program. A Q-type cluster analysis divides the starting sample of chemical analyses of bottom sediments into groups, and the dendrogram structure shows the relationship among these groups. This analysis made it possible to separate the sedimentary unit of Lake Malye Chany into three parts: lower (depth range 357–205 cm), upper (173–0 cm), and transitional (205–173 cm). This separation is consistent with lithological data. An R-type cluster analysis shows correlations among the chemical elements of the sample, which helps to establish the petrogenetic type of sedimentation. Based on the results of the R-type analysis, we have recognized four groups of elements in the Malye Chany sediments:

(1) Ca, Sr, Th, Mn, Br, Fe, and Ni, whose contents are higher in the upper sedimentary section because of the higher amounts of organic matter and carbonates and the presence of pyrite and gypsum;

(2) Zr, U, Mo, K, and Ge, whose contents are, on the contrary, higher in the lower sedimentary section and reflect the higher amount of a terrigenous component in the bottom sediments;

(3) Ti, Nb, V, Rb, Pb, Ga, Y, and Cr, whose average contents are almost constant in the lower and upper sections but drastically decrease at depths of 325–317, 285, 141, and 61 cm;

(4) Cu and Zn, which are evenly distributed throughout the section; their contents increase only at depths of 181 and 0–40 cm.

The U/Ca ratio is used to establish the redox conditions in the bottom water layer. In our case, U/Ca is close to or equal to zero and drastically increases only at depths greater than 180 cm, thus indicating a predominance of oxidizing conditions in the corresponding period (Fig. 8).

Bromine is one of the elements indicating paleoclimatic changes (Kalugin et al., 2009). Its high contents are recorded during warm periods and are correlated with the content of organic matter in the bottom sediments, thus reflecting the lake bioproductivity. Therefore, the content of Br in lake-bog sediments is given special attention. The bottom sediments of Lake Malye Chany are characterized by an increase in Br content in the upper part (0–180 cm) of the core. This depth range also shows an increase in the content of organic matter (high bioproductivity), which might be the cause of the high Br content.

The higher contents of chalcophile elements (Zn and Cu) in the upper 40 cm interval of the sediment layer (Fig. 8) might be due to sedimentation in the presence of hydrogen sulfide, which is confirmed by the presence of pyrite in the upper part of the core, and might also be a consequence of a high man-induced impact. The (Zr + Rb)/Sr and Ca/Ti ratios can be used as indicators of terrigenous contribution and carbonate productivity. Low (Zr + Rb)/Sr and high Ca/Ti values suggest an arid environment (Fig. 8).

According to Smirnova and Shnitnikov (1982), the Malye Chany waters are characterized by $Mg^{2+}/Ca^{2+} = 14$ in March and 2.2 in August, whereas this ratio in the waters of Yarkovsky Pool of Lake Bol'shie Chany virtually does not change and is about 42. The higher Mg^{2+}/Ca^{2+} ratio in the Yarkovsky Pool waters favors the sedimentation of high-Mg carbonates (high-Mg calcite and dolomite), in contrast to Lake Malye Chany, in which low-Mg and intermediate-Mg calcite are deposited.

The determined contents (%) of CaO and MgO in the bottom sediment sections of Lake Malye Chany and Yarkovsky Pool (Lake Bol'shie Chany) show their general tendency to increase upsection in both water basins. This is consistent with the distribution of total carbonates in the cores. However, the Yarkovsky Pool core samples have a higher Mg^{2+}/Ca^{2+} ratio than the Malye Chany ones. This is due to the higher content of Ca and lower content of Mg in the Malye Chany sediments (Fig. 9).

DISCUSSION

The Malye Chany sediments are 300 cm thick. The sediments were formerly characterized by three radiocarbon dates obtained from organic matter and peat (Khazin et al., 2016), showing that the sedimentation lasted 6–7 kyr. Based on the results of mineralogical and crystallochemical studies of the sediments, we have recognized five stages of the lake evolution, which reflect the Holocene environmental and climatic changes in the region (Fig. 2).

The bottom sediments of stage I bedding upon the blanket deposits (crest unit) are twice richer in carbonates (calcite) than the underlying rocks. The content of carbonates gradually decreases to the end of stage I. The contents of

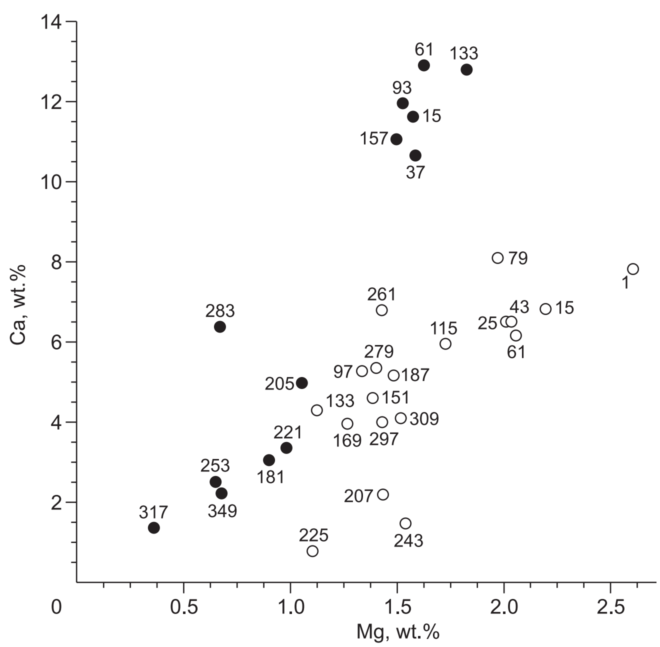

Fig. 9. Ca/Mg ratios in the Malye Chany (black points) and Yarkovsky Pool (white points) sediments. Numerals mark the sampling depth (cm).

quartz and feldspars are high, as in the underlying blanket deposits.

As in Yarkovsky Pool (Zhdanova et al., 2017), the most intense watering of the lake was at stage II (depth range 260–230 cm) with the minimum sedimentation of carbonates. Terrigenous minerals (quartz, K-feldspar, and plagioclase) are predominant in the sediments (Fig. 2).

Stage III (depth range 230–160 cm) was a period of shallow-water environment and high salinity of waters, 4.0–3.2 ka, which agrees with pollen (Zhilich et al., 2016) and ostracod (Khazin et al., 2016) data. This stage is characterized by active sedimentation of intermediate-Mg calcite with $MgCO_3$ = 7–11 mol.% (Fig. 5, sample from the depth range 188–190 cm). Considerable shallowing of the lake in this period is evidenced by a synchronous drastic increase in $\delta^{18}O$ to –7‰ (evaporation dominates over the water inflow) and in $\delta^{13}C$ to –3‰ (absorption of ^{12}C during photosynthesis due to the increased primary organic productivity in the shallow lake and the weakening of the inflow of meteoric waters enriched in light carbon isotope). The input of terrigenous material is preserved, which is reflected in the high contents of quartz and feldspar in the bottom sediments.

Stage IV (depth range 160–80 cm) is characterized by a significant change in sedimentation conditions. The contents of quartz and feldspar in the sediments drastically decreased, and the (Zr + Rb)/Sr ratio also became low, which indicates the reduced input of terrigenous material. The contents of calcium, magnesium, organic matter, and bromine increased. The total content of carbonates increased, but the content of $MgCO_3$ in calcite gradually decreased, and intermediate-Mg calcite was changed by low-Mg one. The sediments that formed at late stage III and early stage IV contain aragonite, which is typical of the Yarkovsky Pool sediments formed at the same stages (Zhdanova et al., 2017). In addition, pyrite is present, which indicates a change of oxidizing conditions to reducing ones. This is confirmed by the absence of uranium from the upper core sediments.

The sediments of stage V (depth range 80–0 cm) are formed predominantly by low-Mg calcites (30–40% of the mineral component). The $\delta^{18}O$ value is lower as compared with the underlying sediments, –8 to –9‰, which indicates a more intense water inflow. The $\delta^{13}C$ values are about 0‰ and do not differ from those in the sediments of stage IV. Organic productivity was still high in the lake, ensuring the absorption of ^{12}C and its domination over the inflow of light carbon. Such a difference in the $\delta^{18}O$ and $\delta^{13}C$ trends is specific to open systems (Talbot, 1990). Pyrite, gypsum, and bassanite point to reducing conditions in the sediments.

The results obtained are generally consistent with earlier paleoclimatic reconstructions based on palynological data (Zhilich et al., 2016). It is no doubt that there were significant climatic and environmental changes in the Baraba lowland at ~3.2 ka, which are reflected both in the increase in carbonate content in the sediments (Fig. 2) and in the change in spore and pollen assemblages. It is hard, however, to agree with the statement by the above authors that the climate in the study area was warm and arid and the lake was permanently shallow at the early stages of its existence (before 3.2–3.4 ka). Such environments are the most favorable for the deposition of authigenic carbonates; nevertheless, we observe the minimum content of carbonate minerals at a depth of 230–260 cm in the studied section. This suggests a high stand and significant desalination of the lake waters. We assume that the climate in the Malye Chany area at that time was unstable and the high-aridity environments were periodically changed by more humid ones.

CONCLUSIONS

Comparative analysis of the mineral composition of bottom sediments from Lake Malye Chany and Yarkovsky Pool of Lake Bol'shie Chany made it possible to establish the general trend of change in the composition of carbonates. The intense sedimentation of carbonates in Malye Chany began about 4000 years ago, and that in Yarkovsky Pool, about 3600 years ago. The earlier response of Malye Chany to environmental changes might be due primarily to the control of its water balance by the influence of the Kargat and Chulym Rivers, whereas sedimentation in the Yarkovsky Pool is controlled mostly by evaporation. The different salinities and Mg/Ca ratios of the waters led to the sedimentation of calcite–dolomite carbonates of different compositions. The Malye Chany sediments include low-Mg and intermediate-Mg calcites, whereas the sediments of Yarkovsky Pool additionally contain high-Mg calcite and Ca-dolomite.

Despite the different compositions of carbonates, they show a single trend of the change in Mg content, reflecting a change in the salinity and Mg content of water, which is a result of regional paleoclimatic fluctuations. The Baraba lowland is influenced by two powerful climatic factors: the inflow of arid and cold arctic air from the north and the supply of heated continental air from the south (Orlova, 1990). The predominance of the particular factor made a significant effect on the environmental and climatic conditions of sedimentation in the Chany lake system. In the earlier studies of lakes in East Siberia, we observed the same cyclic change of the periods of aridization and humidification of the Holocene climate as in the carbonate-containing bottom sediments of Lake Malye Chany. Thus, we can state the effect of global climatic processes in the late Quaternary Northern Hemisphere.

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