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Micromorphological and mineralogical features of saline playa surface sediments from two large Trans-Uralian lakes

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Abstract

The proposed paper is devoted to the features of mineralogical composition and microstructure of saline playa surface sediments from two large drainless lakes in the south west of Western Siberia. The material composing the surface sediments of both playas is an unlithified mixture of clay and sand, with a significant admixture of organic matter. Coarse material is represented mainly by quartz, with an insignificant admixture of feldspar grains and micaceous fragments. In general, terrigenous component is characterized by a comparatively low degree of sorting. Clay material is scarce and composed, presumably of chlorite-hydromica material with a significant admixture of undecomposed organic matter, and traces of ferruginization. Carbonates and evaporates are the most common authigenic minerals. In both cases carbonates occur as microconcretions that correspond to the zone enriched with cysts, plant detritus and other degrading organic matter. Evaporates occur both as the efflorescence on the surfaces of the crusts. The study results have shown that surface crusts contain zones enriched with *Artemia salina* cysts, which are a significant component of sediments. Degrading crusts promote secondary mineral formation, especially formation of carbonates. Surface crusts of two studied playa environments differ in proportion of terrigenous material, clay minerals, as well as the composition of evaporates and carbonates.

Keywords: *Artemia salina,* lakes, Solonchaks, Western Siberia.

Introduction

Small and large lakes, that significantly vary in terms of water chemistry and morphometric parameters are important components of the landscape mosaic in the arid and semiarid regions of Western Siberia and Northern Kazakhstan (Yermolayev and Wizer, 2010). A significant proportion of this water bodies is undrained and rather often saline (Ovdina et al., 2020), which results in the formation of specific aquatic and subaquatic ecosystems adjacent to such environments (Zarubina and Durnikin, 2005; Samylina et al., 2014). Another important feature of the lakes within the territory under consideration is related to the fact that they are very dynamic systems, subjected to significant seasonal, annual and decade-long fluctuations of water level (Meyer et al., 2008; Rudaya et al., 2012), that can result in their full drying off. Global and regional natural and human-induced transformation of the climatic conditions and landscapes can intensify the degradation of these water bodies and even make this process irreversible.

Large saline lakes within the steppe and forest-steppe zone of Western Siberia and Northern Kazakhstan form solonchakous playas around them. During the gradual drying of these water bodies bottom sedimets are exposing to the land surface and are subjected to the processes of the initial soil formation (Kazantsev et

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al., 2005). On the one hand, these surfaces can play a potentially important role for the carbon sequestration (Yakutin et al., 2016a,b); on the other hand, a number of studies have shown that dry environments can also act as sources of CO_2 emissions (Beltrán-Hernández et al., 2007; Ikkonen et al., 2018). It is also worth mentioning, that degradation of saline lakes leads to the formation of immense areas covered with salt crusts, that can act as potential sources of salt-rich dust, and, consequently, lead to further salinization of the adjacent agricultural landscapes (Mees and Singer, 2006).

The above arguments caused a consistent interest to the studies devoted to the biogeochemistry, minerology, properties and microstructure of near-shore *Solonchaks*, and salt crusts covering dry areas of the lake beds (Mees and Singer, 2006). Various studies have been performed for such lake-playa environments in different arid and semi-arid regions of the world (Hammer, 1986; Vizcayno et al., 1995; Castañeda et al., 2005, 2015; Joeckel and Clement, 2005; Castañedaa and Herrero, 2008; Mees et al., 2011; Gutiérrez et al., 2013; Zhang et al., 2013; Acree et al., 2019; Smolentseva and Gavrilov, 2020; Jafarpoor et al., 2021). Within the south of Western Siberia and Northern Kazakhstan near-shore *Solonchaks* and salt crusts were extensively studied for the territories of the Kulunda and central Baraba regions (Lebedeva et al., 2008; Yakutin et al., 2016a). At the same time, for the Trans-Uralian, the south-western part of the Western Siberia, similar studies are much less common; saline landscapes and soils within the territory under consideration are rather poorly studied.

The largest areas occupied by salt playas within the territory of the Trans-Urals are confined to a number of lakes located in the Kurgan region on the border with Kazakhstan (lakes Medvezhye, Sazykul, Gorkoe, Siverga, Elanch, Kaltyk, etc.) (Shulpina, 2004). Investigation of the soils and surface crusts of large saline lakes within study area is important for better understanding the functioning of these systems that experience intense anthropogenic impact associated with a significant recreational load. Resorts, balneological sanatoriums, recreation sites, as well as areas with developed brine shrimp gathering within the region are, as a rule, confined to large saline water bodies.

This work presents the results of a study of the features of the microstructure and mineral composition of the surface sediments of large playas within lakes Medvezhye and Kaltyk.

Material and Methods

Study area and sampling

The studied lakes are situated in the south-western part of the West Siberia Plain within the Tobol-Irtysh interfluve. Lakes Kaltyk and Medvezhye are located in Kurgan Oblast, in the Lebyazhyevsky and Petukhovsky districts, respectively (Figure 1). The territory is characterized by a predominance of low slightly-dissected relief with absolute heights from 120 to 140 m above sea level. Undrained lakes and forest-steppe bogs occupy local depressions. The covering deposits are represented by Late Quaternary carbonaceous loess-like loams, which are underlain by Neogene and Oligocene continental sediments (Novoselov et al., 2019).

The climate of the territory is continental, typical for the forest-steppe subzone of the Southern Urals, with low precipitation, hot summer and cold winter seasons. The annual temperature is 2.7 °C, the annual precipitation is less than 400 mm (Shulpina, 2004). The vegetation of the territory under consideration is strongly transformed by agricultural activities. The typical landscape pattern is characterized by the alteration of ploughed fields with *Luvic Chernozems*, beach forests with *Luvic Phaeozems* and *Mollic Planosols*, as well as *Solonetz* and *Solonchaks* soils under halomorphic vegetation within the areas adjacent to saline lakes.

Field studies were carried out in July 2018 within the areas of playa landscapes in the northern part of Lake Medvezhye and the southern part of Lake Kaltyk.

Lake Medvezhye is one of the largest reservoirs in the Kurgan Oblast. The total length of the coastal zone of the lake is about 60 km, the average depth is 0.5-1.0 m. Sulfide salt-saturated sulfide-silt therapeutic sapropel forms a 0.7 m thick layer in the bottom of the water body (Kurochkin et al., 2014). The brine of the lake has a chloride-sodium composition and mineralization varying in a wide range of 112-350 g L^{-1}. Lake Medvezhye is a large habitat for the *Artemia salina*, which is valuable biological resource (Kurochkin et al., 2014; Litvinenko et al., 2015). The Kaltyk has a similar morphology of the lake bed and is also surrounded by vast saline playas. At the same time, this reservoir is much less studied and is practically not mentioned in the works devoted to the water bodies of the region.

Samples for mineralogical and microscopic studies were collected from different facies of the studied environments.

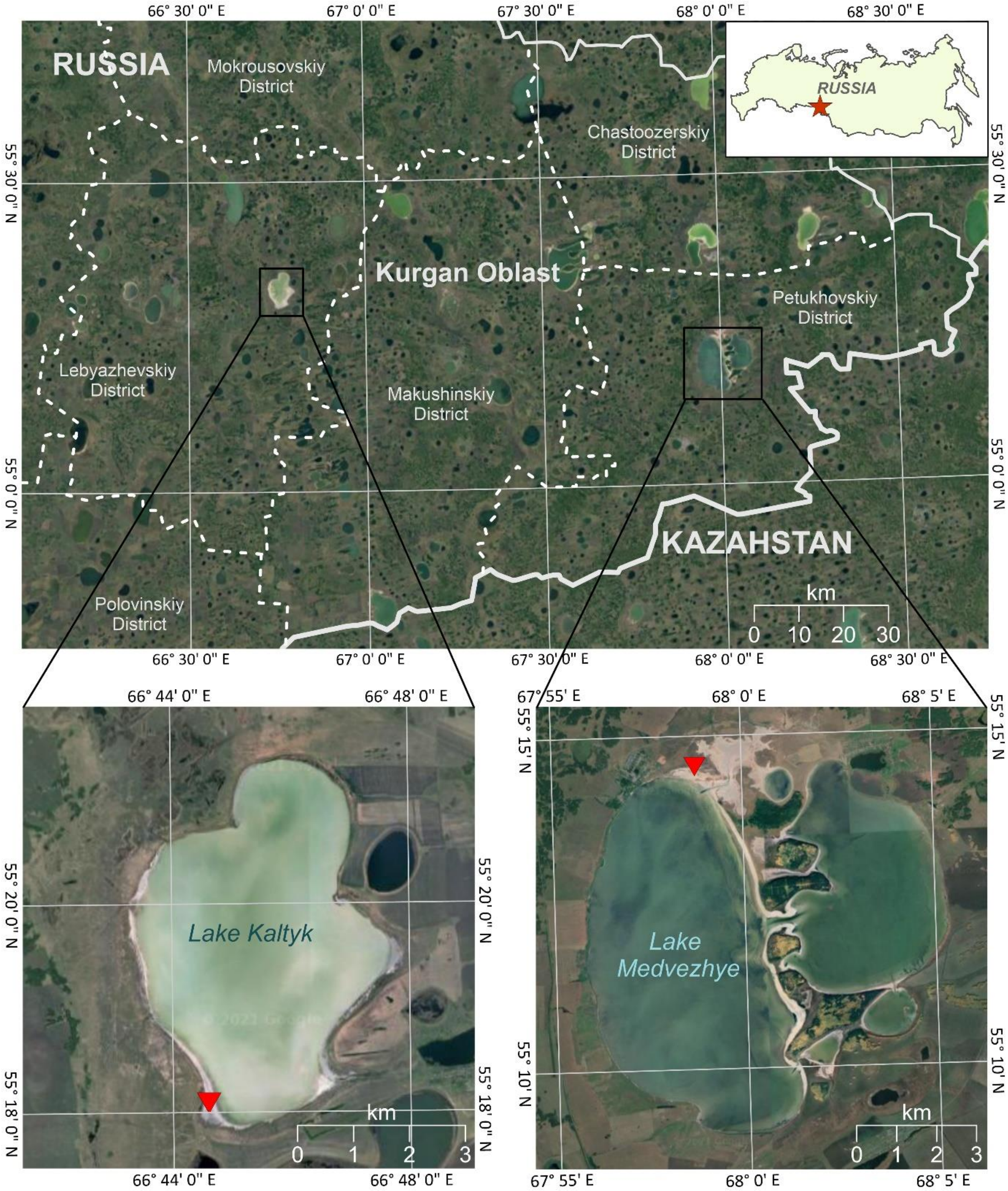

Figure 1. The location of the studied lakes in the southwest of Western Siberia (satellite images from Google Maps). Red triangles denote sampling sites

Mineralogical and microscopic studies

The primary diagnostics of collected samples was carried out using a Leica EZ4 D stereomicroscope (Leica Microsystems, Wetzlar, Germany) with an integrated digital camera. The studies of most representative samples were performed in thin sections using an Eclipse LV100POL polarization microscope (Nikon, Tokyo, Japan). The SEM-EDS analysis was performed using a TM3000 scanning electron microscope (Hitachi, Tokyo, Japan) with a Quantax 70 EDS attachment (Bruker, Billerica, MA, USA) at X100–5000 magnification and a JSM-6390LV scanning electron microscope (Jeol, Tokyo, Japan) with an INCA Energy 450 X-Max80 EDS attachment (Oxford Instruments, Abingdon, UK). The SEM observation were made under high vacuum (HV-mode), mainly in the elemental composition mode (BSE, registration of back scattered electrons). While performing the EDS analysis, the voltage was 15 and 20 kV for the first and second devices, respectively.

The XRD analysis of representative samples from both lakes was performed using Shimadzu XRD-6000C X-ray diffractometer (CuKα radiation, Ni filtr, 30kV, 20 mA).

Results and Discussion

The saline playas of Lake Medvezhye area are widespread within the northern and northeastern shores of the reservoir (Figure 1), where they appear as an isolated shallow liman-like creek filled with water during the high-water period (Figure 2a). The territory of the playa along the entire channel is covered with a fissured dense solid crust, up to 3-4 cm thick, covered with numerous mineral (evaporitic) efflorescences on its surfaces (Figure 2b). The hard crust of the saline playa overlaps the loose moist finely dispersed dark brown sediment without any pronounced stratification and signs of active processes of sulfate-reduction. Interlayers of light red color formed under a dry Takyric crust are characteristic for the peripheral parts of the playa located in the vicinity of the coastal area of the lake. These interlayers are composed from a mixture of coarse mineral material and *A. salina* cysts, mineralized by various degree (Figure 2c,d). Cysts also occur on the surface of the crust, transported by wind and periodic water currents. The largest number of cysts was characteristic for the inshore sediments, were a layer organic capsules cover about 40-50% of the coastal surface.

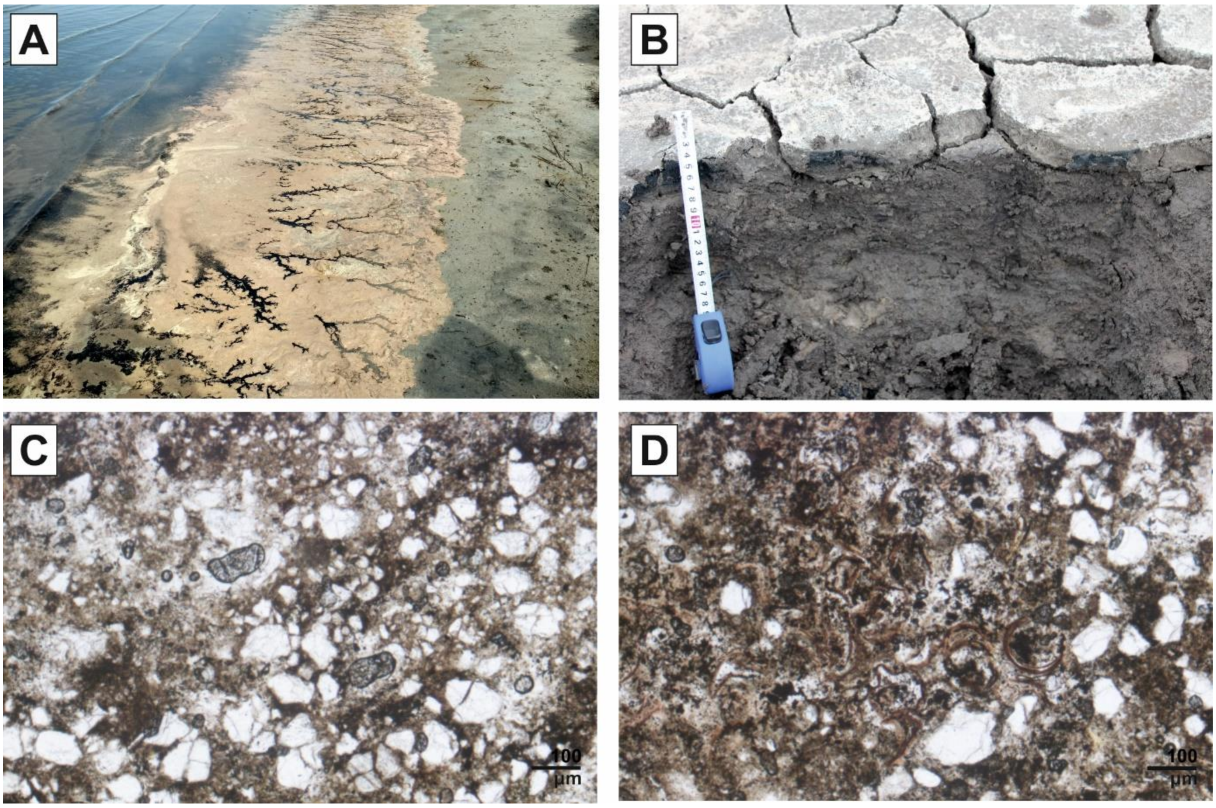

Figure 2. The saline playas of Lake Medvezhye: inshore zone covered with creamy mass of *A. salina* cysts (a); thin dark layer with sulfate-reduction processes under a dense Takyric crust with efflorescences of salts on its surfaces in the drained part of saline playa (b); thin sections (PPL) illustrating the main mineral components and microstructure of the surface sediments. It is clearly visible that they represent a mixture of terrigenous mineral grains, authigenic pelitomorphic carbonate aggregates, mineralized and slightly mineralized organic remains, including abundant of *A. salina* cysts (c and d)

Lake Kaltyk has simpler configuration of the shoreline, as well as the water body and its basin have a round shape. Large saline playa landscapes appear in the western and eastern peripheral parts of the lake (Figure 1). In the south-eastern part of the water body saline playas correspond to the large creek, which most likely correspond to the outlet of the drained stream, cutting into the adjacent arable land (Figure 1b). The main vegetation of playas is represented by *Salicornia europaea* (Figure 3a), a plant in the described range, which is confined to sea coasts with increased soil salinity, periodic flooding with salt water and a lack of oxygen in the soil. The playas of the Kaltyk have a flat, rather wet surface, complicated by large, rounded, sometimes bowl-shaped, spots of dry cracked crusts, about 2-3 cm thick and up to 5-6 m in diameter (Figure 3b,c). Such areas are often covered with efflorescences of evaporitic minerals (Figure 3d,e,f).

Based on the results of the semiquantative estimation of the mineral composition of the surface crusts from Lakes Medvezhye and Kaltyk by X-ray structural analysis it is possible to note the differences characteristic for these two playa environments.

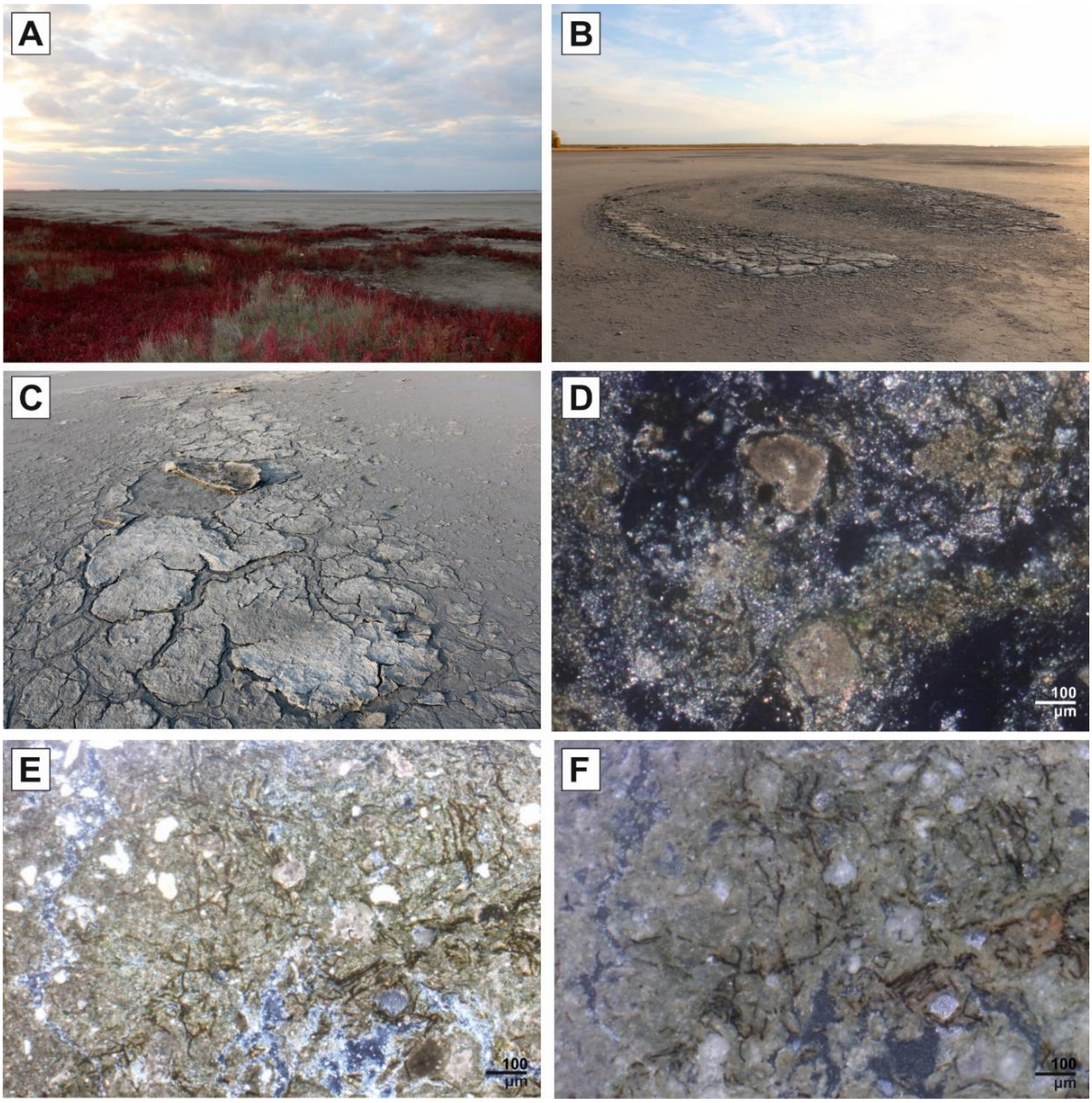

Figure 3. The saline playas of Lake Kaltyk: peripheral part of drained playa occupied by halophilic vegetation (a); dried spots with takyric crusts with efflorescences of evaporitic minerals (b and c); thin section (XPL), illustrating the mineral composition of surface sediments, in the photo there are dense carbonate microaggregates and non-mineralized organic matter (d); thin sections (PPL and XPL) characterizing the main features of microstructure of playa crusts, represented by an alterations of terrigenous material, carbonate microaggregates and slightly mineralized organic matter (e and f)

First of all, one can see that the studies playas differ in terms of the composition of the terrigenous material. The samples from Lake Medvezhye contain a high proportion of quartz and feldspars, that often exceeds 80%, while for the samples, representing Lake Kaltyk this proportion was much lower, up to 26.5%. However, it should be noted that the sediments of Lake Kaltyk also contain a significantly larger amount of allothigenic clay minerals (mainly illite and chlorite).

Carbonates are rather common among authigenic minerals of surface crusts from both saline playa environments. The main carbonate mineral of the sediments of Lake Kaltyk was aragonite (up to 40.9%), partly of authigenic nature, partly, corresponding to external skeletons of benthic organisms. The composition of carbonates of Lake Medvezhye was more diverse. Siderite, which likely indicates the presence of a reducing conditions during the periods of anaerobic functioning of the playas, calcite (up to 2.5%) and Mg-calcite were also abundant in all analyzed samples.

Gypsum was the most common evaporitic mineral in the surface sediments of both playa environments (Lake Medvezhye – up to 3.7%, Lake Kaltyk – up to 9.9%). It is also worth noting that in the salt marsh sediments on Lake Medvezhye, halite is contained only in the form of thin microcrystalline films on the surface of the soil crust, while in the salt marsh sediments of Lake Kaltyk, halite is contained directly in the sediment layer, accounting for up to 20.8% of the total mass of mineral matter.

Results of microscopic studies showed that the terrigenous component of the deposits of Lake Medvezhye is represented mainly by the fine sand fraction, with the predominant grain size 0.1-0.15 mm. The grading is medium, single grains have slight traces of dissolution. Quartz grains are semi-rounded with absence of cracks on their surfaces. Rare grains of feldspars also show minor traces of dissolution and pelitization. Clay minerals, as a rule, are hydrated and partially replaced by authigenic carbonates. Authigenic minerals are mainly represented by pelitomorphic carbonates (calcite, Mg-calcite, and siderite), which form microcrystalline concretions, rarely forming rounded microconcretions (Figure 4a). Basically, carbonates are formed along pelitized, hydrated grains, as well as organic matter - EPS films, decaying plant debris, and cysts of *A. salina* cysts (Figure 4d).

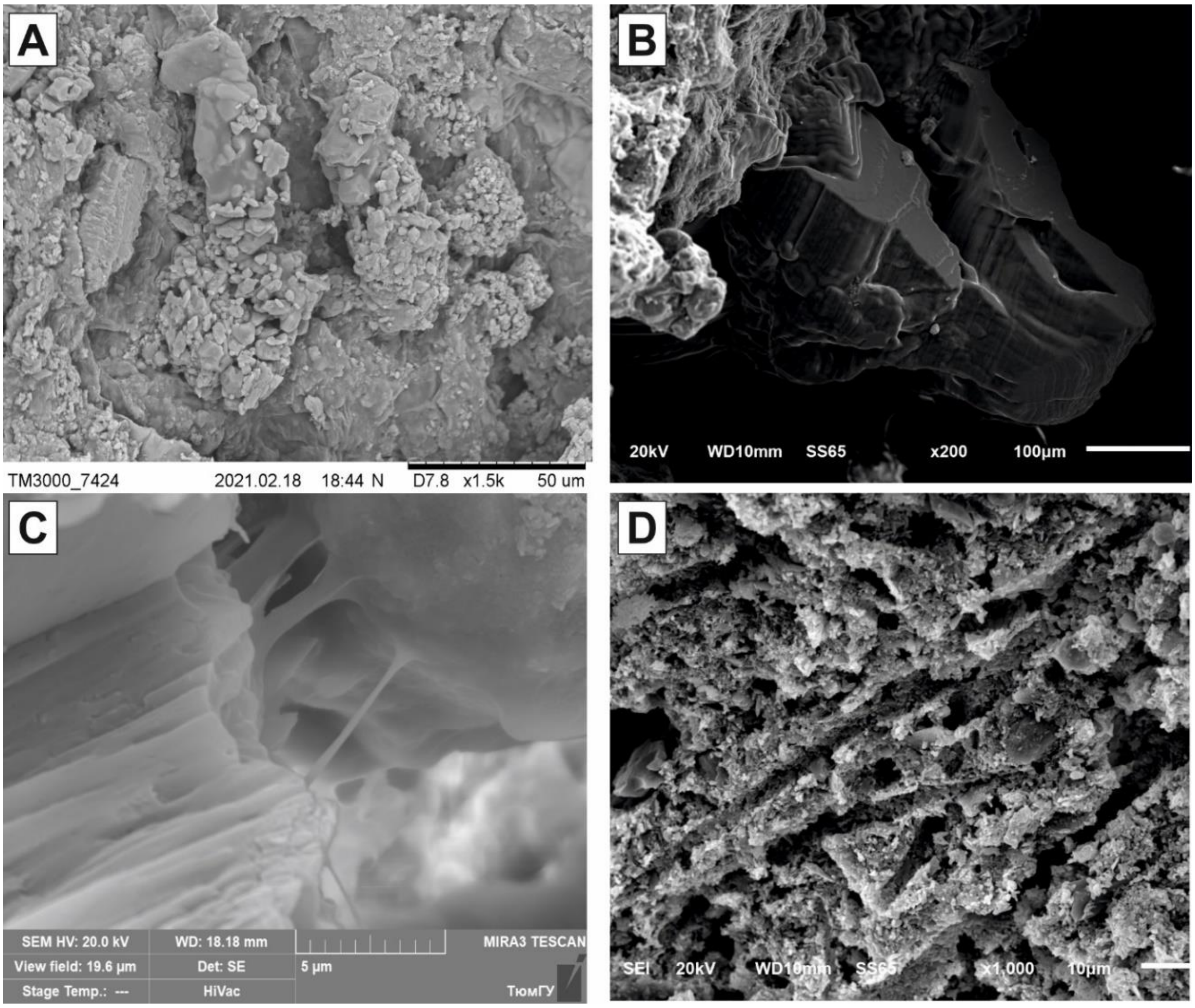

Figure 4. SEM photos of the playa surface sediments: rounded concretions of microcrystals of Mg-rich calcite, confined to organic biofilms (a); evaporite halite crystal with pronounced growth zones and dissolution caverns (b); non-mineralized EPS film (c); large concretion of split sheaf-like microcrystals of Mg-calcite confined to degraded organic matter (d)

Based on the results of the microscopic studies it was shown that the terrigenous component of surface crusts of Lake Kaltyk is represented by coarse silty grains of quartz and feldspars, the predominant size is 0.06-0.09 mm. The coarse material is characterized by a significant sorting and a weak degree of roundness for individual grains. Quartz has normal extinction, weakly pronounced traces of dissolution and rare initial regeneration films. Feldspars grains are often pelitized and partially replaced by clay minerals and pelitomorphic carbonate. The carbonatization of pelitized terrigenous grains and hydrated micas presumably occurred during the formation of playa sediments. Illite and chlorite, in these deposits form the main mineral mass, forming large concretions, cementing terrigenous grains, the content of which does not exceed 20%. Authigenic minerals in the studied crusts are represented mainly by carbonates, including pelitomorphic calcite, magnesium-calcite, and aragonite. Carbonate minerals occur as rather large concretions, up to 0.2 mm in diameter, mainly developing along clay aggregates and degrading organic matter (Figure 4c). Cubic and prismatic halite crystals, with bright growth zones and dissolution caverns, traces of recrystallization are characteristic for the surface crusts of Lake Kaltyk (Figure 4b).

An additional feature of the deposits of Lake Medvezhye is a significant admixture of *A. salina* cysts. Cysts, consisting mainly of nitrogen-containing polysaccharide (chitin), after fulfilling their direct function - preserving the body for a certain time, remain in the sediments in the form of empty membranes (Figure 5). Such shells have a high porosity and a specific surface, which allows them to actively interact with the surrounding colloidal medium. In the investigated sediments of the Medvezhye salt marsh, the shells of Artemia cysts are contained in significant volumes, sometimes up to 15-20% of the total volume of solid matter. Moreover, in drier areas located farther from the modern water line, the percentage of mineralized shells increases. The highly porous organic chitinous substrate is gradually replaced (or overgrown) with pelitomorphic microcrystalline forms of carbonates. Thus, in the presence of a large number of cysts in sediments, carbonate aggregates develop exclusively along them, without forming another kind of separation and not replacing pelitized terrigenous grains.

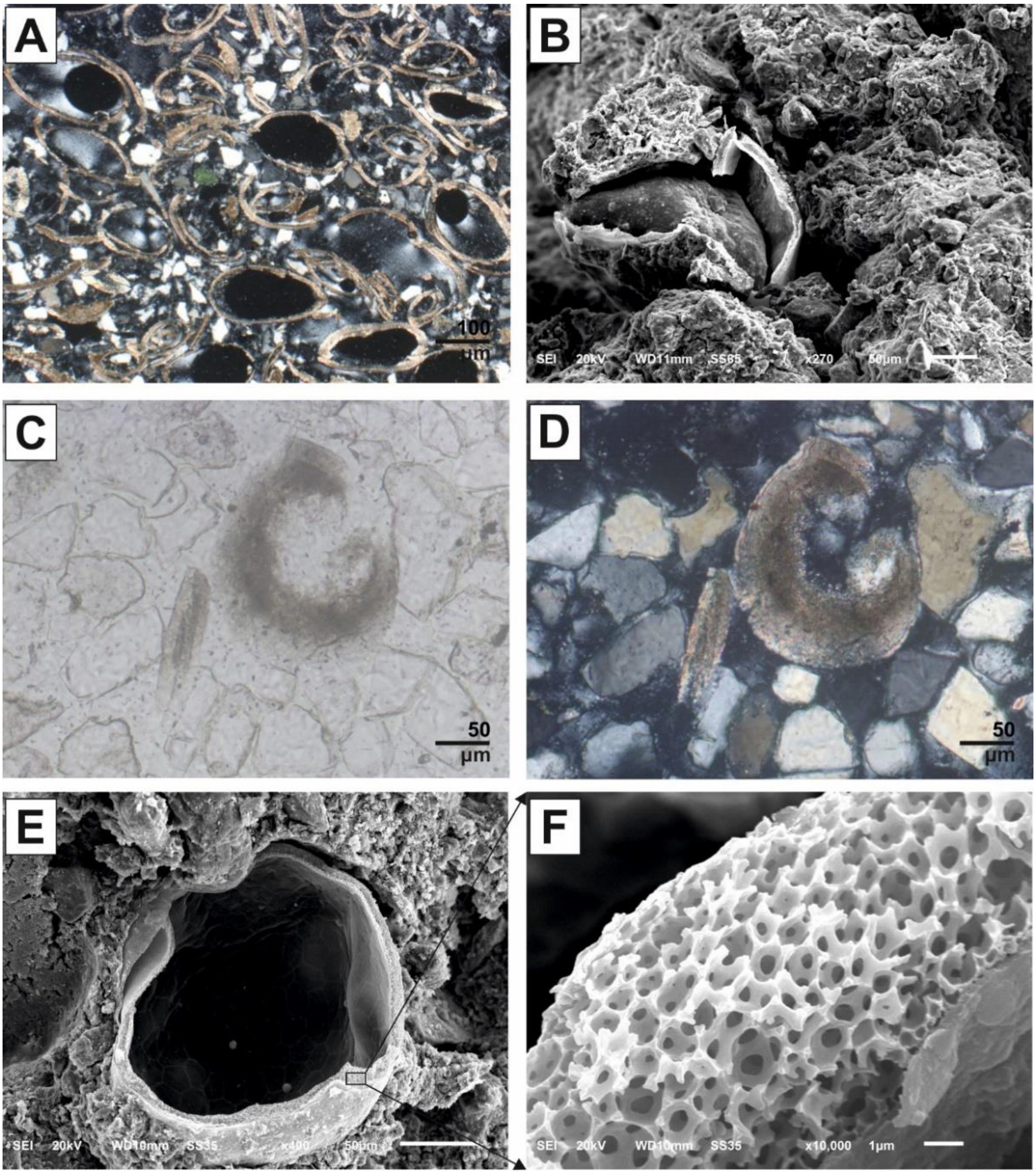

Figure 5. Microscopic features of *A. salina* cysts: thin section the surface crust filled with mineralized cysts (PPL) (a); SEM photo of a cyst with a preserved organic matter (b); thin sections (PPL and XPL, respectively) illustrating cyst shell replaced by pelitomorphic calcite (c and d); SEM photo of the cyst shell structure (e and f)

Conclusion

Playas are rather common environments adjacent to large saline lakes of the Trans-Uralian region. We have studied the features of mineral composition and microstructure of the dense solid fractured crusts developed within the saline playas of Medvezhye and Kaltyk lakes. The study results showed that the surface crusts of these two sites differ in terms of proportion of terrigenous material, clay minerals, as well as the composition of evaporates and carbonates. Authigenic minerals form scattered pelitomorphic concretions, less often dense mineral nodules, often replacing pelitized fragments and organic matter. The content of terrigenous mineral components in the sediments of Lake Medvezhye is much higher than in the samples from Lake Kaltyk. Chitinous shells of Artemia cysts play a significant role in the formation of surface crusts of Lake Medvezhye. In most cases cysts are partially or completely replaced by pelitomorphic carbonates, which is clearly expressed in the sediments of Lake Medvezhye, where the *A. salina* cyst content reaches 20% of the sediment volume.

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