Swelling clay minerals of bottom sediments of Uskol lake
(Republic of Khakassia)

M O Khrushcheva, T S Nebera
Tomsk State University, Lenin Avenue 36, Tomsk, 634050, Russia
E-mail: masha2904@mail.ru, tsnebera@mail.ru

Abstract. Results of study of mineral composition of Uskol lake bottom sediments are given in
the present work. Uskol lake is located on the territory of Uybatskaya steppe, South-Minusinsk basin. These are modern alluvial-deluvial sediments mostly consisting of clays and silts. Presence of such mixed-layer compounds as rectorite, Na-montmorillonite-Na-mica, swelling chlorites at the studied object was stated the first time. Regularity of clay minerals distribution through the section was observed. Its importance is conditioned by clay minerals ability to serve as indicators of paleoclimate and environmental conditions of sediments formation in the region. Bottom sediments mineral composition was defined: clay minerals, zeolite (analcime), quartz, feldspars, calcite, gypsum, halite.

1. Introduction
Uskol lake is located within the territory of South-Minusinsk basin, Uybatskaya steppe, at the left bank of Yenisei river near the Abakan river mouth. The landscape may be described as a combination of hill-flatlands of river valleys, lakeside depressions and low hilly cuesta-like ranges.

Climate is cryoarid with cold winter and hot dry summer. Average annual temperature varies from +1.8°C to -1.0°C. Recorded minimum temperature was -43.8°C (December 1966), maximum temperature – +36.0°C (July 1970). It’s important to notice that strong winds are typical for Uybatskaya steppe; wind speed may be up to 20-30 m/s that helps dust, snow and rock particles transportation [6].

Uskol lake includes three small lakes. Water is bitter and salty in all of them. Lakes are shallow with slightly sloping swampy banks. Sizes of the lakes 1350×977 m, 650×347 m, 815×674 m. Modern alluvial-deluvial sediments mostly consist of clays and silts. Underlying rocks are samokhvalskaya suite (Lower Carboniferous) green ash tuffs and yellowish sandstones with subordinate limestone layers with seldom reddish sandstone interbeds in the upper part [6].

2. Materials and methods
Bottom sediments sampling took place in the end of June 2018 by a research group from Tomsk State University. Sampling of salines across the lake transversely to elongation axis was carried out. Distance between nearest sampling points is 50 m. 10 samples were picked at each sampling point from the surface to 1 m deep at each 10 cm deep. About 80 samples were collected in total. Further the samples were dried and processed in the laboratory.

X-ray diffraction analysis was used for mineral composition study. Samples were powdered and analyzed with use of X-ray diffractometer X’Pert Pro (PAnalytical, Netherlands) with Cu-anode X-ray tube. Acquisition step was 0.02°, 2Ө angles range – 3-70°, rotation speed – 30 rpm, 0.1 s stay at
each point, operation radius – 141 mm. Obtained diffractograms analysis was carried out with use of HighScore software and PDF-4 Minerals international database [8]. The work was done with use of equipment of collective use center “Analytical center of geochemistry of natural systems” of Tomsk State University.

After observing mineral composition in general, clay minerals were analyzed more precisely. Oriented samples were prepared for that purpose: raw material was intensively stirred up in distilled water until all the salts dissolved, then the water was removed. Oriented samples were prepared of what was left. 10 g of the material was intensively stirred in distilled water. First it had been deposited for 3 hours with following decantation. Then it had been deposited for 24 hours at ambient temperature. Upper part of the suspension was removed and dried at 40 °C, 50 mg of obtained material was put in an agate mortar and mixed with 1 ml of distilled water and stirred. 7 drops of this suspension were evenly put on cover glasses 18*18 mm in size with use of pipette. After putting a sample on two glasses, a glycerin drop was added into what was left in a mortar. After stirring glycerin containing suspension was put on a glass too. Oriented samples had been heated in a muffle with thermostroller at 550 °C for two hours.

3. Results and discussion

Previously it was stated that bottom sediments of Khakassia lakes contain following minerals: quartz (SiO₂), albite (Na[AlSi₃O₈]), potassic feldspar (K[AlSi₃O₈]), halite (NaCl), ililit (K₀.₇₅(H₂O)₀.₂₅Al₂(Si₃Al)O₁₀(H₂O)₀.₂₅(OH)₀.₂₅), kaolinite (Al₂[Si₂O₅]OH₈), chlorite ((Mg, Fe, Al, Cr, Ni, Mn)ₓ(Si, Al)ₓ₂O₁₀(OH)ₓ⁻ (Mg, Fe, Mn)ₓ(OH)ₓ), calcite (CaCO₃), dolomite (CaMg(CO₃)₂), anatase (CaCO₃), gypsum (CaSO₄×2H₂O), thenardite (Na₂SO₄), astrakhanite/bloedite (Na₃Mg(SO₄)₂×4H₂O), wawatellite (Na₃Ca(SO₄)₂×4H₂O), epsomite (MgSO₄×7H₂O), eugsterite (Na₈Ca(SO₄)₂×2H₂O) [1, 2, 4].

Uskol lake bottom sediments were found out to have different mineral composition than previously studied sediments had: quartz (SiO₂), analcime (Na[AlSi₃O₈]×H₂O), feldspars (sanidine (KAlSi₃O₈), albite (NaAlSi₃O₈)), calcite (CaCO₃), gypsum (CaSO₄×2H₂O), halite (NaCl), clay minerals. X-ray diffraction characteristics are given below in the Table 1.

Table 1. Mineral composition of Uskol lake bottom sediments

| Mineral phase   | Interplanar distance in angstroms (d(Å)), intensity (I) | No PDF paper |
|-----------------|---------------------------------------------------------|--------------|
| Quartz          | 3.34₁₀; 4.25₂; 1.81₂                                     | [04-005-4718]|
| Analcime        | 3.42₁₀; 5.59₉; 2.9₂; 2.4₂                                | [00-045-0182]|
| Sanidina        | 3.32₁₀; 3.2₂; 3.7₈; 3.2₅                                    | [00-010-0353]|
| Albite          | 3.1₈₁₀; 3.1₉; 4.0₃; 3.7₉                                    | [00-041-1480]|
| Calcite         | 3.0₃₁₀; 2.2₅; 3.8₅; 1.8₇                                    | [00-008-0198]|
| Gypsum          | 7.5₇₁₀; 2.₈₆; 2.₅₈₁                                      | [00-015-4421]|
| Halite          | 2.₈₂₁₀; 1.₉₉; 3.₂₆; 1.₆₂₂                                    | [00-005-0628]|
| Montmorillonite | 1.₃₉₁₀, 4.₅₀; 1.₅₀, 3.₂₅; 2.₅₂                            | [00-012-0204]|

According to mineral composition study results it’s possible to conclude that the sediments consist of terrigenous minerals mostly: quartz, feldspars, zeolite (analcime). There is up to 70% of quartz, up to 20% of feldspars and up to 20% of analcime. Such composition corresponds to features of underlying primary rocks being eroded.

Calcite, gypsum, halite and clay minerals contents in an original sample may be up to 50%, 5%, 3%, 20% respectively. Calcite composes interlayers and impregnations throughout the cross section. Gypsum deposits on the very surface of the sediments (0-20 cm deep).

Detailed study of clay component of the bottom sediments of Uskol lake has revealed swelling minerals presence. It’s clay minerals that can serve as indicators of paleoclimate and environmental
conditions of sediments formation in the region [9-11]. Na-montmorillonite was found in original samples (figure 1).

Montmorillonite group minerals were found in sediments of the studied region though these are magnesium (saponite) or calcium montmorillonites. Na-montmorillonite is distributed immediately within bottom sediments of the lake and is found at any depth in the cross section. Smectite has a relatively symmetrical profile of the main reflection at 12.2-12.4 Å. This is a dioctahedral montmorillonite with Na⁺ in its interlayer space with ability for intracrystalline swelling.

It’s important to notice that zeolites and micas are deposited near the surface. Down the section mixed-layer minerals (like Na-rectorite) appear. Rectorite is a mixed-layer mineral of mica-smectite range with combination of dioctahedral mica sheets and smectite group minerals [3, 5]. There are basal reflections 23.81₁₀, 11.94₇, 3.4₀₂ Å appearing at the diffractogram of Na-rectorite containing sample in air-dry conditions.

**Figure 1.** Original sample diffractogram (collected at the depth of 80-90 cm): red line – in air-dry condition, blue line – after glycerin saturation, green line – after the heating.
Figure 2. Rectorite type mixed-layer mineral (dioctahedral mica-Na-montmorillonite) diffractogram: red line – in air-dry condition, blue line – after glycerin saturation, green line – after the heating. Note: dioctahedral mica (paragonite) – 9.76\,\text{Å}; 4.78\,\text{Å}; 3.21\,\text{Å}.

Precise diagnosis demands a glycerin saturated and pre-heated samples analysis. 17.66 \,\text{Å} reflection appears in the small-angle area after glycerin saturation, 9.76 \,\text{Å} reflection appears after heating. It indicates smectites presence in mixed-layer formations composition (figure 2).

There is reflections drift to 17.46 \,\text{Å} after glycerin saturation and to 9.76 \,\text{Å} after heating for mixed-layer formations of Na-montmorillonite – dioctahedral mica type (figure 3).

Swelling chlorite was found at the depth of 40-60 cm. Swelling chlorite gives 14 \,\text{Å} reflection that drifts to 17.6 \,\text{Å} after glycerin saturation like it does in smectites (Na-montmorillonite). At the same time it drifts to 13.6 \,\text{Å} after heating while in case of montmorillonite it should appear at 9.7-10 \,\text{Å} (figure 4).
Figure 3. Na-montmorillonite – dioctahedral mica type mixed-layer mineral diffractogram: red line – in air-dry condition, blue line – after glycerin saturation, green line – after the heating.

Figure 4. Swelling chlorite diffractogram: red line – in air-dry condition, blue line – after glycerin saturation, green line – after the heating.
4. Conclusions
Detailed study of clay compounds of the bottom sediments allows to conclude that there are mixed-layer minerals like Na-montmorillonite-Na-dioctahedral mica and swelling chlorite. Na-montmorillonite presence indicates hydrothermal material re- sedimentation and volcanic glass erosion within the basin. Na-montmorillonite presence in the bottom sediments also indicates there was alkaline sedimentation environment.

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