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MASTER’S THESIS

TURGOYAK LAKE SEDIMENTS: COMPOSITION AND FORMATION

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Abstract

The magnetic-mineralogical and geochemical studies, calculations of ignition losses, weathering indices, bottom sediment samples were carried out to detect climatic changes in the process of work. The processing and interpretation of the obtained data and apriori geological materials are performed. On the basis of the conducted research, zones of drying and moistening were revealed.

The bottom sediments of Lake Turgoyak (Chelyabinsk region) were selected as the object of research.

The work contains 67 pages, 5 sections, 32 images, 40 sources used.

The goal of the final qualifying work is: to study deposits of Lake Turgoyak using: magnetic-mineralogical analysis (measurement of magnetic susceptibility, natural residual magnetization, coercive spectrometry, differential thermomagnetic analysis), high-precision microscopy of the magnetic fraction of sediment using transmission electron microscopy (TEM) and scanning electron microscopy (SEM), determining the elemental and mineralogical composition, calculating the loss on ignition and. Finding levels of moisture and drying of the climate based on the results. Conducting the interpretation of these levels as analog sources of organic matter for the formation of hydrocarbons.

As a result of the research, features of sediment accumulation processes of Lake Turgoyak were revealed.

Key words: lake sediments, geochemical investigation, magneto-mineralogical investigations,

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NRM- Normal remanent magnetization

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Introduction

This paper is based on materials collected during the expedition in the summer of 2017 to Lake Turgoyak by the staff of institute of geology and petroleum technologies. The author of the final qualifying work is a laboratory researcher at the «Laboratory of Paleoclimatology, Paleoecology, Paleomagnetism» of institute of geology and petroleum technologies the Department of Geophysics and Geoinformation Technologies since September 2016.

The aim of the work is: Finding the levels of humidification and aridization of the climate based on the obtained results of magnetic-mineralogical and geochemical studies. The interpretation of those levels as analog sources of organic matter for formation hydrocarbons.

Objectives of the study: collecting information about the object of study, its geological and geophysical knowledge, measurements of samples of bottom sediments by magnetic and geochemical methods, processing and interpretation of the data obtained.

Chapter 1. Geological and geographical outline of the study area

1.1 Brief physical and geographical outline of the study area

The Turgoyak Lake (N 55°09'13"; E 60°06'31") is located in the Chelyabinsk Region (Southern Ural, Russia) (Figure 1.1). Lake Turgoyak is the deepest in the Urals. The average depth is 19.1 m. The maximum depth is 36.5 m. The water of the lake has a high transparency which is from 10 to 17 m. It is called the younger brother of the Baikal: soft Turgoyak water purity is just the second after Lake Baikal. It is very rare to meet on our planet the lake among the mountains and the beautiful pine forest filling with oxygen the whole district in the same place at the same time. The place where Lake Turgoyak is located is a national park. There are almost no mineral salts in the water that is why the water is very soft. The lake has a tectonic origin like many other lakes in the Southern Urals.

The area of the lake is 26.4 km²; the total catchment area is 76.0 km². Altitude above sea-level is 320 m. The greatest width – 6.3 km and the length of 6.9 km. The climate of the lake basin is continental with a steady snow cover in cold winter and short summer with high rainfall in July [1]. Such rivers as the Kuleshovka, the Bobrovka, the Pugachevka and the Lipovka supply water to this lake.



Figure 1.1 - Lake Turgoyak

The fossil diatom flora from Lake Turgoyak consists of 48 species that belong to 31 genera. The spectra are dominated by planktonic, oligotrophic and alkaliphilous to neutrophilous forms. The species-rich genera include of *Amphora* Ehrenberg, *Tabellaria* Ehrenberg, *Diploneis* (Ehrenberg) P.T. Cleve, *Navicula* Bory, *Staurosirella* D.M. Williams & Round, *Gomphonema* Ehrenberg, *Cymboplectura* (Krammer) Krammer, *Encyonema*, *Cymbella* Agardh and *Cavinula* D.G. Mann & Stickle. At the same time, the presence of centric diatoms *Ellerbeckia arenaria* (Moore ex Ralfs) Crawford indicates the well-developed littoral vegetation, probably with an inclusion of separate species of mosses. The presence of representatives of the genus *Campylodiscus* spp. reveals the high degree of water transparency in the lake [2]

The study area belongs to the territory of the Southern Urals, which covers two federal districts of the Russian Federation (the Ural and Volga regions) and three subjects (the Chelyabinsk and Orenburg regions and the Republic of Bashkortostan).

The geographical position of the Southern Urals: it originates from the top of Yurma, located in the north, ends in the south, on the latitudinal part of the Ural River (Fig. 1.2). In the eastern direction, the Uraltau water divide ridge is moving. The prevailing type of relief is medium mountain. Towards the east, the axial part smoothly flows into a smoother and lower Trans-Ural plain [3].

The relief of the Southern Urals is complex. Uneven ridges of the southwestern and meridional directions are dissected by deep longitudinal and transverse depressions and valleys. The greatest height - 1640 m - Mount Yamantau. Due to the junction of the wide foothills, the Southern Urals expands to 250 km. With an average width of the Ural Mountains from 40 to 150 km. The length of the Southern Urals is 550 km.

The Southern Urals is divided by features of the relief into two parts - the northern and southern. The northern one, taller and more mountainous, reaches the lateral flow of the Belaya River. It is filled with numerous mountain ranges, which extend from the northeast to the southwest and constitute the mountain system. Its axis is the ridge Uraltau. It stretches for 500 km in the eastern part of the Southern Urals, having a width of 5 to 30 km. Its highest peak reaches 1067 m (Arviak-Ryaz, south of the city of Beloretsk); the average height of the ridge is 800–900 m, and the adjacent valleys lie 400–500 m lower. Uraltau consists of several parallel ridges and small spurs, which are separated by wide hollows. The outlines of their aligned, soft; only some peaks raise small hills and ridges of shale, quartzite and conglomerates. Uraltau is a watershed between the basins of the rivers White and the Ural.



Figure 1.2 - Middle and South Urals. Physical map

The valley of the Belaya River separates to the west several parallel higher and rocky chains. The highest ranges in this lane are Zigalga and Mashak, and the highest mountain ranges are Yamantau and Iremel. They are composed of very hard quartz sandstones and shale. Steppe slopes, wide upland terraces and rocky peaks are very characteristic of their relief. The slopes of the mountain ranges are covered with coniferous forest to an altitude of 1100 m, and stone placers predominate above this line. On the mountain terraces and on the

tops, there are still preserved wall-shaped rocks (outcroppings) that make up the crest of some mountains.

To the west is a band of advanced mountain chains, having an average height well below 1000 m, and only a few peaks rise higher. Mountain ranges are separated from each other by wider longitudinal river valleys, and narrow transverse valleys divide each chain into ridges and arrays. The main ranges are Zilmerdak, Yurmatau, Kola, Karatau. The farther west, the lower the mountains. Rocks are also changing: there is more limestone here.

East of xp.Uraltau stretched chain of the advanced eastern ranges of the Southern Urals: Irendyk and Kryktytau. They are composed not only of sedimentary, but also of volcanic rocks. The mountains are severely destroyed, their tops are flat, but where volcanic rocks are exposed, rocks and ridges appear.

The climate of the Southern Urals belongs to the sharply continental, it is characteristic of hot summers and cold winters. 350-800 millimeters of precipitation falls annually. In the summer, prolonged rains are rare. The climate is directly influenced by the Ural Mountains, which create a natural obstacle to the movement of air masses. The weather in the winter season is determined by the Asian anti-cyclone coming from Siberia, and in summer by the tropical winds of Central Asia and Kazakhstan and the Arctic air masses of the Kara and Barents seas. In January, the average temperature is -16 degrees, July +15 degrees. The zone of excessive moisture - mountain forest, temperate - forest-steppe, inadequate - steppe.

1.2 Geological structure of the Southern Ural

In tectonic terms, the whole of the Urals, including the South, is a large anticlinorium, which consists of a complex system of anticlinoria and synclinoria, separated by deep faults. From west to east in the South Urals, there is a change in the structural-tectonic zones of the meridional strike, and with them the change in rocks that differ in lithology, age and origin (Figure 1.3).

All large zones of uplifts and deflections are limited by deep faults. Folded - blocky structures of the Southern Urals are composed of igneous, volcanic and metamorphosed rocks of the Precambrian and Paleozoic ages, among which granites, quartzites, diabases, volcanic tuffs, sandstones, limestone, conglomerates, etc.

The surface is universally covered with quaternary deposits of different composition and origin, and the ancient weathering crust, with which the deposits of a number of minerals are associated.

The following stages are distinguished in the history of the development of the Southern Urals:

- Paleozoic and Pre-Paleozoic. At this time there was deposition of sediments, the formation of folded mountains and intense volcanic activity. The first folding, Baikalsky, was manifested in anticlinoria (Urals and Bashkir).
- Mesozoic and Paleogene. At this time the tendency of the downward development of the relief prevailed. In the Triassic along the fault lines, the eastern part of the folded structures descended, and the foundation of the West Siberian Plate was formed. Consequently, there was a separation of the Ural mountain system. Lava erupted over faults. Cimmerian folding reflected on the eastern slope of the Urals by blocky movements and the creation of simple gentle folds. The high mountains were destroyed and flattening surfaces formed on which weathering crusts formed: placer deposits of precious metals, minerals and other mineral deposits are associated with them.
- Neogene-Quaternary. As a result of neotectonic movements, a folded-block, rejuvenated morphostructure of the modern Urals arose. Vertical movements of individual blocks are reflected in the modern relief of the Southern Urals. Young tectonic movements in the Urals contributed to the rise to the surface of the deep rocks of Paleozoic structures. In the fourth quarter, the Urals underwent glaciation. During the maximum glaciation, the edge of the ice sheet was about 60 ° C. sh. To the south of the ice sheet, glaciers and groups of glaciers were located on separate high peaks: Taganai and Yamantau.

In the southern Urals, the following types of morphosculptures are distinguished:

- erosion-denudation and karst. The main relief-forming processes here are erosive, which created deep, terraced longitudinal and transverse valleys, and karstic, expressed in diverse forms (caves, craters, underground rivers, etc.);
- not dismembered parts of the territory form ancient middle-mountain and low-mountain peneplains;
- arid-erosion denudation.

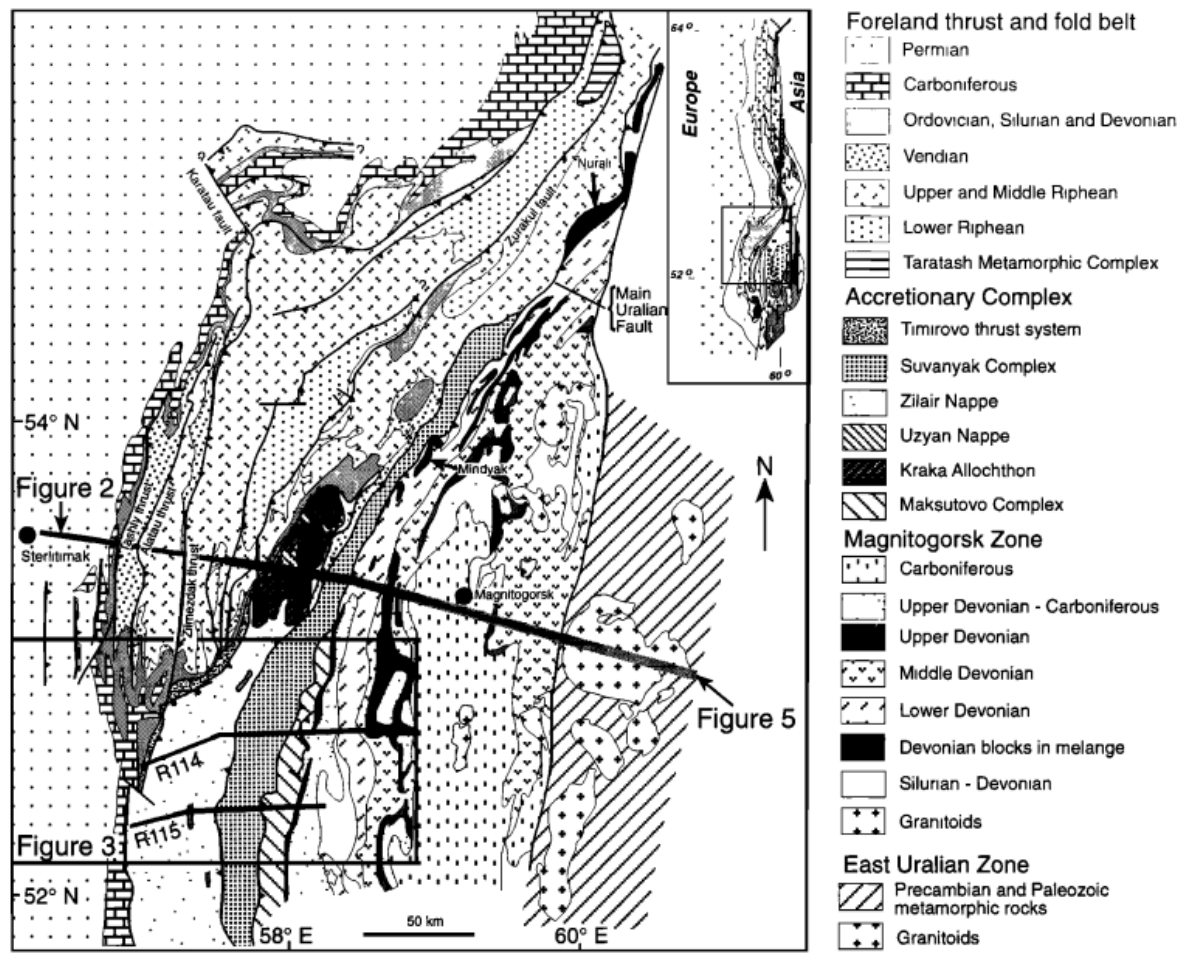


Figure 1.3 - Geological map of the southern Urals

The Uraltau watershed ridge, composed of schists, is shifted to the east and is not the highest in the Southern Urals. The prevailing type of relief is medium mountain. Some shallow peaks rise above the upper boundary of the forest. They are flat, but with steep stony slopes and complicated upland terraces. On the ridge of Zigalga, on Iremel and some other high peaks of the Southern Urals, traces of glaciation were found.

The climate of the Southern Urals is drier and more continental than the Middle and Northern Urals. And its continentality increases when moving from west to east and from north to south.

In winter, the warmer air from the East European Plain flows through the mountains and, without descending, goes further east over the cold Siberian air. In summer, the air passing over the mountains descends along the eastern slope, heats up adiabatically and at the same time moves away from the saturation point. Therefore, there is less precipitation on the eastern slope during the year than on the western (up to 500-300 mm).

Chapter 2. Origin and composition of lake sapropels

Sapropels are formed in anaerobic conditions as the result of physical and chemical, as well as biological transformations of the lakes' aquatic organisms provided different levels of the mineral and organic components involvement from terrigenous flow. The lakes flowage factor plays a great role in the benthic sediments formation. The average annual increase of sediments is 1 to 6.6 mm.

The sapropel sediments in modern lakes are typically not older than 12 thousand years. The freshwater pools sediments with organic substance content not less than 15% are considered sapropel, or else, if the organic substance content is lower, they are considered limnetic sediments. The composition and properties of sapropels from different deposits vary widely due to the parent lake productivity, surface flow peculiarities and climatic conditions.

Sapropel is a jelly-like homogeneous mass, its texture in upper layers is close to cream-like, and in lower layers it becomes denser. The sediments are odorless except for separate types which smell of hydrogen sulfide. Sapropel color depends on organic substance and mineral additions.

Sapropel consists of silt solution, skeleton and colloidal complex. Silt solution includes water and substances dissolved in it – mineral salts, low molecular weight organic substances, vitamins and enzymes. The sapropel skeleton consists of non-decomposed flora and fauna remnants, and the colloidal complex includes compound organic substances causing the jelly-like texture of sapropel.

Sapropel properties are determined by three principal components: water, cindery share and organic substances of a very complicated and versatile composition. Natural humidity of sapropel sediments is 84–96% (in average – 88.4%). The humidity differences can be explained by the versatility of the sapropels chemical composition and different ratio between the cindery and the organic share. The bigger organic share is, the higher sapropel humidity is. Principal share of the water retained by sapropel (up to 80%) is loosely bound water of macropores, retained in the material mechanically, 12–15% is the water immobilized inside of soft colloids, 8–15% is physically bound water, including 3–5% of tightly bound one. Loose water is a medium for microbiological and related processes in the sapropels due to which a range of substances accumulates therein. Well-developed specific surface of sapropels spurs the development of chemical interaction processes between water and solid phase, thus water becomes saturated with many soluble organic and mineral components. Thus the chemical composition of lake sediments water phase has higher overall

mineralization compared to the relevant lake water, increased content of specific macro- and microelements.

Organic matter in sapropels is represented by bitumoids, carbohydrate complex (hemicellulose and cellulose), humic substances (humic acids, fulvic acids), nonhydrolyzed residue. Organic matter content in sapropels is 15–95% of the dry mass. The variegated nature of sapropel formers caused the formation of sediments with different share of organic matter. Humic acids are a principal group of biologically active substances in sapropels, their content in sapropel sediments widely varies, from 4–9 to 50–60% of organic matter. Moreover, the organic matter includes carotenes, chlorophyll, xanthophylls, stearines, organic acids, alcohols, hormone-like substances, enzymes, vitamins of B group (B1, B2, B6, B12), C, E, P and other compounds. The nitrogen amount in sapropels of different types is 2.7–6.0% of the organic matter. 25-50% of nitrogen is included in aminoacids. There were 17 aminoacids found in sapropels (lysine, arginine, methyonine, leucine etc.). Hemicelluloses content is 5–8% of the organic matter.

Mineral share of the sapropels contains a lot of microelements, such as Co, Mn, Cu, B, Br, Mo, V, Cr, Be, Ni, Ag, Sn, Pb, As, Ba, Sr, Ti, and many other enzymes, e.g., catalases, peroxidases, reductases, proteases (Figure 1.3).

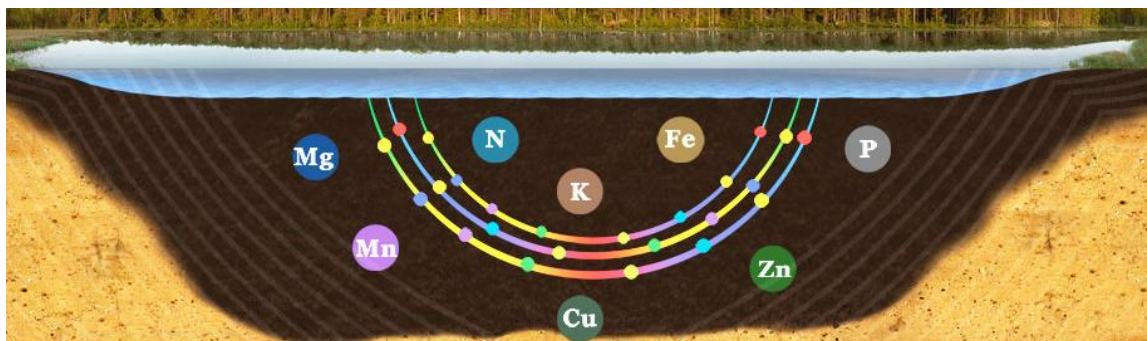


Figure 1.4 – Composition of the microelements of the sapropels

Sapropels («sapro»- rotten, and «pelos» - mud, silt) are centuries-old benthic sediments of freshwater pools which were formed from the defunct water flora, living beings remnants, plankton and the soil detritus particles containing lots of organic substances and humus. In other words, sapropel is organic and mineral natural matter composed of organic and mineral raw components of vegetal and animal origin.

Sapropel pertains to the class of fossil coals known under an umbrella term "Sapropelites". Sapropel sediments are characteristic only for freshwater pools. Thus, there are three main components in sapropels: water (60 to 97%), cindery part (sand, clay,

carbonites, phosphates, silica, iron compounds etc.) and organic matter of a very complex and varied composition. The most valuable components of sapropel are the biologically active substances and a whole set of microelements and aminoacids, which are beneficial for the health of people, animals and plants. It contains proteins, fats, vitamins, hormones, antioxidants, growth stimulants and many other substances.

The set of these substances and their concentration are largely determined by the sapropel bedding conditions, lakes flora and fauna composition, specific features of biochemical zone and bedding depth. Lack of oxygen, minor temperature fluctuations provide special conditions for benthic sediments where all living and dead cells of animals, microscopic algae, soil humus, fungi etc., are reduced to principal components: aminoacids and low molecular weight peptides, nucleotides, nucleosides with the production of “semi-living” cells and tissues, highly active biological substances.

2.1 Characteristics and classification of sapropel

Sapropel is a type of fine-grained and loose sediments, rich in organic matter, deposited in waterbodies. In petrology, the term ‘sapropelic coal’ denotes the sediments that are formed in the aquatic environment from the remains of macrophytes. The term ‘sapropel’ is often used to designate mainly dark-coloured sediments, rich in organic carbon [4].

In a narrower sense ‘sapropel’ (from Greek, ‘sapos’ rotten + ‘pelos’ mud) denotes contemporary or subfossil, colloidal sediments of continental waterbodies characteristic with a fine structure, that contains significant quantities of organic matter and remains of microscopic water organisms with a small amount of inorganic biogenic component content and admixture of mineral ingredients, which may include sand, clay, calcium carbonate and other minerals [5; 6].

Usually sapropel is formed in a relatively anoxic environment, as a result of physicochemical and biochemical transformations of lake hydrobionts with the participation of various mineral and organic substances in terrigenous (from Latin, ‘terrigenus’ created by land) runoff. The sapropel composition and properties in various fields of deposit are very various, and these differences are determined by the productivity of the particular waterbody, surface runoff characteristics and climatic conditions at the area. In general, sapropel is considered to be the specific freshwater sediments with the organic matter content greater than 15%, otherwise, if organic matter content is lower, such deposits are considered to be the mineral lake sediments [5;7].

Peat is a natural resource widely applicable in agriculture as a growth medium, substrate and soil additive [8]; however, the use of peat in many countries, e.g., Switzerland and United Kingdom, will be restricted in near future [9], thus giving a way for development of new soil amendments using alternative resources among which sapropel can be mentioned. Sapropel differs from peat, as summed up in Table 2.1, with its fine structure, reaction, quantity of organic matter, the remains of organisms forming it and the amount of humic substances [5; 10; 11].

Table 2.1 - The main differences between natural resources such as peat and sapropel

Indicators	Natural resource	
	Sapropel	Peat
Environment of formation	Relatively anoxic	Anoxic
Place of formation	Lakes, estuaries, rivers	Marshes, bogs
Organic matter content, %	15-85%	<50
Sources forming the organic matter	Aquatic organisms: phytoplankton, zooplankton, vascular water and coastal plants	Marsh plants: deciduous and coniferous trees, bushes, grasses, moss

Formation of a uniform terminology and classification of lake sediments is burdensome, because each interested science field has developed its own classification and lists of terms, which corresponds to the direction, objectives and certain aims of an individual research [12; 13; 14]. According to the origin of sediments, they can be divided into two large groups: ‘gyttja’ attributed to autochthonous sediments and ‘dy’ – to allochthonous sediments. Later the German scientist R. Lauterborn extended this classification by adding the term ‘sapropel’ describing sediments characteristic with hydrogen sulphide odour [15; 16]. The modern understanding of the term ‘sapropel’ has been introduced by H. Potonie. Classifying lake sediments, H. Potonie singled out two groups: ‘sapropel’ – viscous, finely dispersed residue, containing 25–90% organic matter, and mineralized sediments – ‘sapropelite’, which further can be split according to their mineral components: diatomite, lime, iron and sand [17].

A more detailed and most often used classification of sapropel has been provided by Pidoplichko&Grishchuk. According to their suggestion, lake sediments can be subdivided into seven types [18]:

- Clayey sapropel is highly mineral; usually it is deposited in lakes naturally; it is pasty, heavy, in grey or grey-blue color;

- Calcareous sapropel characteristic with ash content higher than 35% (including 50–65% CaO); deposits are formed in calcium rich groundwater outflow locations; it is of a grey-green colour, after drying out it forms unbound, whitish-grey mass;

- Silicate sapropel has a high ash content – greater than 30% (including SiO₂ >30% and CaO<10%); it is grey-green or green with sand grains and dark-coloured, dense dykes;

- Mixed sapropel has very high ash content (about 70–80%); it can contain a large amount of calcium and silicates, silicate and clay or clayey particles and calcium; such mixed lake sediments are formed from plankton organisms. Mineral supply source for this type of sapropel can be ground or surface waters; it can be greyish, dark green, blue-green or greyish-brown;

- Organic (fine detritus) sapropel has a low ash content not exceeding 30%. It is green, and with an admixture of humus – greenish-brown. Organic sapropel is formed in waterbodies that do not have large mineral matter inflow;

- Coarse detritus sapropel has low ash content. It accumulates in lakes, where in addition to planktonic organisms there are many vascular aquatic plants, whose residues in large quantities remain in sapropel. This sapropel is usually dark green in colour and the higher aquatic plant trace inclusions can be observed therein. It is usually deposited on the other sapropel types and does not form thick layers;

- Peaty sapropel is formed when the peat deposits come into a contact with a lake, or results from overgrowing of eutrophic waterbodies littoral. This is the intermediate formation between sapropel and peat, brown in colour and containing a variety of helmatic plants – residues of reeds, sedges, horsetails and other plants. When pulverized, peat sapropel does not smear, nor stain; it is characterized by a very low ash content (8–10%) and high decomposition (around 25–30%). This type of sapropel is deposited in layers between peat and sapropel deposits.

Changes of nitrogen content in vertical sections of sediments as well as other chemical indicators can be used for sapropel layer splitting in certain stratigraphic horizons.

Content of nitrogen in various types of sapropel ranges from 2.7% to 6% of organic substances and 0.5 to 4.0% dry weight. Organic substances of sapropel, which include animal residues, contain more nitrogen (4.4–4.8%) than algae (3.0–4.2%) or peat forming plant residue (2.6–3.5%) [19].

Content of sulphur in sapropelic organic matter ranges from 0.1% to 1.8%, not exceeding 3% in the dry mass, but while industrially preparing and storing sapropel, sulphur compounds are oxidized, thus the acidity increases [20; 21;22]. The highest sulphur concentrations in organic substances are present in the carbonate sapropel [13].

According to the elemental composition the freshwater sapropel is similar to humus. The sediments of saline lakes contains smaller amount of organic substances (approximately $\geq 10\%$); flora and fauna is poorer in these lakes and mineralization processes are faster [23; 24].

It should be noted that the total content of organic substance in various sapropel types is different: in organic sapropel 70–93% in silicate and carbonate sapropel – 15–70%, in mixed sapropel – 15–70% [25; 26; 21;13].

Chapter 3.Characteristic of bottom sediments of Lake Turgoyak

3.1 Position of the core columns and samples collection

For choosing the best places for coring seismic investigations were carried out. On the basis of seismic data we can determine basin structure, tectonic activity of the region, stratigraphically full record and thickness of sediments, the depth of the water column. A schematic map of the profiles and core sampling points is presented in Figure 3.1. Seismic studies were carried out using the seismic complex "boomer", which was developed in KFU.

Four the core columns of length from 3.84 till 5.46 m were sampled with the use of hydraulic core extractor [27]. Lake sediments are presented by sapropel interlayering from black to light gray colour with interlayers of a greenish-bluish tint. Sampled core was removed by layers from column tube, top semi-liquid sediment with step 10 sm, more dense sediment with step 2 sm. The central undeformed part of core was sampled in marked, oriented, nonmagnetic containers for further paleomagnetic researches. Further the samples were placed to special permalloy shields for exception of influence of external magnetic field. Peripheral part of core was sampled in marked ZIP-packs for laboratory researches. Table 3.1 shows the main characteristics of these core columns.

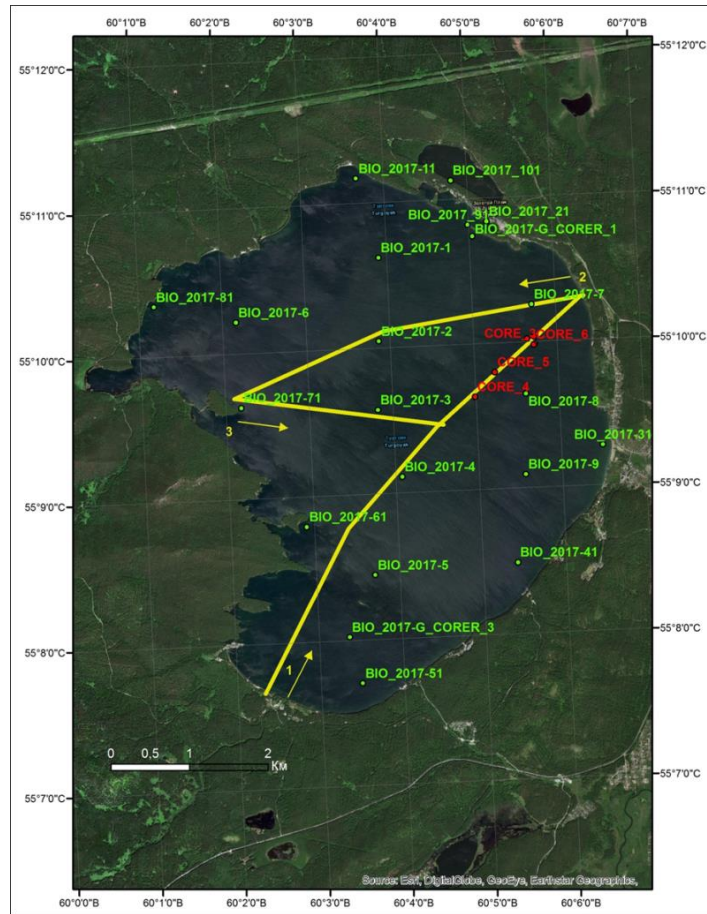


Figure 3.1 - Four seismic profiles covering the study area. 6 long core samples were also taken

Table 3.1 - The main characteristics of core columns sampled from Lake Turgoyak

Core №	Coordinates	Core length, m	Samples count
1	N 55°10'01,9" E 60°05'43,4"	5.46	273
2	N 55°10'01,3" E 60°05'38,5"	3.84	192
3	N 55°09'59,2" E 60°05'44,1"	5.26	263
4	N 55°09'38,3" E 60°04'59,2"	5.34	267
5	N 55°09'48,1 E 60°05'14,2	5.58	279
6	N 55°09'58,8 E 60°05'43,0	5.4	270

Acoustic data showed uneven distribution of sediment, outcrops of bedrock into the water column and break in sedimentation (Figure 3.2). The depth reaches 31 m. The largest thickness of sediments (up to 7 m) was found in the northeastern part of the lake basin. The upper 4 meters are represented with weakly consolidated organogenic sediments, below 3 meters of denser sand sediments [28].

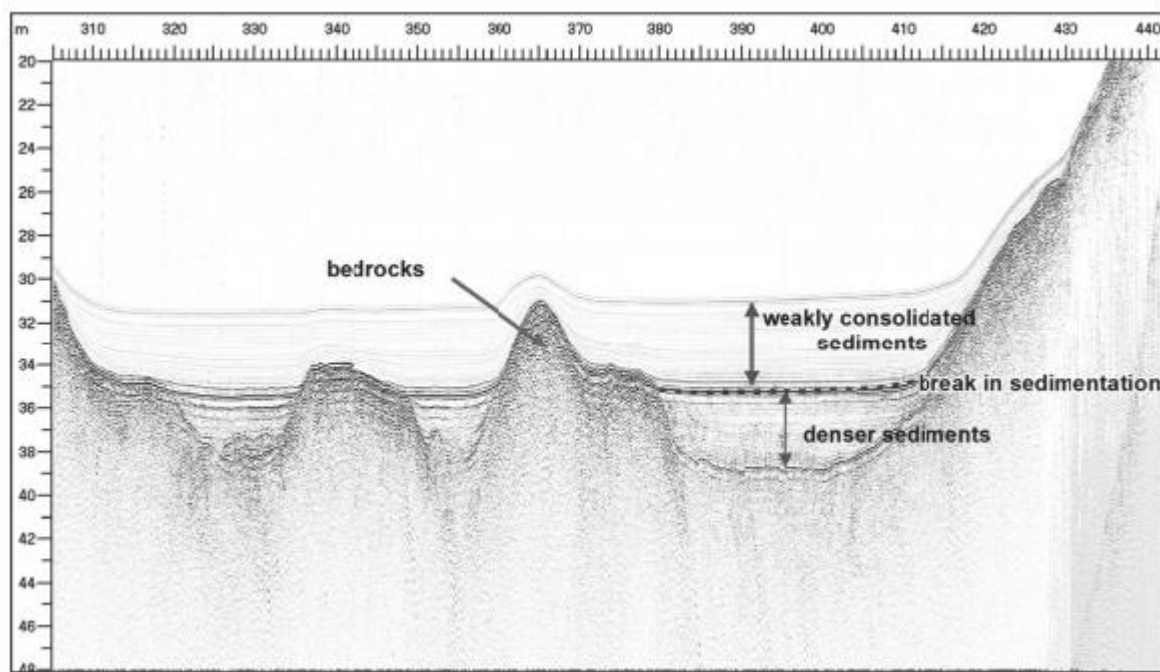


Figure 3.2 - Seismoacoustic profile №1. The most complete stratigraphic sequence

3.2 Lithological description of samples

Lake Bottom substances are represented by organo-mineral sapropelites and mineral sediments. Upper part is represented by weakly consolidated dark olive-brown silt deposit (Figure 3.3a).

Then the layer of sediment alternates with the layer of weakly consolidated sapropel of the same color (Figure 3.3b).



a



b

Figure 3.3 –Upper part of column 6. Section 1

Sediment compact is constant starting from 60 cm down the section. The color of sediments is gradient from dark to grey. Starting from the sediment depth of 342 cm clay components increase. Detrital fractions increase from the depth of 412 cm (clayed coarse-grained sand with mica). From the level of 214 cm the color changes to greenish gray (Figure 3.4a). From the depth of 446 cm sediment is gray consolidated (Figure 3.4 b). Fragments of higher vegetation are often found in samples of sediments on the levels of 54–59 cm, 58, 72, 96, 216, 256, 280, 290, 340, 368 cm. Large terrigenous material was recorded in the intervals of 434, 456 cm.



a



b

Figure 3.4 - Column 6: a) section 2 b) section 3

Chapter 4. Methods

4.1. Magnetic susceptibility and normalremanent magnetization (NRM)

Magnetic susceptibility (MS) was measured of all samples of the core №5 using a Multi-function Kappabridge MFKA1-FA (AGICO, Gzech Republic) (Figure 4.1) at the 976 Hz frequency for correlation core samples. All measured quantities were normalized by volume.

Magnetic susceptibility shows changes in the input of the material (sedimentation rate, type of sediment, indirectly - climate change, environment, etc.) and the conditions of its burial. The magnitudes variations of the magnetic susceptibility of samples in precipitation columns depend on a variety of reasons, most of which are common to the entire sedimentation basin, so this data is successfully used for the detailed correlation of the columns [29].



Figure 4.1 - Multi-function Kappabridge MFKA1-FA

The study of normal remanent magnetization (NRM) is important directions of studying the magnetic properties of sediments of modern lakes, the formation of which depends on many complex processes: fixation of allotygenic (and sometimes authigenic)

grains in the solidifying sediment (detrital magnetization), authigenic processes, such as the formation or reshaping ferrimagnetic grains (chemical or crystallization magnetization), long-term presence of rocks in an external magnetic field (a viscous residual magnetized be) and other [30]. Sometimes the NRM modulus curves are used for the correlation of core columns, but the usage of magnetic susceptibility is more correct.

The normal remanent magnetization was measured on an Enterprise 2G cryogenic magnetometer in the laboratory of geodynamics and paleomagnetism of the Central and Eastern Arctic of the NSU (Novosibirsk, Russia). Samples were measured being placed into special plastic containers with dimensions of 2.2 x 2.2 x 2.2 cm. The obtained values were reduced to the sample volume.

4.2. Coercive spectrometry

The samples from column No. 5 were ground to a powder by using an agate mortar and pestle, then special devices from a nonmagnetic material (made of diamagnetic brass) were packed into paper containers made from a sheet of paper measuring 4x3 cm (Figure 4.2).



Figure4.2 - Samples preparation

The spectrum of normal magnetization reached the fields' level of 1.5 T were obtained by using the coercive spectrometer "J_meter" [31; 32] that allows to record separately the residual and inductive magnetizations of samples at the room temperature.

The usual method of step-by-step magnetization of samples of the investigated substances is implemented and automated in the device. The electromagnet is source of the magnetic field. Inductive and residual magnetizations are measured by using induction sensors (coils), one of which is placed between the poles of an electromagnet, the other is outside the magnetic field in a multilayer permalloy screen.

The sample is placed on a diamagnetic disk rotating at a constant angular velocity with which it is introduced into a magnetic field to magnetize and measure inductive magnetization and is removed from it to measure the residual magnetization. The small step size ΔB turns the processes of magnetization and magnetization reversal into almost continuous ones. The electrical signals induced in the sensors by the magnetic field of a moving sample are amplified, filtered, digitized. The computer manages all parts of the parting, accepts the results of current measurements, processes them, visualizes and saves them to the disk. The role of the operator is to install the sample into the holder and input from the computer keyboard the name of the sample and the parameters of the magnetization process and processing. The block diagram of the electrical circuits of the device is shown in Figure 4.3.



Figure 4.3 - The general view of the coercive spectrometer J_meter

4.3. The differential-thermomagnetic analysis

The thermomagnetic analysis (TMA) is the main type of diagnosis of the composition of the ferrimagnetic fraction of rocks [33; 31]. TMA is based on the study of the dependence of inductive magnetization, residual magnetization or magnetic susceptibility on temperature at heating rates from 10 to 150 °C / min. When the Curie temperature is reached, magnetic ordering is destroyed and the ferrimagnet becomes a paramagnetic. The high heating rate makes it possible to reduce the effect of oxidation, which is important for obtaining more

reliable information about the primary minerals contained in the rock. The expressiveness of research and the dependence of the Curie point is only on the composition of ferromagnetic minerals, not on their percentage, size and shape, are significant advantages of the method. The differential thermomagnetic analysis (DTMA) is the most informative modification of thermomagnetic analysis [33].

Differential thermomagnetic analysis of samples by induced magnetization was performed on autoregistering torsional magnetic weights acting by the zero method (Figure 4.4). The dried sample was ground and placed in a measuring container, which is a quartz tube 3-4 cm long and 3-5 mm in diameter before measuring. Each sample was heated in a magnetic field of 200 mT twice at a heating rate of 100 °C / min. First, the sample was heated to a temperature of 800 °C, then cooled to room temperature and again heated to 800 °C. As a result of measurements, the dependences of the inductive magnetization on temperature for 26 samples were obtained.



Figure 4.4 - Autoregistering torsion magnetic scales

4.4. Determination of the elemental composition of bottom sediments

The X-ray fluorescence analysis (XRF) was applied to determine the elemental composition of lake sediments. The measurements were carried out using a Bruker S8 Tiger X-ray fluorescence spectrometer. An X-ray tube is used as a radiation source. The different values of current and voltage on the tube are used for different groups of elements. Sample

preparation of the sample includes grinding to sample particles to a size of 40-50 microns, and pressing with boric acid on a press with a force of 20 tons, to obtain a tablet with a very smooth surface. This tablet is placed in the device for analysis. Calibration of the instrument was carried out using standard samples. The matrix in standard samples is SiO₂. This allows you to take into account the influence of matrix effects in the analysis of all other elements. Samples for analysis were taken after 0.1 m from column 5.

The determination of organic carbon was carried out according to the following procedure. A small sample of test bottom sediments (about 0.5 g) were placed in ceramic tigers, poured with 10 solutions of hydrochloric acid for 1 day. The reaction stopped during this time. This approach eliminated inorganic carbon. Then the crucibles were calcined in a SNOL1100 muffle furnace to a temperature of 900 ° C for 4 hours. After cooling, the precipitate was weighed, and the loss on ignition was determined.

The study of the patterns of chemical and mineralogical composition of lake sediments, the identification of geochemical indicators of changes in sedimentation conditions is a definite information resource for paleogeographic reconstructions.

The lithochemical ratios or indices are informative to clarify the conditions for the formation of lake sediments:

Al₂O₃ / SiO₂ (inverse SiO₂ / Al₂O₃ ratio [34]) is an alumina-silicon module that reflects the differentiation of silica and hydrolysis products.

TM (Titanium Module [35]) = TiO₂ / Al₂O₃ - indicates the degree of precipitation recyclization; This is a high degree of continentality of the phases, which indicates the maturity of the detrital components and the degree of mechanical sorting of the territory.

(Fe₂O₃ + MnO) / (Al₂O₃ + TiO₂) [35] - iron module: 0.1-0.4 - low and normal iron.

V / Cr (and, or Ni / Co) ratios reflect the redox conditions of sedimentation and aeration of the sedimentation basin. Ratio values less than 1 are comparable to the oxidative conditions of sedimentation and a well-aerated basin [36].

Ca / Mg (or Ca / Sr) is a ratio that can be used as an indicator of the salinity of the sedimentation basin (the lower the ratio, the greater the salinity) [37].

Ti / K is a ratio that indicates the intensity of chemical weathering of feldspars due to changes in climate humidity — the greater this ratio, the greater the rate and degree of chemical weathering and the wetter the climate [36].

The contents of CaO and SrO are also used as indicators of climate (in periods of low content they increase, in periods of warming they decrease).

An increase in the Br content is interpreted as an indicator of warming [38].

Data on the mineral composition were obtained for a more complete presentation of data on the study of mineral resources and climate change: silica, clay minerals, carbonate and sulphate minerals, chloride compounds, for example, according to [39].

4.5. Determination of the mineral composition of bottom sediments

The mineralogical composition of the sediments was determined from samples taken after 0.3 m taking into account the geochemical zoning by X-ray phase analysis, which was performed on a Bruker D2 Phaser diffractometer. Sample preparation involves grinding the sample in a mortar with the addition of 5 g of ethanol. The dried product is evenly applied to the matte surface of the slide, pre-lubricated with petroleum jelly. The surface of the drug is pressed and smoothed with a metal plate so that its surface is perfectly flat. The diffractograms of the samples were obtained in the course of the research, and then the crystalline phases present in the samples and their percentage were determined from them.

4.6. Radiocarbon dating

The radiocarbon method of dating organic materials is widely used in the study of natural objects by measuring the content of the ^{14}C carbon isotope.

Lake sediments usually contain organic carbon in the form of the sum of components of plant origin, formed both in the lake itself and those caught in it from coastal slopes, water flows and the atmosphere, as well as remnants of animal organisms. It is necessary to be confident in the uniqueness and stability of the obtained solution of the problem when conducting radiocarbon dating of bottom sediments. It is possible to minimize the errors of absolute dating by attracting additional information about the conditions of sedimentation, possible post-sedimentation processes. Similar information can be obtained by seismic stratigraphic interpretation of acoustic time sections.

Considering the above, we decided to separate the small fraction of organic matter, which includes plant residues, insect cysts living in the lake and pollen. The reference column was selected for each group and samples were selected for dating since the core columns of Lake Turgoyak are geographically divided into three groups located in different depressions. The sample preparation was carried out on samples taken from columns No. 1.4 and 5 from the levels given in table 4.1 for the purpose of separating the fine fraction of organic matter

Table 4.1 - Selected Samples for Radiocarbon Dating

Core №	Sample №	Depth, cm
1	1-2	17-19
1	13-14	41-43
1	48-49	111-113
1	132-133	279-281
1	176-177	367-369
1	208-209	431-433
1	268-269	551-553
4	1016-1017	447.5-449.5
4	1058-1059	531.5-533.5
5	1218-1219	249.5-251.5
5	1272-1273	357.5-359.5
5	1312-1313	437.5-439.5

The stages of sample preparation included the etching of the samples with 10 acetic acid solution until the manifestations of the reaction course disappeared; centrifuging samples with a heavy liquid to separate organic matter from the mineral fraction; drying at 25 ° C; packing and labeling of samples.

The samples prepared for radiocarbon dating are presented in Figure 4.5.

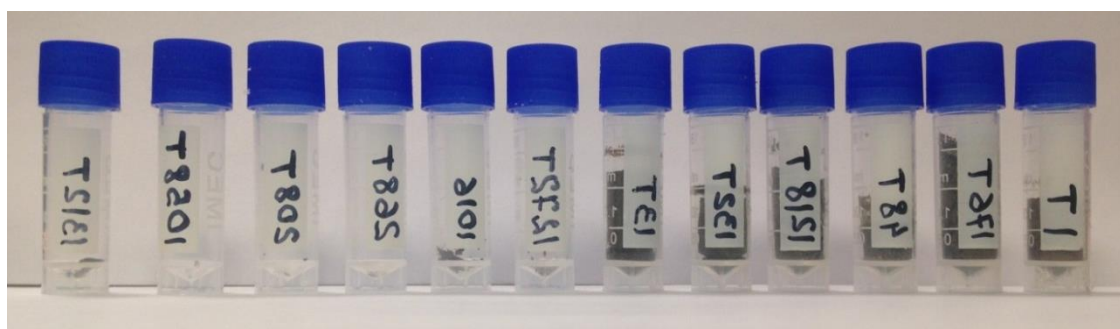


Figure 4.5- Samples for radiocarbon dating

The prepared samples were sent to Taiwan at the National University of Taiwan's Faculty of Earth Sciences (NTUAMS Lab) where measurements were made on a 1.0 MV HVE accelerator mass spectrometer.

The software OxCal v4.2.4 Bronk Ramsey (2013) and the IntCal 13 calibration curve are used to calibrate the age of the samples. This allows determining the time intervals with the highest probability. A probabilistic calibration technique is used and the Gaussian distribution of convective radiocarbon age at the calibration curve is transformed into the probability distribution of the calibrated age. The obtained radiocarbon dates are given in the number of years to the present day with an indication of a possible statistical error. The date – 1950 adopted for the moment of reference.

4.7. Microscopy of magnetic separate of samples

The microscopy is only direct method proving the content of magnetophossies in samples of bottom sediments. The magnetic separation of the sample it is necessary to carry out to be sure that it is magnetic particles that are observed under a microscope. The size, morphology of the crystals and the structure of the compound of the crystals with each other allows identifying magnetic fossils in sedimentary rocks.

The following describes the developed magnetic separation technique. Initially, the sample was ground and poured with distilled water. A rare-earth magnet in the fingertip was placed in a test tube with a sample to prevent contamination. A glass with a sample and a magnet was installed in the stirring unit for 0.5-3 hours depending on the amount of the dry sample (Figure 4.6 a). Then the magnet wrapped in the fingertip was taken over, and magnetic distilled water was rinsed from it into a Petri dish (Figure 4.6 b, c).

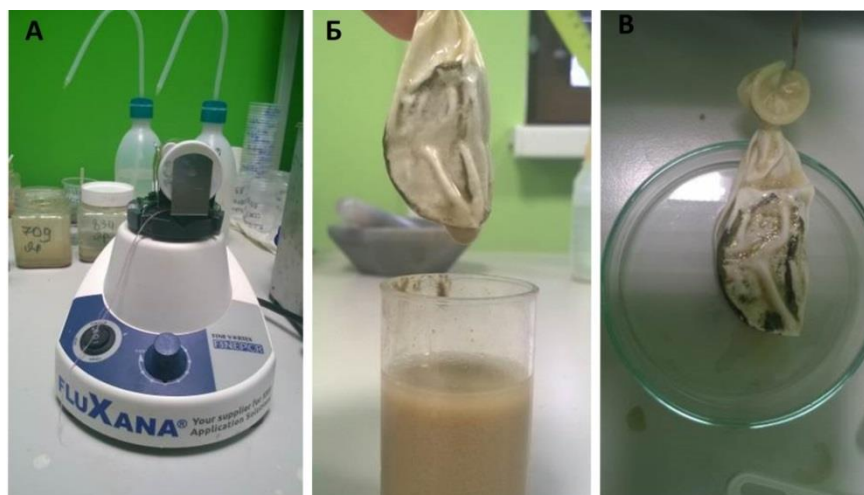


Figure 4.6 - The first stage of magnetic separation: a) stirring apparatus, b) a magnet with separate c) a magnet in a petri dish

A Hitachi HT7700 Excellence transmission electron microscope was used to determine the presence of magnetic microfossils in the samples. The sample preparation technique included placing 10 μ l of a magnetic separable suspension on a 3 mm copper mesh with formvar / carbon substrate, and drying at room temperature. The mesh was placed in a transmission electron microscope after complete drying, in a special holder for microanalysis. The survey was conducted at an accelerating voltage of 80 kV in TEM mode, elemental analysis was carried out in STEM mode with the same parameters using an Oxford Instruments X-Max TM 80T detector.

The studies were conducted on a Merlin autoemission scanning electron microscope by Carl Zeiss. Samples of a magnetic separative specimen fixed to the holder were placed in an electron microscope chamber, and probing was carried out from selected sites. The microscope is equipped with an AZtec X-MAX energy dispersion spectrometer. The resolution of the spectrometer is 127 eV. The measurement accuracy is 0.01-1 and depends on the state of the object under study. Surveying the surface morphology was carried out at an accelerating voltage of 5 keV to improve the depth of field of the image. Elemental analysis was carried out at an accelerating voltage of 20 keV and a working segment of 9 mm, which allows to avoid minimal errors. The depth of sensing is less than 1 micron.

Microprobe analysis was carried out from several points and areas to identify heterogeneity of the sample composition. These points are marked with circles, crosses, or rectangular areas in photographs. For each point marked with a cross, the spectrum and the table of the elemental composition of the probed region are given.

A set of standards set in the Aztec program was used For quantitative analysis (reference standarts for X-RAY microanalysis “Registered Standart No. 8842”).

Chapter 5. The results

5.1 Elemental composition of sediments

The measurement data by the XRPA method are presented in Tables 5.1, 5.2 as percentage contents of elements in the ash part of the samples. Variations of the main macro and microelements are presented in Figure 5.1.

The variation of lithochemical parameters shows in Figure 5.2. According to the indicators of $\text{SiO}_2 / \text{Al}_2\text{O}_3$, STI sediments appear mature. TM indicates the continental genesis of precipitation, the maturity of the detrital component and a high degree of mechanical sorting of terrigenous material. The iron module indicates a high iron composition of precipitation. The content of iron oxide increases up the section. SrO and SO_3 indicate a decrease in the salinity of the sedimentation basin. Up the section, the CaO content decreases, which, along with a decrease in SrO and an increase in the Br content, indicates climate warming, at which ever younger precipitation accumulated. However, it is worth paying special attention to the 3.5-4.8 m section, where there is a sharp change in the values of these indicators, which may be due to a sharp cooling of the climate. The values of Ti / K indicate that in younger sediments the rate and degree of chemical weathering is greater, and they accumulated in a more humid climate.

The core column No. 6 immediately after the selection was divided into 3 sections, packed in containers and sent for continuous analysis by XRF method to the Professor of the Institute of Geology and Mineralogy of the University of Cologne Martin Meles. The measurements were carried out with a step of 2 mm. Some results are presented in Figure 5.3.

Table 5.1 -The contents of macronutrients in the sediments of the column 5c ppm

Sample №	Depth, cm	Na	Mg	Al	Si	S	Cl	K	Ca	Fe	P	Ti
1	2	3	4	5	6	7	8	9	10	11	12	13
1100	13	0.22	0.52	2.53	21.35	0.35	0.03	0.65	1.33	3.31	0.34	0.24
1105	23	0.25	0.63	2.97	20.38	0.41	0.03	0.67	1.12	3.24	0.30	0.21
1110	33	0.19	0.54	2.92	21.85	0.35	0.03	0.72	1.09	3.31	0.32	0.23
1115	43	0.26	0.76	3.77	19.80	0.42	0.03	0.82	1.13	3.11	0.13	0.26
1120	53	0.18	0.59	2.90	22.43	0.36	0.03	0.75	1.16	3.37	0.31	0.25
1125	63	0.26	0.70	3.69	20.64	0.36	0.03	0.91	1.35	3.81	0.24	0.30
1130	73	0.20	0.68	3.59	20.05	0.37	0.03	0.96	1.25	3.90	0.25	0.31
1135	83	0.29	0.79	3.56	20.77	0.39	0.03	0.80	1.14	3.84	0.21	0.27
1140	93	0.26	0.64	2.92	21.46	0.37	0.02	0.88	1.30	4.38	0.40	0.30
1145	103	0.37	1.05	4.07	20.95	0.42	0.03	0.91	1.35	3.57	0.11	0.31
1150	113	0.32	0.94	3.80	19.67	0.41	0.03	0.87	1.22	3.74	0.16	0.31
1155	123	0.32	0.82	3.36	23.24	0.37	0.03	0.74	1.07	3.00	0.16	0.25
1160	133	0.26	0.66	3.01	24.19	0.36	0.02	0.78	1.11	3.13	0.24	0.26
1165	143	0.24	0.60	2.93	24.31	0.36	0.03	0.77	1.01	2.99	0.27	0.24
1170	153	0.18	0.56	2.45	23.79	0.37	0.02	0.65	1.00	2.86	0.32	0.22
1175	163	0.32	0.79	3.07	23.23	0.47	0.03	0.72	1.04	2.64	0.11	0.23
1180	173	0.30	0.66	2.86	22.39	0.45	0.03	0.79	1.11	2.90	0.21	0.25
1185	183	0.25	0.72	2.91	23.98	0.50	0.02	0.71	0.86	2.78	0.15	0.22
1190	193	0.26	0.66	2.75	21.99	0.52	0.03	0.79	1.20	3.18	0.23	0.27
1195	203	0.41	1.00	4.02	20.69	0.58	0.03	1.01	1.28	3.51	0.10	0.32
1200	213	0.34	1.02	4.18	20.29	0.57	0.03	1.26	1.46	5.20	0.33	0.43
1205	223	0.27	0.79	3.49	21.15	0.45	0.03	0.79	0.95	3.25	0.31	0.23
1210	233	0.28	0.82	3.54	21.38	0.45	0.03	0.97	1.26	3.83	0.24	0.32
1215	243	0.31	0.92	3.75	21.29	0.53	0.03	0.91	1.08	3.17	0.10	0.27
1220	253	0.33	0.88	3.68	20.15	0.46	0.03	1.05	1.34	3.90	0.32	0.33

Continuation of the table 5.1												
1	2	3	4	5	6	7	8	9	10	11	12	13
1225	263	0.35	1.03	4.12	20.63	0.47	0.04	0.95	1.21	3.55	0.14	0.31
1230	273	0.31	0.89	3.63	20.80	0.51	0.03	1.03	1.37	3.93	0.29	0.32
1235	283	0.33	1.01	4.39	20.59	0.57	0.04	1.03	1.25	3.83	0.09	0.33
1240	293	0.37	0.93	4.03	21.73	0.50	0.04	1.08	1.30	3.85	0.23	0.30
1245	303	0.43	1.27	5.07	18.78	0.56	0.04	1.21	1.39	4.94	0.36	0.38
1250	313	0.53	1.45	6.08	19.95	0.60	0.03	1.46	1.39	4.94	0.12	0.44
1255	323	0.62	1.50	6.12	18.89	0.90	0.02	1.47	1.56	4.80	0.09	0.43
1260	333	0.69	1.67	6.72	20.84	0.92	0.02	1.60	1.30	4.95	0.08	0.47
1265	343	0.73	1.91	7.46	21.66	1.40		1.80	1.33	5.57	0.08	0.51
1270	353	0.59	1.86	7.58	21.73	0.92	0.02	1.87	2.88	5.56	0.07	0.52
1275	363	0.63	1.80	7.00	20.53	1.83	0.02	1.85	2.06	5.92	0.08	0.51
1280	373	0.50	1.49	5.16	14.95	1.44	0.02	1.56	3.70	4.31	0.09	0.38
1285	383	0.46	1.65	5.45	17.65	1.32	0.02	1.75	7.63	4.65	0.08	0.39
1290	393	0.71	1.91	7.21	20.93	0.86	0.01	2.30	6.05	5.52	0.07	0.54
1295	403	0.67	1.93	7.81	23.15	0.11		2.30	5.65	4.25	0.06	0.56
1300	413	0.63	1.87	7.47	21.94	0.12		2.23	6.50	4.49	0.06	0.57
1305	423	0.67	1.89	7.65	22.57	0.17		2.18	6.65	4.32	0.08	0.56
1310	433	0.58	1.81	7.18	21.11	0.12		2.05	8.00	4.22	0.09	0.53
1315	443	0.54	1.86	7.44	21.89	0.10	0.01	2.29	6.21	4.97	0.07	0.60
1320	453	0.68	2.13	7.83	22.47	0.18	0.01	2.31	5.22	5.11	0.06	0.58
1325	463	0.73	2.27	8.04	22.87	0.14		2.32	4.58	5.41	0.06	0.59
1330	473	0.67	2.32	8.47	23.34	0.12		2.32	2.85	5.77	0.07	0.59
1335	483	0.68	2.19	8.02	22.38	0.13		2.28	4.36	5.58	0.07	0.59
1340	493	0.69	2.19	7.84	22.09	0.09	0.01	2.28	5.20	5.39	0.09	0.56
1345	503	0.52	2.00	7.15	22.56	0.09	0.01	2.19	5.37	5.56	0.07	0.56
1350	513	0.83	2.07	7.65	21.75	0.09		2.20	5.66	5.31	0.08	0.55

Continuation of the table 5.1												
1	2	3	4	5	6	7	8	9	10	11	12	13
1355	523	0.51	1.84	6.75	18.69	0.11		1.92	4.99	4.70	0.08	0.50
1360	533	0.65	2.17	7.95	21.77	0.11	0.01	2.26	5.21	5.46	0.08	0.56
1365	543	0.73	2.13	7.81	22.38	0.12		2.22	4.75	5.15	0.08	0.55
1370	553	0.72	2.11	7.75	22.42	0.11		2.23	4.94	5.52	0.08	0.57

Table 5.2 - The contents of microelements in column 5 ppm sediments

Sample №	Depth, cm	V	Cr	Mn	Zn	Br	Rb	Sr	Zr	Ni	Cu	As
1	2	3	4	5	6	7	8	9	10	11	12	13
1100	13	92.47	69.11	1259.58	121.17	138.00	31.08	103.05	31.07	73.95	87.72	18.94
1105	23	0.00	70.47	1285.14	96.30	146.00	39.30	117.41	44.39	59.00	70.97	10.61
1110	33	113.21	57.47	982.25	111.54	116.00	35.65	84.47	31.07	74.73	81.34	12.88
1115	43	123.30	52.68	763.80	112.35	134.00	50.27	126.70	48.83	81.03	78.95	0.00
1120	53	0.00	81.42	996.97	116.36	126.00	42.04	110.65	34.77	79.45	74.96	9.85
1125	63	106.48	88.26	774.65	140.43	137.00	54.84	134.30	49.57	95.97	101.28	9.09
1130	73	108.73	83.47	874.58	141.23	123.00	54.84	119.94	46.61	90.47	98.89	11.36
1135	83	0.00	84.16	1123.24	126.79	110.00	48.44	135.99	54.01	77.88	85.33	10.61
1140	93	103.68	72.53	2130.28	117.96	92.00	41.13	124.17	48.09	77.88	82.94	9.85
1145	103	105.92	73.89	756.83	109.94	105.00	51.18	141.06	61.41	84.17	79.75	9.85
1150	113	114.33	67.05	917.18	117.96	120.00	48.44	140.21	55.49	95.97	88.52	9.09
1155	123	0.00	69.79	804.86	95.49	102.00	41.13	124.17	53.27	62.15	72.57	7.58
1160	133	108.16	57.47	646.83	109.14	102.00	42.04	110.65	42.17	75.52	80.54	9.85
1165	143	0.00	71.16	859.08	102.72	88.00	39.30	102.20	36.25	65.29	73.37	0.00
1170	153	0.00	58.16	1020.99	101.91	100.00	33.82	103.89	35.51	63.72	70.18	7.58
1175	163	0.00	62.95	632.89	89.07	107.00	37.47	130.92	51.79	65.29	61.41	0.00
1180	173	98.64	67.74	554.65	99.51	111.00	37.47	120.79	42.17	70.80	64.59	8.33

Continuation of table 5.2												
1	2	3	4	5	6	7	8	9	10	11	12	13
1185	183	0.00	53.37	745.21	97.10	114.00	42.96	123.32	53.27	65.29	70.97	11.36
1190	193	112.09	62.26	647.61	110.74	119.00	42.96	130.08	45.87	68.44	72.57	9.09
1195	203	122.74	69.11	658.45	124.38	129.00	51.18	197.65	74.72	83.39	79.75	10.61
1200	213	139.55	111.53	1337.04	162.10	114.00	75.86	201.03	230.83	125.87	105.27	12.88
1205	223	118.81	47.21	1114.72	109.14	103.00	46.61	129.23	51.05	65.29	74.96	0.00
1210	233	107.04	69.79	692.54	150.86	115.00	51.18	140.21	51.79	86.53	90.11	11.36
1215	243	112.09	69.79	563.17	121.17	116.00	53.01	156.26	62.15	72.37	82.94	10.61
1220	253	124.42	78.68	933.45	141.23	115.00	49.35	152.04	50.31	79.45	85.33	8.33
1225	263	118.81	69.11	744.44	136.42	125.00	57.58	162.17	68.80	77.88	84.53	10.61
1230	273	128.90	72.53	810.28	147.65	128.00	52.10	167.24	57.71	83.39	87.72	9.85
1235	283	127.78	72.53	563.94	148.46	127.00	64.89	195.12	76.94	81.81	91.71	0.00
1240	293	127.78	77.32	594.15	139.63	114.00	59.41	180.76	65.85	70.80	75.76	10.61
1245	303	147.40	104.68	1600.42	158.09	126.00	68.55	198.50	89.52	87.32	86.13	12.12
1250	313	145.15	107.42	735.92	165.31	107.00	85.91	239.04	117.63	101.48	89.32	0.00
1255	323	159.73	113.58	584.86	140.43	145.00	77.69	217.92	113.20	96.76	75.76	15.91
1260	333	154.12	104.68	512.04	120.37	119.00	79.52	199.34	120.59	98.33	69.38	15.91
1265	343	159.16	121.11	543.03	125.19	77.00	86.83	204.41	145.01	118.79	68.58	18.18
1270	353	160.85	134.79	604.23	125.19	23.00	101.45	236.50	139.83	131.37	84.53	21.21
1275	363	161.97	109.47	642.18	117.16	118.00	92.31	239.88	148.71	110.13	68.58	30.30
1280	373	120.49	82.79	699.51	92.28	88.00	71.29	319.28	101.36	76.31	45.46	30.30
1285	383	138.43	86.21	940.42	109.94	66.00	80.43	539.74	106.54	80.24	57.42	40.91
1290	393	164.21	121.11	848.24	121.17		93.23	436.69	146.49	111.71	66.19	28.79
1295	403	164.77	106.74	730.49	116.36		103.28	424.02	173.86	96.76	66.99	12.12
1300	413	169.81	131.37	852.11	125.19		98.71	401.21	176.82	106.99	75.76	0.00
1305	423	157.48	130.68	866.06	121.98		96.88	410.50	169.42	99.91	68.58	10.61
1310	433	157.48	113.58	1070.56	108.33		91.40	467.94	167.20	102.27	70.18	14.39

Continuation of table 5.2												
1	2	3	4	5	6	7	8	9	10	11	12	13
1315	443	193.35	119.74	943.52	134.81		99.62	347.16	162.02	132.95	79.75	18.94
1320	453	183.82	163.53	749.86	122.78		102.37	409.66	172.38	166.77	86.92	12.88
1325	463	180.46	192.26	816.48	123.58		104.19	455.27	150.19	179.36	86.13	0.00
1330	473	204.56	176.53	619.72	126.79		110.59	296.48	152.41	213.97	77.35	13.64
1335	483	188.87	177.89	948.94	137.22		103.28	360.67	175.34	195.88	94.10	15.91
1340	493	171.49	166.95	996.20	115.56		100.54	382.63	155.37	156.55	72.57	11.36
1345	503	185.51	167.63	985.35	130.00		103.28	391.92	155.37	177.00	76.56	0.00
1350	513	168.13	163.53	945.85	120.37		100.54	375.03	143.53	160.48	78.15	0.00
1355	523	147.96	145.74	806.41	109.14		89.57	340.40	128.73	142.39	63.00	9.09
1360	533	175.42	180.63	972.18	129.20		102.37	380.94	153.15	173.07	72.57	0.00
1365	543	163.65	162.84	862.96	117.16		94.14	384.32	143.53	156.55	74.16	12.88

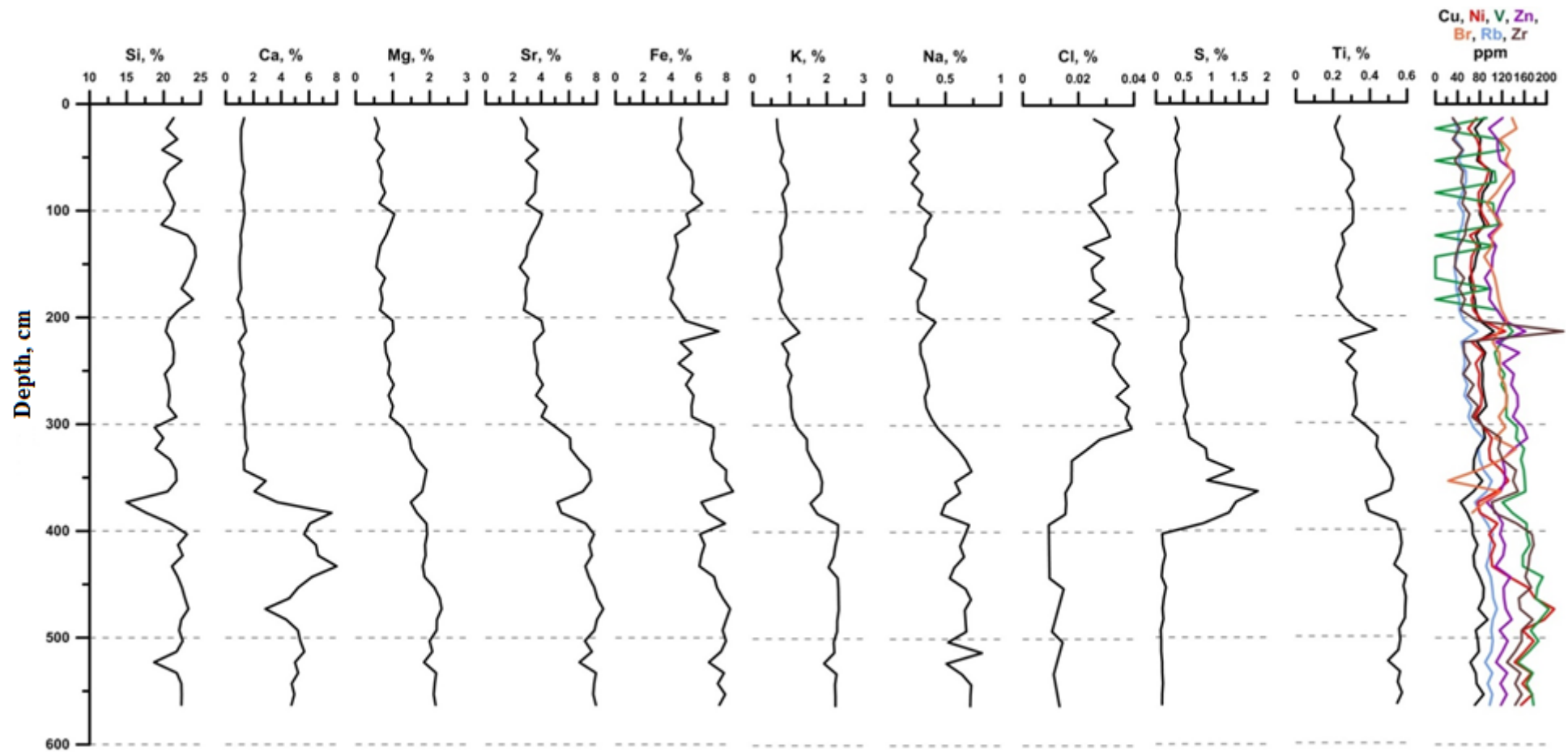


Figure 5.1 - Variations in the content of major macro and micronutrients by section of the precipitation of Lake Turgoyak. Data for column 5

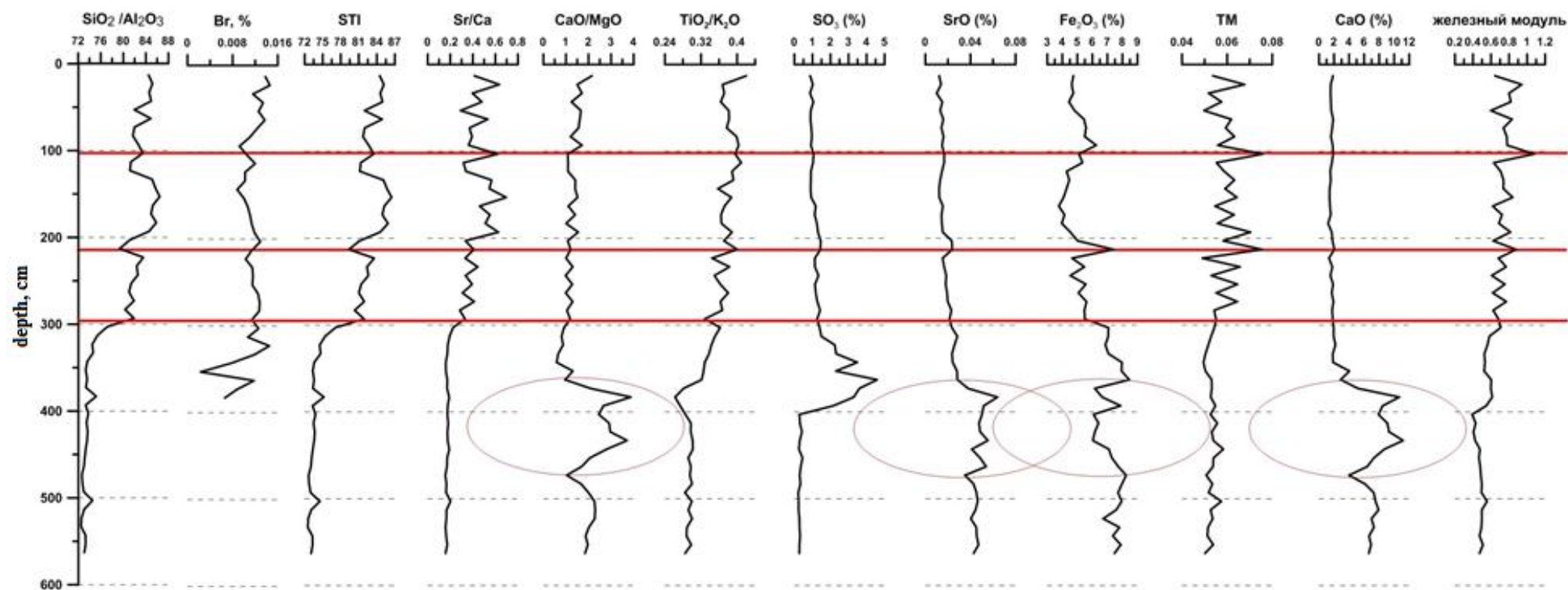


Figure 5.2 - Variations of lithochemical parameters for core 5 of Turgoyak Lake

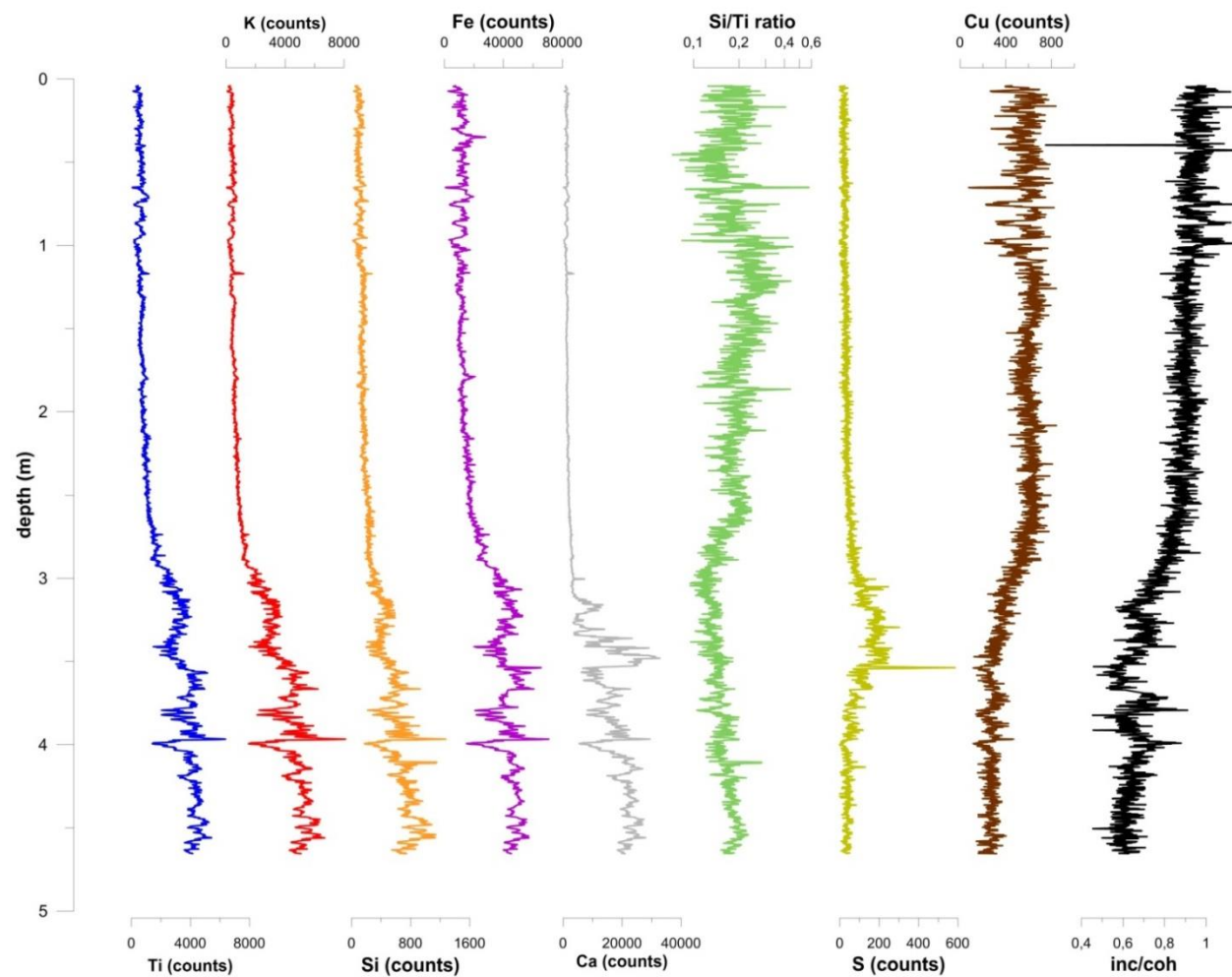


Figure 5.3 - Variations of the content of the main macro and microelements in the section of precipitation of Lake Turgoyak. Data for column 6

The lake sediments are divided into organic (organic matter content > 15) and mineral (organic matter content 0-15) according to the content of organic matter. Organic substances are divided into sapropelites (organic matter content <50) and sapropel (organic matter content > 50) (Corday classification, 1960 [40]). Sapropels are divided into subgroups according to ash content (Lopotko classification, 1978 [40]): silica (ash content is more than 30, silica content in ash is more than 50); carbonate (ash content more than 30, CaO content in ash more than 30); mixed (ash content more than 30, the contents of oxides of calcium and silicon are approximately equal); actually organic, or low-ash (ash content less than 30).

The bottom formations under study are organic and mineral deposits with an organic matter content from 12 to 40%. Such organic deposits in the classification of Corday (1960) are called sapropelites (table 5.3).

Table 5.3 – Classification of Corday

Sample №	Depth, cm	Contents of organic matter	Ash content
1	2	3	4
1100	13	39	61
1105	23	40	60
1110	33	37	63
1115	43	40	60
1120	53	35	65
1125	63	37	63
1130	73	38	62
1135	83	37	63
1140	93	35	65
1145	103	35	65
1150	113	38	62
1155	123	33	67
1160	133	32	68
1165	143	32	68
1170	153	35	65
1175	163	34	66
1180	173	36	64
1185	183	33	67
1190	193	36	64
1195	203	35	65
1200	213	32	68
1205	223	37	63
Continuation of table 5.3			
1	2	3	4

1215	243	36	64
1220	253	36	64
1225	263	36	64
1230	273	35	65
1235	283	34	66
1240	293	32	68
1245	303	34	66
1250	313	29	71
1255	323	30	70
1260	333	24	76
1265	343	18	82
1270	353	17	83
1275	363	19	81
1280	373	37	63
1285	383	25	75
1290	393	15	85
1295	403	13	87
1300	413	15	85
1305	423	13	87
1310	433	16	84
1315	443	15	85
1320	453	13	87
1325	463	12	88
1330	473	12	88
1335	483	14	86
1340	493	14	86
1345	503	14	86
1350	513	14	86
1355	523	26	74
1360	533	14	86
1365	543	14	86
1370	553	13	87
1375	563	14	86

5.2 Mineralogical composition of sediments

The clay minerals are represented by chlorite according to X-ray diffraction data (table 5.4; as an example of figure 5.4).; also in the composition of the samples in the cluster there are mica, quartz, albite, tridymite, cristobalite, less often microcline, amphibole, anti-burning, talc; the carbonate group is represented by calcite and dolomite in the lower part of the section.

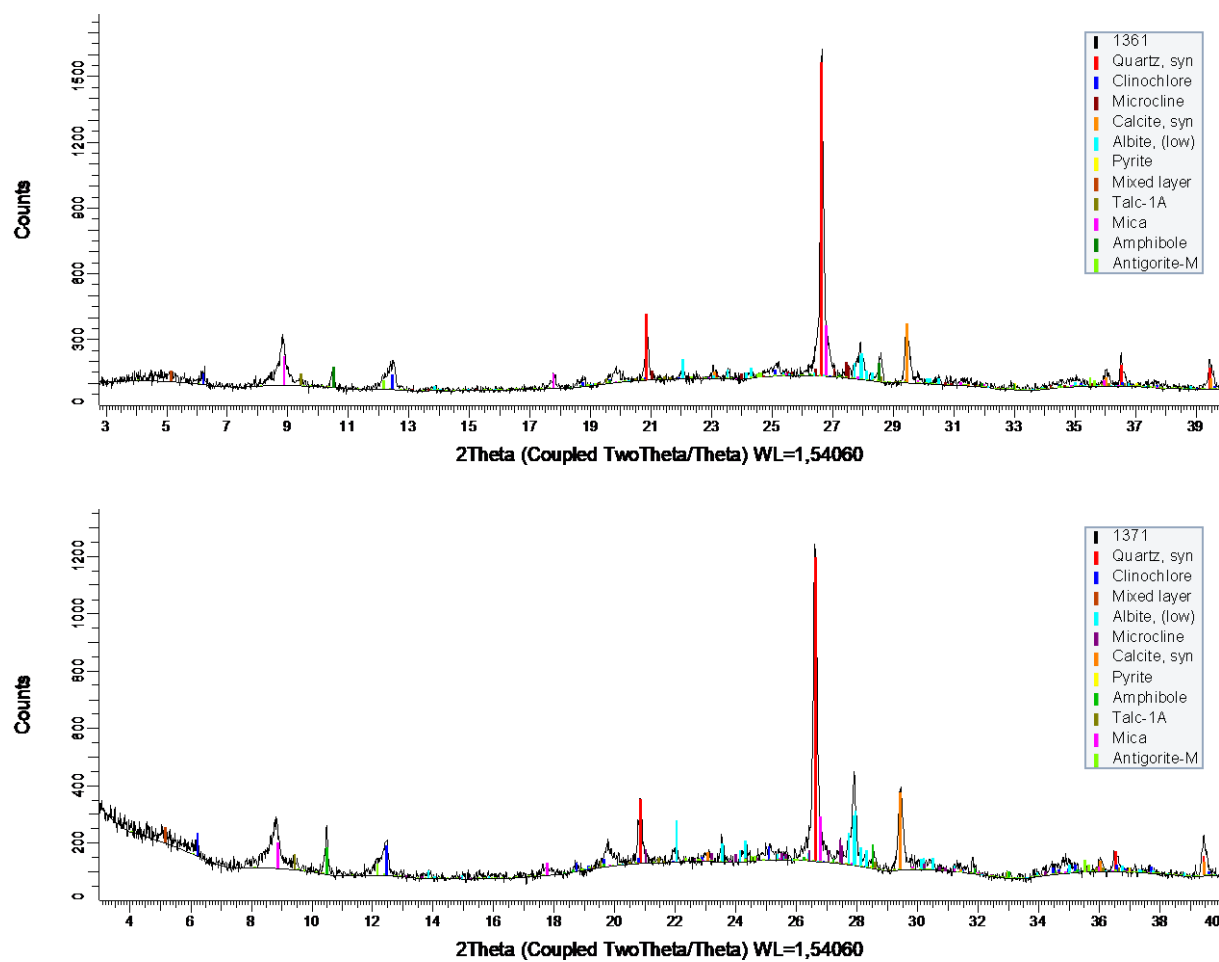


Figure 5.4–The XRF results for samples 1361 (top) and 1371 (bottom)

Table 5.4 –The results of XRF for samples of lake Turgoyak, %

№ образца	Pyrite	Cristobalite	Tridymite	Chlorite	Albite,	Microcline	Amphibole	Antigorite-M	Talc-1A	Mica	Quartz	Mixedlayer	Hydrotalcite	Calcite, syn	Dolomite
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1001	2	5	11	7	24		15			24	12				
1111	2	2	11	8	20		11			29	17				
1121		4	11	9	19		15			27	15				
1131		3	9	9	18		14			28	19				
1141	0.5	4	8	8	20		18			25	16				
1151	2	3	10	6	24		14			21	20				
1161	1	2	6	7	14		18			19	32				
1171	2	4	12	9	23		15			20	16				
1181	1	3	8	7	23	10	16			19	13		1		
1191	2	4	12	6	25		17			16	17				
1201	7	2	6	4	21		12			24	24				
1211	1	3	9	5	20	15	17			18	12				
1221	1	2	6	4	19	11	17			28	13				
1231	2			8	19	11	20			27	14				
1241	2			6	24	7	14			26	21				
1251	1			7	16	7	16	3		19	22	8			
1261	2			6	18	8	10	4	1	24	21	4			
1271	2			6	11	7	5	4	3	22	21	10		8	
1281	3			5	24	7	3	2	2	18	20			15	

1291	2			7	15	10	3	2	2	22	30			7	
Continuation of table 5.4															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1311				5	11	12	3	2	3	23	21			20	
1321				5	13	9	5	3	2	25	28			10	
1331	0.4			6	12	13	4	3	2	27	21	6		6	
1341	0.5			5	13	5	5	3	4	25	20	9		9	
1351	0.3			7	12	6	4	3	3	25	22	9		9	
1361	0.5			4	11	7	9	3	3	23	26	8		7	
1371	0.4			6	16	7	8	3	3	23	18	7		7	

5.3 The correlation of core columns

Magnetic susceptibility and normal remanent magnetization (NRM) are usually used to correlate core columns selected in different parts of the lake. These parameters are sensitive to climatic trends and their changes occur throughout the sedimentation basin simultaneously. The NRM value was measured on an Enterprise 2G cryogenic magnetometer in the laboratory of geodynamics and paleomagnetism of the Central and Eastern Arctic NGU (Novosibirsk, Russia).

Analysis of the measured samples showed that the magnetic susceptibility values of the lake Turgoyak change in the range of 0.35 to $18.35 \cdot 10^{-5}$ units SI. Statistical parameters are presented in table 5.5. It should be noted that, as a rule, magnetic susceptibility is a good correlative parameter and is successfully used to compare core columns selected in different parts of the lake. A comparison of the variations in the magnitude of the magnetic susceptibility over the five selected columns and the correlation lines of the sections are presented in Figure 5.5.

Table 5.5 - Statistical parameters of the magnetic susceptibility of the columns of bottom sediments of the lake Turgoyak (SI 10^{-5})

numbers of column	1	2	3	4	5
Min. value	0.38	0.35	0.47	0.79	0.60
Max. value	14.24	8.91	6.75	17.99	18.35
Range	13.86	8.56	6.28	17.20	17.75
Average value	1.91	1.24	1.77	1.76	1.92

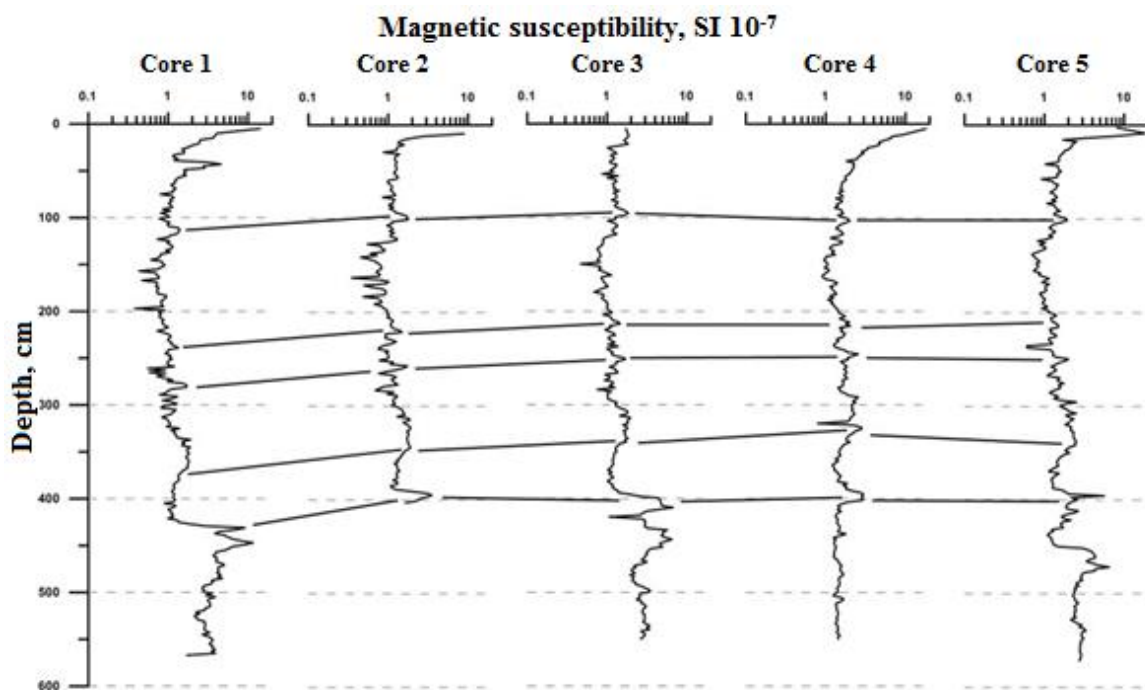


Figure 5.5 – Variations of values of magnetic susceptibility for 5 core columns of the lake Turgoyak

The measured values of the normal remanent magnetization of the samples of all selected columns are in the range from 0.134 to 4.05 mA / m. Comparison of variations of the NRM value for all selected columns is presented in Figure 5.6.

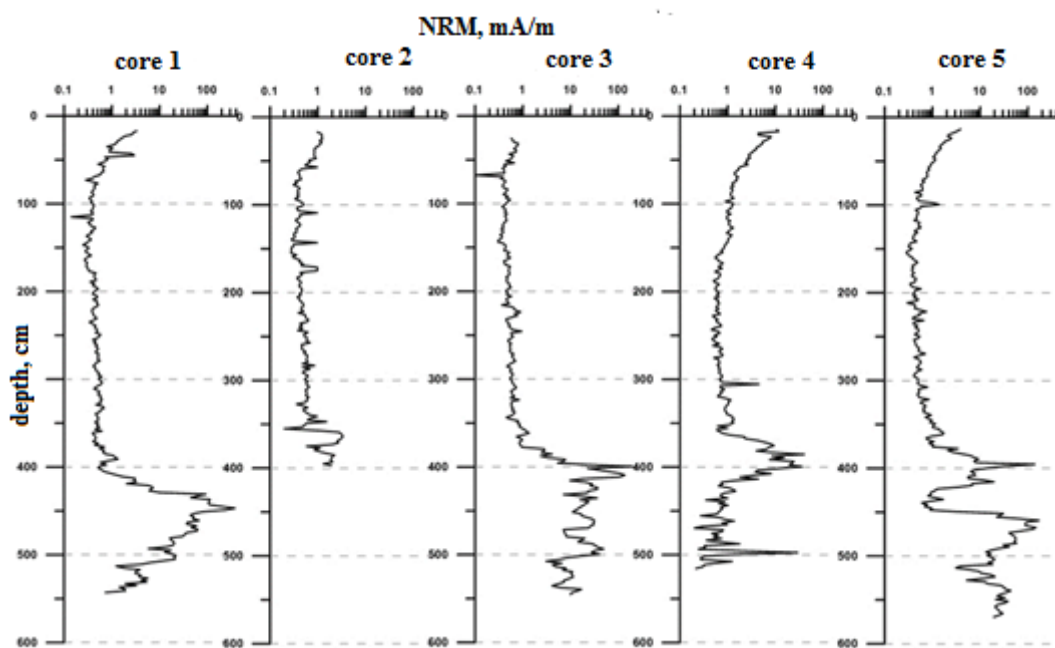


Рисунок 5.6 - Variations of magnitude of the vector NRM five columns core of the lake Turgoyak

Statistical parameters are presented in table 5.6. Like magnetic susceptibility, normal remanent magnetization is often used to correlate core columns.

Table 5.6 - Statistical parameters of NRM (mA / m) columns of bottom sediments of Lake Turgoyak

Number of column	1	2	3	4	5
Min. value	0.14	0.20	0.10	0.20	0.28
Max. value	378.7	3.31	199.10	40.29	171.60
Range	378.56	2.39	199.00	40.09	171.32
Average value	10.07	0.71	7.17	2.30	9.56

According to the thermomagnetic diagrams, the column can be divided into four parts: 0 - 1.42 m, 1.44 - 2.80 m, 2.82 - 3.80 m, and 3.82 - 5.40 m (Figure 5.7). The magnetization in the first three groups during the second heating increases tenfold, which indicates the formation of a more magnetic phase when heated. The first group of samples is characterized by the presence of pyrite, which, when heated, transforms into magnetite and magnetite. To check the magnetite peak, measurements were made at a heating rate of 25 K / min. When measured in this mode, the peak is not detected, since magnetite has time to completely dissociate. The presence of iron sulfides is also characteristic of the second group. After the first heating, the magnetite-magnetite association of minerals is formed. The difference from the first group is a smaller amount of iron sulfide and when it is heated, the formation of a larger amount of magnetite, compared with the first group. The third group is characterized by a high content of iron sulfides, the effect of which can be observed on the repeated diagram. The fourth group is unique in that after the first heating all the magnetic material that was in the sample goes into a paramagnetic state and there are no magnetic effects on the diagrams of the second heating.

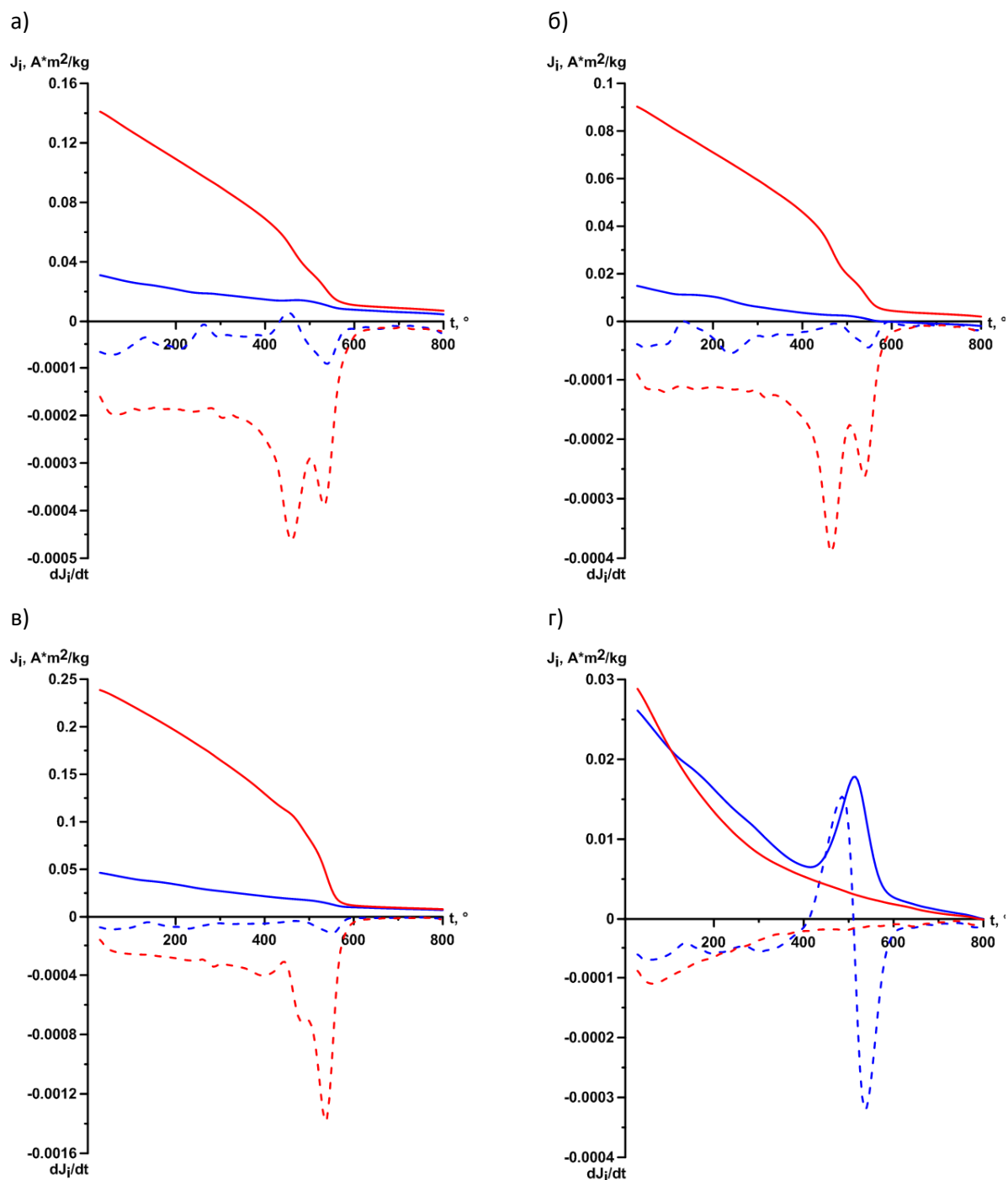


Figure 5.7 - Results of differential thermomagnetic analysis. The solid blue line is the first heating, the red - the second heating; the dotted blue line is the differential of the first heating, the dotted red line is of the second: a) first group, sample 1141; б) the second group, sample 1211; в) the third group, sample 1251; г) fourth group, sample 1311

The ratio of hysteresis parameters (J_{rc} / J_s , B_{cr} / B_c) of sediment samples can demonstrate the presence in the samples of a mixture of single-domain (OD), pseudo-single-domain (AML), multi-domain (MD) and superparamagnetic (SP) grains. Dunlop proposed a theoretical Day diagram, all curves of which were calculated for mixtures of magnetite grains of

various sizes. The obtained parameters of magnetic hysteresis on samples of column 5 are reflected in the Day-Dunlop diagram (Figure 5.8).

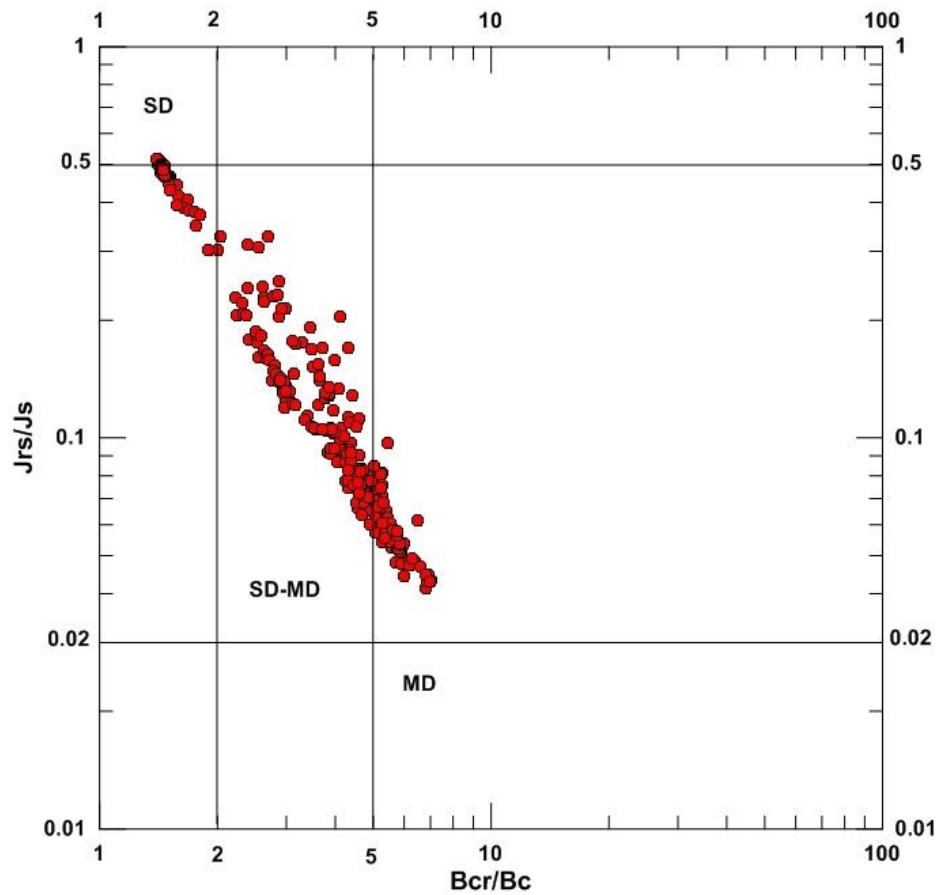


Figure 5.8 - Day-Dunlop diagram of core column #5. SD - single-domain, MD - multi-domain, SD-MD mixture of single-domain and multi-domain grains

Paramagnetic, superparamagnetic and ferromagnetic components: determination of the contribution of the paramagnetic component (k_p) to the common signal from the inductive curve of normal magnetization, determination of the ferromagnetic component (k_f) from the inductive curve of normal magnetization minus the paramagnetic component, and the determination of the ferromagnetic component and their total value (k_{sum}) was carried out for all samples of column 5 (Figure 5.9).

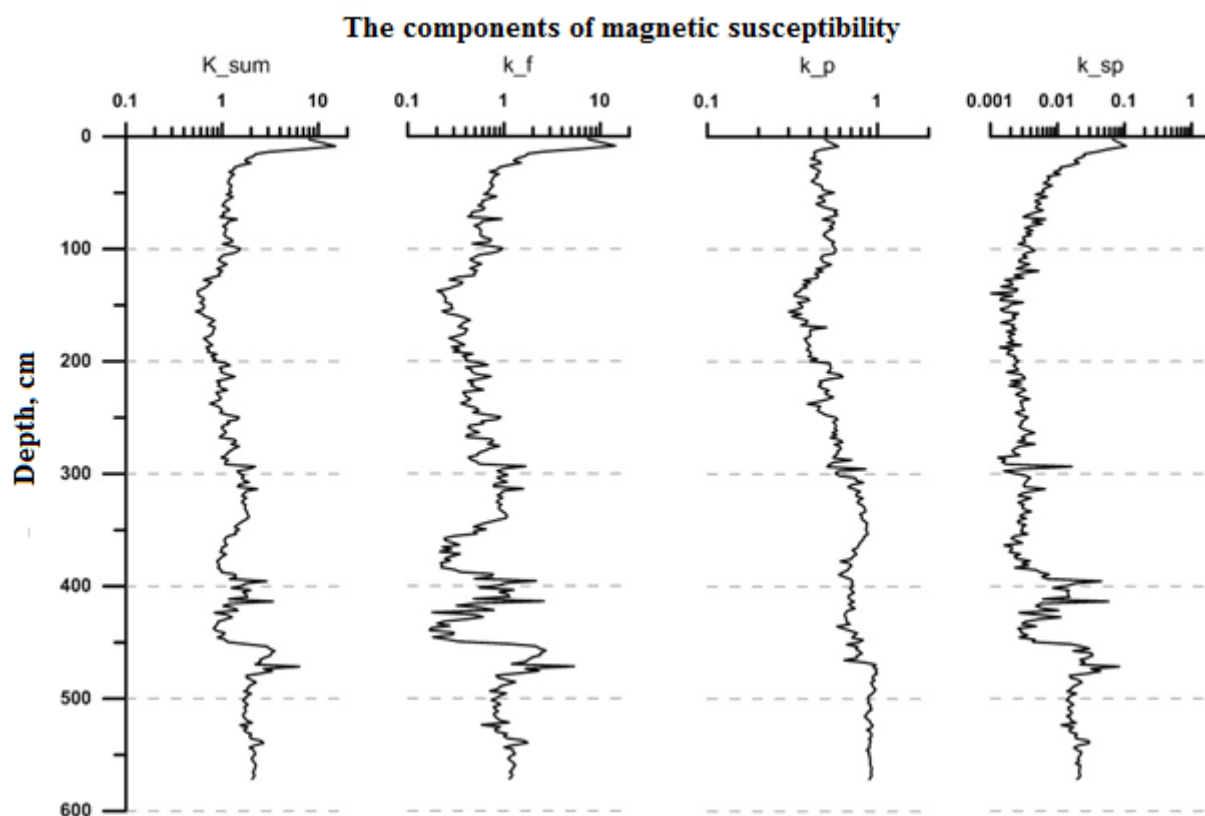


Figure 5.9 - Variations of the components of magnetic susceptibility by samples of column #5 of precipitation of Lake Turgoyak

Analysis of these data allows us to conclude that the ferromagnet is heterogeneous. According to this diagram, the samples under study lie in the region of the mixture of OD, SP, and MD grains. The volume fractions of these components are difficult to estimate, because the calculated lines do not cover the entire surface of the diagram. Approximately we can talk about the main ferromagnetic component represented by single-domain and multi-domain material, with a range from almost 100 to 5 volume fractions, with a noticeable influence of superparamagnetism. Therefore, the OD particles are represented by biogenic magnetic minerals, in our case, magnetite and possibly greigite. The presence of MD grains in the sediment, as a rule, is associated with terrigenous introduction and / or influx of extraterrestrial matter. JV component may have a different origin. A typical example of superparamagnetic in nature are hematite grains or fine magnetite of biogenic origin. Figure 5.10 shows the variation of hysteresis parameters along the section of column #5.

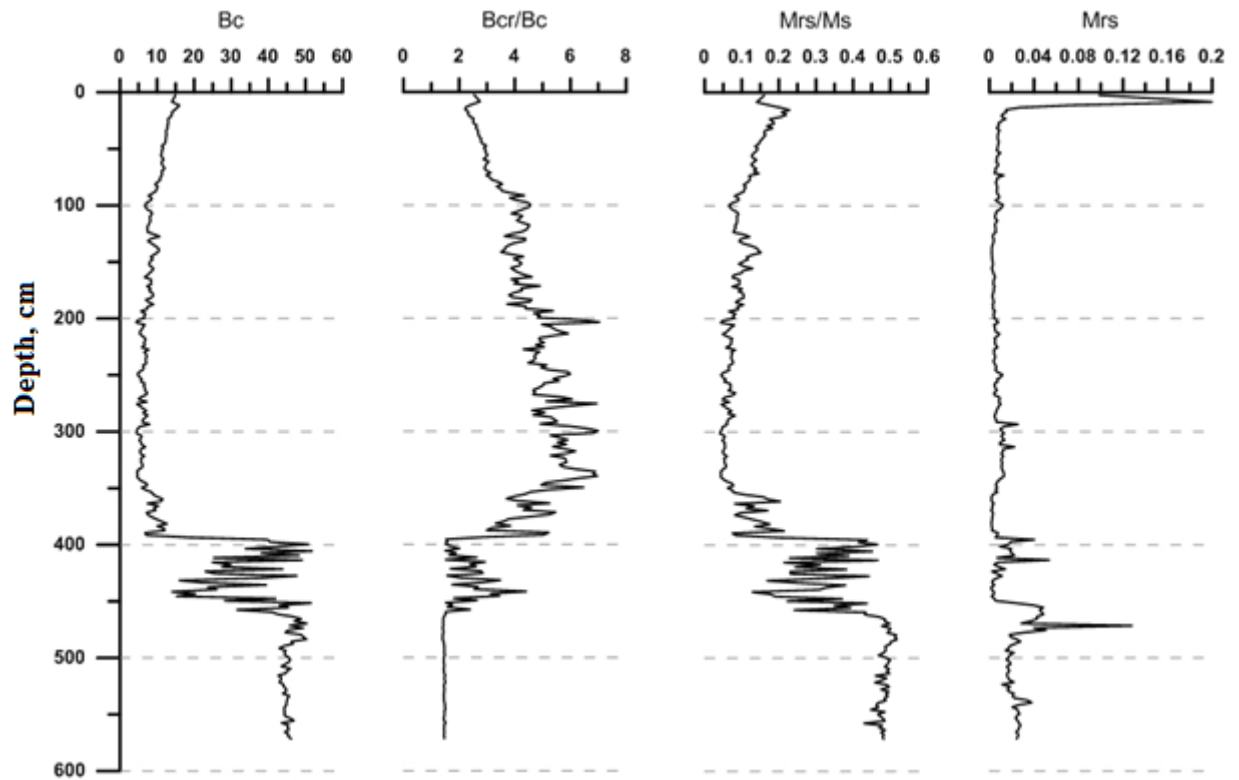
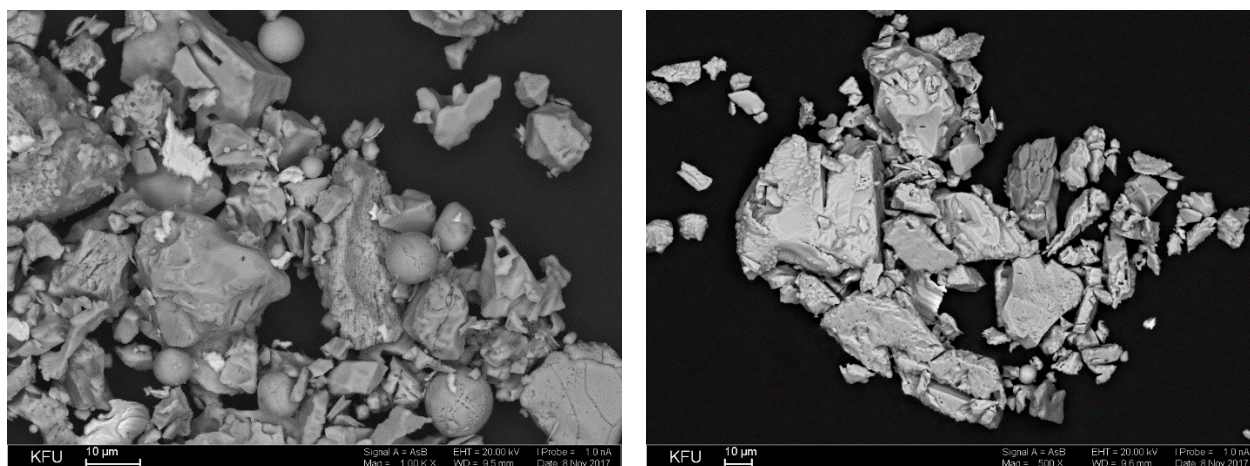


Figure 5.10 - Variations of hysteresis parameters in the section of column #5

Magnetic separative microscopy of Lake Turgoyak by SEM was carried out for core column #5. The magnetic fraction of sample 1141 of Lake Turgoyak from a depth of 96 cm is represented by both large particles reaching 50 μm and much smaller ones. Figure 5.11 a. Large clastic grains are represented by iron oxides with impurities of Cr, Ni, Ti, V, and also with a significant content of Cr. In addition, titanomagnetite crystals with a high Ti content are observed. The magnetic fraction of sample 1214 (depth 242 cm) is also represented by large and significantly smaller particles. Large detrital grains up to 75 microns in size are represented by iron oxides with impurities Cr, Ti, V (Figure 5.11 b). Crystals of titanomagnetite with a high content of Ti are observed. In both samples there is a significant amount of spherules. The surface structure and composition suggests their cosmogenic origin.



a

b

Figure 5.11 - Electron-microscopic images (SEM) of magnetic separate core columns #5 1141 (a) and 1214 (b)

In the magnetic fraction of sample 1114, particles with the shape, size, and composition of the corresponding magnetophossies were detected (Figure 5.12). The particle length is 200 nm. Its composition can be defined as magnetite (see spectrum 10).

The magnetic fraction of sample 1214 also revealed particles in shape, size, and composition corresponding to magnetophossils. The particle length is about 200 nm. The composition is reflected on spectrum 4 (Figure 5.13).

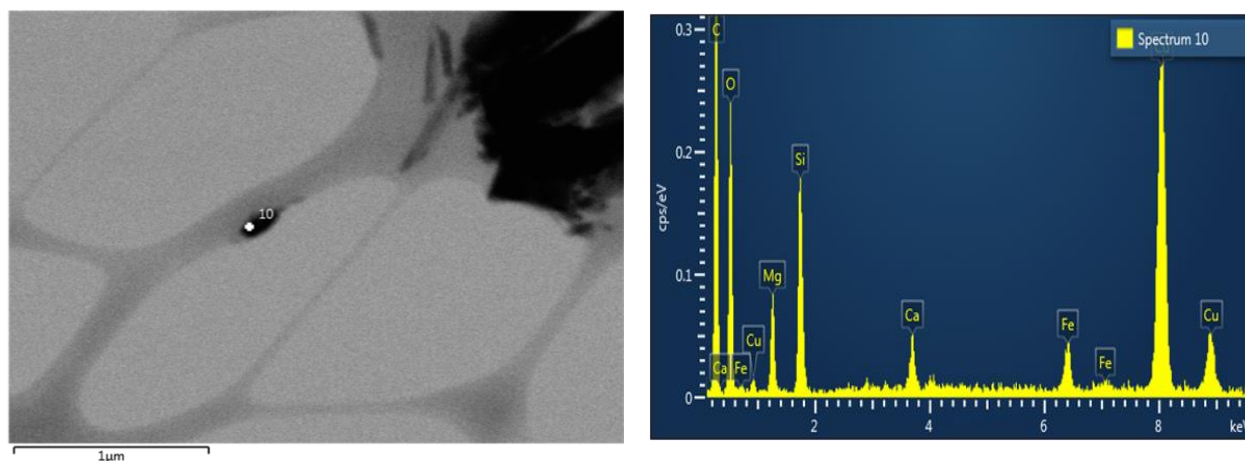


Figure 5.12 - Electron microscopic image (TEM) of magnetic separable images of core column #5. Sample 1141 (depth 96 cm)

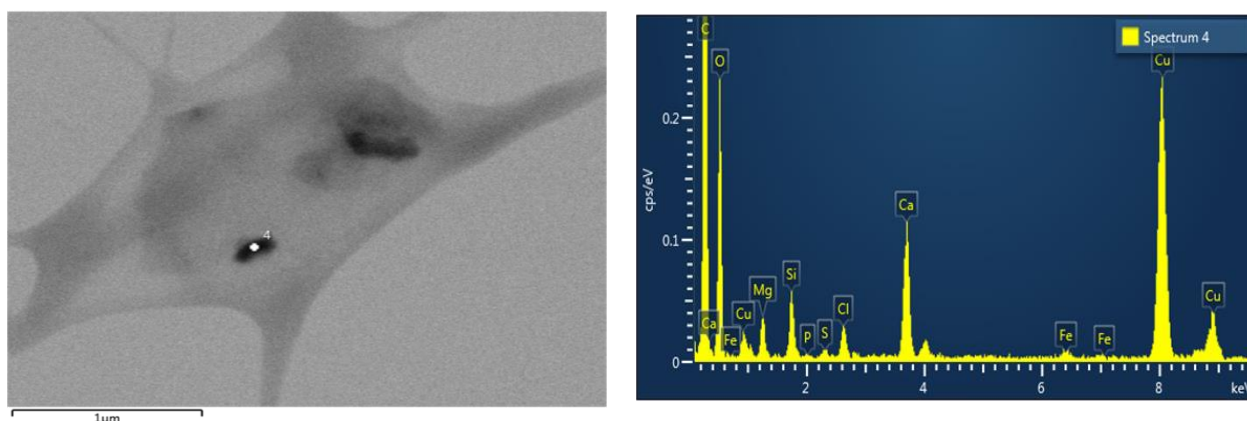


Figure 5.13 - Electron microscopic image (TEM) of magnetic separable samples of a core column #5. Sample 1214 (depth 242 cm)

5.4 The results of geochemical investigation

According to the results of XRF, the main elements of the bottom sediments of the lakes under study are: Na, Mg, Al, Si, S, K, Ca, Fe. In very small concentrations are found: Cr, Zn, Ni, Br, Sr, Zr. In some samples found Co, Vn, Mo, Ba, U, and so on. The change in the concentration of chemical elements in the sediments of Lake Turgoyak occurs in the lower part of the core, at depths of 3.9 meters. Up the section, the Ca content decreases, which, along with a decrease in Sr, indicates climate warming (Figure 5.14).

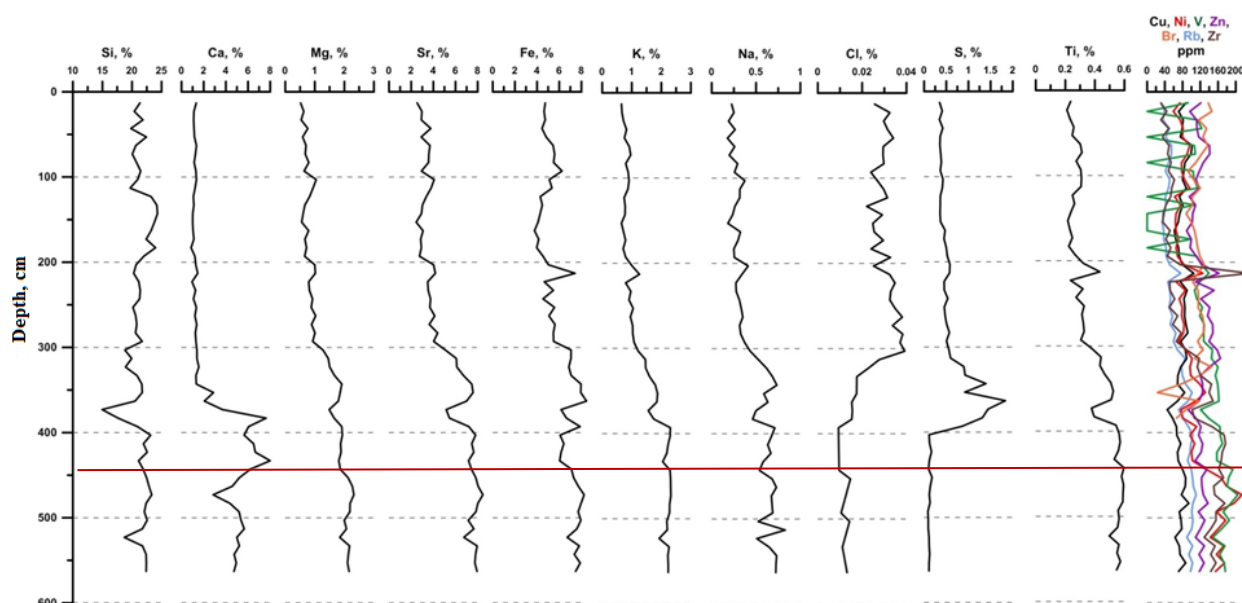


Figure 5.14 - Variations in the content of major macro and microelements in the section of sediments of Lake Turgoyak

According to the X-ray diffractometry of Lake Turgoyak, clay minerals are mainly represented by chlorite (Figure 5.15); mica, quartz, albite, tridymite, cristobalite are also present in the composition of the samples, less often microcline, amphibole, anti-burning, talc; in the lower part of the section, the carbonate group is represented by calcite.

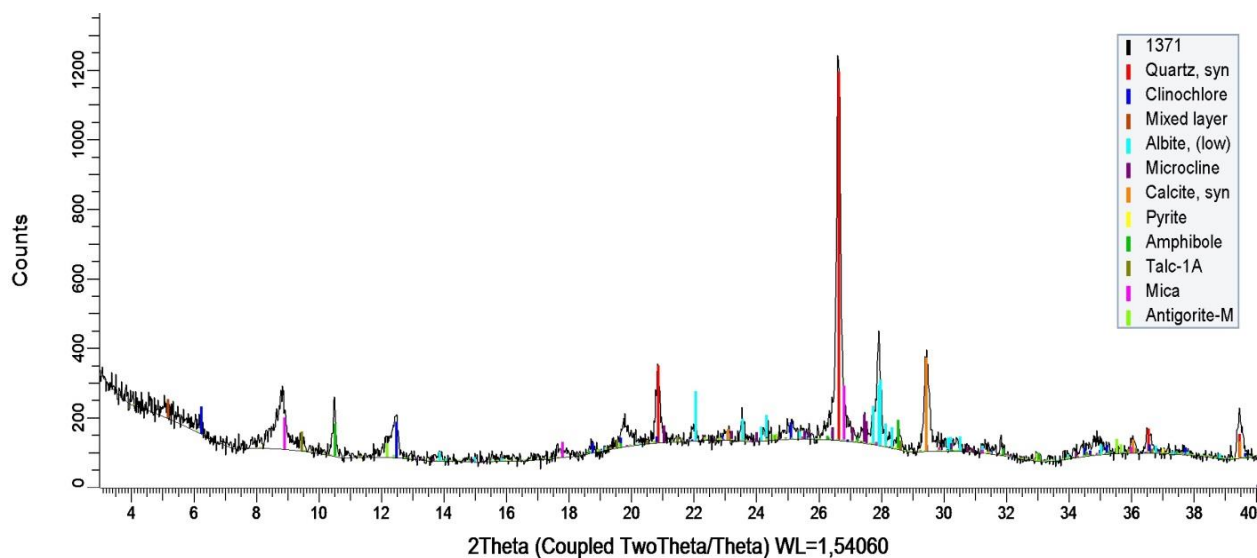


Figure 5.15 - Result of X-ray diffraction of sample 1371 (555 cm) of Lake Turgoyak

To identify the levels of aridization and humidification of the climate, magnetic parameters, loss on ignition, geochemical parameters were compared, and chemical indexes of weathering were calculated.

Fluctuations in the chemical indexes of weathering reflect the fluctuations in the chemical weathering intensity of the catchment areas of the lake basin and, accordingly, the cyclical nature of climate humidification (Figure 5.16).

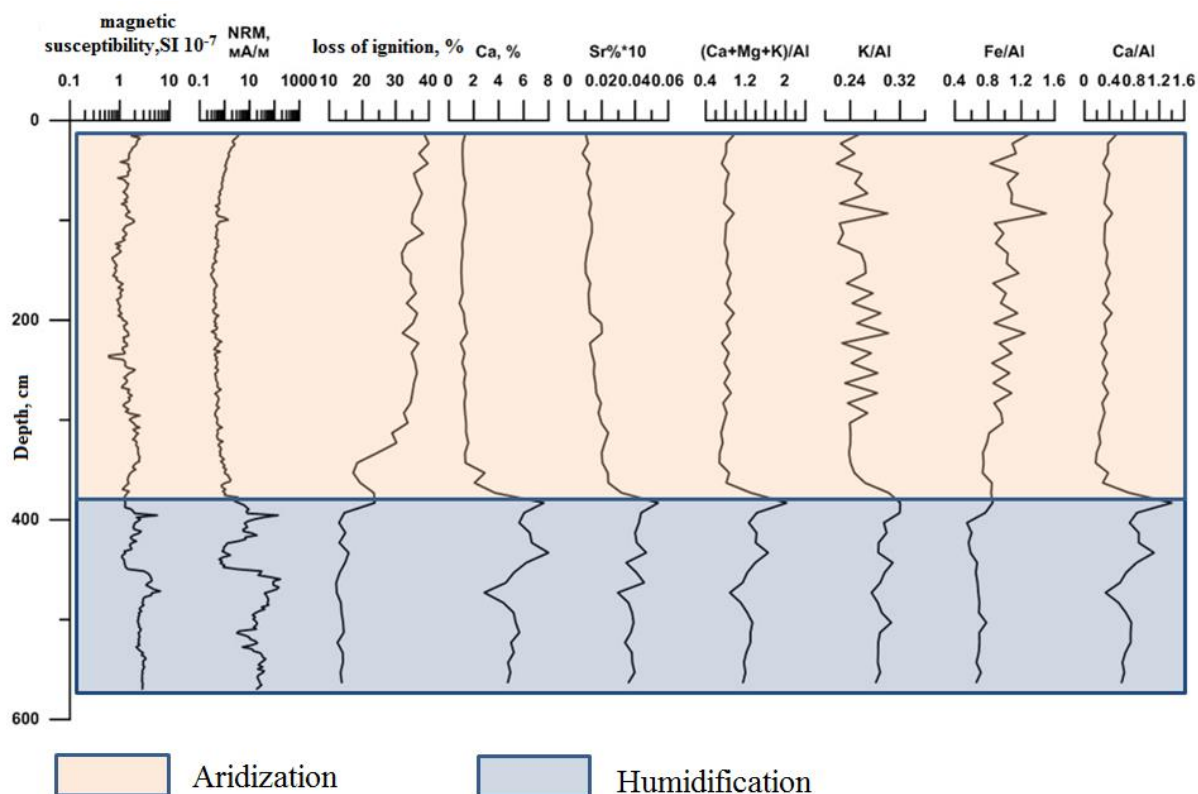


Figure 5.16. Identification of aridization / humidification areas

According to the above plot, the following results were revealed:

- A decrease in magnetic susceptibility values upstream of the section indicates a decrease in humidity;
- Increased values of the loss on ignition indicate the accumulation of organic matter in the sediments, lower - mineral;
- The decrease of contents Ca, Sr up the section reflects climate warming;
- A decrease in weathering index values upstream of the section indicates climate warming.

All changes of chemical elements and mineralogy are compared with the time geological scale, as a result of which the stages of drying and moistening are revealed. The age of the lake is determined by radiocarbon dating. According to the graph below, the approximate change in the condition of sedimentation is in the range of 12000 years (Figure 5.17).

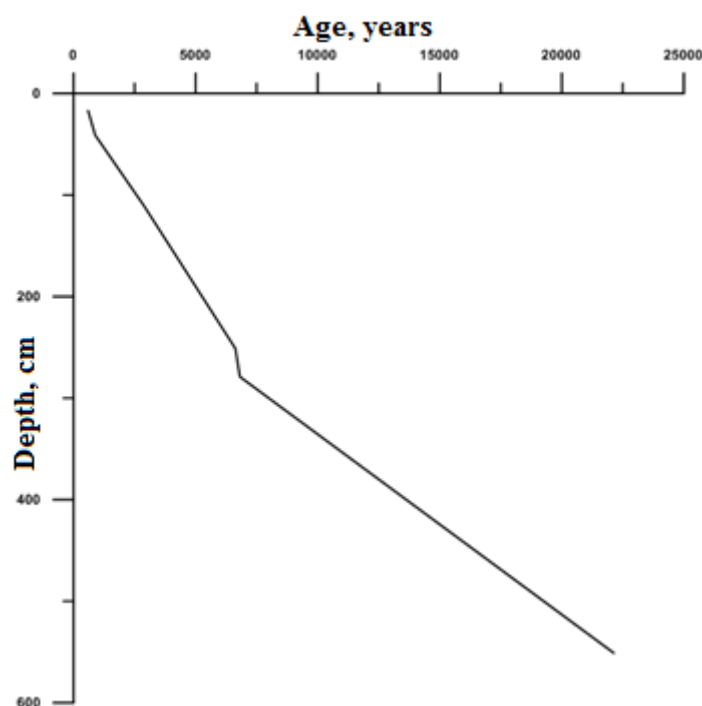


Figure 5.17 - Results of radiocarbon dating

To interpret the levels of moisture and drying as analog sources of organic matter for the formation of hydrocarbons, the content of C, O, H in the sediments of bottom sediments of the lake was determined. Turgoyak. The results are shown in table 5.7.

Table 5.7. Content of C, O, H in studied lake sediments, %

№ образца	Глубина, см	C, %	H, %	O, %
1200	213	2.27	0.47	4.65
1300	413	12.09	2.98	11.93

Kerogen is an insoluble part of organic matter. The main compounds of kerogen of any type are carbon and hydrogen. The dispersion organic matter of rocks is divided into three main types: 1) sapropel, formed mainly by the remains of single-celled algae, in the initial stages of existence. Kerogen, substantially enriched with hydrogen and low content of oxygen groups 2) humus, formed from higher plants, is characterized by the predominance of C = C and C – O bonds over CH₂ – CH₃ and the predominance of carbon-acid and water over hydrocarbons in pyrolysis products. Kerogen is characteristic of source rocks. It is enriched with hydrogen and contains relatively little O₂. 3) intermediate type. Kerogen is characterized by relatively low concentrations of hydrogen in the elemental composition and a high content of O₂. The source of organic matter for kerogen of this type is mainly plants and the products of their transformation - a humus substance. Also in nature is often a mixed type kerogen, a cat. occupies an intermediate

position between the first and third types. This type of kerogen part is called sapropel-humus. Usually, organic matter for mixed type of kerogen is sea OM and brought from the continent. Also distinguish IV type of kerogen. Type IV kerogen contains mostly inert organic substances in the form of polycyclic aromatic hydrocarbons. They do not have the ability to produce hydrocarbons. The classification of kerogen is shown in Figure 5.18. To determine the class of kerogen of the investigated sediments of Lake Turgoyak, the obtained ratios H / C and O / C were plotted on the Van Cleveren diagram (Figure 5.19).

KEROGEN CLASSIFICATION					
PALYNOLOGY	Algal	Amorphous	Herbaceous	Woody	Coaly
MACERALS	Liptinite (Exinite)			Vitrinite	Inertinite
EVOLUTIONARY PATHWAY	TYPE I OR II		Type II	Type III	Type IV
H/C O/C	1.7 – 0.3 0.1 – 0.02		1.4 – 0.3 0.2 – 0.02	1.0 – 0.3 0.4 – 0.02	0.45 – 0.3 0.3 – 0.02
HYDROGEN INDEX	900-50		600-50	200-50	<50
SOURCE MATERIAL	Lacustrine and Marine		Terrestrial	Terrestrial	Terrestrial and Recycled
HYDROCARBONS GENERATED	Mostly Oil		Oil and Gas	Mostly Gas	Very Little Gas

Figure 5.18 - Kerogen classification

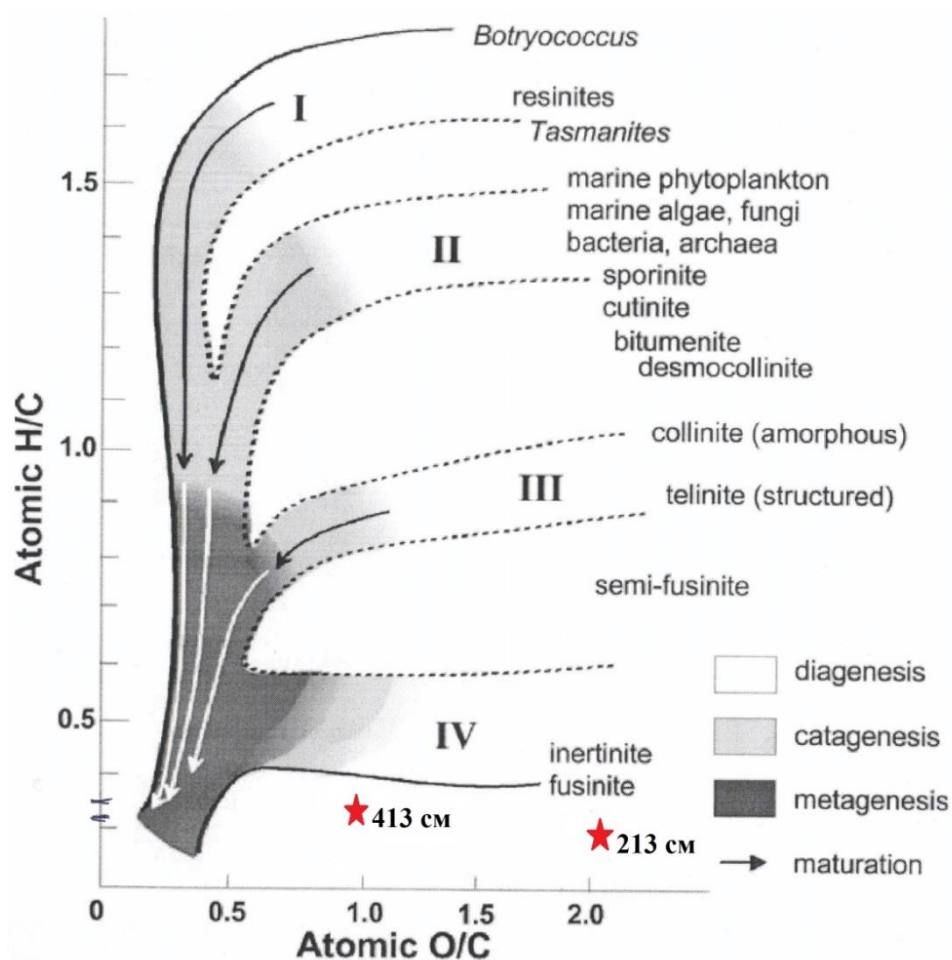


Figure 5.19 - Definition of the class of kerogen on the Van - Cleveren diagram

We see that the point located at a depth of 413 cm, belongs to the area of a greater diagenetic lowland than the point located at a depth of 213 cm.

The investigated sediments are at the stage of diagenesis and close to the zone of kerogen type IV. Kerogen is only being formed and its composition depends on the saturation of the sedimentary environment with oxygen, the rate of sedimentation and the rate of conservation of sedimentary material, redox conditions, climatic changes — changes in wetting and drying of catchment areas — a supplier of plant and detrital material. In the epoch of moistening, the remnants of higher plants (humus material) are introduced, in the epoch of desiccation, there are less remnants of higher vegetation and in the lake sediment there is more sapropel and bacterial mats (probably including magnetobacteria).

The bottom formations under study are organic and mineral deposits with an organic matter content from 12 to 40%. Such organic deposits in the classification of Corday (1960) are called sapropelites (Figure 5.20).

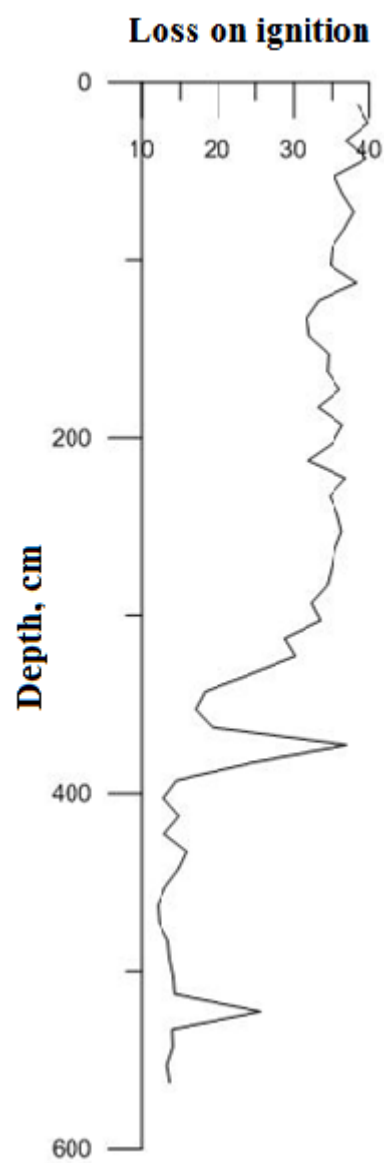


Figure 5.20 - Result of loss on ignition of the sediments of Lake Turgoyak

Conclusion

The all studies allowed to determine the peculiarities of the material composition and the formation conditions of lake Turgoyak sediments by conducting magnetic-mineralogical and geochemical studies, calculating loss on ignition, calculating chemical index of weathering, for to identify climate changes. On the basis of the researches revealed:

- The concentration of most chemical elements of Lake Turgoyak occurs in a depth of 3.9 m;
- Changes in chemical elements and mineralogy are compared with a time geological scale, as a result of which stages of aridization and humidification are revealed. It allowed to divide the section into two parts: the first is from 0 to 3.9 m – level of aridization, and the second is from 3.9 to 5.4 m – level of humidification;
- The change in sedimentation conditions occurred about 12,000 years ago;

The bottom formations of lake Turgoyak are mineral and organic deposits containing from 12 to 40% organic matter are sapropelites called to by Cordaye's classification (1960).

The content of C, O, H in the Turgoyak lake sediments was determined to interpret the levels of aridization and humidification as analog sources of organic matter for the formation of hydrocarbons. The Sediments are at the stage of diagenesis and are close to the type IV kerogen zone. Kerogen is only being formed and its composition depends on the saturation of the sedimentary environment with oxygen, the rate of sedimentation and the rate of conservation of sedimentary material, redox conditions, climatic changes — changes in wetting and drying of catchment areas — a supplier of plant and detrital material. It is necessary to take more samples vertically and laterally to further understand the likely evolution of organic matter in the sediments of Lake Turgoyak.

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