Granulometric, elemental and isotopic composition of bottom sediments of lakes of mountainous areas as a reflection of transformations in their watersheds

Yury A. Fedorov[1,*], *Anna V.* Mikhailenko[1], *Irina V.* Dotsenko[1], *Evgeny A.* Kovalev[1], *Victoria I.* Chepurnaya[1], *Nicolay V.* Dotsenko[1], *Irina Yu.* Gavrilova[2], and *Olga Yu.* Bellinger[1]

[1] Southern Federal University, Rostov-on-Don 344090, Russia
[2] Southern Scientific Center of the Russian Academy of Sciences, Rostov-on-Don 344006, Russia

Abstract. The article provides a brief description of the geological and tectonic structure and technogenic transformations in the drainage basin of two lakes of the Krasnodar Krai (Malyy Liman and Abrau). They belong to a single natural-technogenic system. On the example of these mountain lakes, the grain-size distribution, elemental (mercury) and isotopic (cesium-137) composition of bottom sediments was studied. The use of a set of methods and technologies, including those developed by the authors, made it possible to determine the parameters of the anthropogenic impact layer in bottom sediments and the chronology of its formation. It is closely related to natural and man-made events in the drainage basin.

1 Introduction

Bottom sediments are a quasi-open ecosystem. Their extensive interface with water separates the hydrosphere from the upper thin layer of the lithosphere. They contain both abiotic and biotic (fungi, bacteria, vegetation, hydrobionts, residues of human and other organismal communities) substances. Along with the third (discrete) boundary of the section "water – suspended substance – biota", they are of great importance in the processes of transfer of matter and energy [1; 2]. Bottom sediments are an integral component of the aquatic landscape (Fig. 1), which is especially active in the cycle of matter and energy in shallow water objects. Having a high accumulation capacity, suspended dispersed particles of substances are capable of capturing pollutants and removing them from water during the process of sedimentation. As new layers of precipitation form, dispersed particles and pollutants are conjugately deposited in them. [3]. Accumulating pollutants coming from watersheds for a long period of time, bottom sediments serve as an indicator of the ecological state of the territory, a kind of integral indicator of the level of pollution. It should be noted that the buffering capacity of bottom sediments in relation to pollutants is not unlimited. Bottom sediments with a change in the physicochemical and hydrodynamic

* Corresponding author: fedorov@sfedu.ru

situation can act as a secondary source of pollution of the water column. One of the dominant factors controlling the distribution, accumulation, and dispersion of pollutants in water bodies is their particle size distribution and material composition [4]. In turn, it is formed under the influence of the entry into water bodies of products of destruction of rocks that make up their drainage basins. At the same time, the degree of rock disintegration depends not only on their lithological composition and, accordingly, hardness, but also on the geological and geomorphological conditions of their occurrence.

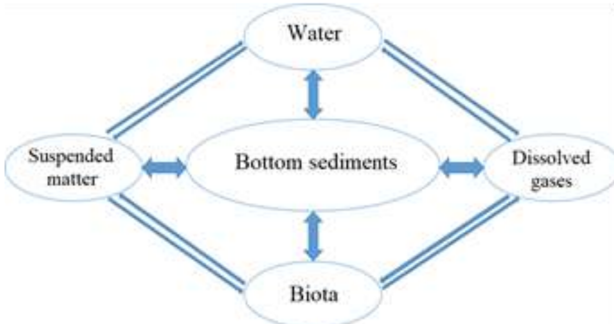

Fig. 1. Conceptual model of interaction of bottom sediments with components of the aquatic landscape.

It should be noted that, according to [5], the Mediterranean-type ecosystems in the Northwestern Caucasus, especially on the Abrau Peninsula, still remain relatively little disturbed compared to coastal ecosystems in other countries of the Black and Mediterranean Seas, which have undergone a strong anthropogenic transformation since ancient times.

In this regard, it is of great scientific and practical interest to investigate the formation of granulometric, elemental and isotopic composition of bottom sediments of water bodies located in one of the mountainous regions of the North Caucasus.

2 Objects, materials, and methods

The entire rock section of the Abrau Peninsula can be classified as seismic gravitational deposits [6-8]. Lake Malyy Liman lies in the south of the Abrau Peninsula, directly off the Black Sea, 1.5 km south of Lake Abrau. It is fenced off from the sea by a stone fill about 35 m wide, rising 3 m above its level. Lake (Fig. 2) is freshwater, although behind a thin bridge is the sea with a water salinity of about 18 g/dm3. The seawater does not enter the lake [4]. It was formed 5-7 thousand years ago due to a strong earthquake [6; 7].

Lake Abrau is located hypsometrically higher above Lake Malyy Liman and is of interest not only in terms of its impact on the water balance of the lower reservoir, but also as an object of social, geological and ecological tourism. The lake is the largest natural body of water in the Krasnodar krai. On its shores is the eponymous village and the famous factory. Lake Abrau fills up due to the flowing into it waters of the Abrau River and the slope runoff, as well as the discharge of groundwater at its bottom. From a hydrological point of view, Lake Abrau is undrained. The sides of the lake are composed of flysch strata of the Cretaceous age. They are represented by rhythmic interlayering of fine gray fine-grained sandstones, siltstones, clay shales, marls and dark gray siltstones [6-8].

Fig. 2. Location map of the Malyy Liman and Abrau lakes.

An expedition was conducted to select columns of bottom sediments up to 95 cm deep in the lakes Malyy Liman and Abrau. Bottom sediments were collected using a bottom-sampling device [4]. Their visual and microscopic description was made. The method of laser granulometric analysis using an analyzer «Laska-TD» was used. Fractions larger than 1.0 mm, represented by materials of anthracites and organic residues, were subtracted from the sample when calculating the granulometric composition and were not included in the amount of 100%. The evaluation of the granulometric characteristics of the samples consisted of statistical processing of the results, calculation of the mass and numerical content of granulometric fractions. The binary logarithmic classification [9] of sand (1.0-0.1 mm), siltstone (0.1-0.01 mm), clayey soil (0.01-0.001 mm) was used to show the percentage contribution of granulometric fractions. In the siltstone fraction there are two subgroups – fine-aleurite (0.05-0.01 mm) and coarse (loess) (0.1-0.05 mm). Determination of the granulometric composition was carried out in the laboratory of SSC RAS [3]. Determination of specific activity of cesium - 137 was carried out in the Center "RET" SFedU by the method [10]. The mercury concentrations were determined by the method of atomic absorption in cold vapor by analyst A.M. Anikanov [1; 11].

3 Results and discussion

3.1 Visual description

The bottom sediments of Lake Malyy Liman were represented by light gray, gray and yellow silt up to the depth of 40-45 cm, changing in the depth interval of 45-70 cm into denser dark-brown clay sediments with plant remains. After that, and until the depth of 95 cm, light gray sediments with admixture of sandy and shell material are observed.

Lake Abrau was characterized by relatively homogeneous bottom sediments of gray color with areas of darker shade. The difference in the color of sampled bottom sediments in Malyy Liman and Abrau lakes is noteworthy. This is explained by the fact that the shores of Lake Abrau are composed of gray and dark gray flysch strata of Cretaceous age, while the Malyy Liman lakes are predominantly lighter rocks of Quaternary and Paleogene age.

3.2 Granulometric composition

Granulometric analysis of Lake Malyy Liman bottom sediments (station №3) showed a very diverse and heterogeneous composition of sediments. Most of them are represented by small siltstones (0.01-0.05 mm) on average 57.1 % and group of pelitic fractions (<0.01 mm) on average 37.6 %. A characteristic feature of the granulometric composition of bottom sediments of Lake Malyy Liman is a high content of fine-silty fractions, the amount of which varies from 39.2 to 77.4 %. The share of coarse siltstone is significantly lower than that of fine-aleurite and averages 4.8%. The pelitic group of fractions (<0.001-0.01) accounts for 10.5 to 59.3%. In the diagram (Fig. 3.) by the arrangement of figurative points, it is clearly seen that the total percentage of pelitic fractions (<0.01 mm) is significantly inferior to the total percentage of siltstone fractions (<0.1 mm). The sand fraction (0.1-0.5 mm) has the lowest % content, which does not exceed 2%. The presence of shell material is detected in places. Almost all the samples were found to contain a high percentage of plant remains.

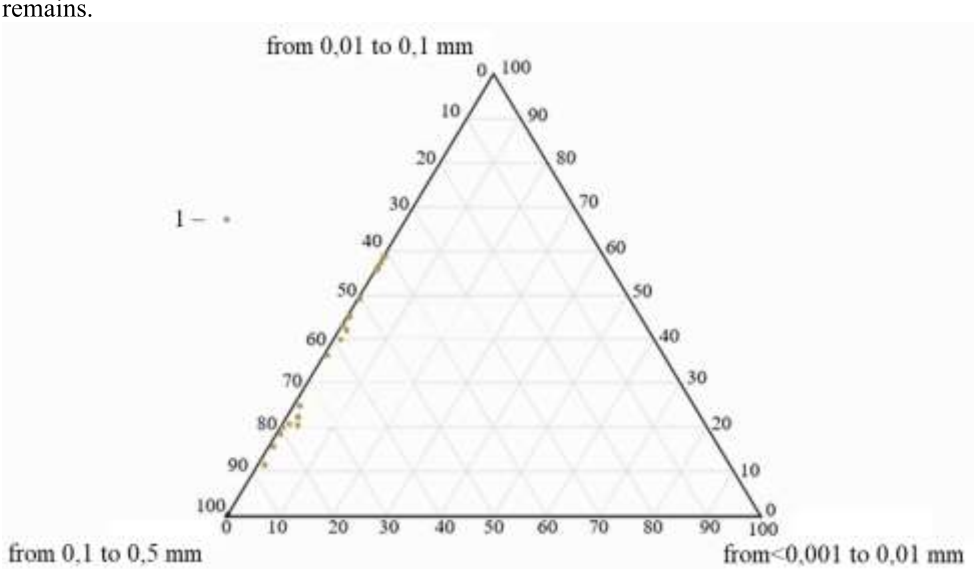

Fig. 3. Diagram of the total percentage content of sands (0.1 to 0.5 mm), aleurite (0.01 to 0.1 mm) and pelites (<0.001 to 0.01 mm) in the bottom sediments of Lake Malyy Liman (1- bottom sediments).

Let us consider the behavior of the granulometric composition of Lake Malyy Liman with sampling depth by the example of the two dominant fractions pelitic and fine-aleurite material. It follows from the graph (Fig. 4) that the greatest amount in percentage of fine-aleurite fractions is episodically concentrated at the depths of 0-2 cm, 5-10 cm and 45-70; 85-95 cm. In general, if we consider the change in the fine-aleurite fraction along the section, we find a weak trend in the growth of its % amount in the depth interval of 35-95 and 0-15 cm, the reason for which is not completely clear. It should be noted that the amount of pelitic fractions is in inverse proportion to that of fine aleurite fractions. It is known [4] that the water regime of the lake is characterized by inconstancy, which led from almost complete desiccation of the reservoir to its overfilling. In dry years, when surface runoff and perched groundwater was a minimal, terrigenous material entered the lake basin. It was represented by a greater amount of highly dispersed dusty particles than in high-water years. This tendency could be broken if during these periods, other natural and anthropogenic processes were superimposed, which contributed to the growth of mineral particles of higher dimension.

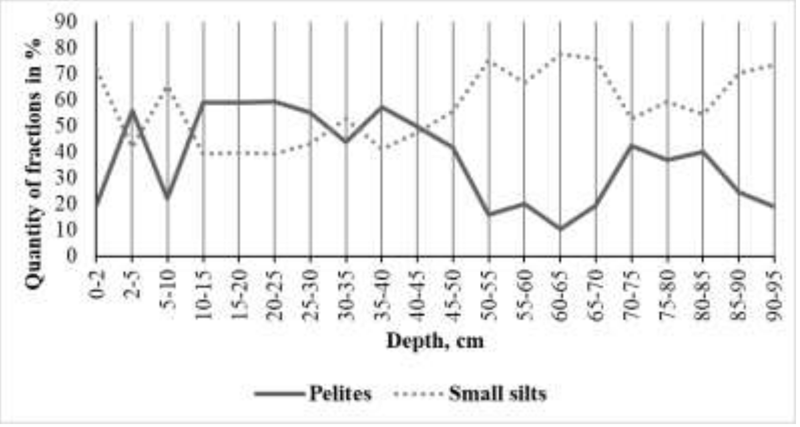

Fig. 4. Variations in the granulometric composition along the bottom sediment section of Lake Malyy Liman.

3.3 Radionuclide composition

Cesium-137 is a long-lived technogenic radionuclide. The study of its distribution in the environment is important both from the ecological point of view and for the purpose of using it as a marker, which activity peaks are used to date bottom sediments [11]. In the 30-cm layer of bottom sediments of Lake Abrau, a specific activity manifestation of ^{137}Cs were found, against which two clear peaks stand out (Fig. 5a). No specific activity was detected below the base of layer. In Lake Malyy Liman, the specific activity of ^{137}Cs is traced up to the depth of 30-35 cm (Fig. 5b). Two clear peaks are also identified here [11]. In both lakes, the first peak of specific activity of ^{137}Cs has a Chernobyl origin in 1986. The second peak is associated with global atmospheric deposition because of nuclear weapons testing in the late 50's - early 60's of the XX century. Using data of ^{137}Cs distributions through the bottom sediment section, their dating was done. This made it possible to determine later in the chronology of lake contamination and to determine the lower limit of anthropogenic impact. Sedimentation rates calculated according to the Chernobyl peak for lake Malyy Liman were on average 3.5 mm/year, for lake Abrau - 4 mm/year; according to the second (global) peak they are the same for both lakes and equal on average to 3.7 mm/year. Weak peak of specific activity in lake Malyy Liman at a depth of 33 cm is most likely a consequence of redeposition under the influence of gravitational-sedimentary landslide processes of the layer contaminated with artificial radionuclide. A similar phenomenon has been described by changes in mercury content in the bottom sediment section of the Kandalaksha Bay of the White Sea [1]. Thus, we can conclude that the lower boundary of the anthropogenic impact layer in both lakes is at a depth of 30-33 cm.

3.4 Elemental composition (mercury)

The total mercury content distribution by depth of bottom sediments in lakes Abrau and Malyy Liman were studied (Fig. 5). In Lake Abrau, the metal content varied between 0.051-0.129 μg/g (average 0.078 μg/g), and in Lake Malyy Liman, it was 0.041-0.19 (average 0.085 μg/g) dry weight. For Lake Abrau, the maximum content of total mercury occurs in the bottom sediment layer of 25 cm and in the Malyy Liman - up to 30 cm. Thus, the increased concentrations of total mercury in the bottom sediments of both lakes are confined to a layer of anthropogenic influence, allocated by us on distribution of specific activity ^{137}Cs.

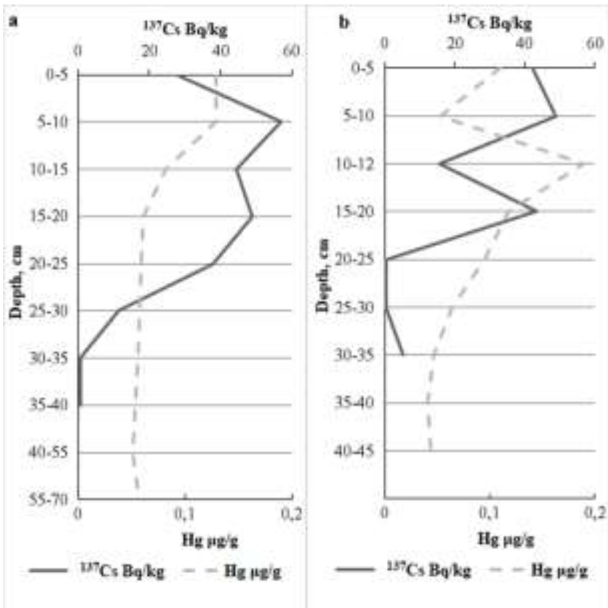

Fig. 5. Distribution of Hg concentration and specific activity of ^{137}Cs in bottom sediments of lakes (a - Abrau, b - Malyy Liman). Data on the specific activity of cesium-137 from the paper [11].

Let us compare the changes in the granulometric composition along the section of the bottom sediments with the depth of their formation to clarify chronology of events, possibly associated primarily with human intervention, taking for example the fine-aleurite fraction, the amount of which, as shown above, appears most contrasting. With an average rate of sedimentation equal to 3.7 mm/year, we calculate that the bottom sediment thickness of 95 cm could have formed in about 257 years. The works [12-13] show that the intensity of anthropogenic transformation of landscapes intensified during the XX century. In particular, within the limits of the territory under study, the structure of landscapes in the watershed of Lake Abrau and Malyy Liman was greatly influenced by clear-cut and selective logging on the gentle slopes of interfluves, carried out in the 50-60s, and the creation of recreational infrastructure on the coast (road construction, construction of other technical facilities, plowing of slopes). Vineyards were planted in place of deforested areas. During the 20th century, the water level in Lake Abrau decreased and its silting increased. This also contributed to the construction of the road to the Black Sea coast, accompanied by backfilling of the soil, some of which could be in the basin of the lake. In the late 70's and early 80's of the last century, several measures to combat silting of the lake were taken - vineyards on the western slope were eliminated, and the slope itself was terraced and planted with Crimean pine. A shallow sediment basin was created on the northern shore of the lake, at the place where the river flows into it. This was intended to reduce the rate of bottom sedimentation in the reservoir. We did not study the granulometric composition of the bottom sediments of Lake Abrau, so we used the information obtained only for the bottom sediments of Lake Malyy Liman. This is acceptable because, as shown in [4], both lakes were formed in similar geological and tectonic conditions and are attributed to a single natural-technogenic system.

The profile of the particle size distribution of bottom sediments in Lake Malyy Liman (Fig. 4), we can distinguish a depression with the lowest amount of % fine aleurite. It is located at a depth interval of 12-35 cm in the section and coincided with the anthropogenic impact layer, which was determined by the specific activity of 137Cs and total mercury content.

Using the information on sedimentation rates, let us calculate that its finding corresponds to the formation of bottom sediments in the period from the early twenties to the eighties of the last century. As shown above, at that time there was an active anthropogenic transformation of the watershed of Malyy Liman and Abrau lakes, which was apparently accompanied by a decrease in the fine-aleurite fraction and an increase in pelitic fraction. After crossing the base of the depression layer, the amount of % of the fine-aleurite fraction began to increase. At a depth of 50-75 cm, a plateau with an increased number of fine-aleurite fractions in the bottom sediments was distinguished, which was synchronous with the decrease in % of pelitic. We believe that between 1810 and 1870, there were natural events (e.g., increased seismic activity) that contributed to the growth of coarser clastic fractions.

4 Conclusion

The relationship between the conjugate in time and space formation of the granulometric, elemental (mercury) and isotopic composition (cesium-137) bottom sediments of lakes with anthropogenic perturbations in the watershed of the Abrau and Malyy Liman lakes has been established. Content in bottom sediments of fractions of different sizes can also serve as an indicator of natural impact on the watershed of mountain territories. The study of the distribution of the specific activity of ^{137}Cs, the gross content of mercury and the pelitic and fine-silty fractions in the bottom sediments of the Abrau and Malyy Liman lakes allowed to establish the parameters of the anthropogenic impact layer and the chronology of its formation in the bottom sediments.

The research was financially supported by the Ministry of Science and Higher Education of the Russian Federation (no. FENW-2023-0008)

References

1. Yu. A. Fedorov, A. E. Ovsepyan, V.A. Savitsky, A.P. Lisitzin, V.P. Shevchenko, A. N. Novigatsky, Oceanology. **59,** 143-150 (2019)
2. R. A. Horne, *Marine chemistry: The structure of water and the chemistry of the hydrosphere* (N.Y., London, Wiley-Interscience, 1969)
3. Yu. A. Fedorov, V. I. Chepurnaya, I. V. Dotsenko, D. N. Gar'kusha, A., Mikhailenko , IOP Conf. Ser.: Earth Environ. Sci.,**1061** 012036 (2022)
4. Yu. A. Fedorov, A.N. Kuznetsov, V.A.Savitsky, B.V. Talpa, I.V. Golovkov, N.V. Dotsenko, K.S. Stanislavsky, V.N. Gabova, Engineering journal of Don, **5(88)**, 500-520 (2022)
5. E.M. Alekseeva *Greek colonization of the Northwest Caucasus* (M., Nauka, 1991)
6. O.E. Vyazkova, Hist. and Arch. Almanac of the Armavir Local History Museum **5**, 52-58 (1999)

7. V. L. Boldyrev, Proceed. of the Inst. of Ocean. **21**, (1957)
8. M.M. Alekseev, N.A. Hodyrev, Materials Kharkiv. Department. Geographical community of Ukraine. **12**, 86-88 (1973)
9. P.L. Bezrukov, A.P. Lisitsyn Tr. Institute of Oceanology of the USSR Academy of Sciences **32,** 3-14 (1960)
10. M.G. Davydov, E.A. Buraeva, L.V. Zorina, V.S. Malyshevsky, V.V. Stasov, *Radioecology: textbook for universities* (Rostov-on-Don, Phoenix,2013)
11. Yu. A. Fedorov, E.N. Lenets, in : Reports of the IX International Conference "New Ideas in Earth Sciences", **3**, 65 (Moscow: Sergo Ordzhonikidze Russian State Geological Exploration University (RGGRU) , 2009)
12. S. A. Litvinskaya, in : *Topical issues of flora and vegetation research in the North Caucasus* 96-100 (1980)
13. A.N. Ivanov, O.A. Leontieva, E.G. Suslova *Nature of the Abrau Peninsula (landscapes, vegetation and animal population)* (Collection of scientific tr. / Ed. - Moscow: Geographical Faculty of Moscow State University, 2000).