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The Sedimentation Rate in the Crimean Hypersaline Lake Aktashskoye Estimated Using the Post-Chernobyl Artificial Radionuclide ^{90}Sr as a Radiotracer

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Abstract: Artificial ^{90}Sr is one of the most important long-lived radionuclides of global radioactive fallout from the atmosphere after the testing of nuclear weapons and the accident at the Chernobyl Nuclear Power Plant in 1986. In addition to fallout from the atmosphere, secondary radioactive contamination of Crimea was mainly from the Dnieper River and the North Crimean Canal, which occurred until 2014. ^{90}Sr was used as the optimal radiotracer for estimating the rate of sedimentation in the Crimean hypersaline lake. Its vertical distribution in the bottom sediments was assessed. In the core of the bottom sediments, the detectable activity of ^{90}Sr in layers 0–1.5 cm and 16.7–21.9 cm was absent, and it was determined again in the layer of 15.5 cm, which was associated with atmospheric fallout of the radionuclide after the Chernobyl NPP accident. There were well-isolated peaks of specific activity in layers at a depth of 4.6 and 13.3–14.3 cm. The calculated rate of sedimentation varied within 0.5–1.5 cm year^{-1}: the minimum rate corresponded to the period 1971–2017, and the highest rate corresponded to the period 1954–1971.

Keywords: ^{90}Sr; Chernobyl accident; sedimentation rate; salt lake; bottom sediments

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1. Introduction

The rate of accumulation of sediments at the bottom depends on many factors and, influencing many processes in a body of water, is an important functional characteristic of aquatic ecosystems [1–7]. The process of sedimentation is also a factor in the self-purification of the water column from radioactive and chemical contaminations [8,9]. Due to this, it is possible to geochronologically reconstruct the dynamics of the input of certain substances into the water body, including pollution [10–12]. Understanding past ecosystem dynamics and their impacts on it is key to predicting possible scenarios for future ecosystem dynamics under conditions of climate variability and anthropogenic impacts [13–15]. To assess the history of anthropogenic impact, layer-by-layer dating of bottom sediments is necessary [16,17]. To date the layers, artificial radionuclides ^{90}Sr and ^{127}Cs can be used as a radiotracer [9,18–21].

The input of artificial radionuclides into the atmosphere is associated with the anthropogenic causes of their release into the environment [9,22]. ^{90}Sr is one of the most abundant long-lived radionuclides in global radioactive fallout from the atmosphere after the first and most intense testing of nuclear weapons in open environments [22,23]; the annual global fallout of bomb ^{90}Sr on the surface of Earth has been observed since 1945, after the Hiroshima and Nagasaki bombings, with the highest activity during 1954–1970 (13.0 PBq and 0.5 PBq, respectively) and with atmospheric testing of hydrogen bombs. Therefore, the specific activity of ^{90}Sr, which was determined in the lower layers of the bottom sediment cores to the layer where the value of the concentration of this radionuclide was below the detection limit, corresponding to the period of global fallout of ^{90}Sr from the atmosphere after the testing of nuclear weapons.

The accident at the Chernobyl Nuclear Power Plant (ChNPP) on 26 April 1986, served as an additional source of the global release of radioactive substances into the atmosphere [9,24]. In May 1986, 1.7–2.4 PBq ^{137}Cs and 0.3 PBq ^{90}Sr fell onto the surface of the Black Sea and the territory of Crimea [9,25]. In addition to fallout from the atmosphere, there was another way through which radioactive products of nuclear explosions and accidents enter distant areas: through transportation by river waters. After the Chernobyl accident, there was also secondary radioactive contamination of the Black Sea and Crimean ecosystems, by the runoff of rivers, mainly the Dnieper (90.2 TBq ^{90}Sr in the period 1986–1995). This chronic radioactive contamination of the Crimean territory occurred until 2014 by Dnieper waters from the North Crimean Canal (NCC) [9,26–28]. In April 2014, the supply of water from the Dnieper River, containing ^{90}Sr, into the NCC, was stopped due to political reasons [28,29]. Therefore, taking into account all of the above, ^{90}Sr can be the optimal radiotracer to assess the rate of sedimentation in water bodies far distant from the ChNPP accident [19,30–32]. In the layers of the bottom sediment core, these events can be assumed as follows: after some absence of the specific activity of ^{90}Sr, its first determination corresponds to the atmospheric fallout of this radionuclide after the ChNPP accident. Later, its concentrations, an order of magnitude higher, could be caused by the waterway of its entry into the study area until 2014. The upper layers of bottom sediments, in which the concentration of ^{90}Sr is below the limit of its detection, corresponding to the period after 2014, when the NCC was closed.

The tasks of this study were: 1. to study the nature of the vertical distribution of ^{90}Sr along the bottom sediments of the hypersaline Lake Aktashskoye, with the identification of the depth for the ‘global’ and ‘Chernobyl’ peaks of ^{90}Sr activity that entered the reservoir; 2. using ^{90}Sr as a radiotracer, to carry out chronological dating of layers from core sediments of the lake; 3. to assess the rate of sedimentation in Lake Aktashskoye.

2. Materials and Methods

2.1. Studied Lake

Lake Aktashskoye, one of the many natural hypersaline lakes in Crimea [33], is located in the north of the Kerch Peninsula and belongs to the Kerch group of salt lakes (Figure 1).

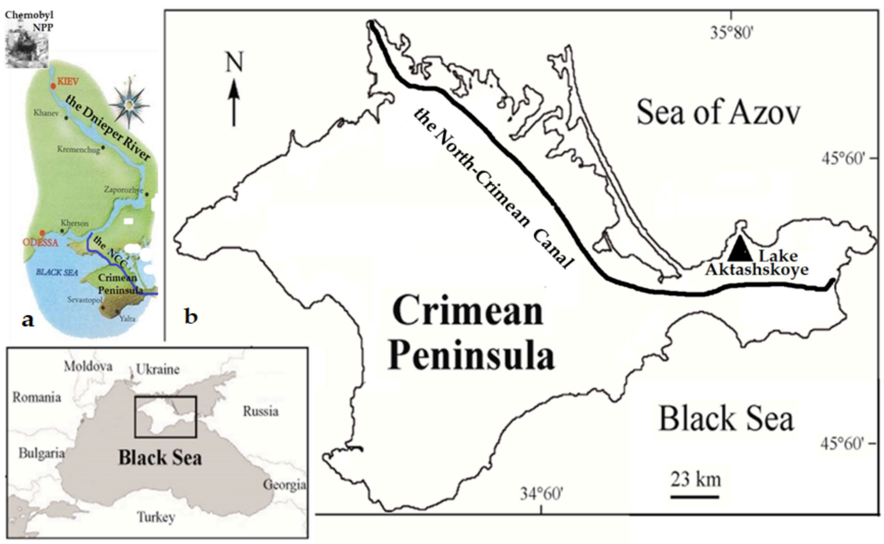

Figure 1. Map scheme location of the Chernobyl NPP area, showing the Black Sea and the Crimean Peninsula (**a**), the position of Lake Aktashskoye, and the NCC on the territory of Crimea (**b**).

The length of the lake is 8 km, the average width is 3.0 km, the maximum is 3.5 km, the depth is 2 m, and the maximum is 3 m. The surface area of the lake is 26.8 km^2, and the drainage basin is 467 km^2. Lake Aktashskoye is a marine salt lake, and salinity in it is characterized by high spatial and temporal variability, from 10 to 280 g L^{-1}. The average annual amount of precipitation falling on the surface of the lake is 400 mm. In Lake Aktashskoye, as well as in other Crimean hypersaline lakes, it was found that at salinity above 120 g L^{-1}, the benthic animals practically disappear, or switch to existence in the plankton [33]. Therefore, the bioturbation of bottom sediments is neglected in them. During 1979–1981, Lake Aktashskoye was planned to be used as a cooling reservoir for the Crimean nuclear power plant under construction, but its construction was stopped due to public protests. Until 2014, the lake was connected to the NCC. At present, the lake is not used for economic activities [34]. However, as our long-term studies show, Lake Aktashskoye is a potentially promising reservoir for the development of aquaculture in hypersaline waters [33,35].

2.2. Determination of the ^{90}Sr Concentration in the Bottom Sediments of Lake Aktashskoye

For geochronology, the artificial radionuclide ^{90}Sr is used as a radiotracer [9,19]. The core of bottom sediments in Lake Aktashskoye was sampled with an acrylic tube (inner diameter 58 mm) with a vacuum lock, with the maximum preservation of the layers on 17 August 2017, and the core sampling coordinates were 45°23.144′ N; 35°50.036′ E. The bottom sediment core was taken by hand. The maximum sampling depth was 50 cm. The resulting core was cut into layers 1 cm thick using a screw extruder [36] in the laboratory of the Department of Radiation and Chemical Biology, the A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS. Immediately after cutting, the samples were weighed, dried at a temperature of 40–50 °C, and then weighed again, determining the amount of evaporated water. To estimate the initial moisture content of bottom sediments, the content of salts dissolved in pore water was calculated [37]. The integrity of layers in the lake was determined from the graph of the cumulative mass of layers in the core, which was calculated using the Excel program [38]. The ^{90}Sr concentration was determined separately for each layer of the bottom sediment core of Aktashskoye Lake. The method is based on the radiometric determination of ^{90}Sr from the Cherenkov radiation of its daughter product 90Y, using a low-background liquid scintillation counter LKB QUANTULUS 1220 (LKB Wallac Oy, Turku, Finland) [9,39]. The lower limit of detectable activity is 0.01–0.04 Bq m^{-3} of the sample. The relative error of the obtained results did not exceed 20%. Control over the correctness of the methodology used and the reliability of the results obtained was carried out through constant participation in international intercalibration under the auspices of the International Atomic Energy Agency (Vienna, Austria) and the RISOE National Laboratory (Roskilde, Denmark). The data on the intercalibration of the methods of determinations obtained from the results of measurements of reference samples and field parallel determinations between the A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS and other institutes indicated that the methodological base used made it possible to assess, with the necessary and sufficient degree of reliability, the contamination of the studied ecosystems with the long-lived radionuclide ^{90}Sr [9].

2.3. Geochronological Studies of Bottom Sediments of Lake Aktashskoye

Determination of the rate of sedimentation is carried out by the depth of the ^{90}Sr activity maximum corresponding to the accident at the ChNPP during 1986–1988, or the period of ^{90}Sr input from the atmosphere after the global fallout (1954). The average sedimentation rate was calculated using the formula [9,19]:

$$\mathrm{SR} = \mathrm{h}/(\mathrm{T} - \mathrm{T_o}) \quad (1)$$

where SR is the sedimentation rate (cm $year^{-1}$); h is the average layer depth (cm); T is the absolute age of the layer (years); and T_o is the year of sampling.

It should be taken into account that the degree of compaction of bottom sediments increases with the depth of the sediment; therefore, the depth of the layer is calculated taking into account its deconsolidation, which was carried out by comparing the density of the core layers of bottom sediments with the surface layer of sediments of the same core.

In addition, the rate of sedimentation in different periods may be different [9,40]. Lake Aktashskoye, as an example, has a high rate associated with the construction of the NCC and its connection to the lake from 1961 to 1971. The construction of the Crimean nuclear power plant around the reservoir in 1979–1981, and other anthropogenic and climatic (heavy precipitation, floods) impacts that affect sedimentation processes in the reservoir are under study. In such cases, it is more appropriate to use the sedimentation rate value for each layer. In some cases, it is possible to use the average value of the sedimentation rate determined by Equation (1), using as the maximum values of the absolute age of the layer in 1962 and 1986. The obtained values of the sedimentation rate make it possible to determine the age of individual layers of bottom sediments. The age of bottom sediment layers in cores was determined by the formula [38]:

$$T = T_o - h/SR \tag{2}$$

2.4. Determination of Sr and Ba in the Bottom Sediments of Lake Aktashskoye

To compare the features of the distribution of ^{90}Sr in the bottom sediment core from Lake Aktashskoye, the concentrations of lithophilic elements, such as stable Sr and Ba, similar in their behaviour in natural environments, were also determined layer by layer [41]. The column of bottom sediments, to determine the layered distribution of strontium and barium in them, was selected on 6 November 2019, the sampling coordinates were 45°23.133′ N; 35°50.028′ E. The core of bottom sediments for the determination of trace elements in them was taken as close as possible to the sampling site of the column of bottom sediments for geochronological studies. To determine trace elements, including heavy metals, a weight of a sample was taken from each layer to determine the content of 1–2 g, samples of bottom sediments were dried in an oven at a temperature of 80 °C to a constant weight. For the analysis of trace elements, 1 g of the dry mass of bottom sediments was taken, ground in a porcelain mortar to a homogeneous state, and acid decomposition was carried out openly in a glass beaker on an electric stove. After the complete dissolution of the sample, the solution was filtered and adjusted with bidistilled water to the required volume.

Determination of trace elements in extracts from samples of bottom sediments was carried out in the laboratory of the Spectrometry and Chromatography Center for Collective Use of the A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS, on an inductively coupled plasma mass spectrometer, PlasmaQuant MS Elite (Analytik Jena, Jena, Germany). The spectrometer was calibrated using a standard solution 'Multi-element calibration standard IV-28, HNO_3/HF, 125 mL' (Inorganic Ventures, Lakewood, CA, USA). The measurement on the mass spectrometer included 7 repetitions of 10 scans for each element being determined with a duration from 10,000 to 100,000 µs, depending on its expected concentration. The limits of detection were individual for each element being determined, and depended on the intensity of the response and the noise level of the mass spectrometer for each specific ratio of the ion mass to its charge. The determination error for each element was no more than 15% of the result obtained.

3. Results

The obtained results on the distribution of ^{90}Sr concentration in the corresponding layers of the column of decompacted desalinated bottom sediments of Lake Aktashskoye are presented in Table 1, Figures 2 and 3.

Table 1. The concentration of ^{90}Sr in the core of bottom sediments was taken in Lake Aktashskoye on 17 August 2017, at a water salinity of 200 g L^{-1}.

The Middle of the Height of the Decompacted Layer, cm	Wet Weight of the Layer, g	Dry Weight of the Layer, g	Dry Desalted Weight of the Layer, g	Mass Cumulative, g/cm^2	^{90}Sr Concentration Corrected for Desalted Mass, Bq kg^{-1} Dry Weight	
					Average	Standard Deviation
0.5	49.3	40.9	38.6	1.5	0 *	0 *
1.5	46.1	37.9	36.2	2.8	0 *	0 *
2.3	31.2	25.4	24.3	3.8	1.4	1.0
3.3	47.5	37.9	36.0	5.1	13.3	1.0
4.6	48.4	36.4	34.0	6.4	52.2	2.7
5.5	50.2	36.9	34.3	7.7	9.5	1.1
6.5	42.9	32.9	30.9	8.9	2.9	0.8
7.5	46.1	36.4	34.5	10.2	0	0
8.6	49.8	39.9	37.9	11.6	9.9	0.7
9.7	51.7	40.4	38.2	13.6	0 *	0 *
10.5	42.0	30.9	28.7	14.2	5.8	1.0
11.4	44.5	30.9	28.2	15.2	0.7	0.9
12.5	48.9	34.4	31.5	16.4	7.3	0.8
13.3	33.7	22.4	20.2	17.2	31.6	0.1
14.3	38.7	26.4	24.0	18.1	56.9	0.3
15.5	45.4	31.4	28.6	19.2	4.1	0.2
16.7	46.9	37.4	35.5	20.5	0 *	0 *
17.9	53.9	44.4	42.5	22.1	0 *	0 *
19.0	56.9	47.4	45.5	23.8	0 *	0 *
20.0	54.4	45.4	43.6	25.5	0 *	0 *
21.0	52.9	43.9	42.1	27.1	0 *	0 *
21.9	47.9	39.9	38.3	28.5	0 *	0 *
23.0	58.9	47.4	45.1	30.3	3.7	0.2
23.9	45.4	35.9	34.0	31.5	2.6	0
24.8	47.9	37.9	35.9	32.9	2.5	0.1
25.9	53.9	41.4	38.9	34.4	0 *	0 *
26.9	49.9	37.9	35.5	35.7	2.6	0.2
27.9	45.4	33.9	31.6	36.9	3.7	0.1
28.7	42.9	30.9	28.5	38.0	4.1	0.2
29.8	53.9	38.4	35.3	39.3	0 *	0 *
30.8	47.4	33.4	30.6	40.5	3.8	0.8
31.7	39.9	28.4	26.1	41.5	0 *	0 *
32.6	38.4	27.9	25.8	42.5	0 *	0 *
33.7	47.9	35.4	32.9	43.7	2.9	0.5
34.9	53.4	39.9	37.2	45.1	2.6	0.4
35.9	46.4	34.4	32.0	46.3	2.9	0.5
36.9	52.4	39.4	36.8	47.7	3.1	0.4
37.9	44.4	33.9	31.8	48.9	0 *	0 *
38.9	47.9	35.9	33.5	50.2	4.2	0.5
39.9	45.4	34.4	32.2	51.4	2.5	0.4
40.9	49.9	37.4	34.9	52.7	2.3	0.4
41.9	49.4	37.4	35.0	54.1	0 *	0 *
42.9	46.9	34.4	31.9	55.3	0 *	0 *
43.9	49.9	35.9	33.1	56.5	2.8	0.4
44.9	40.9	29.9	27.7	57.6	0 *	0 *
45.9	50.4	35.9	33.0	58.8	2.6	0.3
46.9	50.9	37.4	34.7	60.1	2.1	0.3
48.0	49.4	36.9	34.4	61.4	0 *	0 *
48.9	44.9	33.4	31.1	62.6	4.9	0.6
50.0	58.9	44.4	41.5	64.2	1.6	0.3

Note(s): *—below detection limit.

The integrity of the structure of the bottom sediment core layers was checked by the graph of the cumulative core mass (Table 1, Figure 2).

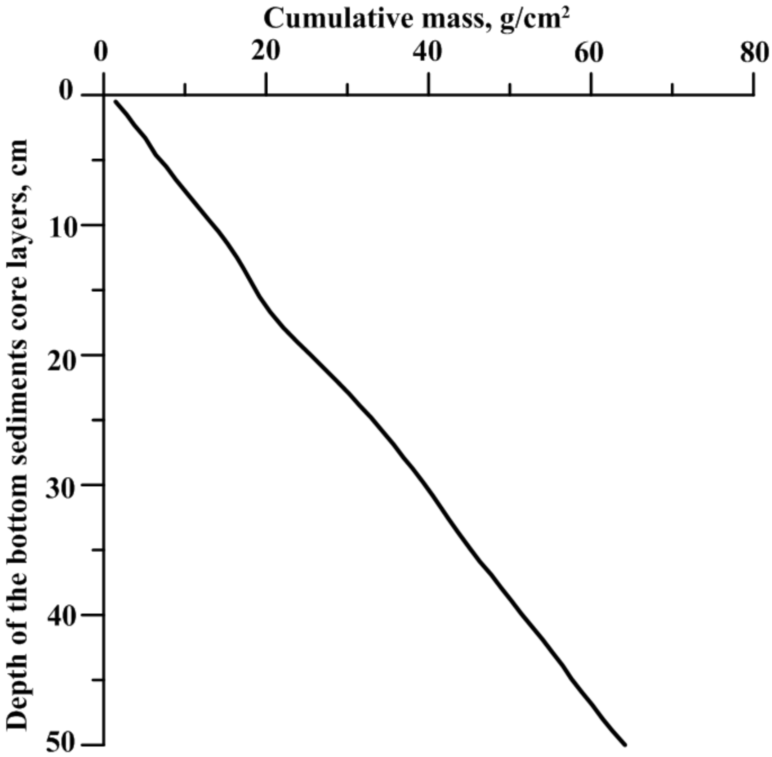

Figure 2. Graph of the cumulative mass of core layers of bottom sediments from Aktashskoye Lake (2017).

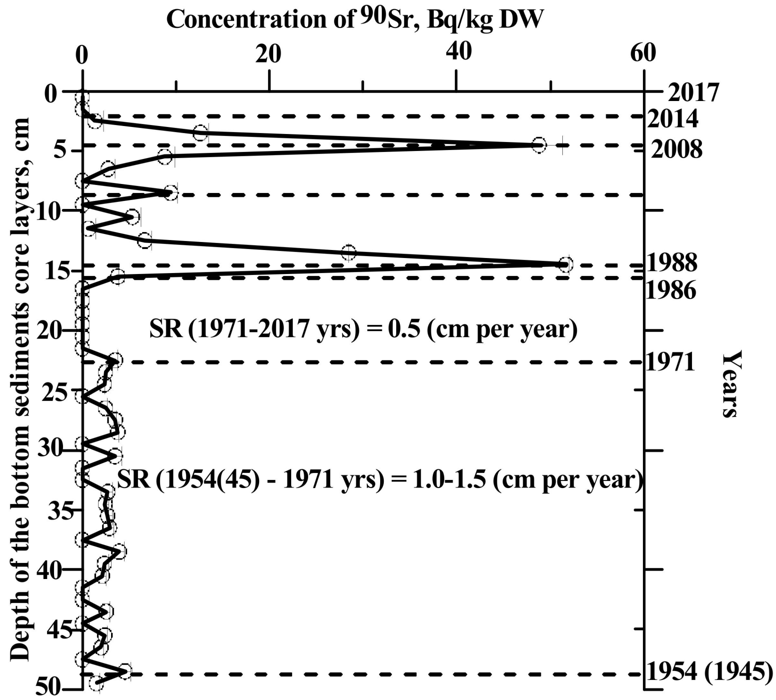

Figure 3. Dating of bottom sediments and the rate of sedimentation in Lake Aktashskoye by ^{90}Sr as a radiotracer.

The analysis of the obtained results (Table 1, Figure 2) allows us to conclude that there are no obvious violations of the integrity of the sampled core of bottom sediments from Lake Aktashskoye. This makes it possible to use the selected core sample for dating the bottom sediments of the lake (Table 1, Figure 3).

A feature of the distribution of the ^{90}Sr concentration in the core of the bottom sediments of Lake Aktashskoye (Table 1, Figure 3) was both the complete absence of detectable activity of the radionuclide in layers 0–1.5 cm and 16.7–21.9 cm, and the presence of two well-isolated peaks of specific activity of ^{90}Sr in layers at a depth of 4.6 and 13.3–14.3 cm. In the layers of the core of the bottom sediments of Lake Aktashskoye, ^{90}Sr concentrations are reliably determined even at a depth of 50 cm. The layer-by-layer distribution of stable Sr showed a decrease in its concentration with depth (Table 2, Figure 4); there is no correlation between stable Sr and ^{90}Sr.

Table 2. Sr (stable) and Ba concentrations in the core of bottom sediments taken in Lake Aktashskoye for geochronological studies (6 November 2019).

Average Column Layer Depth, cm	Age of the Bottom Sediment Layer, Year	The Concentration of Stable Elements, mg kg^{-1} Dry Weight			
		Sr		Ba	
		Average	Standard Deviation	Average	Standard Deviation
0.5	2019	674	14	62.6	2.4
1.5	2016	683	17	60.8	1.3
2.5	2014	742	13	54.0	1.6
3.5	2012	620	8	81.7	3.0
4.5	2010	531	17	66.8	2.7
5.5	2008	411	7	52.4	1.1
6.5	2006	423	5	83.0	2.6
7.5	2004	343	8	67.5	1.4
8.5	2002	371	7	79.2	2.8
9.5	2000	190	4	74.8	2.8
10.5	1998	190	5	52.8	1.0
11.5	1996	215	4	58.7	1.3
12.5	1994	186	3	61.7	1.6
13.5	1992	139	1	63.2	1.8
14.5	1990	110	1	194.0	6.1
15.5	1988	133	4	80.1	1.6
16.5	1986	84	4	78.7	3.3
17.5	1984	103	4	71.6	1.8
18.5	1982	90	2	59.0	1.7
19.5	1980	92	3	47.7	1.2
20.5	1978	96	3	48.9	1.4
21.5	1976	155	4	67.3	2.0
22.5	1974	96	2	52.9	0.9
23.5	1971	247	9	84.6	2.9
24.5	1970	141	3	80.0	3.7
25.5	1969–1970	182	5	65.8	1.8
26.5	1969	197	5	75.6	3.1
27.5	1968	163	6	89.3	2.6

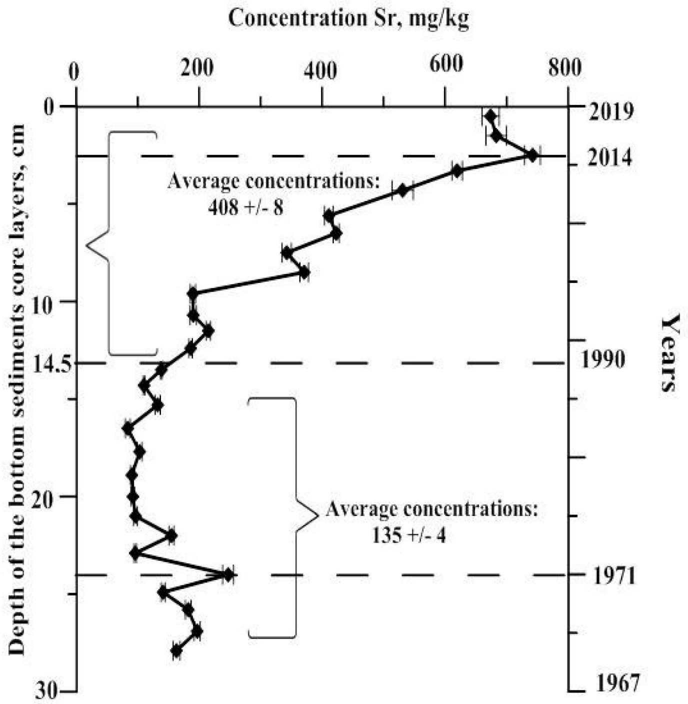

Figure 4. Distribution of Sr (stable isotope) in the core of bottom sediments of Lake Aktashskoye.

The layer-by-layer distribution of Ba in the core of the bottom sediments of Lake Aktashskoye varied in the range of 47.7–89.3 mg kg^{-1} of dry weight, and practically did not differ both in the period before and after 1990 (Figure 5).

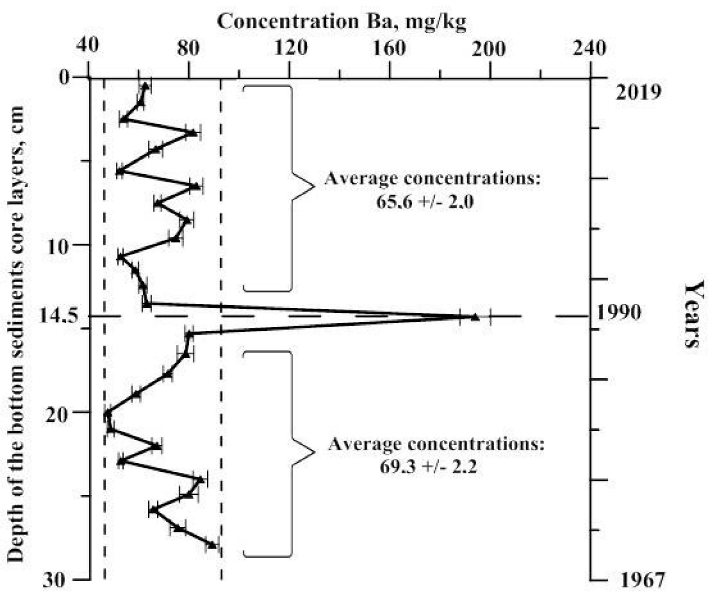

Figure 5. Distribution of Ba (stable isotope) in the core of bottom sediments of Lake Aktashskoye.

4. Discussion

It can be confidently assumed that the 'zero' values of ^{90}Sr concentrations in the surface layers of the core of the bottom sediments of Lake Aktashskoye correspond to the closing period of the NCC, i.e., 2014–2017 [42], while the absence of detectable radionuclide activity in deeper core layers corresponds to the period of cessation of global ^{90}Sr fallout, i.e., from 1970 onwards [22,23]. According to the performed studies [9,30], the concentrations of ^{90}Sr that fell with atmospheric precipitation immediately after the Chernobyl accident on the territory of Crimea and the Black Sea were an order of magnitude lower than the specific activities of this radionuclide that entered such remote territories by the Dnieper water. Therefore, the first reliable determination of the ^{90}Sr concentration in the 15.5 cm layer after the complete absence of its detection in the 16.7–21.9 cm layers is correlated with the atmospheric fallout of the radionuclide after the Chernobyl accident (1986). The authors believe that the presence in the next layer (14.3 cm) of bottom sediments of the peak concentration of ^{90}Sr (restored activity 111.2 Bq kg^{-1} dry mass), the values of which exceed the value of the previous layer by two orders of magnitude (fixed activity 8.6 Bq kg^{-1} dry mass), corresponds to the inflow of the radionuclide into Lake Aktashskoye with Dnieper water through the NCC. Studies in June–August 1986 [43] determined that more than 80% of ^{90}Sr was in dissolved form in the water of the Pripyat-Kyiv reservoir–Dnieper river system, which allowed this radionuclide to practically transit through the Dnieper and the cascade of its reservoirs to such remote areas as Crimea and the Black Sea.

In the bottom sediments of Lake Aktashskoye, the concentration of ^{90}Sr is reliably determined even at a depth of 50 cm. Since ^{90}Sr is an artificial radionuclide, its appearance in the environment cannot be earlier than 1945 [23,24,44]. There are no specific features in the distribution of the specific activity of ^{90}Sr in the core layer from 23 to 50 cm (Table 1, Figure 3). However, the highest concentration of the radionuclide in this thickness of bottom sediments was observed at a depth of 48.9 cm, which allows us to correlate this layer with the period of the beginning of the largest global fallout of ^{90}Sr, namely, 1954 [22,23].

Thus, for the dating of bottom sediments with the vertical distribution of ^{90}Sr in the core of bottom sediments, the following were used as chronological 'landmarks':

- an increase in the specific activity of ^{90}Sr at a depth of 15.5 cm, which is correlated with the atmospheric fallout of this radionuclide after the Chernobyl accident (1986);
- a significant peak of ^{90}Sr activity (14.3 cm), which corresponds to the water (main) route of the radionuclide intake with the Dnieper water [9,30];
- correlation of ^{90}Sr activity below the level of detection in the upper layers of the core (depth 2 cm) to the period of the NCC closure, starting from 2014 [42];
- core layers from 23 to 50 cm, which correspond to the global atmospheric fallout of the radionuclide during 1954–1971.

Analysis of the vertical distribution of the specific activity of ^{90}Sr (Table 1, Figure 3) showed that the rate of sedimentation in Lake Aktashskoye was uneven. The calculated rate of sedimentation in the lake varied from 5 to 15 mm year^{-1}. The minimum sedimentation rate corresponded to the period 1971–2017 (core layers 0–23 cm), the highest sedimentation rate corresponds to the period 1954–1971 (core layers 23–50 cm), and this period coincides with the time of the most active anthropogenic load on the lake, which was associated with the construction of the NCC and its connecting with Lake Aktashskoye. Such construction activity usually led to an increase in the rate of sedimentation in water bodies of different regions [45–48].

The obtained values of sedimentation rates in Lake Aktashskoye were similar to those highest for the Black Sea: at the mouth of Chorokh River (5.3 mm year^{-1}), the Dnieper–Bug Estuary (9.2 mm year^{-1}), and the coastal area of the Danube River (11.5 mm year^{-1}) [9]. At the same time, the rate of sedimentation in the hypersaline protected Lake Koyashskoye (Crimea) was 5–15 times lower than in Lake Aktashskoye [49]. In the regulated hypersaline lake Krasnoye (Crimea), which is used to discharge wastewater from the Crimean soda plant, the rate of sedimentation was 1.7–5 times higher than in Lake Aktashskoye [31]. Thus, a rather high rate of sedimentation in Lake Aktashskoye was associated with the influence of slope runoff from adjacent territories, the shallow depth of the lake itself (compared to sea depths), and a high anthropogenic impact on the lake.

The vertical distributions of the ^{90}Sr radionuclide and the stable isotope ^{88}Sr in the bottom core (Tables 1 and 2, Figures 3 and 4) differ significantly, which indicates the different nature of the input of these elements into the environment. The chronology of the layered distribution of the stable isotope over the depth of the bottom sediments of the lake allows us to determine some features in the periods before (1967–1990) and after the Chernobyl accident (1990–2019) (Table 2, Figure 4). Therefore, the concentration of stable strontium from 1967 to 1990 was three times lower than in the period after the Chernobyl accident, with an increase in the concentration of the element only in 1971 when the Dnieper water reached the Kerch Peninsula by the NCC (Table 2, Figure 4). Since 1990, there has been an increase in the concentration of ^{88}Sr in the bottom sediments, until 2014 (the closure of the NCC). Since stable strontium is used in the radio-electronic industry, in metallurgy, for the reduction of uranium, in the production of permanent magnets, and in batteries [50], after the Chernobyl accident many structures where stable strontium was used were destroyed, which made it possible for Sr possible to migrate, first of all, with the Dnieper water through the NCC, in a dissolved state, to the territory of Crimea, including Lake Aktashskoye. For stable Sr, only Dnieper water through the NCC was the primary source of this isotope income into Lake Aktashskoye, leading to a Sr gradual increase in the post-accident period.

The layer-by-layer distribution of barium in the core of the bottom sediments of Aktashskoye Lake varied in the range of 47.7–89.3 mg kg^{-1} of dry weight, and practically did not differ both in the period before and after 1990 (Figure 5). In 1990 only, chronologically corresponding to the arrival of the 'Chernobyl' Dnieper water in Lake Aktashskoye by the NCC, a sharp increase in the concentration of this element by 2.2–4.1 times was noted. Some Ba compounds, due to their properties, are used in the manufacture of nuclear power plant reactors [50]. Since many Ba salts are of low solubility in water, only a single increase in the concentration of this element was observed over the entire period of the study (Figure 5).

5. Conclusions

The use of ^{90}Sr as a radiotracer made it possible to determine the rate of sedimentation in Lake Aktashskoye, to evaluate and explain its variability. This once again confirmed the effectiveness of using this method to understand the current changes in the ecosystems of saline lakes. The constructed time reference of the layers of bottom sediments allows for the expansion of the range of studies on the reconstruction of temporary changes in the ecosystem of Lake Akhtashskoe in recent decades, in particular, those caused by the Chernobyl accident, the construction of the North Crimean Canal, its closure, and a new startup of water flow. The most interesting results can be obtained by studying changes in the composition and functioning of the biota in sediment cores using the metagenomic approach [51–53].

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