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APPLICATION OF α AND γ SPECTROMETRY IN THE ^{210}Pb METHOD TO MODEL SEDIMENTATION IN ARTIFICIAL RETENTION RESERVOIR

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Abstract: The paper describes the application of the ^{210}Pb method for creating a comprehensive model of sedimentation in the retention reservoir Kozłowa Góra during the 60 years of its use. The model takes into account the temporal and spatial change in the sedimentation conditions. Because of the specific conditions of the young artificial lake, the techniques available to date are not sufficient and it was necessary to modify the ^{210}Pb method. The paper describes such modification of the method and its application to dating the sediments in the reservoir.
For a young lake it is impossible to estimate the activity of authigenic ^{210}Pb with the application of alpha spectrometry because even the oldest sediments contain allochthonous ^{210}Pb. The determination of the activity of authigenic ^{210}Pb in the sediments of the studied reservoir was possible only thank to gamma spectrometry. The gamma ray spectrometry consists of measurements of gamma photons emitted by ^{210}Pb, ^{214}Pb and ^{214}Bi isotopes. Analysis of the ^{210}Pb gamma spectrum line yields information about total activity of ^{210}Pb, while the assessed activity of ^{214}Pb and ^{214}Bi equals to the activity of authigenic ^{210}Pb.

Keywords: ^{210}Pb, lake sediments, Lake Kozłowa Góra, artificial lake.

1. INTRODUCTION

The radioactive isotope ^{210}Po present in the sediments of water reservoirs is formed in the sediment itself from the decay of ^{210}Pb in the ^{238}U series or from decay of that isotope outside the reservoir. The first one is called authigenic lead and it is in radioactive equilibrium with parent members of the ^{238}U series; the latter is allochthonous lead which is introduced to the lake and to the sediment from air or with water supplying the reservoir. The activity of authigenic ^{210}Pb in the layer of sediment is constant in contrast to the activity of allochtonous ^{210}Pb which decreases following the radioactive decay law, with the half-life time $T_{½}$ = 22.26 yr. The presence of allochtonous lead in sediment may be used to determine its age within the range of several half-life times. The lead-210 method is often used for dating young sediments and to determine sedimentation rates. In literature concerning the Polish territory, a growing number of papers describes this method (Goslar *et al.*, 2000; Kotarba *et al.*, 2002; Sikorski and Bluszcz, 2003; Tylmann, 2004; Gąsiorowski and Hercman, 2005).

This paper is a summary of the application of ^{210}Pb method to dating artificial lake Kozłowa Góra. In 2003 presented were the inventory of the sediments (Sikorski and Goslar, 2003) and first tests of applicability of ^{210}Pb method to dating sediments in this lake (Sikorski and Bluszcz, 2003). The main goals of our research were:

- establishing the pattern of sedimentation, determining ages of sediment's layers and sedimentation rates,
- comparison of results received by two independent measurement techniques – by gamma-ray spectrometry and by alpha-ray spectrometry.

2. STUDY SITE

The studied retention reservoir Kozłowa Góra is located 8 km E from Tarnowskie Góry, Upper Silesia (see **Fig. 1**) at the coordinates: 50°26'N 18°57'E. It is one of the artificial reservoirs which are the main water source of drinking water and for industry. The reservoir plays an important role in regulating the river Brynica and it is important in leisure of public.

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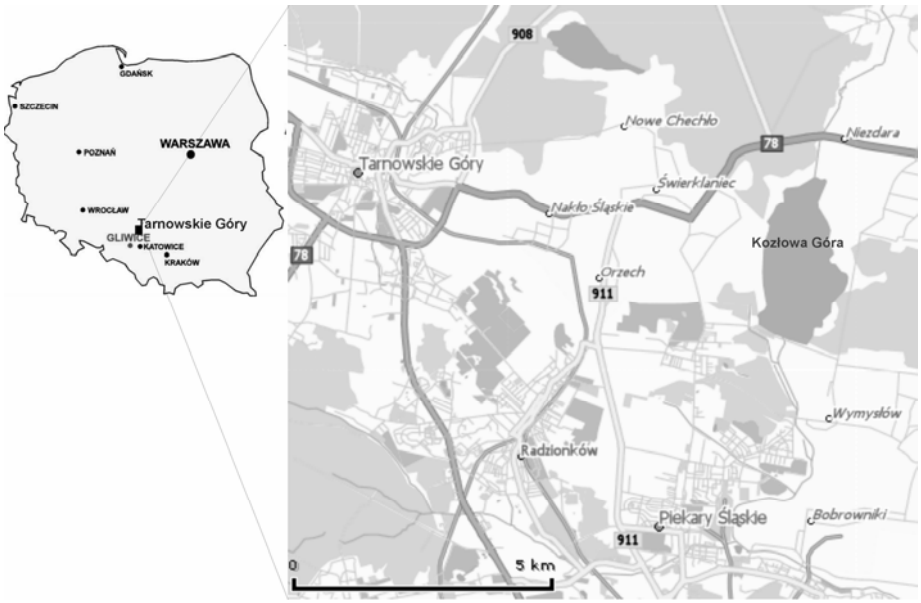

Fig. 1. *Map of Kozłowa Góra region. Location of the examined site (source:* www.zumi.pl*).*

Table 1. *Parameters characterising the reservoir Kozłowa Góra.*

Reservoir	Surface area (km^2) max./min.	Depth (m) max./aver.	Length max. (km)	Width max. (km)	Volume (mln m^3) max./min.	Catchment area (km^2)
Kozłowa Góra	6.3 / 4.6	5.6 / 2.3	3.6	2.0	16.8 / 14.3	184

At present, in the area of Upper Silesia there are no large natural water reservoirs, i.e. reservoirs that were created by tectonics or post-glacial lakes. In the past, natural reservoirs were present, mainly oxbow lakes, ponds and small lakes which were, however, destroyed as a result of industrial activity, mainly coal mining. An intensive influence of the industry on the environment through a relining of the Earth's surface brought about a change in catchment's area. One of the methods increasing the possibility of using water supplies in a given area is the storage of water in retention reservoirs.

Parameters characterising the reservoir Kozłowa Góra are presented in the **Table 1.** These data were taken from Sokół (2001), Stonawski (1997) and Ryborz-Masłowska *et al*. (1997). The surface area and the volume of the reservoir depend on the setting of the release mechanism – the table shows surface area and volume for maximal filling (water surface at the height of 278.99 m a.s.l.) and for normal filling, when the water surface is at 278.58 m a.s.l. The reservoir Kozłowa Góra was built in years 1935-1938 and taken to use in 1939. It was aimed at use for strategic military purposes. The reservoir was created from damming the river Brynica at the 28th km of its course with a soil dam of a height of 7 m and length of 1400 m. The dam is made of local material and it consists of sands and sandstone debris.

3. METHODS

The research presented here included sampling of cores from the reservoir. A total of 16 cores were taken from 13 locations from the reservoir – locations of sampling sites are presented in **Fig. 2**. The cores were taken to ensure a uniform distribution of the sediments in the reservoir; however the northern part of the lake did not have any sediment.

Two methods of taking lake sediment cores were used – freezing in situ method or 5 cm diameter piston corer method. The first method allows obtaining large samples

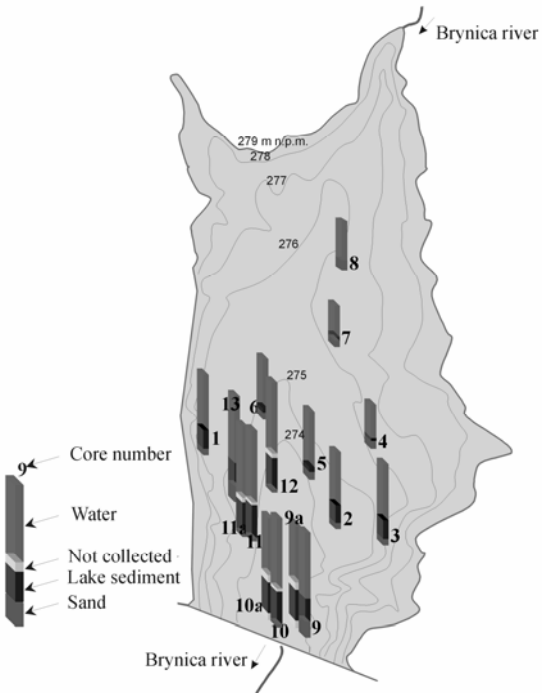

Fig. 2. *Location of cores taken from the lake Kozłowa Góra.*

(30-500 g, on average 250 g) and the sediment is undisturbed. Because it is fairly difficult to retrieve the corer to the surface, a stable floating platform is needed, although sometimes it is impossible to sample young sediments with this method.

On the other hand, the piston corer method can be applied from a boat or canoe. A core sampled using this method shows a sharp border water-sediment. The low (5 cm) diameter of the corer results in a small size of the sample – 20 times smaller than in the case of the freezing method, and it is difficult to avoid loosing young material when the sample is removed from the corer.

The two sampling methods described above led to the conclusion that joining both methods could be useful for our purpose. The pipe method can be used to sample the sediment and after retrieval, the sample can be frozen and removed from the corer. In this way it is ensured that no sample is lost. There exist piston corers free of the flaws described above (Aaby and Digerfeldt, 1986; Glew *et al*., 2001; Haberyan, 2001; Tylmann, 2007), but they were unavailable to authors during sampling.

The cores of sediments were divided into 1-3 cm fragments. The samples were subjected to chemical treatment in order to obtain sources for the measurements of alpha activity of ^{210}Pb (see Sikorski and Goslar, 2003; Sikorski and Bluszcz, 2003). In order to ensure the highest efficiency of deposition of Po and quality of spectrometric measurements, the amounts of substrates, temperature and timing of the preparation steps were determined.

The spectrometric measurements were performed with the application of two independent measurement setups. Each of them used a different semiconductor detector.

The measurements of alpha radiation was performed with the application of an alpha spectrometer manufactured by Canberra (model 7401, a PIPS detector with a resolution ≤20 keV described by the FWHM for the line 5.486 MeV of ^{241}Am at a pressure in the detector chamber of 13-67 Pa) coupled with a multi-channel analyzer.

In the case of γ radiation a germanium gamma well-type detector, manufactured by the Institute of Nuclear Physics in Kraków, was used. The detector is 45 mm high and 46 mm in diameter; the well size is Ø=8×35.5 mm. The detector has a resolution ≤2.5 keV (FWHM for the ^{60}Co 1332.5 keV line; a relative efficiency for this line ≥12%). The preamplifier is included in the detector's corpus and it is cooled with liquid nitrogen. The signal is fed to the input of the amplifier (Canberra 2024) and a multi-channel analyzer.

α and γ spectrometry

A sample for alpha measurement has a form of a thin layer of polonium extracted from the sediment and deposited on a silver disc (Flynn, 1968). Initial dry mass of the sample was 1-2 g. The sample was treated with a hot 65% nitric acid (10-20 ml, 90°C, 60 min). In nitric acid, polonium was extracted from the sediment. The extraction was continued at room temperature during the following 24 h, and subsequently the sediment was separated from the solution by centrifugation (5000 rpm during 10 min). The solution was collected in a Teflon vial, while the remaining sediment was washed with 65% nitric acid and centrifuged again. Both aliquots of the solution were collected in one Teflon vial. After adding 30 ml 30% H_2O_2 (to oxygenate organic matter) the solution is evaporated. After the evaporation, the sample was dissolved with 10 ml 35-38% portions of HCl and evaporated again. After a few dissolution/evaporation steps, nitric acid was fully replaced with hydrochloric acid.

Polonium was deposited on silver from the 0.5 M solution of HCl, containing 0.4 g of hydroxylamine and 0.4 g of sodium citrate, at 90°C. Silver disc of a diameter of 20 mm was placed in a special holder, which enabled polonium deposition on one side of the disc. To speed up the deposition, a magnetic stirrer was placed below the disc. After ca. 3 h of deposition, the disc surface was covered with a white coating. To control efficiency of deposition and alpha detection, a portion of HCl containing a known amount of ^{208}Po, which does not occur in natural environment (manufactured by AERE Harwell, United Kingdom), was added before chemical procedure. Using the alpha spectrometer two count numbers were obtained for each measurement, namely for ^{208}Po and ^{210}Po. In order to obtain specific activity of ^{210}Pb, the activity of ^{210}Po was determined. The half lives of Po are 138.4 days for ^{210}Po, and 2.987 years for ^{208}Po. Taking into account the short life times, in the calculations it was necessary to make two corrections. The first one was for the decay of ^{208}Po during the preparation of the standard solution until the middle of the measurement of the relevant source. The second was connected with the decay of ^{210}Pb from the end of deposition until the middle of the measurement.

The specific activity of ^{210}Pb was determined using the formula (3.1) (Wachniew 1990, 1992). This formula makes allowance for short lived isotope decay, efficiency of the chemical procedure and the geometric efficiency of the spectrometric measurement. The efficiency was determined on the basis of comparison of measured standard's activity with the activity of the sample to which known amount of the standard was added. The efficiency was between 18 and 91%, and mean efficiency was 47%.

$$A_{total} = \frac{I_{^{210}Po} A_s m_s e^{-\lambda_{208Po} t_1} e^{\lambda_{210Po} t_2}}{I_{^{208}Po} M} \tag{3.1}$$

where:

A_{total} – (Bqkg^{-1}) specific activity of total ^{210}Pb (supported and unsupported) in measured sample (layer)

I_{210Po} – (cps) net counting rate of pulses in ^{210}Po peak

I_{208Po} – (cps) net counting rate of pulses in ^{208}Po peak

A_{ps} – (Bq kg^{-1}) specific activity of ^{208}Po standard sample

m_s – (kg) mass of standard sample

λ_{208Po}, λ_{210Po} – (s^{-1}) decay constant for ^{208}Po and ^{210}Po, respectively,

t_1 – (s) time from preparation of standard to the middle of the measurement

t_2 – (s) time from deposition to middle of the measurement

M – (kg) dry mass of sample.

Small size of samples and a low energy of gamma photons emitted by ^{210}Pb (E_{210Pb} = 46.5 keV) required the utilisation of a thin-wall well type detector. The detec-

tor's well contained a portion of sediment of precisely measured mass (about 1-2 g). Each sample was measured for not less than 24 hours. The activities of ^{210}Pb, ^{214}Pb and ^{214}Bi were calculated by analyses of appropriate gamma spectrum lines in the sample and standard spectra. Standard was prepared from material including isotopes of ^{238}U series, which was delivered by Central Laboratory for Radiological Protection, Warsaw.

The activity of ^{210}Pb assessed by gamma measurements is again the total activity of this isotope. Because a secular equilibrium may be assumed in this part of the uranium series, activities of ^{214}Pb and ^{214}Bi isotopes are equal to the activity of authigenic lead.

Concentration of authigenic ^{210}Pb for each sediment layer was determined on the base of spectrometric measurements of gamma radiation of ^{214}Bi and ^{214}Pb. For each samples three values of specific activity for characteristic lines (77.1 keV and 351.9 keV for ^{214}Pb and 609.3 keV for ^{214}Bi) were received, and then weighted mean was calculated.

In the case of gamma spectrometry, the concentration of ^{210}Pb was determined using the formula:

$$A_{total} = \frac{I_{^{210}Pb} A_{st} m_{st}}{I_{st} M} \tag{3.2}$$

where:
A_{total} – (Bq kg^{-1}) specific activity of whole ^{210}Pb (supported and unsupported) in measured sample (layer)
I_{210Pb} – (cps) net counting rate of impulses in ^{210}Pb peak
A_{st} – (Bq kg^{-1}) specific activity of gamma standard
I_{st} – (cps) net counting rate of impulses in ^{210}Pb peak for standard
m_{st} – (kg) dry mass of standard
M – (kg) dry mass of sample

4. RESULTS AND DISCUSSION

Activity of authigenic ^{210}Pb determined on the basis of gamma-ray spectrometry

There are no significant differences between values of measured activity of authigenic ^{210}Pb for particular layers within single core; detailed data were presented by Sikorski (2003). Therefore weighted mean values for each core, (except disjunctive core 8, 10, 10a), were calculated – **Table 2**. Results for all cores are in agreement within one uncertainty. This fact allows us to calculate mean value of activity of authigenic ^{210}Pb for the whole reservoir.

The measurements and calculations indicate that the activity of the authigenic ^{210}Pb for Kozłowa Góra is 12.9±0.9 (Bq/kg).

Comparison of activities determined by α and γ spectrometry

The results for activity of ^{210}Pb, ^{214}Pb, and ^{214}Bi are included in **Table 3**. For each measurement the uncertainty of ^{210}Pb specific activity was calculated using propagation of uncertainty method. To check reliability of the results, a fit of α and γ spectrometry results was tested. The analysis showed that for each layer of sediments results of both methods agree within two uncertainties. At the confidence level of 0.05, the results of measurements of allochthonous ^{210}Pb by α and γ spectrometry are in agreement (**Table 3;** the problem of the results of average activity of ^{214}Pb and ^{214}Bi for cores 7 and 8 differing from these results for other cores is discussed in the text below). In the next step, the weighted mean of results of both methods was calculated for each layer. Results were weighted according to the inverse square of the individual uncertainty.

Table 2. *Weighted mean values of authigenic ^{210}Pb activity for cores from Kozłowa Góra artificial lake.*

No. of core	$A(^{210}Pb)_{aut}$ (Bq/kg)
2	14.5±2.6
3	13.5±2.3
4	11.3±3.3
5	11.7±2.5
6	10.3±2.7
7	16.3±2.5
9	13.7±1.7
All cores	12.9± 0.9

The results obtained from the measurements were used to dating sediments with the application the Constant Initial Concentration (CIC) and Constant Rate of Supply (CRS) models (see **Figs 3** and **4**). The CIC model assumes a constant initial concentration of the allochthonous ^{210}Pb independent from the accumulation of dry mass. The CRS model assumes that the rate of deposition of ^{210}Pb from lake water is constant and it does not depend from the rate of sedimentation (Robbins and Edgington, 1975; Appleby and Oldfield, 1978; Eakins, 1983; Tobin and Schell, 1988; Binford, 1990; Wachniew, 1990; Liu *et al*., 1991; Preiss *et al.*, 1996).

To define the usefulness of mentioned models different simulations were carried out. The main goals of these simulations were to answer the questions:

- how does the change of lead flux or mass flux affect the specific activity of formed sediment layer?
- how does this change affect the present activity profile of allochtonous ^{210}Pb?

For the simulations we made a few assumptions:

- variable flux of the sediment's mass, changing in leaps;
- the appearance of extreme event consists of a sudden increase of mass flux during two consecutive years;
- constant flux of allochthonous lead for CRS model;
- flux of allochthonous lead proportional to sediment's mass flux for CIC model.

Different simulations showed that the best fit to measured values could be obtained when:

- simulations were carried out for each core separately;
- the sedimentation rate was established on the basis of the value for which the calculated sediment thickness was equal to the real thickness;

Table 3. *The results for specific activity of ^{210}Pb, ^{214}Pb, and ^{214}Bi in sediment samples from the Kozłowa Góra reservoir.*

Sample No	Position of layer		Activity α method	Activity γ method	
			Allochthonous ^{210}Pb	Allochthonous ^{210}Pb	Average activity ^{214}Pb and ^{214}Bi
	Depth (cm)	Mass depth (g/cm^2)	*A* (Bq/kg)	*A* (Bq/kg)	*A* (Bq/kg)
core 1					
KG01/9901	4.0	8	220±11		
KG01/9902	12.0	17	171.1±6.9		
KG01/9903	20.0	25	108.3±4.7		
KG01/9904	28.0	34	87.6±8.9		
KG01/9905	36.0	42	67.8±4.5		
KG01/9906	44.0	51	99±11		
KG01/9907	52.0	59	83.3±6.0		
KG01/9908	60.0	68	61.9±8.8		
KG01/9909	70.0	86	153±24		
core 2					
KG02/9901	4.0	9	64.2±3.1	70±30	11.4±3.8
KG02/9902	12.0	17	57.9±2.9	56±28	12.2±3.8
KG02/9903	20.0	26	48.9±2.1	51±29	7.4±3.7
KG02/9904	28.0	34	40.7±1.0	52±29	15.3±3.7
KG02/9905	36.0	43	62.9±3.2	50±29	19.5±3.7
KG02/9906	44.0	52	48.8±2.6	41±29	16.7±3.7
core 3					
KG03/9901	4.0	8	64.2±4.0	81±29	16.0±3.7
KG03/9902	12.0	17	73.2±3.4	50±28	21.3±3.7
KG03/9903	20.0	26	55.9±1.8	44±29	12.0±3.7
KG03/9904	28.0	34	32.3±2.3	54±28	16.1±3.7
KG03/9905	36.0	43	43.4±2.1	28±20	7.6±3.8
KG03/9906	44.0	52	23.0±1.6	42±28	11.4±3.7
KG03/9907	52.0	60	22.6±1.4	34±28	11.2±3.7
KG03/9908	60.0	69	23.1±1.2	28±21	11.0±3.7
core 4					
KG04/9901	1.8	4	72.3±4.0	53±27	9.7±4.6
KG04/9902	5.3	8	57.2±2.9	36±28	14.3±3.6
KG04/9903	8.8	12	30.6±2.5	46±28	11.1±3.7
KG04/9904	12.3	16	29.3±2.1	45±29	8.2±3.8
core 5					
KG05/9901	1.8	4	50.6±4.7	27±29	9.2±3.8
KG05/9902	5.3	7	57.1±4.9	42±35	26.7±4.6
KG05/9903	8.8	11	27.7±1.7	47±28	11.2±3.7
KG05/9904	12.3	15	24.1±0.9	45±28	10.4±3.7
KG05/9905	15.8	19	23.9±1.1	39±33	11.7±4.4
KG05/9906	22.4	34	19.9±0.8	26±27	8.3±3.7
KG05/9907	32.8	45	17.9±0.7	19±17	6.3±3.7
core 6					
KG06/9901	2.0	4	28.1±3.4	42±28	15.5±4.7
KG06/9902	6.0	8	31.9±2.4	29±29	9.6±3.8
KG06/9903	10.0	13	18.2±1.4	54±28	12.5±3.8
KG06/9904	14.0	17	24.7±2.2	25±28	8.5±3.8
KG06/9905	18.0	22	18.8±1.9	29±28	8.2±3.7
KG06/9906	22.0	27	14.8±1.2	15±29	6.2±3.7
core 7					
KG07/9901	2.0	4	92.8±5.3	100±35	32.9±4.0
KG07/9902	6.0	9	56.2±2.7	64±30	11.3±3.6
KG07/9903	10.0	13	48.2±2.5	63±30	25.8±4.6
KG07/9904	14.0	17	52.9±3.6	59±29	12.7±3.7
KG07/9905	18.0	21	58.4±3.4	51±32	25.2±4.6
KG07/9906	22.0	26	35.5±1.2	31±29	33.5±4.5

Table 3. *Continuation.*

Sample No	Position of layer		Activity α method	Activity γ method	
			Allochthonous ^{210}Pb	Allochthonous ^{210}Pb	Average activity ^{214}Pb and ^{214}Bi
	Depth (cm)	Mass depth (g/cm^2)	*A* (Bq/kg)	*A* (Bq/kg)	*A* (Bq/kg)
KG07/9907	26.0	30	20.9±0.9	36±28	13.4±3.7
KG07/9908	34.0	42	20.9±0.9	38±35	22.7±4.5
core 8					
KG08/9901	5.0	15	24.4±1.9	17±29	4.1±3.7
KG08/9902	15.0	33	25.8±0.8	23±30	6.5±3.6
KG08/9903	25.0	51	23.8±2.0	25±29	
core 9					14.2±3.7
KG09/9901	5.0	10	43.7±3.7	29±29	15.2±3.7
KG09/9902	15.0	21	56.2±5.0	52±28	14.7±3.7
KG09/9903	25.0	32	37.1±2.8	45±29	12.9±6.3
KG09/9904	35.0	43	58.4±4.2	41±28	12.6±3.7
KG09/9905	45.0	55	35.8±3.4	24±29	18.2±3.6
KG09/9906	55.0	66	39.4±3.3	37±28	10.1±3.7
KG09/9907	65.0	77	35.0±3.0	29±29	10.7±3.7
KG09/9908	75.0	88	37.7±4.5	32±28	15.3±3.7
KG09/9909	85.0	101	41.6±3.9	54±28	10.4±3.7
KG09/9910	95.0	112	39.7±4.6	41±28	12.7±3.8
KG09/9911	105.0	123	44.1±2.0	49±30	10.6±3.7
KG09/9912	115.0	135	38.7±1.7	30±30	14.2±3.7
KG09/9913	125.0	152	55.3±2.2	49±30	14.4±3.6
core 9a					
KG09a/9901	44.0	8	45.5±3.2	44±29	12.6±4.2
KG09a/9902	52.0	17	44.2±3.4	49±28	15.3±3.6
KG09a/9903	60.0	25	48.4±3.7	65±27	12.0±3.4
KG09a/9904	68.0	34	55.6±3.7	41±31	10.4±3.6
KG09a/9905	76.0	43	45.9±2.8	54±29	16.3±3.5
KG09a/9906	84.0	52	44.1±3.3	29±28	11.9±3.5
core 10					
KG010/9901	20.0	11	55.1±5.2	53±29	14.1±3.7
KG010/9902	30.0	22	43.2±2.6	46±28	15.6±3.7
KG010/9903	40.0	32	52.4±4.0	56±30	11.0±3.6
KG010/9904	50.0	43	49.5±3.7	44±27	11.8±3.5
KG010/9905	60.0	53	50.6±3.4	58±28	13.4±3.8
KG010/9906	70.0	64	61.7±4.2	44±27	14.2±3.6
KG010/9907	80.0	75	53.0±4.1	51±30	12.0±4.0
KG010/9908	90.0	86	44.5±3.6	58±27	13.2±4.2
KG010/9909	100.0	103	36.2±2.8	50±28	14.7±5.3
KG010/9910	110.0	114	57.5±3.6	59±28	10.4±3.8
KG010/9911	120.0	124	49.4±3.5	41±24	12.6±4.1
core 10a					
KG10a/9901	45.0	10	45.1±2.7	59±30	11.7±3.8
KG10a/9902	55.0	20	46.5±2.4	45±27	15.6±3.6
KG10a/9903	65.0	31	52.6±1.7	46±30	13.8±3.4
KG10a/9904	75.0	41	51.6±2.3	46±27	12.9±3.8
KG10a/9905	85.0	52	48.7±2.1	60±29	12.5±3.7
KG10a/9906	95.0	62	36.8±1.8	42±27	15.4±3.7
KG10a/9907	105.0	73	51.2±3.3	49±30	13.8±3.4
core 11					
KG11/9901	15.0	10	78.2±7.0		
KG11/9902	25.0	21	51.1±5.5		
KG11/9903	35.0	32	51.3±3.1		
KG11/9904	45.0	43	58.2±3.9		
KG11/9905	55.0	54	57.1±4.3		

Table 3. *Continuation.*

Sample No	Position of layer		Activity α method	Activity γ method	
			Allochthonous ^{210}Pb	Allochthonous ^{210}Pb	Average activity ^{214}Pb and ^{214}Bi
	Depth (cm)	Mass depth (g/cm^2)	*A* (Bq/kg)	*A* (Bq/kg)	*A* (Bq/kg)
KG11/9906	65.0	65	53.4±3.7		
KG11/9907	75.0	75	28.3±3.1		
KG11/9908	115.0	87	34.0±2.8		
KG11/9909	125.0	104	28.6±2.0		
core 11a					
KG11a/9901	25.0	10	79.2±6.6		
KG11a/9902	35.0	20	55.3±4.4		
KG11a/9903	45.0	31	64.0±5.7		
KG11a/9904	55.0	42	45.5±3.7		
KG11a/9905	65.0	53	55.2±4.0		
KG11a/9906	75.0	63	42.9±3.3		
core 12					
KG12/9901	34.0	9	78.8±7.2		
KG12/9902	42.0	18	50.2±3.8		
KG12/9903	50.0	26	46.1±3.4		
KG12/9904	58.0	34	58.3±4.3		
KG12/9905	66.0	43	65.3±3.7		
KG12/9906	76.0	54	35.9±3.4		
KG12/9907	86.0	68	24.4±2.1		
core 13					
KG13/9901	3.8	8	68.2±5.5		
KG13/9902	11.3	16	53.3±3.8		
KG13/9903	18.8	23	60.7±5.8		
KG13/9904	26.3	31	62.8±4.0		
KG13/9905	33.8	40	43.2±2.8		
KG13/9906	41.3	48	36.1±2.6		
KG13/9907	48.8	57	53.3±2.9		
KG13/9908	56.3	65	65.3±4.4		
KG13/9909	63.8	73	43.8±3.0		
KG13/9910	71.3	81	32.4±2.1		

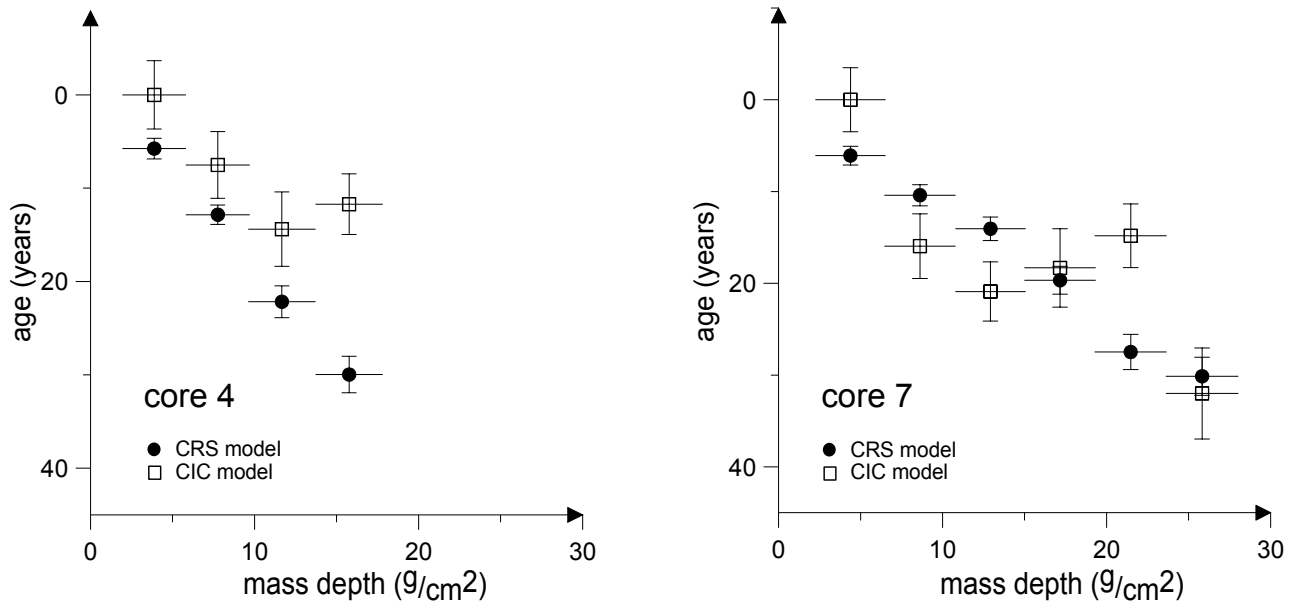

Fig. 3. *The age of the layers of the cores spanning 30 years.*

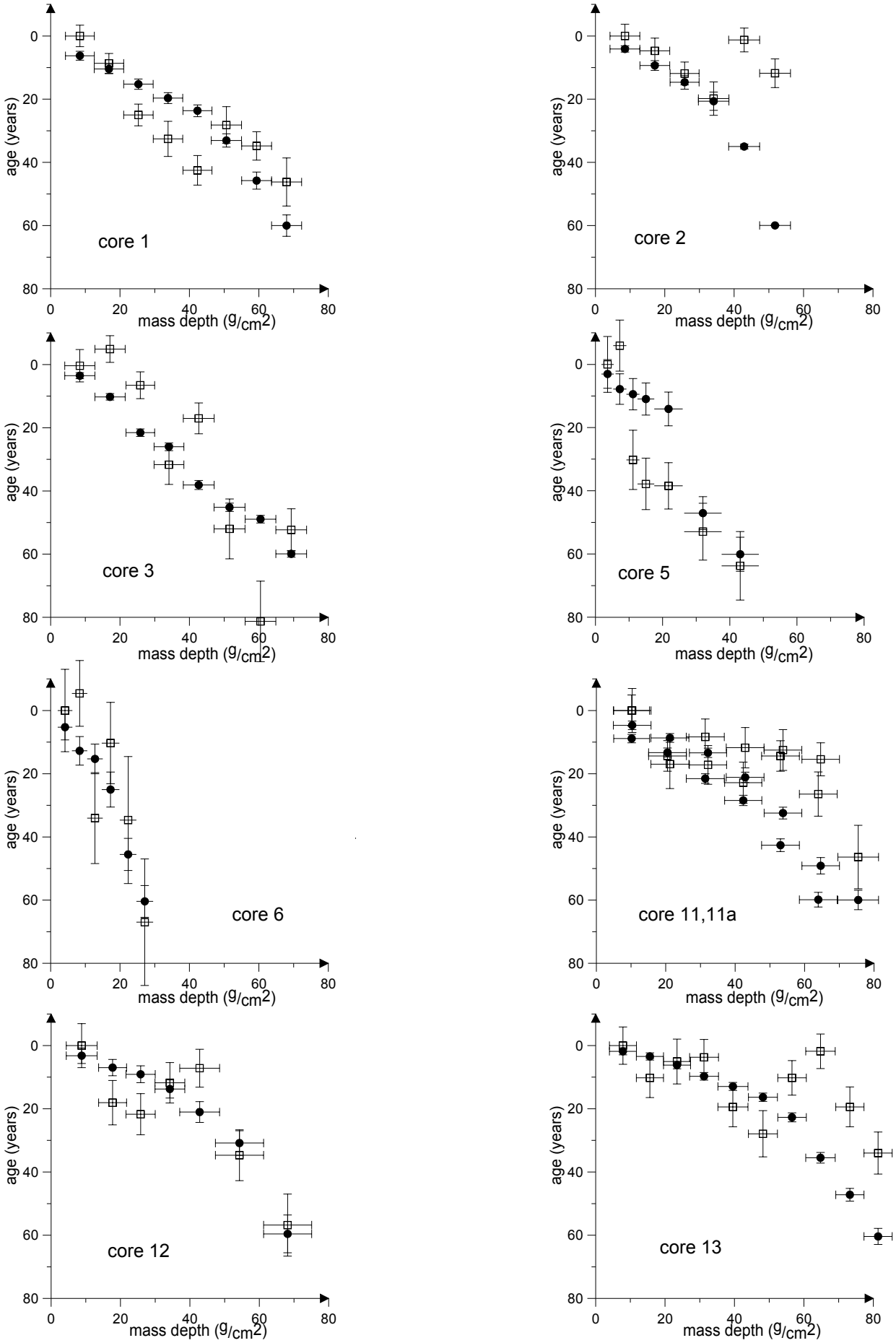

Fig. 4. *The age of the layers of the cores spanning 60 years. The dot indicates the CRS model and the square the CIC model.*

- the sediment flux was constant during first 30 years and then suddenly grew by a factor of 2;
- the lead flux was constant during the whole time;
- the CRS model was used.

The results of the calculations are shown for chosen cores in **Fig. 5** (dashed lines). Kozłowa Góra is a young reservoir. Even the oldest sediments contain allochthonous ^{210}Pb, therefore the standard CRS model should be modified. For the oldest sediments of each core, the value of accumulated surface activity of the allochthonous ^{210}Pb was established to provide condition that the age of layer directly over the bottom is 60 years. The ages of higher layers were calculated according to this condition (see Sikorski and Bluszcz, 2003).

For cores 11, 11a, 12 the youngest sediment's layers were not collected. Values of specific activity for top layers were approximated on the base of activity of deeper layers and from known amount of missing sediment. For shallow reservoir (mean depth 2.5 m) it was possible to determine the location of the corer in the sediment on the ground of height of water column over the corer, knowledge of sediment's bottom location and bathymetry of the reservoir.

The agreement of fitted lines to measurement points and coming from simulation testify the validity of choice of CRS model and correctness of measurements. Received results are also in good agreement with described below historical facts.

CIC model is particularly useful in cases where constant accumulation rate can be assumed (based on the earlier investigations and history of the water reservoir). For Kozłowa Góra reservoir this assumption does not fulfil. It is reservoir of rather small dimensions, but with significant fluctuations of the water level (**Fig. 6**). Flora and fauna occur for its whole volume. Therefore the growth of organic material – the main component of sediments – is proportional to the reservoir volume; and the volume depends on water level.

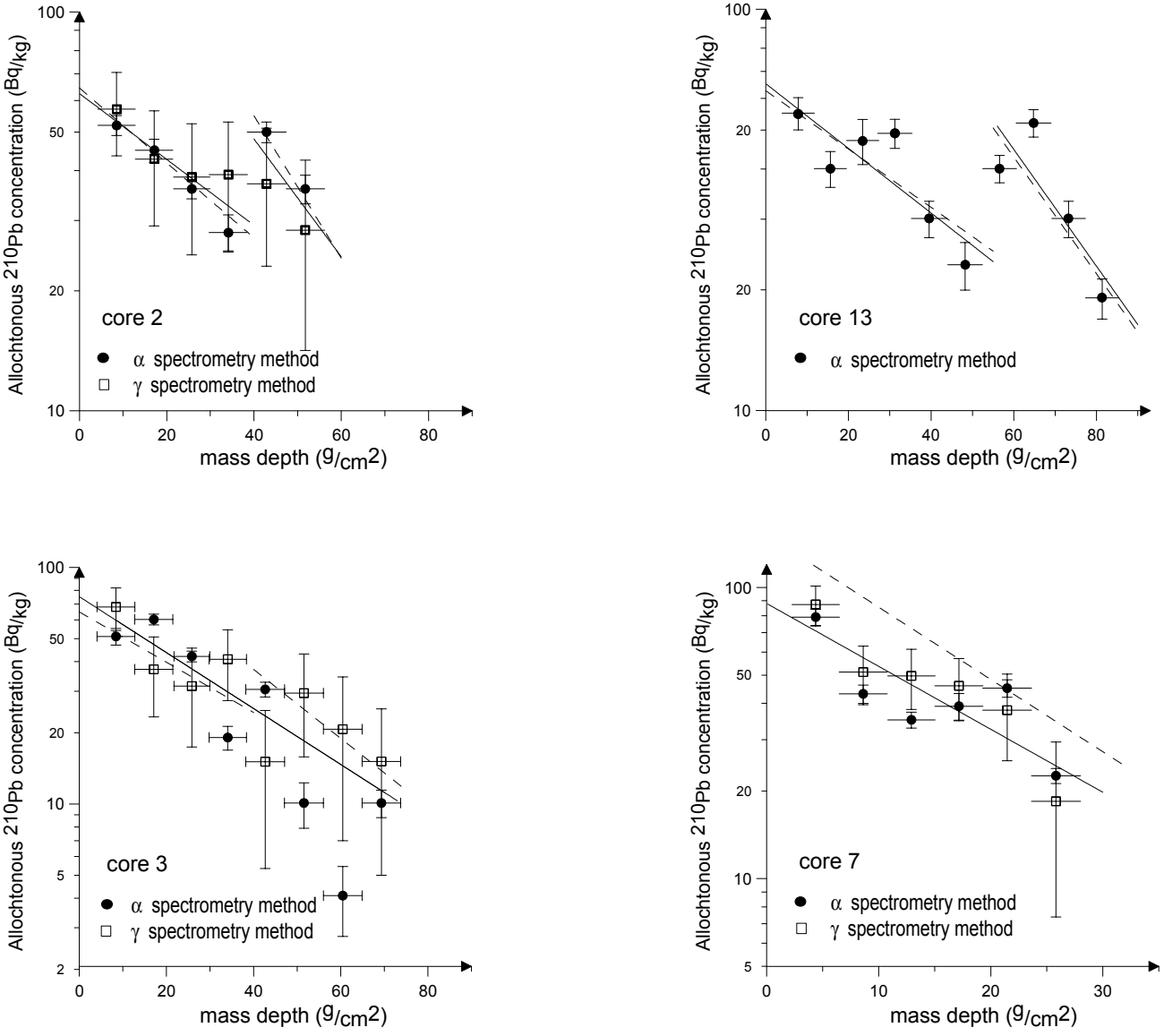

Fig. 5. *Concentration of allochthonous ^{210}Pb in sediment sample vs. mass depth for choosen cores (2, 3, 7 and 13) from Kozłowa Góra. Solid lines – regression lines fitted to results of measurements; dashed lines – simulations lines. Results for cores 2 and 13 were presented earlier (Sikorski and Bluszcz, 2003).*

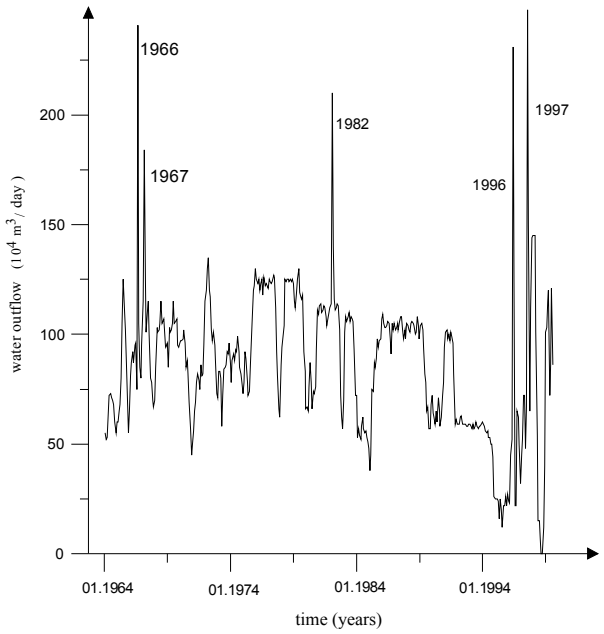

Fig. 6. *Monthly average water outflow of the reservoir Kozłowa Góra.*

During the investigations of the reservoir in Kozłowa Góra it was found that its northern part is devoid of sediments. The greatest amount of sediments is located close to the dam. The length of the taken sediment cores decreases with the distance from the dam. The analysis of the short cores allows drawing the conclusion that the sedimentation of cores 4 and 7 started 30 years ago (**Fig. 3)** and the sedimentation in the northern part (core 8) had not started yet. These phenomena can be explained by the different water depth and changing velocity of the bottom flow. This flow is normal for a flow-through reservoir and it takes place all the time, therefore despite the differences in the average rate of sedimentation in the various parts of the reservoir (see **Table 4**), the conducted research does not point to the possibility of violent event of redeposition.

The cores 9, 9a, 10, 10a (**Fig. 7**) represent locations near the dam, which contain mixed sediments probably as a result of large water turbulences.

The analysis of data from the daily reports describing the water management in the reservoir (see **Fig. 6**) reveals that in August 1966 and in February 1967, two large floods took place (the water discharge noted at the measurement point was 20 and 12 m^3/s respectively). In addition, as a result of the floods the structure was damaged and in year 1969 the dam was renovated. The renovation of the dam is often connected with removing the sediments. From the historical records and information from people worked during dam renovation, in the case of Kozłowa Góra there was none cleaning of the bottom of reservoir, and only the dam height was increased. Of course it can not be excluded that some removing of the sediments was a result of large foods.

After renovation water level of the reservoir was raised. In this way, the volume of the reservoir was increased by about 80%. The mentioned events explain a sudden increase of the sediment influx.

5. CONCLUSIONS

The paper describes research which allowed determining of the ^{210}Pb activity in the sediments in the artificial reservoir in Kozłowa Góra. As a result it was possible to date the layers of the sediment and to calculate the rate of sedimentation and on their basis to create a sedimentation model for this reservoir.

The determination of the activity of authigenic ^{210}Pb in the sediments of the reservoir was possible only thank to gamma spectrometry. For a young lake it is impossible to calculate this activity only with the application of alpha spectrometry because even the oldest sediments contain allochthonous ^{210}Pb.

The analysis showed that on the confidence level 0.05 results of measurements of allochthonous ^{210}Pb by α and γ spectrometry are fitted.

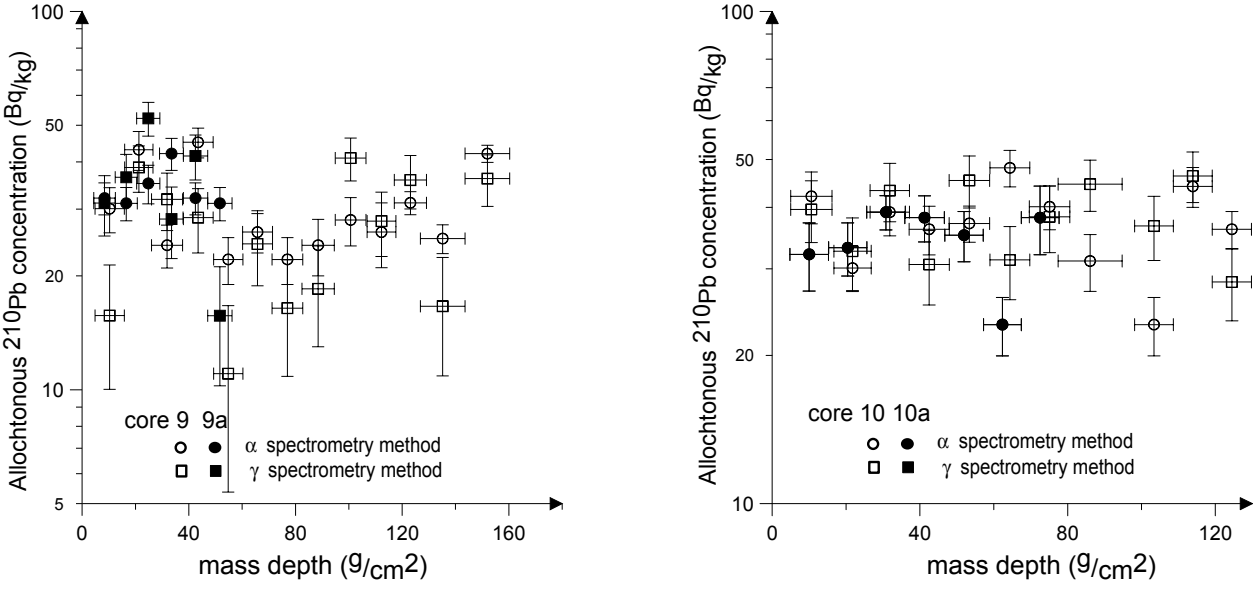

Fig. 7. *Cores 9, 9a, 10, 10a – specific activity of allochthonous ^{210}Pb.*

Events which took place 40 years ago (renovation of the dam, development of the industry and farming) brought about a doubling of the amount of material transported to the reservoir. The increased flux of material had been taking place until the core taking. The increase of the reservoir volume is the cause of an increased water exchange time in the reservoir which can lead to the intensification of biological processes. The assumption of an increased sedimentation rate as the result of the increased height of the water table is further supported by the observed correlation between water depth above the bottom of the reservoir and the quantity of sediment in the place of the depth measurement (Sikorski, 2003).

The change of the level of the water table was the cause of starting the sedimentation in the central part of the reservoir. The deposition of material in the northern part of the reservoir has not started yet because of the bottom flow.

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