TESTING APPLICABILITY OF ^{210}Pb METHOD TO DATE SEDIMENTS OF HUMAN–MADE LAKE KOZŁOWA GÓRA

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Key words:
^{210}Pb, LAKE SEDIMENTS, LAKE KOZŁOWA GÓRA, ARTIFICIAL LAKE

Abstract: **This paper presents results of measurements of ^{210}Pb in sediments of the human-made lake Kozłowa Góra. The measurements were done on the complete sediment cores taken in 1999 and covering the whole 60 years span of life of the lake. For the first time in Poland, the gamma ray spectrometry was employed, additionally to the alpha spectrometry method, what gave the opportunity to date the sediments and also to determine the sedimentation rates, and to correlate their changes with modification of the dam. Analyses of measured ^{210}Pb radioactivity and dating based on a modified CRS model and led to a model of sedimentation that explains most of experimental results.**

1. INTRODUCTION

There are two sources of ^{210}Pb isotope occurring in the water–basin sediments. First of them is the radioactive decay of ^{214}Po, the element of ^{238}U series, included in the deposit. The second source is also ^{214}Po decay, but taking place outside the lake, mainly in the atmosphere and in water flowing into the lake. The lead from the first source, called autigenic, is in a radioactive equilibrium with the mother isotope and two other preceding isotopes (^{214}Pb and ^{214}Bi). The isotope from the second source is called allochthonous. The activity of autigenic ^{210}Pb in the layer of sediment is constant in contrast to the activity of allochthonous ^{210}Pb which decreases, following to the radioactive decay law, with the half–life time $T_{½} = 22.26$ yr. The presence of allochthonous lead in sediment may be used to determine its age within the range of several half–life times.

^{210}Pb method was first applied in the climatic research (Goldberg, 1963) to determine the rate of glacier accumulation. Later, Krishnaswami used the lead method in the lacustrine sediments studies (Krishnaswami *et al.*, 1971). Krishnaswami's work was concerned with dating these sediments and using it in analyses of recent changes in the environment.

The sedimentation conditions, with respect to sediment mass and lead fluxes, for large lakes and seas are relatively constant and, in general, there is no difficulty applying the method to such reservoirs. In case of small lakes changes in their drainage basins and water level could significantly influence the sedimentation conditions. The human–made lake Kozłowa Góra is a relatively small lake, where such changes caused by the economic development took place during the last decades.

2. CHARACTERISTICS OF THE LAKE KOZŁOWA GÓRA

The dammed lake Kozłowa Góra became operable in 1939. Since 1950's the lake has been utilized as a fresh–water reservoir. The lake is situated in Voievodship of Silesia, county Tarnowskie Góry, commune Świerklaniec, about 3 km away from the village of Kozłowa Góra and about 6 km from the town of Piekary Śląskie.

During the last decades, the industrial and agricultural development of this region affected the lake zone and was the main reason of its degradation. In 1969 the dam was rebuilt, which resulted in the almost doubling its volume and eventually changed the sedimentation conditions. The description of Kozłowa Góra lake and lake sediments have been given in the other paper (Sikorski and Goslar, 2003).

3. MEASUREMENTS OF ^{210}Pb RADIOACTIVITY

Sediment cores were gained by the freezing method (Renberg, 1981) by means of the flat wedge–probe. The material was divided into samples from 3 to 10 cm thick.

Measurements of ^{210}Pb activity were done independently by alpha and gamma ray spectrometry methods. About alpha ray spectrometry method see Sikorski and Goslar (2003). The gamma ray spectrometry consists in measurements of gamma photons emitted by ^{210}Pb, ^{214}Pb and ^{214}Bi isotopes. Analysis of ^{210}Pb gamma spectrum line yields information about total activity of lead 210, while the assessed activity of ^{214}Pb and ^{214}Bi equals to the activity of autigenic ^{210}Pb.

Small masses 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 germanium detector. The detector used is 45 mm heigh and is 46 mm in diameter; the well is Ø ≠ 8 x 35.5 mm. The detector'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. 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 series, activities of ^{214}Pb and ^{214}Bi isotopes are equal to the activity of autigenic lead.

Value of autigenic ^{210}Pb for whole lake have been calculated as average for 11 of 16 cores taken from Kozłowa Góra lake. **Fig. 1.** Presents values of the activity of allochthonous ^{210}Pb versus mass depth of the dry sediment (mass depth equals zero at the water–sediment boundary and increases with the sediment depth) for two example cores. Other cores are not analysed yet.

Table 1. *Specific activity of ^{210}Pb for two example cores from the lake Kozłowa Góra.*

			Activity (Bq/kg)					
Layer-centre position			α method		γ method			
Sample no.			total ^{210}Pb		total ^{210}Pb		average activity of ^{214}Pb and ^{214}Bi (autigenic ^{210}Pb)	
	depth (cm)	mass dep. (g/cm²)	A	u(A)	A	u(A)	A	u(A)
core no. 2								
KG02/9901	4.0	9	64.2	3.1	70.0	27.9	11.4	3.8
KG02/9902	12.0	17	57.9	2.9	55.8	28.4	12.2	3.8
KG02/9903	20.0	26	48.9	2.1	51.5	28.9	7.4	3.7
KG02/9904	28.0	34	40.7	1.0	52.1	28.8	15.3	3.7
KG02/9905	36.0	43	62.9	3.2	50.1	29.0	19.5	3.7
KG02/9906	44.0	52	48.8	2.6	41.4	29.4	16.7	3.7
core no. 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				

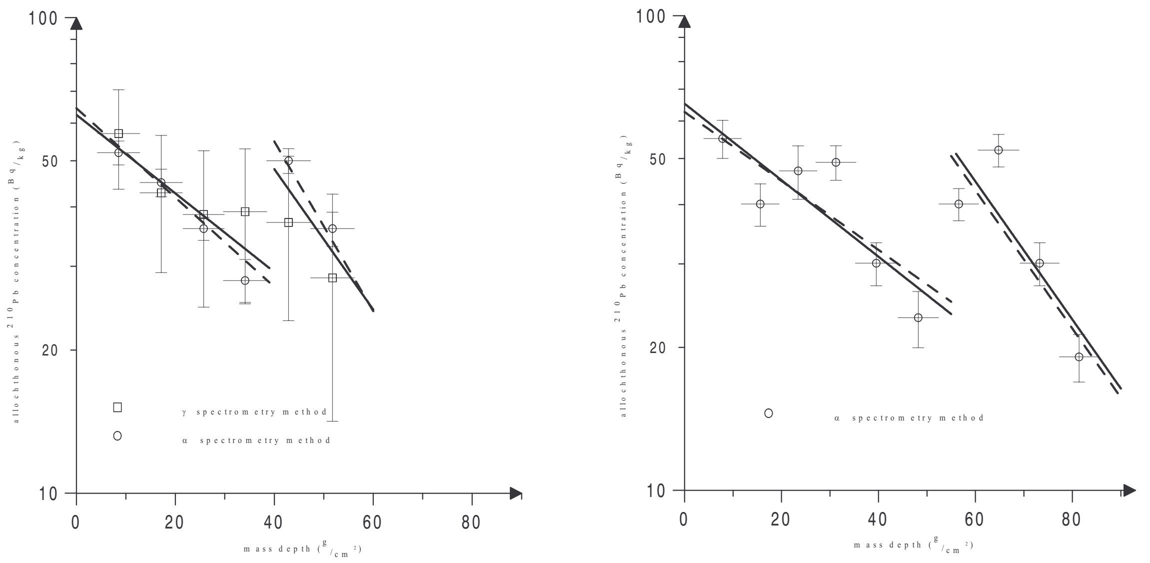

Fig. 1. *Concentration of allochthonous ^{210}Pb in sediment sample vs. mass depth for cores from Kozłowa Góra. Left graph – core no.2; right – core no. 13. Solid lines – regression lines fitted to results of measurements; dashed lines – model lines.*

4. MODEL CALCULATIONS

It is evident from the data presented in **Table 1.** and in **Fig. 1.** that the CIC (constant initial concentration) model does not apply to the investigated lake. Therefore we tried the CRS - Constant Rate of Supply of allochthonous ^{210}Pb (Eakins, 1983; Tobin and Schell, 1988; Liu *et al.*, 1991), model with a modification necessary because of the young age of the lake.

This model assumes the constant flux of allochthonous ^{210}Pb to the lake and leads to following relations:

$$t = \frac{1}{\lambda} ln \frac{A_C(0)}{A_C(m)} \quad \text{and} \quad r = \frac{\lambda A_C(m)}{A(m)}, \qquad (4.1)$$

where:

λ = 0,04492 y^{-1} – decay constant of ^{210}Pb,

t (y) – age of the layer at the depth m (kg m^{-2}),

$A(m)$ (Bq kg^{-1}) – specific mass–activity (concentration) of the allochthonous ^{210}Pb in a layer of deposit at depth m,

$A_C(m)$ (Bq m^{-2}) – accumulated surface–activity of the allochthonous ^{210}Pb below depth m

$$A_C(m) = \int_m^{\infty} A(m)\, dm, \qquad (4.2)$$

$A_C(0)$ (Bq m^{-2}) – total surface–activity of the allochthonous ^{210}Pb in deposit,

r (kg m^{-2} y^{-1}) – sedimentation rate.

However, the lake Kozłowa Góra is only 60 years old and $A_C(m)$ is undefined for $m > m_{max}$, where m_{max} is the maximum mass depth at the sediment – soil boundary. The modification consists in assuming that at this point a value of $A_C(m_{max}) = A_{Cmax}$ is such that

$$t_{max} = \frac{1}{\lambda} \ln \frac{A_C(0)}{A_{Cmax}} \qquad (4,3)$$

gives the actual age of the lake. The modified definition of accumulated surface activity becomes now

$$A_C(m) = \int_m^{m_{max}} A(m)\, dm + A_{Cmax} \qquad (4.4)$$

and $$A_C(0) = \int_0^{m_{max}} A(m)\, dm + A_{Cmax} \qquad (4.5)$$

The relationship between the allochthonous lead activity and the mass depth suggests that the sedimentation rate was fairly constant except a stepwise increase sometime in the lake history. We connect it with the rebuilding of the dam that increased the lake depth and capacity. The sediment accumulated in this lake is of organic origin – it is primarily a decayed biomass produced by micro-organisms living in water – thus increase in water depth and volume led to an increased biomass production and to the higher sedimentation rate.

The model of sedimentation is based on CRS model and assumes the constant flux of ^{210}Pb into the lake over its entire life. It is also assumed that from 1939 to 1969 the sedimentation rate was remaining constant and in 1969 changed and has been remaining constant at this higher value till now. The model's free parameters are:

1. The rate of supply of ^{210}Pb,
2. The initial sedimentation rate,
3. The sedimentation rate increase factor.

There are also two boundary conditions the model had to meet. One is the total thickness of the sediment of the specific core (m_{2max} = 52 g/cm^2 and m_{13max} = 81 g/cm^2 for cores no. 2 and 13 respectively), and the other the known age of the first sedimentation layer (t_{max} = 60 y).

The CRS model was also used to obtain ages of sampled layers of sediment, which are presented in **Fig. 2**.

The model calculations have been done for each core separately and the parameters chosen to fit the data best. The modelled ^{210}Pb activity – mass depth dependence is plotted in Fig 1. and **Table 2**. below gives values of model parameters for each core.

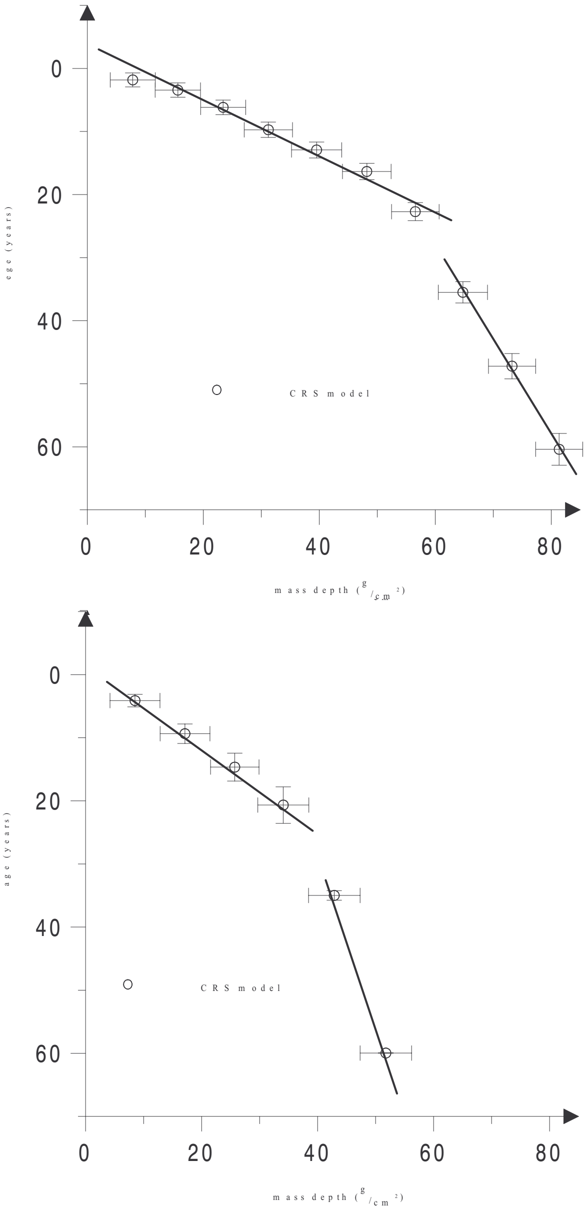

Fig. 2. *Age of sediment (before 1999) versus mass depth for the two cores taken from the lake Kozłowa Góra. Upper – core no. 13, lower graph – core no. 2;*

Table 2. *Values of model parameters*

Core no.	^{210}Pb rate of supply $\frac{Bq}{cm^2 \cdot y}$	Sedimentation rate (kg m^{-2} y^{-1}) Before 1969	After 1969	Sedimentation rate increase factor
2	90	0.76	1.44	1.9
13	110	0.93	1.86	2.0

5. CONCLUSIONS

The gamma spectrometry has been used in this type of study for the first time in Poland and enabled direct measurements of autigenic ^{210}Pb. In young artificial lakes, like the one studied here, it gives the only possibility of assessing the activity of autigenic ^{210}Pb. An accuracy of gamma spectrometry method may be significantly improved either by using a detector with a bigger well (and bigger sample in it) or by extending measurement time. With an accuracy better than in our case, the gamma spectrometry may be the only method needed in ^{210}Pb dating, not only reducing the need for laborious chemical treatment of samples, but also able to provide information about autigenic ^{210}Pb in each individual sample.

The obtained data show a drastic change in sedimentation conditions which we connect with rebuilding of the dam. We have modified the CRS model of ^{210}Pb sedimentation to take into account a fact, that the sedimentation in the lake started in 1939, and used gamma spectrometry to obtain autigenic ^{210}Pb activities. Results of the proposed model of sedimentation in this lake agree very well with the results of measurements. This supports our assumption that the change in sedimentation rate has been caused by the increased water depth.

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