EVALUATION OF RECENT SEDIMENTATION RATES IN THE LAKES OF EAST LITHUANIA BASED ON RADIOISOTOPE DATING

Jonas Mažeika, Julius Taminskas
Institute of Geology and Geography, T. Ševčenkos str. 13, LT-03223, Vilnius
E-mail: mazeika@geo.lt, julius.taminskas@geo.lt

Introduction

Intensive sedimentation took place in the lakes in Holocene and continues till present (Общие…, 1986; Lietuvos…, 1991). It is especially intensive in the central parts of lakes where in about 10 000 years a 12–18 m thick layer of lake sediments has developed. Consecutive analysis of the sediment cores by radioisotope methods and supporting hydrometeorological data can be used as a tool revealing paleoclimatic and paleoecological changes that have taken place in the lakes catchment.

Studies of lake and marine sedimentation by the ^{210}Pb method have been carried out in many regions of the world (Krishnaswami et al., 1971; Koide, Bruland, Goldberg, 1973; Robbins, Edgington, 1975; Robbins, 1982; Bollhöfer et al., 1997; Mažeika, Dušauskienė-Duž, Radzevičius, 2004). This method is often combined with cesium-137 (^{137}Cs) and sometimes with radiocarbon (^{14}C) studies. The ^{210}Pb in lake sediments is of double origin. Part of ^{210}Pb forms *in situ* as a result of ^{226}Ra decay. This part (*supported*) is determined by radioactive equilibrium with ^{210}Pb parent isotopes – ^{214}Pb and ^{214}Bi. The other part of ^{210}Pb is non-equilibrium or unsupported (^{210}Pb excess – unsupported) and is used for dating. It forms while burning the fossil organic fuel and gets into water systems as a result of rapid atmospheric transport and deposition of ^{210}Pb originated from ^{226}Ra decay products. Two chronologically linked events predetermine the distribution of ^{137}Cs in lake sediments – deposition of ^{137}Cs after the accident in the Chernobyl NPP in 1986 and global fall-outs of ^{137}Cs (with their maximum in 1963–1964) as a result of nuclear bombs testing in the atmosphere.

Processes of sedimentation in the lakes Drūkšiai, Baltys, Lydekis, Glėbas, and Varėnis located in the eastern part of Lithuania (Baltic Upland) were investigated by radioisotope methods (Fig. 1).

Two of investigated lakes (Baltys and Glėbas) have no tributaries and are endoheic. They are fed by groundwater base flow from forested anthropogenically almost undisturbed catchments. Rivers with comparable catchments flow across the Varėnis and Lydekis lakes. Part of their catchments is used in agriculture. The Lake Drūkšiai catchment is also used in agriculture but the regulation of its runoff in the 20th century and operation of Ignalina NPP were the factors, which produced the greatest effect on it.

The results obtained by radioisotope dating have been compared with the average annual mass of sediments measured using sediment traps.

1. Geological, Hydrological and Environmental Settings

The Lake Drūkšiai is situated in the northeastern part of Lithuania, Utena County, 2 km south of the Lithuanian–Latvian border. Part of the lake is included into the territory of the Republic of Belarus. Lake Drūkšiai is the largest lake in Lithuania. The area of its water

surface is 49 km², the length is 14.3 km, and the width is 5.3 km (Таутвидас, Ласинскас, 1986). The annual atmospheric precipitation in the lake catchment amounts to 600 mm. There are 174 days with precipitation per year. The surface runoff is 154 mm. A greater part of Lake Drūkšiai catchment is occupied by forests (42 %). The farm lands account for
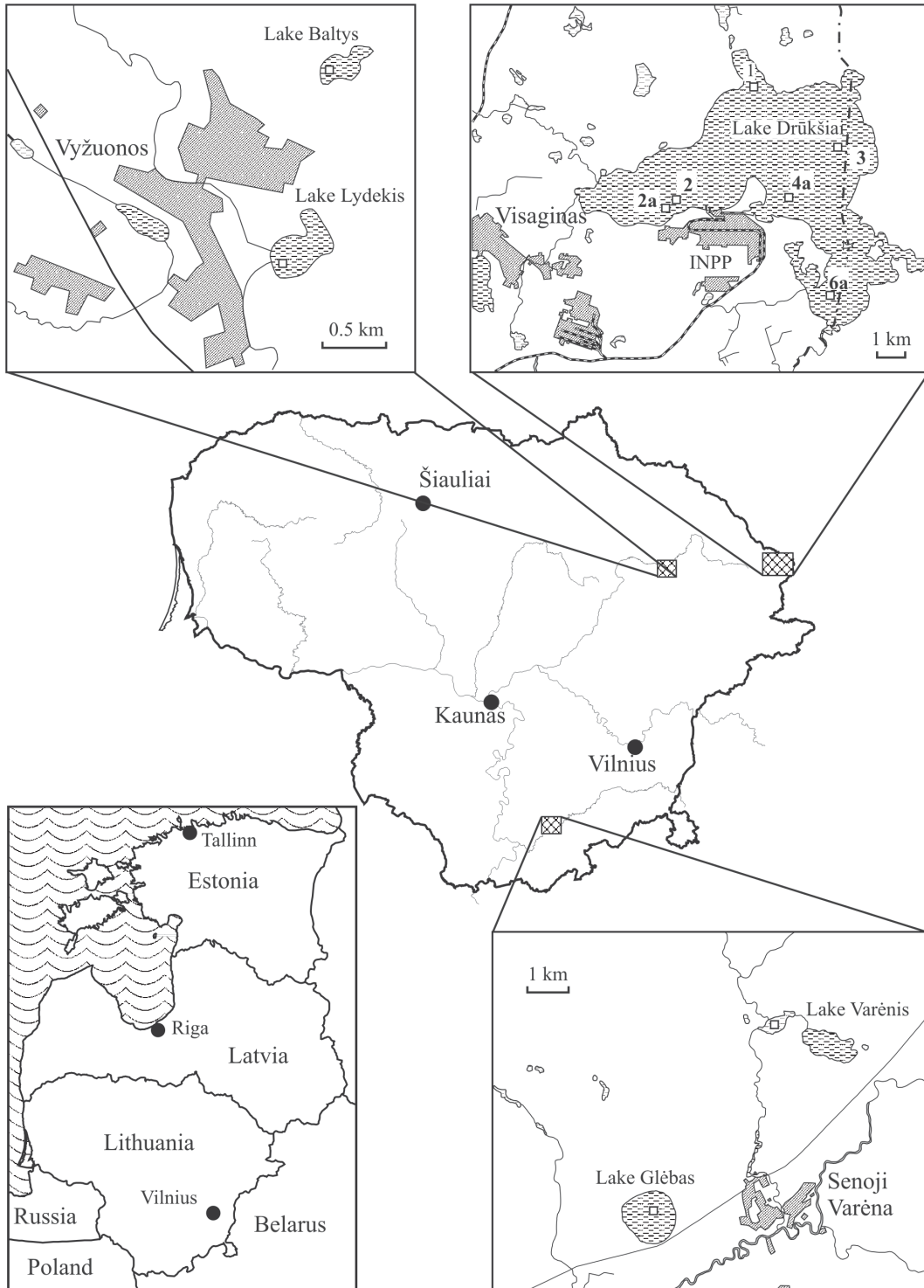

Fig. 1. Location scheme of studied lakes and stations where core samples were taken.

6

17 % including 10 % of arable land. Lakes account for 22.5 %, bogs – for 6.9 % and roads and other man-made covering – for 1.5 % of the basin area. A small Drūkša river used to flow from the south-eastern part of the lake before the beginning of the 20th century. A canal for water-mill between the Lake Drūkšiai and Lake Stavokas (the eastern promontory of the lake) was dug out in about 1912. Since then the lake water has been flowing through the new Prorva canal and through the old one. The runoff through the Drūkša river was blocked in 1953 when a hydroelectric power plant (HEPP) was built on the Prorva canal. The lake catchment area expanded by about 24 % after annexation of Apyvardė river catchment. Since then the Lake Drūkšiai has a few small tributaries with their summary average annual discharge of 3.0 m³/s and one outflow. The HEPP was closed in 1982 but the hydrographic network has not been renaturalized. The Ignalina NPP was started up in 1984. High water level is maintained in the lake for cooling the NPP. Due to this, the annual water level fluctuation amplitude has reduced from 1 to 0.4 m. The Lake Drūkšiai is characterized by a high diversity of recent surface sediments (Гарункштис, 1975).

The lacustrine sediments of the surrounding territories have been less thoroughly investigated. The lakes Lydekis and Baltys are situated in the Utena District, in environs of Vyžuona settlement. Lydekis is drained by Vyžuona rivulet (Table 1).

Judging from geomorphologic signs, the depressions of both lakes are of thermokarst origin. The whole catchment of the Lake Baltys (about 1 km²) is forested. The average annual precipitation in the catchments of Lakes Lydekis and Baltys is 620 mm. There are 168 days with precipitation per year on the average. The average temperature of the warmest (July) month is 17.1°C and of the coldest month (January) is -5.7°C. The average surface runoff of Lake Lydekis is 274 mm. Spring floods account for 36 % of the total annual runoff.

Table 1. Morphometric and hydrological features of the studied lakes.

Lake	Area, ha	Max. depth, m	Average depth, m	Number of tributaries	Number of outflows	Catchment area, km²	Runoff, m³/s
Drūkšiai	4900	33	8	11	Prorva	613	3.20
Varėnis	23	9	3.1	2	Varėnė	396	3.18
Lydekis	18	22	–	1	Vyžuona	381	3.31
Glėbas	135.9	10	–	0	No	6.1	–
Baltys	9.2	9	–	0	No	1	–

The Lakes Glėbas and Varėnis are situated in the Varėna District, in the environs of Senoji Varėna settlement. The Lake Varėnis is drained by Varėnė rivulet (Table 1). Glėbas is an enclosed lake without affluents or effluents. Its bottom is gradually inclining to the centre of the lake where the depth reaches 10 m. The lake depression is situated on the glaciofluvial terrace, which is sloping toward the valley of Merkys River. The depression of Lake Glėbas had been pressed down by a block of dead ice. The depression of Lake Varėnis is of thermokarstic origin. Its surrounding area is covered by glaciofluvial deposits. Sediments of Lake Varėnis are mainly represented by silty clay but they also include all types of lacustrine sediments from sand to lake marl. The sediments of the three other lakes have been poorly investigated.

The average annual precipitation in the catchments of Lakes Glėbas and Varėnis equals to 620 mm. There are 169 days with precipitation on the average. The average temperature in July is 17.2°C and in January it is -5.8°C. The average surface runoff of Lake Varėnis is 258 m. Spring floods account for 28 % of the total annual runoff.

2. Sampling and Methods

The Niemistö gravity corer was used for taking five short (up to 70 cm in length) cores from Lake Drūkšiai. The same technique was used for cores taking from the central parts of the other lakes. The cores were sliced into 1 to 6 cm thick slices. The samples were dried in laboratory and examined for water content, dry bulk density and components of sedimentary matrix. After radiochemical pre-treatment the ^{210}Pb activity in cores taken from stations 1, 2 and 4a was measured at the Institute of Botany using beta-spectrometry (Душаускене-Дуж, 1981).

Development of high quality germanium detectors of gamma-radiation provides a non-destructive tool for direct measuring of ^{210}Pb activity using its week gamma-radiation. All cores were examined by the method of gamma-spectrometry. Standard methods were applied in the pre-treatment of samples for determination the activity of gamma-emitting radionuclides (Gudelis *et al.,* 2000). Activity of gamma-emitting radionuclides in the core samples was measured by germanium detector GWL-170230-S manufactured by 'EG&G Ortec'. In the upper part of some cores ^{60}Co activity (along with ^{210}Pb and ^{137}Cs) was also detected.

3. Results and Discussion

The data on the ^{210}Pb activity were interpreted on the basis of constant rate of supply (CRS) model (Koide, Bruland, Goldberg, 1973). The activity of ^{210}Pb exponentially reduces with depth in the interval of accumulation of unsupported ^{210}Pb. The ^{210}Pb activity below this interval is in equilibrium with the ^{226}Ra. In this case the unsupported activity of ^{210}Pb $\mathrm{Act}\left(^{210}Pb_{xs}\right)$ is derived using formula:

$$Act\left(^{210}Pb_{xs}\right) = Act\left(^{210}Pb_{tot}\right) - Act\left(^{210}Pb_{sup}\right), \tag{1}$$

where $Act\left(^{210}Pb_{tot}\right)$ – measured activity of ^{210}Pb; $Act\left(^{210}Pb_{sup}\right)$ – supported activity of ^{210}Pb in equilibrium with ^{226}Ra (the activity is expressed in Bq/kg of dry weight).

The sediment dry mass accumulation rate (mean) R_m is calculated using formula:

$$R_m = \frac{G_j \times \lambda}{\ln Act(^{210}Pb_{xs(0)}) - \ln Act(^{210}Pb_{xs(Gj)})}, \tag{2}$$

where $Act(^{210}Pb_{xs(0)})$ – according to exponential function approximated activity of ^{210}Pb in the surface of sediments (depth – 0), $Act(^{210}Pb_{xs(Gj)})$ – according to exponential function approximated activity of ^{210}Pb in sediments at a depth G_j; λ – radioactive decay rate (for ^{210}Pb it is 0.031 1/year); G_j – compaction corrected depth; $G_j = \sum_{i=1}^{i=j} \rho_i \times d_i$ where ρ_i – dry bulk density; d_i – sample thickness in the core.

The time of sediment layer accumulation T is derived from the ratio:

$$T = \frac{G_j}{R_m}. \tag{3}$$

The probable (or partial) sedimentation rate for each slice of core is derived from the deviation of unsupported ^{210}Pb from exponential function:

$$R_p = \frac{R_m \times Act(^{210}Pb_{xs(Gj)})}{Act(^{210}Pb_{xs(i)})},$$ (4)

assuming that decreased unsupported activity of ^{210}Pb shows dilution of atmospheric lead-210 by detritus (higher sedimentation rates compared to mean value), increased unsupported activity of ^{210}Pb – lover sedimentation rates.

The sediment dry mass accumulation rate for stations 1, 2a and 4a in the Lake Drūkšiai estimated by ^{210}Pb method are 0.12–0.16, 0.08 and 0.11 g/cm^2/year respectively (Fig. 2).
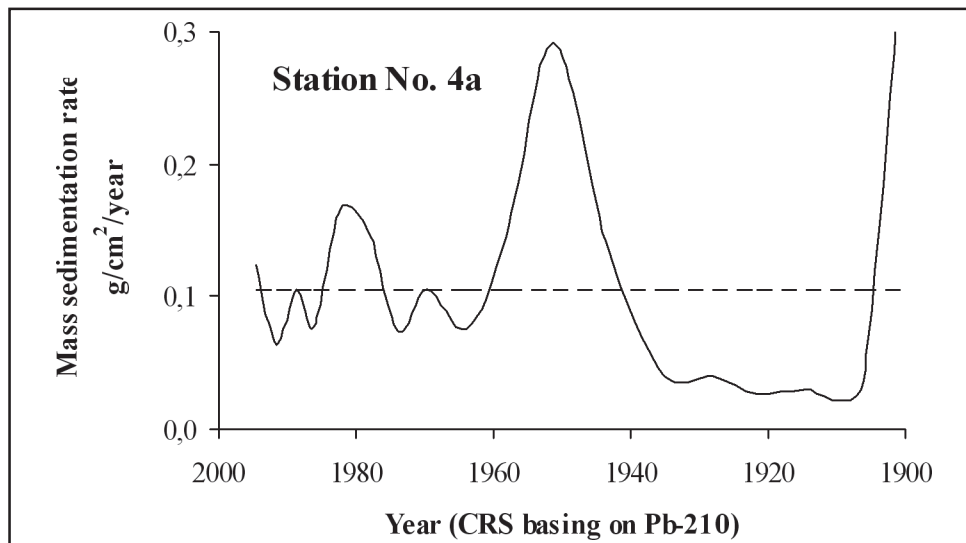

Fig. 2. Variations of sedimentation rates in the Lake Drūkšiai based on CRS age model for gravity cores (solid line – mean, dotted line - partial).

The 70 cm thick layer of recent lake sediments has accumulated in the zones of stations during 85 and 95 years respectively. More pronounced time differences (in comparison with the rates of sedimentation) occur due to dissimilarity of the density of sediments, which, in its turn, depends on the composition and compaction of sediments. Comparison of deviation of sedimentation rates in the stations showed no definite variation tendencies of sedimentation rates over the lake. The even sedimentation in station 2a in the 20th century might have been predetermined by the unique morphometric and hydrodynamic conditions in this part of the lake (the greatest depth of the lake is in its comparatively narrow western bay). Whereas two or three peaks of higher sedimentation rates can be distinguished for stations 1 and 2 (Fig. 2).

Higher sedimentation rate in the area of station 1 occurred in the time frame 1920–1940 and after 1980. Noticeable variations of sedimentation rate were also recorded for station 4a, which is situated closest to the zone of hydrographical transformations entailed by building hydrotechnical constructions in the last century. Three periods of higher sedimentation have been distinguished there: after 1900 (building of the canal and direction of water flow through Prorva; changes of water level in the lake), after 1940–1960 (direction of the water of Apyvardė rivulet to the lake for the needs of HEPP, expansion of the catchment) and after 1980 (building of NPP, digging of canals for technical water discharges and changes of water level in the lake). The rates of sedimentation could have also been predetermined by greater amounts of precipitation in the indicated time frames.

Before starting the Ignalina NPP in 1980–1981 (construction period) sedimentation rates were measured by means of sediment traps in stations 1, 2a and 3 of Lake Drūkšiai (Fig. 1). The sediment dry mass accumulation rate for station 1 and 3 was 0.17 g/cm²/year and for station 2a – 0.29 g/cm²/year. The proportion of mineral material in stations 1 and 3 amounted to 70 % and in station 2a – to 64 % (Тамошайтис, 1989).

The sediment dry mass accumulation rates determined by the method ^{137}Cs in the same zones were 0.13, 0.11 and 0.12 g/cm²/year respectively (Table 2).

Table 2. Recent sedimentation rates in Drūkšiai, Baltys, Lydekis, Glėbas, and Varėnis lakes.

Lake	No of sampling station	Lake depth at the sampling station, m	Lake sediment types	Range of dry bulk density in the core, g/cm³	Mean sediment dry mass accumulation rate, g/cm²/year	
					Method ^{210}Pb	Method ^{137}Cs
Drūkšiai	1	18	Silty clay	0.06–0.22	0.12-0.16	0.13
	2	14	Sandy silt	0.1–0.7	n/m	0.07
	2a	12	Sandy silt	0.06–0.16	0.08	0.11
	4a	6	Clayey silt	0.1–0.6	0.11	0.12
	6a	5	Silt	0.1–0.18	n/m	0.12
Baltys	1	6.8	Gyttja	0.02–0.08	0.05	0.07
Lydekis	1	19.5	Silty clay	0.04–0.12	n/m	>0.5
Glėbas	1	8	Gyttja	0.03–0.05	n/m	0.05
Varėnis	1	4	Silty clay	0.12–0.35	n/m	>0.5

These values are slightly higher than the ones determined by the ^{210}Pb method what implies higher mobility of ^{137}Cs than ^{210}Pb in the lake sediments (Fig. 3).

The presence of the so-called 'corrosive' radionuclide ^{60}Co makes easier the identification of the peak in 1986 because the discharges of ^{60}Co into the lake occurred only after the start of the Ignalina NPP in 1983. Sediment dry mass accumulation rate in stations 2 and 6a were 0.07 and 0.12 g/cm²/year respectively. The highest sedimentation rate has been recorded in the deepest lake area (station 1) and in most eutrophicated part of the lake (station 6a), i.e., in the zones of sedimentation of fine-grained terrigenous and organic material.
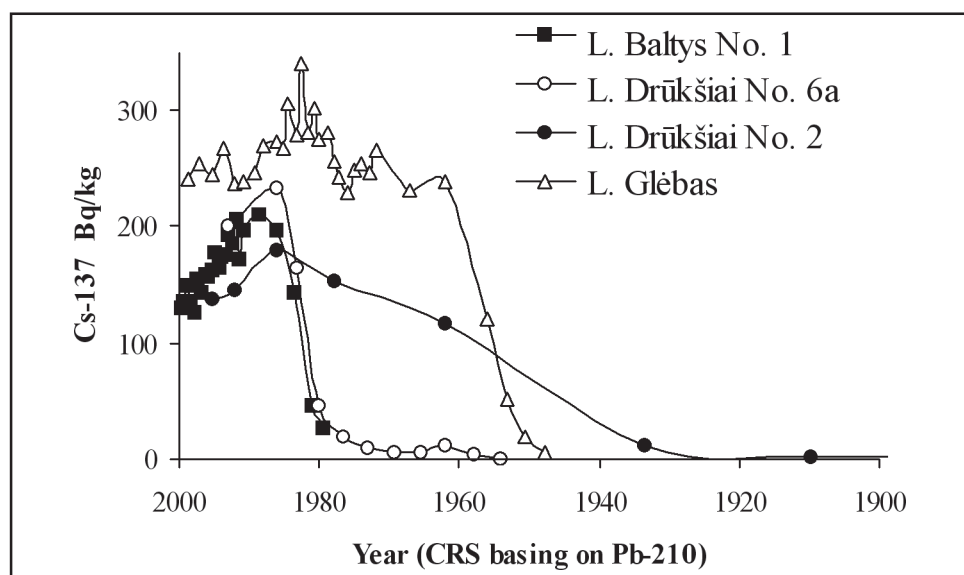

Fig. 3. ^{137}Cs in sediments versus calendar years.

Sedimentation rates determined by ^{137}Cs method for the small and enclosed Baltys and Glūbas lakes were 0.07 and 0.05 g/cm^2/year respectively. For the Lake Baltys comparative values of the measured parameter were obtained by both – ^{137}Cs and ^{210}Pb – methods (Fig. 4). The sedimentation rates measured using sediment traps for other Lithuanian lakes of similar type (Balsis, Akmena, Glūkas) were from 0.03 to 0.21 g/cm^2/year. No distinctive peaks of ^{137}Cs activity were distinguished in the core samples of drained Lydekis and Varėnis lakes.
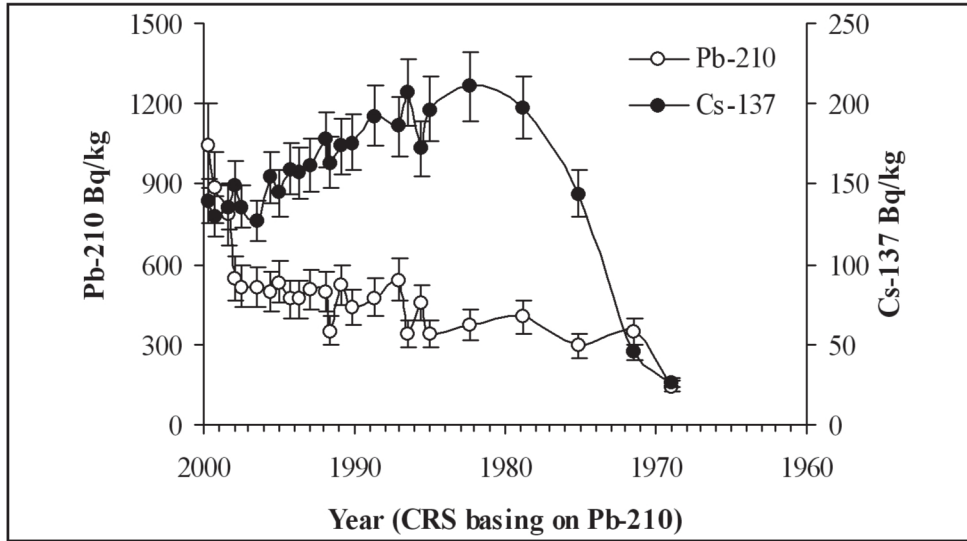
Fig. 4. ^{137}Cs and ^{210}Pb in sediments from Lake Baltys versus calendar years.

This is probably predetermined by active terrigenous sedimentation and turbulence of sediments. The 70 cm thick layer of sediments turned out to be insufficient for analysis. Assuming that the maximal activity of ^{137}Cs occurs in deeper zones we may assume that sedimentation rates in these lakes exceed 0.5 g/cm^2/year. These data have been obtained for the Lake Varėnis (using sediment traps) where the rate of sedimentation reached 1.0 g/cm^2/year.
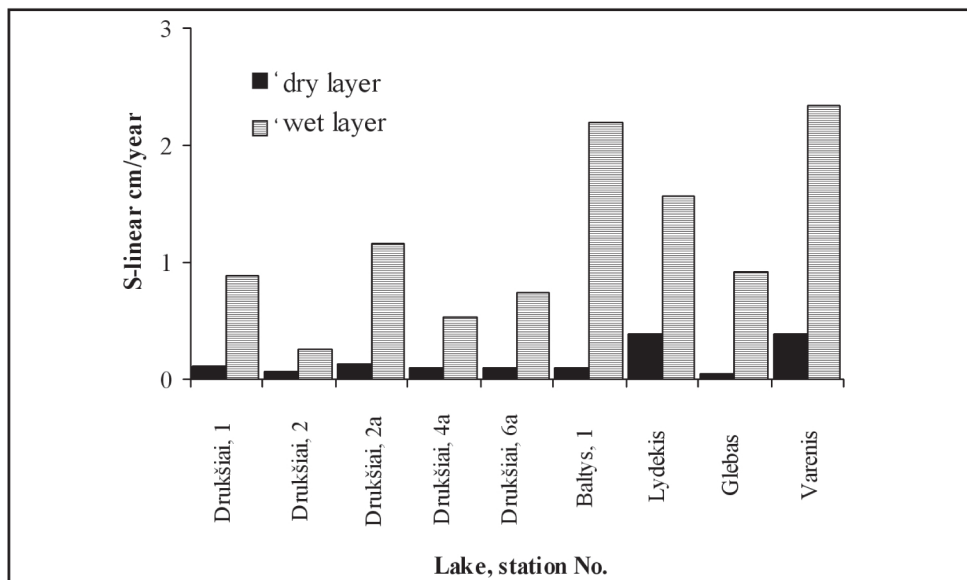

Fig. 5. Mean sedimentation rates in the studied lakes.

The lowest rates of sedimentation have been recorded in the Lake Glėbas where they are predetermined by geomorphology of lake environs contributing to slow input of dominant organic material. Parameters of sedimentation before and after 1986 differed but little – 0.05 and 0.04 $g/cm^2/year$ respectively.

Depending on the composition and post-sedimentary transformations of primary material layers of different thickness can develop at the same average rate of sedimentation (Fig. 5). Thus, at the rate of 0.07 $g/cm^2/year$ a layer of 2.2 cm in thickness accumulates in the Lake Baltys in a year whereas in the Lake Drūkšiai (station 2) – only 0.26 cm (at the same rate value). Both parameters are informative about the processes of sedimentation. The first one shows the physical intensity of sedimentation and the second one is more vivid for spatial perception of the process. It is also necessary to bear in mind that in the course of geological evolution organic material is subject to transformations and can be carried out by and used in biogeochemical processes.

The input of allochthonous particulate sediments with the surface runoff depends on precipitation as well. It has been determined that high water periods recur cyclically – in about 23–33 years. The data of annual precipitation from the Vilnius meteorological station (Fig. 6) show that four high water cycles can be distinguished in the 20th century.
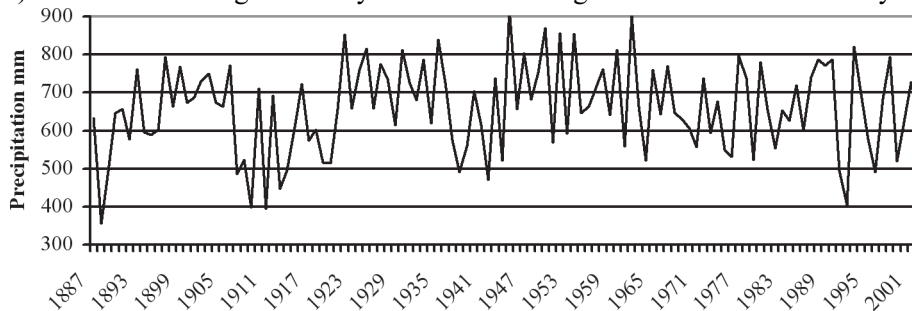

Fig. 6. Annual dynamics of atmospheric precipitation in Vilnius.

The first occurred at the end of the 19th–the beginning of the 20th century. It is, probably, responsible for higher rates of sedimentation in station 4a. The second high water cycle of 1925–1940 could have left its traces in the sediments of station 1. The traces of the third high water cycle (1950–1978), are, presumably, seen in station 4a and the traces of the fourth high water cycle (in about 1990) – only in station 1. Due to complicated configuration of Lake Drūkšiai depression, runoff regulation in the 20th century and large amounts of water taken for cooling the Ignalina NPP close to station 2a and heated water discharge close to station 4a the direction and velocity of currents, amount of particulate material and intensity of re-suspension have been periodically changing. This may account for the differences of the sedimentation rates in the studied areas.

Conclusions

The possibilities of evaluation of recent sedimentation parameters by radioisotope methods are shown on the example of a few Lithuanian lakes. Positive results have been obtained by a few methods: ^{137}Cs, ^{210}Pb and even ^{60}Co. Enclosed lakes among the small ones are more suitable for such investigations than the drained ones.

The mean sediment dry mass accumulation rate in studied lakes ranged in the 20th century from 0.05 to 0.16 $g/cm^2/year$. The deviations from the mean values were related with the major climatic and hydrological events and hydrographic changes in the catchments of relevant rivers.

The divergence of results obtained by different methods may be related with the noticeable diffusive downward (in rarer cases upward) transport of radioisotopes, their remobilization to the water and, sometimes, with the representativeness of samples (difference of thickness) and their pre-treatment.

References

Bollhöfer A., Mangini A., Lenhard A., Wessels M., Giovanoli F., Schwarz B. (1997). High-Resolution ^{210}Pb Dating of Lake Constance Sediments: Stable Lead in Lake Constance, *Environmental Geology*, Vol. 24, p. 267–274.

Gudelis A., Remeikis V., Plukis A., Lukauskas D. (2000). Efficiency Calibration of HPGe Detectors for Measuring Environmental Samples, *Environmental and Chemical Physics*, Vol. 22, No. 3–4, p. 117–125.

Krishnaswami S., Lal D., Martin J. M., Meybeck M. (1971). Geochronology of Lake Sediments, *Earth Planet Sci. Lett.*, Vol. 11, p. 407–414.

Koide M., Bruland K. W., Goldberg E. D. (1973). Th-228/Th-232 and Pb-210 Geochronologies in Marine and Lake Sediments, *Geochim. Cosmochim. Acta*, Vol. 37, p. 1171–1187.

Lietuvos geologija (1991). A. Grigelis, V. Kadūnas (sud.), Vilnius: Mokslas.

Mažeika J., Dušauskienė-Duž R., Radzevičius R. (2004). Sedimentation in the Eastern Baltic Sea: Lead-210 Dating and Trace Element Data Implication, *Baltica*, Vol. 17, No. 2, p. 79-92.

Robbins J. A., Edgington D. N. (1975). Determination of Recent Sedimentation Rates in Lake Michigan using ^{210}Pb and ^{137}Cs, *Geochim. Cosmochim. Acta*, Vol. 39, p. 285–304.

Robbins J. A. (1982). Geochemical and Geophysical Applications of Radioactive Lead Isotopes. *Biogeochemistry of Lead*. J. O. Nriagu (Ed.), p. 285–393.

Гарункштис А. А. (1975). Седиментационные процессы в озерах Литвы, Вильнюс: Мокслас.

Душаускене-Дуж Р. (1981). Распределение свинца-210 в экосистеме Балтийского моря. *Гидробиологический журнал*, т. 17, вып. 2, с. 85–95.

Общие закономерности возникновения и развития озер (1986). *Сер.: История озер СССР: Методы изучения истории озер.* Д. В. Севастьянов (отв. ред.). Ленинград: Наука, Ленинградское отделение.

Тамошайтис Ю. (1989) Интенсивность современных седиментационных процессов. *Базовое гидрофизическое состояние озера Друкшяй*, Вильнюс: Мокслас, с. 134–145.

Таутвидас М., Ласинскас М. (1986). Физико-географическая характеристика водосбора оз. Друкшяй. *Сер.: Теплоэнергетика и окружающая среда*, Вильнюс: Мокслас, т. 5, с. 7–14.

Jonas Mažeika, Julius Taminskas
Geologijos ir geografijos institutas, Vilnius

Rytų Lietuvos ežerų dabartinės sedimentacijos analizė radioizotopiniais metodais

Santrauka

Darbe pateikiami kelių Rytų Lietuvos ežerų (Drūkšių, Balčio, Lydekio, Glėbo ir Varėnio) dabartinės ir netolimos praeities sedimentacijos tyrimų rezultatai. Du tirti ežerai (Baltys ir Glėbas) neturi intakų ir yra nenuotakūs, juos maitina tik požeminis vanduo. Varėnio ir Lydekio ežerais prateka upės, kurių vidutinis metinis debitas atitinkamai – 3,18 ir 3,31 m³/s. Dalyje šių upių baseinų ūkininkaujama. Drūkšių ežero baseinas taip pat naudojamas žemės ūkyje, tačiau didžiausią poveikį ežerui turėjo jo nuotėkio reguliavimas XX a. ir Ignalinos AE veikla.

Iki 50–70 cm ilgio nuosėdų kolonėlės buvo paimtos Niemisto gravitaciniu vamzdžiu, lauko sąlygomis jos buvo suskirstytos į įvairaus storio – nuo 1 iki 6 cm – sluoksnelius. Laboratorijoje išdžiovinti mėginiai buvo tiriami aukštos skiriamosios gebos gama spektrometrijos metodais, juose buvo nustatomi ^{210}Pb ir ^{137}Cs savitieji aktyvumai.

Tyrimų rezultatai interpretuoti pastovaus srauto modeliu, įvertinant vidutinį sedimentacijos greitį. Pagal ryškius ^{210}Pb aktyvumo nuokrypius nuo modelinių dydžių kai kuriais atvejais buvo įvertintos ir sedimentacijos greičio variacijos. Nustatyti šie parametrai: sausosios masės kaupimosi greitis (g/cm²/m.), linijinis sausos ir drėgnos būsenos sluoksnio prieaugio greitis (cm/m.). Taip pat nagrinėti duomenys apie analogiškus parametrus, įvertintus ežeruose pastatytais nuosėdų gaudytuvais. Drūkšių ežere dabartinis sedimentacijos greitis, išmatuotas nuosėdų gaudytuvais, buvo nuo 0,17 iki 0,29 g/cm² per metus, Varėnio ežere – nuo 0,64 iki 1,0 g/cm² per metus. Tirtuosiuose ežeruose vidutinis sausosios masės kaupimosi greitis kito nuo 0,05 iki 0,16 g/cm²/m. Kituose nepratakiuose ežeruose sedimentacijos greitis kito nuo 0,03 iki 0,19 g/cm²/m., o pratakiuose – nuo 0,15 iki 0,21 g/cm²/m.