GEOLOGIJA. 2006. T. 54. P. 49–60

Sedimentologija • Sedimentology • Седиментология

Component-based and radioisotope signature of lacustrine sediments in Eastern Lithuania

Jonas Mažeika,

Arūnas Gudelis

Mažeika J., Gudelis A. Component-based and radioisotope signature of lacustrine sediments in Eastern Lithuania. *Geologija*. Vilnius. 2006. No. 54. P. 49–60. ISSN 1392-110X

Results of investigation of sedimentation processes in a few lakes located in the eastern part of Lithuania are presented. The Niemistö gravity corer was used for taking short (up to 80 cm in length) sediment cores. The sliced and dried samples were examined for ^{210}Pb and ^{137}Cs specific activity and for components of sedimentary matrix. The estimated parameters were mean sediment mass accumulation rate (g/cm^2/ /year), derived linear rate of accumulation of wet bulk sediment layer (cm/year), percentage of components of sedimentary matrix. The radioisotope geochronology of sediments was outlined based on constant ^{210}Pb flux and constant sedimentation rate model. Basing on radioisotope geochronology, temporal changes of the components of sedimentary matrix in particular lakes related to environmental changes have been studied. The dry mass accumulation rate for particular cores from different lakes was the following: Lake Drūkšiai 0.06 g/cm^2/year, Lake Mažasis Beržinis 0.024 g/cm^2/year, Lake Šventas 0.017 g/cm^2/year, Lake Duobulis 0.012 g/cm^2/year. The linear sedimentation rates of wet sediments for cores from different lakes were derived: Lake Drūkšiai 0.3–0.9 cm/year, Lake Mažasis Beržinis 0.1–0.6 cm/year, Lake Šventas – 0.3-1.0 cm/year, Lake Duobulis 0.1–0.4 cm/year. Based on radioisotope geochronology, the time intervals of change of sediment sources related with the major hydrological events and hydrographic changes in the relevant catchments were determined.

Key words: lakes, sedimentation rate, lead-210, caesium-137, radioisotope geochronology

Received 22 February 2006, accepted 23 March 2006

Jonas Mažeika, Institute of Geology and Geography, T. Ševčenkos 13, LT-03223 Vilnius, Lithuania and Vilnius University, M.K. Čiurlionio 21/27, LT-03101 Vilnius, Lithuania. E-mail: mazeika@geo.lt

Arūnas Gudelis, Institute of Physics, Savanorių 231, LT-02300 Vilnius, Lithuania. E-mail: gudelis@ktl.mii.lt

INTRODUCTION

Lakes are dynamic response systems that integrate environmental, climatic and tectonic forcing into a continuous, high-resolution archive of local and regional changes (Gierlowski-Kordesch, Kelts, 2000). These changes are studied basing on palaeolimnological approach with the key goal to develop continental palaeorecords comparable to those available from oceans or ice cores.

Much of existing understanding of continental Quaternary palaeoclimate and ecological changes came from the study of fossil pollen in lakes, bogs and peatlands. Today, numerous additional proxies of environmental changes are routinely applied in the analysis of lacustrine sedimentary records: isotopes

(Talbot, 2001), diatoms (Stoermer, Smol, 1999), sedimentary organic matter, sediment lithology and facies, etc. (Talbot et al., 1984).

The use of fallout radionuclides (^{210}Pb and ^{137}Cs) as a sediment tracer and dating tool supported by component-based analysis of lacustrine sediments appears to offer a considerable potential for assembling information on main sediment sources and sedimentation rates within lakes.

Caesium-137 is an artificial radionuclide with a half-life of 30.17 years. The widespread global distribution of ^{137}Cs into the environment began with the atmospheric testing of high-yield nuclear weapons in the 1950s and the early 1960s. Following the Chernobyl Nuclear Power Plant accident in 1986, certain areas in the Northern Hemisphere received additional inputs of ^{137}Cs. ^{137}Cs is released into the stratosphere and circulates globally. Subsequent to its deposition as a fallout, ^{137}Cs is rapidly and strongly adsorbed by fine-grained particulate matter on the soil surface (Frissel, Penders, 1983), and its redistribution is primarily associated with erosion and deposition within lacustrine sediments and the processes in the system "bottom water – sediment" (Tarasiuk, Špirkauskaitė, Druteikienė, 2003.).

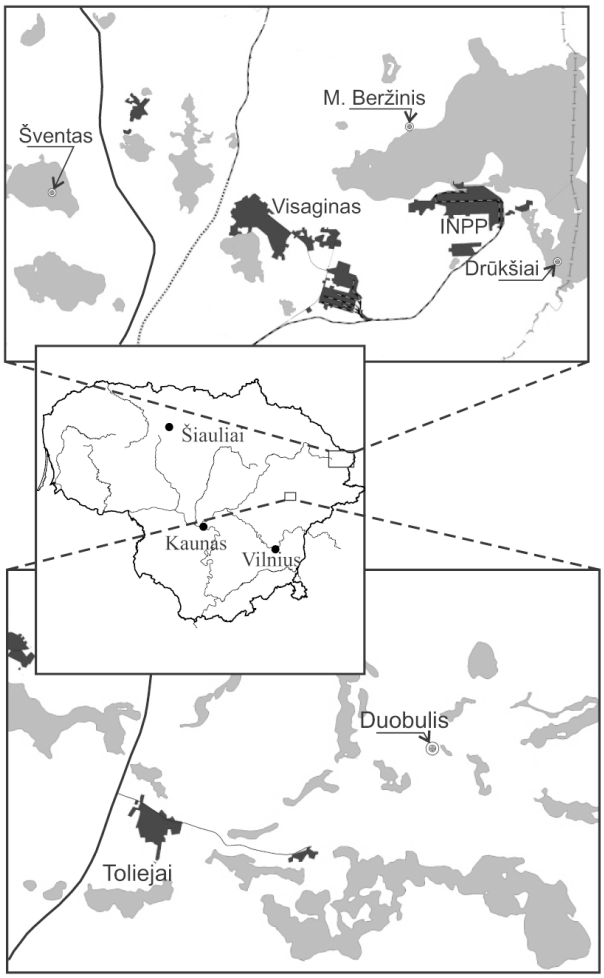

Fig. 1. Study areas with location of coring stations (Drūkšiai – N55°34'41", E26°37'16"; Mažasis Beržinis – N55°37'44", E26°32'02"; Šventas – N55°36'29", E26°18'21"; Duobulis – N55°17'02", E25°37'00"

1 pav. Tyrimų rajonai bei kolonėlių paėmimo vietos: Drūkšių – N55°34'41", E26°37'16"; Mažojo Beržinio – N55°37'44", E26°32'02"; Švento – N55°36'29", E26°18'21"; Duobulio – N55°17'02", E25°37'00"

Lead-210 is a natural product of the ^{238}U decay series, with a half-life of 22.3 years. It is derived from the decay of gaseous ^{222}Rn, the daughter of ^{226}Ra. Radium-226 occurs naturally in soils and rocks and will generate ^{210}Pb which will be in equilibrium with its parent. Diffusion of a small quantity of ^{222}Rn from the soils introduces ^{210}Pb into the atmosphere, and its subsequent fallout provides an input of this radionuclide to the soil surface which is not in equilibrium with its parent ^{226}Ra. This fallout component is commonly referred to as "unsupported" or "excess" ^{210}Pb. More additional ^{210}Pb forms while burning the fossil organic fuel and gets into water systems because of rapid atmospheric transport and deposition of ^{210}Pb originated from ^{226}Ra decay products. ^{210}Pb fallout input has been essentially constant through time and its supply to the soil surface is continuously replenished. As a fallout radionuclide ^{210}Pb is rapidly and strongly adsorbed by the surface soil and is redistributed within lacustrine sediments.

The aim of the present study is, firstly, to estimate the mass accumulation rate of sediments in several lakes (Drūkšiai, Mažasis Beržinis, Šventas and Duobulis) located in the eastern part of Lithuania (Fig. 1) and, secondly, to define the periods of environmental changes in relevant lake catchments basing on radioisotope geochronology and components of the sedimentary matrix.

Environmental settings

Lake Drūkšiai is situated in the north-eastern 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. The area of its water surface is 49 km^2, the length is 14.3 km and the width 5.3 km (Таутвидас, Ласинскас, 1986). Forests occupy a significant part of Lake Drūkšiai catchment (42%). 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 a water mill between 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 finally 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. The Ignalina NPP was started up late in 1983. Lake Drūkšiai is characterized by a high diversity of

recent surface sediments and sedimentation rates (Гарункштис, 1975; Maþeika, Taminskas, 2005).

The other three lakes and their environs are considerably less investigated (Tamoðaitis, 1974; Kilkus, Pumputytë, 2001). Judging from geomorphologic signs, the depressions of those three lakes are of thermokarst (kettle) origin.

Lake Maþasis Berþinis is in the north-eastern bank of Lake Drūkšiai. It is separated from Lake Drūkšiai by a swampy belt a few tens of metres wide, overgrown with shrubs and trees. The area of Lake Mažasis Beržinis is 4.9 ha and the altitude of water level is 142 m a.s.l. The greatest depth does not exceed 3 m and the thickness of lacustrine sediments is more than 8 m.

The kettle Lake Þventas is located in a pine forest in Zarasai district. The surrounding landscape abounds in hills and hollows. The surface altitude exceeds 170 m a.s.l. The altitude of the water surface today is about 158.5 m a.s.l. Þventas is the largest endoheic lake in Lithuania. Due to this, its long-term water level fluctuations (with a historical amplitude reaching 2.5–3 m) depend on the humidity cycles. According to historical data (Tamoðaitis, 1974), the water level of Lake Þventas used to be high until 1930–1938, reaching up to 160.5 m a.s.l. Later it fell down and in 1973 was lowest (157.5 m a.s.l). Later, the water level again rose and stabilized. Lake Þventas is not far from the Nemunas and Dauguva river divide and belongs to the Nemunas–Þventoji basin. The lake area is 442 ha; the lake catchment area is 15.8 km^2, maximum depth 18.2 m, mean depth 6.4 m, and the thickness of lacustrine sediments 2.4 m.

The small kettle Lake Duobulis is located in a pine forest in Molėtai district. The surrounding landscape abounds in hills and hollows. The altitude of the locality exceeds 170 m a.s.l. The altitude of water surface is about 152.9 m a.s.l. High (20–30 m) and steep slopes surround the lake. It is not far from the Lakaja and Virinta river divide but belongs to the Lakaja River basin. The lake is drained. The lake area is 3.8 ha, lake catchment area 19 ha, maximum depth 16 m, mean depth 6.6 m, approximately 60% of water input to the lake is formed by groundwater baseflow, and the water exchange time is 3 years.

MATERIAL, SAMPLING AND METHODS

The Niemistö gravity corer (inner diameter 54 mm) was used for taking short (up to 80 cm in length) cores from the lakes Drūkšiai (coring station location – N55°34'41'', E26°37'16'', water depth 6.95 m), Maþasis Berþinis (N55°37'44'', E26°32'02'', water depth 2.45 m), Þventas (N55°36'29'', E26°18'21'', water depth 16.15 m) and Duobulis (N55°17'02'', E25°37'00'', water depth 15.90 m) (Fig. 1). Two representative sediment cores were taken from the central deepest parts of each lake or isolated bay, as is the case with Lake Drūkšiai. The cores were taken from ice in March 2003. One of the double cores was sliced into 1 cm thick slices *in situ* in order to determine the depth distribution of ^{210}Pb and ^{137}Cs. The second of the double cores was sliced into 3 cm thick slices *in situ* in order to determine the depth distribution of main components (carbonates, clastic, biogenic) of the sedimentary matrix.

The selected samples from the cores (Lake Drūkšiai core – 25, Lake Mažasis Beržinis – 24, Lake Šventas – 22, Lake Duobulis – 23 samples) were examined by the method of gamma ray spectrometry. The samples were dried at 105° C and desegregated prior to assay. Gamma ray assay was undertaken at the Institute of Physics, Vilnius, using the well-type detector (GWL-170230-S manufactured by 'EG&G Ortec') with a sensitive volume of 170 cm^3 and the well inside the germanium crystal 16 mm in diameter and 40 mm in depth. It can accommodate small samples with the effective volume up to 4 cm^3. The calibration procedure of the gamma ray spectrometric system used in this study is described elsewhere (Gudelis et al., 2000).

A number of naturally occurring radioisotopes from the U and Th decay series as well as the man-made radioisotope ^{137}Cs were determined. Concerning natural radioactivity, a special attention has been paid only to the ^{210}Pb activity concentration in samples, as the remaining gamma-radiation was attributable to variation of background. The gamma-ray spectrometric system has been calibrated against samples with the known ^{210}Pb and ^{137}Cs activities, the measuring container filling height was taken into account during both the efficiency calibration and actual sample measurements. As typical sample volume was 3 cm^3, the detection limits for 100000 s counting time were 7 Bq/kg and 40 Bq/kg, while measurement errors did not exceed 8% and 15%, for ^{137}Cs and ^{210}Pb, respectively.

All 3 cm thick samples (Lake Drūkšiai core – 23, Lake Mažasis Beržinis – 26, Lake Šventas – 24, Lake Duobulis – 18 samples) were examined for the main components of the sedimentary matrix (Bengtsoon, Enell, 1986). Firstly, the samples were slowly dried at 50–80° C and later at 105° C to constant weight, desegregated and sieved to pass a 0.25 mm mesh. Organic matter was estimated using loss of weight on ignition at 850° C, carbonates by titration with HCl, and the clastic component of the sediment matrix was calculated. The water content and dry bulk density of sediments were estimated by weighing standard volume samples dried at 105° C.

RESULTS AND DISCUSSION

Any given lake sediment may consist of a mixture of detrital sediment grains, algal or terrestrial organic

matter and inorganically precipitated carbonates, along with numerous other fossil components. The component-based analysis scheme used in this study comprises three basic sediment components common to lacustrine sediments (Kelts, 1988): (1) clastic sediments (could be referred to as mineral / terrestrial), (2) chemical sediments (could be referred to as carbonates), and (3) biogenic sediments (could be referred to as organic carbon).

Clastic sediments are composed of discrete grains of generally allochthonous origin deposited by physical processes of sedimentation (air fall, sub-aqueous transport). The clastic component of lacustrine sediment can serve as a monitor of landscape changes, yielding signals of varying rates of basin landscape denudation, strength of regional deflation processes, vegetation dynamics and/or tectonic activity.

The carbonate sediments refer to sediments in which non-biogenic, authigenic and diagenetic carbonate minerals are the principal component. The majority of endogenic lacustrine carbonates come from chemical precipitation resulting from pH shifts induced by biologic activity or physical changes in the lake waters (temperature, CO_2, water depth variation, recharge by groundwater). The carbonate phase is also sensitive to climatic and drainage basin conditions. There are cases of biogenic carbonate that developed from charophytes; however, lacustrine carbonates are rarely dominated by biogenic carbonates (Dean, 1981).

Biogenic sediments can comprise a variety of mineralogies (e.g., CH_2O, $CaCO_3$, SiO_2), but all are essentially the fossil remains of former living organisms. Biogenic sediment may be composed of the well preserved to highly degraded remains of organisms (plant and/or animal). Biogenic sediments could be divided into carbonaceous sediments composed of the remains of organisms lacking hard skeletal parts, and fossiliferous sediments, termed oozes or hashes, depending upon the grain size (Mazzulo et al., 1988). Carbonaceous sediments are derived from the accumulation of organic matter in lacustrine basins. Organic matter may derive from organisms inhabiting the lake (cyanobacterial mats, macro- and microphytes, phytoplankton, zooplankton, benthic organisms or faeces from aquatic or terrestrial organisms) or from organic matter introduced into the lake from the surrounding drainage basin (terrestrial herbaceous and woody plants), though the latter is generally less common (Kelts, 1988). The fraction of biogenic component in sediments is a function of autochthonous and allochthonous organic production, bacterial decay and the rate of clastic sediment input, and it is a measure of lake productivity.

The term sapropel is traditionally used for fine-grained organic matter. Sapropel is an aquatic ooze or "sludge" rich (>50% of the total organic matter) in amorphous or very fine-grained (<0.1 mm) matter. The organic matter may originate from either algal or bacterial elements or the decomposition of land and aquatic plants.

Component-based analysis allowed to describe or to classify particular sediments. The most abundant component (>50%) provides the principal name (e.g., clay, carbonates, sapropel), which defines the sediment class (clastic, biogenic, chemical). Major and minor modifiers are employed for the further cha-

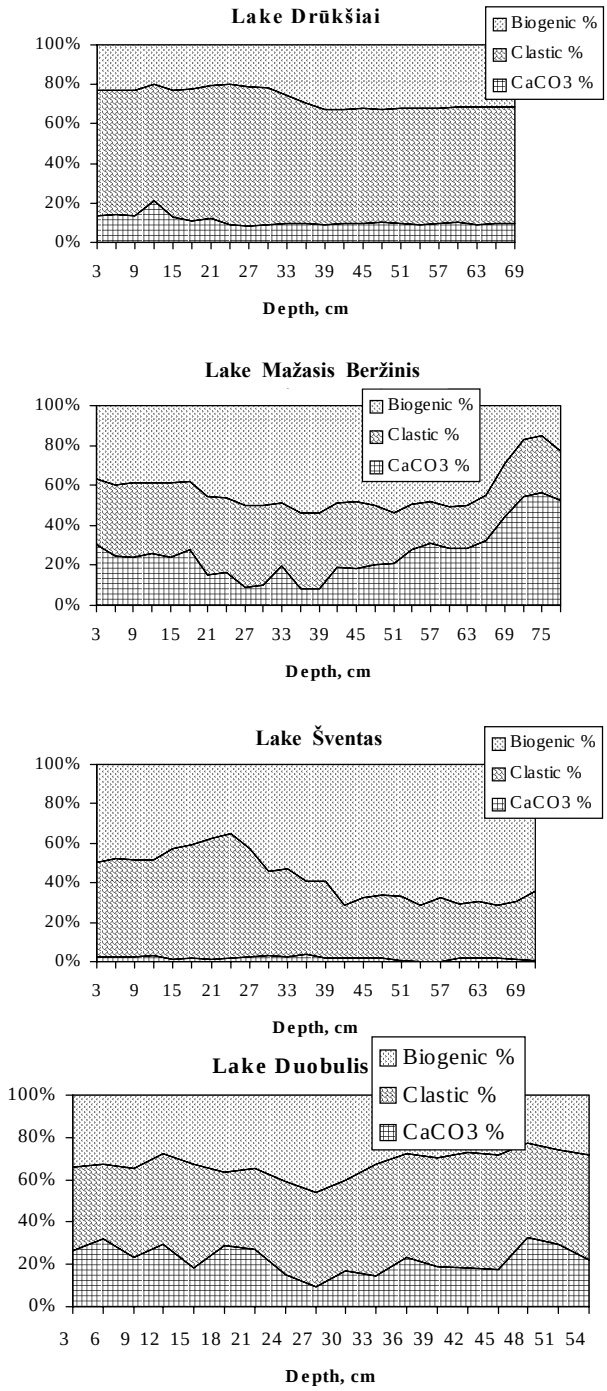

Fig. 2. Depth distribution of sedimentary matrix components in cores collected from the lakes in eastern Lithuania

2 pav. Dugno nuosėdų medžiaginės sudėties pasiskirstymas ir gylis tirtuose Rytų Lietuvos ežeruose

racterization of the sediment components that constitute a major (25–50%) or minor (15–25%) component of sediments (Гарункштис, 1975; Schnurrenberger, Russell, Kelts, 2003.).

Data on the component-based analysis of bottom sediments of the lakes studied are given in Fig. 2.

The concentration of carbonates in the sediment core from Lake Drūkšiai ranges within 8.2–21.1%. The highest values occur at the depth interval 9–12 cm and the smallest at the depth interval 24–27 cm. The content of clastic material ranges within 57.6–71.2%. The highest value is characteristic of the depth interval 45–48 cm and the smallest 21–24 cm. The content of biogenic material ranges within the interval 19.6–32.6%. The highest value occurs at a depth of 36–39 cm and the lowest 9–12 cm. *Clastic* material dominates in this core. A slight but even change of the material composition with depth (except the interval of 9–12 cm) is characteristic.

The content of carbonates in the core of Lake Maþasis Berþinis ranges within 8.0–56.3%. The depth interval of the highest values is 72–75 cm and of smallest values 24–27 cm. The content of clastic material ranges within the interval of 20.0–41.3%. The depth interval of the highest values is 24–27 cm and of the smallest values 60–63 cm. The variation interval of biogenic material is 15.1–54.1%. The highest values occur at a depth of 33–39 cm and the smallest at a depth of 72–75 cm. The dominant material component in this core varies with the depth. The variations are sharp and uneven. *Biogenic* material dominates within the interval of 0–63 cm and *carbonates* within the interval of 66–78 cm. Some extremities coincide with the extremities in the core from Lake Dūkšiai.

The carbonate content in the core of Lake Þventas ranges within 0.2–3.9%. The depth interval of highest values is 33–36 cm and of smallest values 54–57 cm. The content of clastic material ranges within the interval 26.5–63.3%. The depth interval of the highest values is 21–24 cm and of the smallest values 60–63 cm. The variation interval of biogenic material is 37.7–71.6%. The highest values occur at a depth of 39–42 cm and the smallest at a depth of 18–21 cm. *Biogenic* material dominates in this core (except the interval of 12–27 cm). A slight but even change of the material composition with depth (except the mentioned interval of 12–27 cm) is characteristic.

The content of carbonates in the core of Lake Duobulis ranges within 9.4–32.6%. The depth interval of the highest values is 45–48 cm and of smallest values 24–27 cm. The content of clastic material ranges within the interval of 34.7–54.5%. The depth interval of the highest values is 39–42 cm and of the smallest values 15–18 cm. The variation interval of biogenic material is 22.4–45.8%. The highest values occur at a depth of 24–27 cm and the smallest at a depth of 45–48 cm. *Clastic* material dominates in this core, except the intervals 15–18 cm and 24–27 cm where *biogenic* material is dominant. The variations of material composition with depth are sharp and uneven.

In case of a relatively constant content of clastic material, the highest content of biogenic material

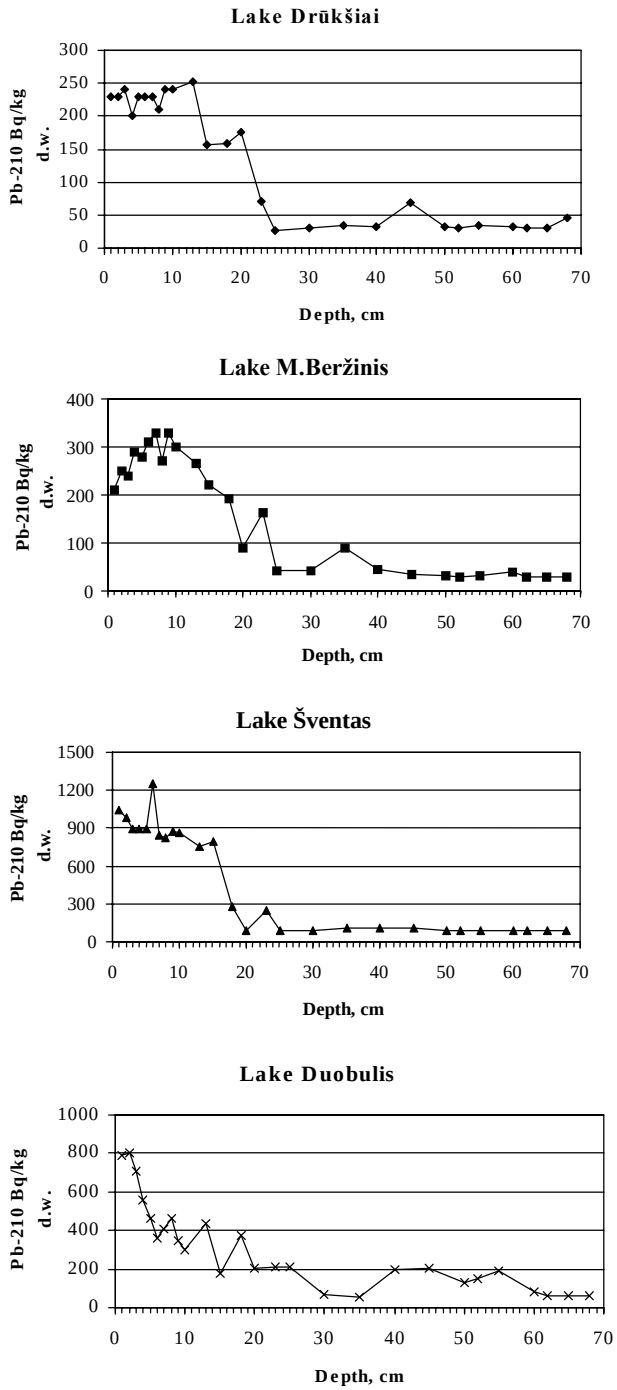

Fig. 3. Depth distribution of ^{210}Pb specific activity in sediment (d.w. – dry weight) cores collected from lakes in eastern Lithuania

3 pav. ^{210}Pb savitojo aktyvumo dugno nuosėdose (sausajam svoriui) pasiskirstymas ir gylis tirtuose Rytų Lietuvos ežeruose

coincides with the smallest content of carbonates and *vice versa* in the majority of cores (pH shifts).

Data on ^{210}Pb in the vertical profile of sediments are given in Fig. 3.

The specific activity of ^{210}Pb in the upper 13 cm interval of Lake Drūkšiai core ranges within 200 and 250 Bq/kg and slightly increases at a greater depth. Elevated concentrations of carbonates and lower concentrations of biogenic material occur in the mentioned interval. This is the interval of ^{210}Pb dilution. Lower, at an interval of 13–30 cm, the specific activity of ^{210}Pb evenly reduces until it reaches a constant level of 30–40 Bq/kg. The ^{210}Pb chronology can be applied to this interval.

The specific activity of ^{210}Pb in the upper 9 cm interval of Lake Maþasis Berþinis core ranges within 180 and 300 Bq/kg. Elevated concentrations of carbonates and lower concentrations of biogenic material occur in the mentioned interval if compared with the lower one. This is the interval of ^{210}Pb dilution. At an interval of 9–30 cm the specific activity of ^{210}Pb evenly reduces until it reaches a constant level of 30-40 Bq/kg. The ^{210}Pb chronology can be applied to this interval.

The specific activity of ^{210}Pb in the upper 15 cm interval of Lake Þventas core almost evenly reduces from 1000 to 800 Bq/kg, except the interval of 5–6 cm where the specific activity of ^{210}Pb is highest (1250 Bq/kg). In the interval 15–20 cm the specific activity of ^{210}Pb evenly reduces from 800 to 90–100 Bq/kg. Taking into consideration the material composition, the ^{210}Pb chronology can be applied to the interval of 0–20 cm.

The specific activity of ^{210}Pb in the upper 10 cm interval of Lake Duobulis core almost evenly reduces from 800 to 300 Bq/kg. In the lower 10–30 cm interval, the specific activity of ^{210}Pb reduces from 300 to 70 Bq/kg. Yet considerable variations are characteristic of this interval. Elevated values of the specific activity of ^{210}Pb are also characteristic of the interval 34–54 cm. Taking into consideration the material composition, the ^{210}Pb chronology can be applied to the interval 0–30 cm. This sediment core shows a very uneven sedimentation. At the moment of sampling and slicing, signs of CH_4 degasation were observed, implying that radioisotopes might have been remobilized from the lower layers to the upper ones and partly into the water column.

Data on the specific activity of ^{137}Cs in the vertical profile of sediments are given in Fig. 4.

The greater part of ^{137}Cs is distributed in the upper 20–30 cm layer of sediments. The highest specific activity of ^{137}Cs in the sediment cores is the following: 314 Bq/kg in Lake Šventas, 167 Bq/kg in Lake Drūkšiai, 141 Bq/kg Lake Mažasis Beržinis, and 113 Bq/kg Lake Duobulis.

The data on radioisotope distribution in cores were used for sedimentation rate assessment and description of sediment geochronology. One of the most popular methods of lacustrine sediment dating on a time scale of 100–150 years (more precisely for 60–70 years) is dating by unsupported ^{210}Pb. Goldberg (1963) was the first who outlined the ^{210}Pb geochronology, Krishnaswami et al. (1971) applied it to the dating of lacustrine sediments and Koide et al. (1972) later applied it to marine sediments.

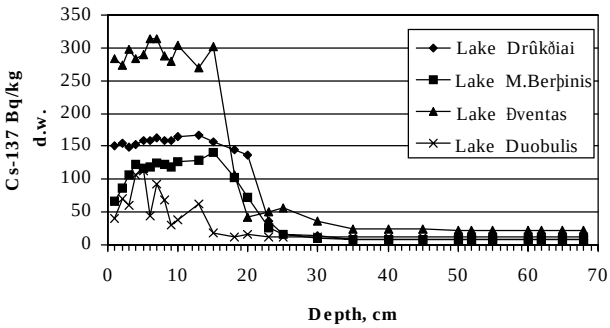

Fig. 4. Depth distribution of ^{137}Cs specific activity in sediment (d.w. – dry weight) cores collected from lakes in eastern Lithuania

4 pav. ^{137}Cs savitojo aktyvumo dugno nuosėdose (sausajam svoriui) pasiskirstymas ir gylis tirtuose Rytų Lietuvos ežeruose

Data on ^{210}Pb activity were interpreted based on the constant sedimentation rate (CSR) model (Goldberg, 1963; Krishnaswami et al., 1971; Koide et al., 1973; Matsumoto, 1975; Matsumoto, 1987; Mažeika, Dušauskienė-Duž, Radzevičius, 2004). The activity of unsupported ^{210}Pb in cores of regular sedimentation exponentially reduces with depth in the interval of accumulation of unsupported ^{210}Pb. ^{210}Pb activity below this interval is in equilibrium with ^{226}Ra (supported ^{210}Pb) and constant for a certain lithology.

Assuming that both excess ^{210}Pb flux and the particulate material sedimentation rate are constant, the excess ^{210}Pb activity (A_t) in a sedimentary column is governed by the exponential law which is described as

$$A_t = A_0 \exp(-\lambda t), \quad (1)$$

where A_0 is the activity of excess ^{210}Pb at the sediment surface ($t = 0$) (Bq/kg), λ is the decay constant of ^{210}Pb, 0.0311 year^{-1}, and t is the time (year). Equation (1) can be transformed as follows:

$$A_x = A_0 \exp\left(-\frac{\lambda}{s} x\right), \quad (2)$$

where s is the sedimentation rate, cm/year and x is the depth below the sediment surface, cm.

This model has been called a “simple” model (Krishnaswami et al., 1971; Matsumoto, 1975; Robbins, 1978), or the constant ^{210}Pb flux and constant sedimentation rate (c.f.:c.s.) model (Appleby, Oldfield, 1983; Oguri et al., 2003). When the activities

of excess ^{210}Pb are plotted on a logarithmic scale against *x*, the resulting profile will be linear. The slope of the profile can be determined by using the least-square fit procedure. Similarly, the sedimentation rate can be determined from the slope, and the sediment date (*t*) can be inferred from $t = x/s$.

Particulates settle loosely on the lake bottom and may be subjected to significant compaction under the weight of additional settled material (Athy, 1930; Christensen, 1982). Without taking into consideration the compaction effect, the apparent sediment age is too young. The porosity of sediments is closely related to water content in the sediments and additionally depends on the density of solid matter. The porosity of sediments is usually very high (>0.97) near the sediment-water interface. Deep down (to 10 cm) it decreases and lower it is rather constant and changes in a narrow interval (0.88 ± 0.02). The density of solid particles usually changes from 2.3 to 2.6 g/cm^3. A more complicated distribution of water content and consequently porosity versus depth takes place when the lithology of sediments changes considerably (Fig. 5).

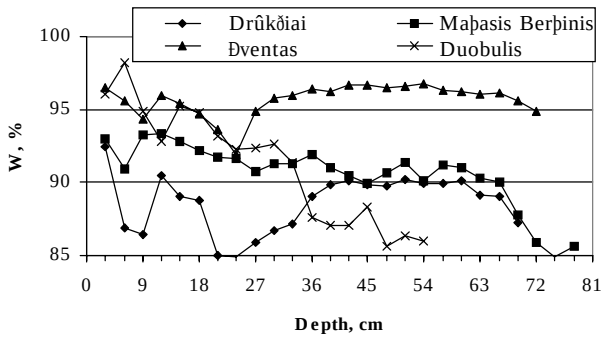

Fig. 5. Depth distribution of water content in sediment cores collected from lakes in eastern Lithuania

5 pav. Drėgmės pasiskirstymas dugno nuosėdose ir gylis tirtuose Rytų Lietuvos ežeruose

The water content of sediments for different cores changes as follows: Lake Drūkšiai 84.9–92.5%, Lake Maþasis Berþinis 84.9–93.0%, Lake Þventas 91.9–96.5%, Lake Duobulis 85.7–98.2%.

An alternative method to remove compaction effect is by expressing excess ^{210}Pb as a function of cumulative weight per area unit, massdepth (Robbins, 1978; Christensen, 1982; Matsumoto, 1987). In this case, the mean sediment dry mass accumulation rate is determined for a core under analysis.

After determining the ^{210}Pb geochronology of cores corresponding to a certain mean sediment dry mass accumulation rate value, the distribution of ^{137}Cs peaks (1963 and 1986) was analysed. In some cases, the ^{210}Pb geochronology was slightly corrected according to ^{137}Cs. For this purpose, plots of ^{137}Cs load in sediments (Bq/m^2) were used (Fig. 6).

The main ^{137}Cs peak of 1963 in the cores was determined at different depth intervals: Lake Drūkšiai

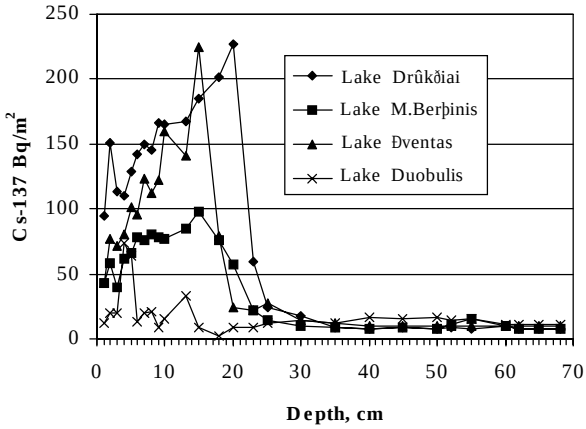

Fig. 6. Depth distribution of ^{137}Cs load in sediment cores collected from lakes in Eastern Lithuania

6 pav. ^{137}Cs apkrovos dugno nuosėdose pasiskirstymas ir gylis tirtuose Rytų Lietuvos ežeruose

19–20 cm, Lake Mažasis Beržinis 14–15 cm, Lake Šventas 14–15 cm, Lake Duobulis 12–13 cm. A somewhat less pronounced ^{137}Cs peak of 1986 was also detected in some cores.

The load of ^{137}Cs in sediments for different cores is: Lake Drūkšiai – 2320 Bq/m^2, Lake Maþasis Berþinis – 1110 Bq/m^2, Lake Þventas – 1570 Bq/m^2, Lake Duobulis – 450 Bq/m^2.

The dry mass accumulation rate for cores from different lakes is the following: Lake Drūkšiai 0.06 g/cm^2/year, Lake Maþasis Berþinis 0.024 g/cm^2/year, Lake Þventas 0.017 g/cm^2/year, Lake Duobulis 0.012 g/cm^2/year. The highest dry mass accumulation rate is characteristic of the south-eastern bay of Lake Drūkšiai, which is rather well drained.

The linear sedimentation rate of wet sediments for cores from different lakes changes depending on the composition and compaction of sediments: Lake Drūkšiai 0.3–0.9 cm/year, Lake Mažasis Beržinis 0.1–0.6 cm/year, Lake Šventas 0.3–1.0 cm/year, Lake Duobulis 0.1–0.4 cm/year.

Changes of the components of sedimentary matrix for cores from different lakes versus calendar years based on ^{210}Pb and ^{137}Cs geochronology are outlined in Tables 1–4.

A sediment core 69-cm long, taken from the Lake Drūkšiai, accumulated from 1859 until 2002. Muddy clay accumulated from 1859 until 1977. At the end of the time span, the portion of biogenic material reduced, whereas the content of clastic material and carbonates increased. In the time span 1983–1988, the type of sedimentation changed. Muddy calcareous clay began to accumulate. In later years, the processes of sedimentation stabilized, muddy clay being the main sedimentary material. The mentioned changes of sedimentation were related with the construction of the Ignalina NPP and the initial period of its operation.

A sediment core 66-cm long, taken from Lake Maþasis Berþinis, accumulated from 1725 until 2002.

Carbonates had accumulated before 1725. This implies a lower water level than today. In later years, sedimentation types changed very frequently. Sedimentary material was either clayey calcareous mud or sapropel. Even four time spans of sapropel accumulation show a higher water level. During the mentioned time spans, the water from Lake Drūkšiai might have broken forth. Since 1932–1944, sedimentation stabilized, the main sedimentary matter being calcareous clayey mud.

A sediment core 51-cm long, taken from Lake Ðventas, accumulated from 1864 until 2002. Three types of sediments were deposited during this period. Sapropel had accumulated before 1923. Muddy clay was accumulating from 1923 until 1976. Clayey sapropel was the main sedimentary material in later years. The intermediate time span with the maximal content of clastic material indicates changes of the water level (high water, drop of water level and stabilization). The water level variations can also be supported by historical data.

A sediment core 54-cm long, taken from Lake Duobulis, accumulated from 1612 until 2002. This lake is characterized by the lowest sedimentation rates and a rather high diversity of sedimentary material; frequent transitions from calcareous muddy clay to muddy calcareous clay. The varying types of sediments are closely related. Clastic material was the dominant one. Yet the mentioned sedimentation dynamics shows the sensitivity of sedimentation to environmental changes. The greatest amount of clastic material accumulated in the time span 1713–1775. Biogenic sedimentation dominated in the period from 1890 until 1909. Since 1974 until present, sedimentation of muddy clay is rather constant.

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 combining ^{210}Pb and ^{137}Cs dating procedures with the component-based analysis of sedimentary matrix.

The dry mass accumulation rate for particular cores from different lakes was the following: Lake Drūkšiai 0.06 g/cm^2/year, Lake Mažasis Beržinis 0.024 g/cm^2/year, Lake Šventas 0.017 g/cm^2/year, Lake Duobulis 0.012 g/cm^2/year. Linear sedimentation rates of wet sediments for cores from different lakes were derived: Lake Drūkšiai 0.3–0.9 cm/year, Lake Mažasis Beržinis 0.1–0.6 cm/year, Lake Šventas 0.3–1.0 cm/year, Lake Duobulis 0.1–0.4 cm/year.

Based on radioisotope geochronology, the periods of change of sedimentary material sources, related

Table 1. **Characterization of sediments and radioisotope geochronology for cores taken from Lake Drūkšiai in 2003**
1 lentelė. **2003 m. Drūkšių ežere paimtos kolonėlės nuosėdų apibūdinimas ir chronologija**

Sampled interval depth, cm	Components of sedimentary matrix, %			Sediment description	Calendar years based on ^{210}Pb and ^{137}Cs geochronology
	$CaCO_3$	Clastic	Biogenic		
0–3	13.8	62.9	23.3	Muddy clay	1998
3–6	14.0	62.8	23.2		1993
6–9	13.6	63.2	23.2		1988
9–12	21.0	59.4	19.6	Muddy calcareous clay	1983
12–15	12.7	64.4	22.9	Muddy clay	1977
15–18	10.9	66.0	22.1		1965
18–21	12.2	67.2	20.6		1961
21–24	9.0	71.2	19.8		1952
24–27	8.2	70.9	20.9		1944
27–30	9.1	68.8	22.1		1937
30–33	9.5	64.6	25.9		1929
33–36	9.7	60.5	29.8		1923
36–39	9.2	58.2	32.6		1917
39–42	9.7	57.9	32.4		1912
42–45	9.6	58.0	32.4		1966
45–48	10.0	57.6	32.4		1901
48–51	9.4	58.7	31.9		1895
51–54	9.1	58.6	32.3		1889
54–57	9.7	58.4	31.9		1884
57–60	10.4	58.2	31.4		1878
60–63	8.8	59.7	31.5		1873
63–66	9.4	59.5	31.1		1864
66–69	9.7	59.2	31.1		1859

Table 2. **Characterization of sediments and radioisotope geochronology for cores taken from Lake Mažasis Beržinis in 2003**
2 lentelė. **2003 m. Mažojo Beržinio ežere paimtos kolonėlės nuosėdų apibūdinimas ir chronologija**

Sampled interval depth, cm	Components of sedimentary matrix, %			Sediment description	Calendar years based on ^{210}Pb and ^{137}Cs geochronology
	$CaCO_3$	Clastic	Biogenic		
0–3	30.7	32.8	36.5	Calcareous clayey mud	1995
3–6	24.7	35.7	39.6		1988
6–9	24.1	37.1	38.8		1979
9–12	26.0	35.7	38.3		1971
12–15	24.2	37.0	38.8		1963
15–18	27.7	34.4	37.9		1954
18–21	15.4	39.3	45.3		1944
21–24	16.4	37.6	46.0		1932
24–27	8.9	41.3	49.8	Clayey mud	
1919					
27–30	9.8	40.0	50.2	Sapropel	
1907					
30–33	19.7	31.4	48.9	Calcareous clayey mud	1896
33–36	8.1	37.8	54.1	Sapropel	1884
36–39	8.3	37.6	54.1		1871
39–42	19.2	32.2	48.6	Calcareous clayey mud	1857
42–45	18.6	33.4	48.0		1842
45–48	20.3	29.5	50.2	Sapropel	1828
48–51	20.7	25.2	54.1		1812
51–54	27.7	22.6	49.7	Clayey calcareous mud	1792
54–57	31.2	20.5	48.3		1775
57–60	28.7	20.7	50.6	Sapropel	1757
60–63	28.4	21.5	50.2		1740
63–66	32.6	22.5	44.9	Clayey calcareous mud	1725
66–69	44.3	26.5	29.2	Carbonate sediments	n/c
69–72	54.5	28.2	17.3		n/c
72–75	56.3	28.7	15.1		n/c
75–78	52.7	24.8	22.5		n/c

n/c – not calculated.

Table 3. **Characterization of sediments and radioisotope geochronology for cores taken from Lake Šventas in 2003**
3 lentelė. **2003 m. Švento ežere paimtos kolonėlės nuosėdų apibūdinimas ir chronologija**

Sampled interval depth, cm	Components of sedimentary matrix, %			Sediment description	Calendar years based on ^{210}Pb and ^{137}Cs geochronology
	$CaCO_3$	Clastic	Biogenic		
0–3	2.3	47.8	49.9	Clayey sapropel	1998
3–6	2.8	49.2	48.0		1992
6–9	2.6	48.9	48.5		1985
9–12	3.0	48.6	48.4		1976
12–15	1.1	56.0	42.9	Muddy clay	1964
15–18	2.0	56.9	41.1		1950
18–21	1.5	60.8	37.7		1939
21–24	1.7	63.3	35.0		1930
24–27	2.6	54.6	42.8		1923
27–30	3.3	42.8	53.9	Sapropel	1916
30–33	2.8	44.6	52.6		1909
33–36	3.8	37.2	59.0		1901
36–39	2.2	38.4	59.4		1893
39–42	1.8	26.6	71.6		1886

Table 3 (continued)
3 lentelės tęsinys

Sampled interval depth, cm	Components of sedimentary matrix, %			Sediment description	Calendar years based on ^{210}Pb and ^{137}Cs geochronology
	$CaCO_3$	Clastic	Biogenic		
42–45	1.6	30.6	67.8		1879
45–48	2.2	31.8	66.0		1872
48–51	0.7	32.7	66.6		1864
51–54	0.2	28.6	71.2		n/c
54–57	0.2	32.5	67.3		n/c
57–60	2.0	27.2	70.8		n/c
60–63	2.0	28.3	69.7		n/c
63–66	1.9	26.5	71.6		n/c
66–69	1.1	29.7	69.2		n/c
69–72	0.9	35.1	64.0		n/c

n/c – not calculated.

Table 4. **Characterization of sediments and radioisotope geochronology for cores taken from Lake Duobulis in 2003**
4 lentelė. **2003 m. Duobulio ežere paimtos kolonėlės nuosėdų apibūdinimas ir chronologija**

Sampled interval depth, cm	Components of sedimentary matrix, %			Sediment description	Calendar years based on ^{210}Pb and ^{137}Cs geochronology
	$CaCO_3$	Clastic	Biogenic		
0–3	26.6	39.2	34.2	Calcareous muddy clay	1994
3–6	32.2	35.0	32.8		1981
6–9	23.5	41.9	34.6		1974
9–12	29.8	42.4	27.8	Muddy calcareous clay	1968
12–15	18.4	49.0	32.6	Calcareous muddy clay	1956
15–18	29.1	34.7	36.2	Calcareous clayey mud	1944
18–21	27.1	38.4	34.5	Calcareous muddy clay	1930
21–24	15.1	43.9	41.0		1909
24–27	9.4	44.9	45.7	Clayey mud	1890
27–30	16.8	42.7	40.5	Calcareous muddy clay	1866
30–33	14.5	52.7	32.8		1837
33–36	23.1	49.2	27.7		1807
36–39	19.1	51.1	29.8		1775
39–42	18.4	54.5	27.1		1746
42–45	17.7	53.7	28.6		1713
45–48	32.6	45.0	22.4	Muddy calcareous clay	1681
48–51	29.6	44.6	25.8		1649
51–54	21.9	50.0	28.1	Calcareous muddy clay	1612

with the major hydrological events and hydrographic changes in the catchments, were determined.

The divergence of results obtained by different methods may be related with the diffusion of radioisotopes downward, their re-mobilization upward in the core and even to the water column and even measurement errors for ^{210}Pb.

ACKNOWLEDGEMENTS

The Lithuanian State Science and Studies Foundation funded this study within the frame of the program "Research and development in the field of radwaste generation, migration and impact on the environment and human health – RASSA" (contract No. C-19/2003). The authors are grateful to N. Skuodienė and G. Davainis for assistance in the laboratory. Special thanks go to reviewers Dr. N. Špirkauskaitė (Institute of Physics, Vilnius), Dr. N. Mikhailov (Institute of Geochemistry and Geophysics of the NAS of Belarus, Minsk) and Prof. R. Mokrik (Vilnius University) whose comments resulted in a significantly improved manuscript.

References

Appleby P. G., Oldfield F. 1983. The assessment of ^{210}Pb data from sites with varying sediment accumulation rates. *Hydrobiologia*. ***103***. 29–35.

Athy L. F. 1930. Density, porosity and compaction of sedimentary rocks. *Bulletin of American Association of Petroleum Geologists*. ***14***. 1–24.

Bengtsson L., Enell M. 1986. Chemical analysis. B. E. Berglund (Ed.). *Handbook of Holocene Paleoecology and Paleohydrology*. Chichester: J. Wiley. 568.

Christensen E. R. 1982. A model for radionuclides in sediments influenced by mixing and compaction. *J. Geophys. Res.* ***87***. 566–572.

Dean W. E. 1981. Carbonate minerals and organic matter in sediments of modern north temperate hard water lakes. *Society of Economic Paleontologists and Mineralogists*. Special Publication. ***31***. 213–231.

Frissel M. J., Pennders R. 1983. Models for the accumulation and migration of ^{90}Sr, ^{137}Cs, $^{239-240}$Pu and ^{241}Am in the upper layer of soils. P. J. Coughtrey, J. N. B. Bell and T. M. Roberts (eds.) *Ecological Aspects of Radionuclide Release.* Blackwell, Oxford. 63-72.

Gierlowski-Kordesch E. H., Kelts K. (Eds). 2000. Lake basins through space and time. *AAPG Studies in Geology.* ***46***. American Association of Petroleum Geologists, Tulsa, OK. 648.

Goldberg E. D. 1963. Radioactive dating. International Atomic Energy Agency. Vienna. STI/PUB/68. 121–131.

Gudelis A., Remeikis V., Plukis A., Lukauskas D. 2000. Efficiency calibration of HPGe detectors for measuring environmental samples. *Environmental and Chemical Physics*. Vilnius. ***22(3-4)***. 117–125 p.

Kelts K. 1988. Environments of deposition of lacustrine petroleum source rocks: an introduction. A. Fleet, K. Kelts and M.R. Talbot (eds.) *Lacustrine Petroleum Source Rocks*. *Geological Society Special Publication.* ***40.*** 3–26.

Kilkus K., Pumputytė N. 2001. Ledo luisto guolio ežerų ontogenezės hidrologinė interpretacija. *Geografijos metraštis*. ***34(2)***. 15–23.

Koide M., Soutar A. and Goldberg E. D. 1972. Marine geochronology with ^{210}Pb. *Earth Planet. Sci. Lett.* ***14***. 442–446.

Krishnaswami S., Lal D., Martin J. M. and Meybeck M. 1971. Geochronology of lake sediments. *Earth Planet. Sci. Lett.* ***11***. 407–414.

Matsumoto E. 1975. ^{210}Pb geochronology of sediments from Lake Shinji. *Geochem. J.* ***9***. 167–172.

Matsumoto E. 1987. Pb-210 geochronology of sediments. *Studies of the San'in Region (Natural Environment)*. ***3***. 187–194.

Mažeika J., Dušauskienė-Duž R. and Radzevičius R. 2004. Sedimentation in the eastern Baltic Sea: lead-210 dating and trace element data implication. *Baltica*. ***17(2)***. 79-92.

Mažeika J., Taminskas J. 2005. Evaluation of recent sedimentation rates in the Lake Drūkšiai, northeastern Lithuania. *Limnological Review*. ***5***. 167–173.

Mazzulo J. M., Meyer A. and Kidd R. B. 1988. New sediment classification scheme for the Ocean Drilling Program. J. Mazzullo, A. G. Graham (eds) *Handbook for Shipboard Sedimentologists*. ODP Tech. ***8***. 45–67.

Oguri K., Matsumoto E. Yamada M., Saito Y. and Iseki K. 2003. Sediment accumulation rates and budgets of depositing particles of the East China Sea. *Deep-Sea Res. II*. ***50***. 513–528.

Robbins J. A. 1978. Geochemical and geophysical applications of radioactive lead. J. O. Nriagu (eds.) *Biogeochemistry of lead in the environment*. *Elsevier Scientific.* Amsterdam. 285–393.

Schnurrenberger D., Russell J. and Kelts K. 2003. Classification of lacustrine sediments based on sedimentary components. *Journal of Paleolimnology*. ***29***. 141–154.

Stoermer E. F., Smol J. P. 1999. The Diatoms: Applications for the Environmental and Earth Sciences. Cambridge University Press. Cambridge. 469.

Talbot M. R. 2001. Nitrogen isotopes in palaeolimnology. W. M. Last and J. P. Smol (eds.) *Tracking Environmental Change using Lake Sediments. Physical and Geochemical Methods*. ***2***. Kluwer Academic Publishers, Boston. 401–439.

Talbot M.R., Livingstone D. A., Palmer P. G., Maley J., Melack J. M., Delibrias G. et al. 1984. Preliminary results from sediment from Lake Bosumtwi, Ghana. *Palaeoecology of Africa and the Surrounding Islands*. ***16***. 173–192.

Tarasiuk N., Špirkauskaitė N., Druteikienė B. 2003. Modern concept of the migration and accumulation processes of technogenic radionuclides in water systems. *Environmental and Chemical Physics*. ***25(4)***. 202–210.

Tamošaitis J. 1974. Kodėl senka Švento ežeras? *Geografijos metraštis*. ***13***. 85–95.

Гарункштис А. А. 1975. Седментационные процессы в озерах Литвы. Вильнюс: Мокслас. 297 с.

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

Jonas Mažeika, Arūnas Gudelis

RYTŲ LIETUVOS EŽERŲ DUGNO NUOSĖDŲ MEDŽIAGINĖS IR RADIOIZOTOPINĖS SUDĖTIES YPATUMAI

S a n t r a u k a

Radioizotopų metodais tirti sedimentacijos procesai kai kuriuose Rytų Lietuvos ežeruose (Drūkšių, Mažajo Beržino, Švento, Duobulio). Nesuardytos struktūros dugno nuosėdų kolonėlių iki 80 cm ilgio paėmimui nuo ledo buvo panaudotas Niemistö gravitacinis vamzdis su pakeliamuoju mechanizmu. Lauko sąlygomis dugno nuosėdų kolonėlės buvo padalintos į 1 arba 3 cm aukščio mėginius. Paruošus ir ištyrus mėginius laboratorijoje buvo nustatyti šie rodikliai: ^{210}Pb ir ^{137}Cs specifinis aktyvumas dugno nuosėdose, nuosėdų drėgnis ir tankis sausam tūriui bei medžiaginė sudėtis. Remiantis eksperimentinių matavimų duomenimis, buvo suskaičiuoti šie parametrai: vidutinis nuosėdų sausosios masės kaupimosi greitis (g/cm^2/metai), linijinis gamtinio būvio nuosėdų kaupimosi greitis (cm/metai), medžiaginės sudėties komponentų procentinis pasiskirstymas. Pagal minėtus sedimentacijos parametrus atliktas nuosėdų geochronologinis apibūdinimas kalendoriniais metais panaudojant ^{210}Pb pastovaus srauto ir pastovios sedimentacijos modelį, suderintą su pagrindinėmis ^{137}Cs

pasiskirstymo smailėmis. Gautos šios tirtų ežerų dugno nuosėdų kolonėlių vidutinio nuosėdų sausosios masės kaupimosi greičio ir linijinio gamtinio būvio nuosėdų kaupimosi greičio vertės: Drūkšių ežere – 0,06 g/cm^2/metai ir 0,3–0.9 cm/metai; Mažojo Beržinio ežere – 0,024 g/cm^2/metai ir 0,1–0,6 cm/metai; Šventо ežere – 0,017 g/cm^2/metai ir 0,3–1.0 cm/metai; Duobulio ežere – 0,012 g/cm^2/metai ir 0,1–0,4 cm/metai. Remiantis radioizotopų geochronologija, nustatyti nuosėdų šaltinių ir sedimentacijos tipų pasikeitimo laikotarpiai, susiję su ekologiniu požiūriu svarbesniais hidrologiniais įvykiais bei hidrografiniais pokyčiais vandens surinkimo baseinuose.

Йонас Мажейка, Арунас Гудялис

ОСОБЕННОСТИ ВЕЩЕСТВЕННОГО И РАДИОИЗОТОПНОГО СОСТАВА ДОННЫХ ОТЛОЖЕНИЙ ОЗЕР ВОСТОЧНОЙ ЛИТВЫ

Резюме

В некоторых озерах Восточной Литвы (Друкшяй, Мажасис Бяржинис, Швянтас, Дуобулис) радиоизотопными методами исследовались процессы современной седиментации. Для отбора колонок донных осадков естественной структуры длиною до 80 см использована гравитационная трубка Немисто с подъемным механизмом. В полевых условиях колонки донных осадков были разделены на интервалы толщиной 1 и 3 см. Подготовленные пробы исследовались в лаборатории: определялись вещественный состав, физические параметры и удельная активность ^{210}Pb и ^{137}C. На основе экспериментальных результатов дана геохронологическая характеристика донных осадков с использованием модели постоянного потока ^{210}Pb и постоянной седиментации, согласованной с основными пиками распределения ^{137}Cs. Получены значения средней скорости накопления сухой массы осадков и линейной скорости накопления осадков естественного состояния: для оз. Друкшяй – 0,06 г/см^2/год и 0,3–0,9 см/год; для оз. Мажасис Бяржинис – 0,024 г/см^2/год и 0,1–0,6 см/год; для оз. Швянтас – 0,017 г/см^2/год и 0,3–1,0 см/год; для оз. Дуобулис – 0,012 г/см^2/год и 0,1–0,4 см/год. По данным радиоизотопной геохронологии определены интервалы времени изменения источников и типов седиментации, связанные с главными климатическими и гидрологическими изменениями.