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Development of Lake Rėkyva and its environment in Late Pleistocene and Holocene

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Results regarding the development of Lake Rėkyva (Lithuania) are presented. Radiocarbon dating, pollen and diatom analysis enabled to reveal Late Pleistocene and Holocene conditions in the lake and its environs. Lake Rėkyva sediments were drilled from the ice surface. Organogenic sediments occur in a 2-m thick layer. The radiocarbon age of sediments determined in four intervals (182–183, 181–182, 128–130, and 78–80 cm) was found to correspond to the Alleröd, Late Dryas, Atlantic and the beginning of the Subboreal. Pollen analysis confirmed that sedimentation was going on constantly during the whole Late Pleistocene Holocene. Diatom investigations indicated that water level in the lake was low all that time, with just small fluctuations. Lake Rėkyva was formed when melt water filled a shallow depression, where bogging began in the Alleröd with the climate getting warmer. Western currents and winds drove peat moss remains around the lake and settled them on the bottom.

Key words: Lake Rėkyva, organogenic sediments, radiocarbon dating, pollen analysis, diatom investigations, Late Pleistocene, Holocene

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INTRODUCTION

Lake Rėkyva, the tenth by area in Lithuania, lying at the southern outskirts of Šiauliai City, with the surrounding peat bogs belongs to the second region of Lithuanian wetlands (after the Nemunas delta). This is a shallow remnant lake formed when the glacier melt-water filled a meridional inter-ridge depression.

The general features of palaeogeographical development of Lithuania's surface at the end of the Pleistocene and Holocene were described by A. Basalykas (1958, 1965), A. Seibutis and F. Sudnikavičienė (1960), M. Kabailienė (1990, 1993, 1998, 2006), R. Kunskas (1985–1986, 1988, 2005), M. Stančikaitė (2004) and others.

Detailed investigations of Lake Rėkyva are scarce. First investigations of near-lake peat bogs were carried out in 1955–1962 while compiling the inventory of bogs. Peat deposit was investigated at that time, and near-lake bog plans were drawn. The development of the Rėkyva lake–bog complex was later studied by T. Bumblauskis (1979). The lake and bog development history was described by J. Tamošaitis and M. Grigelytė who had analysed peat composition and defined the morphometric parameters of the lake (Tamošaitis, Grigelytė, 1979). Using pollen data, B. Vaičvilienė (1979) described the Holocene stratigraphy and palaeogeography of three bogs – Šiluvos Tyrelis, Didysis Tyrulis, and Kievis – in the nearby region on the East Žemaičiai plateau.

Data on the comprehensive geological mapping of Lithuania done by the Lithuanian Geological Survey at a scale 1 : 50 000 (LGT, 1997) and material collected by AB Šiaulių Hidroprojektas have been used in the paper (Inžinerinių-geologinių tyrinėjimų..., 1982).

The goal of the paper was to restore the development of Lake Rėkyva by means of the latest data. Lake Rėkyva lies in the Kuršas–Žemaičiai region, East Žemaičiai plateau, the northern part of the Tytuvėnai–Šiaulėnai micro-region (Basalykas, 1965). On the eastern coast of Lake Rėkyva, there is a 1-km wide till ridge eroded by glacier melt-water on its both sides. The lake basin slope height is 6–8 m. The northern, southern and western slopes are flat, smoothed down by ice-margin waters.

Rėkyva is a bogging lake. Its shape is nearly a circle; the major part of its shores, except eastern ones, is composed of peat. The peaty shores are eroded; waves and currents spread the eroded matter around the lake and settle it on the bottom. According to the measurement post data, the long-year mean water level is at 130.6 m a. s. l. The thickest sediment layer is about 4 m, the average being 3 m. According to the geological research reports, sapropel or clayey sapropel occur in the sediments of the lake (Inžinerinių-geologinių..., 1982).

METHODS

Investigations of the lake sediment section

In order to detail the section of Lake Rėkyva sediments, a borehole was drilled with a manual Hiller corer. The drilling site was chosen in the south-eastern part of the lake about 250 m from its eastern shore formed of till loam and sandy loam rather resistant against erosion. The borehole co-ordinates in the LKS-94 (Lithuanian Co-ordinate System) are 6190770N and 4572110E (Fig. 1).

The borehole was drilled in winter from ice surface. The total length of the core obtained was 2.0 m and the depth of the sediment top was 2.63 m under the water level in the lake. The macroscopic study did not enable to single out separate layers. The section showed only a variation of peat colour and an increase in fine sand particles in the lower part of the core; the contact zone between organic and mineral sediments, however, was sharp (Table 1).

Table.1. **Lake Rėkyva sediments**
1 lentelė. **Pragręžtų nuogulų pjūvis**

Range, cm	Sediments
0–5	Bottom silt, dark grey
5–110	Peat, dove-colour, with macro-remains of plants
110–115	Peat, light brown, with macro-remains of plants
115–181	Peat, dark brown, well-rundown with rare macro-remains of plants
181–187	Peat light dove-colour, sandy with macro-remains of plants
187–200	Sand, light grey, fine-grained with rare macro-remains or plants

To study the development of Lake Rėkyva and its bogged area, several methods were applied, as well as data of investigations done earlier were used.

The peat core was divided into 1–2-cm thick portions, and samples were taken for radiocarbon dating as well as pollen and diatom analyses. Such division of the core enables to reach a good correlation of palaeobotanical and diatom data to the absolute age data.

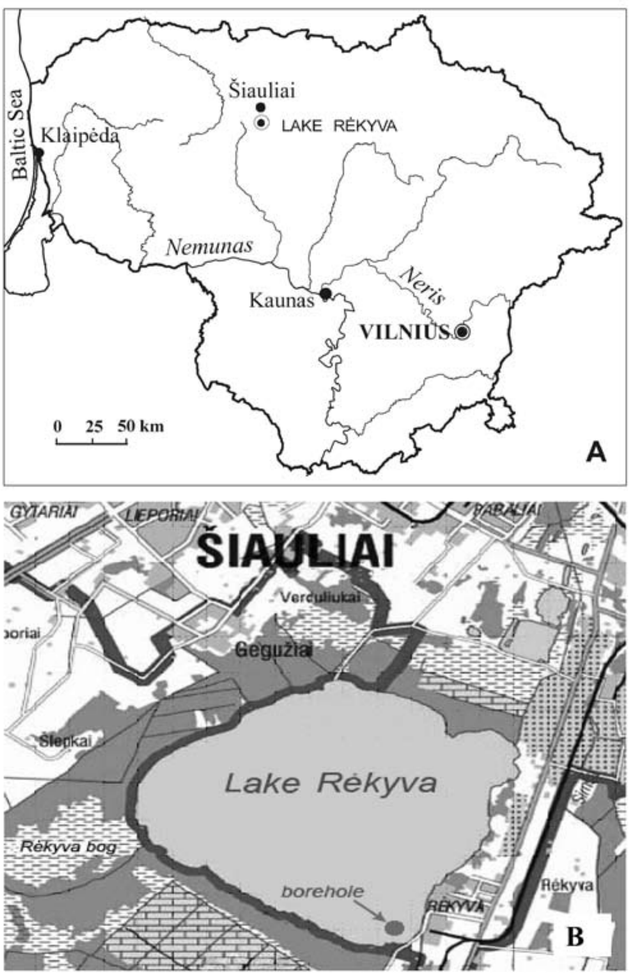

Fig. 1. Location of borehole: *A* – in Lithuania, *B* – in local site
1 pav. Gręžinio vieta: *A* – Lietuvoje, *B* – Rėkyvos ežere

Radiocarbon dating. Absolute age was determined at the Radiocarbon Laboratory of Belarus National Academy of Sciences (head N. Michailov) in four borehole core intervals: 181–182, 182–183, 128–130, and 78–80 cm.

Pollen analysis. The core was divided into 112 samples for pollen analysis which was performed for 25 samples prepared at the laboratory of the Geology and Geography Institute applying the methods proposed by V. Grichuk and G. Erdtman. Pollen were investigated with a Nikon ECLIPSE 50i light microscope (400×). Pollen and diatom analysis data were treated with TILIA (version 2) and TILIA–GRAPH (version 2.0 b.5) (Grimm, 1990, 1992) software. Pollen analysis at Vilnius University Faculty of Natural Sciences (M. Sc. M. Kazlauskas) was consulted by Dr. M. Stančikaitė, head of the Geology and Geography Institute Quaternary Department, and Assist. Prof. Dr. L. Kalnina, Latvian University.

Diatom analysis. For diatom analysis 25 samples were taken. The diatom frustules were prepared by standard method (Battarbee, 1986). Permanent slides were prepared, and diatoms were mounted with "Naphrax". At least 500 diatom valves per slide were identified and counted along horizontal transects using biological microscope "Leica" at × 1000 magnification. Algae were identified to species level using the taxonomic works by Krammer and Lange-Bertalot (1986–1991). Diatoms were divided into groups according to their ecological requirements (Van Dam et al., 1994). The analyses were performed by Dr. G. Vaikutienė at the Vilnius University Faculty of Natural Sciences

RESULTS

The dated sediments correspond to Alleröd, Late Dryas, Atlantic and the beginning of the Sub-Boreal (Table 2).

Pollen analysis data were used to compile a pollen diagram in which 14 local pollen zones (LPZs) were distinguished according to the pollen zones adapted by M. Kabailienė for the area of Lithuania (Kabailienė, 1998) (Fig. 2). Plant names were specified and their systematics was determined according to Z. Gudžinskas' Plant Systematics (Gudžinskas, 1999).

LPZ-1 *Pinus–Betula–Artemisia* (200–191 cm). The count of pollen at the beginning of the interval is very low, just 8000

Table 2. **Results of radiocarbon dating organogenic sediments of Lake Rėkyva**
2 lentelė. **Rėkyvos ežero dugno organogeninių nuogulų radiokarboninio datavimo rezultatai**

Name or sample	Number of sample	Substance	Depth, cm	Number of laboratory	^{14}C date, th. year BP	BC = Calibrated calendared age, Year before Christ	
						1δ (68.3%)	2δ (95.4%)
					^{14}C year	Calibrated age varies from BC	
Rėkyva	71	Peat	78–80	IGSB–1097	4950 ± 110	3940–3870 cal BC 3810–3640 cal BC	3970–3510 cal BC 3400–3390 cal BC
Rėkyva	46	Peat	128–130	IGSB–1098	6470 ± 130	4600–5555 cal BC 5520–5510 cal BC 5505–5270 cal BC	5595–5210 cal BC 5170–5140 cal BC 5110–5080 cal BC
Rėkyva	19	Peat	181–182	IGSB–1099	10850 ± 145	11975–10675 cal BC	11000–10525 cal BC
Rėkyva	18	Peat	182–183	IGSB–1100	11700 ± 150	11975–11400 cal BC	12275–11150 cal BC

per cm^3, with tree pollen prevailing: pine (*Pinus* L.) 52% and birch (*Betula* L.) 23%. Rather high is content of herb pollen (22%).

LPZ-2 *Betula–Pinus* (191–186 cm). Pollen quantity is nearly stable in the whole interval and is similar to that of LPZ-1 with tree pollen prevailing (birch 32% and pine 30%).

LPZ-3 *Betula–Pinus–Alnus* (186–182 cm). Pollen content is significantly higher than in the underlying sediments. Tree pollen makes the major part, the content of herb pollen remains unchanged, while that of shrubs increases. Birch (26%) and pine (22%) pollen prevail with admixture of alder (*Alnus* Mill.) – (18%) and hazel (*Corylus* L.) – (17%).

LPZ-4 *Alnus–Corylus–Betula* (182–174 cm). The part of herb and shrub pollen increases slightly, while that of trees decreases but remains prevailing and makes 66%, including alder (25%), hazel (21%) and birch (19%). *Poaceae* (R. Br.) Bernhart dominate among the herbaceous plants.

LPZ-5 *Alnus–Corylus* (174–170 cm). The average content of pollen is lower than in the above-mentioned two pollen zones. Trees (78%) prevail, shrub pollen increases, while herb pollen decreases to 7%. Pollen of alder (30%), hazel (23%) and birch (13%) make the most part. Pollen of pine, oak (*Quercus* L.), hornbeam (*Carpinus* L.) and ash (*Fraxinus* L.) is sparse in this sediment interval. *Carex* and *Artemisia* pollen was mainly detected among the herbs.

LPZ-6 *Alnus–Corylus–Betula–Ulmus* (170–154 cm). Pollen content in the sediments is nearly unchanged: trees and shrubs make, correspondingly, 67% and 24%, while herb microspores make up 7%. The pollen spectrum shows alder (28%), hazel (23%), birch (15%) and elm (*Ulmus* L.) (12%). This interval contains also pollen of willow (*Salix* L.), spruce (*Picea* A. Dietr.), hornbeam, plum-tree (*Prunus* L.), *Poaceae*, *Carex*, *Artemisia*, *Ranunculus* L., *Taraxacum* F. H. Wigg.) *Potamogeton* L., *Urticaceae* Juss., *Filipendula* Mill., as well as spores of *Equisetum* L. and *Polypodium* L.

LPZ-7 *Corylus–Alnus–Ulmus* (154–133 cm). Pollen content increases, with ligneous plants as the main part of the spectrum and a low content of herbs (7%). Hazel microspores were found to make 28%, followed by pollen of alder (25%), elm (13%), and birch (11%).

LPZ-8 *Alnus–Corylus–Pinus* (133–91 cm). Pollen content slightly decreases, with tree pollen prevailing (68%) and herbs making 19%. The major part of the ligneous plant spectrum is formed by alder (21%), hazel (20%), and pine (14%). The pine pollen increase in the zone was observed to be very sharp.

LPZ-9 *Alnus* (91–72 cm). Tree and herb pollen make, respectively, 70% and 18% of the spectrum. The content of non-ligneous plant pollen within the zone decreases. Alder (21%), pine (13%), hazel (11%), and birch (11%) prevail.

LPZ-10 *Pinus–Picea* (72–56 cm). The content of herb pollen increases to 20%, but tree pollen dominates (72%), pine pollen making up nearly a third of the spectrum. The first peak of spruce reaching 20% of the total tree pollen sum is observed.

LPZ-11 *Alnus–Pinus* (56–48 cm). This zone differs from adjacent ones by an increase in pollen content, tree pollen making the major part of the spectrum. Peaks of alder and elm are observed. Spruce pollen decreases, while hazel pollen increases. The zone is specific by a sharp decrease of *Carex* pollen and *Equisetum* spores as well as a unique content of *Polypodium* spores. For the first time, pollen of *Epilobium* L. and *Rumex acetosella* L. was detected.

LPZ-12 *Pinus–Alnus* (48–35 cm). Pollen content decreases in this zone. A certain increase in the pollen of birch, pine, hazel, hornbeam, viburnum, oak and lime (*Tilia* L.) was found. Spruce pollen curve reaches the lowest level.

LPZ-13 *Pinus–Picea–Betula* (35–18 cm). Pollen content is low. The ratio of tree, shrub and dwarf shrub pollen remains similar to that of the above-described zone. Pine pollen content is rather high – on average 18%. The content of birch, spruce and hazel pollen reaches their peaks, respectively 13%, 16%, 12% of the total tree pollen spectrum. The zone correlates to the second spruce peak in the mid-Subatlantic.

LPZ-14 *Pinus* (18–0 cm) zone is notable for an increase in pollen content. There is a decrease in shrub pollen, an increase in tree pollen and a stable level of herb pollen. Pine microspores prevail in the spectrum, reaching 43% in the total tree pollen spectrum at a depth of 12 cm. The major part of herb pollen consists of Carex and Poaceae. The pollen of *Ericaceae* Juss., *Rumex* L., *Secale* L. and *Artemisia* is rather abundant.

Diatom analysis data were used to study the section of Lake Rėkyva peat sediments settled in the nearshore zone of the lake. The peat layer overlying the sand indicates slight water level fluctuations during the whole Late Glacial and Holocene.

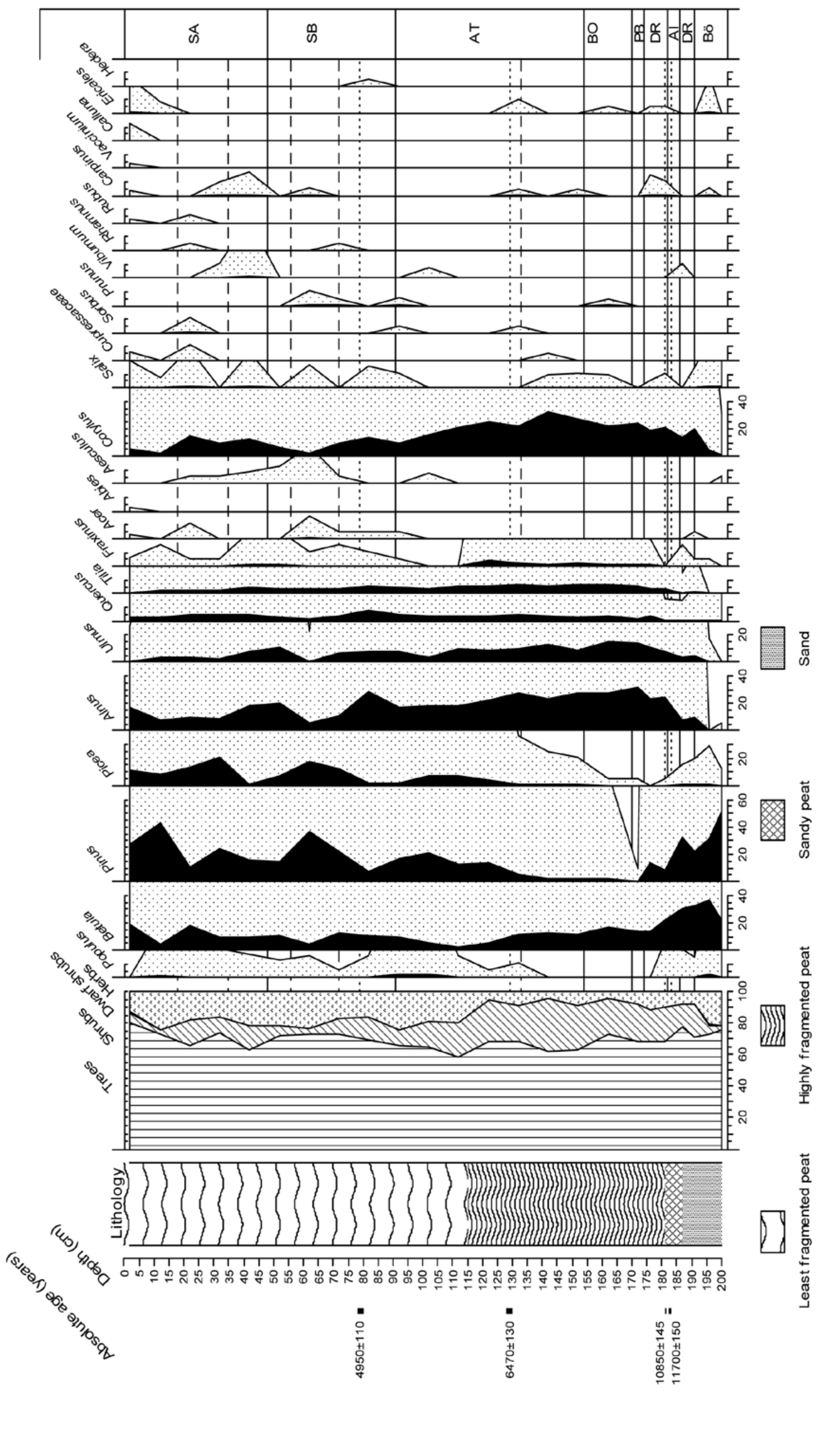

Fig. 2. Pollen diagram of Lake Rėkyva bottom sediments. Anlysed by M. Kazlauskas, 2005
2 pav. Rėkyvos ežero dugno nuosėdų sporų-žiedadulkių diagrama. Sudarė M. Kazlauskas, 2005

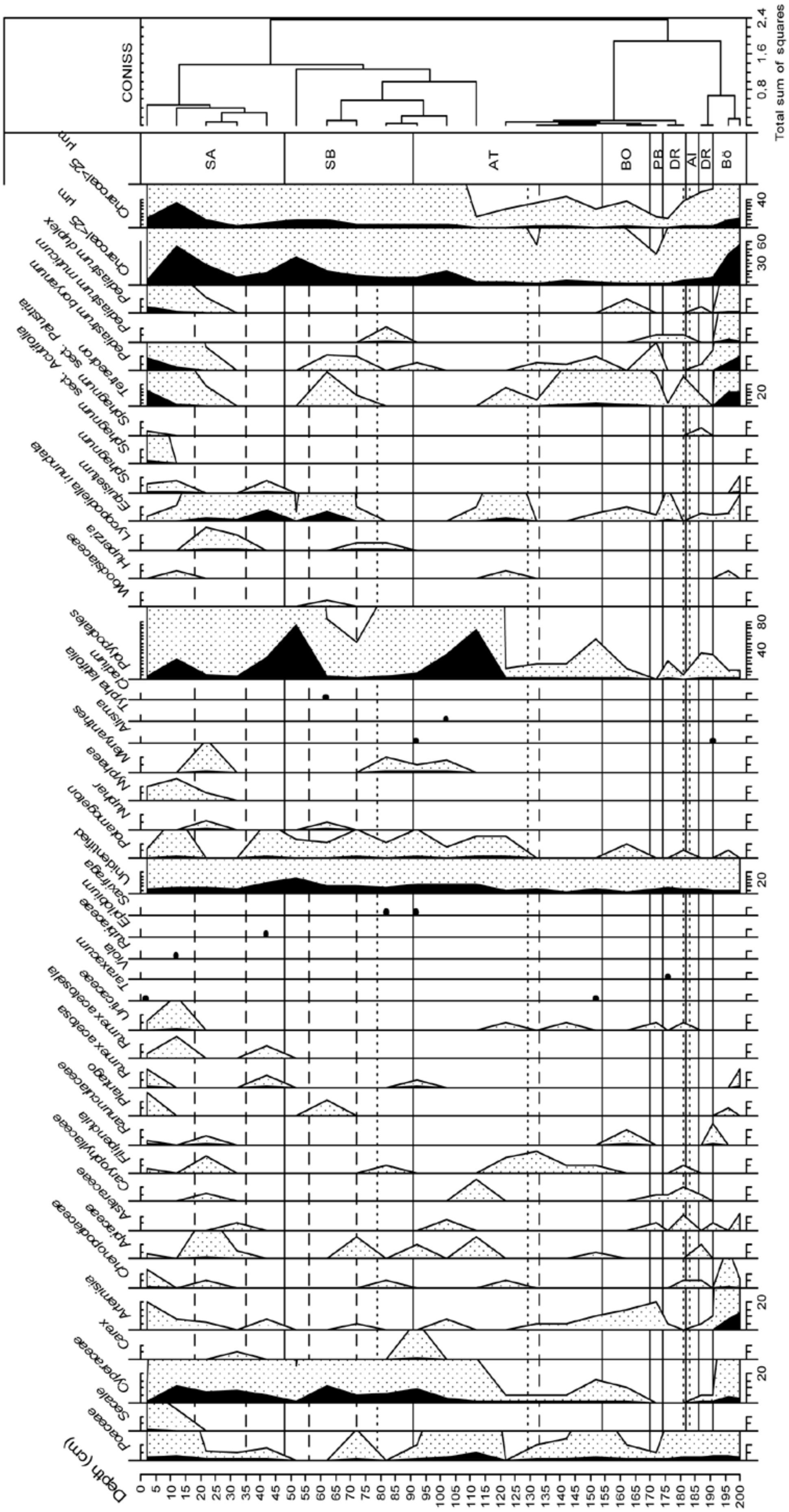

Fig. 2. (continued)
2 pav. (tęsinys)

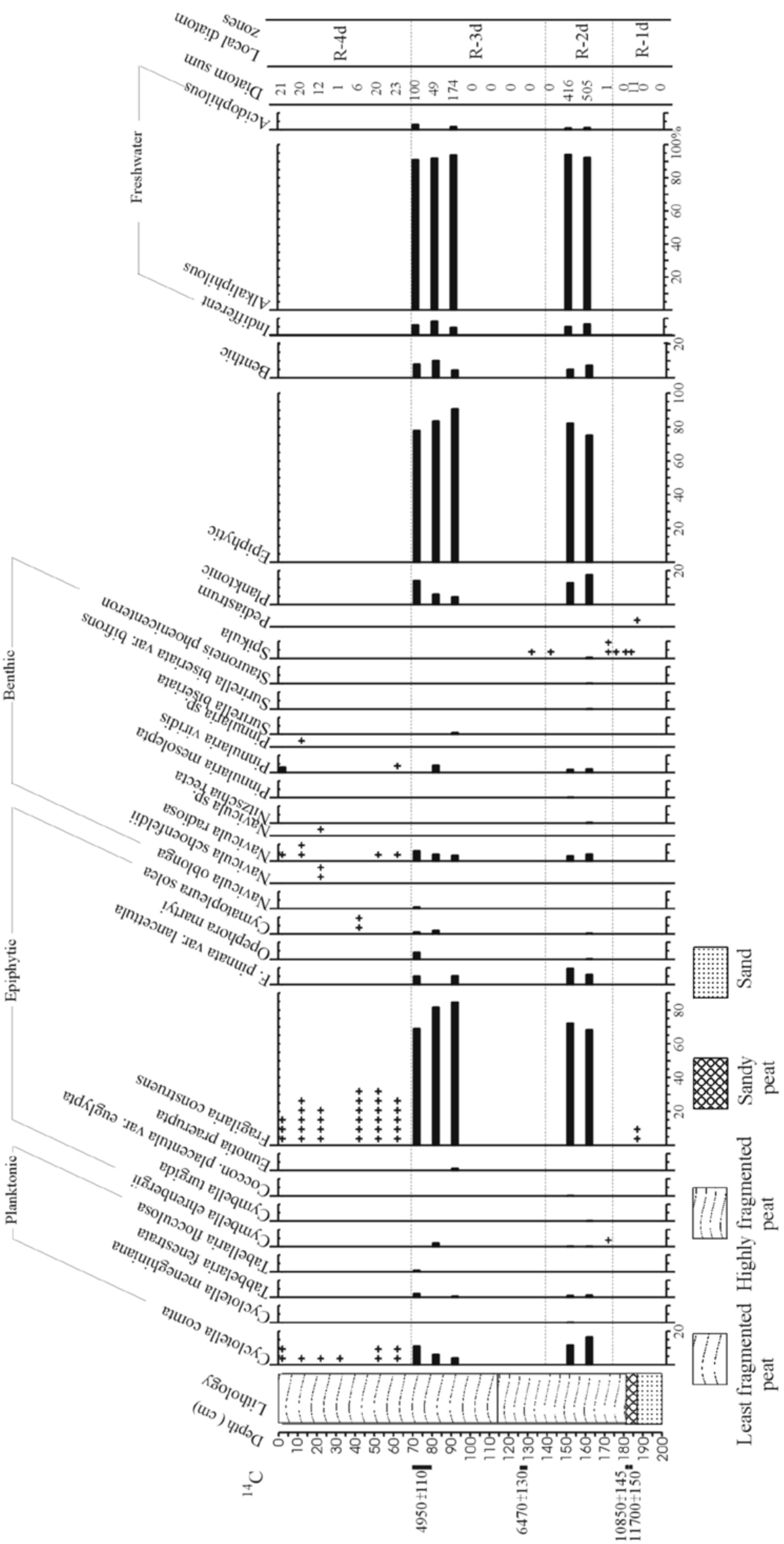

Fig. 3. Diatom diagram of Lake Rėkyva bottom sediments. Analysed by G. Vaikutienė, 2005
3 pav. Rėkyvos ežero dugno nuosėdų diatomėjų diagrama. Sudarė G. Vaikutienė, 2005

The abundance of diatoms and species variety were not high, and there were no sharp changes in sediment type and diatom assemblages.

Sand occurring in the lower part of the sediment section was found to contain no diatoms. Peat overlying the sand contained diatoms of four local diatom zones (LDZ) distinguished according to their species composition (Fig. 3).

R–1d. The 175–187 cm depth interval of sandy peat and peat contained single freshwater epiphytic diatoms *Fragilaria construens* (Ehrenberg) Grunow which are typical of eutrophic stagnant waters and live attached mainly to water plants. Sponge spicules were also detected.

R–2. The 140–175 cm interval of peat was found to be rich in diatoms with the alkaliphilous freshwater epiphytic species of *Fragilaria construens* prevailing (to 75%). This interval contained also some other epiphytic diatoms typical of slow-running or stagnant lake nearshores, e. g., *Fragilaria pinnata* var. *lancettula* Ehr., freshwater benthic species *Pinnularia viridis* (Nitzsch.) Ehrenberg, and *Navicula radiosa* Kützing. The interval of 160–165 cm shows an increase in alkaliphilous planktonic diatoms *Cyclotella comta* (Ehrenberg) Kützing (up to 17%) living in deeper parts of lakes.

R–3d. The 70–140 cm interval can be divided into two parts. The lower part, at a depth of 95–140 cm, contained no diatoms; only single sponge spicules were detected.

R–3d. The 70–95 cm interval is rich in diatoms with epiphytic species prevailing and *Fragilaria construens* most abundant. The benthic diatoms *Pinnularia viridis*, *Navicula radiosa* and rather numerous planktonic diatoms *Cyclotella comta* were also detected. Acidophilous diatoms *Tabellaria fenestrata* (Lyngbyae) Kützing and *T. flocculosa* (Roth) Kützing, living both in littoral and pelagic areas of lakes but typical of stagnant and peat-forming lakes, are also present. These diatoms indicate a rise in the water acidity and an intensification of peat formation in the lake.

R–4d. The upper interval (0–70 cm) of the section contains small number diatoms. They are freshwater *Fragilaria construens, Navicula radiosa*, typical of shallow lake nearshore overgrown with vegetation, prevailing most often in the whole section with single specimens of planktonic *Cyclotella comta*.

INTERPRETATION OF LAKE RĖKYVA DEVELOPMENT AND PALAEOGEOGRAPHIC CONDITIONS IN ITS ENVIRONS

The results of the investigations enabled to reconstruct the most typical stages of Lake Rėkyva development and the natural environment in the region.

The basin of Lake Rėkyva was formed by two melting glacier bodies: a tongue in the upper reaches of the Šušvė River and the Nevėžis glacial lobe (Basalykas, 1965). Melt-water, dammed at the glacier margin, filled the depression hollow and settled fine-grained, aleurite / clay deposits. This palaeo-lake was twice as large as the present-day lake and covered the area of 2400 ha (Tamošaitis, Grigelytė, 1979).

The sediments of the Oldest Dryas, Bölling and Old Dryas periods are difficult to identify in the section studied. Sparse vegetation, cold and severe climate determined accumulation of calcareous sediments with a low content of organic matter. The sponge spicules found indicate that the water could be alkaline at that time.

Alleröd sediments are well identified by radiocarbon data (depth interval 182–183 cm). The rise in pollen content and the appearance of more thermophilous plants (*Alnus, Corylus*) indicate a climate warming. The section shows accumulation of microspores of the prevailing trees – birch and pine. With the climate getting warmer and vegetation flourishing, shallow lake margins were rapidly overgrowing, and peat was forming.

Sediments of the Youngest Dryas are indicated by radiocarbon data (at a depth interval of 181–182 cm). They contain a decreased number of pollen as compared with the previous time span. It was a colder climate that caused a decrease in tree pollen and a rise in herb microspores.

The sediments settled during the whole Late Glacial contain very few diatoms, therefore, it is impossible to single out lake level fluctuations. Sediments of this period were found to contain single diatoms typical of stagnant water, thus, allowing to suppose that water level in the lake was low, the environment was unfavourable for diatoms due to the cold climate, and sand deposits were unfit for diatom accumulation and preservation.

At the start of the Holocene, in the Preboreal and Boreal, peat began accumulating intensively in Lake Rėkyva, with sapropel found in its lower part. More pollen of thermophilous plants (*Corylus, Quercus, Ulmus*) appeared in the sediment section. Tree microspores took the dominant position. The woodless areas around the lake were favourable for grass growth. A stable soil was forming on the coast. In the Preboreal and the early Boreal, with climate warming, peat accumulated diatom species that were typical of epiphytic (especially *Fragularia construens*), as well as benthic diatoms which indicate that the water level was still low. At the end of the Boreal, a rise in planktonic diatoms (*Cyclotella comta*) indicates that the water level rose slightly due to better water running conditions in the lake, and its bogging in it slowed down (Kabailienė, 1990).

In the Atlantic, forests with abundant thermophilous plants spread in the area of the lake. The abundance of tree pollen of lime, oak and elm rose very significantly. At the end of the period, when the climate became wetter, alder trees spread widely at the water body margins. It became still more warmer, but only at the end of the Atlantic the water level rose, and conditions favourable for diatom spreading appeared. The lake was shallow, conditions typical of a shallow nearshore prevailed, water acidity increased, peat was intensively accumulating. At the end of the Atlantic and in the early Subboreal the lake level could be relatively higher, thus, water covered the peaty margins. Water level fluctuations were low as shown by small changes in diatom species composition and a single type of sediments' grain-size.

At the end of the Atlantic and the beginning of the Subboreal, the climate slightly cooled down and was drier. The early the Subboreal was dated by radiocarbon method. There were rather large changes of vegetation cover in the lake environs. More meadows appeared, broad-leaved trees (lime, oak, elm) declined, and shady spruce stands enlarged. Pine forests were spreading on the soils favourable for them.

As the Subatlantic began, spruce stands slightly declined, forests became brighter – pine-, birch-, and alder-woods settled. A variety of grass vegetation widened. Microspores of cultivated plant – rye – related to human activities appear in the pollen spectrum. The landscape became more open. In the Late Subatlantic, the climate became cooler again, and wide spruce stands spread at the lake. In the second half of the Subboreal and Subatlantic, the content of diatoms in the sediments is low. With the climate getting drier, the water level subsided again, and the conditions for diatoms were unfavourable. Expansion of peaty margins in the lake made its open water area smaller. In the Subatlantic, the water level of Lithuanian lakes slightly rose (Kabailienė, 2006), however, Lake Rėkyva remained shallow, its margins were rapidly bogging, and water currents spread peat-forming plants around the lake and settled them on the bottom.

CONCLUSIONS

Investigations of Lake Rėkyva revealed how the lake and its environs were developing in the Late Pleistocene and the Holocene. The sediments were found to be uniform without clear marks of changes in sedimentation conditions. Organic matter was accumulating at a low water level and low fluctuations of the level. All this was due to the small area of the lake basin (about 30 square km). The diatom assemblage formed in it is not notable for abundance and species variety; there are no clear variations in sediments and diatom assemblages. The pollen data correspond to diatom data and correlate well with the radiocarbon dating.

From its very start, the lake was shallow. In the postglacial time, peat formation affected first of all its shallow northern, western and southern shores. Peaty shores are affected by erosion; currents and winds are transporting the eroded organic matter and settle it on the bottom in the whole area of the basin. The lake is gradually bogging up and getting shallower. The eastern shore remains without peat; it is stable, although it is also affected by erosion in some places.

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RĖKYVOS EŽERO GAMTINĖS APLINKOS RAIDA VĖLYVAJAME PLEISTOCENE IR HOLOCENE

Santrauka

Šis straipsnis apibendrina Rėkyvos ežero raidos tyrimo rezultatus. Pasinaudojant radiokarboninio datavimo, palinologinės bei diatomėjų analizės duomenimis išryškintos ežero ir artimiausios aplinkos vystymosi sąlygos vėlyvajame pleistocene ir holocene. Rėkyvos ežero nuogulos buvo pragręžtos nuo ledo. Organogeninės storymės storis – 2,0 m. Radiokarboninis nuosėdų amžius nustatytas keturiuose intervaluose (182–183 cm; 181–182 cm; 128–130 cm; 78–80 cm) ir atitinka aleriodo, vėlyvojo driaso, atlančio bei subborealio pradžios laikotarpius. Palinologinė analizė patvirtina, kad nuosėdos ežere nuosekliai klostėsi viso vėlyvojo pleistoceno ir holoceno metu. Diatomėjų tyrimo duomenys rodo, kad visą ežero gyvavimo laiką vandens lygis buvo gana žemas, svyravimai nedideli. Rėkyvos ežeras susiformavo ledyno tirpsmo vandeniui užpildžius seklų duburį, kuris aleriodo laikotarpiu, atšilus klimatui, pradėjo pelkėti. Pirmiausia užpelkėjo lėkštos šiaurinės, pietinės, vakarinės pakrantės. Vandens srovės, vėjas nešiojo durpojus po visą ežerą ir klostė ant dugno.

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РАЗВИТИЕ ЕСТЕСТВЕННОЙ СРЕДЫ ОЗЕРА РЕКИВА В ПОЗДНЕМ ПЛЕЙСТОЦЕНЕ И ГОЛОЦЕНЕ

Резюме

Статья основана на результатах исследования истории развития озера Рекива и ближайших его окрестностей. С использованием полученных данных датирования абсолютного возраста органических осадков, палинологического и диатомного анализа выявлены условия развития территории в позднем плейстоцене и голоцене. Толща органических отложений была пробурена с поверхности льда озера. Мощность органических осадков составила 2,0 м. Радиокарбонное датирование отобранных проб показало возраст аллерёда, позднего дриаса, атлантиса и начало суббореаля. Палинологический анализ осадков подтверждает постепенное осадконакопление в позднем плейстоцене и голоцене. Диатомный анализ показывает низкий уровень и незначительные колебания уровня воды. Озеро Рекива образовалось, когда неглубокую ложбину заполнили талые ледниковые воды. Потепление климата и развитие растительности вызвало формирование органических осадков, которые накапливались на глубине мелководного озера в виде торфа. Ветер и водные течения разносили остатки растений по всему озеру и укладывали их на дне. По данным исследований, во время существования озера Рекива скорость накапливания осадков составила 0,11–0,12 см в год.