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Varvometric estimation of the duration of Daniglacial glaciolacustrine sedimentation in Lithuania

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Development of glaciolacustrine basins and varved clay sedimentation in Lithuania were closely connected with the course of ice-cover retreat during the Daniglacial time from 16,000 to 13,000 years BP. The sedimentation of varved sediments of glaciolacustrine basins in Lithuania lasted 3,000 years. In the sections of glaciolacustrine sediments of the Balbieriškis outcrop and clay quarries of Girininkai and Joniðkëlis a detailed sedimentological analysis and varve counting have been carried out. According to the lithology and character of lamination the Balbieriškis profile has been subdivided into four units of laminated varved sediments and the Girininkai and Joniðkëlis sections into three units. According to the varve/year counting, the Simnas–Balbieriðkis glaciolacustrine basin has existed for about 440 years, Kaunas–Kaiðiadorys glaciolacustrine basin for about 250 years and Mûða glaciolacustrine basin 166 years. A chronostratigraphical scheme of the end of the Upper Pleistocene in Lithuania, partially based on varve counting, has been made. Varve investigations enabled to evaluate the duration of climate warming with a more intensive melting of the ice-cover of South–Middle Lithuanian and Middle–North Lithuanian inerphasials of the Nemunas glaciation Baltija stadial.

Key words: annually laminated sediments, clay, sedimentation, varve, glaciolacustrine basins, chronostratigraphical scheme, Daniglacial

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INTRODUCTION

The distribution of the largest glaciolacustrine basins in the territory of Lithuania (Fig. 1) and the formation of glaciolacustrine clayey sediments were closely related to the character of the retreat of the ice-sheet at the end of Last (Nemunas) Glaciation, the topography of the deglaciated territory, and climatic variations. Mostly these factors caused sediment formation of different series, which reflected the dynamic conditions of glacier degradation which, in turn, had been determined by the recessions and oscillations of phasial glaciers. According to G. De Geer (1940), glacial extinction in the Baltic area consisted of three large intervals of time: (1) Daniglacial (20,000–13,000 years BP), (2) Gothiglacial (13,000–10,000 years BP) and (1) Finiglacial (10,000–8,000 years BP). Development of glaciolacustrine basins and varved clay sedimentation in Lithuania were closely connected with the course of ice retreat during the Daniglacial time from 16,000 to 13,000 years BP. The sedimentation of varved sediments of glaciolacustrine basins in Lithuania went on for about 3,000 years. The age of the boundary between the Daniglacial and Gotiglacial was established at 13,200 years BP due to the dating of some interstadial deposits in central Latvia (Raukas et al., 1993, Gaigalas, 1994). So the clay-varve investigations of laminated glaciolacustrine sediments in combination with radiocarbon (^{14}C) dating can help to construct a detailed time-scale, suitable for various attempts to reconstruct environmental changes in the past. For a detailed investigation have been chosen three sections (Balbieriðkis, Girininkai and Joniðkëlis) of glaciolacustrine sediments best reflecting the Late Nemunas deglaciation pattern in Lithuania: (1) the section of the Balbieriškis outcrop reflecting sedimentation conditions in the Simnas–Balbieriškis glaciolacustrine basin, whose development depended on three local oscillations of the margin of the glacier of the South Lithuanian phase, (2) the section of the Girininkai quarry reflecting sedimentation conditions in the Kaunas–Kaišiadorys glaciolacustrine basin during the Middle Lithuanian phase, and (3) the section of the Joniðkëlis quarry reflecting sedimentation conditions in the Mûða glaciolacustrine basin during the North Lithuanian phase. In these sections of the glaciolacustrine sediments a detailed sedimentological analysis and varve counting have been carried out. Our research was based on clay-varve counting, and the main problem was to identify the character of lamination (non-seasonal, seasonal, interseasonal, diurnal, etc.). A number of researchers have investigated this problem and have suggested biological and chemical differences within summer and winter layers, such as greater carbonate sedimentation in summer (Brunskill, 1969, Kenedy, Smith, 1977) and organic detritus in winter (Ludlam, 1979). According to G. Ashley (1985), a sharp grading from silt to clay should be present in the varves, and every year the clay layer should be of almost the same thickness. Varve is defined as "a sedimentary bed, or lamina or sequence of lamina deposits that were laid in a body of still water within one year time. There is normally a lower summer layer consisting of relatively coarse graded light colored sediments (silt and sand), which grades into a thinner winter layer composed of (often organic) dark sediment" (De Geer, 1912).

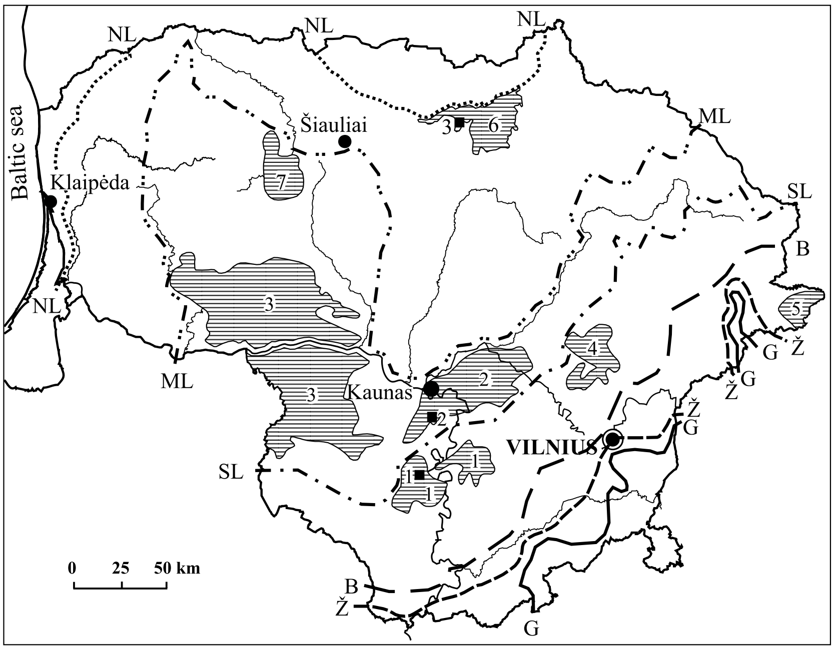


Fig. 1. Distribution of glaciolacustrine basins and location of the sections studied on the map with limits of retreating ice-sheet in Lithuania. Glaciolacustrine basins: *1* – Simnas–Balbieriškis, *2* – Kaunas–Kaišiadorys, *3* – Jûra–Ðeðupë, *4* – Vievis–Širvintos, *5* – Dysna, *6* – Mûða, *7* – Venta. Limits of stadials and phasials of retreating ice-sheet: G – Grûda stadial, Þ – Þiogeliai phasial, B – Baltija stadial, SL – South Lithuanian phasial, ML – Middle Lithuanian phasial, NL – North Lithuanian phasial. Sites of the sections studied: *1* – Balbieriškis outcrop, *2* – Girininkai quarry, *3* – Joniðkëlis quarry

1 pav. Limnoglacialiniø baseinø ir tirtø pjûviø padëtis þemëlapyje su atsitraukianèios ledyno dangos ribomis Lietuvoje. Limnoglacialiniai baseinai: *1* – Simnas–Balbieriškis, *2* – Kaunas–Kaišiadorys, *3* – Jûra–Ðeðupë, *4* – Vievis–Širvintos, *5* – Dysna, *6* – Mûða, *7* – Venta. Atsitraukianèio ledyno stadijø ir faziø ribos: G – Grûdos stadijos, Þ – Þiogeliø fazës, B – Baltijos stadijos, SL – Pietø Lietuvos fazës, ML – Vidurio Lietuvos fazës, NL – Ðiaurës Lietuvos fazës. Tyrinëtø pjûviø vietos: *1* – Balbieriškio atodanga, *2* – Girininkø karjeras, *3* – Joniðkëlio karjeras

PREVIOUS INVESTIGATIONS

More detailed investigations of glaciolacustrine basins and clayey sediments in Lithuania started about 50 years ago. During 1950s and 1960s, several trends were pronounced in the research of glaciolacustrine sediments:

1. The study of clay as a useful mineral resource. The results of these researches (information on drilling, grain size analyses, chemical and physical properties) are compiled in reports on prospecting and exploration of clay deposits, which are available at the library of the Geological Survey of Lithuania.

2. Problems of geomorphology and palaeogeography of glaciolacustrine basins were studied by investigating their formation conditions (Басаликас, 1967, Микалаускас, Микутене, 1970, Гарункштис, 1975), the basins' shoreline deposits (Galvydytë, 1958, Basalykas, 1965, Klimavièienë 1973), their origin, structure and relation to other

forms of glacial relief (Basalykas, 1977, Басаликас, 1967, Юргайтис, 1970).

3. Studies of the largest glaciolacustrine basins' lithology and geological structure. A number of studies on this topic had been carried out by V. Mikaila. He studied the relationships between the glaciolacustrine basins and the glacier of the last glaciation (Mikaila, 1958), the basins' distribution and duration (Mikaila, 1957, 1959, Gudelis, Mikaila, 1960), the texture, structure, lithology, and facial properties of glaciolacustrine sediments (Mikaila, 1959, 1966) and the composition, distribution, and formation of calcareous concretions (Mikaila, 1975, 1991).

Some studies on the sedimentology of laminated clay were carried out as well (Dvareckas, Basalykas, 1959, Микшис и Гайгалас, 1983, Гайгалас и др., 1996, Kazakauskas, Gaigalas, 2000, Kazakauskas, 2001).

Glaciolacustrine laminated sediments have been formed in proglacial lakes dammed near the margin of the retreating ice-sheet of the last glaciation. The general deglaciation pattern in the region of Lithuania is known (Gaigalas, 1994). The glacier of the Baltija stadial of Nemunas Glaciation, retreating from its maximum areal range, readvanced several times and formed the recessional end moraine ridges of South Lithuanian, Middle Lithuanian, and North Lithuanian phases (Gudelis, Mikaila, 1960). All phasial halts of the glacier margin caused the development of proglacial lakes, whose size and duration were different. The damming of proglacial lakes depended on the surface topography of the deglaciated territory. A. Basalykas (1965) identified the shorelines of the former proglacial lakes at the following altitudes: 120–130, 115–102, 85–80, 60, 40, 20–16, and 8–6 m.

The composition of oxygen and carbon stable isotopes of calcareous sediments of the Balbieriškis, Girininkai and Joniðkëlis sections reflect climatic fluctuations of the Daniglacial time (16,000–13,000 BP) in Lithuania (Gaigalas et al., 2001). Lithuania's largest glaciolacustrine basins were ascribed to the facies of proglacial lakes that developed through the interaction of glacial and proglacial environments (Ðinkûnas, Jurgaitis, 1998). The lithofacies of glaciolacustrine sediments of Lithuanian proglacial lakes have been discussed and sedimentary environments in proglacial lacustrine basins reviewed earlier by us (Kazakauskas, Gaigalas, 2000). A palaeomagnetic investigation of glaciolacustrine sediments of the Girininkai section has been carried out by us too (Gaigalas et al., 2002). The declination (D), inclination (I), and intensity (J) of the natural remanent magnitization of glaciolacustrine clays in this section were measured. The obtained shallow inclination may indicate a compaction of the sediments after their deposition in a glaciolacustrine basin.

In varved clay sections of the Balbieriškis outcrop and Girininkai quarry, trace fossils (*Gordia, Helminthoidichnites, Galaciichnium, Cochlichnus, Warvichnium*, and curved ridges) have been found for the first time (Gaigalas, Uchman, 2004). The presence of trace fossils in varved clay of proglacial glaciolacustrine basins of the Upper Pleistocene reflect the climatic fluctuations during glaciolacustrine – lacustrine sedimentation of the South-Lithuanian, Middle-Lithuanian or North-Lithuanian phasials and interphasials of the Nemunas Glaciation Baltija stadial. The traces of fossils in laminated sediments of aquatic origin in Lithuania correspond to interphasial episodes of the Late Pleistocene.

CHARACTERISTICS OF GLACIOLACUSTRINE BASINS

The proglacial lakes were dammed near the margin of the receding ice-sheet of the last (Nemunas) glaciation. The maximum of the Nemunas Glaciation in Lithuania dates to about 20,000–18,000 years BP (Grûda stadial). The glacier of the Baltija stadial reached its maximum 17,000–16,000 years ago and retreating from its maximum areal range (Fig. 1), readvanced several times and formed recessional end moraine ridges of South Lithuanian, Middle Lithuanian and North Lithuanian phases (Gudelis, Mikaila, 1960). Three oscillatory moraine branches are traced in the zone of South Lithuania's recessional phase. All phasial halts of the glacier margin resulted in the development of proglacial lakes, whose size and duration were different. The largest glaciolacustrine basins were dammed near the glacier margin during the South Lithuanian (Simnas–Balbieriškis, Vievis–Širvintos), Middle Lithuanian (Kaunas–Kaiðiadorys, Jûra–Ðeðupë, Venta), and North Lithuanian (Mûða) recessional phases.

Different basins were formed under the influence of different lobes of the phasial glaciers. The development of the Dysna glaciolacustrine basin started during the retreat of the Dysna lobe (Grûda stadial), and later, during the readvance and retreat of the Tvereèius and Breslauja lobes (Baltija stadial), Vievis–Ðirvintos – during the retreat of the Lower Neris lobe (South-Lithuanian phase), Simnas–Balbieriškis – during the oscillatory retreat of the Middle Nemunas lobe (South-Lithuanian phase), Kaunas–Kaišiadorys – during the retreat of the Middle Nemunas and Lower Neris lobes (Middle-Lithuanian phase), Jûra–Ðeðupë – during the retreat of the Lower Nemunas lobe (Middle-Lithuanian phase), Venta – during the retreat of the Middle

Venta lobe (Middle-Lithuanian phase), Mûða – during the retreat of the Mûða–Lëvuo lobe (North-Lithuanian phase) (Basalykas, 1965, 1981). Glaciolacustrine sediments were frequently deposited on the uneven surface of basal till deposits whose surface altitudes range from 37 m to 132 m. The thickness of glaciolacustrine sediments varies from 1–2 to 26 m: in the Dysna basin they generally are 7–9 m thick in the central part and about 15 m in the deepest parts, Vievis–Širvintos – generally 3–5 m, Simnas–Balbieriškis – from several to 20 m, Kaunas–Kaišiadorys – from 1–2 to 26 m, Jûra–Ðeðupë – from 2 to 15 m, Venta – from several meters to 18.5 m, Mûða – in the central zone the thickness reaches 3–4 m and in the northern zone up to 10 m. Such a variety in the the thickness of glaciolacustrine sediments was generally caused by the basins' bottom–topography. The roughness of these surfaces was smoothed away by the filling up of glaciolacustrine basins with sediments.

The altitudes of the surface of glaciolacustrine sediments vary from 40–75 m (in the Jûra–Ðeðupë basin) to 124–140 m (in the Dysna basin). The sediments of the glaciolacustine basins are frequently exposed at the ground surface, but sometimes they are overlain by aeolian sand or bog peat. The varved sediments of glaciolacustrine basins could be subdivided into a series according to structural and textural features. The glaciolacustrine sediments of the Dysna, Vievis–Širvintos and Mûða basins are generally divided into two main series and the Simnas–Balbieriðkis basins into three series. The Kaunas–Kaiðiadorys, Jûra–Ðeðupë, Venta basins are usually divided into two series, although in their deepest parts – into three main series (Gudelis, Mikaila, 1960).

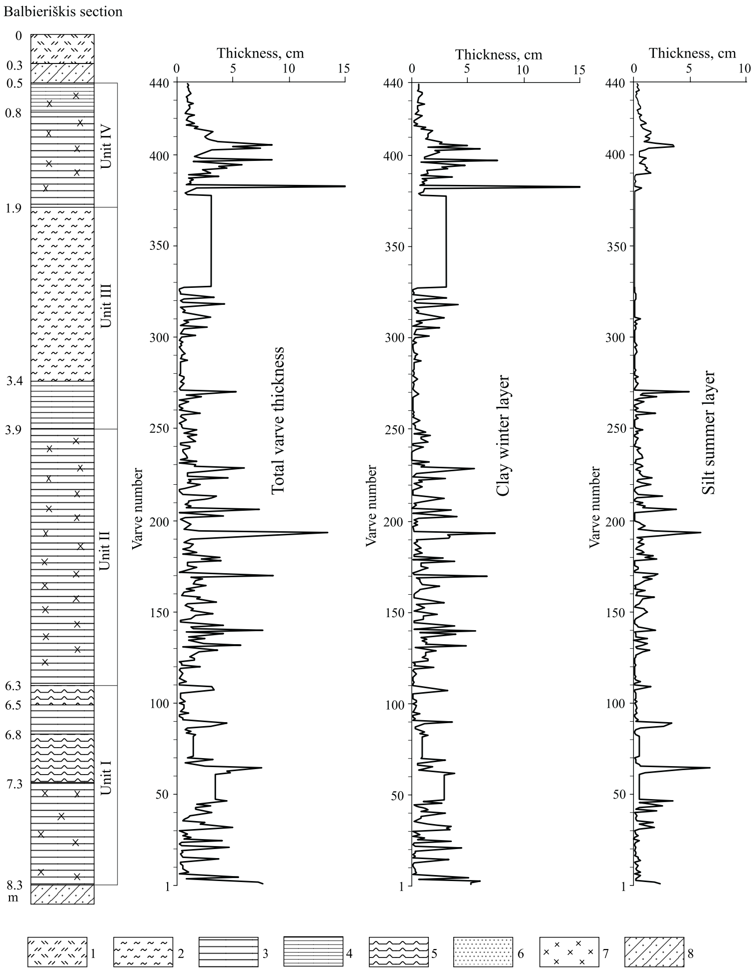


Fig. 2. Sedimentologically investigated Balbieriškis section and varve thickness graph. *1* – soil, *2* – massive clay, *3* – varved clay (thick varves), *4* – varved clay (thin varves), *5* – clay disturbed by cryogenic processes, *6* – fine-grained sand, *7* – carbonates, *8* – till

2 pav. Sedimentologikai tyrinëtas Balbieriðkio atodangos pjûvis ir varvø storiø diagrama. *1* – dirvoþemis, *2* – masyvus molis, *3* – varvinis molis (storos varvos), *4* – varvinis molis (plonos varvos), *5* – kriogeniniø procesø sujauktas molis, *6* – smulkus smëlis *7* – karbonatai, *8* – morena

RESULTS

All three investigated sections (Balbieriðkis, Girininkai and Joniðkëlis) of glaciolacustrine sediments represent exposures, so we had a possibility to observe different types of lamination "in field" by visual inspection in both vertical and horizontal directions. The outcrops were scraped for producing the vertical faces; all sections were photographed. The initial varve counting was carried out "in field" and later from photographs by Kazakauskas and Gaigalas.

Balbieriškis section is situated on the left bank of the Nemunas River (Fig. 1), about 0.5 km north of the small town of Balbieriškis (54°32'06" N; 23°53'16" E) at an elevation of 92 m. Its relative height is about 40 m. The thickness of varved sediments reaches 8.3 metres (Fig. 2). There are two beds of varved deposits, divided by Upper Pleistocene tills. The upper bed of varved sediments is bedding directly on the till of the South Lithuanian phasial of the Nemunas Glaciation Baltija stadial. The contact of glaciolacustrine sediments with the basal till is distinct. According to the lithology and character of lamination the profile can be subdivided into four units of laminated varved sediments.

Above the basal till (Fig. 2) glaciolacustrine clay (sediments at a depth of 8.3–6.3 m) is deposited (unit I). Varves are commonly 1.4–3.4 cm thick, with prevailing winter layers composed of dark-brown clay, and summer layers composed of coarse calcareous silt with clasts of till material. The winter layers are 0.1–6.1 cm thick (mostly 0.8–2.9 cm) and the summer layers are 0.1–6.8 cm thick mostly (0.2–0.5 cm). The thickest winter layers are bedding in the lower part of this unit. We suggest that these sediments of contrasting composition (unit I) were deposited in the proximal part of a glacial lake and reflect cold climatic conditions near the margin of the melting glacier with distinct seasonal changes. Glaciolacustrine sediments in the upper part of this unit (sediments at a depth of 7.3–6.3 m) are dislocated by cryogenic processes, which could originate under the conditions of shallow water at the initial formation stage of this glacial lake. The character of dislocation is analogous to the glaciostructure of the pushed moraine of the Dovainionys outcrop (Gaigalas, 1984). The distinguished oscillatory moraine is expressed by a thin layer, however, it has the same structural elements: lenses, thrusts and wrinkles. The lower part of the dislocated layer is overlain by a thin layer of ablation moraine. Thus, the glaciolacustrine sedimentation could have had a regressive variant of glaciolacustrine–glacial sedimentation, which, with the warming climate, again changed to a glaciolacustrine sedimentation with varved lamination. In this unit (I) 82 varves were counted.

The second unit (II) of varved sediments (Fig. 2) begins with the 83th and ends with the 271th year varve (sediments at a depth of 6.3–3.9 m). Varves are commonly 0.5–1.8 cm thick but range up to 13 cm in places. The summer layers (0.1–6.0 cm thick) are composed of light yellowish brown calcareous silt and sand and the winter layers (0.1–7.4 cm thick) of brown clay. In the lower part of the unit (sediments at a depth of 6.3–5.8) the laminated sediments are more clayey, but upwards become siltier. In the unit II the thickness ratio between the winter and summer layers is balanced. The varves' differentiation becomes more expressed. At the end of summer and beginning of autumn, carbonates were deposited and overlay the sand and silt layers formed in the summer. As the glacier melted more intensively, the frozen till clasts were deposited within the summer layers. Sometimes the sediments are so varied that winter thaws and summer floods can be observed in the varve layers. This sedimentation type often coalesced with lacustrine sedimentation, *i.e.* traces of a warm lacustrine environment appeared in the basin's development. Seasonal and interseasonal lamination is visible within the series. We suggest that this type of interphasial sedimentation occurrred under warm climatic conditions with prevailing lacustrine vegetation, whose remains comprised organic layers within the summer layers. These calcareous sediments from the unit II were dated by the radiocarbon (^{14}C) method at the Radiocarbon Laboratory of Silezian Technical University. The obtained radiocarbon dates (Gd-11592: 40600 ± 2300, Gd-12195: >41300, and Gd-11527: 45300 ± 5000) are too old compared to the real age (14,000–15,000 yrs BP) of the deposition of glaciolacustrine sediments in this proglacial lake. The obtained radiocarbon dates suggest that an essential part of carbonates was redeposited from older eroded carbonate terrains. Thus, for a reliable dating of these sediments we need to select samples with a high content of organic matter. In this unit (II) 189 varves (83–271) were counted. In the Balbieriškis outcrop, interphasial lacustrine sedimentation does not end the proglacial lake formation, but, again, with climatic cooling and readvancement of the glacier it changes into a glaciolacustrine sedimentation. During this period, at first varved clay (sediments at a depth of 3.9–3.4 m), and then homogeneous clay (at a depth of 3.4–1.9 m) of the unit III (sediments at a depth of 3.9–1.9 m) were deposited. In the lower part of the unit (sediments at a depth of 3.9–3.4 m) varves are 0.1–4 cm thick with prevailing winter layers composed of dark-brown clay and summer layers composed of yellowish brown calcareous silt. The winter layers are 0.1–4.1 cm and the summer layers 0.1–0.6 cm thick. The upper part of Unit III (sediments at a depth of 3.4–1.9 m) is represented by a thick (1.5 m) bed of dark-brown homogeneous clay without visible lamination. Deposition of massive clay may have resulted from low sedimentation rates and increasing distance from the influence of meltwater and associated with glacier stabilization and climate warming (Lemmen et al., 1987). The annual rate of sedimentation of this homogeneous clay bed is not known, so we proposed that its sedimentation rate was 3 cm/year, similar to the average annual rate of sedimentation of varved sediments deposited below and above the bed of homogeneous clay. At this sedimentation rate of 3 cm/year proposed for this massive clay bed, the total accumulation period for this bed would have been 50 years (329–378 varves), but it could last longer or shorter depending on the real annual rate of sedimentation which is not yet known. So the total accumulation period for glaciolacustrine sediments of Unit III could have been about 107 years (varves 272–378).

The fourth unit (IV) of varved sediments (sediments at a depth of 1.9–0.5 m) begins with the 379th and ends with the 440th year varve. This unit is represented by varved sediments with distinct lamination. Varves decrease in thickness upwards towards a bed of ablation till (deposits at a depth of 0.5–0.3). In the lower part of Unit IV (sediments at a depth of 1.9–0.8 m) varves are commonly 1–3 cm thick but range up to 18 cm in places.

The winter layers (0.2–17.9 cm thick) are composed of dark brown clay and the summer layers (0.1–3.6 cm thick) of yellowish brown calcareous silt. In the upper part of unit IV (sediments at a depth of 0.8–0.5 m), varves (417–440) become thiner; they are generally 0.8–1 cm thick. The ratio between the thickness of the winter and summer layers is almost balanced. We interpret these 24 uppermost varves and the overlying thin bed of ablation moraine to represent the final stages of the Simnas–Balbieriškis proglacial lake caused by the final glacier retreat and climate warming. This proglacial lake was drained after the retreat of the ice margin from the South-Lithuanian ridge of end moraines. According to clay-varve calculations, the total accumulation period for glaciolacustrine sediments of the Balbieriškis section was about 440 years (Fig. 2).

Girininkai section is located in the southern part of the Kaunas–Kaišiadoriai glaciolacustrine basin, in the quarry of the Rokai ceramic plant (54°46’32" N; 23°55’04" E) at 65.5 m above sea level. This section of laminated sediments reflects the sedimentation conditions that existed in the Kaunas–Kaišiadorys glaciolacustrine basin during the Middle Lithuanian phasial about 14000 years BP. Varved glaciolacustrine sediments are bedding directly on the till of the South Lithuanian phasial of the Nemunas Glaciation Baltija stadial. The contact of glaciolacustrine sediments with the till is distinct.

Above the basal till (Fig. 3), varved clay with distinct lamination (sediments at a depth of 9.4–6.6 m) was deposited (unit I). Varves are commonly 0.9–2.5 cm thick but range up to 13 cm in places with prevailing winter layers composed of reddish brown clay and summer layers composed of greenish white calcareous silt. The winter layers are 0.2–13.5 cm thick (mostly 0.8–2.0 cm) and the summer layers are 0.1–4.5 cm thick (mostly 0.1–0.3 cm). In the lower part (sediments at a depth of 9.4–8.9 m), the summer layers consist of clasts of till material and pebbles commonly contained in winter layers. We interpret these lowermost sediments (varves 1–14) to represent the initial stages of a glacial lake. With the further retreat of the glacial margin and warming climate, glaciolacustrine sedimentation with a characteristic thermal regime and water stratification, as well as deposition of rhythmically laminated sediments becomes prevalent (sediments at a depth of 8.9–7.6, varves 15–82). These varves (15–82) decrease in thickness upwards, but in the upper part (sediments at a depth of 7.6–6.6, varves 83–129) gradually become thicker again. We interpret these varves (15–129) as deposited in the distal part of the glacial lake without direct contact of the glacier with the lake at that time under a relatevily stable climate. In this unit (I) 129 varves were counted.

The second unit (II) of varved sediments begins with the 130th and ends with the 186th year varve (sediments at a depth of 6.6–2.6 m). In this unit 57 varves were counted. This unit is represented by an indistinctly laminated bed of homogeneous clay. The varves are commonly 2–5 cm thick but range up to 40 cm in places. The summer layers are mostly yellowish gray silty calcareous clay. The finer winter layers consist of ungraded clay and are predominantly dark grayish brown to dark brown. The winter layers are generally 1.9–3.9 cm thick but range up to 40 cm in places. The summer layers are commonly 0.1–0.2 cm thick. Lamination in this unit (II) is hardly recognized by naked eye, so our determi-

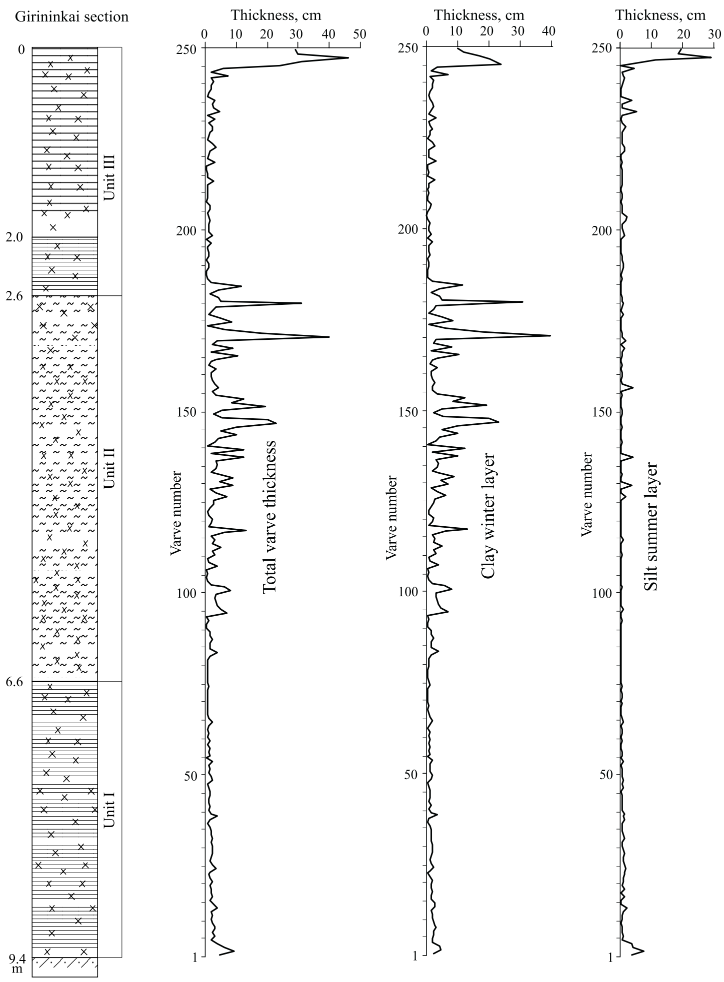


Fig. 3. Sedimentologically investigated Girininkai section and varve thickness graph.
Litological legend as in Fig. 2
3 pav. Sedimentologiðkai tyrinëtas Girininkø molio karjero pjûvis ir varvø storiø diagrama. Sutartinius þenklus þr. 2 pav.

nation of annual layers could be not always right. We interpret these varves (130–186) as deposited in the distal part of the glacial lake under the conditions of glacier stabilization and climate warming.

The third unit (III) of varved sediments begins with the 187th and ends with the 250th year varve (sediments at a depth of 2.6–0 m). Varved lamination is well expressed in the lower part of this unit (sediments at a depth of 2.6–2.0 m). Varves are commonly 0.8–1.6 cm thick with prevailing winter layers composed of reddish brown clay and summer layers composed of grayish yellow calcareous silt. The winter layers are mostly 0.2–4.4 cm thick and the summer layers are generally 0.2–0.3 cm thick. In the upper part of unit III (sediments at a depth of 2.0–0 m) varves sharply increase in thickness and range from 24 to 46 cm. Varves are composed of poorly sorted silty and calcareous clays of massive structure; in places they are mottled. We interpret these uppermost varves (247–250) to represent the final stages of the Kaunas–Kaišiadorys proglacial lake caused by the retreat of the glacier. We suggest that these sediments were deposited in a shallow proglacial lake under the climate warming conditons. The total accumulation period for glaciolacustrine sediments of the Girininkai section comprised 250 years (Fig. 3).

Joniškëlis section is located in the south part of the Mûða glaciolacustrine basin in the former Joniðkëlis clay quarry (56°02’40" N; 24°08’59" E) at 50 m a.s.l. This section of laminated sediments reflects the sedimentation conditions that existed in the Mûða glaciolacustrine basin during the North Lithuanian phasial (about 13,000 years BP) of the Baltija stadial of Nemunas Glaciation. Varved glaciolacustrine sediments are bedding on a 0.7 m thick layer of glacifluvial sand (sediments at a depth of 3.1–2.4 m) with thin interlayers of remobilized till material (in the upper part of a sand bed), which was deposited on the basal till (Fig. 4). According to the lithology and character of lamination this section can be subdivided into three units of laminated varved sediments.

Above the glaciofluvial sand, distinctly laminated (typical varves) calcareous clay (sediments at a depth of 2.4–1.7 m) was deposited (unit I). Varves are commonly 0.4–1.0 cm thick with prevailing winter layers composed of reddish brown clay and summer layers composed of grayish white calcareous silt. The winter layers are mostly 0.3–1.0 cm and the summer layers thick 0.1–0.2 cm thick. The varves increase in thickness upwards. We interpret these varves as deposited in the distal part of the glacial lake without direct contact of the glacier with the lake at that time. In this unit (I) 84 varves were counted.

The second unit (II) of varved sediments begins with the 85th and ends with the 111th year varve (sediments at a depth of 1.7–1.1 m). In this unit 27 varves were counted. Varves become thicker and range from 0.8 to 7.1 cm thick (mostly 1.5–3.2 cm dominating) with prevailing winter layers (0.2–5.6 cm thick with 0.3–1.0 cm) composed of dark-brown clay. The summer layers (0.1–1.5 cm thick, mostly 0.2–0.7 cm) are composed of greenish white calcareous silt. In the upper part of this unit (sediments at a depth of 1.4–1.1 m) laminated sediments are disturbed by glaciotectonic deformations. We suggest that these clayey sediments of unit II were deposited under the conditions of a short glacial readvancement.

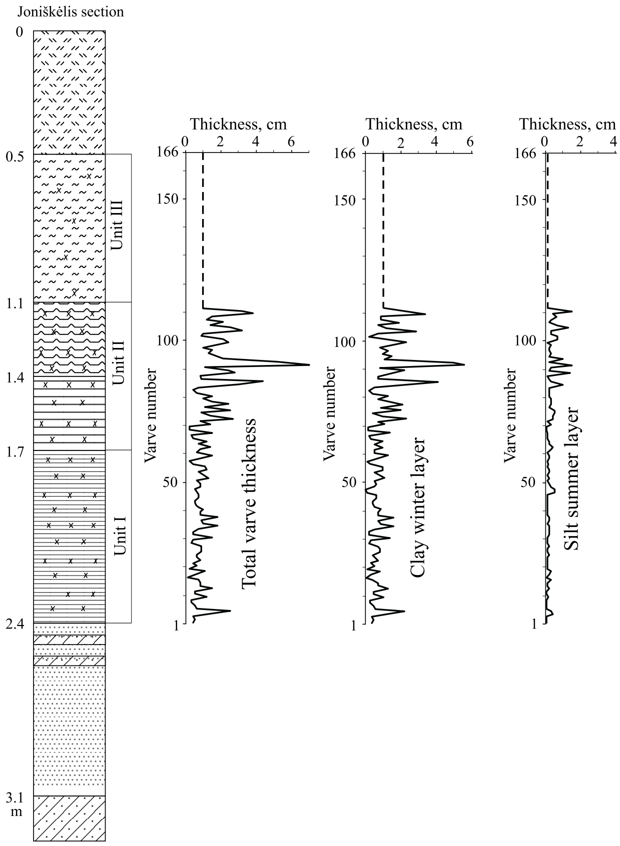


Fig. 4. Sedimentologically investigated Joniðkëlis section and varve thickness graph.
Litological legend as in Fig. 2
4 pav. Sedimentologiðkai tyrinëtas Joniðkëlio molio karjero pjûvis ir varvø storiø diagrama. Sutartinius þenklus þr. 2 pav.

The third unit (III) is represented by a 0.55 m thick bed of dark grayish brown homogeneous clay (sediments at a depth of 1.1–0.5 m) without visible lamination. As we mentioned above (describing sediments of the Balbieriškis section), the deposition of massive clay may have resulted from low sedimentation rates. The annual rate of sedimentation of this homogeneous clay bed is not known, so we proposed that sedimentation rate was 1 cm/year, similar to the average annual rate of sedimentation of varved deposits in unit I. At this sedimentation rate of 1cm/year for this homogeneous clay bed, the total accumulation period for unit III would have been 55 years (112–166 varves). We suggest that the deposition of the homogeneous clay bed resulted first from glacier stabilization and then from its further gradual retreat and the increasing distance from the glacier. The total accumulation period for glaciolacustrine sediments of the Joniðkëlis section lasted about 166 years (Fig. 4).

As we have mentioned above, varve measurements in the sections studied were carried out under field conditions and later from photographs, and the main problem for us was to identify the character of lamination (seasonal, interseasonal, diurnal, etc.). It was hard to identify the annual layers in the unit II of the Balbieriškis section. The beds of homogeneous clay also were problematic for varve investigation. In the future, we are planning to study microscopically all these intervals of complicated lamination by analysing the microfeatures of different layers.

CHRONOSTRATIGRAPHICAL SUCCESSION AND AREAL DISTRIBUTION OF SEDIMENTS OF GLACIOLACUSTRINE BASINS

The distribution patterns of the largest glaciolacustrine basins in Lithuania and the formation of sediments were closely associated with the glaciodynamics of the Baltija stadial of Nemunas Glaciation, *i.e.* with the phasial recessions and oscillations of the glacier. The largest glacial lakes were dammed near the margin of the halted glacier during the South Lithuanian, Middle Lithuanian, and North Lithuanian recessional phases of the Baltija stadial of Nemunas Glaciation. The zonal spread of glaciolacustrine sediments is related to a recessional degradation of the active ice cover. Climate warming and intensive ice melting of the retrating glacier caused an intensive deposition of glaciolacustrine clayey and silty laminated sediments. Climate cooling and glacier re-advances caused a sedimentation shift from glaciolacustrine to glacial with the deposition of till. Stabilization of climatic conditions with a stable position of the glacier margin resulted in low sedimentation rates with the deposition of thin varves or indistinctly laminated clayey sediments. Thus, the distribution of glaciolacustrine basins in the territory of Lithuania and varved clay sedimentation reflect all main recessional stages of the retreating glacier of the Baltija stadial of Nemunas Glaciation (Fig. 5). The sedimentation of varved sediments in glaciolacustrine basins of Lithuania lasted about 3000 years. All the above-mentioned glacial lakes emerged at different time and were of different duration. The varved clay sedimentation was limited in time. Sedimentological analyses and varve counting allowed to determine the duration of the sedimentation in the glaciolacustrine basins studied (Figs. 2–4): the Simnas–Balbieriškis glaciolacustrine basin in the place of the Balbieriškis section existed for about 440 years, the Kaunas–Kaišiadorys glaciolacustrine basin in the place of the Girininkai section for about 250 years and the Mûða glaciolacustrine basin in the place of the Joniðkëlis section 166 years. The duration of glaciolacustrine sedimentation during glacier retreat of the North Lithuanian phasial was almost two times shorter (difference 84 years) than during the Middle Lithuanian phasial. The duration of varve sedimentation in basins of the Middle Lithuanian phasial was obviously shorter (difference 190

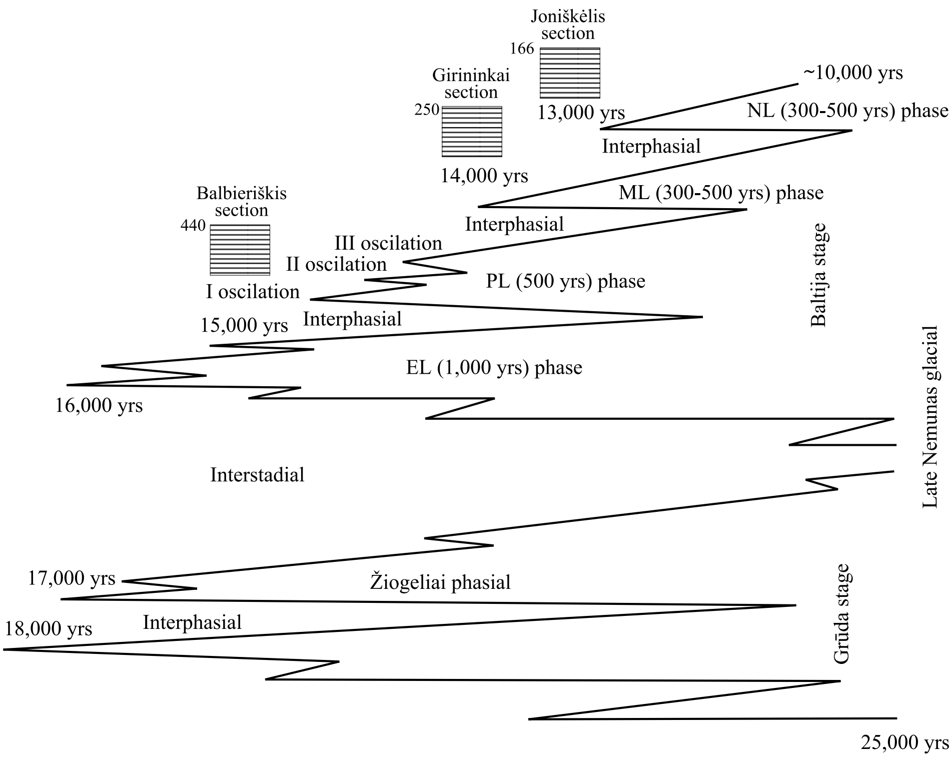
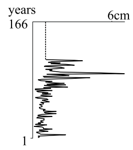
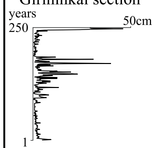
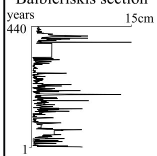


Fig. 5. Relation of the sections studied to the retreat of ice cover of Baltija stadial of Nemunas glaciation in Lithuania

5 pav. Tirtø pjûviø padëtis atsitraukianèios Baltijos stadijos Nemuno apledëjimo ledyno dangos atþvilgiu Lietuvoje

Table. **Chronology of Upper Pleistocene (Upper Nemunas Glaciation) and varve thickness graphs**
Lentelë. **Virðutinio pleistoceno Nemuno apledėjimo chronologija ir varvometrinës diagramos**

Stratigraphical unit		Interstadial and stadial	Interphasial and phasial	^{14}C Age (BP)	Varvometric data	The age, years
Nemunas glaciation	Upper (glacial)	Žiemgala last glacial (gotiglacial 13200 - 10000)	Upper Dryas phasial			10900
			Alleröd interphasial	11970±180 11500±430		11900
			Middle Dryas phasial		Joniškėlis section 	12300
			Bölling interphasial	12160±120 12700±80		12800
			North Lithuanian phasial		Girininkai section 	
		Linkuva interphasial				13500
		Baltija stadial (daniglacial 16500 - 13200)	Middle Lithuanian phasial	14040±240	Balbieriškis section 	
			Šušvė interphasial			14500
			South Lithuanian phasial			15900
			Punia interphasial			
			East Lithuanian phasial			16500
		Pavytė interstadial				
		Grūda stadial	Žiogeliai phasial			18000
			Krikštonys interphasial			
			Puvočiai phasial			22000

ration of climate warming with a more intensive melting of the retreating glacier of the South-Middle Lithuanian and Middle-North Lithuanian inerphasials of the Baltija stadial of Nemunas Glaciation. We failed to get reliable radiocarbon dates from the studied sections due to the lack of organic material in these sediments, so the floating varve chronology from the sections studied is not directly linked to absolute chronology: the age of the boundary between the Daniglacial and the Gotiglacial was established at13,200 years BP by dating some interstadial deposits in central Latvia (Raukas et al., 1993, Gaigalas, 1994). To construct a more detailed time-scale, we need to use clay-varve investigations of annually laminated glaciolacustrine sediments (varves) in combination with the methods of absolute dating.

years) than during the South Lithuanian phasial. In the South Lithuanian phasial there were distinct traces of three oscillations of ice cover. The different duration of glaciolacustrine sedimentation during the retreat of glaciers of the South Lithuanian, Middle Lithuanian and North Lithuanian phasials depends on the character of melting ice cover. The ice recession in Lithuania went in an active frontal form during the South Lithuanian and Middle Lithuanian phasials. A passive areal and the dead ice form of deglaciation began after the North Lithuanian phasial (Гайгалас и др., 1967). Dead ice was melting away, the water level was rapidly sinking. The existence of dammed glaciolacustrine basins and sedimentation in it was shorter. The data of clay-varve investigations were arranged into a chronostratigraphical scheme of the Upper Pleistocene (Table) compiled by A. Gaigalas (2000). Thus, these varvometric data allowed to evaluate the du-

CONCLUSIONS

The investigated sections consist mainly of clastic rhytmites, which are interpreted as seasonal deposits. The formation of these varves provides both chronological and palaeo-environmental information. The deglaciation evolution is archived in the variations of varve structure, composition, and thickness. According to the lithology and character of lamination, the Balbieriškis profile was subdivided into four units of laminated varved sediments and the Girininkai and Joniðkëlis sections into three units. The age of the boundary between the Daniglacial and the Gotiglacial was established at 13,200 years BP. The glaciolacustrine sedimentation had a sporadic and rhythmic character in time. According to varve/year counting, the Simnas–Balbieriðkis glaciolacustrine basin existed for about 440 years, the Kaunas–Kaiðiadorys glaciolacustrine basin 250 years and Mûða glaciolacustrine basin 166 years. Sedimentological analyses of the Balbieriškis, Girininkai and Joniðkëlis sections and varve counting in combination with ^{14}C datings helps to construct a detailed time scale of this time period. The estimation of the duration of varve sedimentation gives the possibility to restore in a more detailed way the history of the development of glaciolacustrine basins as well as to reconstruct the ice-sheet dynamics of the last glaciation.

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LIMNOGLACIALINËS SEDIMENTACIJOS TRUKMËS ÁVERTINIMAS DANIGLACIALO LAIKOTARPIU LIETUVOJE REMIANTIS VARVOMETRINIAIS TYRIMAIS

S a n t r a u k a

Limnoglacialinë sedimentacija vëlyvajame pleistocene lydëjo atsitraukianèio (recesuojanèio) ledyno fazinius stabtelëjimus Nemuno apledëjimo Baltijos stadijos metu. Ji vyko atskiruose, prie faziniø recesiniø ledyno pakraðèiø pasitvenkusiuose baseinuose. Vëlyvojo pleistoceno Daniglacialo laikotarpio limnoglacialinës sedimentacijos sluoksniuotos molingos, aleuritingos ir smëlingos nuosëdos intensyviai kaupësi tirpstant ledynui ir jam traukiantis atðilimø metu. Ledynui pakartotinai progresuojant limnoglacialinæ sedimentacijà pakeisdavo ledyniniø moreniniø nuogulø kaupimasis. Esant stabiliam ledyno pakraðèiui pradþioje taip pat ne ið karto susidarydavo patvenktiniai prieledyniniai ledo tirpsmo vandenø baseinai, kuriuose klojosi sluoksniuotos nuogulos stovinèio vandens aplinkoje. Todël laiko atþvilgiu limnoglacialiniø sluoksniuotø varviniø nuosëdø kaupimasis buvo sporadiðkas, taèiau ritmiðkai pasikartojantis. Limnoglacialinës nuosëdos Lietuvoje taip pat yra erdviðkai iðsidëstèiusios zonomis einant ið pietø á ðiauræ. Tà zoniðkumà lëmë ledyno pasitraukimas ir limnoglacialinës sedimentacijos epizodiðkumas klimatui atðilus metu. Tyrinëtø didþiøjø patvenktiniø baseinø limnoglacialiniø nuogulø vertikalus ir horizontalus pasiskirstymas laiko ir erdvës atþvilgiu buvo sàlygotas atsitraukianèio ledyno pakartotinø recesijø ir osciliacijø; tai akivaizdþiai matyti pateiktoje iliustracijoje (5 pav.).

Varvometriniai matavimai (jø duomenys perkelti á virðutinio pleistoceno stratigrafinæ skalæ (lentelë), sudarytà A. Gaigalo (Gaigalas, 2000)) padëjo nustatyti limnoglacialiniø sluoksniuotø nuosëdø sedimentacijos trukmæ tirtuose Balbieriðkio (440 metø), Girininkø (250 metø) ir Joniðkëlio (166 metai) pjûviuose (1–4 pav.). Atlikus sluoksniuotø molingø nuosëdø varvometrinius matavimus, pirmà kartà gauti konkretûs varvometriniai duomenys, kurie padeda konkretizuoti Pietø–Vidurio Lietuvos ir Vidurio–Ðiaurës Lietuvos tarpfaziniø ledyno pasitraukimø trukmæ Lietuvoje klimato atðilimo ir intensyvaus ledyno tirpsmo metu. Gauti duomenys taip pat leidþia ávertinti ledynø intensyvaus tirpsmo trukmæ aktyvaus recesuojanèio ledyno tarpfaziniais ðiltesniais laikotarpiais.

Вайдотас Казакаускас, Альгирдас Гайгалас

ПРОДОЛЖИТЕЛЬНОСТЬ ЛИМНОГЛЯЦИАЛЬНОЙ СЕДИМЕНТАЦИИ В ДАНИГЛЯЦИАЛЕ В ЛИТВЕ ПО ВАРВОМЕТРИЧЕСКИМ ДАННЫМ

Ð å ç þ ì å

Ôàçèàëüíûå îñòàíîâêè îòñòóïàþùåãî ëåäíèêà áàëòèéñêîé ñòàäèè íÿìóíñêîãî îëåäåíåíèÿ ñîïðîâîæäàëèñü ëèìíîãëÿöèàëüíîé ñåäèìåíòàöèåé. Ïîñëåäíÿÿ ïðîèñõîäèëà â ïîäïðóæåííûõ ôàçèàëüíûì ëåäíèêîì áàññåéíàõ. Ñëîèñòûå ãëèíèñòûå, àëåâðèòèñòûå è ïåñ÷àíûå îòëîæåíèÿ íàêàïëèâàëèñü â ëèìíîãëÿöèàëüíûõ áàññåéíàõ â ïîçäíåì ïëåéñòîöåíå âî âðåìÿ äàíèãëÿöèàëà ïðè èíòåíñèâíîì òàÿíèè îòñòóïàþùåãî ëåäíèêà. Ïðè ïîâòîðíîì íàäâèãå ëåäíèêà ëèìíîãëÿöèàëüíóþ ñåäèìåíòàöèþ ñìåíÿëî ãëÿöèàëüíîå íàêîïëåíèå ìîðåííûõ îòëîæåíèé. Ïðè ñòàáèëüíîì ïîëîæåíèè êðàÿ ëåäíèêà òàêæå íå ñðàçó ðàçëèâàëèñü ïîäïðóæåííûå ïðèëåäíèêîâûå áàññåéíû òàëûõ ëåäíèêîâûõ âîä, â êîòîðûõ íàêàïëèâàëèñü ñëîèñòûå îòëîæåíèÿ â ñðåäå ñòîÿ÷åé âîäû. Ïîýòîìó ïî îòíîøåíèþ êî âðåìåíè íàêîïëåíèå ñëîèñòûõ ëèìíîãëÿöèàëüíûõ îòëîæåíèé (âàðâ) ïðîèñõîäèëî ñïîðàäè÷åñêè, îäíàêî îíî íîñèëî ðèòìè÷åñêèé õàðàêòåð ïåðèîäè÷åñêîãî ïîâòîðåíèÿ. Ëèìíîãëÿöèàëüíûå îòëîæåíèÿ â Ëèòâå òàêæå ïðîñòðàíñòâåííî ðàñïðåäåëåíû çîíàëüíî, ñ ïåðåõîäîì ñ þãà íà ñåâåð. Ýòó çîíàëüíîñòü îáóñëîâèëà ýïèçîäè÷íîñòü îòñòóïàíèÿ ëåäíèêà è ëèìíîãëÿöèàëüíîé ñåäèìåíòàöèè. Âåðòèêàëüíîå è ãîðèçîíòàëüíîå ðàñïðåäåëåíèå èçó÷åííûõ ëèìíîãëÿöèàëüíûõ îòëîæåíèé êðóïíûõ ïîäïðóæåííûõ ïðèëåäíèêîâûõ áàññåéíîâ ïî âðåìåíè è ïðîñòðàíñòâó îáóñëîâëåíî ïîâòîðíûìè ðåöåññèÿìè è îñöèëëÿöèÿìè.

Âàðâîìåòðè÷åñêèå èññëåäîâàíèÿ ïîçâîëèëè îïðåäåëèòü ïðîäîëæèòåëüíîñòü ñåäèìåíòàöèè ñëîèñòûõ ëèìíîãëÿöèàëüíûõ îòëîæåíèé â èçó÷åííûõ ðàçðåçàõ Áàëüáåðèøêèñ (440 ëåò), Ãèðèíèíêàé (250 ëåò) è Éîíèøêåëèñ (166 ëåò). Âàðâîìåòðè÷åñêèå äàííûå ïåðåíåñåíû â ñòðàòèãðàôè÷åñêóþ øêàëó âåðõíåãî ïëåéñòîöåíà, ñîñòàâëåííóþ À. Ãàéãàëàñîì. Òàêèì îáðàçîì, âïåðâûå ïîëó÷åííûå âàðâîìåòðè÷åñêèå äàííûå ïîçâîëÿþò êîíêðåòèçèðîâàòü ïðîäîëæèòåëüíîñòü þæíîëèòîâñêèõ-ñðåäíåëèòîâñêèõ è ñðåäíåëèòîâñêèõ-ñåâåðîëèòîâñêèõ ìåæôàçèàëüíûõ îòñòóïàíèé ëåäíèêîâ â Ëèòâå âî âðåìÿ êëèìàòè÷åñêèõ ïîòåïëåíèé è ïåðèîäîâ èíòåíñèâíîãî òàÿíèÿ ëüäà. Ïîëó÷åííûå äàííûå òàêæå ïîçâîëÿþò îöåíèòü ïðîäîëæèòåëüíîñòü èíòåíñèâíîãî òàÿíèÿ àêòèâíûõ ðåöåññèðóþùèõ ëåäíèêîâ.