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Palaeogeography and evolution of the Dubičiai glaciolacustrine basin in southern Lithuania

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Abstract. The Dubičiai glaciolacustrine basin was studied by means of geomorphological, lithological and cartographic methods in order to reconstruct water level changes during postglacial time. The formation of the basin and respective sedimentation processes began immediately after the deglaciation. Glaciolacustrine terraces in the Dubičiai basin formed during the Frankfurt (Grūda) Stage of the last glaciation, and during the Dryas–Allerød, Boreal and Subatlantic chronozones. Intense evolution of the basin took place at the end of the Late Pleistocene and in the Early Holocene. The greatest changes in the topography were due to thermokarst processes which began in the Allerød and continued until the Boreal. Climate became warm and moist at the beginning of the Preboreal and thus created good conditions for accumulation of gyttja, peat and freshwater lime. The latest stage in the development of the Dubičiai basin occurred in the 19th century. In 50 years the area of the basin decreased by 10 times: from 221 ha in 1850 to 20 ha in 1900. The last major change in the hydrographic network of the basin occurred in 1958–59 when an artificial drainage project was completed.

Key words: thermokarst, Dubičiai glaciolacustrine basin, Lithuania, Late Weichselian, lake water level.

INTRODUCTION

The rapidly changing climate has been one of the major challenges for mankind in the last decades. Global climate warming is expected to be responsible for quickly melting glaciers in the polar zones and mountains, for degradation of permafrost and several other phenomena. The greatest amount of evidence about consequences of climate change can be derived from past glacial records and from the structure and bedding of related deposits. Sediments of former glaciolacustrine basins contain especially important palaeoenvironmental information on the change from cold to warm climate. At the time of rapid glacier recession a large part of Lithuania's territory was inundated by glaciolacustrine basins where thick sediment layers accumulated in a few thousand years. Complex analysis of the relief and sediments allows reconstructing palaeogeographical conditions of that time.

Important data can be obtained from water level fluctuations in glaciolacustrine basins. The configuration of the basins can be rather easily traced in current topography. Due to fallen water levels littoral zones of the former glaciolacustrine basins have been converted into glaciolacustrine terraces.

Proglacial Lake Dubičiai in southern Lithuania (Fig. 1) is notable because of its great size. It is a unique relict lacustrine basin where, after the gradual fall of the water level, several separate lakes existed until the middle of the 20th century and a few smaller lakes have survived until today.

Geomorphological and lithological investigations of Dubičiai environs were carried out in 2007–08 within the project 'Palaeoclimate', supported by the Lithuanian Science and Studies Foundation. Based on the obtained data, a palaeogeographical reconstruction of the former glaciolacustrine basin was made and is presented in this publication.

RESEARCH METHODS

The Dubičiai glaciolacustrine basin was analysed by using different field investigation methods. During the expeditions of 2007–08 geomorphological measurements in situ (shoreline altitudes, lengths and inclinations of terraces slopes) were undertaken together with the sampling of lacustrine sediments. In addition, the data reported by earlier authors (Kunskas 1963–1964; Eitmanavičienė & Endzinas 1977; Garunkštis 1988; Šinkūnas et al. 2001; Baltrūnas 2002; Stančikaitė et al. 2002) were incorporated into reconstructions of the evolution of the Dubičiai basin.

Geomorphological investigations

Coastal sediments and landforms allowed determining water level fluctuations in the ancient basin. Decreasing

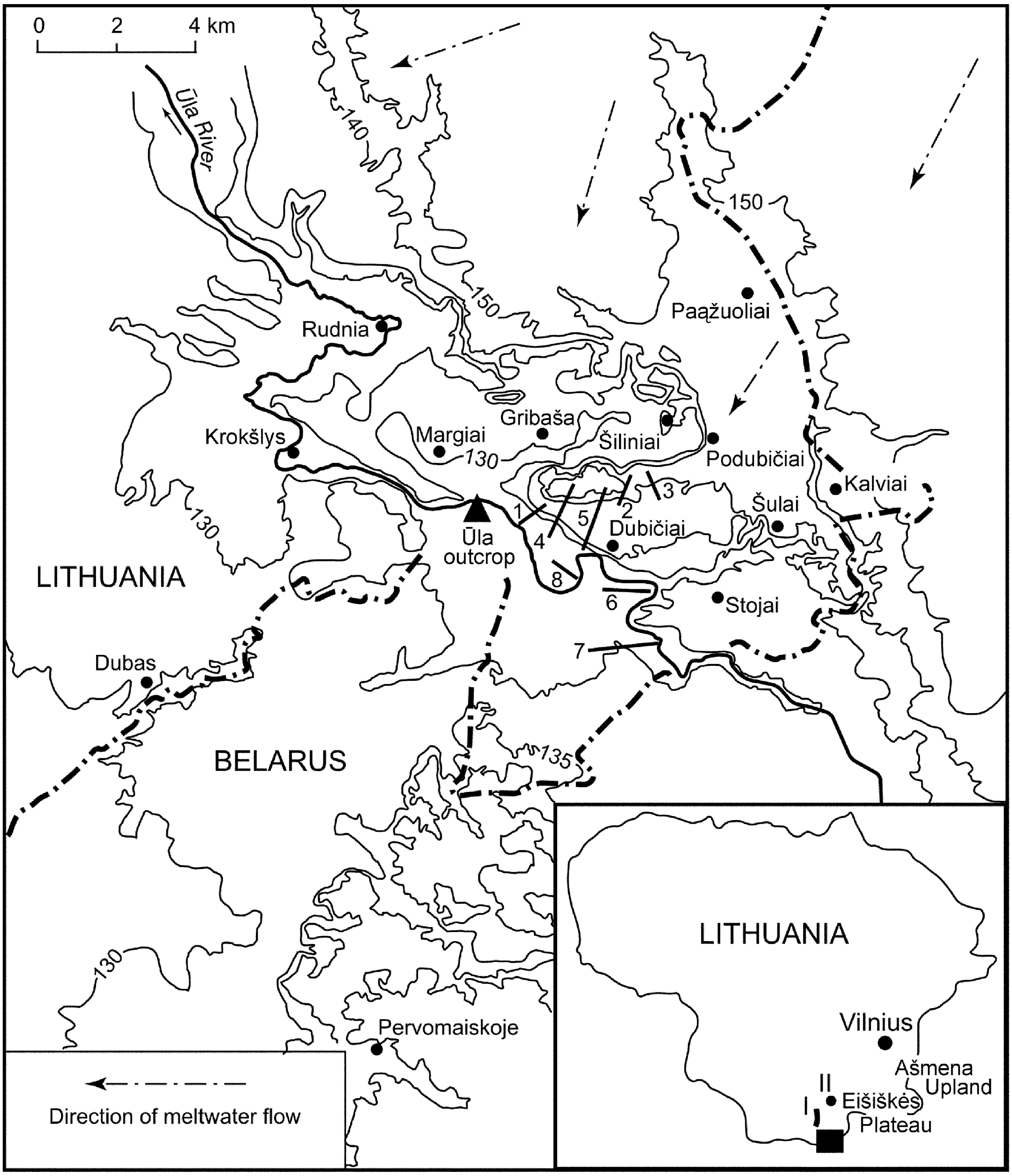

Fig. 1. Location of the Dubičiai glaciolacustrine basin and general topography of the region. The bold dashed line shows the Lithuanian–Belarusian border; filled circles indicate villages; arabic numbers 1–8 indicate location of cross sections presented in Fig. 2. In the excerpt: I, Skroblus moraine ridge; II, Matuizos erosional remnant from the Žiogeliai moraine ridge, the black square shows location of the study area in southern Lithuania.

water level exposes littoral zones which eventually turn into beaches. Water level decrease by more than 2 m exposes the entire littoral zone which turns into a lacustrine terrace. The distribution pattern of those terraces reveals a number of events of water level falls.

The area surrounding the Dubičiai glaciolacustrine basin was explored in order to locate former abrasion banks. Usually banks of this type are marked by beaches with gravel and pebbles. However, due to intensive post-glacial surface processes of erosion and accumulation, the former littoral zones of the Dubičiai basin have substantially changed and no abrasion banks or scarps were identified. Levelling of the wide littoral zones and higher terraces provide evidence about slow changes in water level in the majority of cases when it fluctuated. This was probably due to the large area and volume of the lake, and because of limited water inflow, conditioned by slow climate changes. Water level rise and inundation of the lowest lacustrine terrace usually produced a second littoral zone (ca 2 m deep) at a higher altitude. In this case the older littoral zone at a greater depth became shortly covered by mud and other types of lacustrine sediments (Garunkštis 1988).

Lithological investigations

Sediment composition and their bedding patterns give information about the amplitude of water level fluctuations. With rising water levels sediment zones shift towards the shoreline. And on the contrary, sand or gravel overlying muddy sediments imply a fall of the lake water level. Small water level fluctuations (within the range of 2 m) have almost no effect on the bottom sediments in deep water areas. A marked change in sediment characteristics took place when the water level fell by 5–10 m. Accumulations of freshwater lime and peat covered large bottom areas of the early Lake Dubičiai. The bedding pattern of lacustrine sediments in the Ūla outcrops and in excavations in the littoral zones and terraces of the early lake were described and utilized in palaeogeographic reconstructions. Sediment samples from the Ūla outcrops were taken for further lithological analysis.

Cartographic methods

Altitudes of the Dubičiai palaeolacustrine terraces were determined with an electronic tachometer 'Leica SmartStation'. The planar positions of points on terraces were fixed with an accuracy of 10 mm and the vertical position of 20 mm. Variations in the altitudes of the terraces were traced by instrumental topographic levelling. The relative height and altitude of the water levels in the glaciolacustrine basin were reconstructed from the combination of levelling and detailed cartographic data. The area once occupied by proglacial Lake Dubičiai was determined from large-scale (1 : 25 000 and 1 : 50 000) topographic maps.

RESULTS AND DISCUSSION

Geomorphological development of the Dubičiai region

Glaciers of the Late Nemunas (Late Weichselian) glaciation reached Lithuania at ca 23.0 ka BP (Baltrūnas 2002). Glacier lobes of the Grūda Stage (23.0 ka BP) started to melt ca 20.0 ka BP and glaciers of the subsequent, Žiogeliai Stage (19.5 ka BP) started to melt ca 18.0 ka BP (Baltrūnas 2002). Glaciers of the latter stage designed main topographic features of the study region.

The margin of the Grūda glacier reached the slope of the Ašmena Upland (Fig. 1) and only partly covered the western half of the Eišiškės Plateau (Švedas et al. 2004) but no end moraines were developed. Apparently, the margin of the receding glacier was thin and poorly saturated with diamicton. As a result only small hillocks composed of loam and sandy loam formed at the eastern edge of Dubičiai village (Fig. 1). The hillocks represent an extension of the Eišiškės Plateau towards Kalviai village. Scattered low hillocks are present also south of Dubičiai village. Dunes located at the northern edge of Dubičiai village have a different character. They extend from Šulai and Šiliniai villages to Gribaša and Rudnia. Relative altitude of the higher dunes reaches 20–25 m and that of the lower dunes 6–10 m. Absolute altitude of the hill tops reaches 170 m. In the course of time the thin edge of the receding glacier split into large ice blocks which were later covered by a thick layer of sand that helped to preserve the buried ice blocks for a long time. The buried ice blocks decayed completely in the Allerød to Boreal chronozones and formed a number of small thermokarst holes which hosted lakes.

Meltwater from the other glaciolacustrine basins in more elevated areas in the northeast was drained into the depression left by the Lower Merkys–Katra glacier lobe, located west of the Dubičiai basin. At that time the water level in proglacial Lake Dubičiai was at 140 m a.s.l. or even more (Švedas et al. 2004).

Glacial sediments of the Žiogeliai Stage (19.5 ka BP) are spread north of Grūda end moraine formations and have no direct impact on the topography of Dubičiai environs. However, meltwater from this ice margin eroded away end moraines and replenished the glaciolacustrine Katra–Čepkeliai basin southwest of Dubičiai (Švedas et al. 2004). At that time the highest water level in the Dubičiai glaciolacustrine basin may have been ca 140 m a.s.l.

Glaciofluvial streams from the ice recession period distributed sediments in the lower areas and reworked large amounts of sand and pebbles which formed surfaces at an altitude around 135 m a.s.l. (Figs 2 and 3). Smoothened surfaces at that altitude are present in the environs of Gribaša, Margiai and Krokšlys. Later the dry glaciofluvial sand was wind-blown into dune massifs in the Rudnia and Krokšlys environs. The highest points of the dunes reach altitudes between 145 and 155 m a.s.l.

During the Baltija Stage of the last glaciation (17.0 ka BP) meltwater flew along the previously generated valley and eroded through the northern part

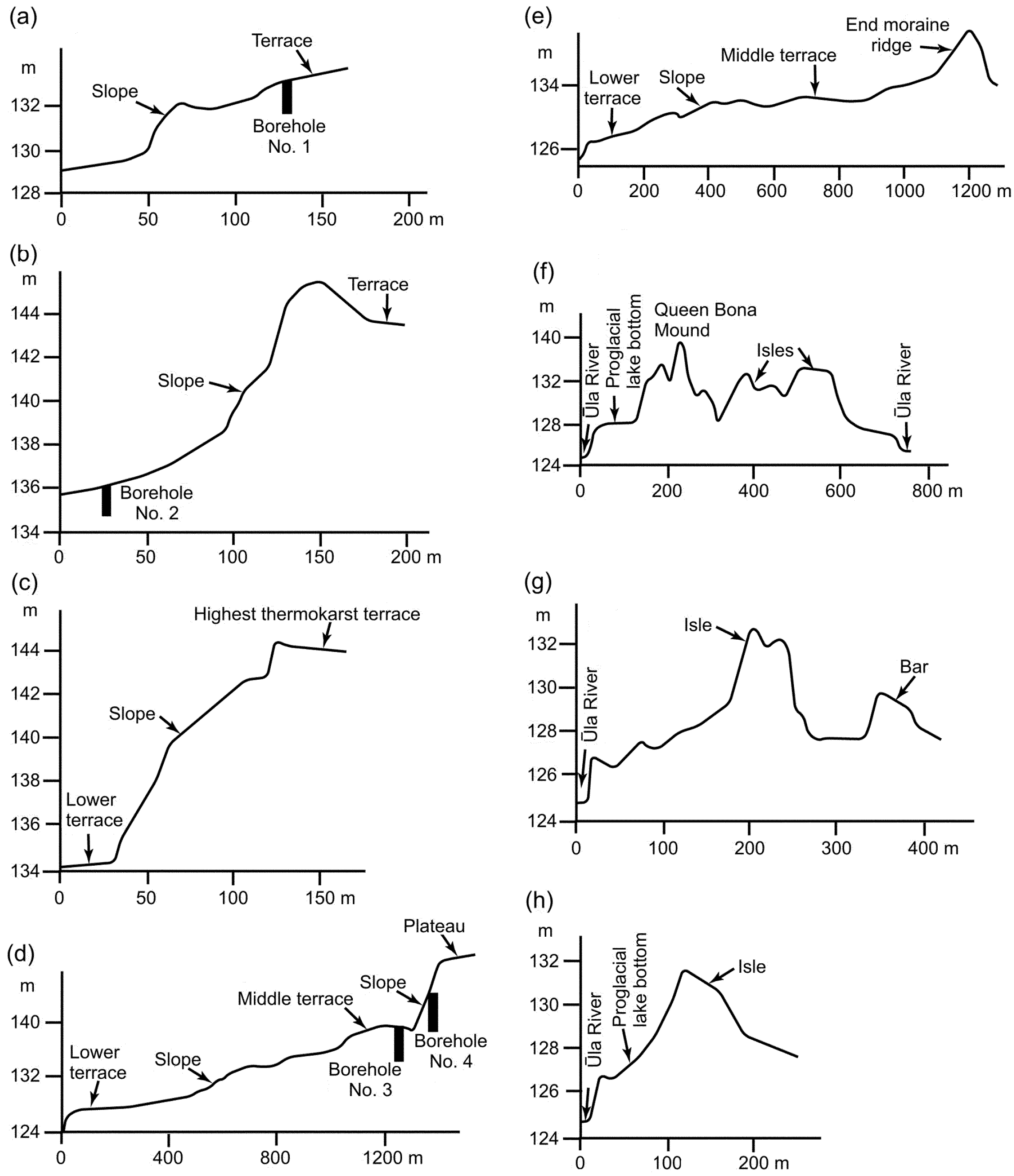

Fig. 2. Geomorphological cross sections from the Dubičiai glaciolacustrine basin: (a) northern shore; (b) upper levels of the northern shore; (c) highest levels in the north of the basin; (d) lower, middle and highest terrace of the northern shore; (e) lower and middle terrace and the end moraine ridge; (f) eastern shore with end moraine hummocks ('isles'); (g) eastern shore with end moraine hummocks ('isles') and bars; (h) central part of the glaciolacustrine basin with end moraine hummocks.

of the low Skroblus moraine ridge, then cut off the Matuizos erosional remnant from the Žiogeliai moraine ridge and headed towards the Katra–Čepkeliai basin along the Grūda River valley (Fig. 4) (Švedas et al. 2004). By that time an undulating glaciolacustrine sandy plain developed at the edge of the Eišiškės Plateau.

Intensive transformations in glacial topography took place at the end of the late (Weichselian) glacial and in the Early Holocene. The topography was markedly changed due to the formation of glaciokarstic lakes and subglacial to periglacial flow channels. Many small lakes, including lakes Dumblys, Dumblalis, Grikis, Katiušis and Tabalis

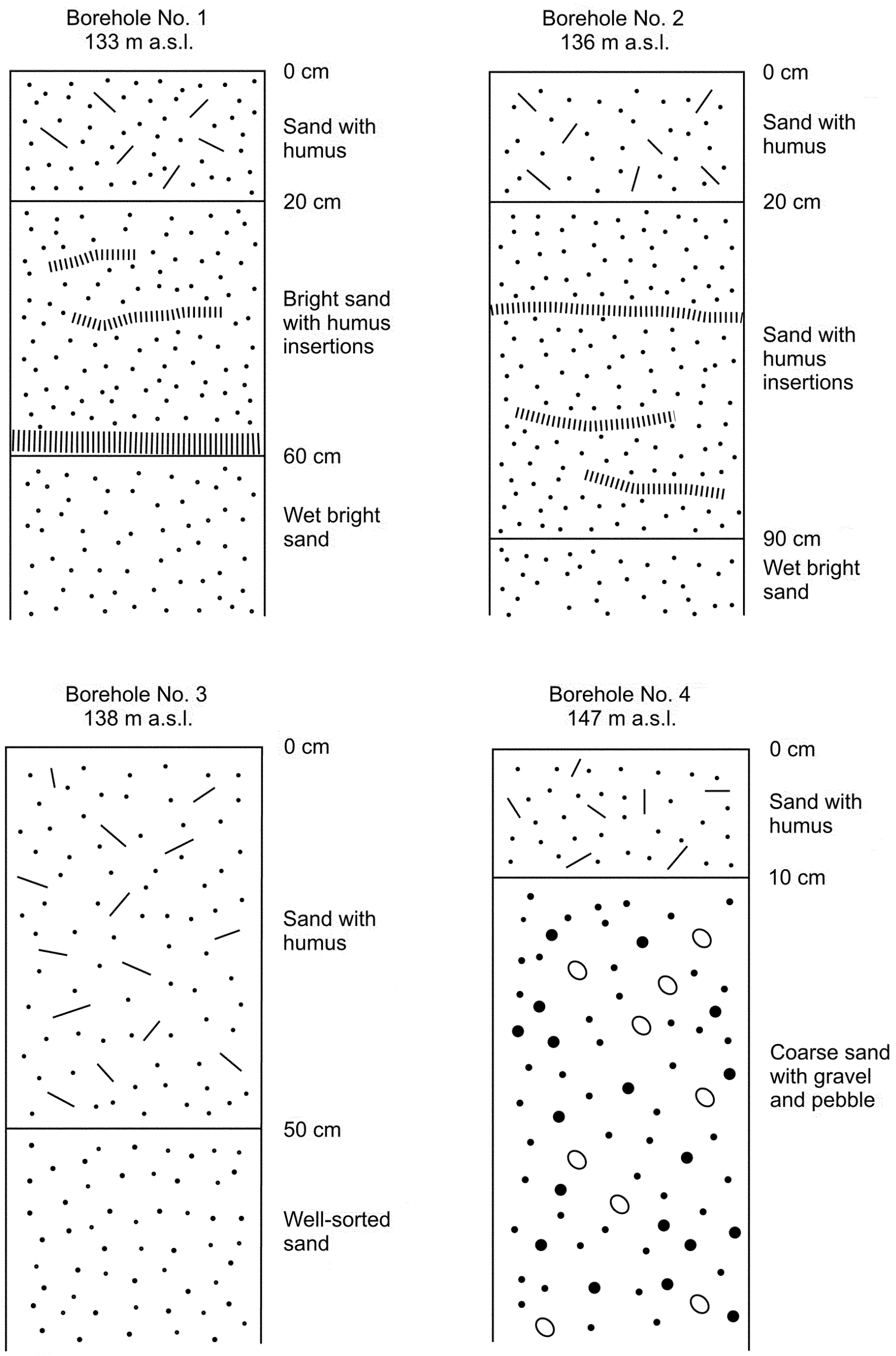

Fig. 3. Lithology of sediments in boreholes on the lower, middle and upper Dubičiai glaciolacustrine terraces. Location and numbers of boreholes are shown in Fig. 2.

(Fig. 4), were formed along the glacier edge of that time. Subglacial–periglacial flow channels at Paąžuoliai, Šiliniai and Podubičiai, which have preserved until today, also witness to the deglaciation process. Lakes Pelesa and Dūba that formed in the flow channels persisted the longest – until the first half of the 20th century.

Intensive wind activity during the Boreal was another factor that notably affected the relief of the Dubičiai basin. Bitinas (2004) has determined that aeolian processes in Lithuania started already in the late glacial and ended approximately 6000 years ago, that is in the second half of the Atlantic chronozone.

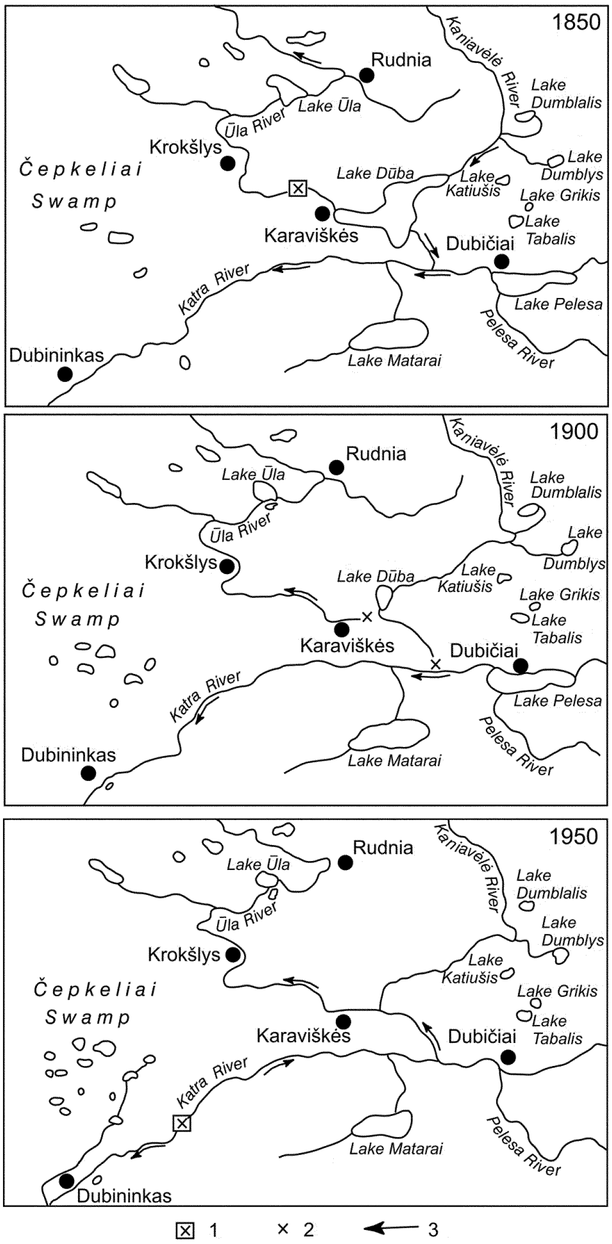

Fig. 4. Recession of lakes in the Dubičiai glaciolacustrine basin in historic times. 1, long-time watershed between the Ūla and Katra rivers; 2, short-time watersheds between the Ūla and Katra rivers; 3, direction of river flow.

Earlier Satkūnas et al. (1991) concluded that the most favourable conditions for the formation of large dune massifs in Lithuania occurred during the late glacial. In the middle Holocene, during the Atlantic chronozone, air temperature and humidity were increasing and the ground water level rose, contributing to vegetation development, which helped to stop aeolian sand movement.

Evolution of the Dubičiai glaciolacustrine basin at the end of the last glaciation

During the last glaciation large glaciolacustrine basins persisted for a long time in the southern part of the current Lithuanian territory. Sedimentation in some of these basins has lasted for almost 20 000 years. Deposited sediments include terrigenous material and remains of organic matter with spores, pollen and detritus of algae. From this material evidence on climate changes and water level fluctuations in Lithuania has been derived by a number of authors (Seibutis & Sudnikavičienė 1960; Kunskas 1963–1964; Savukynienė 1976; Seibutis & Savukynienė 1998; Stančikaitė et al. 2002; Švedas et al. 2004).

During the Older and Middle Dryas climate in Lithuania was prevailed by permafrost (Kabailienė 2006). Climate slightly improved during the Bölling chronozone, contributing to solifluction processes and slow formation of soils. At the beginning of the late glacial in Lithuania (16.5 ka BP) the water level in the Dubičiai basin was high. Judging from the levelling profiles (Fig. 2), the shores of the glaciolacustrine basin must have been at ca 140–145 m a.s.l. The coastal zone above the shoreline was not high, normally 2–3 m and occasionally 5 m above the water level (Figs 2 and 5). In the Allerød chronozone (12 900–11 900 cal BP) the water level decreased in the basin but the water remained cold in spite of change to warmer and more humid climate. Thermokarst processes resulted in the appearance of shallow lakes in the regenerated lower parts of topography. The river valleys began to form and small streams (Kaniavėlė, Nočia, Nizelė and Draciliškė) as well as the upper reaches of the current Ūla River started to develop. Small developing valleys of these rivulets drained the thermokarst lakes of Dumblys and Dumblalis into small Lake Tabalis and later into the Dubičiai basin (Fig. 4).

In the second half of the Allerød (12 500 cal BP) large amounts of lacustrine carbonates deposited in the Dubičiai basin, evidencing outflow of carbonate-saturated groundwater. In parallel the amount of organic matter in lake water and sediments increased. Sand, loam and clay, followed later by gyttja and peat, accumulated in the basin (Fig. 6). At the end of the Allerød (ca 12 000 cal BP) the first settlements appeared at the lake shores of the region (Rimantienė 1974).

Climate of the Younger Dryas (11 900–11 000 cal BP) was cold and dry. The water level in the Dubičiai basin dropped dramatically and water was cold and transparent. Bottom sandy deposits from this period show a decrease in organics content and cover peat, gyttja and freshwater lime of Allerød age (Kabailienė 2006).

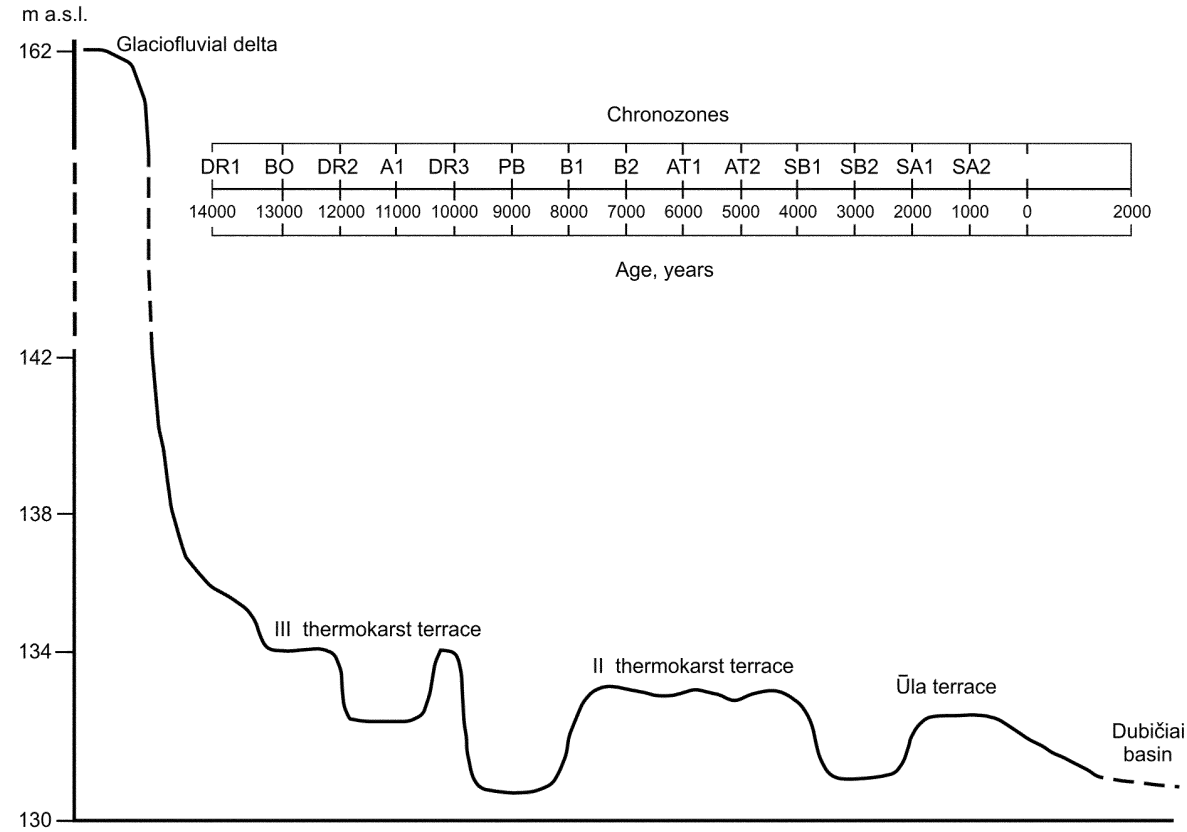

Fig. 5. Diagram representing changes in water level altitudes in the Dubičiai basin. Timetable and chronozones after Kabailienė (2006).

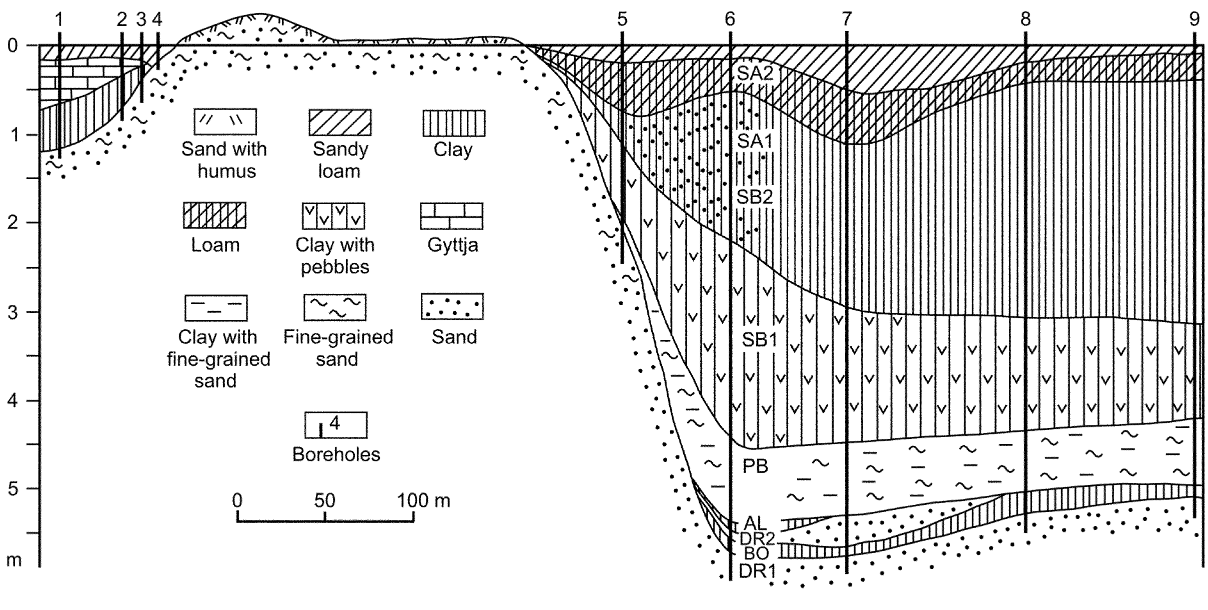

Fig. 6. Lithological cross section from the eastern part of the Dubičiai basin (after Kabailienė 2006).

Development of the basin after the late glacial

Climate of the Preboreal and early Boreal was slowly turning warm and humid. During the late Boreal, Atlantic and Subboreal chronozones the air temperature and humidity increased even more. In the early Subatlantic the average annual air temperature may have exceeded the present values by 1–2 °C, and the annual precipitation exceeded the recent precipitation values (Švedas et al. 2004). Spores and pollen present in the sediments indicate that climate during the Subatlantic chronozone was warmer than in the last hundred years (Stančikaitė et al. 2002; Kabailienė 2006). Only in the late Subatlantic the climate conditions approached the recent ones.

Climate variations have entailed water level fluctuations in lake basins. During the Preboreal and early Boreal the water level in lakes was at ca 129–130 m a.s.l., being evidently the lowest during the Holocene (Fig. 5).

Temperature rise in the Boreal and Atlantic created favourable conditions for accumulation of organic materials (e.g. peat). Particularly high pollen concentrations (600×10^3 to 700×10^3 pollen grains/cm^3) were determined in the sediments of littoral zones, indicating intensive accumulation of organic materials (Stančikaitė et al. 2002). The accumulation of gyttja and freshwater lime was also intensive during the Boreal and Atlantic chronozones. As a result the abundance of terrigenous clastic materials in the lacustrine sediments of that time is low. Thus, the late Boreal, Atlantic and early Subboreal were the times when accumulation of carbonates, organic-rich mud and gyttja was the most intensive (Fig. 7). This period was followed by paludification and peat accumulation in the Late Holocene.

Fragments of charcoal found in the sediments of the Boreal and Atlantic chronozones testify to the beginning of primitive agriculture in the Dubičiai environs ca 3000 years ago (Rimantienė 1974; Kabailienė et al. 2001). In the early Subatlantic conditions for agriculture declined gradually due to water-saturated soils. By the late Subatlantic recent soils developed and agriculture intensified in the region again (Seibutis & Savukynienė 1998).

The water level in the Dubičiai basin underwent frequent fluctuations during the late glacial and the Holocene (Fig. 5). In general, in the Atlantic and Subboreal the water level rose and water exchange in the smaller lakes improved. However, an episode of dramatic water level decrease occurred at the beginning of the Subboreal (Fig. 5). As a result of this event, the shallow littoral zone of the lake turned into bogs. The accumulation of organic material was very intensive and drainage conditions in the basin deteriorated. In the early Subatlantic the water level rose again, drainage conditions improved and the lakeside bogs became slushy.

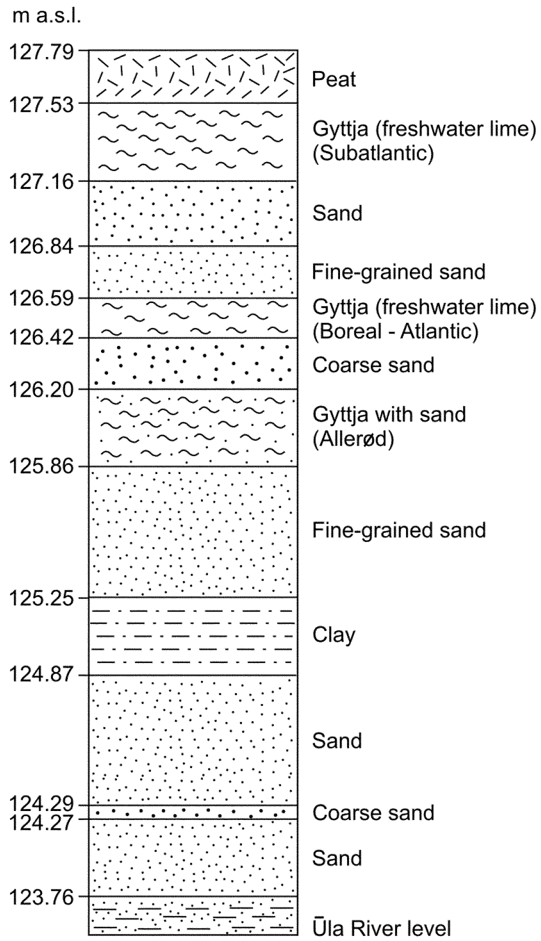

Fig. 7. Sediment sequence at the Ūla River in the northern part of the Dubičiai glaciolacustrine basin.

In the late Subatlantic the water level in the basin decreased slowly (Šinkūnas et al. 2001) and only three regions of the former large lake survived as bodies of water: lakes Dūba, Pelesa and Matarai, which persisted until the 19th century (Fig. 5).

Historic times – palaeogeography and settlement history

Changes in the hydrographical network reflect the development of lakes Pelesa, Dūba and Matarai, which preserved longest in the Dubičiai basin. In 1850 the area of Lake Dūba was 221 ha, whereas in 50 years, by 1900, it had reduced to 20 ha (Eitmanavičienė & Endzinas 1977). According to local people the lake once abounded in fish. During high spring floods the water rise in Lake Pelesa would be sufficiently high for Dubičiai fishermen to boat from Dubičiai to Lake Dūba (Fig. 5). The boats were moored by the stockyards standing on the low shore of the lake. This situation lasted until 1920–30 when the upper reaches of the Ūla River were eroded deep enough, or cleaned for rafting, which resulted in the capture of the Kaniavėlė and Katra rivers. That was later followed by drainage of lakes Pelesa and Matarai through the Ūla River. Lake Matarai persisted the longest due to its deepest depression, but even it disappeared a few decades after the large-scale land amelioration was concluded in the former area of the Dubičiai glaciolacustrine basin in 1958–59. After the amelioration works even small thermokarst lakes dried and are almost overgrown by now. This is exemplified by Lake Tabalis, from which a nameless rivulet takes its source and falls into the Ūla River at Dubičiai village (Švedas et al. 2004).

The evolution of the Dubičiai glaciolacustrine basin is evidenced also by archaeological data collected by researchers of the Lithuanian Institute of History. According to them (Rimantienė 1974), along with the Dubičiai settlement two more settlements – Mesolithic and Neolithic ones – existed on the island and in the shore of the glaciolacustrine basin near Margiai village. The Dubičiai settlement was situated in the southern part of the present Dubičiai village, i.e. in the so-called Salaitė hillock on the bank of the Ūla River. The riverbank is about 50 m wide and 100 m long. This settlement site was investigated by archaeologists from the Lithuanian Institute of History (headed by A. Bernotaitė) in 1959 and 1962, and a cultural layer of the Stone Age with typical artefacts was uncovered. This settlement is dated to the end of the Late Neolithic, from 3rd to 2nd millennium BC.

Above the Stone Age cultural layer there is another, 0.4–0.5 m thick cultural layer dated mostly to the 1st–2nd centuries AD, while its uppermost horizon is from the 14th–16th centuries (Rimantienė 1974). The third settlement site in the Dubičiai environs is located on the left bank of the Ūla River about 100 m from the river channel. This settlement was developed on one of the larger (0.8 ha) hillocks in the area. At the times of high water stands the hill became an island. This settlement site has three cultural layers – Early Neolithic (4th millennium BC), Late Neolithic and Early Feudalism.

CONCLUSIONS

1. Levelling of the wide littoral zones and higher terraces provide evidence about slow changes in water level in the majority of cases when it fluctuated. This was probably due to the large area and volume of the lake, and because of limited water inflow, conditioned by climate changes. Water level rise and inundation of the lowest lacustrine terrace usually produced a second littoral zone (ca 2 m deep) at a higher altitude.
2. Under the conditions of a stable water level terrigenous sediments deposited in the littoral zone while gyttja, freshwater lime, plant and shell detritus accumulated in deeper areas. The following rise in water level shifted sedimentation zones towards the shores. The older littoral sandy sediments were overlain by organic mud. Water level fluctuations within 2 m have produced no great effect on deep water sediments but the fall in the water level by 5–10 m radically changed sedimentation conditions in the basin.
3. The highest glaciofluvial thermokarstic terrace (155–160 m a.s.l) formed in the course of the recession of the Žiogeliai glacier (18.0 ka BP). The lower terraces were formed during the Dryas–Allerød (14 000–12 000 cal BP) period at an altitude of 144 m a.s.l., and during the Preboreal–Atlantic (11 000–7 000 cal BP) at ca 134–135 m a.s.l. The Ūla River terrace (132 m a.s.l.) developed during the Subatlantic (ca 4500 cal BP). About 150–100 years ago the final natural drainage of the basin took place, which in the 1950s was developed further by artificial drainage through land amelioration works.
4. Intensive change in the topography of the region occurred at the end of the late glacial and the Early Holocene. Thermokarst processes and subsequent regeneration of periglacial flow channels began in the Allerød and resumed in the Boreal chronozone. Small lakes (e.g. Dumblys, Dumblalis, Grikis, Katiušis and Tabalis), located next to the ice-marginal zone, originate from that time.
5. Variations in climate conditions have entailed water level fluctuations in the Dubičiai basin. In the Preboreal and early Boreal the water level was the lowest (129–130 m a.s.l.) throughout the Holocene. The most intensive accumulation of lacustrine carbonates and gyttja in the Dubičiai basin took place in the late Boreal, Atlantic and early Subboreal chronozones. Paludification and peat accumulation started in the Subatlantic.
6. The latest stage in the development of the Dubičiai glaciolacustrine basin began in the middle of the 19th century. In 50 years the area of lakes reduced tenfold – from 221 ha in 1850 to 20 ha in 1900. In the first half of the 20th century, due to erosion of the Ūla River channel, part of the Katra River drainage basin was captured by the Ūla River and water from the few existing lakes (Matarai, Pelesa and Dūba) was gradually drained into the Ūla River. Remnants of the old Lake Dubičiai ceased to exist after the land amelioration works were carried out in 1958–59.

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Dubičiai (Lõuna-Leedu) jääjärvelise tekkega basseini paleogeograafia ja evolutsioon

Algimantas Česnulevičius ja Kęstutis Švedas

Dubičiai jääjärveline bassein moodustus vahetult pärast viimase jäätumise liustike (Žiogeliai faas) taganemist ja sellele järgnenud termokarstiprotsesside ning settekuhjumise käigus. Vastavalt veetasemete üldisele, lühikeste tõususperioodidega vaheldunud langusele kujunesid välja peamised terrasside tasemed 155–160 m, 144 m, 134–135 m ja 132 m absoluutkõrgusel. Boreaalist alates toimus intensiivne jütja ja järvelubja ladestumine, soostumine ning järvede kinnikasvamine intensiivistus Subatlantikumis. Ajaloolistest andmetest on teada, et 19. sajandi teise poole 50 aasta jooksul vähenes Dubičiai nõos paiknevate järvede pindala 221 hektarilt 20 hekatrini. Viimane etapp piirkonna järvede hääbumises saabus 1958.–59. aastal toimunud maaparandustööde tagajärjel.