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Glaciolacustrine kame terraces as an indicator of conditions of deglaciation in Lithuania during the Last Glaciation

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Abstract

Over the recent years, while executing the geological mapping of the Lithuanian territory at a scale of 1:50 000, attention have been given to kame terraces adjoining the recessional marginal ridges left by glacier lobes of the Last (Upper Nemunas, Late Weichselian) Glaciation. For a long time, only the kame terraces formed between dead ice blocks and the internal (with respect to the glacier lobe), i.e. proximal slopes of the marginal morainic ridges have been known. During the process of mapping, the kame terraces have been subdivided into the glaciofluvial (sand, gravel) and glaciolacustrine (clay, silt) according to their lithological composition. The glaciolacustrine kame terraces adjoining the distal slopes of the recessional marginal morainic ridges of the Middle Lithuanian, North Lithuanian and Pajūrio phases of the Last Glaciation have been found and examined. The origin of these terraces could be explained only by the hypothesis that the accumulation of the above-mentioned marginal ridges and kame terraces took place between the margin of active ice lobes and the blocks of dead ice. Supposing that when the glacier of the Last Glaciation was melting, it was the arial and not the frontal deglaciation that was definitely dominating. The cold periods of glacier activation (so-called stadials and phasials) were changed with warmer periods. However, the latter periods were too cold and too short that the territory could be deglaciated completely, that is why they cannot be interpreted as interstadials or interphasials according to the climatostratigraphic criterion.

Keywords: Glaciation; Kame terrace; Marginal ridge; Deglaciation; Glaciolacustrine sediments

1. Introduction

In geological dictionaries, kame terrace is defined as a "terrace-shaped ridge formed by stratified sand and gravel layers and resulting from ice meltwater sediments accumulated between the melting glacier or dead ice blocks and the higher slope of the glacier valley or lateral moraine" (Gary et al., 1979). The kame terrace is also "commonly pitted with "kettles" and has an irregular ice-contact slope" (Hawley and Parsons, 1980). Kame terraces in Lithuania and neighbouring regions are distributed in the relief formed by the glacier of the Last (Upper Nemunas, Late Weichselian) Glaciation. For a long time, kame terraces have been identified as terraces formed by glaciofluvial processes (Basalykas, 1969; Jurgaitis, 1984; Mikalauskas, 1985; Šinkūnas and Jurgaitis, 1998). Since 1981, while compiling large-scale (1:50 000) Quaternary geological and geomorphological maps in the Baltic countries, kame terraces have been subdivided into glaciofluvial and glaciolacus-

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trine ones (Grigelis, 1981). Both types of terraces have the same geomorphological form but different lithological composition. Glaciofluvial kame terraces are composed of sand and gravel, while glaciolacustrine kame terraces contain mainly of clay and silt, i.e. deposits of these terraces were formed in different sedimentological conditions. Even before, all the terraces known are dislocated between dead ice and the internal (regarding the glacier lobe), i.e. proximal slopes of the marginal morainic ridges. However, over the recent years, the glaciolacustrine kame terraces have been found on the distal slopes of Middle Lithuanian, North Lithuanian and Pajūrio recessional marginal morainic ridges (Fig. 1). In order to explain the origin of the above-mentioned terraces, we have to change completely the imagination about palaeaogeographical conditions in Lithuania that existed during the decay of ice-sheet of the Last Glaciation.

2. Methods

There have been no exhaustive studies of glaciolacustrine kame terraces on Lithuania until the recent time. These terraces are mapped when large-scale (1:50 000) Quaternary geological and geomorphological maps are compiled and the related aerial photographs of various scales (1:17 000–1:21 400) are interpreted. Results of these interpretations are usually checked under field conditions by making shallow (1.0–1.2 m depth) digs or hand-made borings. Only in single places that full thickness of sediments of glaciolacustrine kame terraces have been opened by boreholes. Therefore, the glaciolacustrine kame terraces in Lithuania were recognised using geomorphological and, particularly, lithological criterions.

This paper presents only the very first results of lithological investigations of sediments of glaciolacus-

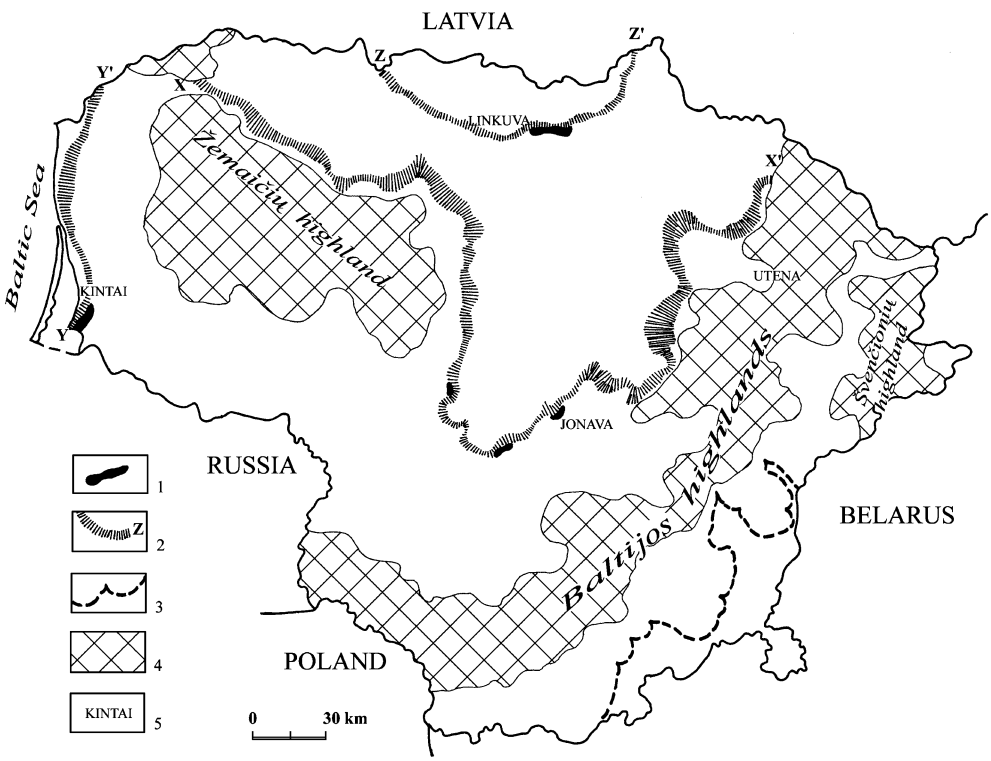

Fig. 1. Situational scheme. (1) Glaciolacustrine kame terraces (size not in a scale); (2) the most expressed recessional marginal morainic ridges of the Last (Upper Nemunas, Late Veichselian) Glaciation: X-X′ —Middle Lithuanian, Y-Y′ —Pajūrio, Z-Z′ —North Lithuanian; (3) limit of the ice-sheet of the Last Glaciation; (4) the main highlands of Lithuania formed during the Last Glaciation; (5) locations mentioned in the text. The limit of the ice-sheet of the Last Glaciation and location of recessional morainic ridges indicated according to Guobytė (2002).

trine kame terraces. The geological structure and lithological composition of these terraces has been determined only close to Linkuva (Fig. 1), on a terrace adjoining the marginal ridge of the North Lithuanian phase. Granulometric composition of terrace sediments of 81 samples taken from four boreholes has been examined. In these sections, a macroscopic analysis of glaciolacustrine terrace sediment textures has also been carried out. The main lithological types of sediments have been identified according to granulometric classification used in the Geological Survey of Lithuania, i.e. clay (particles < 0.005 mm), silt (0.005–0.05 mm), sand (0.05–2.0 mm), and gravel (>2.0 mm).

3. Geological structure of glaciolacustrine kame terraces

Three fragments of glaciolacustrine kame terraces adjoining the distal slope of the Middle Lithuanian recessional morainic ridge have been detected (Fig. 1). There is a more detailed information about kame terrace close to Jonava because only this area was mapped at a large-scale. This glaciolacustrine kame terrace (Fig. 2) is up to 4 km long, its width varying from 400 to 700 m. The terrace is 40–45 m above an alluvial plain stretching at the distal edge of the marginal ridge. The surface of the terrace, with its absolute height of 80–90 m, is very uneven, intersected by ravines and gullies, sometimes pitted, slightly inclined to the slope of the terrace. The glaciolacustrine kame terrace is composed of brown, rich, plastic clay with the thickness varying from 6 to 20 m. The clay thickness is interbedded with thin (up to 10 mm) layers of brownish silt. In the upper part, the clay contains up to 10% of coarse sand, gravel and carbonaceous concretion admixture. In some places of the lower part of the kame terraces, the interlayers (1–2 m thick) of silty–clayey sand occur in the clay sediments.

The geological structure of the glaciolacustrine kame terrace adjoining the distal eastern slope of the

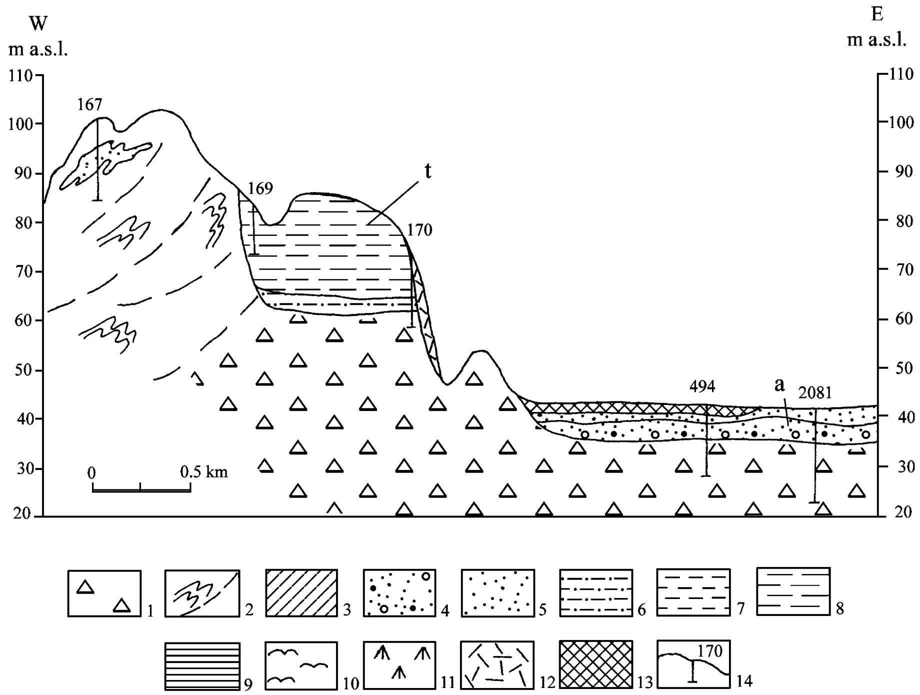

Fig. 2. Geological cross-section via marginal morainic ridge and glaciolacustrine kame terraces close to Jonava. Deposits of the Last Glaciation and Holocene: (1) basal till; (2) deformation till; (3) flow till; (4) gravel; (5) sand; (6) silty sand or sandy silt; (7) silt; (8) clay of massif structure; (9) laminated (varvic) clay; (10) gyttja; (11) peat; (12) deluvium. (13) antrophogenic deposits; (14) borehole and its number. Indicated by indexes: t—sediments of glaciolacustrine kame terrace; a—alluvium.

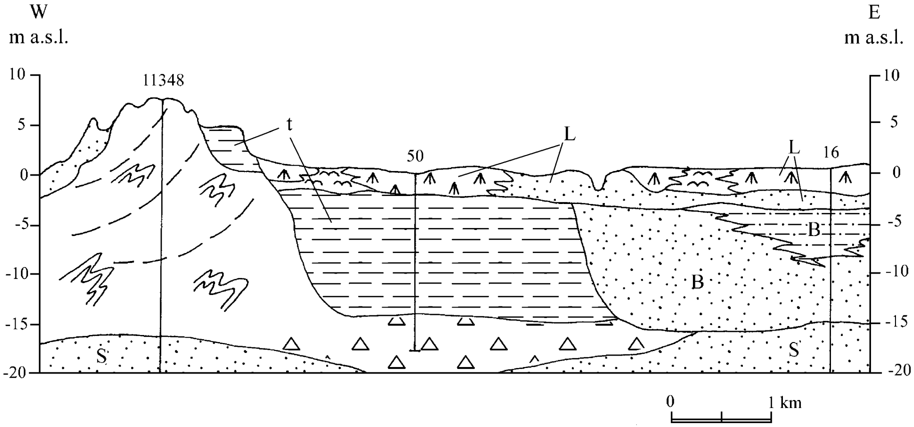

Fig. 3. Geological cross-section via marginal morainic ridge and glaciolacustrine kame terraces close to Kintai. For legend, see Fig. 2. Indicated by indexes: t—sediments of glaciolacustrine kame terrace, L—marine and organogenic sediments deposited during the Litorina Sea stage; B—glaciolacustrine sediments deposited in the Baltic Ice Lake, S—glaciolacustrine sediments of Saalian Glaciation.

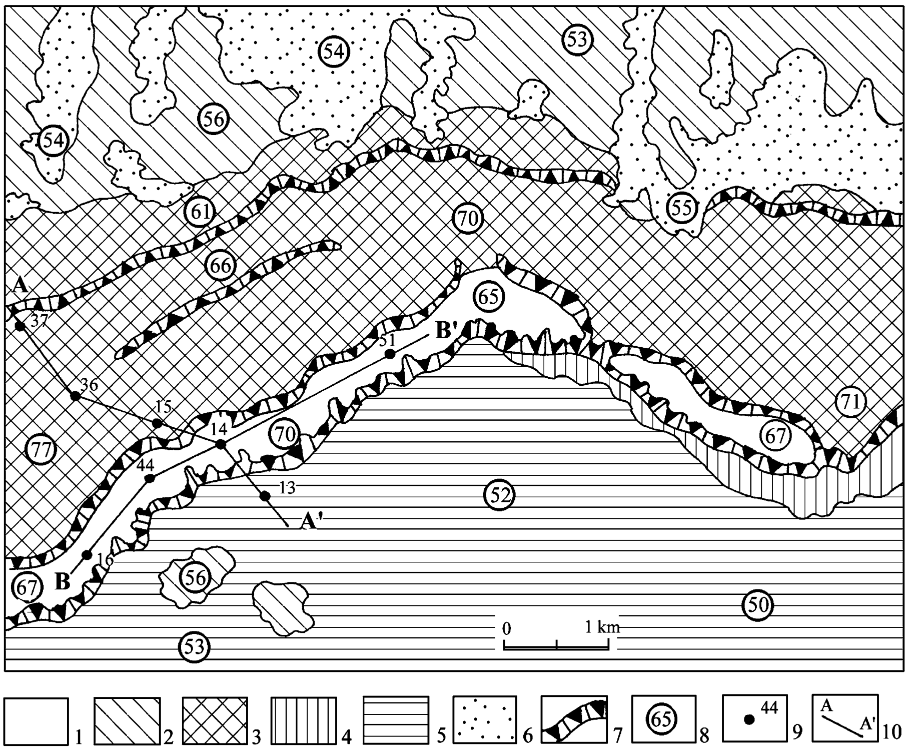

Fig. 4. Geomorphologic scheme of marginal morainic ridge and glaciolacustrine kame terrace, east from Linkuva. (1) Glaciolacustrine kame terrace; (2) basal till plain; (3) marginal morainic ridge; (4) solifluction sheet; (5) glaciolacustrine plain of ice-dammed lake; (6) plain formed by sediments of different genesis (glaciofluvial, glaciolacustrine, lacustrine, etc.); (7) steep slope; (8) prevailing altitude of relief, in metres; (9) borehole and its number; (10) line of geological cross-section, in Fig. 5.

marginal morainic ridge of Pajūrio phase close to Kintai have some differences from terraces in other localities (Fig. 3). There are two kame terrace levels (or two terraces) in this area. The upper terrace (from 0.2 to 1.2 km width) traces a few kilometres to the east-north and to the south-west from Kintai along the eastern slope of marginal ridge. The flat surface of the terrace is located on the 5–6-m absolute height. Glaciolacustrine sediments of the kame terrace are presented by brown or yellowish brown clay of massif structure, in some places—by silty or sandy–silty clay. The lower terrace is completely buried under late glacial and Holocene sediments accumulated during the Baltic Ice Lake and the Litorina Sea transgressions, or covered by bog deposits. According to the borehole data, the lower terrace stretches in sub-meridianal direction for about 4 km, and it can be 2.0–2.5 km wide. The top of the glaciolacustrine clay occurs about 2–3 m below the present sea level. The terrace is formed of 8–12-m-

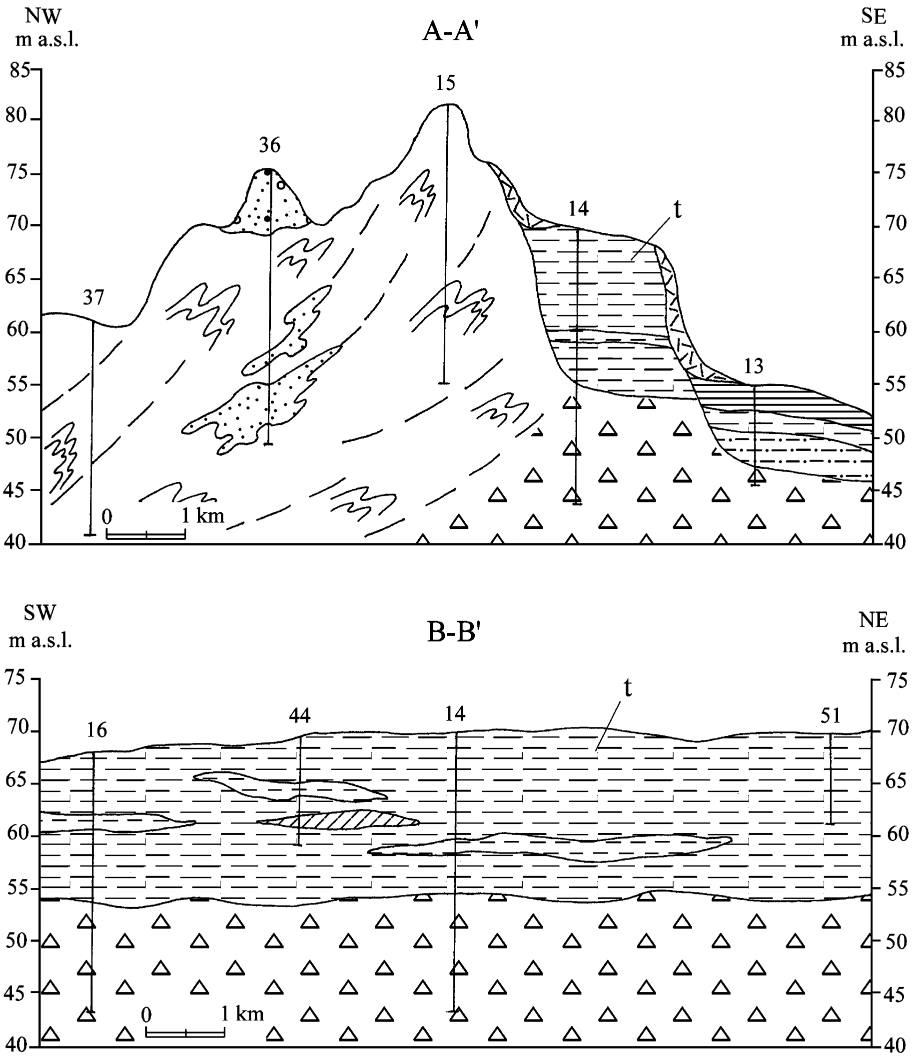

Fig. 5. Geological cross-sections via marginal morainic ridge and glaciolacustrine kame terrace close to Linkuva. Location of cross-sections indicated in Fig. 4. For legend, see Fig. 2.

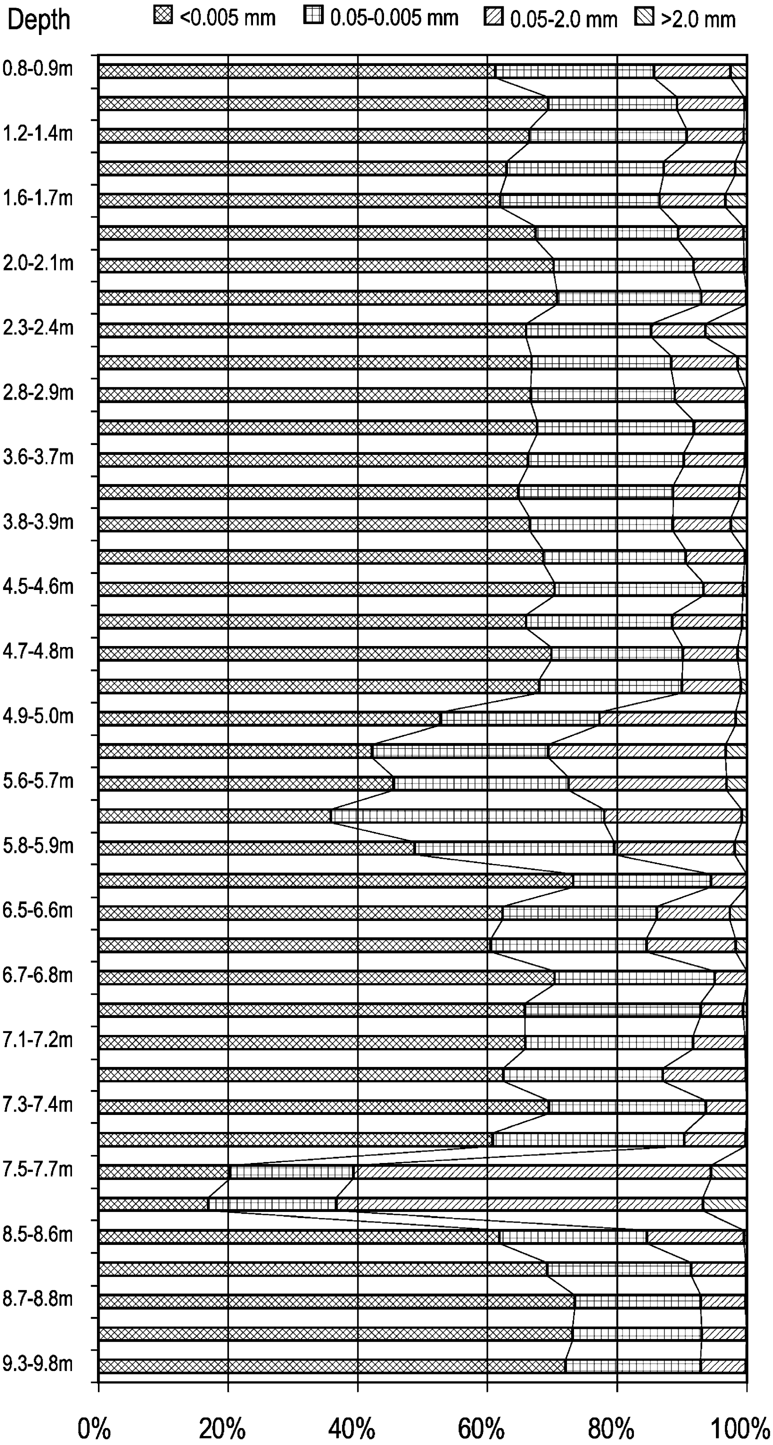

Fig. 6. Granular compositions of kame terrace sediments in borehole No 44.

thick clay of massif structure. The colour of the clay varies from brown or greyish-brown to greenish-grey and grey. Silt interlayers of various thicknesses (from 1–2 mm to 10–20 cm) are rather frequently found in the clay sediments.

The glaciolacustrine kame terrace, stretching at the edge of the distal part of the North Lithuanian marginal morainic ridge close to Linkuva is about 10 km long and 500 m wide (Fig. 4). Its surface, slightly inclined southward, reaches 65–70 m in absolute height. The northern edge of the terrace is bound by the marginal ridge, which rises more than 80 m above sea level. The surface of the terrace is 10–15 m above the glaciolacustrine plain of ice-dammed lake (sediments presented generally by varved clay) that is located to the south of the terrace (Fig. 4). Ravines intersect the slope of the kame terrace. The solifluction debris is developed in the eastern part of terrace foot. In general, the kame terrace consists of glaciolacustrine sediments; its fixed maximal thickness is 15.3 m (Fig. 5). Glaciolacustrine sediments are presented by brown clay of massif structure (or silty clay), in some places with small lenses (up to 1–2 cm thick) of fine-grained sand. The rhythmic structure of clayey sediments was determined only in few places. The admixtures of gravel and carbonaceous concretions (diameter up to 10 mm) in clay sediments is up to 3–5%. Sometimes in the clayey sediments 0.1–1.2-m-thick interlayers of silty–sandy clay or clayey–sandy silt (Fig. 6, depth 4.9–6.0 m) as well as flow till insertions (Fig. 6, depth 7.5–8.3 m) is found.

Special attention should be taken to the fact that in the whole Lithuania the surfaces of glaciolacustrine kame terraces as a rule are relatively higher (up to 15–20 m) than the surfaces of sediments of ice-dammed lakes. On the other hand, the sediments of glaciolacustrine kame terraces are generally presented by clay of massive structure, while laminated sediments, especially varved clay, are common only for the deposits of ice-dammed lakes of Lithuania (Kazakauskas, 2000) and neighbouring areas (Pavlovskaya, 1999). A preliminary comparison of granulometric composition of sediments of ice-dammed lakes (Kazakauskas, 2000) and glaciolacustrine kame terraces (Fig. 6) shows, that the latter sediments contain bigger amount (up to 5–10%) of sand particles. More detailed sedimentological analysis of glaciolacustrine kame terraces is possible only after future investigations.

4. Theoretical model of formation of glaciolacustrine kame terrace

Appearance of the glaciolacustrine kame terrace adjoining the distal slope of marginal morainic ridge, to our opinion, could be explained exclusively by the hypothesis that both these geomorphologic forms occurred between the active lobe of glacier and blocks of dead ice. This supposition served as a basis for elaborating a theoretical model of the formation of glaciolacustrine kame terrace (Fig. 7).

When the glacier lobe advancing without any major obstacles is on its way, in the lower part of the glacier a basal till is formed (Fig. 7A). Upon the climate becoming warmer (the so-called interstadial or interphasial), the glacier melting begins, the glacier lobe split into separate fields and blocks of dead ice. In the internal part of the glacier lobe, the areal ice melting prevails, the thickness of ice-sheet shield decreases (Fig. 7B).

With the beginning of the new cold period (so-called stadial or phasial), the ice-sheet become thicker again, its advance restarts (Fig. 7C).

After the climate gets warmer again, the glacier advancement slows down, the glacier lobe margin for a certain period of time remains in more or less stable position, and a ridge of marginal morainic formation presented by deformation till appears here (Fig. 7D).

During further ice-sheet melting, the boundary between the older dead ice blocks and a newly appearing marginal ridge often becomes the main meltwater flowing way, with the formation of rather wide and deep valley. Under certain conditions in some places the valley was damped; narrow and deep glaciolacustrine basin has been formed in which clayey sediments accumulated (Fig. 7E). A big thickness of clay of massif structure indicates that the water regime in such basin was relatively stable, so seasonal (winter–summer) fluctuation did not have influence (or it was very weak) in the process of sedimentation. Sometimes the stable regime of sedimentation was disturbed only by mudslides from steep slopes of dead ice blocks or of morainic ridge; they left the flow till intersections in the clay thickness (Fig. 5).

During further ice-sheet decay, inversion of the relief took place, and the clayey thickness that had filled the valley form basin became a glaciolacustrine

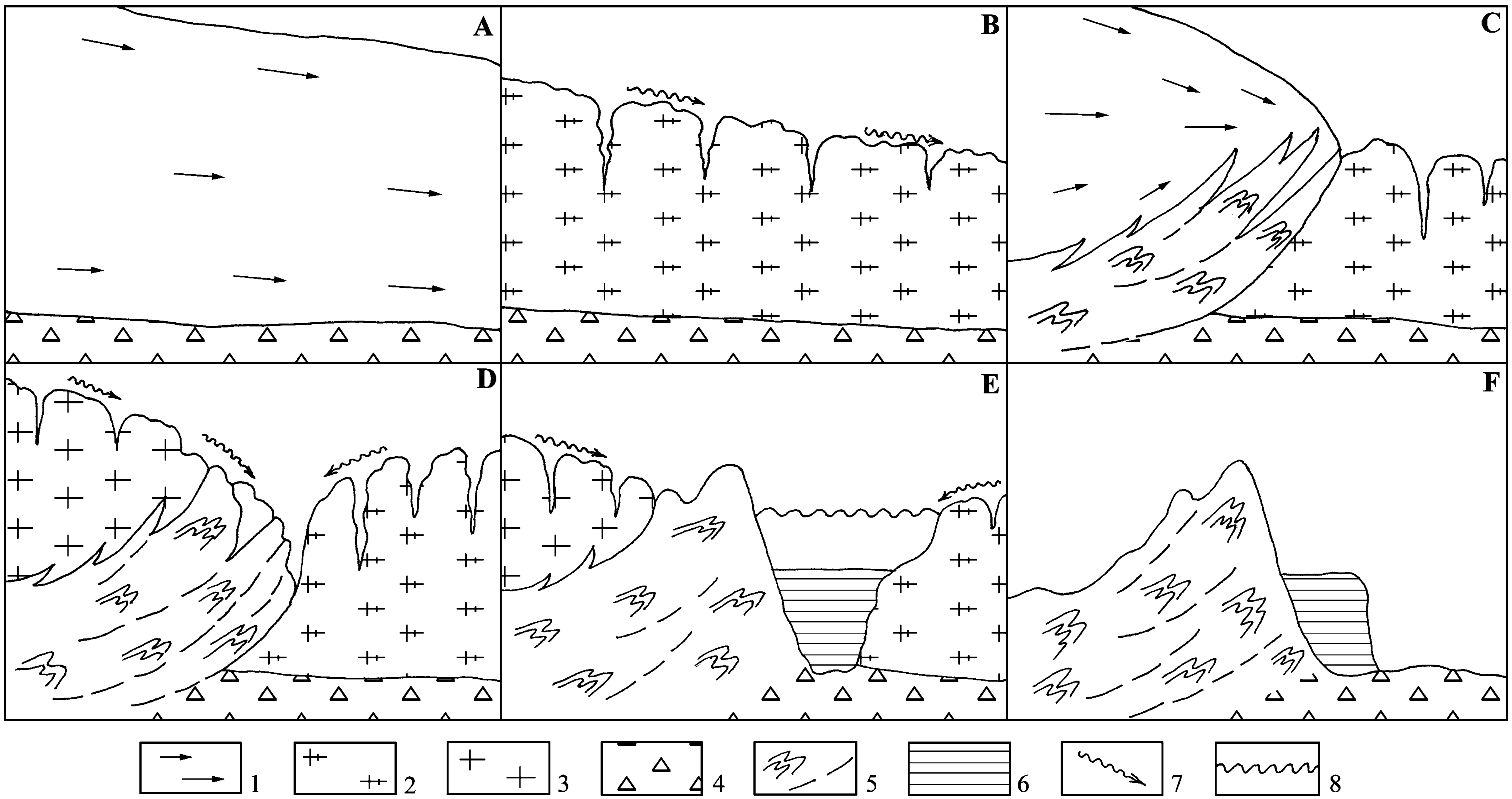

Fig. 7. Theoretical model of formation of glaciolacustrine kame terrace. (1) Active ice; (2) dead ice of older glacier oscillation; (3) dead ice of younger glacier oscillation; (4) basal till; (5) deformation till (glaciodislocations); (6) glaciolacustrine sediments (clay, silt); (7) main direction of meltwater flow; (8) meltwater basin.

kame terrace adjoining the distal slope of marginal morainic ridge (Fig. 7F). Probably, in some places the process of glacier melting and flooding of meltwater basins had a cyclic character, so, a few levels of glaciolacustrine kame terrace could have been formed (Fig. 3).

5. Discussions and conclusions

The described hypothesis of the formation of glaciolacustrine kame terraces brings essential changes into the currently predominant concept of the dynamics of deglaciation of Lithuania and the adjacent regions at the end of the Last Glaciation. So far, the opinion prevails that the stadials and phasials of the Last Glaciation were interrupted by a rather long and warm periods when the interstadial and interphasial sediments (organogenic, lacustrine) accumulated, i.e. the territory have been deglaciated completely during these periods. Such opinion is reflected in the published palaeogeographic schemes of deglaciation of territory of Lithuania (Mikalauskas, 1985) or in the local stratigraphic schemes of the Quaternary (Gaigalas, 1995, 2001). However, either in Lithuania or in the adjacent regions that were covered by ice-sheet of the Last Glaciation no geological section containing interstadial or interphasial sediments have been found. Previously, a few geological sections containing organogenic sediments both in Lithuania and the adjacent regions were attributed to the so-called interstadial formations of the Last Glaciation; some of them at a certain period of time were even recognised as the stratotypes of interstadial deposits (Gudelis, 1973; Savvaitov et al., 1964). Later, after the more exhaustive studies, it has been determined that sediments of Antaviliai interstadial formed during Butėnai (Holstein) interglacial (Satkūnas and Hütt, 1999). It was estimated that sediments of the Ūla interstadial formed in the postglacial time (Blažauskas et al., 1998) and that sediments of Raunis interstadial occurs not in situ, i.e. in the glaciodislocations (Dreimanis and Zelčs, 1995).

The necessity to revise the approach to the dynamics of the ice-sheet of the Last Glaciation and to the deglaciation of the glaciated territories is also supported by the recent results of other geological investigations. For example, results of geological mapping in North Lithuania showed that even after detailed lithostratigraphical studies of petrographic composition of gravel part of tills, the moraine formed by the glacier of the Last Glaciation it is impossible to subdivide into stadial or phasial formations in its vertical sections. Only in the East Lithuania, in the region situated closer to the border of the maximal expansion of the last ice-sheet (Utena environs), it was possible to distinguish two lithologically different till layers of the Last Glaciation. According to the petrographic composition of gravel part of tills, these two layers were interpreted as the Grūda and the Baltija stadial moraines (Gaigalas et al., 1989). Glaciofluvial and glaciolacustrine deposits intersect the two till layers in some localities. However, the attempt to reconstruct the palaeogeographic conditions of the formation of these deposits resulted in the conclusion that in the period between the Grūda and the Baltija stages cold climate predominated and on the study area large blocks of unmelted dead ice were stretched (Bitinas, 1998).

Thus, geomorphologic and geological data presented in the paper, to our opinion, testify to the hypothesis that accumulation of the so-called stadial of phasial recessional marginal morainic ridges and glaciolacustrine kame terraces took place between the active lobes of glacier and the blocks of dead ice. We are inclined to maintain that the glacier melting was definitely accompanied by the areal deglaciation that prevailed against the frontal one. The separate cycles of glacier activation were interrupted by rather cold and relatively short periods (maybe not longer than a few hundred years) when the territory could not deglaciate completely. Probably, this is the main reason why we cannot find any section with sediments formed in interstadial or interphasial conditions (i.e. organogenic, alluvial or lacustrine sediments). According to the demands of Lithuanian Stratigraphic Guide (Grigelis et al., 2002), the Quaternary stratigraphic subdivision is made by applying climatostratigraphic criterion. Therefore, all the climatostratigraphic units representing sediments of cold or warm climate period (including stadials and phasials) must have its stratotypes. However, so far there are no stratotypes for stadials and phasials. Therefore, the so-called stadials (Baltija, Grûda) and phasials (Pajūrio, North Lithuanian, Middle Lithuanian and others) of the Last Glaciation should be more properly called as oscillations.

We think that proposed theoretical model of the formation of glaciolacustrine kame terraces allow important assumptions regarding the climatostratigraphic and palaeogeographical problems. Therefore, we expect that glaciolacustrine kame terraces deserve more attention of researchers of Quaternary not only in Lithuania, but also in other regions covered by ice-sheet of the Last Glaciation.

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