ENVIRONMENTAL ENGINEERING

The 8th International Conference
May 19–20, 2011, Vilnius, Lithuania
Selected papers

ISSN 2029-7106 print / ISSN 2029-7092 online
ISBN 978-9955-28-826-8 (1 Volume)
ISBN 978-9955-28-827-5 (3 Volumes)

http://enviro.vgtu.lt

CLAY AS A NATURAL ISOLATING COVER: ITS FORMATION IN SUPRAGLACIAL AND PROGLACIAL SUBENVIRONMENTS IN NORTH LITHUANIA

Danguole Karmaziene[1], Rimante Zinkute[2], Bronislavas Karmaza[3], Algimantas Cesnulevicius[4]

[1, 2, 3]*Nature Research Centre Institute of Geology and Geography, T. Ševčenkos str. 13, LT-03223, Vilnius, Lithuania.*
E–mails: [1]d.karmaziene@geo.lt; [2]zinkute@geo.lt; [3]karmaza@geo.lt
[4]*Department of General Geography, Vilnius Pedagogical University, Studentų str. 39, Lt-08106 Vilnius, Lithuania.*
E–mail: [4]algimantas999@takas.lt

Abstract. The North Lithuanian region since long ago has been known as a zone of dominant glacial erosion. The Pleistocene bed in the central part of North Lithuania is overlying the Upper Devonian dolomite, marl, limestone, clay, and gypsum layers. The varying resistance of these deposits to mechanical and chemical impacts as well as different bedding and tectonic conditions were responsible for different scale of erosion in various areas of the region. Geological and geomorphological investigations through digging of test pits and investigation of outcrops, field observation and interpretation of aerial photographs were the basis for the geological-geomorphological reconstructions. Macroscopic description, graphic fixation and photography of the quarry walls were used to examine the Pleistocene succession of the study area. Two types of clayey glaciolacustrine sediments were investigated according to data of 2 boreholes. One type was formed in supraglacial subenvironment, i.e. in glaciolacustrine kame terrace on the marginal ridge of North Lithuanian phase. Another type was in proglacial subenvironment, i.e. on the territory of ice-dammed proglacial lake bottom. Regularities of the distribution, bedding conditions and structure have been revealed for both types as well as their grain-size distribution and geochemical differences according to Al, Ag, B, Ba, Co, Cr, Cu, Ga, La, Li, Mn, Mo, Nb, Ni, P, Pb, Rb, Sc, Sn, Sr, Ti, V, Y, Yb, Zn and Zr.

Keywords: clay, kame terrace, glaciolacustrine plain, grain-size, chemical element contents.

1. Introduction

Clay is well known as a good natural isolating cover, i.e. it is almost impermeable. However, its permeability depends on grain-size. The differences in the latter properties might be predetermined by the origin of clay. Till as natural isolating cover and its sedimentation in glacial environment has been already investigated (Baltrunas *et al.* 2005a; Česnulevičius *et al.* 2005). Clay is even more impermeable. Most of clay deposits are related to glaciolacustrine facies. Some geochemical peculiarities of soil of glaciolacustrine plains were investigated (Zinkutė *et al.* 2010).

Glaciolacustrine facies are one of the seven types of facies distinguished and discussed in detail by Brodzikowski and Van Loon (1991). According to these researchers, most glacigenic lakes are in proglacial subenvironment (facies II-B-4), however, they also occur in terminoglacial subenvironment (facies II-A-4), supraglacial subenvironment (facies I-A-4) and subglacial subenvironment (facies I-C-4).

Most of glaciolacustrine sediments were formed in in proglacial subenvironment, because according to Brodzikowski and Van Loon (1991) mainly these deposits have a reasonable chance of survival. However, glaciolacustrine sediments formed in supraglacial subenvironment can also be found. It is accepted by many researchers that kames and kame terraces contain supraglacial sediments (Klatkowa 1972; Schwan and Van Loon 1979; Schwan *et al.* 1980; Shaw 1972).

The term kame terrace usually describes forms of relief that have been developed between the glacier and a neighbouring valley slope. It was originally used by Salisbury (Salisbury 1894). Most kame terraces were aggraded by glaciofluvial activity, but glaciolacustrine forms also occur. Kame terraces mostly form at the edge of valley glaciers, but sometimes also at the margins of large ice masses.

Sediments of proglacial and supraglacial sediments subenvironments are also spread in North Lithuania. This region since long ago has been known as a zone of dominant glacial erosion where Quaternary sediment bed is thin and has a specific structure. The Pleistocene bed in the central part of North Lithuania is overlying the Upper Devonian dolomite, marl, limestone, clay, and gypsum layers. The varying resistance of these deposits to mechanical and chemical impacts as well as different bedding and tectonic conditions were responsible for different scale of erosion in various areas of the region. The thickness of the Quaternary deposits varies from 1.0 to 39.0 m. The thinnest layer of the Quaternary deposits is in the river valleys whereas the thickest layer is related with the altitude of the present relief or with rare palaeovalleys of the sub-Quaternary surface. The thickness of the Quaternary deposits is 10–12 m on the average (Fig.1).

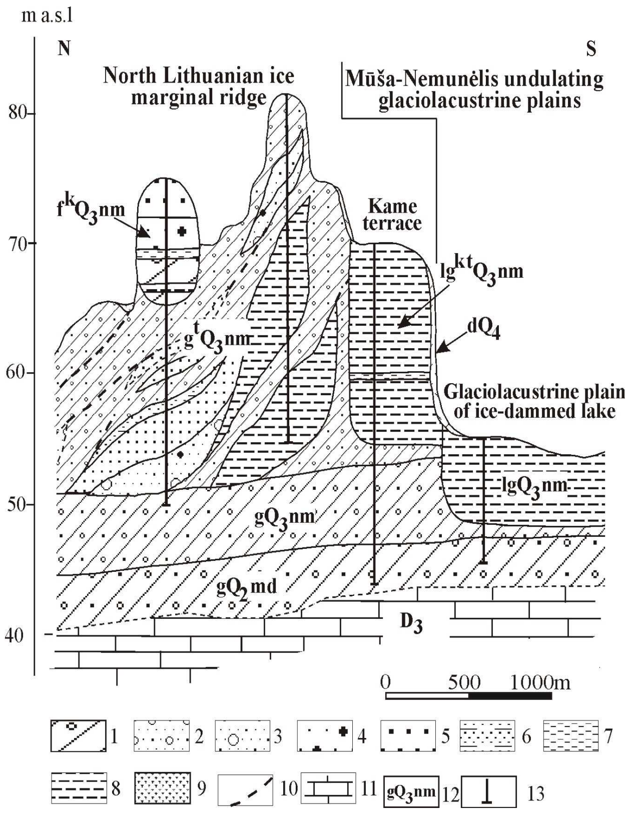

Fig 1. Structure of Quaternary stata of North Lithuania: 1 – till; 2 – gravel and cobble; 3 – sand with gravel and cobble; 4 – various grained sand; 5 – fine sand; 6 – silty sand; 7 – silt; 8 – clay; 9 – peat; 10 – shear lines; 11 – dolomite (D_3); 12 – genetic and stratigraphic index of deposits (gQ_2md – Medininkai till; gQ_3nm – Nemunas basal till; g^tQ_3 – Nemunas deformation till; $lg^{kt}Q_3nm$ – Nemunas glaciolacustrine kame terrace; f^kQ_3nm – Nemunas glaciofluvial kame; lgQ_3nm – Nemunas glaciolacustrine; dQ_4 – deluvial); 13 – borehole

The lower (older) till complex somewhere has a trinomial structure (Baltrūnas *et al.* 2005b). In the lower part it is composed of brown clayey solid till with poorly expressed orientation of the long axes of gravel and pebbles. Somewhere in the middle part of the complex (up to 1.5 m thick), the brown clayey till merges into grey less clayey till with a greater portion of gravel. In the upper part of the complex, the grey till merges into comparable brown till. According to research data of intertill deposits, this till complex is preliminary attributed to the Middle Pleistocene Medininkai sub-formation. They are underlying a glacial complex of the Baltija Stage of the Nemunas (Weichselian) Ice Age. The complex is composed of tills accumulated in two phases by a glacier advancing from the North. From older tills they differ by smaller amount of imported clastic material and higher content of local material.

The morphosculptural relief of the area was formed by the Mūša-Lėvuo and Žiemgala glacial streams and their melting water, so the relief is characterized by flat and slightly wavy moraine plain. Part of the relief was formed and reworked by postglacial exogenic processes.

Glaciolacustrine formations (supraglacial and proglacial subenvironment) are not widespread in North Lithuania. The glaciolacustrine sedimentation had a sporadic and rhythmic character in time.

As North Lithuanian phase glacier retreated, clayey sediments were accumulating in Mūša proglacial basin. Clay deposits of this basin are not characterized by greater thickness or better quality. Accordingly there are only limited possibilities of discovering deposits of clay in this area. All largest deposits of clay were discovered during the previous prospecting.

However, glaciolacustrine supraglacial areas were discovered in the Linkuva marginal ridge, the thickness of the useful bed in the areas is more than in the promising areas discovered in the Mūša glaciolacustrine basin, but the quality of this clay is less stable.

The aim of research was to find out grain-size and geochemical differences between clayey sediments of glaciolacustrine kame terrace located on the territory of North Lithuanian phase marginal formations and ice-dammed proglacial lake formed during the same phase. These deposits were formed in different sedimentary conditions: supraglacial and proglacial subenvironment.

Two boreholes were selected for detailed investigations of clayey sediments accumulated in different subenvironment: No. 3 located on the territory of glaciolacustrine kame terrace of Linkuva hill-ridge ($lg^{kt}Q_3nm$) and No. 4 located on the territory of Mūša ice-dammed glaciolacustrine basin of North Lithuanian phase (lgQ_3nm) (Fig. 2).

Test boreholes were made with vibrating drill. The number of tested samples was 41 in borehole No. 3 and 34 in borehole No. 4. Sampling depth in borehole No. 3 was from 0.3 to 9.8 m, in borehole No. 4 from 1.5 to 7.7 m.

2. Methods

Geological and geomorphological investigations. Digging of test pits and investigation of outcrops, field observation and interpretation of aerial photographs (scale 1:17000; year 1952) were the basis for the geological-geomorphological reconstructions. Macro-scopic description, graphic fixation and photography of the quarry walls were used to examine the Pleistocene succession of the study area.

Grain-size composition investigations. The grain-size distribution analysis was carried out using the sieving and pipette methods. It was carried out using 13–sieve set where dry debris was subdivided into the following fractions: >10; 10–5; 5–2; 2.0–1.0; 1.0–0.5; 0.5–0.25; 0.25–0.1; 0.1–0.05; 0.05–0.01; 0.01–0.005; 0.005–0.002; 0.002–0.001 and <0.001 mm. Grain-size was analysed at the laboratory at the Geological Survey of Lithuania. Sediments and their grain-size fractions are described using classification suggested by Last (2001).

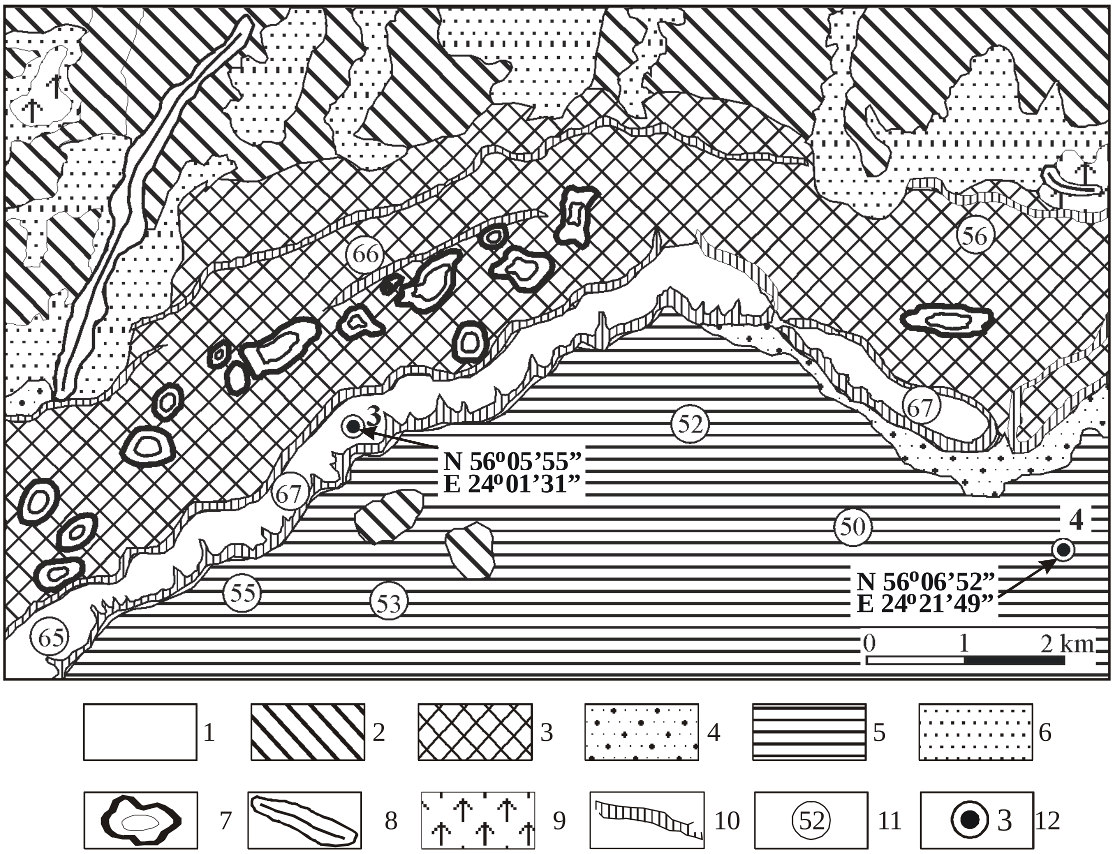

Fig 2. Geomorphologic scheme of marginal ridge with glaciolacustrine kame terrace and glaciolacustrine plain of ice-dammed lake: 1 – glaciolacustrine kame terrace; 2 – basal till plain; 3 – marginal ridge; 4 – solifluction sheet; 5 – glaciolacustrine plain of ice-dammed lake; 6 – plain formed by sediments of different genesis (glaciofluvial, glaciolacustrine, lacustrine, etc.); 7 – kame; 8 – glaciofluvial ridges and eskers; 9 – moor plain; 10 – steep slope; 11 – prevailing altitude of relief, in metres; 12 – borehole

Geochemical investigations. All samples were analysed in laboratory of the Institute of Geology and Geography. Optical atomic emission spectrophotometry (OAES, spectrometer DFS-13) was used for determination of real total contents of 25 chemical elements Al, Ag, B, Ba, Co, Cr, Cu, Ga, La, Li, Mn, Mo, Nb, Ni, P, Pb, Sc, Sn, Sr, Ti, V, Yb, Zn and x-ray fluorescence (XRF, x-ray spectrometer ARF-6) for determination of real total content of Rb. Before AOES the samples were air-dried, homogenised and milled. Sample preparation for x-ray fluorescence was analogous, only pellets were formed from milled material.

Statistical methods. Cluster analysis dendrogram was used to find out the geochemical similarity between samples of 2 boreholes. To create this dendrogram, Ward‘s method of amalgamation and Euclidean distance as a measure of similarity of the samples were applied to standardised contents of 26 chemical elements, which have been determined. Mann-Whitney U-test was used to reveal for each variable (chemical element of weight percentage in defined fraction) the significant ($p<0.01$) differences between boreholes. Median, mean, minimum and maximum values of variables as well as coefficients of variation were determined in both boreholes. For each chemical element according to all clay samples Spearman rank correlation coefficients R were determined between the content of this element and each fraction as well as respective p-values. Then maximum R value and respective fraction were found for each element.

3. Results and discussion

3.1. Regularities of the distribution and grain-size composition in two areas

Glaciolacustrine kame terrace. It is 22 km long and 0.5–1.0 km wide and located on the distal slope of the North Lithuanian ice marginal moraine ridge (Bitinas *et al.* 2004). Its surface is slightly inclined southward and reaches up to 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 kame terrace is 10–15 m above the glaciolacustrine plain of ice-dammed lake that is located to the south of the terrace. 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: their fixed maximal thickness is 15.3 m. These 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. Clay particles (fraction <0.005 mm) compose about 70–75% of sediments, whereas silt particles make up only 20% (Fig. 3). The rest, sandy fraction, amounts to 10% of sediments. The content of gravel and carbonaceous concretions (diameter up to 10 mm) in clay sediments is up to 3–5%. The massive clay of this lithofacies is the result of suspension settling. The homogeneous character indicates that clay particles could settle equally all over the lake.

It must be emphasized here that the thickness of the massive clay is unusual when related to the dimensions of the lake. Such thick massive clayey sediments are well known from glaciomarine deposits, where they are formed by prolonged settling of large amounts of fine-grained suspended sediment (Miall 1983).

Ice-dammed glaciolacustrine basin. It was formed to the south from the North Lithuanian marginal ridge, after glaciolacustrine kame terrace was formed. The absolute altitudes of the surface of the glaciolacustrine plain are 45–55 m. It has been established that the maximal thickness of reddish-brown clays reaches up to 13.9 m there (an average thickness is 4.5 m). Glaciolacustrine sediments overlay the till of the Middle Lithuanian phasial of the Nemunas Glaciation Baltija stadial. The contact of glaciolacustrine sediments with the basal till is distinct. Correlation between the thickness of glaciolacustrine sediments and till roof is significant negative (–0.82).

According to the lithological composition and character of lamination the sediments are represented by dark grey-brown massive clay without visible lamination. The fractions of 0.005–0.001 mm and <0.001 mm (56–74%) predominate in clay (Fig. 4). The glaciolacustrine sedimentation had a sporadic and rhythmic character in time. According to varve/year counting, the North Lithuania glaciolacustrine basin existed for about 166 years (Kazakauskas and Gaigalas 2005).

3.2. Grain-size distribution and geochemical differences between clayey sediments in two boreholes

Aiming to compare only clay, 4 samples from borehole No. 3 at a depth from 5.5 to 5.9 m were eliminated, because the content of clay there is lower than 50 %. The weight percentage of sediments in clay fraction (<0.005 mm) is significanty (p<0.01) higher in borehole No. 4, meanwhile the weight percentages in silt fraction (0.005–0.05 mm) and coarse fraction (>0.05 mm), on the contrary, are significantly higher in borehole No. 3 indicating great difference between the boreholes according to grain-size (Table 1). The results show that median percentage of clay fraction in glaciolacustrine plain sediments is 1.09 times higher than in kame terrace. Fine clay fraction dominates in both boreholes. Middle clay fraction is on the second place.

The content of each of these two fractions is significantly (p<0.01) higher in glaciolacustrine plain, respective medians are 1.12 and 1.16 times higher in borehole No. 4. The difference between the boreholes according to coarse clay and fine silt fraction is not significant (p>0.01). For most of the coarser fractions (coarse silt fraction 0.05–0.01 mm, 3 sand fractions from 0.1 mm to 1 mm and one gravel fraction 5–2 mm), the opposite regularity is obvious, i.e. sediments of kame terrace are significantly (p<0.01) enriched in these fractions. The relationship between mean values in two boreholes is analogous to relationship between respective two median values. As concerns the coefficients of variation, in most fractions they are higher in borehole No. 4; however, in two finest fractions of clay they are higher in kame terrace sediments. To conclude, in comparison with kame terrace sediments, glaciolacustrine plain sediments are enriched in the finest fractions of clay and the content in these two fractions is less variable.

There are also many significant geochemical differences between two boreholes with sediments from different subenvironments (Table 2).

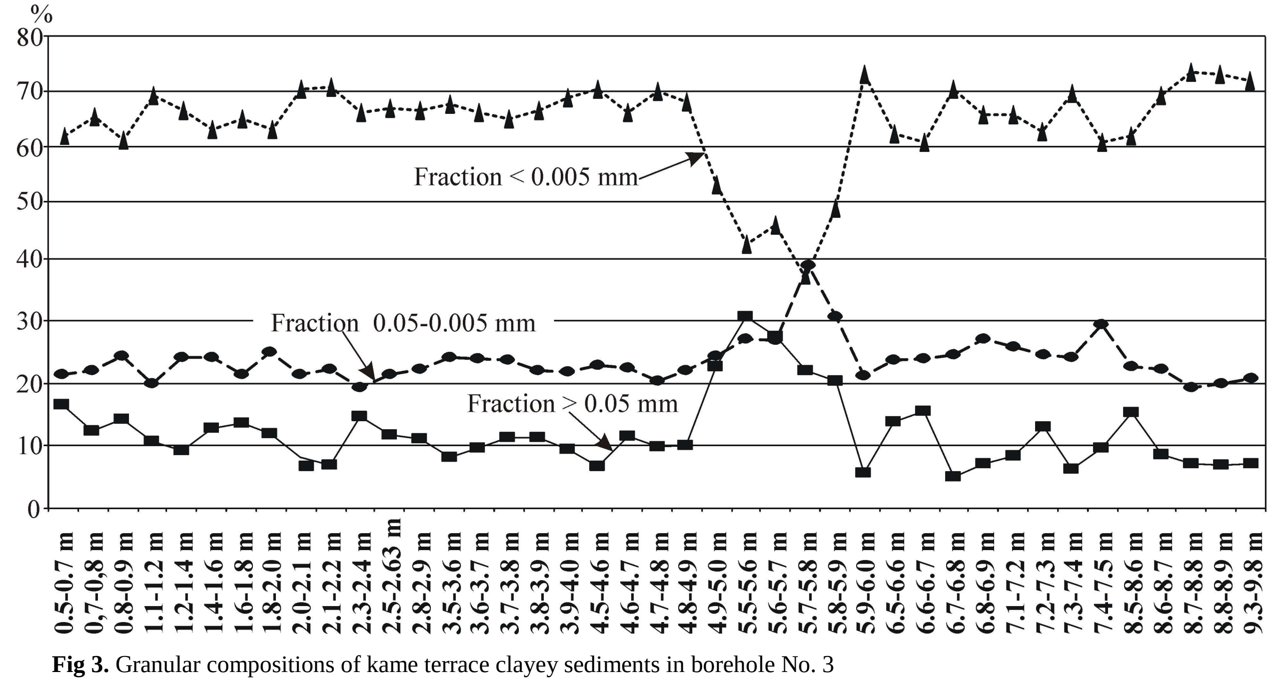

Fig 3. Granular compositions of kame terrace clayey sediments in borehole No. 3

Table 1. Weight percentage characteristics in fractions of boreholes on kame terrace and glaciolacustrine plain

Fractions (mm)	Means in boreholes		Medians in boreholes		Coefficients of variation in boreholes		Range in boreholes		Ratio of medians in No.4 to No.3
	No. 3	No. 4	No. 3	No. 4	No. 3	No. 4	No. 3	No. 4	
<0.005	66.4	**73.2**	66.5	**72.5**	6.5	**6.6**	52.8–73.5	65.3–84.3	1.09
0.05–0.005	**22.9**	18.6	**22.5**	18.6	9.4	**19.4**	19.2–29.5	10.6–25.0	0.83
>0.05	**10.7**	8.1	**10.0**	6.7	34.1	**47.5**	4.98–22.8	2.64–18.4	0.66
<0.001	40.3	**46.4**	41.0	**46.1**	**8.3**	10.4	31.3–45.9	38.2–59.1	1.12
0.002–0.001	11.5	**13.0**	11.2	**12.9**	**20.0**	15.5	7.15–16.5	8.45–17.6	1.16
0.05–0.01	**12.2**	7.9	**12.3**	8.1	17.5	**35.6**	7.13–17.6	2.17–12.5	0.66
0.25–0.1	**1.91**	1.33	**1.76**	1.06	34.7	**88.5**	0.90–3.97	0.23–5.07	0.60
0.5–0.25	**1.08**	0.73	**1.02**	0.63	36.3	**75.0**	0.49–2.52	0.21–2.39	0.61
1–0.5	**0.88**	0.43	**0.83**	0.40	43.1	**50.8**	0.36–2.20	0.07–0.83	0.48
5–2	**0.34**	0.13	**0.23**	0.11	**97.6**	93.1	0–1.44	0–0.43	0.46

Note. Only the fractions for which Mann-Whitney test revealed significant ($p<0.01$) differences between the boreholes are presented. The first three fractions are generalised, other 7 fractions are from 13 investigated. The higher value from two means, two medians and two coefficients of variation is in bold

Table 2. Geochemical characteristics of boreholes on glaciolacustrine kame terrace and glaciolacustrine plain

Element	Means in boreholes		Medians in borehole		Coefficients of variation in boreholes		Range in boreholes		Ratio of medians in No.4 to No.3	MaxR	Fraction (mm) of MaxR
	No. 3	No. 4	No. 3	No. 4	No. 3	No. 4	No. 3	No. 4			
P	545	**865**	450	**900**	**39.8**	16.2	250–1000	500–1200	2.000	0.304	<0.001
Pb	21.1	**30.9**	21.0	**30.5**	**12.8**	11.4	15–27	26–40	1.452	0.418	<0.001
B	102	**140**	100	**140**	**13.5**	12.2	76–125	100–180	1.400	0.479	<0.001
Li	37.0	**51.8**	38.0	**52.0**	**11.2**	7.7	25–45	44–60	1.368	0.614	<0.001
La	24.8	**32.2**	24.0	**32.5**	11.0	**13.7**	19–33	25–48	1.354	0.418	<0.001
Cr	88.2	**116**	88.0	**115**	**13.2**	7.5	62–110	100–150	1.307	0.499	<0.001
Yb	2.5	**2.9**	2.4	**2.9**	**14.1**	5.4	2.1–4.0	2.6–3.3	1.208	0.415	<0.001
Nb	9.0	**10.6**	9.0	**10.5**	**26.9**	6.9	6.0–17.5	9.8–13.0	1.167	0.280	<0.001
Mn	497	**562**	490	**550**	**19.0**	8.9	350–860	480–680	1.122	0.281	<0.001
Ba	499	**590**	520	**580**	**21.7**	11.0	20–640	500–780	1.115	0.354	<0.001
Rb	144	**161**	145	**161**	5.0	5.0	130–162	145–179	1.106	0.623	<0.001
Ti	3828	**4123**	3800	**4200**	**14.4**	9.4	2900–5700	3300–5000	1.105	0.199	0.002–0.001
Co	13.2	**14.8**	13.0	**14.3**	**25.0**	13.4	8–27	12–19	1.096	0.417	<0.001
Mo	1.0	**1.2**	1.1	**1.2**	**19.8**	9.0	0.7–1.8	1.0–1.4	1.095	0.316	<0.001
Sr	111	**119**	110	**120**	**7.4**	5.4	84–123	108–129	1.089	0.486	<0.001
Ga	22.7	**25.5**	23.0	**25.0**	**15.9**	4.8	14–31	24–28	1.087	0.248	<0.001
Ni	52.6	**55.2**	52.0	**55.5**	**13.0**	8.5	38–70	47–66	1.067	0.202	0.01–0.005
Ag	**0.056**	0.054	0.050	**0.053**	**58.2**	10.5	0.030–0.230	0.045–0.070	1.050	0.251	>10
Sn	4.55	**4.62**	4.5	**4.7**	**11.2**	5.3	3.3–6.0	4.2–5.2	1.044	0.209	0.005–0.002
V	**130**	127	130	130	**11.9**	5.9	92–160	110–150	1.000	0.178	10–5
Cu	**31.9**	33.1	33.0	33.0	**30.7**	9.3	12–60	28–45	1.000	0.265	10–5
Zn	91.5	**92.4**	90.0	90.0	**24.5**	16.4	35–140	70–130	1.000	0.221	0.1–0.05
Y	**24.8**	21.9	**24.0**	22.0	11.0	11.0	19–33	18–28	0.917	0.465	0.05–0.01
Al	**7.5**	6.4	**7.6**	6.4	**11.9**	8.5	5.8–10.5	5.4–7.6	0.842	0.501	0.5–0.25
Zr	**180**	147	**176**	147	**8.3**	5.5	158–241	129–158	0.830	0.633	0.05–0.01
Sc	**15.7**	11.6	**14.0**	11.0	**18.6**	10.8	12–23	10–15	0.786	0.531	0.05–0.01

Note. The elements for which U-test revealed significant ($p<0.001$) differences between the boreholes are in bold. The higher value from two means, two medians and two coefficients of variation is in bold. MaxR – maximum Spearman correlation coefficient between element and one of 13 fractions, this fraction is in the last column

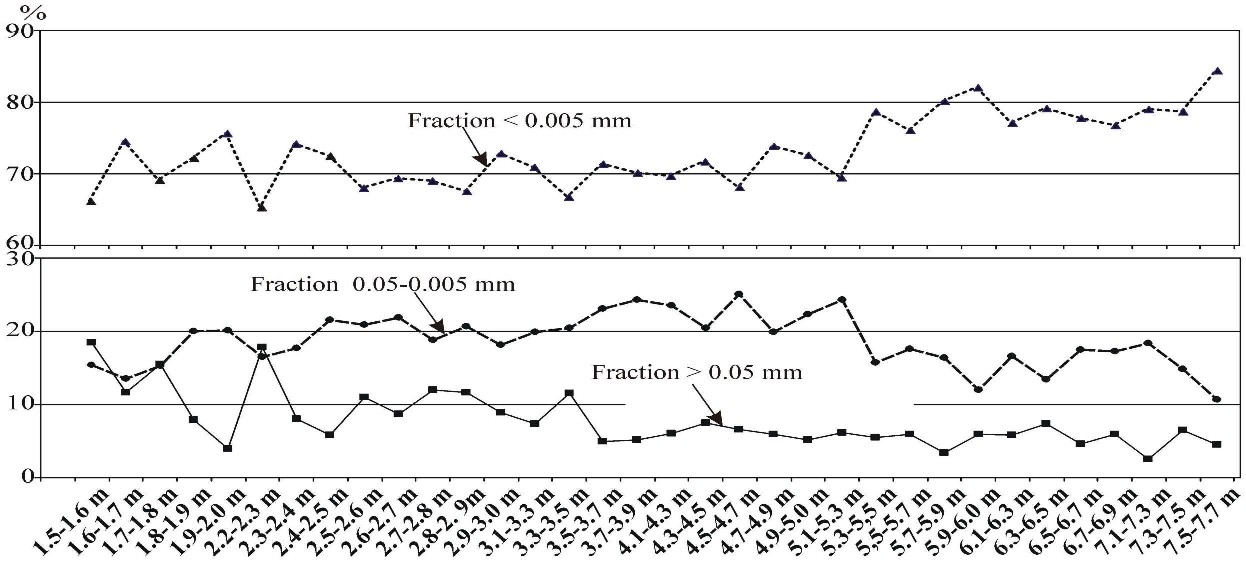

Fig 4. Granular compositions of ice-dammed lake glaciolacustrine plain clay in borehole No 4

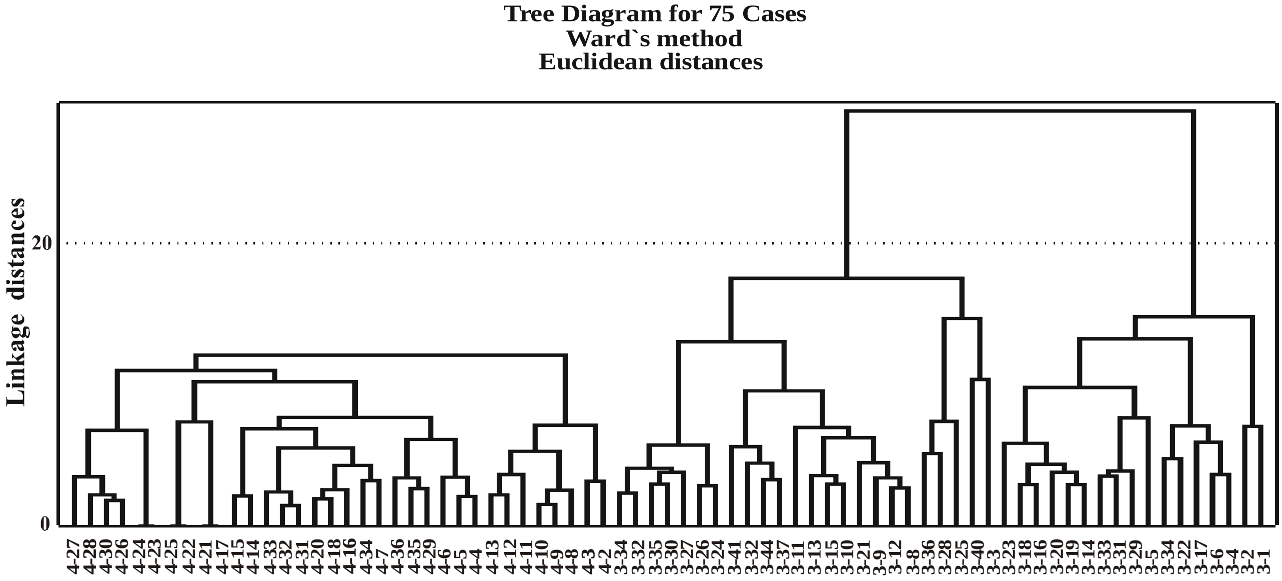

Fig 5. Cluster analysis grouping of kame terrace and ice-dammed lake clayey samples according to their chemical composition

The contents of 16 chemical elements (P, Pb, B, Li, La, Cr, Yb, Nb, Mn, Ba, Rb, Ti, Co, Mo, Sr and Ga) are significantly ($p<0.01$) higher in borehole No. 4 compared to borehole No. 3.

Their median values are from 2 to 1.087 times higher in glaciolacustrine plain compared to kame terrace. The same tendency is characteristic of mean values of these chemical elements. For all these elements, except Ti, maximum Spearman correlation coefficient, which is significant ($p<0.05$) is with the content of fine clay fraction (<0.001 mm). Maximum Spearman correlation coefficient of Ti is with medium clay fraction, however, fine clay is the next fraction according to magnitude of Spearman correlation coefficient. Though both coefficients are not significant ($p>0.01$), some influence of the finest clay fractions on the content of this element is obvious.

As the content of fine fraction is significantly higher in glaciolacustrine plain than in kame terrace, this explains the above-mentioned enrichment of clayey sediments from proglacial subenvironment in 16 chemical elements.

As concerns clayey sediments of supraglacial environment, they are enriched only in Yb, Al, Zr, Sc. These 4 chemical elements are mostly correlated with coarser fractions: Zr, Sc, Yb with coarse silt (0.05–0.01 mm) and Al with medium-grained sand (0.5–0.25 mm).

For other 6 chemical elements (Ni, Ag, Sn, V, Cu, Zn) no significant differences were determined between sediments of different subenvironments. Three of them (V, Cu, Zn) have even equal median values in both boreholes. These chemical elements are also mostly correlated with different coarser fractions: Sn with coarse clay (0.005–0.002 mm), Ni with fine silt (0.01–0.005 mm), Zn with very fine sand (0.1–0.05 mm), other elements with gravel fractions (V, Cu with fraction 10–5 mm, Ag with fraction >10 mm). As there is no significant difference between the boreholes according to all above-mentioned fractions (Table 1), the geochemical differences are also insignificant.

The coefficients of variation of all chemical elements, except La, Rb and Yb, are higher in borehole No. 3. This is in accordance with higher coefficients of variation of the finest clay fractions in kame terrace compared to glaciolacustrine plain (Table 1).

While there are many significant geochemical differences between sediments formed in different subenvironment, the excellent separation of samples from different boreholes is quite reasonable (Fig. 5).

5. Conclusions

1. Clay of glaciolacustrine kame terrace is on the distal slope of the North Lithuanian marginal ridge. In general, the kame terrace consists of glaciolacustrine sediments: its fixed maximal thickness is 15.3 m. Glaciolacustrine sediments are presented by brown clay of massif structure, 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. Clay particles (fraction <0.005 mm) compose about 70–75 % of sediments, whereas silt particles make up only 20 %. The rest, sandy fraction, makes up 10 % of sediments. The amount of gravel and carbonaceous concretions (diameter up to 10 mm) in clay sediments is up to 3–5 %. The massive clay of this lithofacies is the result of suspension settling. The homogeneous character indicates that clay particles could settle equally all over the lake. The ice-dammed glaciolacustrine basin was formed to the south from the North Lithuanian marginal ridge, when glaciolacustrine kame terrace was formed. The absolute altitudes of the surface of the glaciolacustrine plain vary from 45 to 55 m. It has been established that the maximal thickness of reddish-brown clay reaches up to 13.9 m. Glaciolacustrine sediments overlay the till of the Middle Lithuanian Phase (Baltija Stage of the Nemunas Glaciation).
2. Data on two boreholes from North Lithuanian region indicate that glaciolacustrine facies in supraglacial and proglacial subenvironment are visually very similar and usually have massif structure. However, there are many grain-size composition and geochemical differences between clayey sediments on glaciolacustrine kame terrace and on glaciolacustrine ice-dammed plain. The latter sediments are enriched in fine and medium clay fractions, meanwhile the former in the following coarser fractions: coarse silt (0.05–0.01 mm), 3 sand fractions 0.25–0.1 mm, 0.5–0.25 mm, 1–0.5 mm and gravel fraction 5–2 mm.
3. The contents of 16 chemical elements P, Pb, B, Li, La, Cr, Yb, Nb, Mn, Ba, Rb, Ti, Co, Mo, Sr and Ga, which are mostly correlated with fine clay fraction, are significantly ($p<0.01$) higher in borehole No. 4 compared to borehole No. 3.
4. Only the contents of Yb, Al, Zr, Sc are significantly higher in supraglacial environment, they are mostly correlated with coarser fractions: Zr, Sc, Yb with coarse silt (0.05–0.01 mm) and Al with medium-grained sand (0.5–0.25 mm). For other 6 chemical elements (Ni, Ag, Sn, V, Cu, Zn) no significant differences were determined between sediments of different subenvironments, they are also correlated with coarser fractions.

References

Baltrunas, V.; Dundulis, K.; Gadeikis, S.; Karmaza, B.; Rackauskas, V. 2005a. Basal till as a natural isolating cover: its formation and peculiarities. In *The 6th International Conference "Environmental Engineering"*: Selected papers, vol. 1. Ed. by D. Čygas, K. D. Froehner. May 26–27, 2005, Vilnius, Lithuania. Vilnius: Technika, 30–33.

Baltrūnas, V.; Karmaza, B.; Karmazienė, D. 2005b. Pleistoceno nuogulų sandaros ir formavimosi ypatybės Šiaurės Lietuvoje [Peculiarities of structure and formation of Pleistocene deposits in Northern Lithuania]. *Geologija* [Geology], 52: 22–33.

Bitinas, A.; Karmazienė, D.; Jusienė, A. 2004. Glaciolacustrine kame terraces as an indicator of conditions of deglaciation in Lithuania during the Last Glaciation. *Sedimentary Geology*, 165: 285–294.

Brodzikowski, K.; Van Loon, A. J. 1991. *Glacigenic sediments*. Amsterdam: Elsevier. 674.

Česnulevičius, A.; Valiūnas, J.; Ramonas, A.; Veteikis, D. 2005. Geologinė aplinka – biosferos mineralinis pagrindas [Geological environmental as the mineral substratum of the biosphere]. In *Lietuvos žemės gelmių raida ir ištekliai* [Evolution of Earth crust and its resources in Lithuania]. Ed. By V. Baltrūnas. Vilnius: Petro Ofsetas. 416–422.

Kazakauskas, V.; Gaigalas A. 2004. Varvometric estimation of the duration of Daniglacial glaciolacustrine sedimentation in Lithuania. *Geologija* [Geology], 48: 44–54.

Klatkowa, H. 1972. Region Łódźki [The Łódź region]. *Geomorfologia Polski* [Geomorphology of Poland], 2: 240–270.

Last, W. M. 2001. Mineralogical analysis of lake sediments. In *Tracking Environmental Change Using Lake Sediments,* vol 2. Ed. by M. L. Last, J. B. Smol. Dordrecht: Kluwer Academic Publishers, 143–187.

Miall, A. D. 1983. Glaciomarine sedimentation in the Gowganda Formation (Huronian), northern Ontario. *J. Sediment Petrol*, 53: 477–491.

Salisbury, R. D. 1894. Surface geology – Report of progress, 1892. *New Jersey Geological Survey, Annual Report of the State Geologist for the year 1893*: 35–328.

Schwan, J.; Van Loon, A. J. 1979. Structural and sedimentological characteristics of a Weichselian kame terrace at Sønderby Klint, Funen, Denmark. *Geol. Mijnbouw*, 58: 305–319.

Schwan, J.; Van Loon, A. J.; Van der Gaauw, P. G.; Steenbeek, R. 1980. The sedimentary sequence of a Weichselian intraglacial lake at Ormehøj (Funen, Denmark). *Geol. Mijnbouw*, 59: 129–138.

Shaw, J. 1972. Sedimentation in the ice-contact environment, with examples from Shropshire, England. *Sedimentology*, 18: 23–62.

Zinkutė, R.; Radzevičius, A.; Kazakauskas, V. 2010. Allothigenic and allothigenic accessory trace elements contents in different age soil of glaciolacustrine basins. *Geologija* [Geology], 52: 46–52.