GEOLOGIJA. 2014. Vol. 56. No. 3(87). P. 65–73

The multilayered structure of Žemaitija and Medininkai tills and the question of its origin in South Lithuania

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Baltrūnas V., Karmaza B., Pukelytė V. The multilayered structure of Žemaitija and Medininkai tills and the question of its origin in South Lithuania. *Geologija*. Vilnius. 2014. Vol. 56. No. 3(87). P. 65–73. ISSN 1390-110X.

Logs of two boreholes were chosen for a detailed analysis. They form a triangle what gives a possibility to evaluate the variation of till material along the lines from N to S and from NW to SE. Grain-size analysis was performed for tills from all three boreholes and the index of relative entropy of grain-size was calculated. The composition of Žemaitija (Odra, Dnepr) and Medininkai (Warta, Sozha) till complexes implies glacial advances of at least two glaciations and their stages. The Žemaitija tills were formed by glaciers advancing from NW–N across the spread area of the Lower Palaeozoic, Mesozoic and Devonian rocks. The Medininkai tills were left by glaciers advancing from NE across the spread area of the Devonian rocks. The macroscopically homogeneous Žemaitija and Medininkai till complexes have a rhythmic multilayered structure well reflected by log and grain-size data. The sedimentological nature of this rhythmicity is partly revealed by variation analysis of relative entropy of grain-size composition in the vertical section. The index of relative entropy, reflecting the degree of mixing, allowed distinguishing 2–4 zones of higher entropy (better mixing) in the vertical section. Their presence may be explained by a repeated input of morainic material in the basal part of the glacier during its activation stage.

Key words: Pleistocene, South Lithuania, sedimentology, relative entropy, multilayered structure, till

Received 23 July 2014, accepted 19 August 2014

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INTRODUCTION

In the areas of continental glaciations, Pleistocene tills have a multilayered structure, which can be seen visually (colour, texture, interlayers, etc.) and by data obtained with various analytical (grain-size, geochemical, etc.) methods (Gaigalas, 1971, 1979; Baltrūnas, 1995, 2002; Baltrūnas, Gaigalas, 2004). There has been a long-lasting discussion about the origin of the multilayered structure of tills, which can be rather variable (Lavrushin, 1980; Dreimanis, 1990; Brodzikowski, Van Loon, 1991; Lisicki, 2003; Adam, Knight, 2003; Wysota, 2007; and others). The practice of various statistical indices of analytical data enables identifying the origin of the multilayered structure and sedimentation conditions of tills.

The present investigation allowed formulating a hypothesis on the multilayered structure of the most widespread in Lithuania Žemaitija and Medininkai tills and their links with the glacier activity stages and phases. These tills are characterized

by a continuous spread; often without a visual boundary between them. The greatest thickness of a till layer often occurs in the depressions of the sub-Quaternary surface and at the bottom of palaeoincisions (Vonsavičius, 1967; Baltrūnas, 1995, 2002; and others). Recently, a correlation between the Žemaitija till with the Odra till in Poland and the Dnepr till in Belarus and Russia has been determined. Meanwhile, the Medininkai till has been correlated with the Warta till in Poland and the Sozha till in Belarus (Gaigalas, Satkūnas, 1994; Satkūnas, Kondratienė, 1995; Ber, 2000, 2006; Velichkevich et al., 2001).

The Žemaitija and Medininkai tills of South Lithuania in the Alytus (borehole No. 475 – Vaikantonys) and Varėna districts (borehole No. 490 – Lavysas) were chosen in the reference area for a detailed study. The boreholes are comprised of sections from NW to SE and S and present a possibility to follow up the variation of till material along the line from N to S (Fig. 1). The boreholes are spaced 23.5 km. The sub-Quaternary surface of this region and the features of the Quaternary system were discussed in a few publications (Šliaupa, 2004; Baltrūnas, 1995, 2002; Baltrūnas, Gaigalas, 2004). The stratigraphical interpretation of the Quaternary deposits proposed by these publications was taken as a basis for the present paper. The aim of the present article was to evaluate the multilayered structure of Žemaitija and Medininkai tills on an example of an area representative of South Lithuania.

METHODS

32 samples were taken from the cores of two boreholes for grain-size analysis: 16 from the Žemaitija till and 16 from the Medininkai one. The clastic material coarser than 5 mm was not included into the samples for too small sample weight. The statistical parameters of the distribution of fractions and the correlation coefficients were calculated using Excel and Statistics programs. The minimal sample number (N) for the Žemaitija and Medininkai tills was determined taking into account the average x of

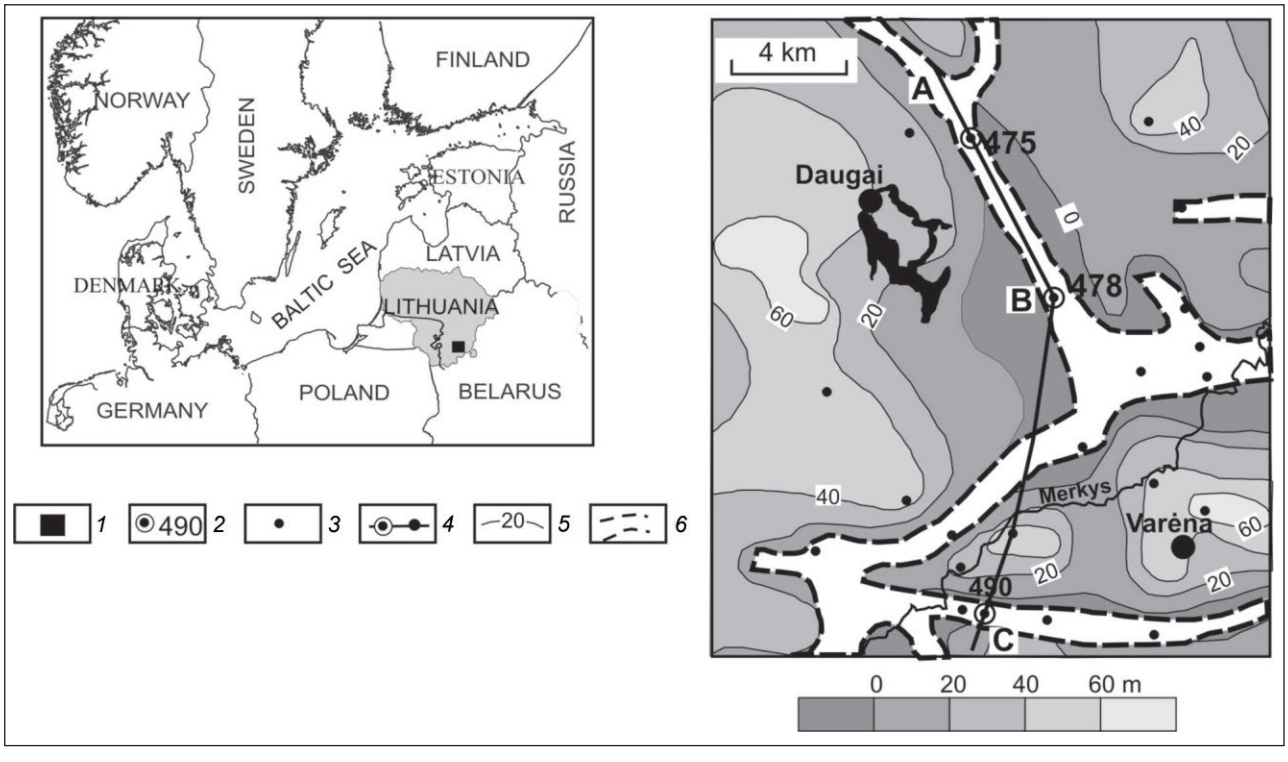

Fig. 1. Location of the study area and its sub-Quaternary surface.

1 – study area; *2* – borehole investigated and its number; *3* – other boreholes; *4* – geological cross-section; *5* – altitude isoline (m a. s. l.) of sub-Quaternary surface; *6* – palaeoincision

1 pav. Tyrimų ploto padėtis ir jo subkvartero paviršius.

1 – tirtas plotas; *2* – tirtas gręžinys ir jo numeris; *3* – kiti gręžiniai; *4* – geologinis pjūvis; *5* – sub-kvartero paviršiaus absoliučiojo aukščio izolinija (a. a., m); *6* – paleoįrėžis

relative entropy, the variation coefficient *v*, the significance level *t* (0.95) and the measurement bias of average λ according to the formula $N = (tvx/100\lambda)^2$.

The grain-size fractions of till material were obtained during granulometric analysis using the sieving and pipette methods: 5.0–2.0; 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 mm. Four sets of fractions were tried for optimal relative entropy. The relative entropy (R_1 and R_2, Table) was calculated for all the 9 and 8 fractions (8 fractions – joining the finest particles into one fraction <0.01 mm). The relative entropy was also calculated for 4 incorporated fractions (two variants: R_3 and R_4): 5–1, 1–0.1, 0.1–0.05, <0.05 and 5–1, 1–0.1, 0.1–0.01, <0.01 mm. Its evaluation has been recently discussed in publications (Baltrūnas, Pukelytė, 2003; Baltrūnas, Gaigalas, 2004; Baltrūnas et al., 2005; 2008).

Based on the archival material of geological mapping, stratigraphical interpretation of the heavy and light minerals (fraction 0.25–0.1 mm) of tills, petrographic composition of gravel and pebbles, and coefficient k (the ratio of dolomite content and the sum of Ordovician and Silurian limestone), the calculation and evaluation of the relative entropy of granulometric composition were also performed.

RESULTS

Stratification of Žemaitija and Medininkai tills

The sub-Quaternary surface of South Lithuania and its geological structure are described in publications (Šliaupa, 2004; Baltrūnas, Gaigalas, 2004). The areal representative is situated on the solitary elevations (+77 – +40 m a. s. l.) on the middle level of the palaeosurface (+40 – 0 m a. s. l.) and palaeoincision (0 – –142 m b. s. l.) (Fig. 1). The both analysed sediment sections are situated in palaeoincisions where the thickness of the Pleistocene deposits reaches 220.0 m (borehole No. 475) and 262.5 m (borehole No. 490) (Fig. 2).

In borehole No. 490, the Žemaitija till occurs on the widespread and palynologically well analysed Butėnai (Holsteinian, Mazovian, Alexandrian, Likhvinian) interglacial minute and fine sand deposits reaching up to 91 m in thickness (Baltrūnas, 1995; 2002). The palynologically well analysed Merkinė (Eemian, Murava, Mikulino) interglacial deposits in borehole No. 52 (Kančėnai) overlying the Medininkai till not far from borehole No. 745 have been known for some time already. (Kondratienė, 1965; Baltrūnas, 1995). In the region between the Žemaitija and Medininkai tills, only one palynologically analysed 11 m thick sediment section was identified (borehole No. 489) which implies cold interstadial sedimentation conditions (Baltrūnas, 1995).

The features of the sub-Quaternary surface influenced the spread and composition of the Žemaitija and Medininkai tills. The middle level of the palaeosurface favoured the even and ample accumulation of till material. The petrographic composition of gravel and pebbles shows three dominant groups of transitory rocks: crystalline rocks, Devonian dolomite and Ordovician and Silurian limestone (Figs. 3–4). Fragments of local rocks occur seldom and in small amounts (Lower Triassic claystone and sandstone, Lower Cretaceous

Table. **Comparison of relative entropy (R_1–R_7) for the Žemaitija (žm) and Medininkai (md) till composition in sediment sections of boreholes No. 475 and No. 490. R_1 and R_2 were calculated for all 9 and 8 (joining the finest particles into one fraction <0.01 mm); R_3 – for fractions 5–1, 1–0.1, 0.1–0.05 and <0.05; R_4 – for fractions 5–1, 1–0.1, 0.1–0.01 and <0.01; R_5 – for petrographic groups; R_6 – for heavy minerals; R_7 – for light minerals**

Lentelė. **Žemaitijos (žm) ir Medininkų (md) morenų komponentų santykinės entropijos (R_1–R_7) palyginimas gręžinių Nr. 475 ir Nr. 490 pjūviuose. R_1 ir R_2 skaičiuoti 9 ir 8 frakcijų; R_3 – 5–1; 1–0,1; 0,1–0,05; <0,05 frakcijų; R_4 – 5–1; 1–0,1; 0,1–0,01; <0,01 frakcijų; R_5 – petrografinių grupių; R_6 – sunkiųjų mineralų; R_7 – lengvųjų mineralų**

Rate	R_1		R_2		R_3		R_4		R_5		R_6		R_7	
Borehole No.	**475**	**490**	**475**	**490**	**475**	**490**	**475**	**490**	**475**	**490**	**475**	**490**	**475**	**490**
Md	0.887	0.888	0.872	0.856	0.871	0.876	0.877	0.877	0.852	0.753	0.693	0.727	0.450	0.450
Žm	0.768	0.868	0.840	0.820	0.662	0.841	0.716	0.853	–	0.730	0.672	0.674	0.531	0.467

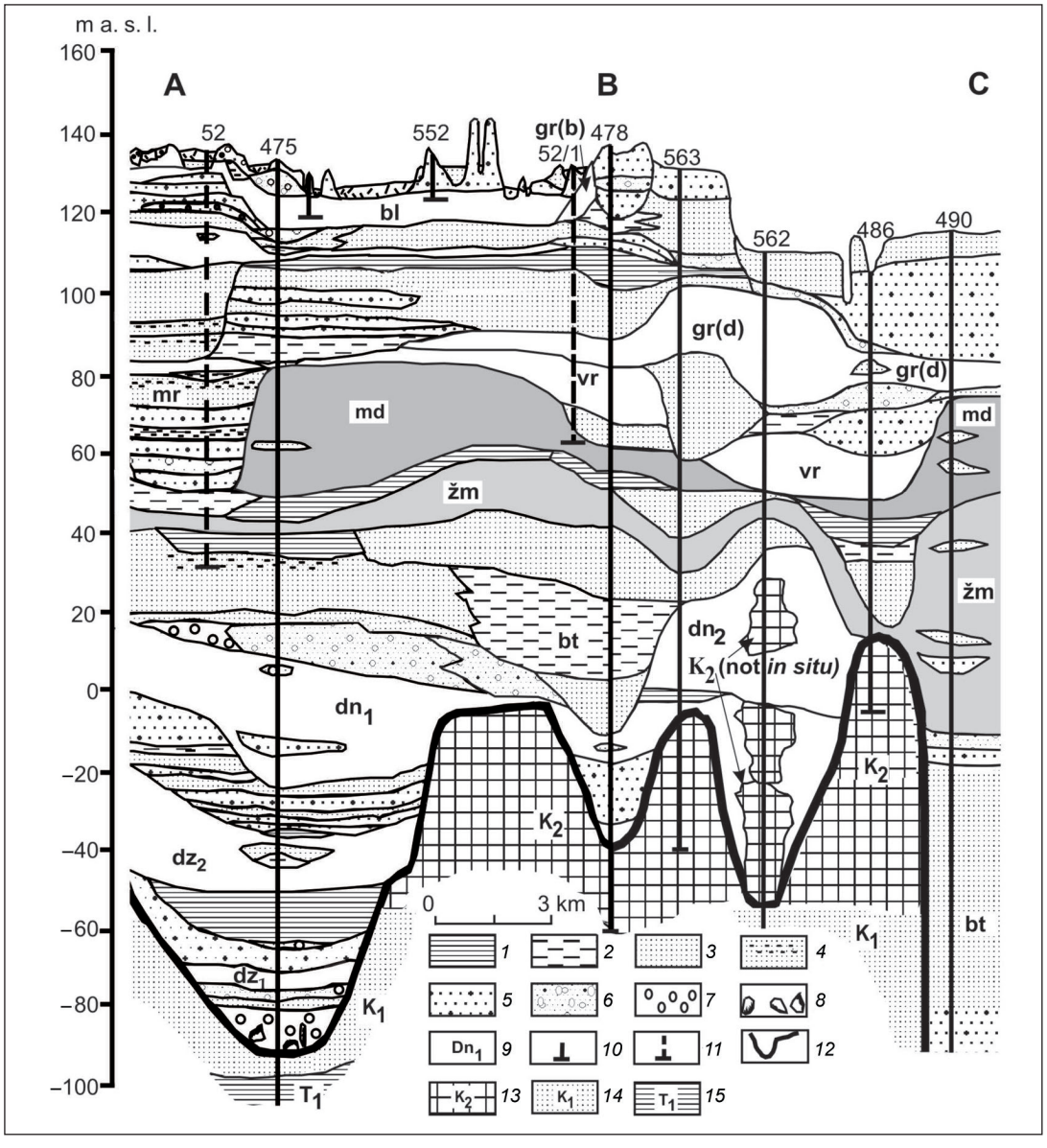

Fig. 2. Geological cross-section (A–B–C) of Pleistocene deposits (according to Baltrūnas and Gaigalas (2004) with corrections).

1 – clay, *2* – silt, *3* – fine sand, *4* – clayey sand, *5* – various sand, *6* – pebbly sand, *7* – pebbles, *8* – boulders, *9* – stratigraphical index of till or interglacial sediments, *10* – borehole, *11* – supporting borehole, *12* – surface of sub-Quaternary, *13* – Upper Cretaceous chalk and marl, *14* – Lower Cretaceous glauconitic sand, *15* – Lower Triassic argillitic clay.

Stratigraphical indexes of tills: dz_1 and dz_2 strata – Dzūkija; dn_1 and dn_2 strata – Dainava; žm – Žemaitija (grey in cross-section); md – Medininkai (grey in cross-section); vr – Varduva; gr(d) and gr(b) strata – Grūda; bl – Baltija. Stratigraphical indexes of interglacial sediments: bt – Butėnai; mr – Merkinė

2 pav. Pleistoceno nuogulų geologinis pjūvis (A–B–C) (pagal Baltrūną ir Gaigalą (2004) su korekcijomis).

1 – molis, *2* – aleuritas, *3* – smulkus smėlis, *4* – molingas smėlis, *5* – įvairus smėlis, *6* – smėlis su gargždu, *7* – gargždas, *8* – rieduliai, *9* – moreninių nuogulų arba tarpledynmečių nuosėdų stratigrafinis indeksas, *10* – gręžinys, *11* – šalia esantis gręžinys, *12* – subkvartero paviršius, *13* – viršutinės kreidos kreida ir mergelis, *14* – apatinės kreidos glaukonitinis smėlis, *15* – apatinio triaso argilitinis molis.

Moreninių nuogulų stratigrafiniai indeksai: dz_1 ir dz_2 kompleksas – Dzūkija; dn_1 ir dn_2 kompleksas – Dainava; žm – Žemaitija (pjūvyje pilka); md – Medininkai (pjūvyje pilka); vr – Varduva; gr(d) ir gr(b) kompleksas – Grūda; bl – Baltija. Tarpledynmečių nuosėdų indeksai: bt – Butėnai; mr – Merkinė

glauconitic sand, Upper Cretaceous chalk, marl and flint). The ratio of Devonian dolomite versus Ordovician and Silurian limestone (k) in the Žemaitija and Medininkai tills is a typical index indicating different directions of glacial advance. The higher content of Devonian dolomite and the lower content of the Ordovician and Silurian limestone clasts (k = 0.85–1.6; 1.07 on the average) of the Žemaitija till show glacier advance from NW–N across the Baltic Sea bottom, the spread

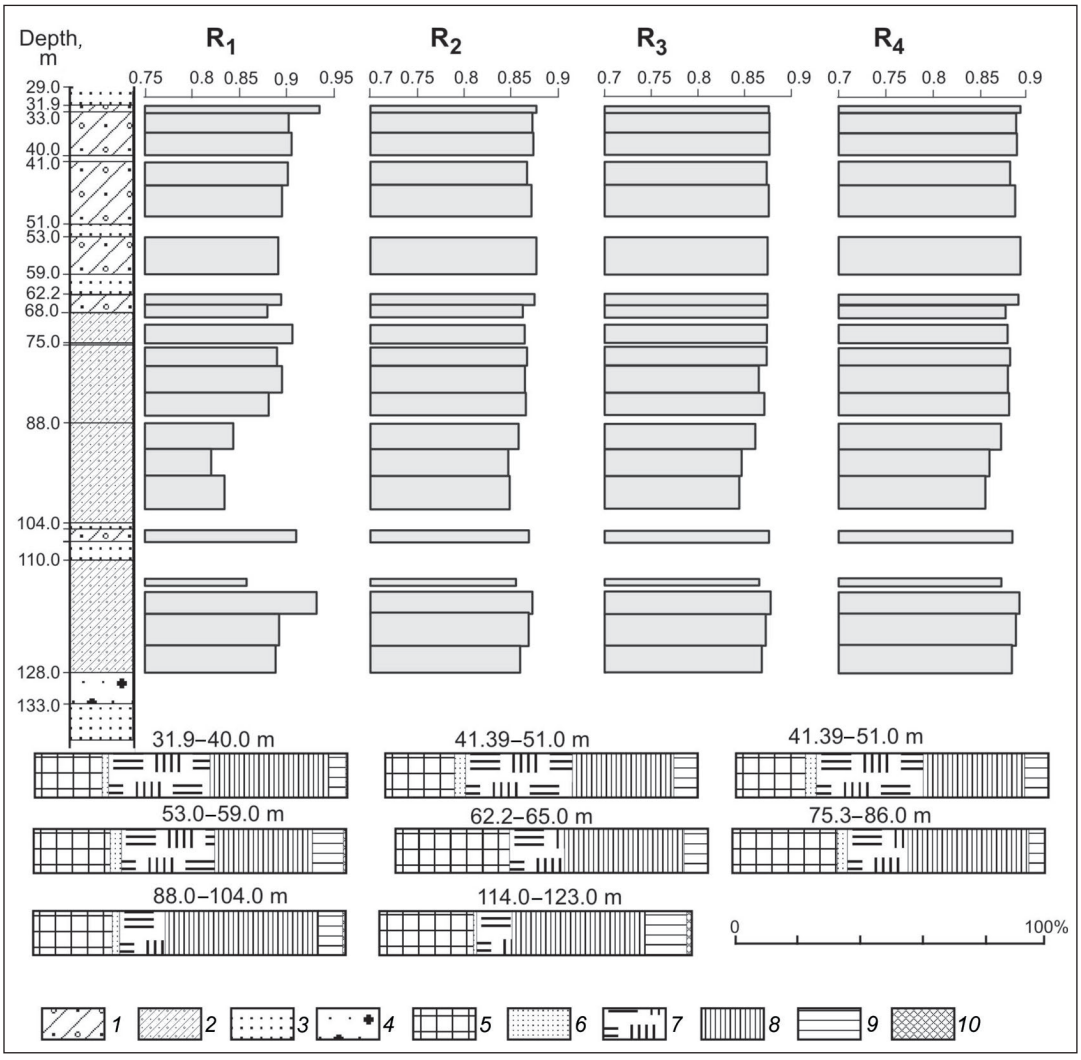

Fig. 3. Sequence of Žemaitija and Medininkai tills in borehole No. 475.

R_1 and R_2 – variation in relative entropy of the grain-size of Žemaitija and Medininkai tills for 9 and 8 fractions; R_3 and R_4 – variation in relative entropy of the grain-size of Žemaitija and Medininkai tills for 4 fractions (two variants, see methods).

1 – Medininkai till, *2* – Žemaitija till, *3* – sand, *4* – sand with gravel.

Petrographic composition of till: *5* – crystalline rocks, *6* – sandstone, *7* – dolomite, *8* – Ordovician and Silurian limestone, *9* – Permian limestone, *10* – other rocks and minerals

3 pav. Žemaitijos ir Medininkų moreninių nuogulų pjūvis gręžinyje Nr. 475.

R_1 ir R_2 – Žemaitijos ir Medininkų moreninių nuogulų 9 ir 8 frakcijų granuliometrinės sudėties santykinės entropijos kaita; R_3 ir R_4 – Žemaitijos ir Medininkų morenų 4 frakcijų granuliometrinės sudėties santykinės entropijos kaita (du variantai, žr. metodiką).

1 – Medininkų moreninės nuogulos, *2* – Žemaitijos moreninės nuogulos, *3* – smėlis, *4* – smėlis su žvirgždu.

Morenų petrografinė sudėtis: *5* – kristalinės uolienos, *6* – smiltainis, *7* – dolomitas, *8* – ordoviko ir silūro klintis, *9* – permo klintis, *10* – kitos uolienos ir mineralai

area of Ordovician and Silurian limestone, and Mesozoic and Devonian rocks. The proportions of these rocks (k = 0.27–1.38; 0.58 on the average) in the Medininkai till show glacier advance from NE, across the area of Devonian rocks. The obtained results are in good agreement with the data of previous investigations of tills (Gaigalas, 1979; Gaigalas, 1995).

Relative entropy of grain-size composition of tills and its change in the sediment sections

Grain-size analysis of the tills has shown the prevalence of glacial sediments of typical composition, i. e. sandy till and silty till in which the fine fraction (<0.01 mm) accounts for 35.3–76.2%. In the upper part of the Medininkai till, this fraction accounts for 23.5% and in the lower part of the Žemaitija till for 46.1%. An anomalously large amount of fine material has been found in three samples of the Žemaitija till: 76.2% (borehole No. 475) and 60.9–62.4% (borehole No. 490).

Calculations of the relative entropy of grain-size composition for 9 and 8 fractions (R_1 and R_2) have shown that this index in the vertical section of tills varies rhythmically (Figs. 3, 4). A comparison of the average values of this index revealed that the relative entropy for 9 and 8 fractions in both boreholes was higher in the Medininkai than in the Žemaitija tills (Table). The same difference of relative entropy between these tills was obtained by calculations based on the both sets of four fractions, petrographic groups, heavy minerals and light minerals (Table). The relative entropy increases with the mixing level of tills, i. e. the content of all components equalizes (Baltrūnas, Pukelytė, 2003; Baltrūnas, Gaigalas, 2004; Baltrūnas et al., 2005). This may be accounted for by different glaciodynamic conditions of Žemaitija and Medininkai glaciers.

Calculation of the relative entropy of grain-size composition for 9 and 8 fractions of all samples (R_1 ir R_2) and in both sets of four fractions (R_3 ir R_4) (Table) showed that this index in the vertical section of the tills of the same age was variable and in some places (intervals) the variation bore a rhythmic character (Figs. 3, 4). The set of 9 fractions (R_1) is most informative according to the variations of relative entropy. The set of 8 fractions (R_2) is slightly less informative yet both sets complement one another. The sets of 4 fractions are less informative yet retain similar variation trends of R_3 and R_4 as the sets of 9 and 8 fractions.

In the Žemaitija till borehole No. 490 (int. 128–68 m), the relative entropy gradually increases from bottom to top (except in the thin interval 113–112 m.) to 105 m (Fig. 3). Beginning with 104 m, the reduced relative entropy again increases towards the top (to 68 m). The Medininkai till

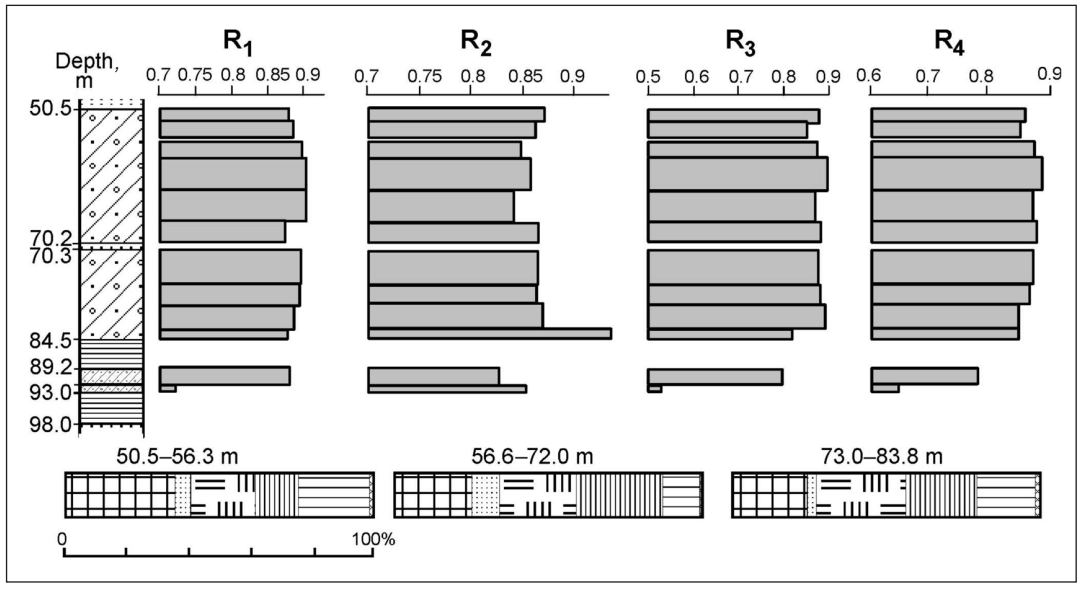

Fig. 4. Sequence of Žemaitija and Medininkai tills in borehole No. 490. Explanations in Fig. 3

4 pav. Žemaitijos ir Medininkų moreninių nuogulų pjūvis gręžinyje Nr. 490. Sutartinius ženklus žr. 3 pav.

(int. 68–41 m) begins with the layer with smaller relative entropy. The overlying visually similar till (int. 40–31.9 m), according to the bedding conditions and differences of the composition of heavy minerals, is attributed to the Upper Pleistocene Grūda stage of last glaciation. Thus the gradual increase of the relative entropy in the Medininkai till is observed to the top. In borehole No. 490 of the Žemaitija till, two sedimentation cycles are distinguished, whereas in the Medininkai till only one cycle is distinguished.

In borehole No. 475, the Žemaitija till (int. 93–89.2 m) is thin. The relative entropy of grain-size of its two samples is small suggesting only the preservation of the lower part of the till complex (Fig. 2). The Medininkai till (int. 84.5–50.5 m) is characterised by three sedimentation cycles (int. 84.5–73, 72–59.5 and 59.5–50.5 m) starting with low relative entropy layers in their lower parts (Fig. 4).

DISCUSSION: THE ORIGIN OF THE MULTILAYERED STRUCTURE OF TILLS

It was long ago observed that the Žemaitija and Medininkai till complexes of South Lithuania are visually comparable and composed of a few beds of tills. The till grain-size composition in the vertical section is often varying in a rhythmic character. The sedimentological sense of this variation pattern is revealed by variations of the relative entropy of grain-size composition, which indicate the mixing level of till material. Up to three zones of higher (better mixing) and lower entropy can be distinguished in the vertical section of the Žemaitija till complex and in the Medininkai till complex. The higher amount of fine sandy and silty material and the smaller amount of clayey material in the zones of smaller entropy (worse mixing) could be associated with exaration processes at the glacier base at the beginning of glaciation and stages of stable and retreating glacier during and at the end of glaciation.

The increased values of the relative entropy of till grain-size distribution are also reflected by changes in the preferred orientation and dip of the clast fabric. This fact can be taken as a proof that formation of the relative entropy zones was associated with glacier activation (Baltrūnas et al., 2005). The successive subglacial depositional processes detected in the basal tills of the Lower Vistula valley in North Poland are very noteworthy (Wysota, 2007). The three till facies must have been formed by complex subglacial sedimentary processes during the first Late Weichselian ice advance.

In the Polish Odra (Žemaitija) glaciation complex till formations (layers) of two stages and in the Warta (Medininkai) complex till formations of three stages have been determined (Ber, 2000). The glaciation complex Dnepr (Žemaitija) in Belarus is composed of two stadial and two interstadial sub-till basin deposits suggesting the possible glacier advances into the territory of Lithuania (Velichkevich et al., 2001). In the Sozha (Medininkai) glaciation complex of the present Belarusian relief, marginal formations of two stages (Mogiliov and Oshmiany) are distinguished whose equivalents have been registered in boreholes No. 475 and No. 490 of the South Lithuanian Medininkai till complex.

CONCLUSIONS

Investigations of the stratification, grain-size and petrographic composition of the South Lithuanian Žemaitija and Medininkai till complexes allow the following conclusions:

1. The structure and composition of the South Lithuanian Middle Pleistocene Žemaitija and Medininkai till complexes are indicative of at least two glaciations and their stages. The Žemaitija till was formed by glaciers advancing from the NW–N across the area of Lower Palaeozoic, Mesozoic and Devonian rocks. The Medininkai till was formed by glaciers advancing from the NE across the area of the Devonian rocks (dolomite, sandstone).

2. The macroscopically homogeneous Žemaitija till complex and the Medininkai till complex have a rhythmic multilayered structure revealed by analytical and statistical data.

3. The sedimentological nature of the rhythmicity of the till structure is partly revealed by analysis of relative entropy variations in the vertical section. The index of relative entropy (indicating the degree of mixing) allowed distinguishing up to 2–3 higher entropy zones in the vertical section of tills.

4. The presence of the mentioned zones in the till strata can be explained by repeated inputs of new morainic material in the basal part of the glacier during its activation (stage, phase). The change of the composition of erratic and transitory material

may be indicative of the change of the glacier advance route, i. e. new glaciation or its new important phase.

ACKNOWLEDGEMENTS

This research is performed within the framework of Project No. MIP-11149 funded by the Research Council of Lithuania.

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ŽEMAITIJOS IR MEDININKŲ MORENINIŲ NUOGULŲ DAUGIASLUOKSNĖ STRUKTŪRA IR JOS KILMĖS KLAUSIMAS PIETŲ LIETUVOJE

Santrauka

Išsamiam tyrimui buvo parinkti Pietų Lietuvos dviejų gręžinių pleistoceno pjūviai, iš kurių atlikta morenų granuliometrinė analizė (archyvinė medžiaga) ir apskaičiuotas visų mėginių granuliometrinės sudėties santykinės entropijos rodiklis. Žemaitijos ir Medininkų moreninių kompleksų sudėtis liudija mažiausiai dviejų apledėjimų ir jų stadijų antslinkius. Žemaitijos moreną suformavo ledynai, į regioną atslinkę iš šiaurės–šiaurės vakarų per apatinio paleozojaus, mezozojaus ir devono nuogulų paplitimo sritį. Medininkų moreną suformavo ledynai, į regioną atslinkę iš šiaurės rytų per devono nuogulų paplitimo sritį. Makroskopiškai homogeniškos Žemaitijos ir Medininkų morenų kompleksai pasižymi dažnai ritmiška daugiasluoksne struktūra, kurią gerai fiksuoja granuliometrinės analizės duomenys. Ritmiško kaitumo sedimentologinę esmę iš dalies atskleidžia granuliometrinės sudėties santykinės entropijos kaitos vertikaliame pjūvyje analizė. Santykinės entropijos rodiklis, rodantis medžiagos išmaišymo lygį, leido morenų vertikaliame pjūvyje išskirti 2–4 didesnės entropijos (t. y. geresnio išmaišymo) zonas. Jų buvimas gali būti paaiškintas naujos (papildomos) moreninės medžiagos pasikartojančia prietaka ledyno bazinėje dalyje jo suaktyvėjimo (stadijos, fazės) metu.

Raktažodžiai: pleistocenas, Pietų Lietuva, sedimentologija, santykinė entropija, daugiasluoksnė struktūra, moreninis priemolis