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Hypsometric assessment of the pre-last Glaciation (Late Saalian) topography, the south-east Lithuania

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Abstract The article deals with the hypsometric assessment of the pre-last Glaciation (Late Saalian) topography which represents a glaciogenic landforms of the Medininkai stadial in south-east Lithuania. The study area belongs to two elevations as orographic units: the Lyda Plateau and the Ašmena Upland. Cartometric topography analysis has been performed in nine reference areas based on large-scale (1:25 000) cartographic maps. The topographic relative height varies from 11.8 m to 30.6 m and depends on the surface altitude (correlation coefficient R = 0.85). The correlation links between the base and top surfaces (R = 0.74–0.92), concave-convex graph of hypsometric curves and value of hypsographic integrals (0.45–0.58) indicate that in general pre-last Glaciation topography of south-east Lithuania at the present stays in equilibrium conditions.

Keywords • *Hypsometric analysis • Late Saalian • pre-last Glaciation • Middle Pleistocene • south-east Lithuania*

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INTRODUCTION

The main features of the recent Lithuania's relief were formed by the Middle Pleistocene (Saalian) and Late Pleistocene (Weichselian) glaciations. The modern surface of Lithuania made up of the Late Glacial and Holocene (20.3% of the area), Upper Weichselian (Nemunas) (75.9%), and Upper Saalian (Medininkai) deposits (2.2%) (Guobytė *et al*. 2001). The Late Saalian (Medininkai) glaciogenic landforms are spread in the south-eastern part of Lithuania and occupies parts of the Lyda Plateau and Ašmena Upland (their greater parts stretch into the area of Belarus).

The limit dividing the terrain areas of pre-last Glaciation and last glaciations is traced along the western foots of Ašmena Upland and Lyda Plateau (Basalykas 1981). It is stated that the Medininkai and Žemaitija tills differ from each other less than the Saalian tills differ from the Elsterian and Weichselian tills (Guobytė, Satkūnas 2011; Satkūnas, Bitinas 1995). According to Baltrūnas (1995), the Lyda Plateau and the Ašmena Upland are of the same or almost the same age. During the last Glaciation they were not glaciated, therefore, they are considered as the oldest glacial surface formation in study area ((marine isotope stage MIS-6; Baltrūnas 1995; Baltrūnas *et al.* 2010).

The glacial and post-glacial processes generated heterogeneous system of the landforms (Kudaba, 1983; Česnulevičius, 1999). The Lyda Plateau is predominated by large low and medium-height hills and flat undulating plains. The topography of the Ašmena Upland is considerably more variable, and it is predominated by large and medium-size hills. The seventeen morphometric assemblages of the landforms are identified here (Minkevičius *et al*. 1985). The Ašmena Upland mesorelief is composed predominantly by sand, gravel and pebbles. The Lyda Plateau is made up by till loam and sandy loam, whereas washed out sand, gravel and boulders cover the troughs and the foot of slopes (Basalykas *et al*. 1976; Kudaba 1983).

The surface height makes one of the key parameters that enable to perform a quantitative description of the unevenness of the land surface (Lastochkin 1991; Česnulevičius 1999). Thus, the height could be interpreted as a function of geodetic point of reference, and it corresponds the conditions for unambiguity, continuity and completeness (Kerimov 2009). This makes it possible to carry out hypsometric assessment in different areas and geomorphologic targets of different rank (Hurtrez *et al.,* 1999; Harrison *et al.,* 1983; Kazansky, 2005; Lorenz *et al.,* 2011; Česnulevičius *et al.* 1992; Česnulevičius, Morkūnaitė 2003).

Hypsometric analysis (area-altitude analysis) is a study on distribution of horizontal cross-sectional areas of a landmass with respect to elevation (Strahler 1952). Routinely, the frequency of altitudes expressed by hypsometric and hypsographic curves with their shapes related to the geomorphologic evolution of the relief. The hypsometric curve can be interpreted in terms of degree of basin dissection and relative landform age: the convex-up curves are typical of youthful stage and un-dissected landscape; smooth and S-shaped curves, crossing the centre of the diagram, characterise mature (equilibrium stage) landscapes; and concave-up curves typify the old and deeply dissected landscape (Strahler 1952). The hypsographic curve also can be evaluated according to quantitative parameter – hypsographic integral (HI). The hypsometric integral is the area beneath the curve, which relates the percentage of total relief to cumulative percent of area and shape of the hypsometric curve, that could indicate the age of the relief. Its value ranges from 0 to 1 (Strahler 1952; Schumm 1956). Often different curves may have a comparable hypsographic integral. In such cases, statistical parameters (asymmetry and excess coefficients) used for characterisation of fine variations of curves, whereas the hypsographic curve itself can be described by a polynomial function (Harlin 1978; Luo 2002).

Hypsometric assessment is one of the main instruments to study tectonics and neotectonics of the earth crust (Filosofov 1975; Chen *et al.* 2003; Zakarevičius *et al.* 2009), surface lithology (Lifton, Chase 1992; Hurtrez, Lucazeau 1999), relief genesis and dissection (Česnulevičius 1999; Česnulevičius *et al* 1992; Šliaupa, Gelumbauskaitė 1972; Česnulevičius, Morkūnaitė 2003), erosion and glaciers dynamics (Masek *et al.* 1994; Česnulevičius 1999; Brocklehurst, Whipple 2004). In Lithuania, hypsometric studies of the topography mainly confined to indication of maximum, minimum or average altitudes. The most comprehensive information about the earth surface altitudes can be found in the works about landforms morphology and morphometry (Krasauskas 1976; Česnulevičius 1986, 1999; Česnulevičius *et al.* 1992), and in the geomorphologic studies (Mikalauskas 1985; Kondratienė, Mikalauskas 1986). Kudaba (1983) first published a succinct description of hypsographic curve of Lithuania, relative heights and hypsometric situation of large orographic elements of the surface, and distinctive features of hypsographic curves of main uplands and their links with the relief age. The vertical segmentation of landforms is closely related with hypsographic curve of topography (Basalykas 1977). The mentioned works demonstrate that surface altitude is an important source of information which, when expressed in absolute and relative meaning, allows comparing discrete relief elements or areas and revealing their differences or similarities. It is an objective criterion for description of natural processes and phenomena.

The present paper describes a statistic study of patterns and altitudes of the oldest glaciogenic relief of the south-east Lithuania. This relief is represented by hilly morainic upland with valleys that occupies the highest position in the hypsographic curve (Basalykas 1977). Earlier morphometric studies have stated that the relief differs considerably from other ice marginal formations of Lithuania. It is distinguished for specific unevenness of the land surface (Česnulevičius 1986, 1999) and, most likely, hypsometric features.

ASSESSMENT DATA AND METHODS

Considering the geomorphological regionalisation of Lithuania (Basalykas 1981), the hypsometric investigations of the study area took up nine micro-landform assemblages in which reference areas were chosen for cartography measurements. The reference areas represent the altitudes from the lowest plateau surface to the top of marginal ridge, and include all types of sediments covering the surface ((Fig. 1). The reference areas occupy from 80–120 km^2 to 200 km^2, and their total account exceeds 50% of the topography surface. The sediments here are characterised by low genetic diversity and negligible composition differences. The larger part of the surface represented

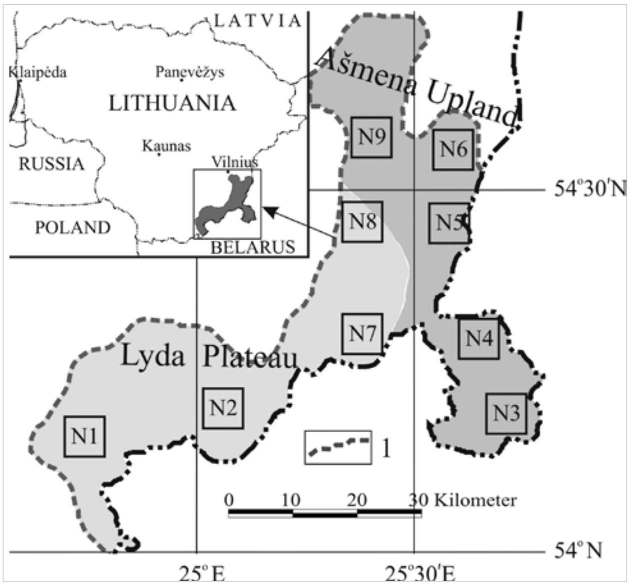

Fig. 1 Location of the study site in south-east Lithuania and distribution of reference areas (N1–N9). 1 – boundary of the last glaciation (after Guobytė 1998).

by glacioaquatic (27.3–68%) and glaciogenic (12.1–51.3%) formations. Younger alluvial, bog and deluvial sediments somewhere cover the glaciogenic formations. In the reference areas, it counts for 5.9% to 30.3% of the total area (Table 1).

Table 1 Distribution of deposits (%) of the pre-last Glaciation of the south-east Lithuania in nine reference areas (N1–N9) figured up from the basic geological map (Guobytė, 1998).

Age and genesis of deposits		No. of reference area (see Fig. 1)								
Age	Genetic types	N1	N2	N3	N4	N5	N6	N7	N8	N9
Holocene	Alluvium	2.0	1.5	7.7	0.0	4.4	3.0	2.5	5.1	4.1
	Deluvium	6.4	0.4	1.8	0.7	6.7	20.6	2.3	10.2	13.5
	Moor	8.7	6.2	5.1	5.2	12.5	6.8	7.5	0.6	3.6
Saalian Glaciation	Basal till	25.5	51.3	12.1	13.8	37.0	27.2	33.0	29.7	46.5
	Marginal glaciofliuvial	42.1	36.8	62.3	68.0	34.7	29.5	46.8	53.5	27.3
	Glaciofluvial	5.9	3.2	11.0	12.3	3.8	9.1	7.9	0.8	4.3
	Glaciolacustrine	9.4	0.6	0.0	0.0	0.9	3.9	0.0	0.0	0.7

The hypsometric survey in the reference areas was based on cartography measurements of topographic maps at a scale of 1:25 000. The data about surface altitudes have been taken from the maps in course from every square of the grid of coordinates. The squares in their turn were divided in half-and-half (in latitudinal and meridional directions) to match grid size 500 x500 m. The read data have been approximated based on the hexagonal network by the method of moving averages (Berliant 1978; Spiridonov 1975). Absolute maximum and minimum heights characterise the relief in an each grid cell. Analysing the data, the maximum topography altitudes were assumed as the top surface, whereas the minimum ones made the base surface. The altitude input data from each reference area were analysed by statistical methods. According to these methods, the relief height approached as a casual dimension and its statistical characteristics are calculated based on the altitude input data (Harlin 1978; Luo 2002). Based on the input data, distribution curves of altitudes were drawn and their hypsometric integrals calculated for each reference area. The hypsometric integral (HI) stands for relief area below the hypsometric curve and calculated according to the ratio of altitude differences (Strahler 1952):

$$HI= (E_{mean}–E_{min})/(E_{max}–E_{min}),$$

E_{mean} – average altitude of relief, E_{min} – minimum altitude, E_{max} – maximum altitude.

RESULTS

Hypsometric limit between the upland and the plateau

The boundary between the south-east Lithuania geomorphologic regions of the elevations of the pre-last Glaciation is indistinct (Basalykas 1981). This boundary can be stated by the hypsometric data on altitude variation of topography. Kudaba (1983) identifies the uppermost boundary of Lyda Plateau with the isoline of 180 m. Yet the variations of the relative (this height may serve as one of the parameters identifying the hypsometric boundary between the plateau and the upland) and absolute altitudes of surface prompt that this boundary should be drawn at a higher altitude. The amplitude of absolute altitude was reduced to provisional hypsometric level at intervals of 10 m, and the relative average of the relief altitude was calculated for each level. With gradual increase of the absolute altitude of the surface, its relative height also increases. Yet the increase of relief altitude is uneven though approximated by linear dependence ($R^2 = 0.77$).

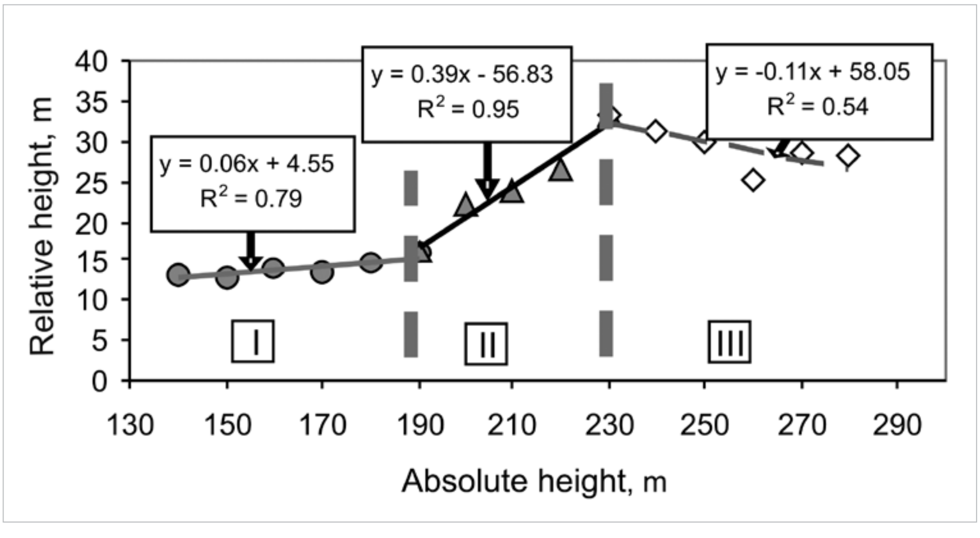

Fig. 2 Relation of relative height and absolute height of the relief hypsometric levels I–III. Circle – Lyda Plateau, triangle – Ašmena Upland (increase of relative height), rhomb – Ašmena Upland (decrease of relative height).

Three topography levels of the pre-last Glaciation were distinguished with different relative height and gradient (Fig. 2). The lowest surface, up to 190 m above sea level (further a.s.l.), is recorded for relatively small and almost unvarying elevations (height 12.9–16.2 m). The relative height markedly increases from the 190 m a.s.l. reaching the value of 22.3 m. At higher altitude (190–230 m a.s.l.), the relative height increases by 20–22% on the average at every provisional hypsometric level and ranges within 22.3–33.4 m. The increase of the average relative height presumably marks the hypsometric boundary between the plateau and the upland. Beginning with 230 m a.s.l., the relative height slightly decreases yet remains rather high. Thus, the 1st hypsometric level of the relief (up to 190 m) is identified as a plateau with the average relative height of 14.8 m; the 2nd level (from 190 m to 230 m) has the average relative height 25.7 m; and the 3rd level (above 230 m) has the average relative height 29.1 m; the latter two levels attributed to elevated relief.

Altitude of topography and hypsographic curves

According to the data from the reference areas, the absolute altitude in the area of the pre-last Glaciation ranges from 130 m to 292.5 m. The newest data show the maximum altitude of relief reaches 293.8 m. The average height of the surface in the reference areas ranges from 168.5 m to 186.9 m on the plateau and from 201.7 m to 237.6 m on the upland. Almost symmetric monomodal distribution of altitudes (close to normal) is dominant. The empirical normality of the distribution of altitudes was checked using Pearson's Chi-square (χ^2) criterion at significance ά = 0.05. According to this criterion, the empirical distribution of altitudes corresponds to normal distribution pattern in all three-reference areas. Thus, the distribution hypsometric curves of altitudes belong to one type yet with different average altitude and standard deviation. It observed that with increasing relief altitudes the distribution amplitude of altitudes also widens. The distribution of altitudes changes correspondingly (Fig. 3).

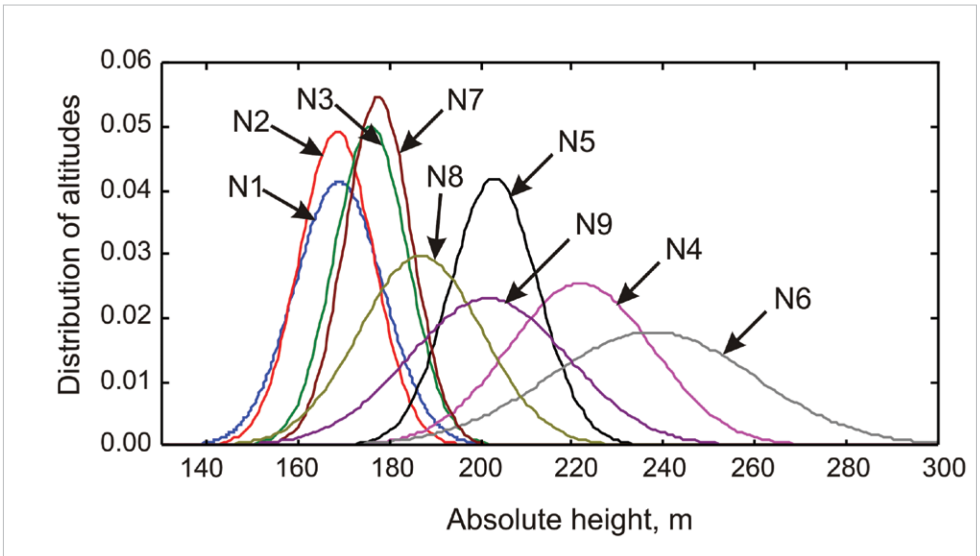

Fig. 3 Distribution of altitudes versus absolute height (m) in the reference areas (N1–N9).

The shape of the hypsographic curves of distribution pattern of topography altitudes (diagram of the integral function of altitude distribution of relief) may serve as a basis for judgement about the relief evolution stage. The hypsographic curves in the reference areas of the plateau and the upland differ but little. In the majority of cases, the lower part of the curve is convex to a different degree, whereas the upper part is concave resembling letter S (Fig. 4). This form of the curve (Strahler 1952) implies that denudation processes have affected the relief for a long time, considerably transformed and entered the mature stage. It can be assumed that the Ašmena Upland's morainic hilly relief has passed through the initial cycle of young relief and at present is in the initial stage of maturity. The hypsometric integral (HI) describing the topography area below the hypsographic curve ranges within 0.45–0.58 (Fig. 4). The topography area under the hypsographic curve can be approximated by a third degree polynomial function with a high determination coefficient (R^2 = 0.97–1.00). According to Shumm's (1956) types of relief evolution based on HI values, the relief of the reference areas corresponds to the mature stage of relief. The HI value is partly related to the relief altitude, yet only if the approach is differentiated. The correlation of HI with the surface to the height of 200 m and the correlation of HI to the height above 200 m are strong (Fig. 5). Yet these correlations do not answer the question as to the difference of the relief stages on the plateau and on the upland. The hypsometric data, i.e. average HI values on the plateau (0.52) and on the upland (0.54), are almost identical what does not allow to state that these forms of relief belong to different stages.

Altitudes of the top and base surfaces

The top surface links up the highest points of the relief, and the base surface links up the lowest points. The difference between these surfaces shows the relief energy potential and the vertical distribution (Filosofov 1975; Lastochkin 1991). The altitude of the joining line along the highest relief points varies from 150–200 m on the plateau and from 200 m to 292.5 m on the upland. The lowest top surface in the peripheral part of the plateau rises towards the upland and is slightly sloping in the southern direction. On the plateau, the average level of the surface ranges from 174.4 m to 197.3 m. On the upland, the average top surface elevates to 212.5–253.0 m (Table 2). It should be pointed

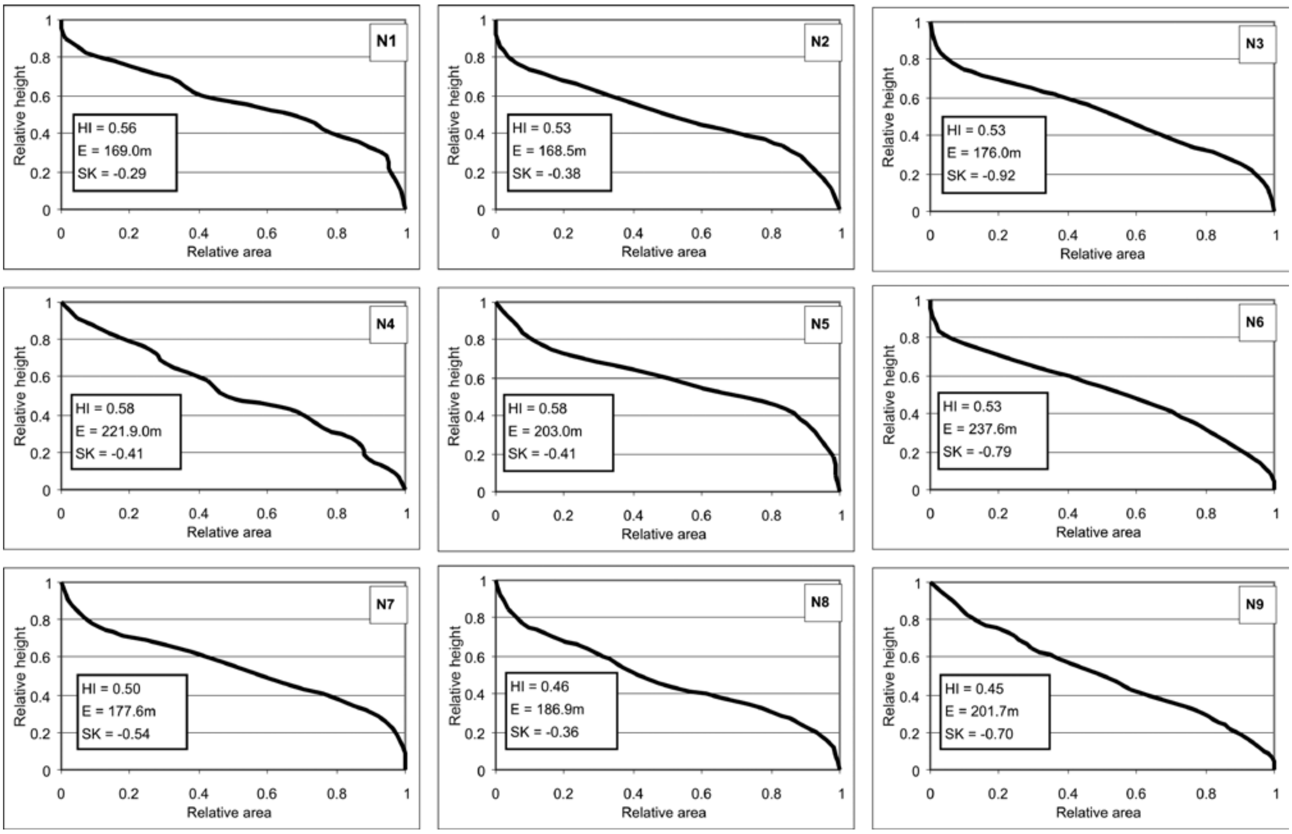

Fig. 4 Hypsographic curves of the reference areas (N1–N9) and their statistics: HI – hypsometric integral, E – average height, SK – skewness.

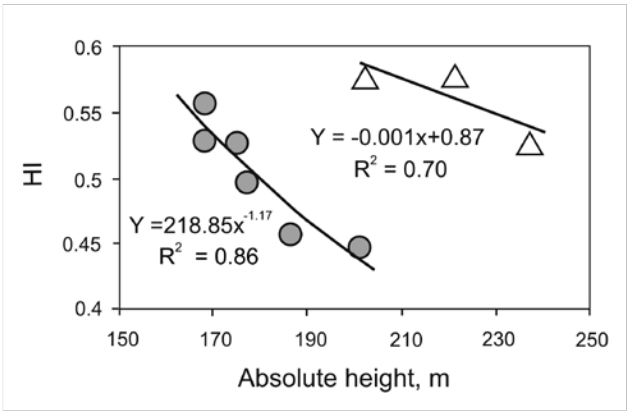

Fig. 5 Hypsometric integral (HI) and statistical ratio of the average surface heights in the reference areas (N1–N9). Circle – Lyda Plateau, triangle – Ašmena Upland.

out that the average height of the top surface is not variable: on the plateau its variation coefficient is 4.1–5.0%, whereas on the upland it is slightly higher – 7.1–8.7%. The reference areas are predominated by the mono-modal altitude distribution of top surface what corresponds with the traits of normal distribution. The distribution of normal altitude distribution criterion (ά = 0.05) in the reference areas (N6, N3) is different (Table 2). In the reference area N3, the distribution of altitude is close to amodal type because most of the altitude (65.4%) are almost evenly distributed in four 170–190 m intervals thus implying possible sloping of the top surface.

The top surface is perceptible and based on data whereas the hypsometric level of the base surface – valleys, troughs and other depressions – is rather hypothetical. The base surface linking the lowest points of the relief is identified with the lower boundary of recent erosion processes, which in the reference areas varies within a wide range. The lowest point (130–140 m) of the base surface occurs in the boundary between the Lyda Plateau and the neighbouring Dainava Plain. Moving away from the boundary, it gradually elevates and reaches 240–270 m on the upland. The average height of base surface in the reference areas varies within the range of 161.8–222.3 m. The variation amplitude of altitude is related to the expression of the topography (Table 2). Yet the statistical characteristics of the altitude distribution of the base surface imply a certain role of morphological differences of the relief. This is illustrated by the data from the plateau reference areas (N1–N3, N7) showing that the average altitude of the base surface varies within 161.8–171.7 m, yet the characteristics of altitude distribution are almost identical. They are not characterised by adequate variation amplitude of altitude values. The peripheral part of the plateau makes the only exception (N1) (Table 2). Greater variations of the base level in this area should be related to deeper river valleys and relief declensions many of which (20 %) occupy high hypsometric position (165–170 m). Due to more complicated relief morphology, the altitude of the bottom of negative

Table 2 Statistical characteristics of vertical segmentation of the top and base surfaces in reference areas (N1–N9).

N	E_{mean} (m)	$Q_1 – Q_3$ (m)	δ	SK	Chi square, χ^2		
					Statistics	df	p
Base surface							
N1	161.8	152.5–172.5	11.4	–0.25	17.39	6	0.008
N2	162.6	157.5–170.0	8.9	0.03	6.76	4	0.149
N3	167.2	160.0–172.5	8.3	0.09	4.14	2	0.126
N4	209.0	200.0–220.0	14.8	–0.15	6.29	5	0.284
N5	193.5	188.5–200.0	10.4	–0.55	6.95	5	0.224
N6	222.3	200.0–240.0	23.7	–0.12	36.72	8	0.000
N7	171.7	165.0–177.5	8.0	0.02	10.10	4	0.038
N8	176.5	165.0–185.0	14.9	0.10	6.71	6	0.349
N9	188.3	175.0–200.0	17.1	0.30	9.96*	8	0.268
Top surface							
N1	176.3	170.0–182.5	8.8	–0.50	4.86	4	0.301
N2	174.4	170.0–180.0	7.9	–0.20	3.69	3	0.297
N3	184.9	177.5–192.5	8.6	–0.35	15.11	3	0.002
N4	234.8	225.0–250.0	17.8	–0.26	3.44	4	0.486
N5	212.5	207.5–220.0	9.7	–0.19	5.71	4	0.222
N6	253.0	240.0–267.5	21.8	–0.45	23.16	7	0.002
N7	183.5	180.0–187.5	7.5	0.13	6.84	4	0.144
N8	197.3	190.0–207.5	13.9	0.19	3.19	6	0.785
N9	215.1	202.5–230.0	18.5	0.16	3.14	4	0.534

N1 – number of reference area; E_{mean} – average altitude; Q_1–Q_3 – altitude of the first and third quartiles; δ – standard deviation; SK – skewness; df – degrees of freedom; p – probability; * Log–normal distribution.

forms on the upland is distributed within a wide altitude range (Table 2). The average height of the base surface marked by a higher variation coefficient than that of the top surface: on the plateau 4.6–7.0%, and on the upland 5.5–10.7%.

The distribution of the altitudes of the base surface in the reference areas is close to symmetrical and can be described as the normal or lognormal distribution. Yet comparison of empirical and theoretical distribution patterns of altitude shows that in reference areas N1, N6 and N7 they differ considerably and do not match the pattern of normal distribution (Table 2). These areas are marked by features of amodal distribution thus implying absence of the dominant altitude, as most points of base surface at different altitude are evenly distributed.

On the Lyda Plateau and on the Ašmena Upland, the variation of the top surface altitudes is mostly accompanied by analogous variation of base surface, i.e. the latitude variation of both surfaces bear synchronic character. The interaction of these surfaces is approximated by linear dependence (Fig. 6). Comparison of different reference areas has shown that on the plateau the mentioned interaction is slightly weaker (R = 0.74–0.86) than on the upland (R = 0.81–0.92). Based on the principle of hypsometric correlation (Khudiakov 1971), it is assumed that the strong correlation links between the base and top surfaces in the area of the pre-last Glaciation reflect a sustainable evolution of topography and its present status close to equilibrium.

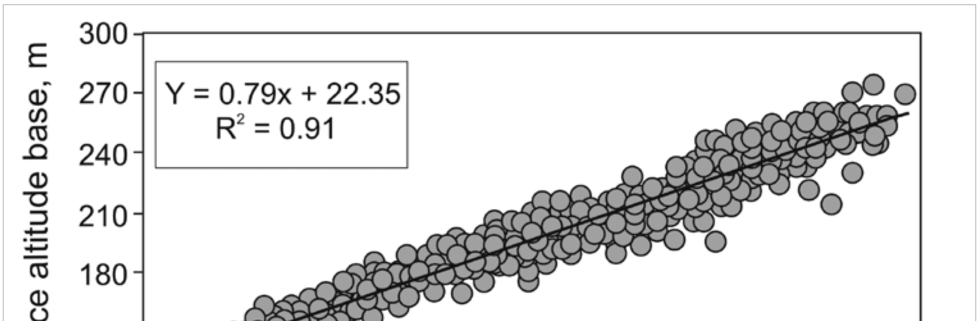

Fig. 6 Statistical ratio between the relief top and base altitude surfaces according to data of all reference areas (N1–N9).

The altitude difference between the top and base surfaces shows the relative height of the surface forms. At the same time, this difference taken as the value of the vertical dissection of topography, which shows relief energy (Filosofov 1975; Spiridonov 1975). The comparability of the base and top surfaces imply a

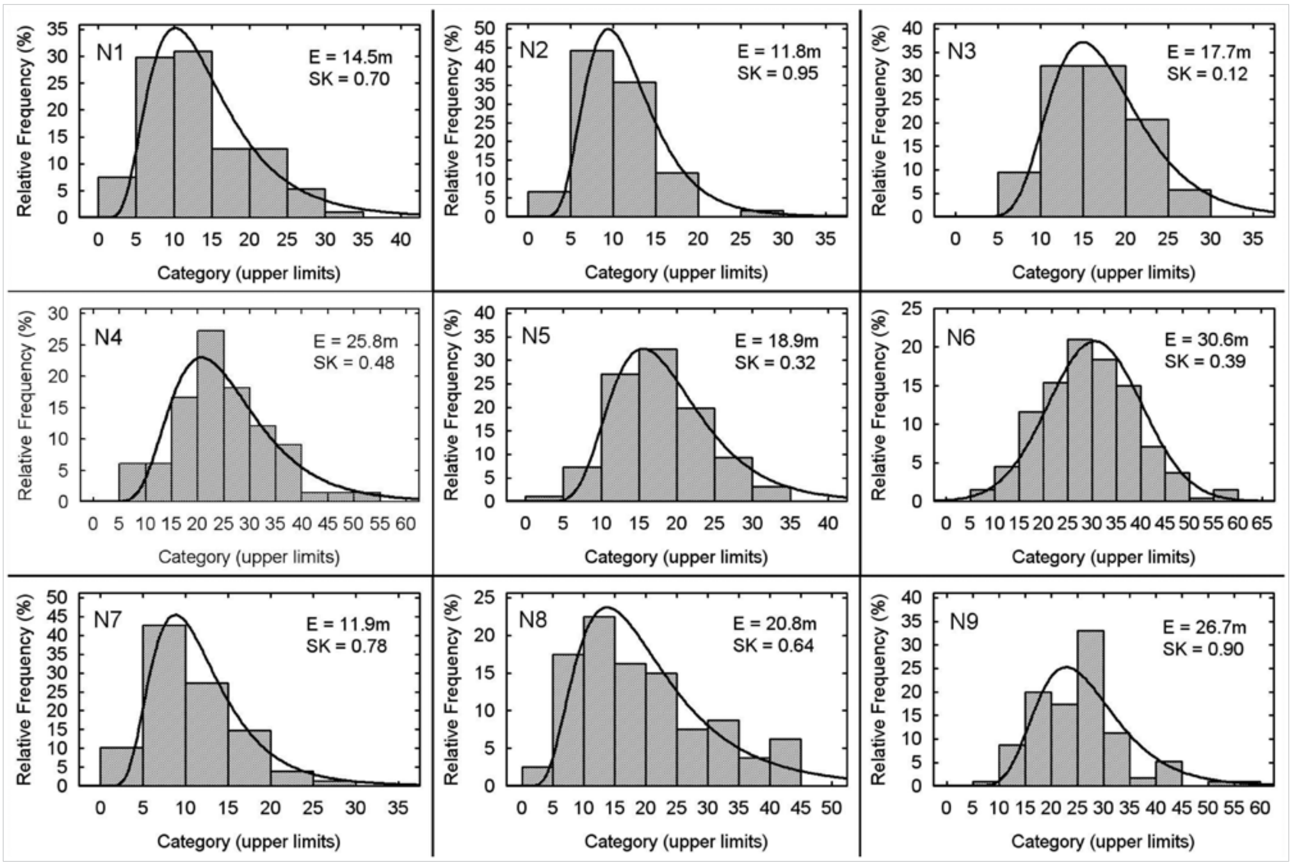

Fig. 7 Histograms of the distribution of relative heights (vertical dissection) of topography in the reference areas, their approximation by lognormal distribution curves, average height (depth) E, and asymmetry coefficient SK in the reference areas (N1–N9). Approximation of the distribution of heights according to normal distribution pattern in area *N6.

low hypsometric gradient and low relief energy. The relative depth of the vertical dissection of the relief of the pre-last Glaciation varies from a few metres to 30–40 m or even to 50–60 m, i.e. the amplitude is wide and the variation coefficient is high (30–50%). The less sensitive to deviations and more informative inter-quartile difference (Q_1–Q_3) takes up 50% of all distributions. It shows that the relative depth of the vertical dissection of topography in the reference areas of the plateau is between 7.5 and 20.5 m, whereas in the reference areas of the upland it increases to 15–37.5 m. The average relative depth of topography dissection in the reference areas varies from 11.8 m on the plateau to 30.6 m in the central part of the upland. The distribution of the relative height of the forms of relief is mono-modal, characterised by slight asymmetry (of the right side). It usually approximated by lognormal or normal distribution patterns (Fig. 7). The relative depth of the vertical relief dissection partly depends on the surface altitude. Having in mind that the depth of vertical dissection predetermines position of the base surface, not the other way round the supremacy of the top surface should be recognised. The interaction between the relative depth of the vertical dissection and the top surface is approximated based on the total data from all reference areas and using the weaker linear dependence ($R^2 = 0.42$) rather than based on the local values from reference areas ($R^2 = 0.85$). The variation of the hypsometric gradients of base and top surfaces show that relief energy potential, as well as morphogenesis intensity on the plateau and on the upland is not identical; the difference may have three times.

Cluster analysis of topography heights and vertical segmentation

The surface altitudes in the reference areas and their distribution patterns have similarities and may be joined applying cluster analysis. Having joined the hypsometric similar topography by Ward's method, the reference areas have been divided into two groups. The first group includes areas N4, N5, N6, and N9. This group distinguished by the highest relief altitude is further divided into two sub-groups (Fig. 8A). The average altitude of the surface in the first sub-group (N9 and N5) is 204.4 m, and in the second group (N6 and N4) it is 229.8 m. The second group includes other reference areas, which are further divided into sub-groups. The average height of the reference areas in the first sub-group reaches 180.2 m. The second sub-group include the lowest old glaciation surface points

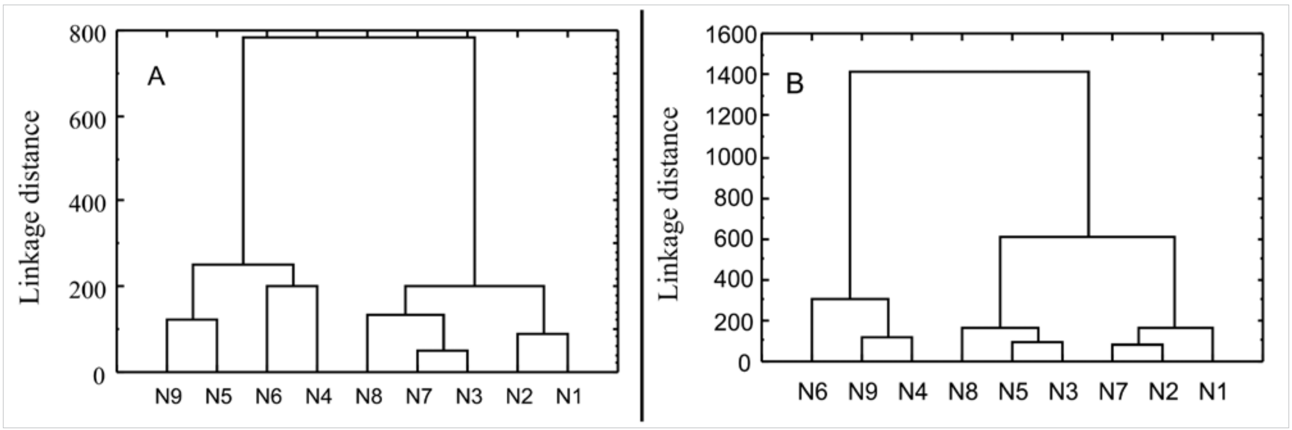

Fig. 8 Cluster dendrogram of topography height (A) and vertical dissection (relative height, B) in reference areas (N1–N9).

occupying the southern part of the Lyda Plateau. Their average height does not exceed 169.0 m (Fig. 8A).

In the presented dendrogram (Fig. 8A), the distinguished groups of reference areas match the orographic units. The first group joins the elevated areas with the average absolute altitude 201.7 m to 237.6 m, i.e. above 200 m. The second group includes the lower relief (<190 m) of the plateau, where the average height of areas varies from 168.5 m to 186.9 m. According to the distinguished groups, the average altitude of the Lyda Plateau is 175.6 m and that of the Ašmena Upland is 216.1 m. These data of cluster analysis do not completely match the geomorphological regions because according to geomorphological regionalisation of Lithuania (Basalykas 1981), area N3 represents the upland topography, whereas according to hypsometric data it is closer to the plateau topography.

Somewhat different data are obtained by cluster analysis, when reference areas are grouped according to the relative vertical dissection of the relief. In this case, two groups are distinguished. The first group includes the surfaces of deepest vertical dissection (N4, N9 and N6). The dissection depth in them varies from 25.8 m to 30.6 m. The average relative vertical dissection is 27.7 m (Fig. 8B). The second cluster includes the areas divided into two sub-groups. The average relative vertical dissection in the areas of the first sub-group (N3, N5 and N8) varies from 17.7 m to 20.8 m. The average relative vertical dissection in the second sub-group (N1, N2 and N7) is 11.8–14.5 m (Fig. 8B). The data obtained by cluster analysis show that there are three relative vertical dissection areas in old Ašmena Upland area. The deepest dissection is observed in the central part of the upland generated under the conditions of inter-lobe glacigenic accumulation (Basalykas *et al*. 1976). Hill ridges extend from the central part submeridionally. The average relative vertical dissection in this highest point of the upland is 27.8 m. The surfaces of smaller relative vertical dissection (average 19.1 m) take up the slope bottom and adjoining higher part of the plateau. In the remaining lower part of the plateau, the relative vertical dissection of the relief is the smallest (average 12.7 m).

DISCUSSION

The surface shape, its altitude and distribution patterns of altitude, is permanently changing under the effect of different geodynamic processes. Thus, surface hypsometry is one of the sources about relief formation processes. The south-east Lithuania's relief is a result of glaciogenic accumulation, which took place under the conditions of active tectonic uplift, and subsequent geomorphological processes (Basalykas 1976). The relief is polygenetic (see Table 1), marked by morphometric diversity (Minkevičius *et al*. 1985) and wide amplitude of absolute altitude reaching 160 m. The relative height of the surface elevation (vertical relief dissection) varies within a narrower range, which partly depends on the absolute altitude of relief. The noticeable variation of the relative height of the surface (beginning with the altitude of 190 m) are related with the hypsometric boundary between the Lyda Plateau and the Ašmena Upland (see Fig. 2). The stepped character of topography (plateau, upland slope and upland stem) predetermined by glacio-accumulative peculiarities, glacier dynamics and the inherited relief of the previous glaciations (Basalykas 1976; Kudaba 1983).

The absolute altitudes of plateau and upland surface differ but the statistics and distribution of altitudes with a slight asymmetry are comparable. A symmetric relief implies that it is stable, i.e. in the stage of dynamic equilibrium. The asymmetric distribution of altitudes is related to the impact of geological factors, morphological features of the surface, and character and intensity of geomorphological processes. In the greater part of the plateau and upland (N1–N6) surfaces, the distribution of altitudes with negative asymmetry is dominant. In the remaining part of relief, including the plateau edge bordering with the upland and the western part of the upland (N7–N9), the distribution of altitudes is characterised by positive asymmetry. A major part of recent surface is notable for a deeper dissection of the relief. Meanwhile, opposite processes take part in the other part of relief, i.e. the potential relief energy reduces, linear erosion weakens and the relief is in the phase of smoothing related to the inversion of tectonic regime. Yet a small amplitude of the values of asymmetry coefficient from –0.33 to 0.27 (asymmetry below 0.5 is insignificant) shows that the surface morphogenesis of the pre-last Glaciation is close to the equilibrium stage. This is proved by synchronic changes of the top and base surfaces implying that geomorphological processes transform the surface of both positive and negative forms of the relief.

According to the vertical dissection of the relief, the intensity of geodynamic processes on the plateau and on the upland differs up to three times. Similar differences also proved by the data about recent exogenic processes (Valiūnas 2004). According to the data of neotectonic investigations (Zakarevičius *et al.* 2009), the earth crust in the south-eastern part of Lithuania has been recently subsiding at an average rate of 1–2 mm per year. Having this in mind it can be assumed that further development of the surface will be associated with accumulation of denudation material in the negative forms of relief, reduction of the vertical dissection and smoothing of the surface.

The data obtained by cluster analysis of topography altitudes and vertical dissection are comparable with the data of the previous morphometric investigations (Minkevičius *et al*. 1985). According to morphometric classification of the landforms (Česnulevičius 1999), three vertical dissection clusters are distinguished (see Fig. 7), which can be identified with morphometric types of low, medium and high hills.

CONCLUSIONS

Analysis of the relative and absolute altitude of the pre-last Glaciation relief based on the relative hypsometric levels showed the stepped character of the topography. The noticeable variations of the relative altitude observed above the 190 m related with hypsometric boundary between the Lyda Plateau and the Ašmena Upland. The absolute altitude of the plateau and the upland surfaces differs but the distribution pattern of altitudes holds the typical slight asymmetry that is close to normal distribution. The shape of hypsographic curve and the values of hypsographic integral show that the pre-last Glaciation landforms have mature surface. The close relationship between the top and base surfaces implies morphogenetic equilibrium and harmonious development of the relief.

The depth (relative height) of the vertical dissection is in direct dependence of the topography altitude and partly reflects relative intensity of geodynamic processes. According to this index, the dissection of the elevated relief should be three times more active as the modification of the plateau.

The present relief surface, its hypsometry is a result of geomorphologic processes and one of the conditions of the recent relief dynamics. Having in mind that the area developed during the pre-last Glaciation is subsiding, it can be assumed that further development of the surface will be associated with accumulation of denudation material in the negative forms of relief, reduction of the vertical dissection and smoothing of the surface.

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