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Glacial geology of North Lithuanian ice marginal ridge and surrounding plains

Danguolė Karmazienė, Bronislavas Karmaza, Valentinas Baltrūnas

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Abstract During the last decades many studies were concentrated on the North Lithuanian ice marginal ridge of the Last Glaciation (Late Nemunas, Late Weichselian). The North Lithuanian ice marginal ridge or so–called Linkuva ridge was formed by Žiemgala Ice Lobe that advanced at the end of the glaciation through the Gulf of Riga. This ridge is considered as a boundary of glacier limit during the North Lithuanian recessional phase of the Late Nemunas Baltija stage. Linkuva ridge is stretching about 130 km as a bow-shaped ridge and is marking the boundary of an active ice lobe. The thickness of Quaternary deposits is 10–12 meters on the average but varies from 1.0 to 39.0 meters: the thinnest Quaternary cover is characteristic for river valleys, whereas the thickest one is related with the highest altitudes of the present topography or with rare palaeoincisions of the sub–Quaternary surface. Pleistocene strata are subdivided to three till complexes in some places separated by inter–till sediments.

Keywords *• End moraine • Kame terrace • Massive clay • Glaciolacustrine plain • Ice–dammed lake • Drumlins • Till • North Lithuania*

✉ *Danguolė Karmazienė, Bronislavas Karmaza (karmaza@geo.lt), Valentinas Baltrūnas, Nature Research Centre, Institute of Geology and Geography, 13, T. Ševčenkos Str., 03223 Vilnius, Lithuania.*

INTRODUCTION

The North Lithuanian ice marginal ridge, or so–called Linkuva end moraine, is stretching for 130 km as a bow–shaped formation and is marking the boundary of an active ice lobe (Fig. 1). It is considered that the ridge is marking the limit of glacier advance during the North Lithuanian recessional phase of the Late Nemunas Baltija stage. This ridge is stretching along the entire southern edge of Žiemgala morainic plain and is one of the best expressed end moraine ridges in the Baltic region. It is distinguished among analogue glacial landforms of relief by its integrity: there are no gaps within 80 km interval of the ridge. The surface of the entire North Lithuania was formed during deglaciation of the last Scandinavian Ice Sheet (SIS).

First Linkuva end moraine was described by B. Doss (1910) and later studied by many scientists. According to some authors, starting from the North Lithuanian ice marginal ridge, the SIS decay began in the Baltic Sea basin, as well as in the Northern Vidzeme, Middle Gauja and all over of the Central Latvian Lowland (Zelčs, Markots 2004). According to Āboltiņš *et al.* (1972) the Linkuva phase is the second lobate deglaciation phase after the Gulbene or Middle Lithuanian phase. During the Linkuva phase, the Burtnieks, Žiemgala and Iecava drumlin fields and associated landforms were formed (Straume 1979; Zelčs 1993). The Linkuva line is clearly marked by the push moraine arc in the Central Latvian Lowland (Doss 1910) and is correlating with the Haanja phase in Estonia (Raukas *et al*. 1995). However, as it noted by Zelčs *et al.* (2011), the Linkuva glacial phase marginal formations can rather be correlated with the Otepää ice-marginal zone in Estonia. Further continuation of the Linkuva ice–marginal formations along the up–glacier margin of the East Latvian Lowlands into Russia is only based on morphological evidence. Different views exist on this marginal landforms rank. The North Lithuanian ice marginal ridge in Lithuania has a "phase" rank (Kudaba 1983; Gaigalas, Melešytė 2001), while its prolongation in Latvia – it is ranked as an "oscillation" (Aboltin 1963; Zelčs, Markots 2004).

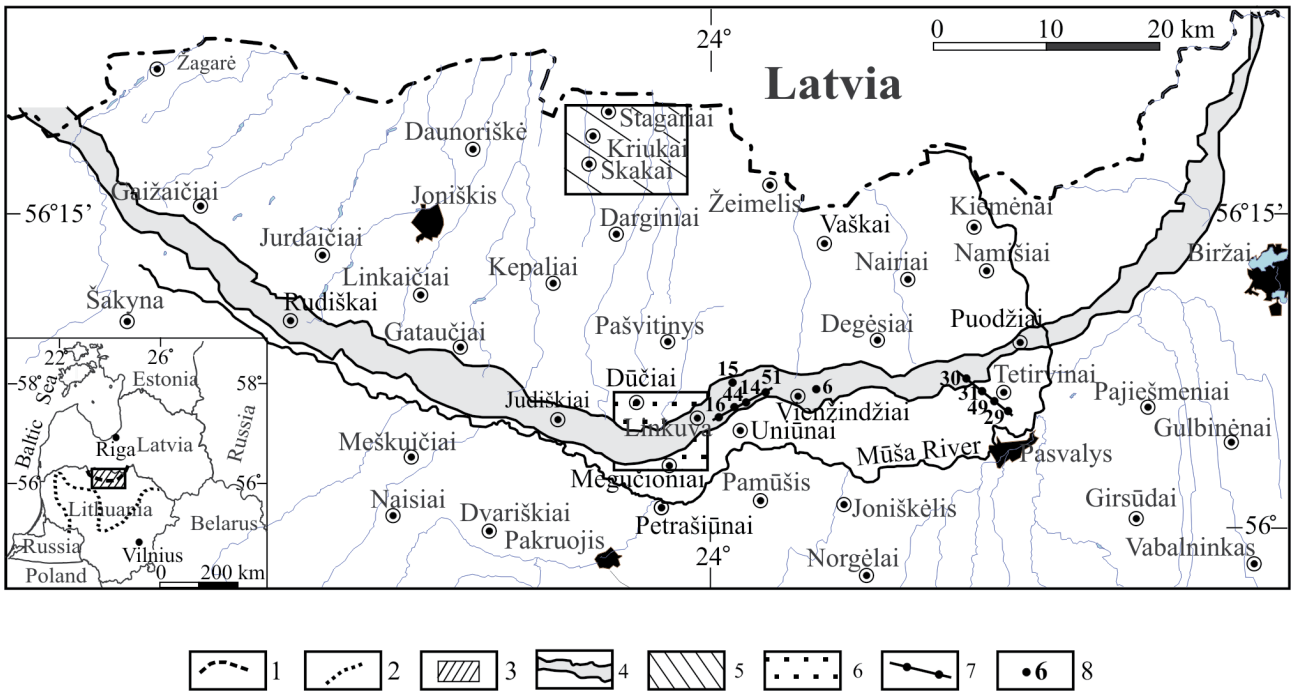

Fig. 1 Location of study area: 1 – limit of North Lithuanian phase; 2 – limit of Middle Lithuanian phase; 3 – investigated area; 4 – North Lithuanian ice marginal ridge; 5 – Kriukai drumlin area (Fig. 8); 6 – location of geomorphological map shown in Fig. 2; 7 – location of geological cross–section line; 8 – borehole site and its number. Compiled by B. Karmaza, 2013.

The age of this end moraine zone decreases from south–east (Poland) to north–west (Karelia). The Slupsk Bank Phase in northern Poland was dated to 16.0–15.6 ka BP (calibrated from 13.5 to 13.2 ka ^{14}C BP; Gelumbauskaitė 1991; Uścinowicz 1999; Marks 2002) and is correlative with Linkuva ice marginal formation in Latvia to 15.6–15.4 ka BP (calibrated from 13.0–13.2 ka ^{14}C BP; Zelčs, Markots 2004), the Haanja Stade in Estonia between 15.7 and 14.7 ka BP (Raukas *et al*. 2004) and the Luga moraine in Karelia, which was dated prior to 14250 years ago (Saarnisto, Saarinen 2001). These ages are somewhat older than the weighted mean ^{10}Be age (13.3±0.7 ka) of nine boulders on the North Lithuanian moraine ridge (Rinterknecht *et al.* 2006, 2008).

The aim of the present paper is to report new information on structural peculiarities and geomorphology of North Lithuanian ice marginal ridge and surrounding plains.

MATERIALS AND STUDY METHODS

Geological and geomorphologic investigations of digging test pits and investigation of outcrops, field observation and interpretation of aerial photographs (scale 1:17 000; year 1952) were a basis for the geological–geomorphologic reconstructions. Macroscopic description, graphic fixation and photos of the pits walls were used to examine the Pleistocene succession of the study area. The results of interpretation for the purposes of both geological–geomorphologic and anthropogenic load maps were verified and adjusted during the fieldwork. The results obtained from over 80 boreholes drilled earlier (up to 20–25 metres depth) in the course of state geological mapping at a scale of 1:50 000 were also used. The borehole coordinates were established by means of GPS and the borehole mouth height by grading the drilling profiles. Shallow geophysical investigations were conducted along several drilling lines by the electro–tomography method.

Grain size analysis of till and clay sediments was carried out using 13–sieve set: >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, pebble and sand >5; 5–2.5; 2.5–1.25; 1.25–0.63; 0.63–0.315; 0.315–0.14; <0.14 mm. Grain size was analysed at the laboratory of the Lithuanian Geological Survey.

The investigation of coarse grained clastic material of tills included petrographic analysis of gravel and pebbles (fraction 50–5 mm). The petrographic analysis of the clasts in fraction 5–30 mm of tills was performed using the widespread method developed by Gaigalas (1979). Laboratory methods were used for determining groups of crystalline rocks (granites, gneisses, diorites, etc.), limestones, dolostones, sandstones and other kinds of clastic material (fossils, calcite, flint, etc.). The petrographic indices were calculated according to the methods proposed by Ber (2000), Gaigalas, Melešytė (2001), Pettersson (2002) and Lisicki (2003). Samples were analysed at the laboratory of the Nature Research Centre, Institute of Geology and Geography, Vilnius.

RESULTS

Structure and peculiarities of formation of Pleistocene deposits in North Lithuania

The North Lithuania has been known as an area of dominant glacial erosion where the Quaternary cover is relatively thin and has a specific structure. A previous studies has shown that the character of glacial erosion and glacial material transportation are reflected in the structure of Pleistocene deposits, particularly in tills (Gaigalas, Marcinkevičius 1982; Baublys *et al.* 1970; Gaigalas 1997; *et al*.).

Pleistocene deposits in central part of North Lithuania are overlying the Upper Devonian dolostones, marls, limestones, clay, and gypsum layers (Bucevičiūtė *et al.* 1992). Varying resistance of these deposits to mechanical and chemical impacts as well as the different bedding and tectonic conditions were responsible for the different scale of erosion in various areas of the region. According to the available data, paleorelief is characterized by uplifts, solitary closed dips and troughs, long and narrow palaeoincisions (Šliaupa 1997). A trough–shaped meridional declension whose axis extends across Vaškai towards Panevėžys stands out as a prominent feature. A sub–latitudinal Palaeo–Mūša incision is located to the south of the marginal ridge.

According to the available borehole data, the Pleistocene cover is composed of three complexes of glacigenic deposits (Baltrūnas *et al*. 2005). In the stratigraphical scheme used in Lithuania (Guobytė, Satkūnas, 2011) these glacial deposits were attributed to the Middle Pleistocene, Medininkai (Warthian), and the Upper Pleistocene, Upper Nemunas (Upper Weichselian), subformations. The Pleistocene strata are not rich in intertill deposits. The thin intertill deposits and sediments can rarely be encountered, only in solitary boreholes. In the area of the North Lithuanian ice marginal ridge these deposits form some marks which help to separate the Medininkai till and Upper Nemunas glacial subformations. According to Savvaitov and Straume (1963), the lower till was laid down during transgression of the maximal stage of Valdai (Upper Weichselian) glaciations, but the upper was deposited by the subsequent stage of that glacier.

The glacial deposits of the Medininkai subformation are spread locally in the region. They overlie the Upper Devonian rocks and are represented mainly by brown sandy till. The till under consideration is densely compact. The maximum thickness (38 m) of this till unit was detected in the palaeoincision 24 km to NW of Pasvalys, the prevailing thickness is reaching 10–15 m. In some places the till of the Medininkai subformation is only 3–5 m thick. The till left by the Medininkai glacier includes some rafted blocks of Devonian rocks. The thickest glacial raft (21 m) was found in a borehole 28 km to the north of Pakruojis (Baltrūnas *et al.* 2005).

Glacial deposits of the Upper Nemunas subformation cover the whole area. These deposits overlie Medininkai subformation or rarely Upper Devonian sedimentary rocks. At some places the glacial deposits of the Upper Nemunas subformation underlie glaciofluvial, lacustrine or other types of sediments. The maximum thickness of this formation (34 m) was reached in an incision near the Žeimelis borough. In the Petrašiūnai dolostone quarry the lacustrine sediments of the Lower Nemunas subformation were distinguished. The inter-till complex in the surroundings of the Petrašiūnai quarry is widespread, lithologically diverse but thin (up to 2 m). Yellowish grey and greyish yellow silt, sandy silt and fine grained silty sand in places underlie a layer of glaciolacustrine sediments up to 1 m in thickness. Pollen analysis of the 1.75 m thick silt layer has shown that pollen is well preserved. Its concentration is small. At the time of silt and sandy silt deposits, the climate was cold and the plant cover poor. The spores and pollen spectra provided no basis for a more precise biostratigraphical correlation. According to the OSL datings, the deposition took place during 86.1–81.6 thousand years BP (Baltrūnas *et al.* 2005).

The North Lithuanian ice marginal ridge

The 1–3 km width ridge stretches for a distance of 130 km as a bow exposing its convexity to the south and is clearly demonstrating the contour of the southern margin of the glacier lobe. There is not any gap in the ridge, except the rivers intersections in the north–west and eastern sections. A. Basalykas (1981) distinguished two types of Linkuva ridge relief in his geomorphologic map: 1 – slightly hilly relief of ice marginal formations; 2 – undulating relief of ice marginal formations (dubbed by proglacial basins). A. Česnulevičius (1995, 2011) separated three zones in the Linkuva end moraine ridge clearly differed by topographical indexes of the relief. According to our data of geological and geomorphologic land–surveying research, the ridge contains three sections.

The western (Rūdiškiai) section rises above the surrounding plains by 12–15 m and is visible only from the distal side of the ridge. Singular morainic hills and kames show up on the background of undulating ridge surface in this section. There is an abundance of structureless "scattered" small (50–100 m diameter) and bigger (500–700 m diameter) kettles of the glaciokarstic origin on the crest of the ridge, filled with limnic sediments. The relief of the ridge crest is strongly altered by anthropogenic factors, i.e. after several stages of improvement, when kettles and small hollow of relief were evened and the tops of the 1–3 m height hills were diminished. The ramparts on the surface of the ridge are oriented towards the north-west–south-east direction. Most often length of the ramparts is 500–700 m, and sometimes – 200–300 m, up to 1.0–2.0 m, the width at the base is 50–80 m. Relative and absolute height of the ramparts sink from the crest of the ridge to the north.

The average height of the ridge in the central (Linkuvos) section rises up to 20 m, and in regard of singular hills up to 27 m (Fig. 2). The length of the central section is 30 km. Separate summits of the kames reach 84 m of above sea level, although the local relief rarely exceeds 7–10 m. Prevailing relative height of the hills is 3–5 m. The surface of the crest of the ridge is undulating and contains densely "implanted" glaciolacustrine kames. Glaciofluvial kames are rare. Kames take oval and elongated forms, with gentle slopes, from 200–300 m to 1 km width at the base. Relative height is from 3 to 5 m, and rarely reaches 5–7 m. Eskers are formed in the proximal part of the ridge. The eskers ridge is straight, 500–1000 m long and 50–100 m wide, up to 4–6 m high. The eskers are built up by strata of gravel and sand with lenses of sandy–clayey till.

The eastern (Puodžiai) section of the ridge rarely rises more than 10 m above the surrounding topography, but the relative relief of 3–5 m are common. The distal slope is fixed fragmentary, and the proximal edge the ridge coalesces with the glaciolacustrine plain. The crest of the ridge is undulating, exposing only

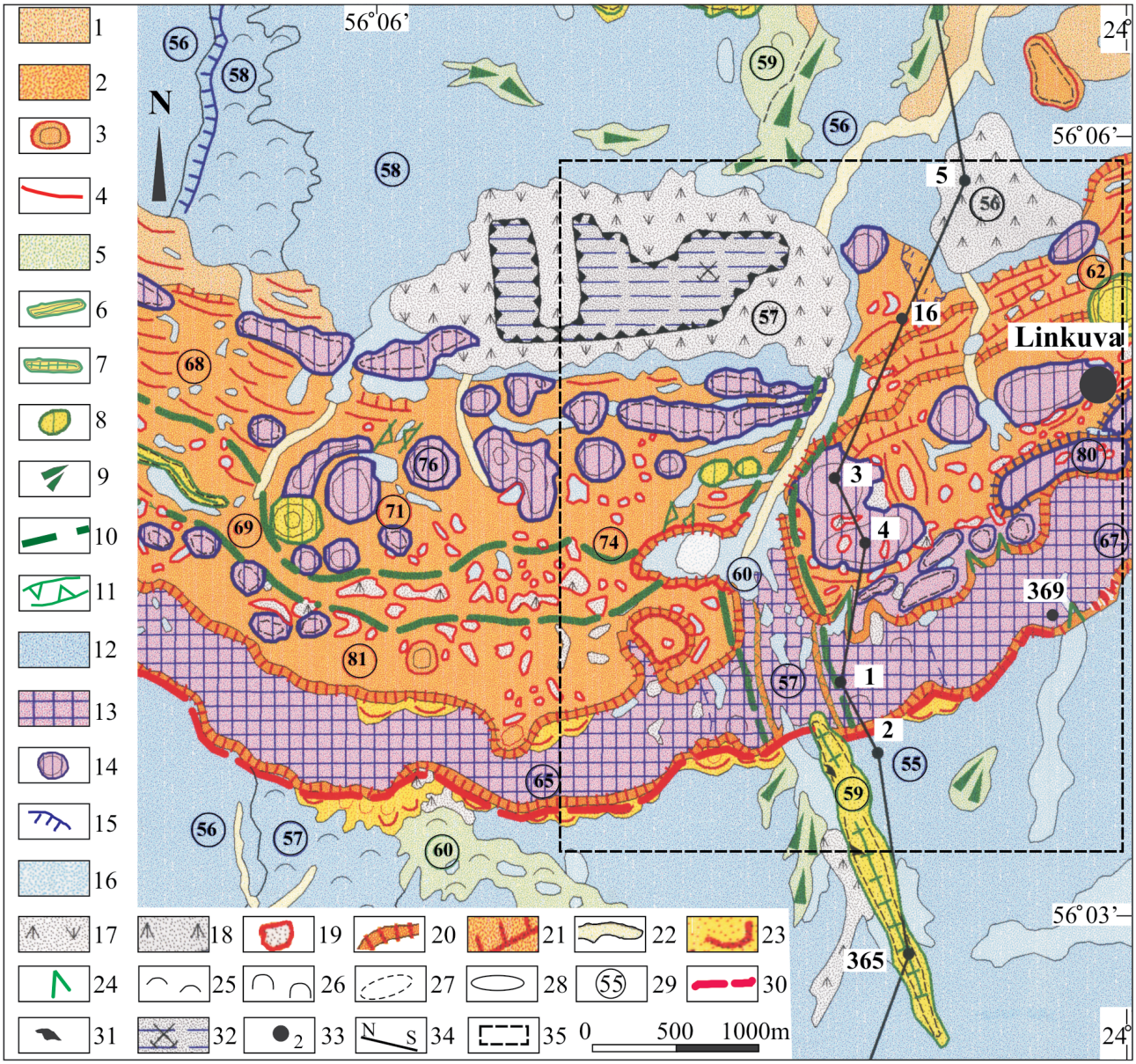

Fig. 2 Detailed geomorphological map of North Lithuanian ice marginal ridge fragment in vicinity of Linkuva: 1 – till plain; 2 – ice marginal formations; 3 – morainic hill; 4 – morainic ramparts; 5 – outwash plain; 6 – crevasse fillings forms; 7 – esker; 8 – glaciofluvial kame; 9 – glaciofluvial delta; 10 – meltwater drainage channel; 11 – flow meltwater channel; 12 – glaciolacustrine plain; 13 – glaciolacustrine kame terrace; 14 – glaciolacustrine kame; 15 – levels of glaciolacustrine plain; 16 – lacustrine plain; 17 – combined type moor plain; 18 – low moor plain; 19 – glaciokarst kettle; 20 – steep slope; 21 – accumulative levels of glacigenic landforms; 22 – floodplain river valley; 23 – solifluction sheet; 24 – gully; 25 – slightly undulating plain (up to 1–2 m); 26 – undulating plain (up to 2–3 m); 27 – very low hill (up to 1–3 m); 28 – low hill (up to 3–5 m); 29 – prevailing altitude of land surface, in metres; 30 – limit of North Lithuanian phase; 31 – gravel pit; 32 – abandoned quarry; 33 – borehole site and its number; 34 – location of geological cross–section line (see Fig. 4); 35 – topographic LiDAR mapped area (Megučioniai gap, see Fig. 3). Compiled by D. Karmazienė, 2012.

small hills, rare low hills and surges. The ramparts are parallel, with the length of 500–700 m, relative height 3–5 m, the width at the base is 50–100 m. The absolute height of the ramparts gradually lowers from the crest of the ridge towards north. The surface of the ridge is evened by the waters of proglacial basins. The lowest places in the ridge are covered with lacustrinesediments.

The ridge as a genetically smooth body is absent of any incision. Only at the of Megučioniai the incision can be observed. Meltwater appearing in the depression of the glacier lobe of Žiemgala, accumulated by the ridge, flooding new areas free of glacier. The North Lithuanian ice marginal ridge was natural southern board of the glaciolacustrine basin. When the basin level reached the critical (lowest) watershed point on the ridge crest – the outburst water took way down to the tunnel formed by the discharge of postglacial water and eroded 10 m depth Megučioniai break across the ridge massif (Fig. 3). The width of this drainage valley is 500 m. The surface of the ridge from altitude of 67 m at the bottom of the valley decreases to 57 m. After comparison of pre–Quaternary surface and geomorphologic maps an obvious relationship was established between recent forms and pre–Quaternary surface. It was found that the North Lithuanian ice marginal ridge corresponds to elevation of the pre–Quaternary rocks (Fig. 4).

The North Lithuanian ice marginal ridge composed of clayey till, lenses of silt and clay (Veinbergs 1972). Till stratify above Medininkai Formation of clayey till, silt loam and the Upper Nemunas Formation lodgement till. Marginal formations of the North Lithuanian phase forming the body of North Lithuanian ice marginal ridge is 23.5 m thick. The North Lithuanian deformation till looks like a clay because it contains a great amount of fine (clayey) particles. In till according to grain size analysis 0.05–0.005 mm particles constitute 23–36%, in average 30%. Fraction < 0.005 mm constitutes 39–45% of till. Moreover, the input of gravel is negligible, less than 2%. The till delaminates into 1–2 mm thin layers when breaking it. Such the micro–layered till could form only because of regelation, i. e. was caused by periodical thawing and freezing events within a moving glacier (Lavrushin 1980).

Petrographic composition of till coarse–fragmented material is variable and its range spans quite large interval (Fig. 5). Petrography of gravel and pebbles is featuring by fragmented rock carried from far (Ordovician and Silurian limestone) and greater amount of local fragmented rock (Devonian dolostone and limestone of other age). In tills of North Lithuanian ice marginal ridge separate clay strata were discovered in form of lenses. The thickness is very variable and varies from 2.3 to 9.3 metres. There are 73.3% smaller than 0.005 mm particles in the clay (borehole No. 15). Range of particles <0.005 mm does not exceed 10% in vertical course (Fig. 6). There is a glaciolacustrine kame terrace on the slope of North Lithuanian ice marginal ridge. Terrace is dislocated on the distal slope of the central part of the North Lithuanian ice marginal ridge in the Judiškiai–Megučioniai–Linkuva–

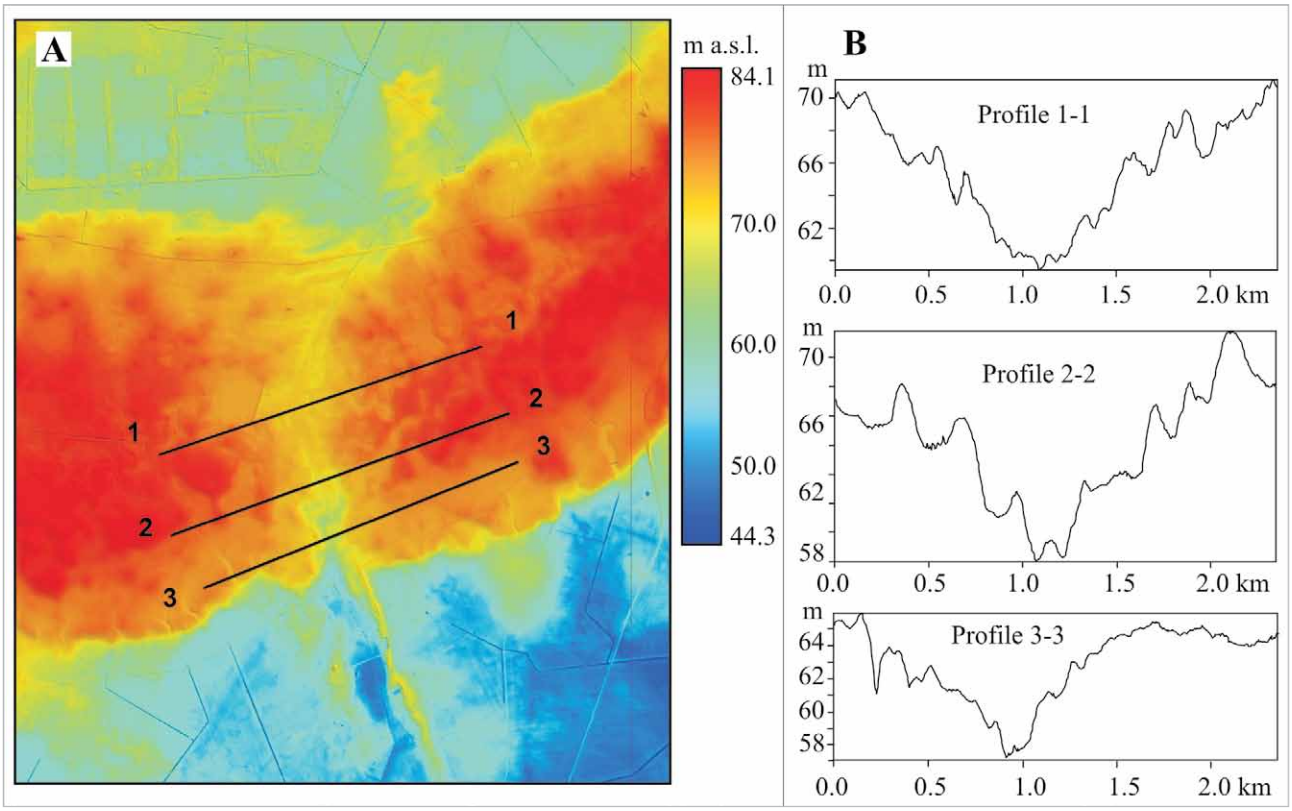

Fig. 3 Megučioniai gap three–dimensional surface model (up by topographic LiDAR data); for location see Fig. 2: A – topographic LiDAR mapped; B – morphological profile. Compiled by B. Karmaza, 2012.

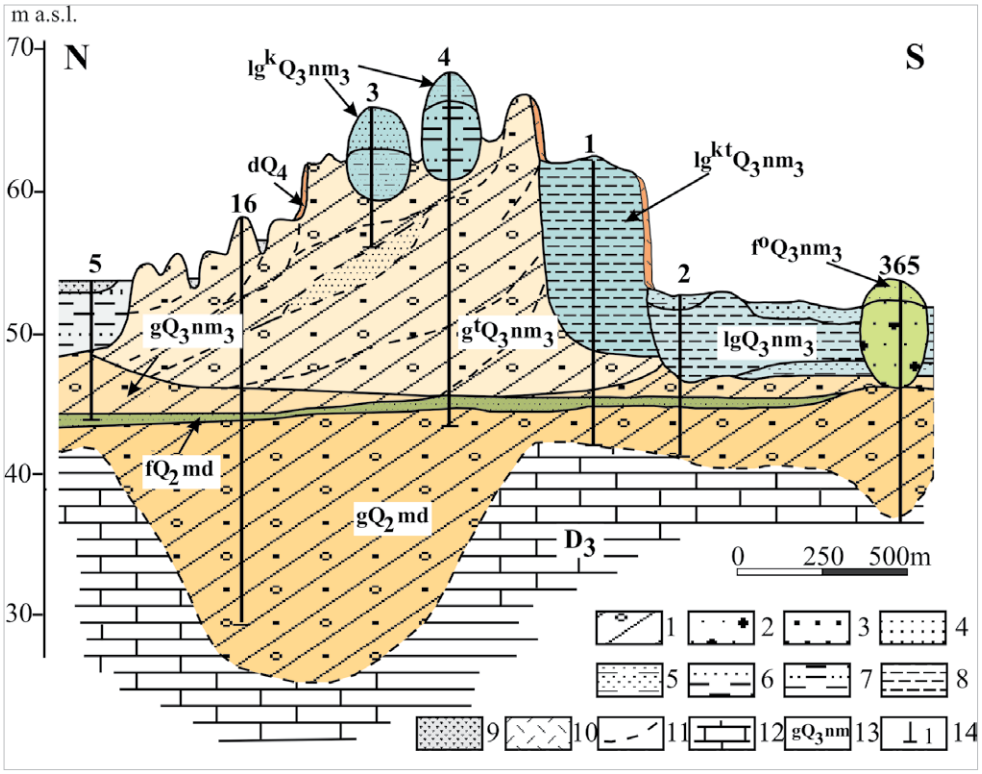

Fig. 4 Geological structure of the North Lithuanian ice marginal ridge in the vicinities of Linkuva: 1 – till; 2 – sand with gravel and cobble; 3 – various grained sand; 4 – fine grained sand; 5 – silty sand; 6 – sandy silt; 7 – sandy silty clay; 8 – clay; 9 – peat; 10 – clayey sand with gravel; 11 – shear planes; 12 – dolostone (D_3); 13 – genetic and stratigraphic index of deposits (gQ_2md – Medininkai till; fQ_2md – Medininkai glaciofluvial; gQ_3nm – Nemunas lodgement till; $g^{t}Q_3nm$ – Nemunas deformation till; $lg^{kt}Q_3nm$ – Nemunas glaciolacustrine kame terrace; $f^{k}Q_3nm$ – Nemunas glaciofluvial kame; $f^{o}Q_3nm$ – Nemunas glaciofluvial esker; lgQ_3nm – Nemunas glaciolacustrine; lQ_4 – lacustrine sediments; dQ_4 – colluvial deposits); 14 – borehole site and its number. For location of the geological cross–section line see Fig. 2. Compiled by D. Karmazienė, B. Karmaza, 2012.

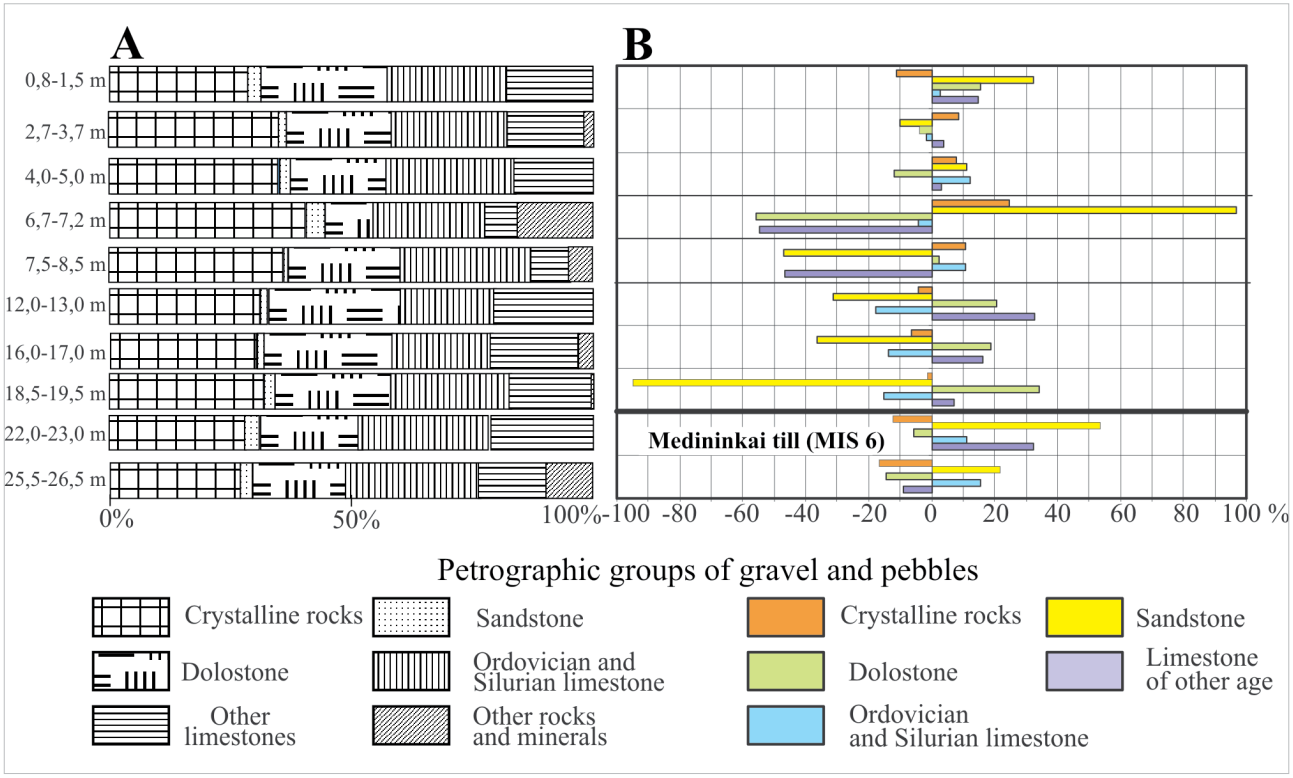

Fig. 5 Petrographical composition of till coarse clastic material (A) and its deviation from the average (B) in the North Lithuanian ice marginal ridge (borehole No. 6, for location of the borehole site see Fig. 1). Compiled by V. Baltrūnas, 2012.