Palaeolandscapes from Saalian to Weichselian

PERIBALTIC

LITHUANIA

June 25–30, 2013

LIETUVOS GEOLOGIJOS TARNYBA
LITHUANIAN GEOLOGICAL SURVEY
Lietuvos mokslo taryba
INSTITUTE OF GEOLOGY & GEOGRAPHY
LIETUVOS EDUKOLOGIJOS UNIVERSITETAS
VĮ VILNIAUS REGIONO KELIAI

Palaeolandscapes from Saalian to Weichselian

South Eastern Lithuania

Excursion guide

International Field Symposium

2013

Palaeolandscapes from Saalian to Weichselian, South Eastern Lithuania. Excursion guide of International Field Symposium, June 25 – 30, 2013, Vilnius–Trakai, Lithuania / Eds: J. Satkūnas and R. Guobytė; Lithuanian Geological Survey, Lithuanian Geological Society, Vilnius, 2013.

SYMPOSIUM PROGRAMME

June 25th
The registration of participants at the Lithuanian Geological Survey
(S. Konarskio 35, Vilnius)

3 p.m. – Departure to Trakai
Visiting the Trakai Castle
6 p.m. – Introduction lecture
7 p.m. – Ice Break party

June 26th
Paper and poster sessions

June 27th
Stops 1–8
Vilnius environs
Medininkai Heights, Eišiškės Plateau

June 28th
Stops 9–14
Environs of Aukštadvaris, Birštonas, Alytus

June 29th
Stops 15–18
South Lithuania: Merkinė, Zervynos
7 p.m. Conference dinner

June 30th
Stop 19
The Neris Regional Park
Arrival to Vilnius (at noon)

Guides:
Jonas Satkūnas, Algimantas Česnulevičius, Rimantė Guobytė, Bronislavas Karmaza, Vaidotas Kazakauskas, Eugenija Rudnickaitė, Miglė Stančikaitė, Vaida Šeirienė, Petras Šinkūnas, Giedrė Vaikutienė

The field symposium is held in the South Eastern Lithuania. It focuses on the boundary of maximum extent of the last ice sheet, glacial and glaciofluvial landforms of Saalian and Weichselian age, stratigraphy of the Late Pleistocene from Eemian to Late Weichselian, thermoerosion and periglacial phenomena, morphotectonics, aeolian formation etc.

Organizers:

Lithuanian Geological Society
Lithuanian Geological Survey
Institute of Geology and Geography, Nature Research Centre
Department of Geology and Mineralogy, Vilnius University
Lithuanian University of Educational Sciences
INQUA Peribaltic Working Group (INQUA TERPRO Commission)

The Symposium was financially supported by the Research Council of Lithuania
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Lithuanian Geological Survey

Content

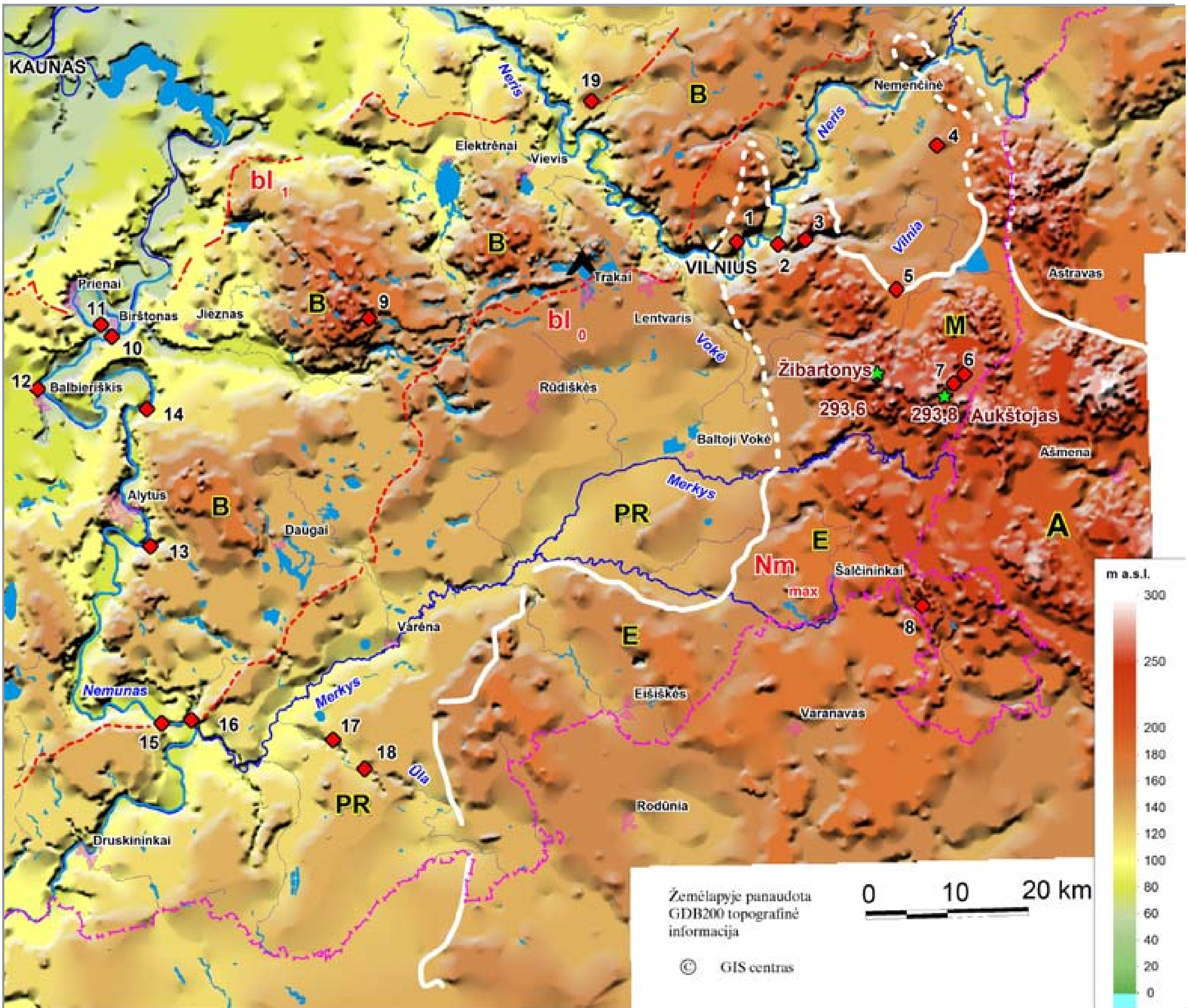


Fig. 1M. Topography of southeastern Lithuania, showing excursion stops.

A – Ašmena (Oshmianskaya) Upland
M – Medininkai Heights
E – Eišiškės Plateau
PR – South-eastern Lithuanian Lowland
B – Baltija marginal Uplands

Nm_{max} – boundary of the Last Glaciation
Ice marginal zones:
bl_0 – Baltija (Pomerania)
bl_1 – South Lithuania

EXCURSION STOPS

- **Stop 1.** The Karolina Ravine
- **Stop 2.** Hills of Vilnius Castles
- **Stop 3.** Pūčkoriai Outcrop
- **Stop 4.** Skersabaliai dunes
- **Stop 5.** The LGM limit
- **Stop 6.** The Medininkai Castle
- **Stop 7.** Juozapynė Hill
- **Stop 8.** Mikališkės gravel pit
- **Stop 9.** Devil's Hole
- **Stop 10.** The Nemunas Loops
- **Stop 11.** Škėvonys Outcrop
- **Stop 12.** Balbieriškis Outcrop
- **Stop 13.** Alovė Outcrop
- **Stop 14.** Punia Mound
- **Stop 15.** Netiesos Outcrop
- **Stop 16.** Merkinė Mound
- **Stop 17.** "Ūlos Akis" Outcrop and Spring
- **Stop 18.** Zervynos Outcrop
- **Stop 19.** Runestone

EXCURSION PROGRAMME

Thursday, June 27th

Stop 1. **The Karolina Ravine**
Guides Jonas Satkūnas, Rimantė Guobytė, Eugenija Rudnickaitė

Stop 2. **Hills of Vilnius Castles**
Guide Jonas Satkūnas

Stop 3. **Pūčkoriai Outcrop**
Guide Jonas Satkūnas

Stop 4. **Skersabaliai dunes**
Guide Jonas Satkūnas

Stop 5. **The boundary of the Last Glaciation**
Guide Jonas Satkūnas

Stop 6. **The Medininkai Castle**
Guide Jonas Satkūnas

Stop 7. **Juozapynė Hill**
Guides Jonas Satkūnas, Rimantė Guobytė

Stop 8. **Mikališkės gravel pit**
Guides Petras Šinkūnas, Algimantas Česnulevičius

Friday, June 28th

Stop 9. **Devil's Hole**
Guides Jonas Satkūnas, Bronislavas Karmaza

Stop 10. **The Nemunas Loops Regional Park**
Guide Jonas Satkūnas

Stop 11. **Škėvonys Outcrop**
Guide Jonas Satkūnas

Stop 12. **Balbieriškis Outcrop**
Guides Vaidotas Kazakauskas, Bronislavas Karmaza

Stop 13. **Alovė Outcrop**
Guide Jonas Satkūnas

Stop 14. **Punia Mound**
Guide Miglė Stančikaitė

Saturday, June 29th

Stop 15. **Netiesos Outcrop**
Guide Vaida Šeirienė

Stop 16. **Merkinė Mound**
Guide Miglė Stančikaitė

Stop 17. **"Ūlos Akis" Outcrop and Spring**
Guides Petras Šinkūnas, Jonas Satkūnas

Stop 18. **Zervynos Outcrop**
Guide Miglė Stančikaitė

Sunday, June 30th

Stop 19. **Runestone. The Neris Regional Park**
Guide Jonas Satkūnas

Arrival to Vilnius (at noon)

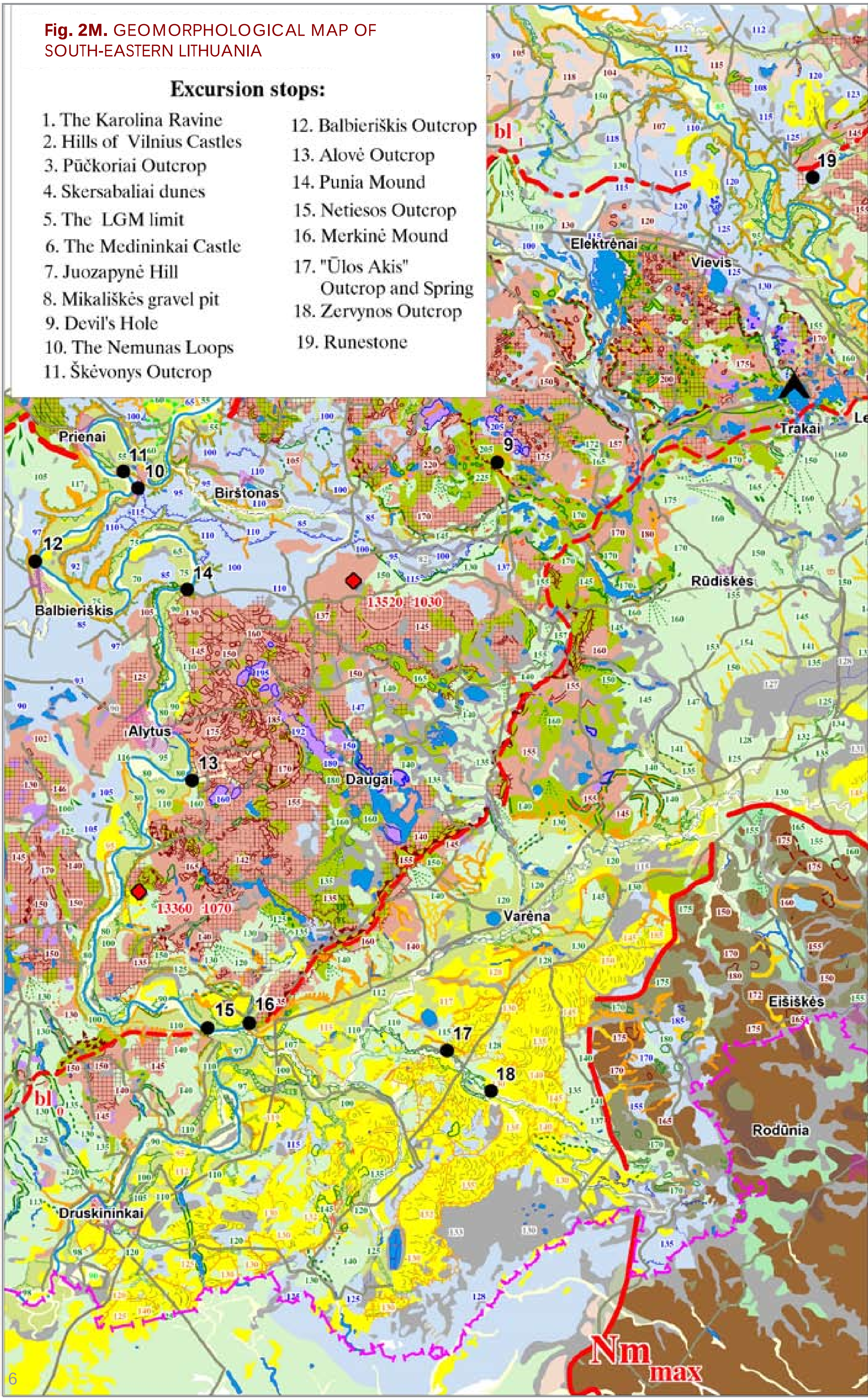
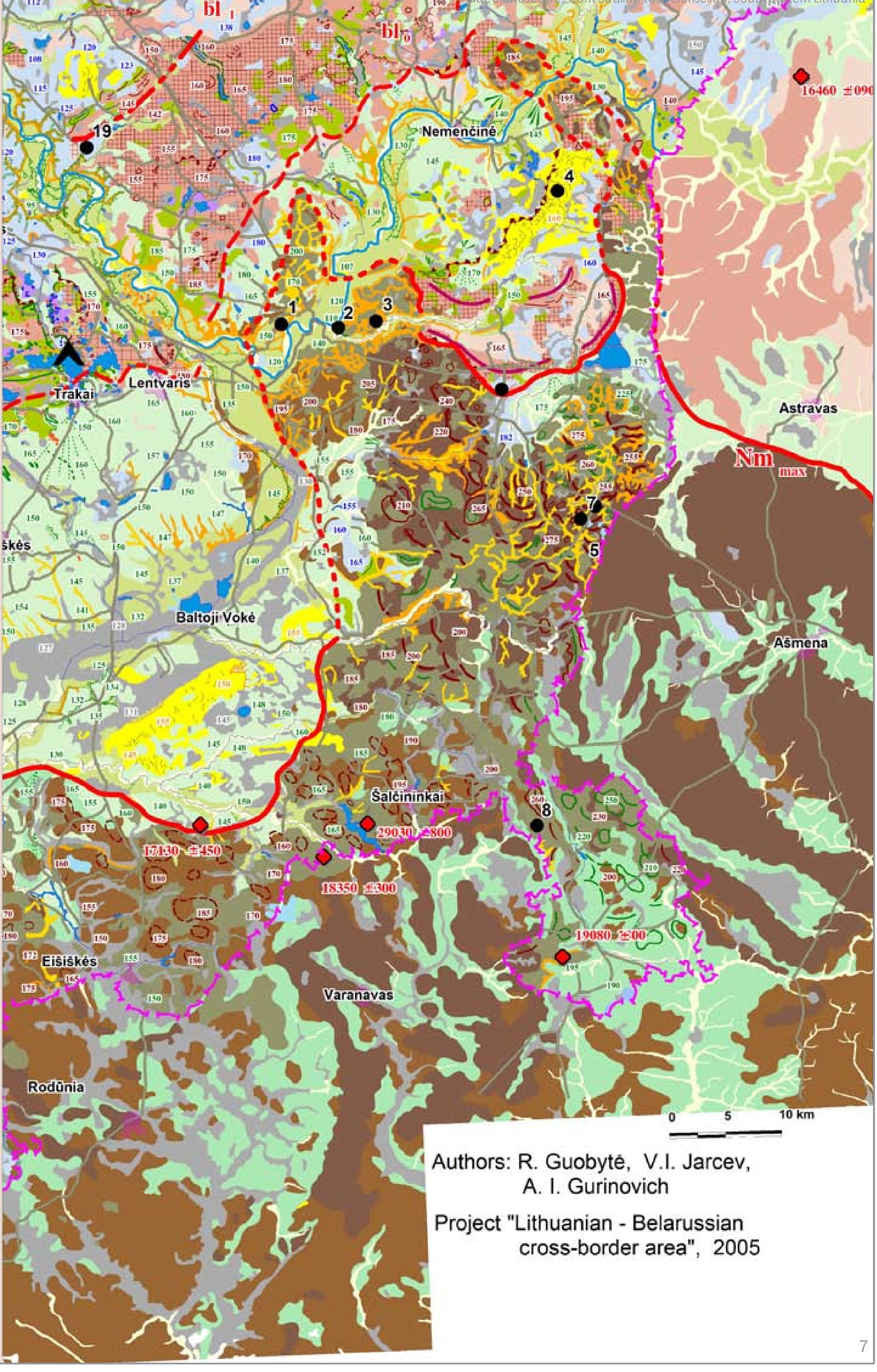


Fig. 2M. GEOMORPHOLOGICAL MAP OF SOUTH-EASTERN LITHUANIA


bl 1
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Nemenčinė
Trakai
Lentvaris
Astravas
Nm max
Baltoji Vokė
Ašmena
Šalčininkai
Eišiškės
Varanavas
Rodūnia
16460 ±090
17130 ±450
29030 ±800
18350 ±300
19080 ±00
0 5 10 km
Authors: R. Guobytė, V.I. Jarcev, A. I. Gurinovich
Project "Lithuanian - Belarussian cross-border area", 2005

Fig. 3M. LEGEND

GEOMORPHOLOGICAL SYMBOLS

LATE GLACIAL AND HOLOCENE

GRAVITATION LANDFORMS
- Slope (to the scale)
- Gully, ravine

GLACIOKARST LANDFORMS
- Kettle hole

BIOGENOUS LANDFORMS
- Bog plain (type not identifined)
- 130 Altitude of the bog plain

FLUVIAL LANDFORMS
- Flood plain valley
- Late Glacial valley with terraces
- Erosion valley (Late glacial)

AEOLIAN LANDFORMS
- Aeolian relief
- Aeolian accumulative slope
- Dunes
- 102 Altitude of the aeolian relief

UPPER PLEISTOCENE

LATE NEMUNAS (LATE WEICHSELIAN) GLACIATION

GLACIOLACUSTRINE LANDFORMS
- Glaciolacustrine plain
- Plateau-like hill, kame terrace
- 102 Altitude of the glaciolacustrine plain

GLACIOFLUVIAL LANDFORMS
- Outwash plain
- Hilly glaciofluvial relief
- Outwash cone
- Delta
- Channel of meltwater streams
- The Žeimena-Neris-Vokė-Merkys-Nemunas ice marginal river valley (uhrstromtal)
- 102 Altitude of the glaciofluvial landforms

GLACIAL LANDFORMS
- Till plain
- Hummocky moraine
- Prominent end-moraine ridges
- Hill (medium size and high)
- Crest of morainic ridge
- accumulative slope
- ice contact slope
- 150 Altitude of the glacial relief

MIDDLE PLEISTOCENE

MEDININKAI (LATE SAALIAN) GLACIATION
- Glaciofluvial plains
- Till plain
- Ice marginal glaciofluvial landforms
- Ice marginal landforms
- Glaciofluvial ridges and hills
- Glacial ridges and hills
- Crest of the ridges
- Crest of the ridges
- Surface plunge direction
- Gentle slope ridges hills

LIMITS OF ICE MARGINAL ZONES
- bl_1 South-Lithuanian phase
- bl_0 Baltija stage

The maximum extent of the Last glaciation
- Nm_{max} distinct
- undetermined

OTHER SYMBOLS
- 10480±780 10 Be dating of boulders (age in yr BP)
- 6 Excursion stops

LITHOLOGICAL SYMBOLS

- peble and koble
- gravel and peble
- sand with gravel
- sand various size grained
- fine grained sand
- very fine grained sand
- silty sand
- clayey sand
- silt
- sandy silt
- clay
- silty clay
- sand with peat
- peat (type not identified)
- lacustrine marl
- gyttja
- glacial loam

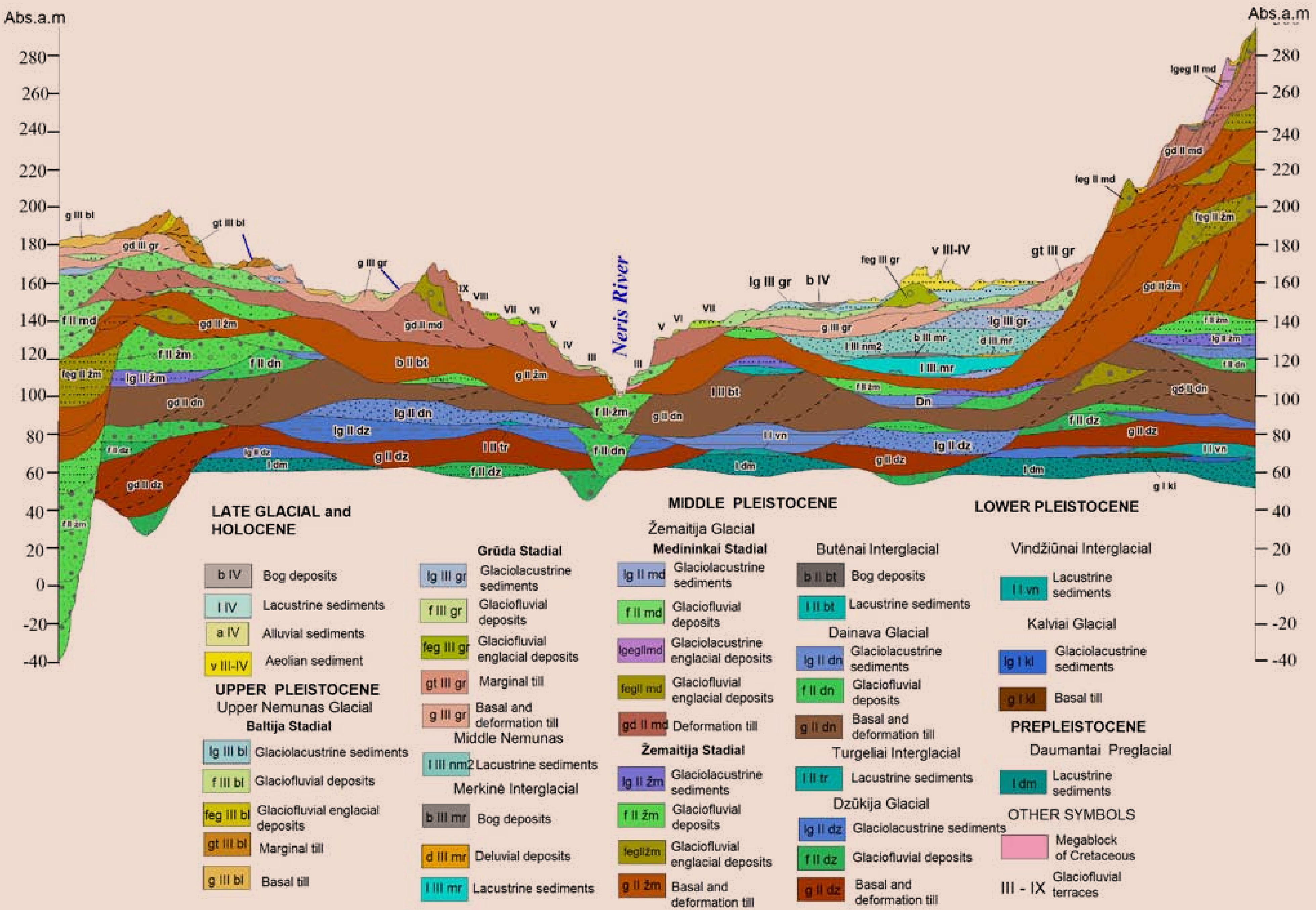


Fig. 4M. Integrated cross-section of the Vilnius environs

Stop 1

THE GREAT KAROLINA RAVINE IN KAROLINIŠKĖS (VILNIUS)

Jonas Satkūnas, Rimantė Guobytė, *Lithuanian geological Survey*
Eugenija Rudnickaitė, *Department of Geology and Mineralogy, Vilnius University*

Erosional hills are a characteristic feature of the Vilnius city surface. The hills represent former high slopes of the Medinininkai Heights dissected by ravines and gullies in the Vilnia and Neris river valleys. Two geomorphologic and seven landscape reserves were established in order to protect the Vilnius erosional hills from their destruction and urbanization in this area (Fig. 1). The first Karoliniškės Landscape Reserve on the right side of the Neris valley was established in 1960. It occupies an area

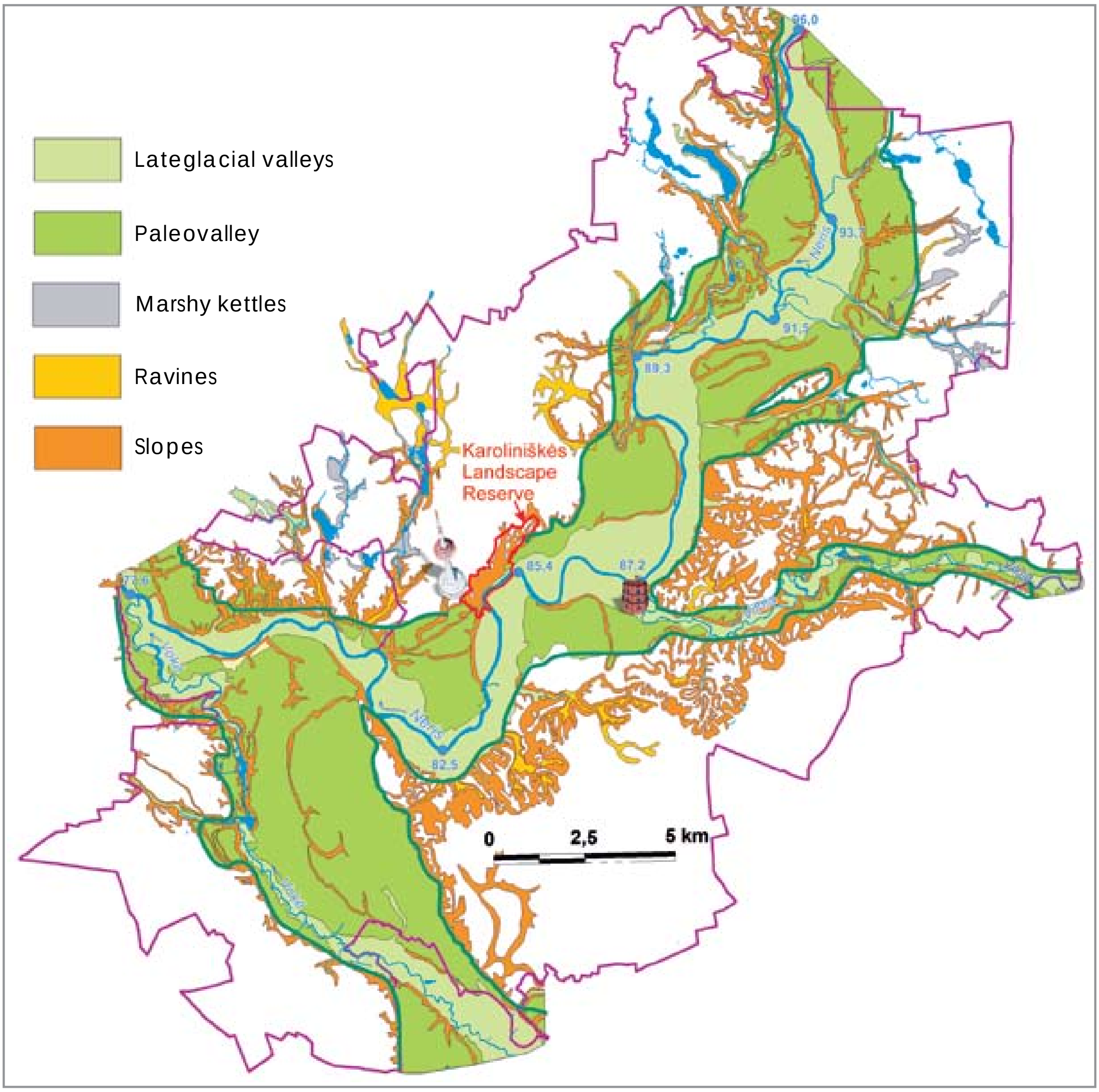


Fig. 1. Erosional slopes of the Neris-Vokė palaeovalley

of 160 ha. Six old, flat-bottomed ravines and narrow relicts of ancient landscape are preserved in the Reserve. The three southern ravines open to the Neris flood-plain while the three northern ones open to the higher, 5th terrace (Fig. 2). The Plikakalnis Outcrop which used to be a subject of student study for a long time is also included in the Reserve from 1992. The Middle Pleistocene layers outcropping here have been studied by Gaigalas and others (Гайгалас et al., 1984; Gaigalas and Melešytė, 1993).

A young and active gully emerged on the bottom of the wide Karolina Ravine after the extensive rains in 2009. A 3–5.0 m thick layer of till, brown on the bottom and greenish-grey on the top, outcropped on the right ravine flank at the depth of 20 m measured from the top of the Neris valley slope (Fig. 3). Strata of fine-grained sand interlayered with dislocated glauconite sand are exposed beneath the till.

A complex of data: structural, biostratigraphical, lithological, paleogeomorphological etc., is commonly used for a stratigraphic identification of tills. Among the lithological methods, the investigation of chemical composition (oxides) of tills is one of the most informative, because it reflects not only an integrated lithological composition but also some diagenetic features. The investigation of chemical composition of till was carried out in the course of geological mapping of the Vilnius environs, and the data is presented in the Table 1.

Table 1. Summary of chemical composition of all tills in the Vilnius environs (for the integrated cross-section see Fig. 4M)

Stratigraphy	Number of samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	CO_2
Late Weichselian g III gr	61	69,78	0,36	6,54	1,52	1,22	7,58	2,6	8,44
Upper Saalian g II md	130	69,28	0,32	6,31	1,55	1,22	7,73	2,57	7,64
Lower Saalian g II žm	182	71,68	0,33	6,08	1,86	0,93	6,14	2,85	6,36
Upper Esterian g II dn	149	72,97	0,35	6,66	1,54	1,01	5,42	2,36	5,18
Lower Esterian g II dz	92	74,24	0,42	6,44	1,61	0,82	5,61	1,88	5,08

The chemical analysis of samples 1–3 and 5–7 taken from the brown (below) and greenish tills shows that the greenish till is much richer in carbonates and clay (Table 2). The data could be interpreted as that greenish and the brown tills are of different age, however there is no visible contact of tills.

Table 2. The till chemical analysis of the Karolina Ravine Outcrop

No of sample	Name of sediments	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	k.n.	H_2O
1	Till – sandy loams	75.96	6.83	1.85	1.82	4.09	9.20	0.40
2	Till – sandy loams	76.73	8.53	0.47	2.80	4.46	6.71	0.38
3	Till – sandy loams	80.68	5.06	2.62	1.76	3.44	6.14	0.26
5	Till – sandy loams	82.70	5.81	0.13	1.63	2.50	6.83	0.31
6	Till – sandy loams	81.98	5.79	0.24	1.80	3.03	6.83	0.22
7	Till – sandy loams	82.65	6.42	0.15	2.00	2.47	6.01	0.30

CHEMICAL ANALYSIS DETERMINED BY B. KRINICKIENĖ, LABORATORY OF LITHUANIAN GEOLOGICAL SURVEY

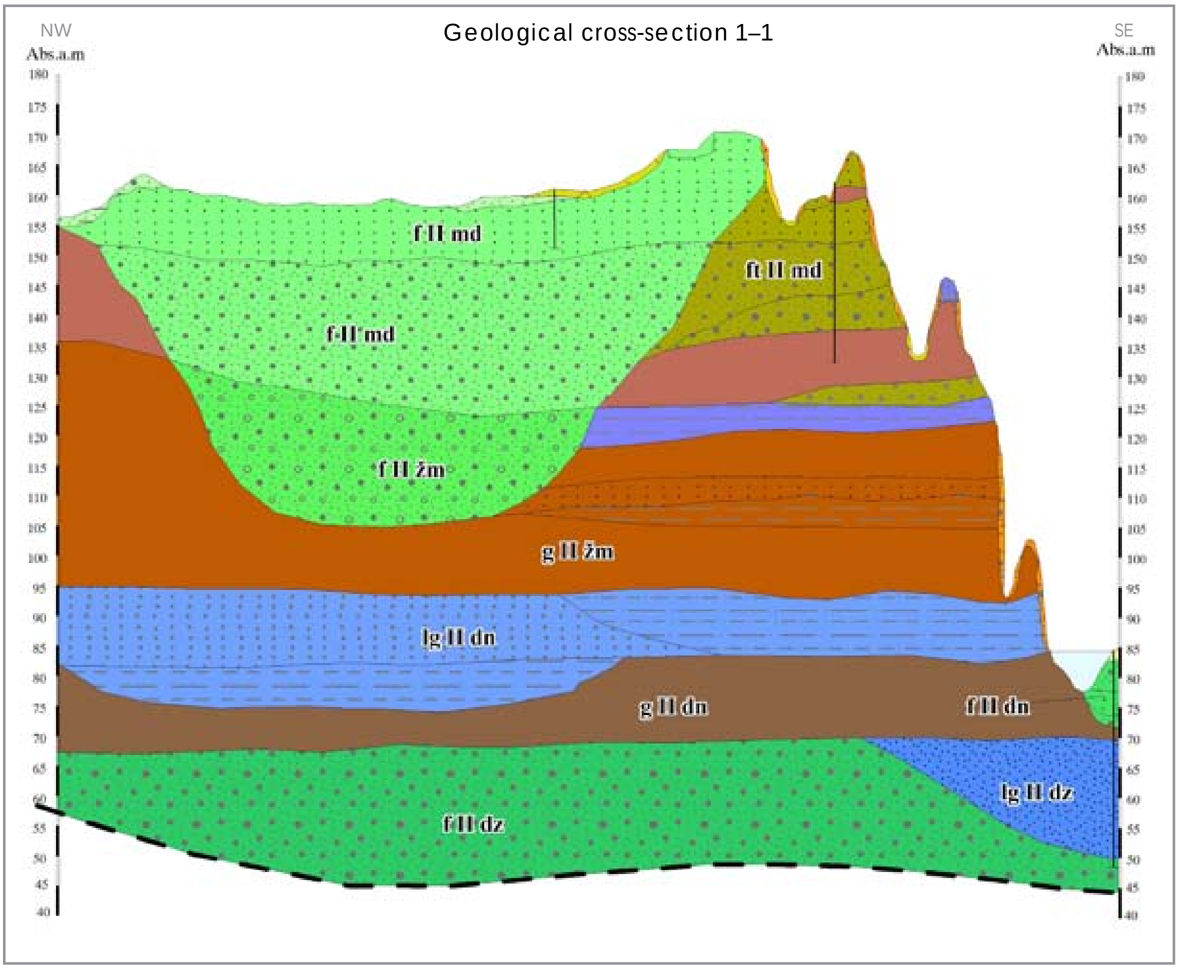


Fig. 2. Geological cross-section near the Karolina Ravine

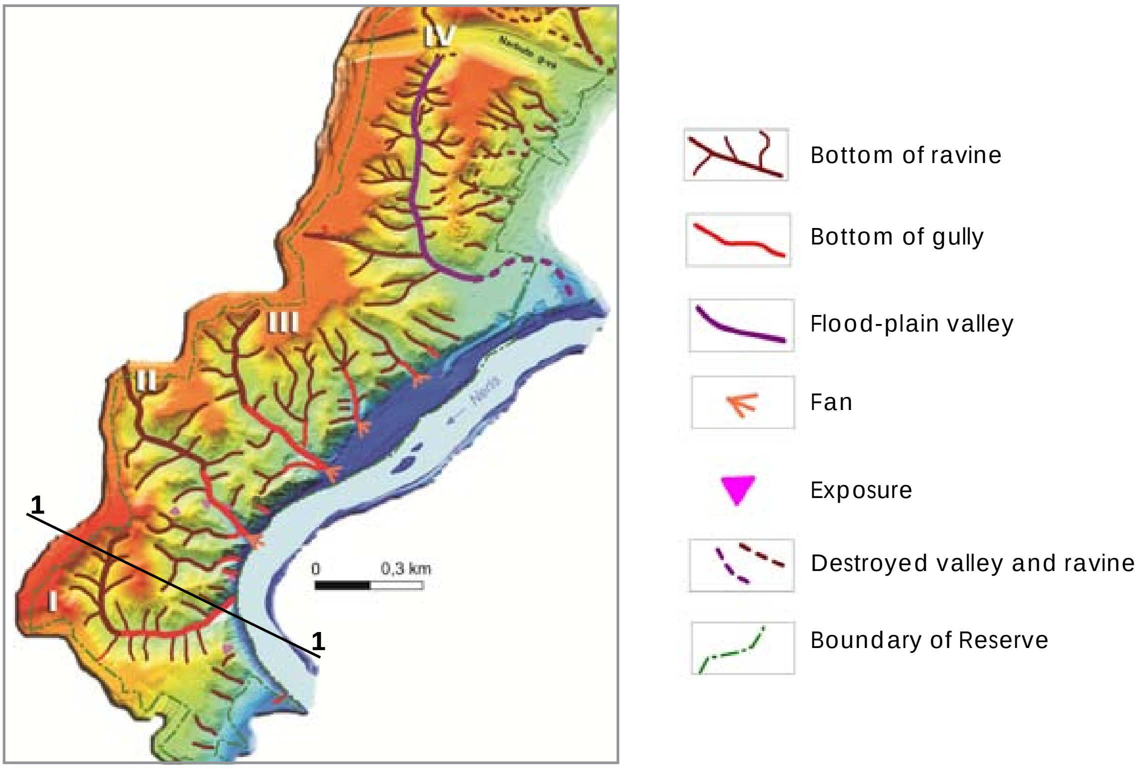


Fig. 3. LIDAR topography of the southern part of the Karoliniškės Landskape Reserve: TV Tower Ravine (I), Karolina Ravine (II), Šimulionis Ravine (III) and Narbutas Ravine (IV)

Fig. 4. The contact of brown (below) and greenish tills in the outcrop of the Karolina Ravine and sampling points for chemical and carbonate analysis presented in the Table 2

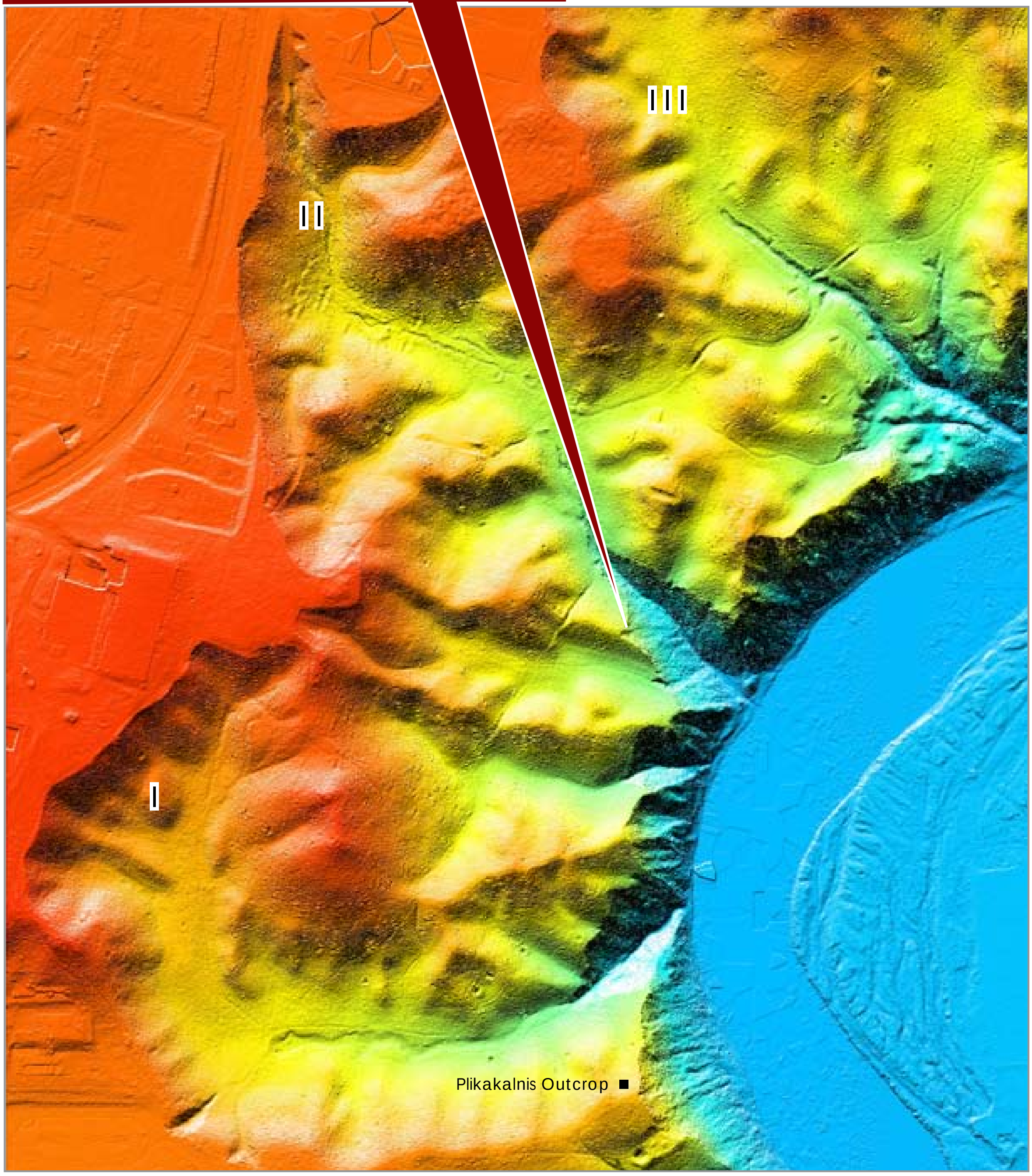
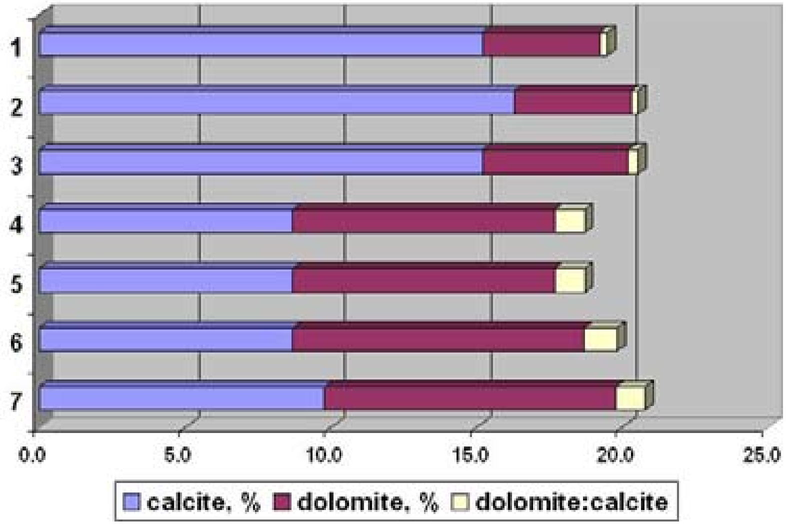


Fig. 5. Lidar topography of the Karolina Ravine

A



B

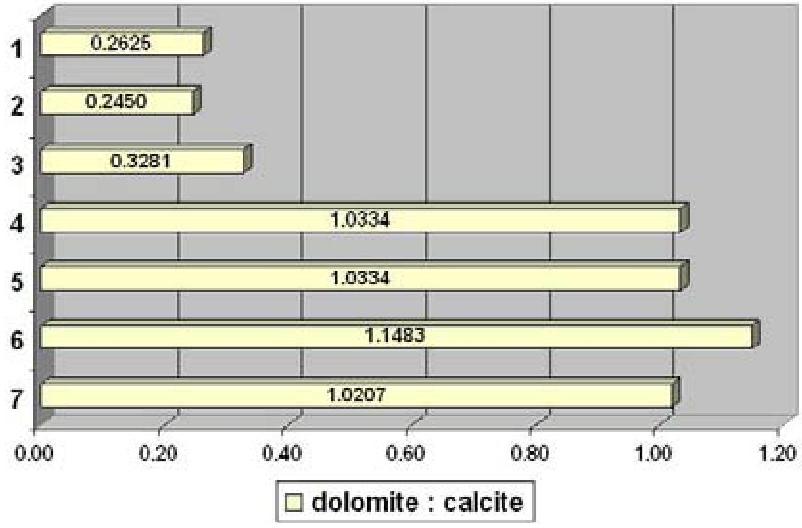


Fig. 6. The carbonate analysis of tills in the Karolina Ravine Outcrop (analysed by E. Rudnickaitė)

The bulk content of carbonate material in the tills of the different Pleistocene age bodies from the Karolina Ravine Outcrop was determined. The sediments fraction less than 1 mm was used for the carbonate content analysis according to the methodology described in the literature (Sanko et al., 2008; Kabailienė et al., 2009). The dolomite and calcite ratio was calculated from dolomite and calcite data. As a rule, the percentage and ratio of the latter minerals is different in tills of different age (Rudnickaitė, 1980, 2008; Rudnickaite, 1983).

The results show that the total carbonate content, calcite and dolomite quantities and their ratio are different in the brown and greenish tills of the Karolina Ravine Outcrop and possibly indicating their different age. The ratio determined for samples No. 4–7 is 1 to 1.14, indicating higher values of dolomite to calcite. That ratio is characteristic for the Medininkai till.

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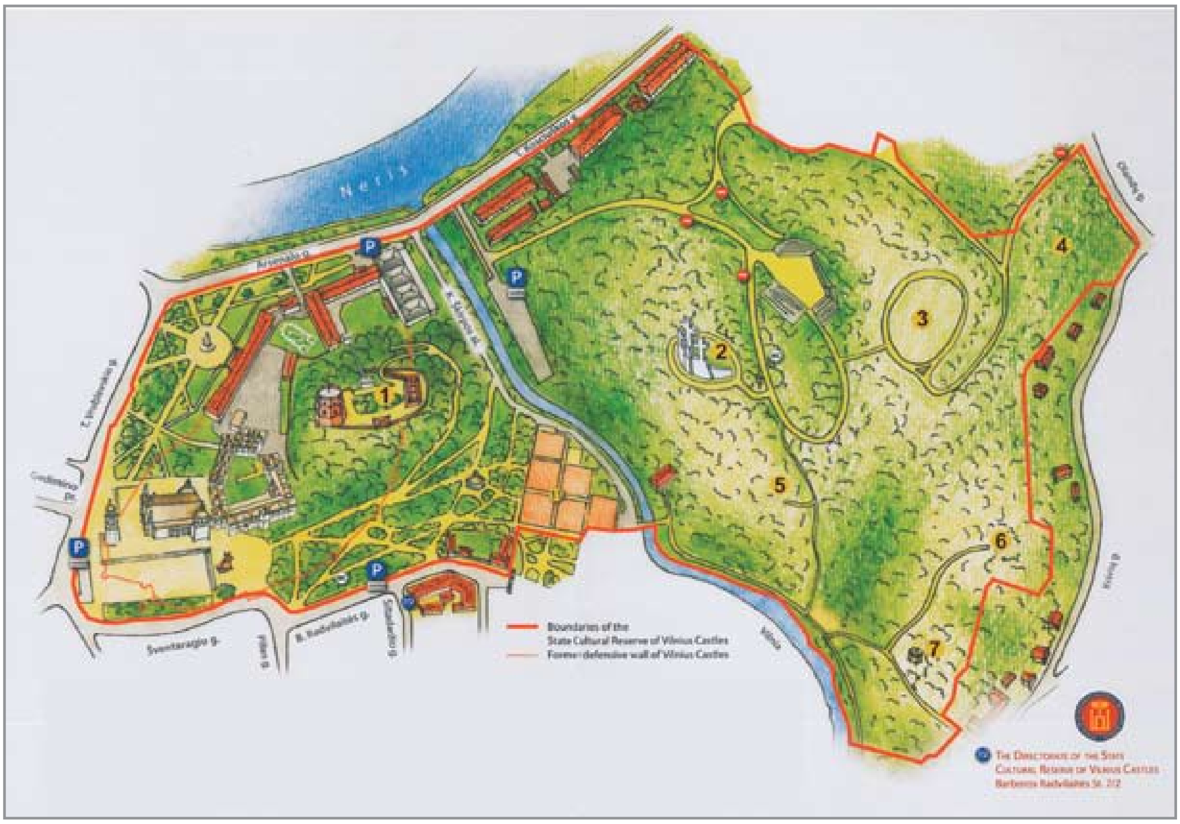
Stop 2

THERMOEROSIONAL HILLS OF THE VILNIUS CASTLES

Jonas Satkūnas, *Lithuanian Geological Survey*



Gediminas (The Higher) Castle (1) (ramparts of the defensive wall, palace and the southern tower, the western tower encircled by a stone wall with three massive towers. In the 13th–15th c. was an important political and administrative centre of Lithuania. The Castle was badly damaged in the middle of the 17th c. during the war with Russia and gradually turned into ruins. When Lithuania was incorporated into the Russian Empire, the Castle area became a military fortress. Meantime, the western tower of the Higher Castle, so called Gediminas Castle, is turned into the Lithuanian National Museum.

Barren (Three Crosses) Hill (2). Written sources of the 14th–15th c., the archaeological artefacts and historic research evidence prove that a wooden castle stood on the Barren (Three Crosses) hill. It is named Kreivoji or Curvum Castrum (Curved). In 1390 it was burned down by the Crusaders and never rebuilt.

The memorial of Three Crosses is situated on the top of the hill. According to a legend, pagans killed seven Franciscan missionaries. In memory of these monks, three wooden crosses were erected. In 1916, architect Antanas Vivulskis built concrete crosses. In 1950, by the order of the Soviet authorities they were blown up. On the initiative of the Lithuanian movement for the restoration of independence Sąjūdis the crosses were re-erected in 1989.

Stalo (Table) Hill (3). A small irregular and quadrangular shaped square is on its top. In the western part of the hill archaeologists discovered remains of burnt homesteads linked with the fire of the Curved Castle in 1390. Due to its form the hill is called Stalo (Table).

Bekeś Hill (5). A Hungarian military leader of the Commonwealth Caspar Bekesh (Gaspar Bekeś) was buried in 1580 on one of the hills on the bank of the Vilnia. As an Antitrinitarian he could not rest in a Catholic cemetery. Later the hill was renamed after him. On his grave an octagonal, nearly 20 m high monument was erected, but in the 19th c. it was washed away by the waters of the Vilnia.

Gediminas Grave Hill (6). It is a high, round and steep hill with a flat square on the top. A stone sacrifice altar is there. Ramparts of a small settlement (12th–13th c.) were found during archaeological excavations. It is considered that the Grand Duke of Lithuania Gediminas was buried there.

Origin of hills

The location of the Vilnius Castles is determined by peculiarities of topography and hydrography. The Castles are located in a cofluence of the Neris and Vilnia rivers. This area is characterised by hilly topography with variety of landforms, formed by fluvial, suffosion, gravitational and erosional processess (Fig. 1). The altitude of relief varies from 87 m a.s.l. in the cofluence of the Vilnia and Neris rivers to 230 m of Rokantiškės hill, with difference of altitude of some 100 m in distance of 1 km in some places (Fig. 2).

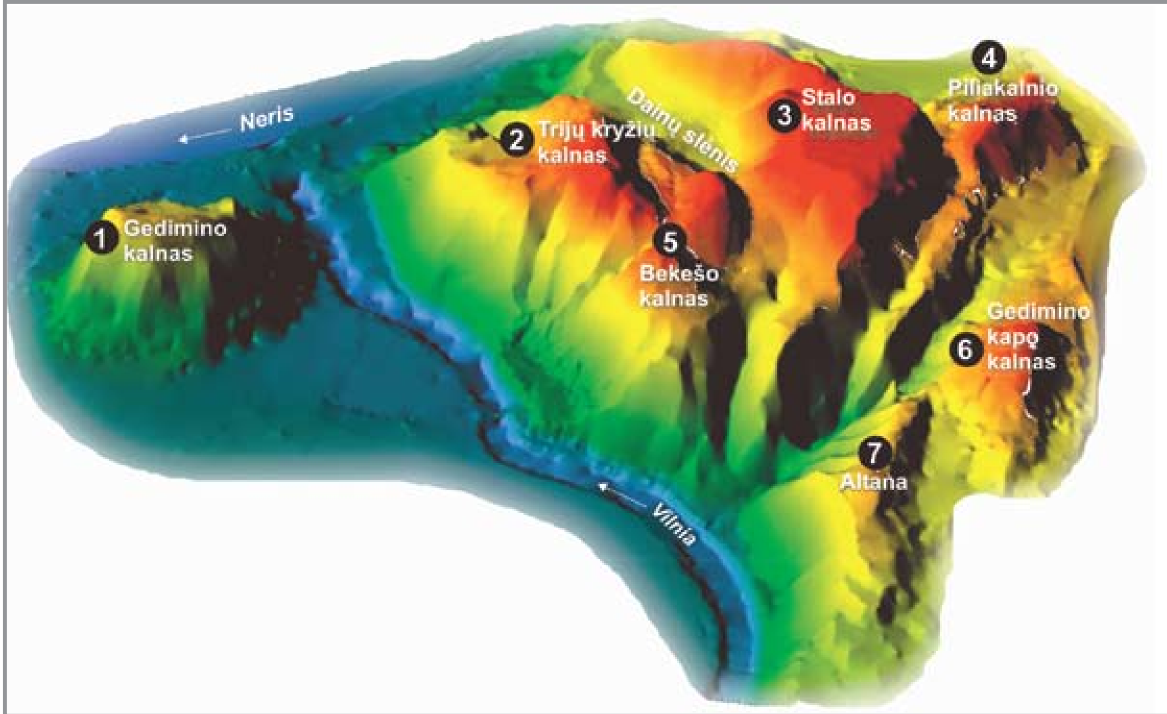


Fig. 1. The Castles hills. Topography is carved into hills with steep slopes by dissecting ravines of different depth

A thickness of Quaternary in the Vilnius city area varies from ca. 20 m in valleys of the Neris and Vilnia to 200 m in higher places and in palaeoinsicions. The data of engineering geological investigations (eg. Gediminas Castle Hill, Fig. 3) show that the Castles hills are composed of Elsterial and Saalian glacial and glaciofluvial deposits. According to the recent geological map at a scale of 1:10 000 (Guobytė, 2012) Vilnius downtown and castles are located in a plot of very margin of the

Fig. 2. A generalized surface profile through the Vilnia River valley from Rokantiškės to Gediminas Hill

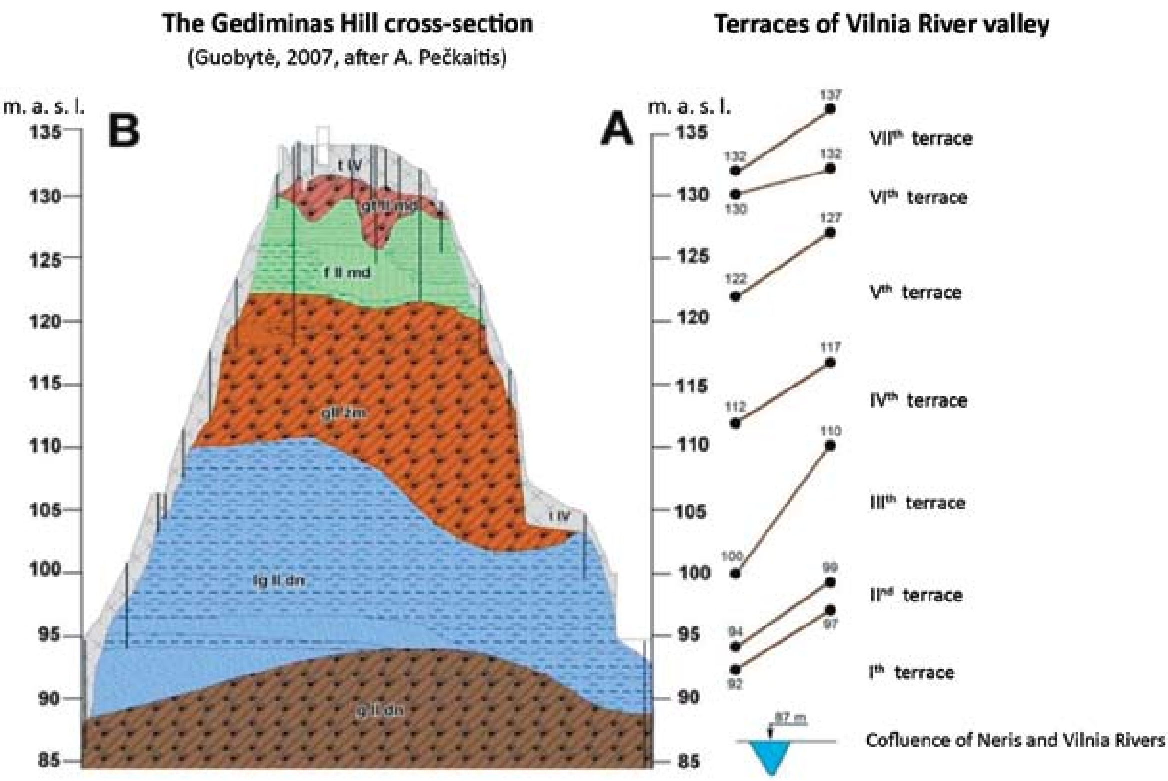


Fig. 3. The Gediminas Hill cross-section (Guobytė, 2007) showing intercalation of tills and sandy-silty glaciofluvial and glaciolacustrine sediments of Elsterian – Saalian age. Upper part (thickness of 3–5 m) is composed at a man-made (cultural) strata (for legend see Fig. M4)

maximum advance of the Weichselian glaciation. However, it seems the impact of Weichselian ice sheet on Vilnius hills is expressed more by periglacial phenomena, than accumulation and deformational impact. During the Last Glacial Maximum (LGM) the original area of the Castles likely was a flat plateau of Saalian glacial formations.

Erosional phenomena naturally are determined by permanent and temporal water streams from precipitation and melting ice and snow. It is assumed, that precipitation at the LGM and at a begining of deglaciation was very low as a consequence of climate aridization, and, therefore surficial erosion was insignificant during this time. Furthermore, glacial meltwater was drained by the rivers Neris and Vilnia and formed higher terraces which were lower than top of the Castles Hills plateau (Fig. 2). The 8th and 7th terraces of the Vilnia river are higher and prominent. Their altitudes are 130–140 m a.s.l., when the tops of Hills of Vilnius Castles reach 160 m a.s.l. at present. It means that there was no direct erosional impact of meltwater for the formation of upper reaches of the highest ravines.

Therefore, it is proposed that main features of the Vilnius Castles Hills were formed by periglacial thermal erosion, i.e. the movement of land masses due to thawing of permafrost. This phenomena is well known from regions of permafrost in the present Arctic and Subarctic (Photo).


Photo of a thermoerosional circus in North Siberia (by A. Kizyakov) as a result of thawing permafrost (left); The thermoerosional ravine of the Dainų valley (right)

Depth of frozen ground in Vilnius is unknown, however it could be noted, that thickness of permafrost in north central Europe during the peak of the last cold stage of Weichselian could have reached even 120–140 m (Delisle et al., 2003). At a moment of the climate change and beginning of the Wechselian ice body retreat, the masses of thawing ground became unstable and slided into opening valleys of the Vilnia and Neris rivers. The sequence of formation of thermoerosional ravines is proposed in the Fig. 4.

The typical thermoerosional valley is the Dainų (Songs) valley which is of some 50–60 m wide and 200 m long. A distinctive feature of the thermoerosional ravines is that their mouths are descending down to levels of the 8th–6th terraces. Later on, after permafrost has thawed, the erosional ravines with increasing precipitation were progressing and dissected an original plateau into separate hills. The younger ravines are descending to the lowest terraces of the Vilnia.

Also, in historical time people were reshaping the slopes of hills for living and defence purposes. For example, the saddle connecting the Gediminas and Three Crosses Hills existed (Fig. 5) until hitorical times, when an artificial channel for the Vilnia river was dug and the two Hills were separated.

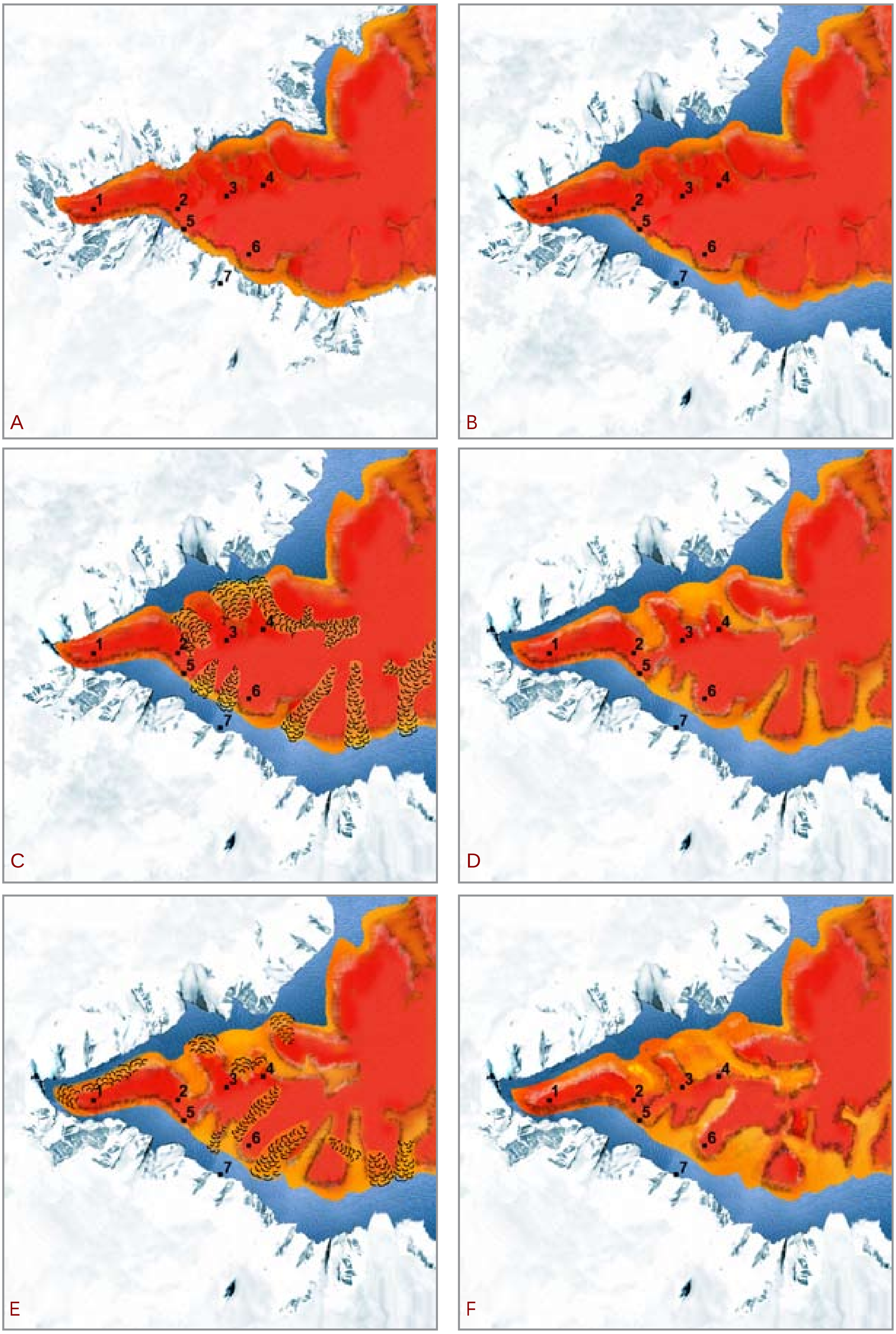


Fig. 4. Stages of development of the thermoerosional ravines: A, the plateau of Castles is under permafrost conditions at the LGM; B, a gap forms between land and ice; C, the 1st stage of thermoerosion begins; D, the highest thermoerosion ravines; E, second stage of thermoerosion; F, a „backbone“ framework of the Castles Hills is formed; 1–7, Vilnius Castles Hills

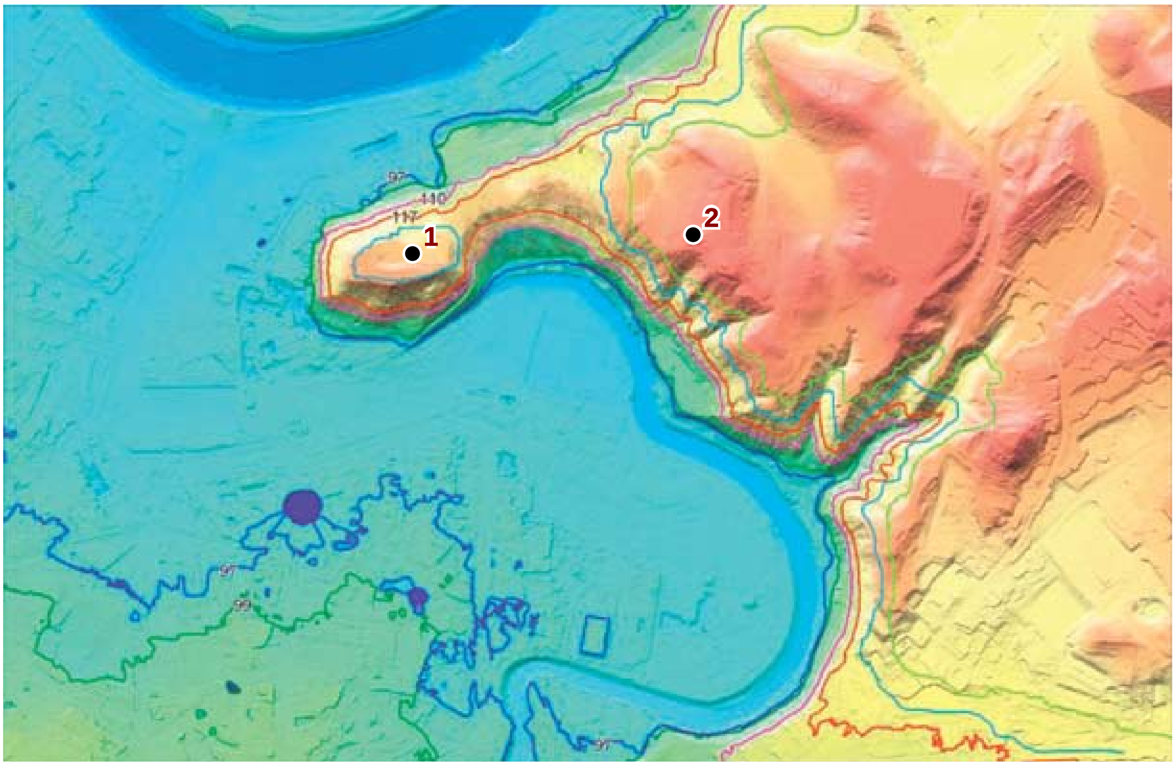


Fig. 5. The Hills of Vilnius Castles during the formation of the first Vilnia river terrace. Slopes are being modified by erosional procesess. The Gediminas Castle Hill is still connected by a saddle with the hilly massif of the Three Crosses

The development of the Vilnia river terraces was closely connected with a drainage of the lacustrine and glaciolacustrine systems in Mickūnai glacialdepression. It is assumed that the Vilnia river was draining the Mickūnai palaeolake during Eemian Interglacial and Pleni-Glacial. The present day valley of the Vilnia river evolved during the drainage of the Mickūnai glaciolacustrine basin since the LGM.

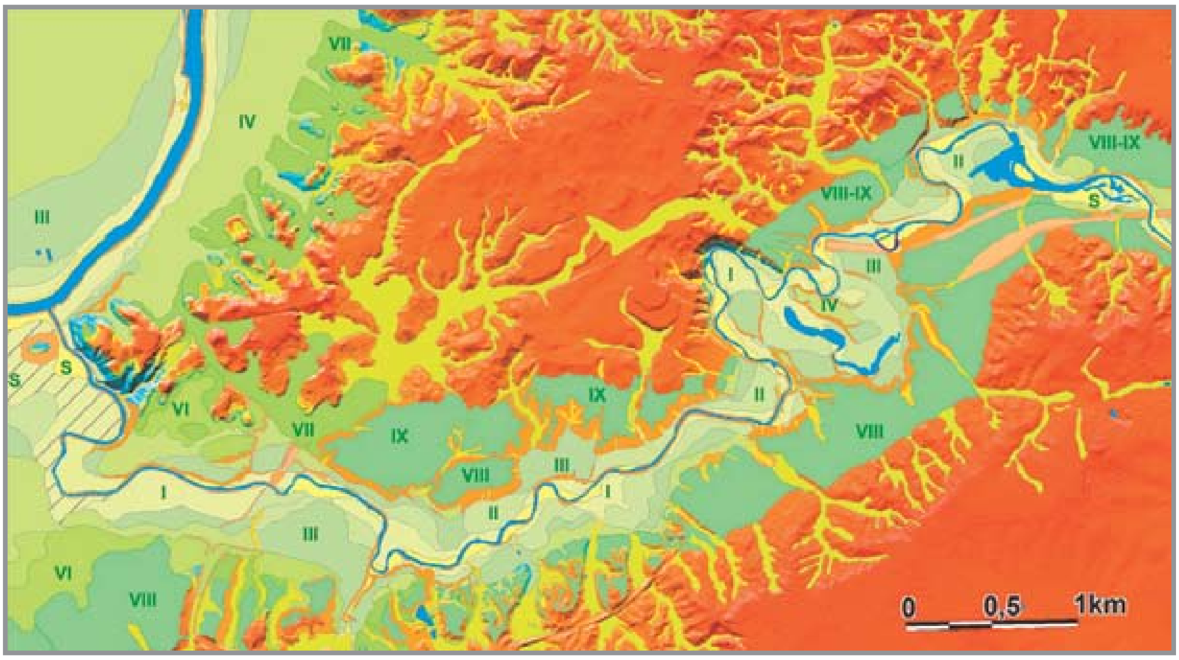
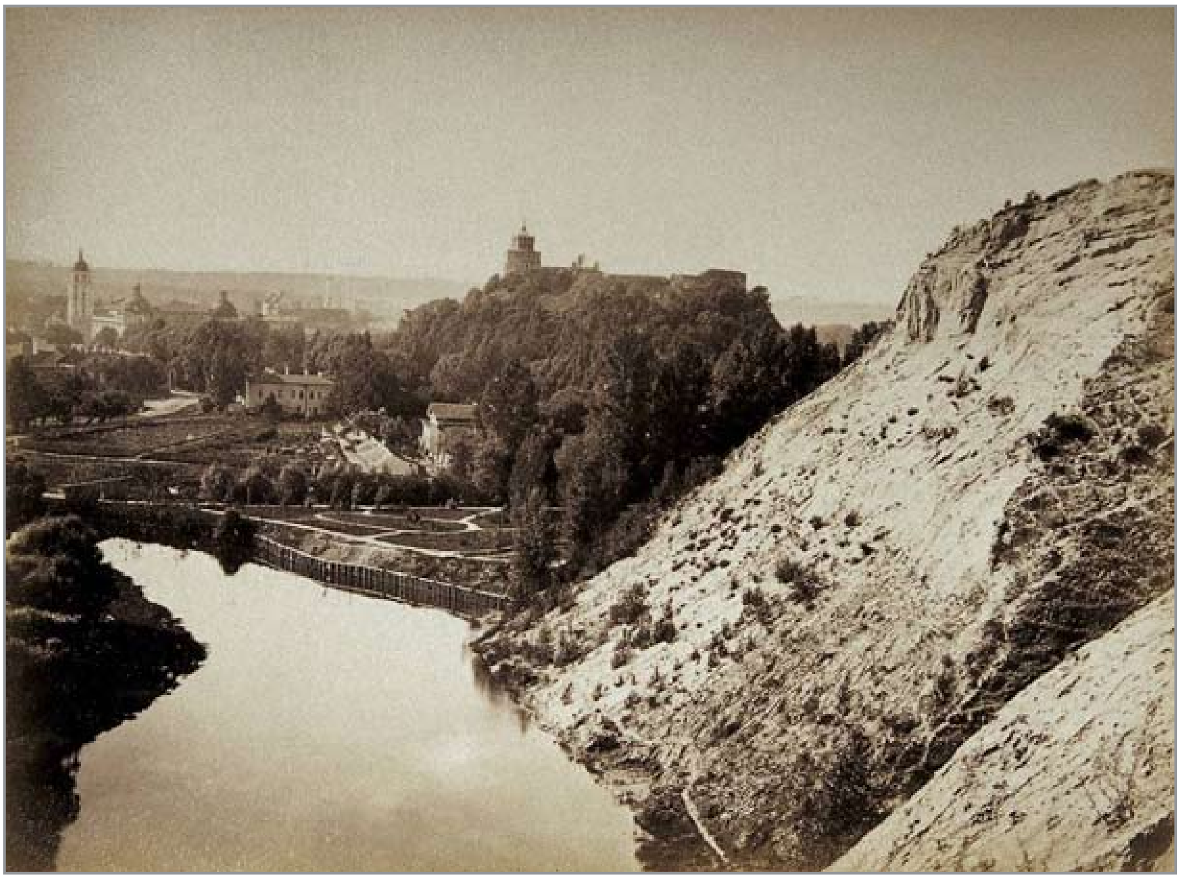


Fig. 6. Terraces of the Vilnia river (composed by R. Guobytė, 2012). Thermoerosional ravines are descending to levels of the 8th–6th terraces or are pendant near the upper parts of slopes. Typical thermoerosional ravines are depicted by yellow colour



An active slope of the Bekeś Hill in 1875 m.

The slope deformations and landslides happen because of steep slopes of the Castles Hills since historical past up to present. Landslides are usually accelerated and trigerred by meteorological and human factors (Satkūnas et al., 2008). For instance, in the Livonian chronicles dated 1396 is mentioned that western slope of the Gediminas Hill slided down and destroyed estate of Monvydas the Voivod of Vilnius causing deaths of 15 people. Also, it is known, that the Bekes Hill with part of the tower of the grave slided to the Vilnia valley in 1838. Remaining part of the Bekes grave and tower colapsed in 1843 (Michelevičius and Sarcevičius, 2012).

A young ravine dissecting slopes of the Bekeś Hill

The mouth of a young erosional ravine separating the Altana and Table Hills. This ravine is descending at the surface of the 1st terrace of the Vilnia River

A thermoersional ravine between the Bekeś and Stalo (Table) Hills. Note a flat bottom and ample diameter. At the right side, a young ravine is initiated and descending to the level of the 1st terrace of the Vilnia River

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Stop 3

PŪČKORIAI OUTCROP

Jonas Satkūnas, *Lithuanian Geological Survey*

The Pūčkoriai is Lithuania's highest outcrop i.e. 63,2 m (according to the earlier measurements it was 65 m). The outcrop is 260 m long, its top altitude above sea level is 208,2 m. The exposure is located on the right slope of the Vilnia river (left tributary of the Neris river) valley. The Pūčkoriai Outcrop was designated in 1974 as a geological monument and is located in the Verkiai Regional Park.

The outcrop was formed in Lateglacial and Holocene when the Vilnia river was deepening its valley and draining basin of the Mickūnai glacialdepression, however the present shape of the oucrop is rather young, as slope processes are very rapid.

The thickness of Quaternary at the top of the Pūčkoriai Outcrop is approximately 120 m. The outcrop inner structure is typical for the northernmost spur of the Medininkai Heights (part of the Ašmena Upland) that forms Vilnius topography. The Pūčkoriai Outcrop is outside the limit of the Last Glaciation, and its structure is affected neither by accumulation nor by erosion of the Weichselian ice sheet.

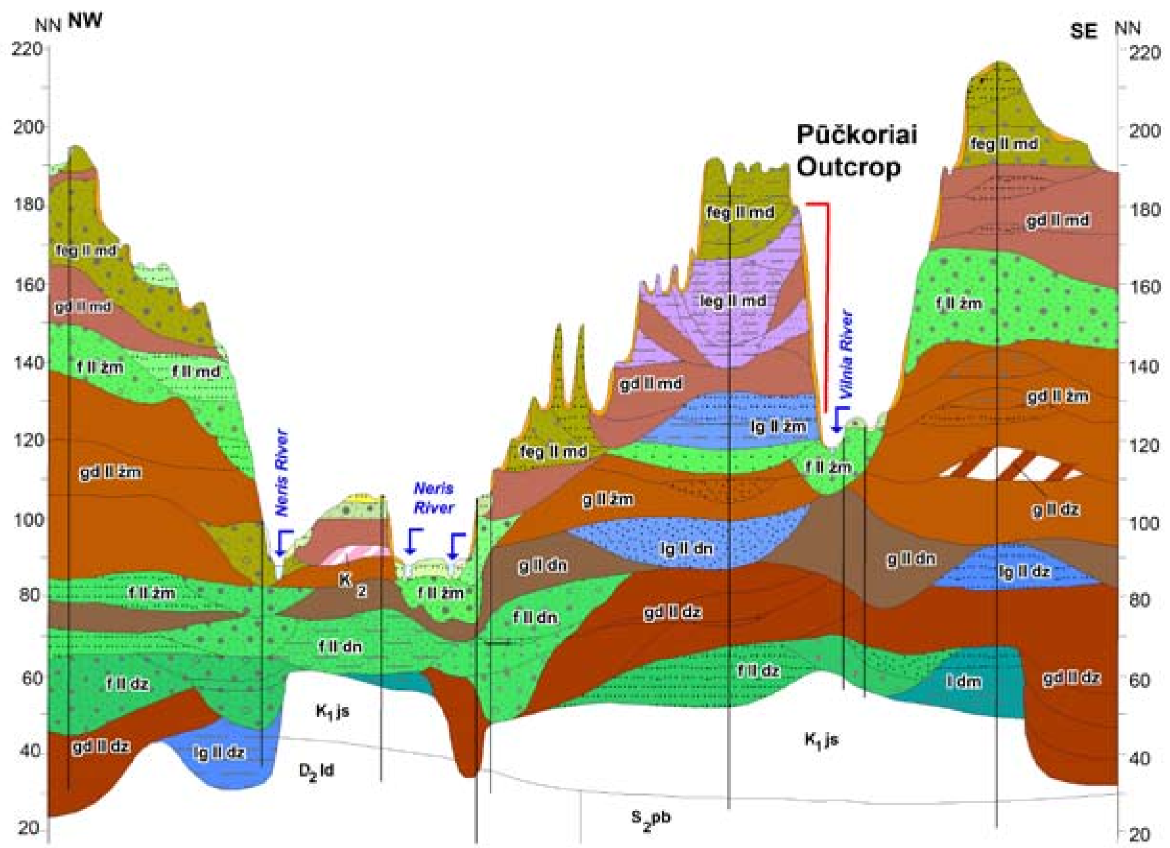

Fig. 1. Quaternary cross-section of the Vilnia river valley at the Pūčkoriai (For legend see Figs. M3 and M4)

Fig. 2. Pūčkoriai Outcrop in 1981 (after Mardosienė et al., 1981)

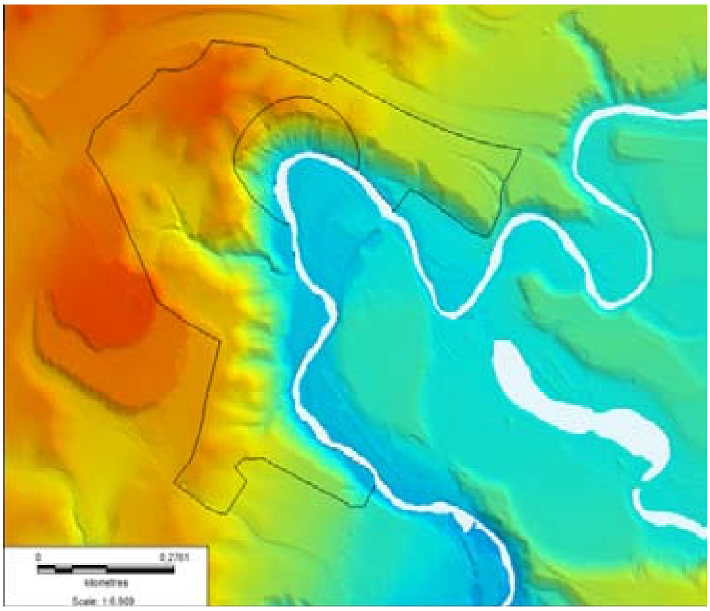

Fig. 3. LIDAR topography of the Vilnia loop at the Pūčkoriai

Fig. 4. To the left: the Pūčkoriai Outcrop in a beginning of 20th century (photo of unknown author, collection of Vida Petiukonienė). To the right: the outcrop in autumn 2012 (photo by V. Mikulėnas)

The Pūčkoriai Outcrop is a section of the glacial deformations of Saalian age composed of glacial loam with boulders, gravel, sand, silt, clay, etc. Therefore, these rocks occur in a great disorder, mosaicaly: in some places almost horizontally, elsewhere obliquely, somewhere else nearly vertically overturned or with distinct signs of glacial dislocations: folds, lumps, diapir folds (i.e. wedges), domes and blocks. Besides, in such a Quaternary rock mass the inserted blocks of Mesozoic rocks have been found. B. Rydzewsky (1925) studied the Pūčkoriai Outcrop and described the Jurassic block (J3ox) of grey clay with considerable admixture of white mica and remains of belemnites, ammonites and other fauna. L. Micas (1946) mentioned about a large block of white chalk of Cretaceous system (K2) which stuck in the upper part of the outcrop.

In spite that outcrop is well accesible for investigations, the documented section is available from report of investigations carried out in 1945 (Fig. 5). It was planned to construct a dam accross the Vilnia valley and supply water through pipes for a hydroelectric power plant in Antakalnis.

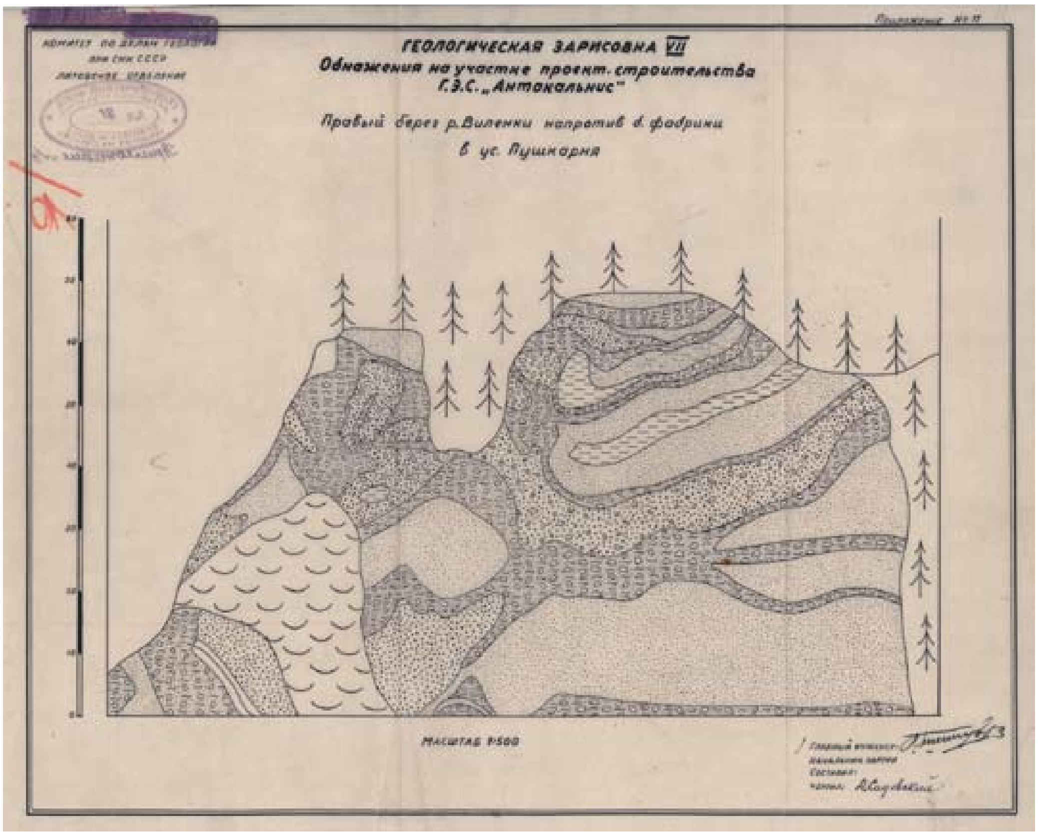

Fig. 5. The Pūčkoriai Outcrop section after Halicki and Jaroshevich-Halickaya, 1945

The Pūčkoriai Outcrop is permanently changing the slope of the Vilnia river valley. The lateral erosion of the Vilnia river stimulates its unstability, however lately the Vilnia river is unable to clean off the abundant colluvium from the outcrop foot, and it is overgrowing by vagetation.

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Stop 4

MICKŪNAI GLACIAL DEPRESSION AND SKERSABALIAI DUNES

Jonas Satkūnas, *Lithuanian Geological Survey*

The Mickūnai (Vilnia–Neris) glacial depression occupies the lowland between the Neris and Vilnia valleys (Fig. 1). The depression is very important from the point of view of Quaternary stratigraphy, since the sequence of sediments deposited during the Eemian Interglacial, Early-, Middle- and Late Weichselian is present (Fig. 2).

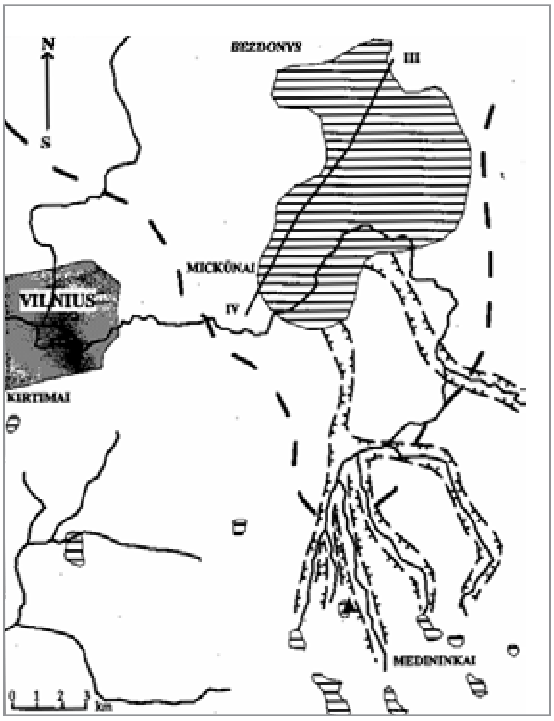


Fig. 1. Eemian palaeohydrography

In the course of geological mapping a continuous occurrence of Merkinė Interglacial deposits has been documented in the Vilnia–Neris glacial depression. It was determined that, in the area of 200 km^2, the interglacial deposits are situated at the same altitude, i.e. 102 m at the bottom, i.e. 120 m at the top.

The interglacial deposits are represented by lacustrine silt, silty sand, lacustrine marl and sand with abundant mollusc shells. According to the data from 17 mapping boreholes the average thickness of the Merkinė Interglacial sediments is 10–15 m. The bottom of the Merkinė sediments is located at an altitude between 102.3 m (in central part of the basin) and 118.0 m (in the periphery) a.s.l. The top of these deposits registered in all mapping boreholes occurs at 119.4 – 120.0 m a.s.l. This denotes that deposits were accumulated in a large interglacial lake. According to the pollen data the sediments were deposited continuously during the Merkinė Interglacial. A notable feature of the investigated deposits is the presence of lacustrine marl containing 25–58% of CaCO3. The pollen analyses indicate that the marl was deposited during the climatic optimum of the Merkinė Interglacial. The upper part of the Merkinė Interglacial deposits in the Mickūnai glaciodepression contains the fine-grained sand mostly. This indicates that at the end of the Interglacial, the lake became shallower and was completely filled by sediments. The Merkinė Interglacial deposits of the Mickūnai basin are covered by deposits of the Nemunas (Weichselian) age.

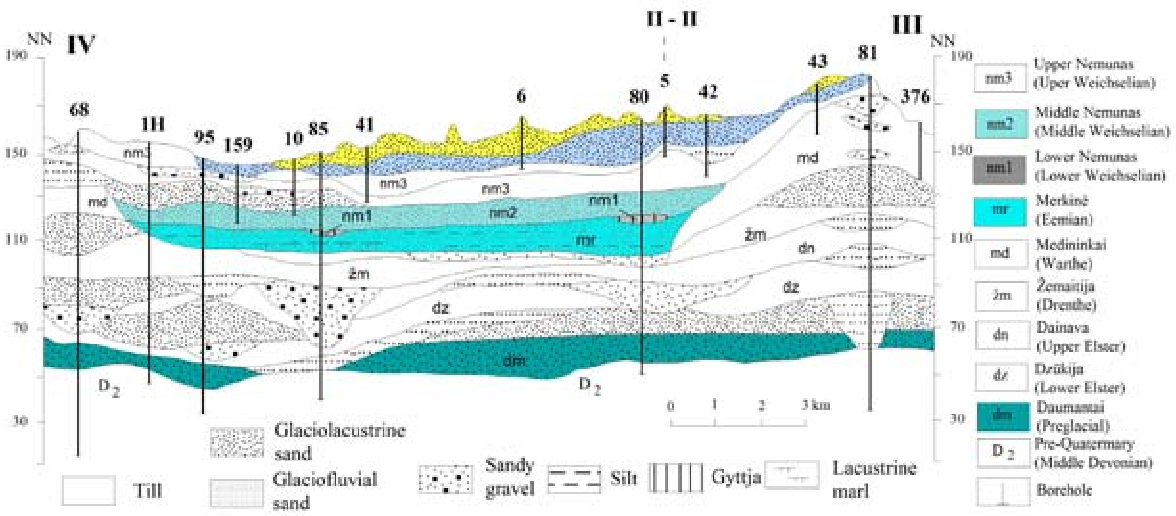


Fig. 2. Geological cross-section IV–III. Structure of the Quaternary of the Vilnia–Neris glacial depression (for the location of the cross-section see Fig. 1)

The sediments attributed to the Early Weichselian interstadials in this depression are represented by peat, silt with organic matter and sometimes by unsorted sandy-silty sediments of deluvial origin. The Lower Weichselian sediments are 1–3 m thick and are observed only in a few boreholes. It means, that they have no continuous distribution over the depression. The origin of the sediments shows that after the Eemian Interglacial peatland with small lakes existed in this depression at least some time during the Early Weichselian.

Above the Lower Weichselian organic-bearing sediments a regular presence of the lacustrine sand and silt has been revealed continuously distributed over the central part of the Mickūnai depression. These sediments were interpreted as being formed in a large palaeolake or palaelacustrine system, which occupied the depression during the Middle Weichselian. In 1996–1998 in scope of the project “Correlation of stratigraphic events of Upper Pleistocene in central and peripheral parts of the last glaciation” four boreholes: Gaidūnai, Popierinė, Rokantai and Mickūnai-184P have been drilled in Vilnia river valley in order to get more data on stratigraphy of the Upper Pleistocene (Satkūnas and Grigienė, 2012).

On the basis of lithology and pollen analyses the studied sections were subdivided into thermomers (time periods with relatively warmer climate) and cryomers (time intervals with colder periods). In the Mickūnai site it were determined seven thermomers and eight cryomers occurring above the Eemian Interglacial. The thermomers of the Middle Weichselian, however, were defined only by slight climatic changes in the background of general climatic deterioration.

The presence of the palaeolacustrine sequence in Mickūnai implies that nonglacial palaeoenvironments persisted in eastern Lithuania since the end of the Eemian interglacial until the Late Weichselian ice advance.

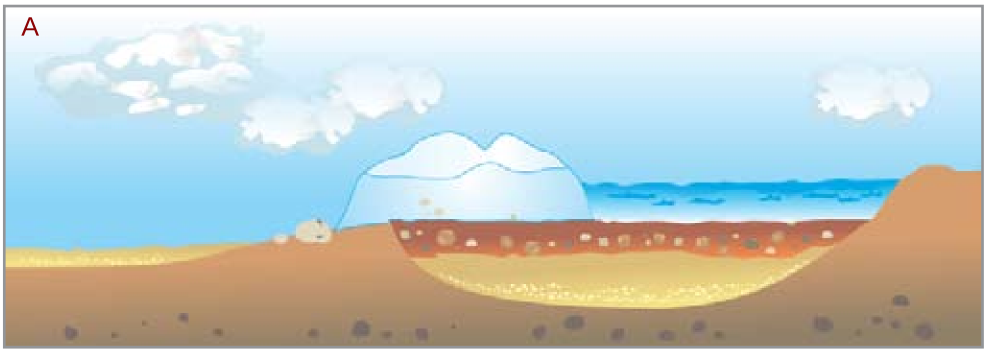
The Upper Weichselian in this area is represented by glacial, glaciofluvial and glaciolacustrine sediments accumulated during the maximum extension of the Last glaciation.

Dunes

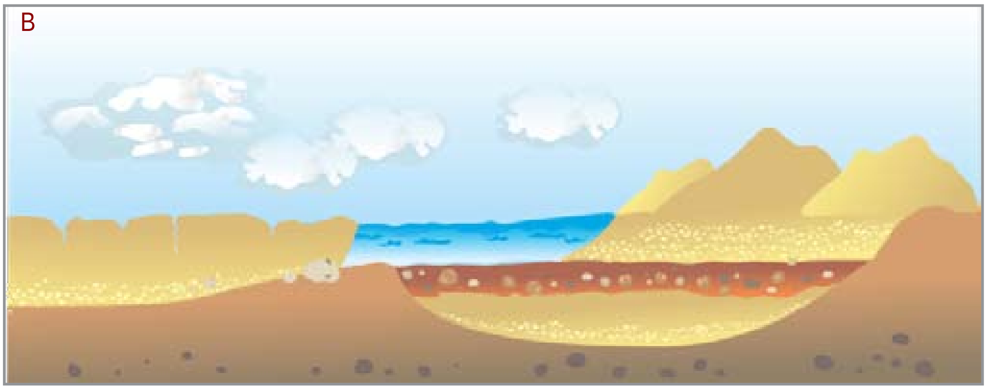
The continental Skersabaliai dunes field is located in a very central part of the Vilnia – Neris (or Mickūnai) glacial depression. The dunes field is 2–3 km wide and 14 km long.

The dunes have been formed on the Weichselian glaciolacustrine sandy deposits. There are dicernible two levels of of sediments of the glaciolacustrine basin: higher level is 160–170 m a.s.l. and the lower level – 140–150 m a.s.l. The levels witness that ice of the Weichselian maximal advance that occupied the Mickūnai depression was melting gradually. The drainage of the glaciolacustrine basin of the Mickūnai depression is reflected in the Vilnia river terraces.

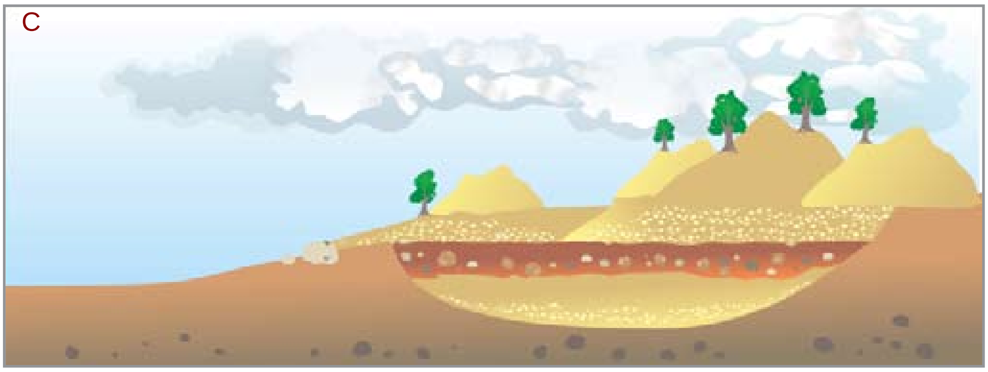
When basin of the higher level was drained, sediments of this basin became dry and aeolian processes started and high dunes of the Skersabaliai field were formed. When the lower level of basin drained, aeolian processes started.



Drainage of the higher glaciolacustrine basin, and formation of the7th terrace of the Vilnia valley



Drainage of the lower glaciolacustrine basin, and formation of the 6th terrace of the Vilnia valley. The formation of the Skersabaliai dunes field



The Mickūnai depression is entirely dried and the 5th terrace of the Vilnia valley is formed. Dunes at the lower level of the glaciolacustrine basin were formed

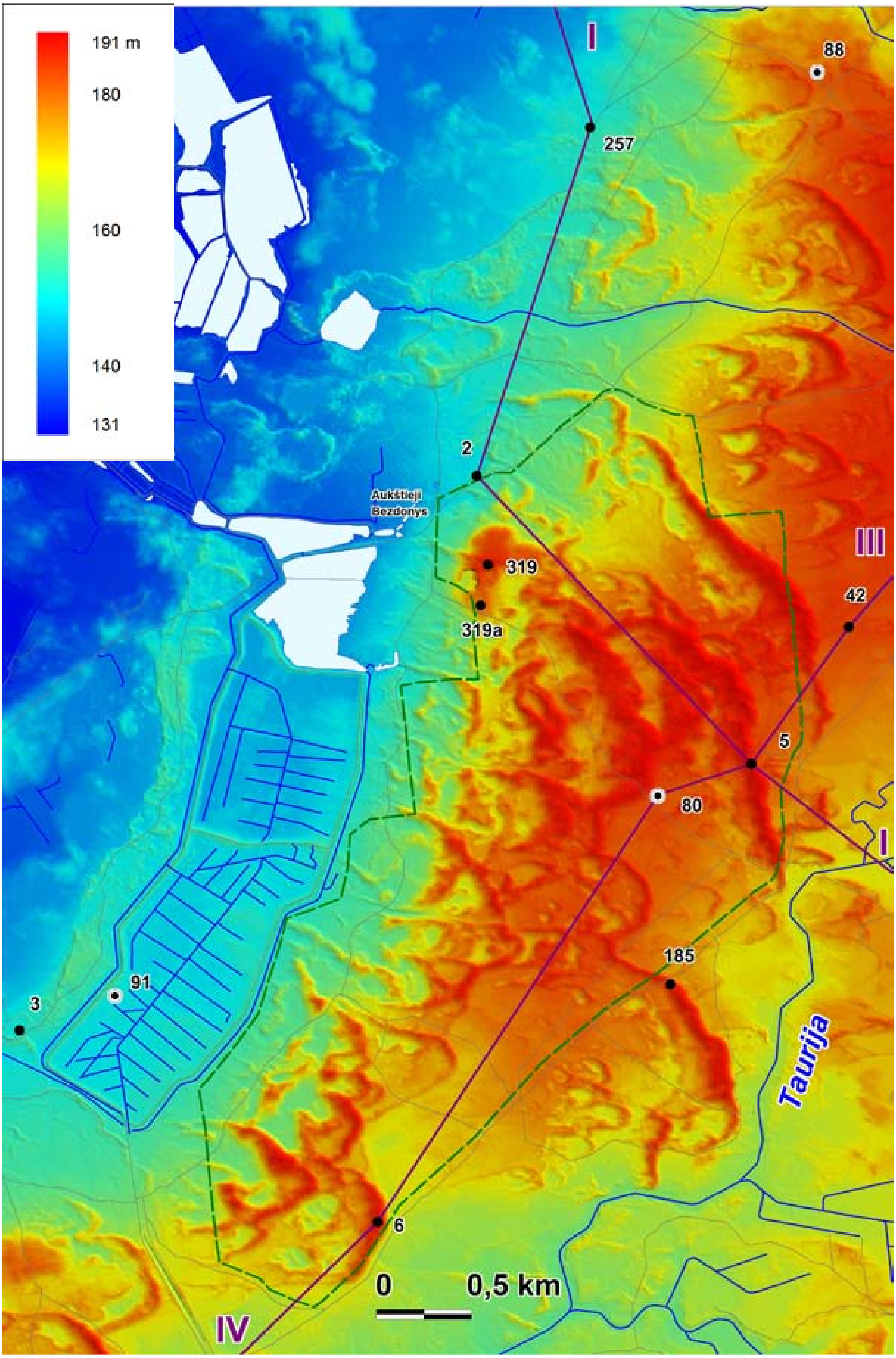


Fig. 3. LIDAR topography of the Skersabaliai dunes field (compiled by V. Minkevičius)

Long axies of main dunes are oriented from NW to SE, meaning that wind blow was directed to NE (Fig. 3). Some dunes are 14–18 m. and 1.5 – 2 km long. Aeolian sand is fine, very well sorted, composed of quartz (average 98%, SiO_2 makes 94%). The thermoluminescence datings of sand from the highest dunes gave an age of 13 200–10 000 years (Satkunas et al., 1991) (Fig. 4).

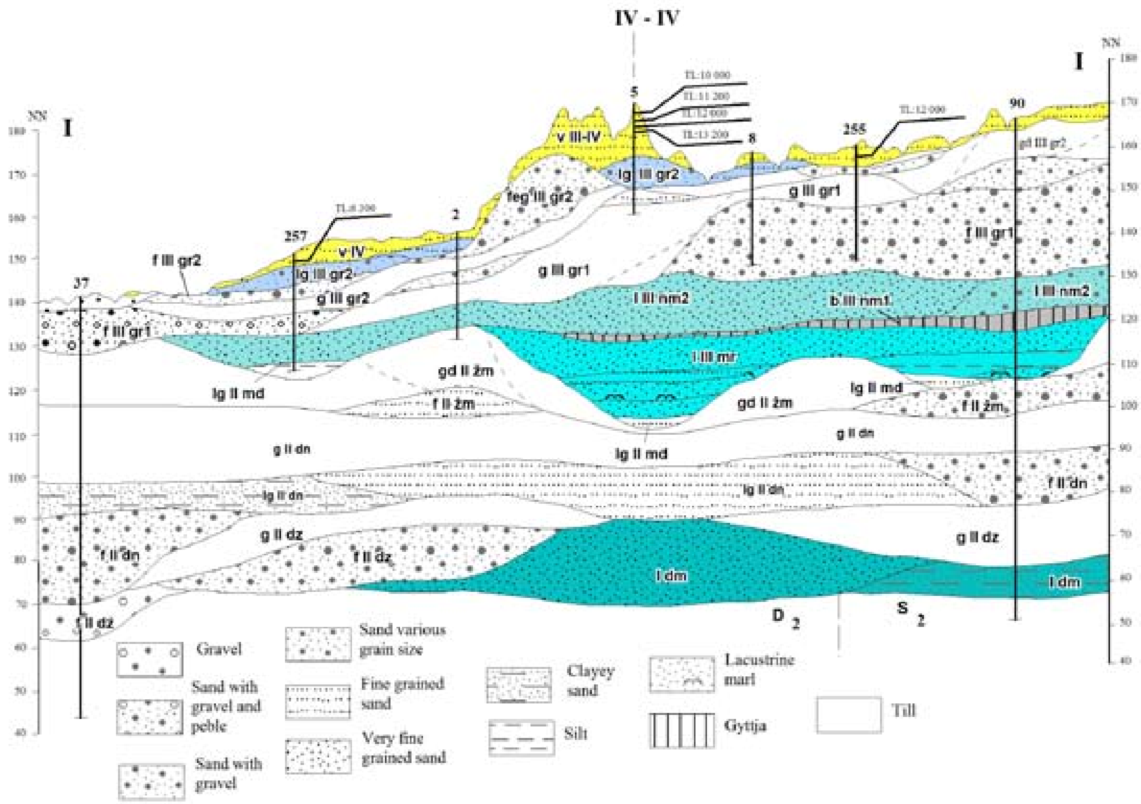


Fig. 4. Geological cross-section of the Skersabaliai dunes field (for the location of the cross-section I–I see Fig. 3)

Due to well developed continental dunes the Skersabaliai field is proclaimed as a geomorphological reserve.

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Stop 5

THE BOUNDARY OF MAXIMUM EXTENT OF THE LAST (WEICHSELIAN) GLACIATION

Jonas Satkūnas, *Lithuanian Geological Survey*

The age of the Medininkai Heights till and the position of the outer margin of the Last Glaciation Maximum (LGM) in SE Lithuania has been discussed until 1990-ies. In the most geomorphological maps and schetches the Medininkai Heights had been interpreted as being formed during the Late Saalian (Medininkai) glaciation, however, some researchers considered this Heights as a marginal formation of the maximum (Grūda, Brandenburg) Stage of the Last (Weichselian) Glaciation (e.g. Vonsavičius, 1982).

The number of criteria were applied for detection of the boundary of the LGM: geomorphological, paleogeographical (presence of periglacial phenomena, hydrological pattern), geochemical and biostratigraphical. For example, a comparison of the geochemical composition of the surficial tills of the Baltic Upland and the Medininkai Heights shows, that the associations of trace elements are dependent on a different degree of weathering (Bitinas and Satkunas, 1995). The Medininkai Heights till, formed during the Medininkai glaciation, is characterized by a strong association of "resistant" trace elements like Zr, Mn, Ti, Cu, Y, Yb. For the surficial tills of the Baltic Upland the association of Ga, Cr, Co, V, Ni is characteristic. The geochemical data thus indicate that these uplands have been formed during the different glaciations and do support the same conclusions based on geomorphological, litho-and biostratigraphical data.

Nevertheless, the biostratigraphical criteria is of the highest significance, therefore occurrence and structure of the Merkinė Interglacial deposits in the region of the boundary of LGM was studied in oder to date the surficial till and, in general, the age of the Medininkai Heights. If Eemian sediments are not covered by Weichselian tills, it means, that the Heights were located outside the maximum extent of the Weichselian glaciation and, therefore, must be attributed to the formations of the Saalian glaciation.

Up to 1991, the Eemian (Merkinė) Interglacial deposits in the Medininkai Heights were known from two localities: Kirtimai (the suburb of Vilnius) and the Medininkai village (Kondratienė, 1978; Kondratienė and Klivečkienė, 1983; Kondratienė et al., 1984, 1986; Kondratienė and Vonsavičiūtė, 1986). The Eemian (Merkinė) Interglacial sediments have been identified and dated on the basis of only pollen analysis.

The similar conditions are characteristic for the sediments of the Murava (Eemian) Interglacial described from the Karachaishchina village (Vazniachuk et al., 1978) and at several other sites (Pavlovskaja and Satkūnas, 1995) in adjacent areas of Belarus.

A new data on Upper Pleistocene stratigraphy and age of the Medininkai Heights have been obtained by geological mapping at a scale of 1:50 000, which has been performed for the environs of Vilnius in 1986–1991. Within the mapping project special attention has been paid to the problem of geological age of the Medininkai Heights. The nine of the most representative depressions (now occupied by peatlands) in the Medininkai Heights have been selected for drilling. It was assumed that these depressions represent Eemian palaeolacustrine basins. Organic sediments of Eemian and Weichselian age were found in all of these depressions (Fig. 1).

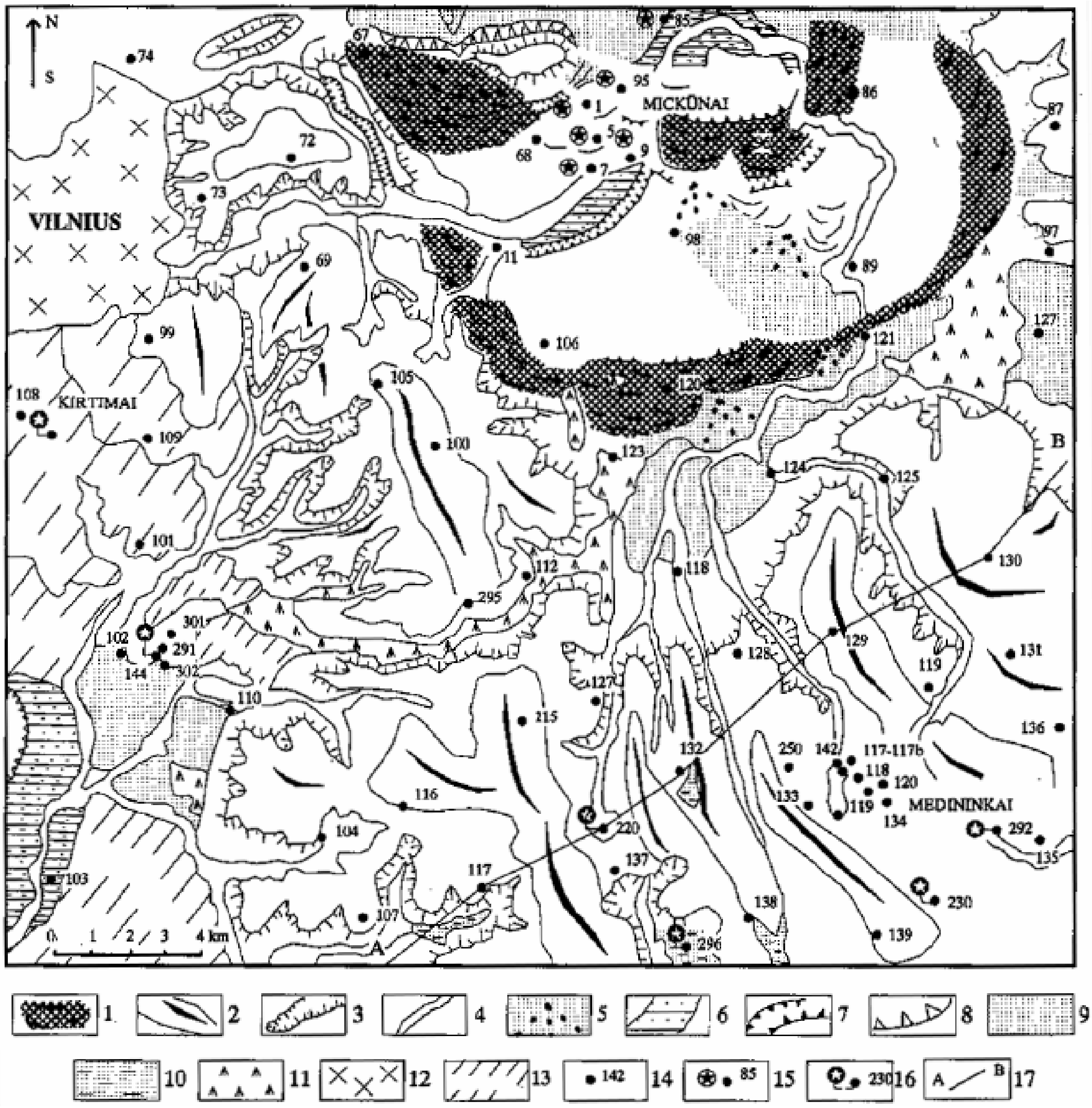

Fig. 1. Geomorphological map of the Medininkai Heights and the Mickūnai glacial depresion (by R. Guobytė). Location of Merkinė (Eemian) Interglacial deposits

1 – end moraine ridges of the oscillations of the Grūda advance of the Late Weichselian (Nemunas);
2 – massifs and ridges of the Medininkai (Warthe) glaciation;
3 – ravines;
4 – flood plain valleys;
5 – sandur cones;
6 – glaciofluvial terraces;
7 – erosional slopes;
8 – ice contact slopes;
9 – glaciolacustrine plains;
10 – marshy lacustrine plains;
11 – bog plains;
12 – Vilnius urban area;
13 – morainic plateau of the Medininkai glaciation;
14 – location of borehole;
15 – borehole with Merkinė (Eemian) deposits covered by Late Nemunas (Weichselian) till;
16 – borehole with the Merkinė deposits without coverage of Nemunas (Weichselian) till;
17 – cross-section

The composition of the Merkinė deposits of all these sites of the Medininkai Heights is rather similar. Gyttja with wood remnants dominate. The kettles of the Merkinė palaeolakes are of different size. Their size of aquatories vary between 0,2 and 2 square kilometers and the altitudes of the Merkinė

Interglacial lacustrine deposits vary from 142 m to 257 m a.s.l. This indicates that the sediments were deposited in separate lakes, scattered in the glacial relief of Saalian (Medininkai) age. The morphology of the palaeolakes suggest presence of a network of small rivers during the Interglacial. The reconstructed river network shows that the palaeolakes of the Medininkai Heights were hydrographically connected with the Mickūnai palaeolake during the Merkinė Interglacial **(See Fig. 1 of the Stop 4).**

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Stop 6

THE MEDININKAI CASTLE

Jonas Satkūnas, *Lithuanian Geological Survey*

Fig. 1. The Medininkai Castle

13th–17th century the presently slumbering small village Medininkai located just 2 km from Belarus, was a lively commercial centre with a town hall, marketplace, residential buildings, and a Castle. Ruins of the olden castle indicate that the locality has outstanding and mysterious history. The Medininkai Castle was built in the late 13th century or the first quarter of the 14th century. A wooden castle was rebuilt into a stone and brick castle in early 15th century.

Castle is quadriangle „fence type“ establishment that occupies 2 hectares (with moats and ramparts – 6,5 hectars). It had four towers (now remained only one) up to 30 m high. Walls were up to 14–15 m high and 1,9 m thick at the bottom. Perimeter of the walls is 568 m. Loopholes at the top of the wall were accesed from wooden parapet walks which were approached by ladders from the bailey, or by steps from the towers. Its high, relatively thin walls indicate that Medininkai Castle was built when neither wall ramming techniques nor gunpowder were in use. The four gates with shelds could be lowered and rised. The largest of four, the northeastern tower was adapted for living quarters and was the oldest known brick residence in Lithuania. The huge bailey indicates that people from the surrounding areas sought refuge in the Castle.

Medininkai Castle is first mentioned in 1387, in chronicles of crussaders. The castle was taken by crussaders in 1402. This campaing was aimed to take Vilnius, however it failed.

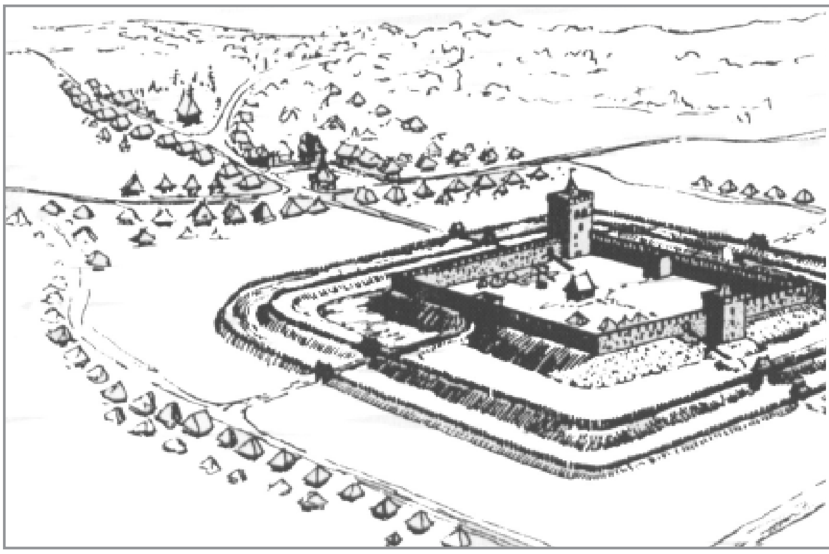

Fig. 2. The Medininkai Castle reconstruction (author S. Lasavickas)

In 1415, the Great Duke of Lithuania wrote a letter to Magister of the Crussaiders that has been send from Medininkai Castle. In 15th century the castle lost its defensive significance.

That a very scarse historical facts of the history of Medininkai Castle.

From the geological point of view it note worthy that the walls of the castle are built of stones collected in vicinites and some of the have features of periglacial polishing (ventifacts), that is proper for cold and harsh climate conditions.

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Stop 7

JUOZAPYNĖ HILL AND MEDININKAI HEIGHTS

Jonas Satkūnas, Rimantė Guobytė, *Lithuanian Geological Survey*

Fig. 1. The Aukštojas Hill (Photo by V. Baltrūnas)

Fig. 2. The Žibartonys Hill (Photo by B. Karmaza)

The Medininkai Heights in southeastern Lithuania is a northwestern extension of the Ašmena (Oshmianskaja) Upland located in northwestern Belarus (see Figs. 1M and 2M). The Medininkai Heights, reaching 200–290 m above present sea level, is the highest part of Lithuania. The highest point of Lithuania is situated here. That honor until 2007 had Juozapynė Hill (Lithuanians call it Juozapynė Mount). Its altitude is 292.83 m. In 1978, 500 m to the south from the Juozapynė Hill was observed the possibly higher hill. In 2004, repeated measurements has been carried out which confirmed that the southern hill, the current Aukštojas Hill (Fig. 1), is 1 m higher than the Juozapynė. Thus, the highest point in Lithuania is 293.8 m a. s. l. In 2007, the Žibartonys Hill (Fig. 2) which situated 8,8 km to the west from Juozapynė Hill was also found to be the second highest peak of Lithuania: 293,57 m a.s.l.

The Medininkai Heights is mainly built up by marginal ice-pushed moraines, formed by an active glacier (Fig. 3). The morainic landforms have a clearly elongated shape, with an orientation from northwest to southeast. It is a characteristic feature that the tills, glaciolacustrine and glaciofluvial sediments are strongly glaciotectonically disturbed, reflecting an active glacial push towards southeast. The glaciotectonic deformations have been observed in numerous outcrops and gravel pits. No lakes exist today on the Medininkai Heights, and this is a characteristic feature.

The periglacial features of cover deposits on the Medininkai Heights were studied in Norvaišai and Juozapynė gravel pits by Baltrūnas et al. (2010).

The cover of Quaternary deposits (Fig. 3) in the Medininkai Heights is in average 200–250 meters thick. It is composed by pre-Pleistocene (Preglacial) lacustrine sediments (Daumantai formation), Early Pleistocene (Kalviai Glacial and Vindžiūnai Interglacial), Middle Pleistocene tills, glaciolacustrine and glaciofluvial sediments. The presence of sediments of the Late Pleistocene age (Eemian with periglacial Weichselian cover) is very regular also.

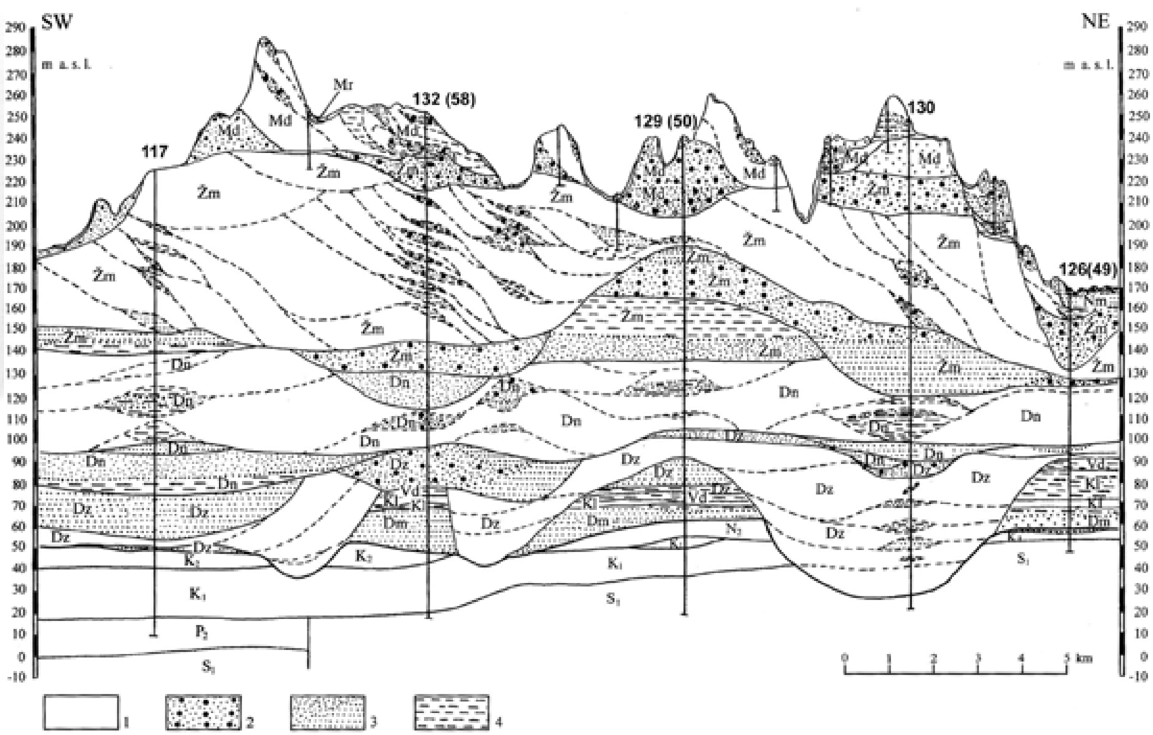

Fig. 3. Cross-section of Quaternary cover of the Medininkai Heights (for location of the cross-section see Fig. 1 on Stop 5.)

Stratigraphic indexes:
S1 – Lower Silurian;
D3 – Upper Devonian;
P2 – Upper Permian:
K1 – Lower Createaceous,
K2 – Upper Cretaceous,
N2 – Upper Neogene,
Dm – Daumantai,
Kl – Kalviai,
Vd – Vindžiūnai,
Dz – Dzūkija,
Dn – Dainava,
Žm – Žemaitija,
Md – Medininkai,
Mr – Merkinė,
Nm – Nemunas.

Lithology:
1 – till;
2 – gravel;
3 – sand;
4 – silt and clay.

Reference

Baltrūnas, V., Karmaza, B., Molodkov, A., Šinkūnas, P., Švedas, K., Zinkutė, R., 2010. Structure, formation and geochronology of the late Pleistocene and Holocene cover deposits in South-Eastern Lithuania. Sedimentary geology, 231, 85–97.

Stop 8

PERIGLACIAL COVER DEPOSITS AND MIKALIŠKĖS GLACIOFLUVIAL DELTA

Algimantas Česnulevičius, Kęstutis Švedas, *Lithuanian University of Educational Sciences*
Petras Šinkūnas, *Department of Geology and Mineralogy, Vilnius University*

Fig. 1. Location of Mikališkės quarry

Medininkai Heights and Eišiškės (Lyda) Plateau were not glaciated in the Weichselian and have experienced considerable extraglacial conditions in a periglacial zone. The Medininkai Heights is mainly built up by ice-pushed moraine – ridges of elongated shape of NW-SE orientation. As it can be observed in many places, the ridges composing sediment sequence are strongly glaciotectonically disturbed, reflecting an active glacial push towards the southwest (Satkūnas, 1997). Contrary, the sediment sequence in Mikališkės sand and gravel quarry (Fig. 1) shows any evidence to have been glaciotectonised. The sediment sequence there represents the proglacial sedimentation by glacial melt water. The accumulated glaciofluvial form represents a terrace shaped landform adjoining the slope of marginal ridge at its southern slope. The delta foreset lithofacies (Fig. 2) comprising of large scale planar cross-beds of southern dip direction towards the proglacial lake disclose the origin of the deposit. The upper surface of foreset poorly sorted gravel and gravelly sand layers more or less correspond to the former proglacial lake-level. This surface is covered by deltaic topset trough cross-bedded sediment sequence created by the subaerial lakeward migration of glaciofluvial sediments on the delta plain in braided streams. Lithofacies of subhorizontally laminated and ripple bedded fine grained well sorted sand usually characteristic of deltaic bottomsets can by observed in some distal delta part. The landform of glaciodeltaic origin is being created by glacial ice melt water drainage, but the features of the drainage system can be hardly interpreted. The glaciofluvial delta can be related to the activity of the glacier of the Last Glaciation, however the features of periglacial processes maintain the opinion for its older age.

Fig. 2. Mikališkės glaciofluvial delta foreset bedding

The Periglacial processes had changed the surface of Medininkai Heights and Eišiškės Plateau generating secondary forms and complicating the subsurface layer of sediments. The dens network of ravines had covered the Heights with their lengths of 15 km per km^2 at the northern part of it (Švedas, Česnulevičius, 2009).

The layer of up to 2 m thick of calcareous sandy loam of specific colour and iron content, having cryogenically complicated structure covers in many places the glaciofluvial delta deposits in Mikališkės quarry. However the features of the periglacial processes are better exposed in Stakai small gravel pit (Fig. 3) some 0.5 km to NW of Mikališkės quarry (Fig. 1).

In general a 5–7 m thick layer of sandy loam and clayey material covers the surface of the Medininkai Heights. In respect to their composition, colour, iron and carbonate content, and cryogenic structures, the periglacial cover formations have been subdivided into 3–4 lithocomplexes (Baltrūnas et al., 2007). The lithocomplexes are separated by thin layers of organic matter, however the content of Corg is quite low, and not exceeding 0.28–0.70%. They are similar to hydromorphic immature soils. The buried soils of similar type, with the content of Corg do not exceeding 0.01–0.63%. They resemble present-day permafrost soils.

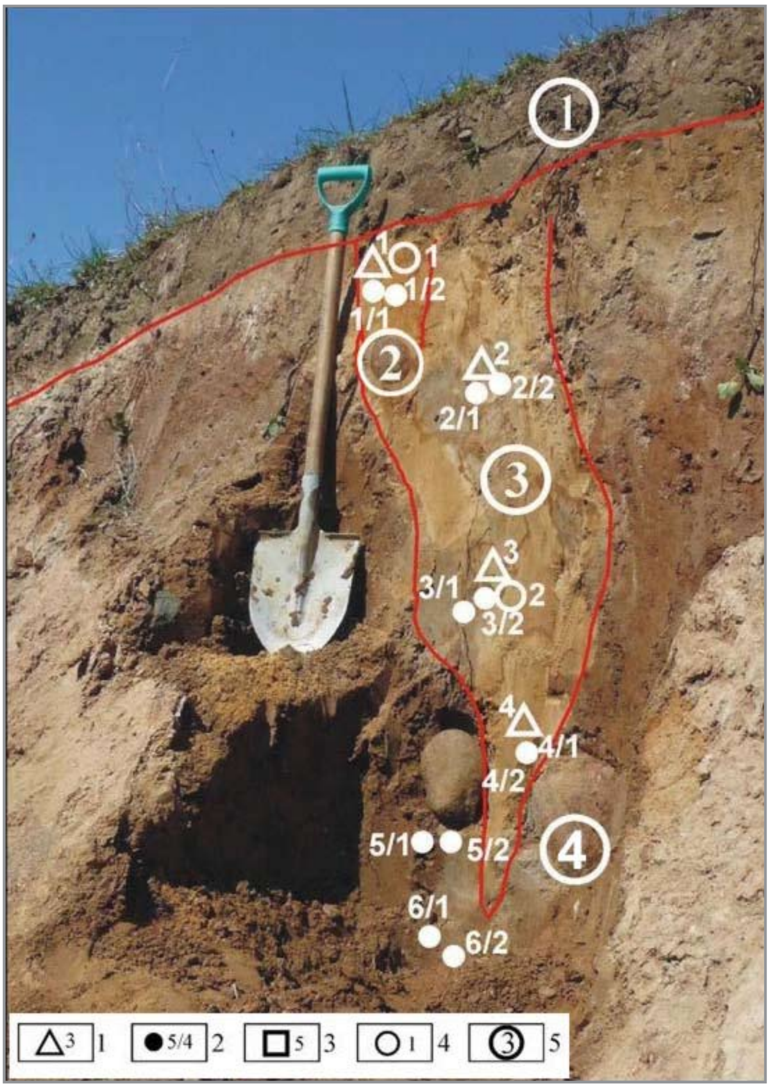

Fig. 3. Outcrop of the northern wall of Stakai quarry with ice-wedge pseudomorph. Sampling sites with the numbers for the different analysis types:

1 — grain-size analysis;
2 — geochemical analysis;
3 — petrographical analysis;
4 — IR-OSL dating;
5 — layer number

The lowest, 1–3 m thick lithocomplex is composed of unstratified fine-grained sand and sandy loam with the clay and gravel beds, resulted from the process of segregation. Segregation is the tendency for the coarse particles to separate from the finer particles in zone of permafrost, which has undergone repeated freeze-thaw action. The rapid change of lithology and involutions of cryogenic origin are characteristic of the complex.

Table 1. IR-OSL dating results for the sediment samples from Stakai quarry

Layer number	IR-OSL age (ka)	Short description
1	5.3±0.8	Soil
2	9.7±0.8	Loam brown, with gravel and weathered brownish grey and grey sandy loam with gravel and cobble with the uneven and obscure boundary.
3	21.0±1.6	
	Sand with pebbles and boulders in ice-wedge pseudomorph body.	
4	74.8±5.8	Till brown

The intermediate lithocomplex (~2 m thick) is composed of fine-grained sandy loam-like material. It is enriched in iron oxides, contains folded involutions, and pseudomorphoses of different size, which were formed in the place of former ice wedges.

The upper lithocomplex with the thickness of 1–2 m is composed of unstructured fine-grained sand, sandy loam and silt with the sparse gravel beds. The involutions are unclear whereas the pseudomorphoses are rare here. The upper lithocomplex is covered by the modern soil.

An overall enrichment in fine-grained material, when the 0.1–0.05 mm sized particles make up ca 48%, the 0.05–0.01 mm ones ca 23%, and the clay particles (less than 0.01 mm) from 9.8% to 18% of the total, implies a strong impact of cryogenic and other cold-related processes on the soils. A repetitive cycle of freezing and thawing accelerates the weathering of the rock particles. As a result the silt and clay particles accumulate at high rates, and the soils become similar to loesses. An impact of cold on the soils is confirmed by abundant cryogenic structures. This indicates the typical extraglacial subenvironment.

Three-layer structure of periglacial formation is observed in the numerous quarries of Medininkai Heights and Eišiškės Plateau. The most impact of permafrost processes on the middle (second) layer is observed.

Cover deposits in the area studied are often deformed by solifluction and fluvial erosion and penetrated by ice-wedge pseudomorphs. Granulometric, geochemical and petrographical investigations of the deposits have demonstrated that they are characterized by different sources of sedimentary material supply as well as different degree of physical and chemical weathering. The Ca/Zr ratios of cover deposits show that the upper beds usually are stronger chemically weathered, what is associated with warmer climate. According to the geochronological data available (Table 1), at least 4 clusters of IR-OSL dates can be distinguished in the late Pleistocene environmental history of Medininkai Heights and Eišiškės Plateau: about 100 ka (MIS 5c, Merkinė interglacial), 88–70 ka (MIS 5a, Merkinė interglacial), about 40 ka (MIS 3, Rokai interstadial) and 21–12 ka (late Nemunas). One cluster of IR-OSL dates (9.7–5.3 ka) is obtained for the first half of Holocene (Baltrūnas et al., 2010).

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Stop 9

THE DEVIL'S HOLE

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Jonas Satkūnas, *Lithuanian Geological Survey*

The Aukštadvaris regional park is known by glaciokarst forms. The anomalously deep hole in South-Eastern Lithuania, vicinities of the Aukštadvaris settlement, is called as "Devil's Hole". According to old legends, a church was built in the place of the hole, but it was cursed and disappeared without leaving a trace. Other ones tell about a new bell which fell from cart accidentally, when it was carried to the Užuguostis church, and rattled down into the hole. Also it is told that a calf who had drowned in a pit, emerged shortly in the little Škilietai lake located nearby (Baltrūnas and Šliaupa, 1980).

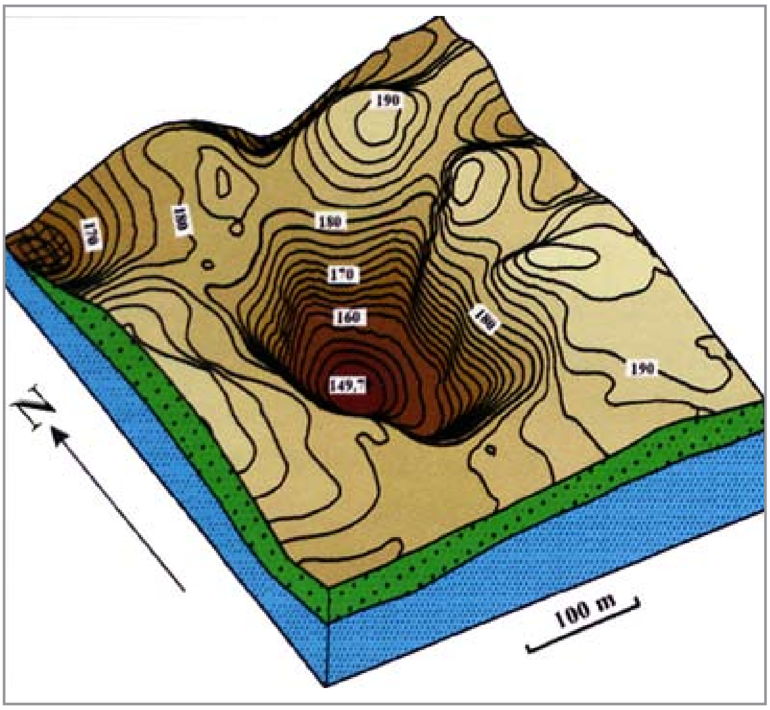

Fig. 1. Morphology of the Devil's Hole (according to Baltrūnas and Karmaza, 2007)

The mentioned hole is well-rounded, 200 m in diameter and c. 40 m deep (Fig. 1). The last 9,5 m is a thick layer of peat (Fig. 2). In 1964 this hole, as a one of the deepest in Lithuania, was declared as the geological monument of nature of national significance protected by law. However, scientists became interested in origin of this interesting geological-geomorphological form; they were tempted by the mystery of the Devil's Hole origin. This landform is located within the area of marginal moraines of the Late Weichselian Glaciation (Grūda Stadial). At first, it has occurred to them that the deep round depression was formed at foot of waterfall which fell down from an edge of glacier. Later a hypothesis of its glaciokarst origin emerged. It seems that the pit appeared in the place of an ice block buried under thick cover of sand. When it thawed, the sand cover fell down, and a deep funnel, the shaped pit, appeared in the place of the buried ice block. It was also suspected, that the pit may be a meteoritic crater. The cosmic hypothesis of this monument of nature is attractive; however it is little substantiated by the results of investigations until now.

The drillings into the bottom and the analysis of pollen from the peat indicated that the peat underlying sand was formed in the Late Glacial i.e., during the Late Dryas (Fig. 2). The accumulation of peat started in Preboreal, and was most intensive in the first half of Holocene. The data testify that lime trees and elms predominated in the hole environs, also there was plenty of hazels and alders. The determination of an age by radiocarbon method in the laboratory of the Institute of Geology and Geography (Nature Research Centre) showed that the peat started to form about 9.4 thousand years ago. Hence, the hole itself is not younger.

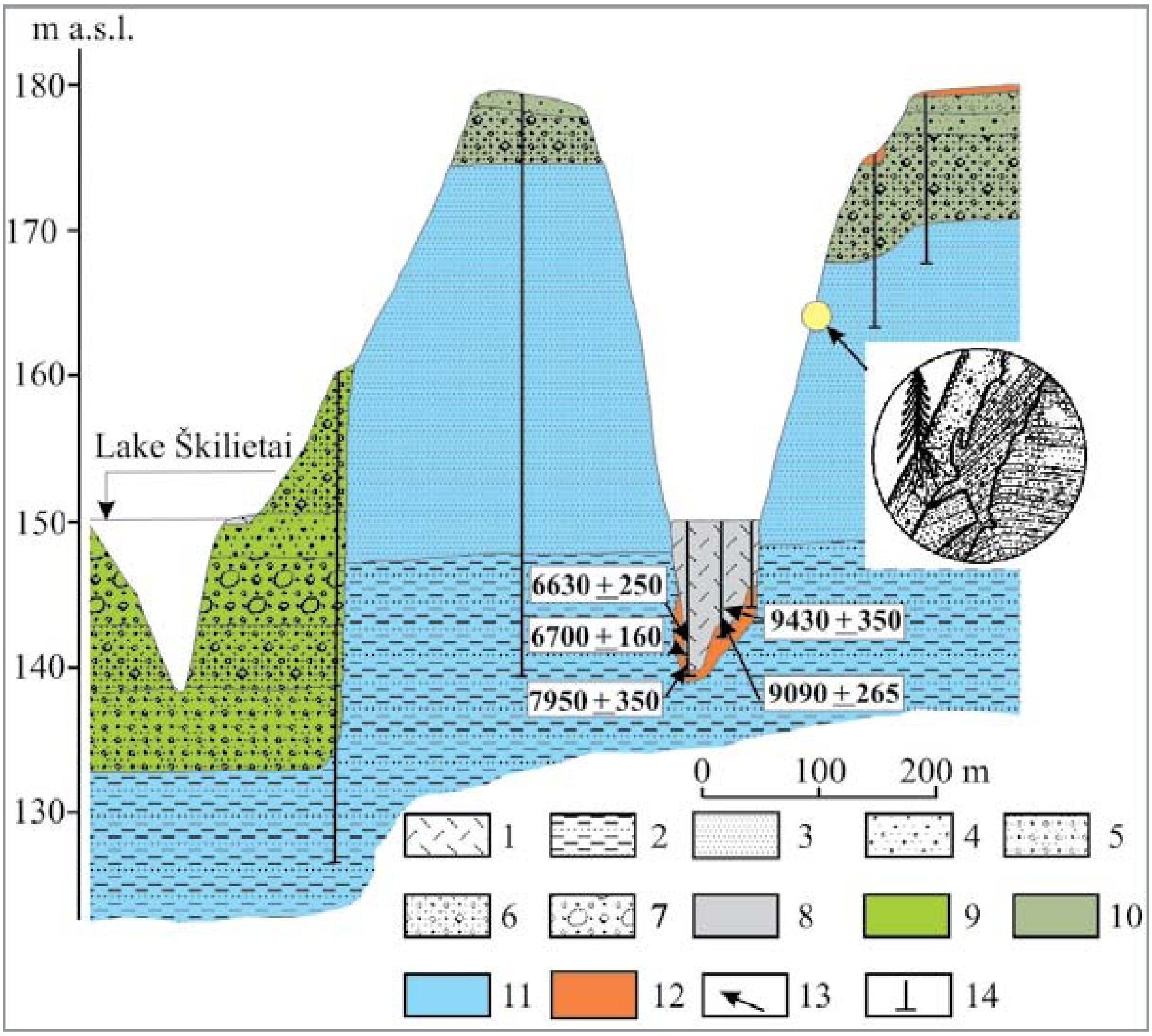

Fig. 2. Geological cross-section of the Devil's Hole (according to Baltrūnas and Karmaza, 2007):

1 – peat;
2 – silty sand;
3 – fine-grained sand;
4 – medium- and coarse-grained sand;
5 – coarse-grained sand with gravel;
6 – gravely sand;
7 – gravel origin of the sediments;
8 – organic;
9 – glaciofluvial (proglacial);
10 – glaciofluvial (intraglacial);
11 – glaciolacustrine sediments;
12 – problematic genesis;
13 – sampling points for radiocarbon (14C) analysis;
14 – borehole

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Stop 10

THE GREAT NEMUNAS LOOPS: A MORPHOTECTONIC PATTERN

Jonas Satkūnas, *Lithuanian Geological Survey*

The regional park of the Great Nemunas Loops was established in 1992 for protection of landscape, cultural and biological values of unique pattern of meanders of the Nemunas valley.

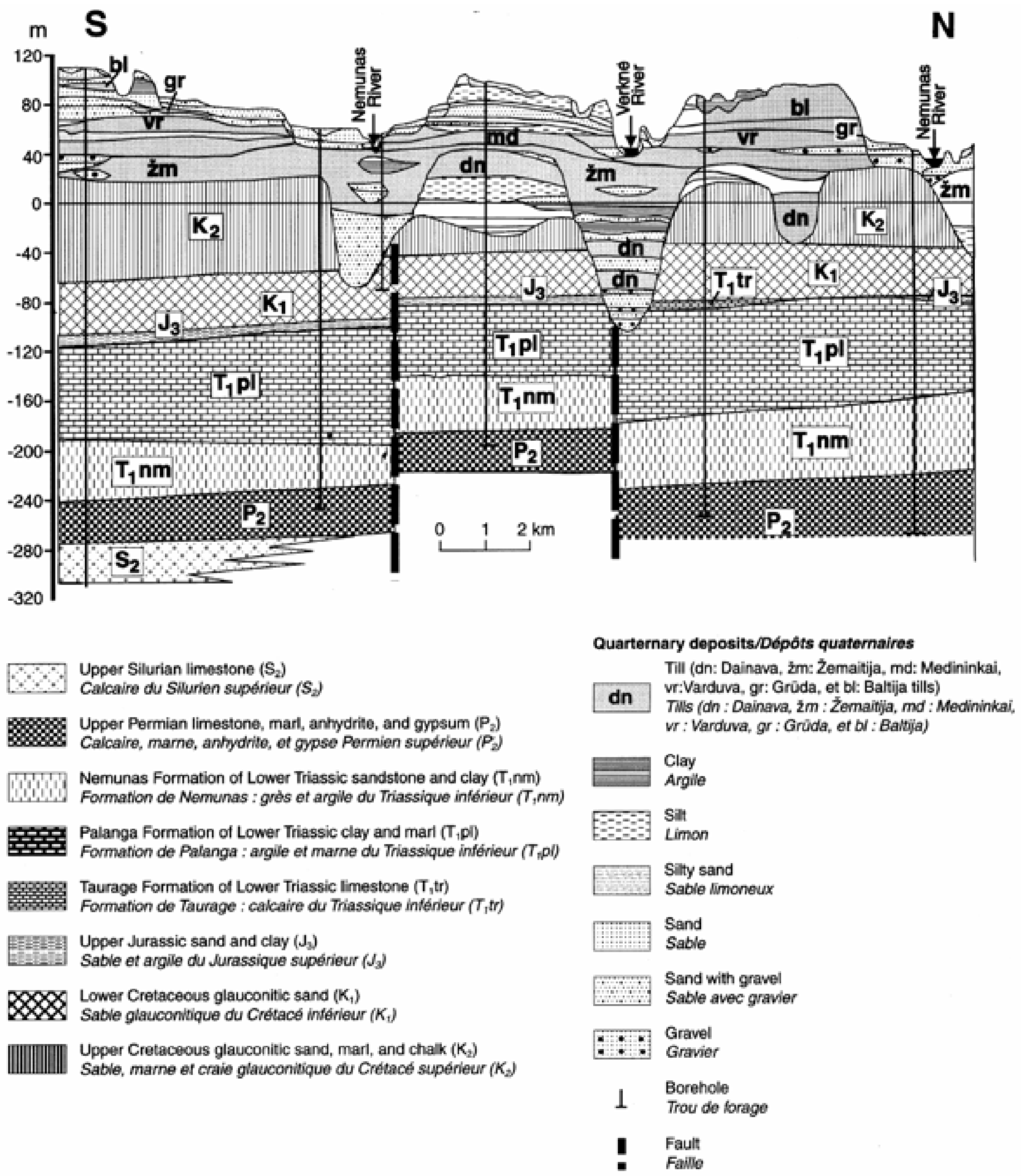

Fig. 1. Geological cross-section of the the Great Nemunas Loops (Baltrūnas et al., 2005)

The Nemunas River, one of the largest rivers of the Baltic region, is characterised by a generally straight valley. In the middle part of its course the Great Nemunas Loops are distinct feature that occupies an area of 320 km^2 near the Birštonas resort. The Nemunas valley here is 1.5–5 km wide and 45–80 m deep. The loops are cut into a glaciolacustrine plain. To the north from the Loops there are glacial and deltaic complexes formed during the Last glaciation (Baltrūnas et al., 2005).

The data on geology, tectonics, geomorphology and paleogeography of the Great Nemunas Loops was collected during the geological and geophysical mapping at a scale of 1:50 000 carried out in the 1970s. The numerous fresh and mineral-water supply boreholes provided information on the Quaternary and sub-Quaternary geology. The stratigraphy and tectonic pattern of the sedimentary succession was reconstructed from the deep (800 m) well drilled to the crystalline basement, 15 geological mapping wells 200–400 m deep (down to the Permian and Silurian), and several hundred hydrogeological wells.

The tectonic control the looping of the Nemunas River. It was proposed that tectonic deformations in the sedimentary cover are related to the block tectonics of the underlying crystalline basement (Šliaupa and Popov, 1998). The gravity and magnetic maps (scale of 1:50 000 and 1:200 000) were used to identify tectonic elements of the crystalline basement that occurs at a depth of 800–900 m.

The role of tectonics is implied from hydrogeochemical anomalies related to the faults cutting the crystalline basement and the sedimentary cover. Birštonas is known as a mineral water resort since 1846. The mineral water springs and high salinity anomalies are mapped in the Quaternary, Cretaceous, and Jurassic aquifers and are related with penetration of the Upper Permian saline water across 150 m thick Lower Triassic shales and 35 m thick Upper Permian anhydrites. It can be explained by presence of a fractured system crossing the sedimentary cover and underlying basement rocks.

Despite their small magnitudes, the neotectonic structures within the depression significantly influenced the glacial and meltwater sedimentation (hence, the topography) that controlled the geometry of the Nemunas valley. The inspection of the drill cores revealed the inheritance of the Nemunas valley from underlying paleovalleys of Eemian and Holsteinian Interglacials (Baltrūnas et al., 2005).

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WEATHERING CRUST OF THE MERKINĖ INTERGLACIAL

Jonas Satkūnas *(according to Valentinas Baltrūnas (2002)*

This particular phenomena was investigated by Baltrūnas (2002) in the Alovė Outcrop near the Alytus town, in outcrops of the Nemunas River at Škėvonys and Siponys (Birštonas environs) and also in sections No 307 (Kisieliškės) and No 357 (Margionys) drillings. The thickness of the interglacial weathering crust, formed on brown hard till, reaches up to 2–3 m, sometimes 5 m. In the weathering profile along with zones of intensive weathering and oxidation there are also parent rocks. In the zone of intensive weathering, the changes of colour from reddish brown in the lower part to bright yellow in the upper part, increased arenosity with secondary concretions of carbonates are observed.

A grain-size analysis of the weathering crust shows that the till changes from loam to sandy loam and sand upwards. In the profile, the content of clay particles slightly decreases and that of sand and gravel increases. A comparison of correlative bonds (CB) of grain-size fractions in the weathered and non-weathered till shows that the positive CB between fractions of sand and fine gravel disintegrates. In the fraction 0.1–0.05 mm of the weathering crust the content of quartz, garnet, iron oxides and hydroxides slightly increases upwards, whereas the content of potassium feldspars, carbonates, pyrite and other less resistant minerals decreases. The content of hornblende changes quite differently in different sections. In the weathered till, the positive and the negative CB between dolomite and other minerals appear.

The chemical analysis (determination of oxides) shows that in the fraction less than 1mm the content of SiO_2 increases upwards, while of Al_2O_3 and CaO decreases. The distribution of microelements is peculiar to the weathering crust, too. In the outcrops upwards, though unevenly, the content of Cu, Zr and the values of the Mn/V, Zr/Cu, Zr/B, Zr/Ni ratios increases, while the content of Ti, Cr, Ni, V, B, Sc and the Mn/Cu, Ti/Cu, Ti/Zr ratios decreases. The CB is also peculiar to the weathering crusts. For example, Mn and Pb lose positive CB with Ti, Cr, Ni, V, but their positive CB with Cu and Yb appear.

The investigated and described weathering crust of the the Merkinė (Eemian) Interglacial is of great stratigraphical (as a sign of marking layer) and palaeomorphological (as a sign of wide-spread plain relief) significance. The following identification signs of the weathering crust may be distinguished: 1, gradual change of composition upwards; 2, washing, infiltration and oxidation traces; 3, areal persistence; 4, normal mode of occurrence. These four identification signs of weathering crust are applied in practice for description and stratigraphical subdivision of Pleistocene deposits.

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Stop 11

ŠKĖVONYS OUTCROP

Jonas Satkūnas, *Lithuanian Geological Survey*

The Škėvonys Outcrop (33 m high) exposes tills of Upper and Middle Pleistocene The boundary of Upper and Middle Pleistocene is marked by weathering crust (Fig. 1). The outcrop is composed by Weichselian tills (from top to 5.1 m); glaciofluvial sand and gravel (5.1–8.2 m); till (8.2–10.1 m) sand and gravel (10.1–14.7 m); tills with sandy interlayers (14.7–25.25 m); varved clay (25.25–25.4 m) with gravel in lower contact; Saalian (Medininkai) till (25.4–30.7 m) which upper part is weathered.

Fig. 1. Weathering crust of the Medininkai till in the Škėvonys Outcrop (photo V. Baltrūnas, 2009)

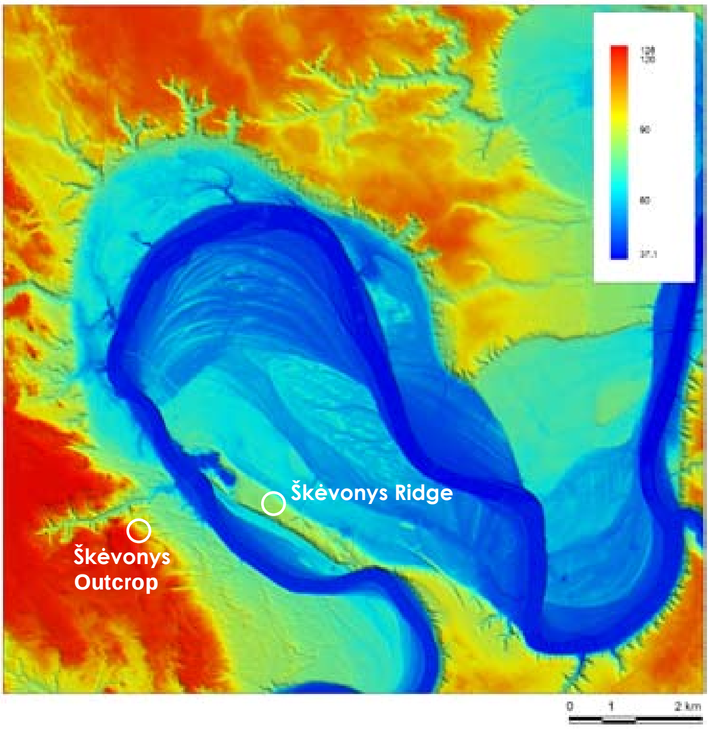

Fig. 2. Lidar topography of the Nemunas River Prienai Loop (compiled by V. Minkevičius)

The Škėvonys Outcrop is the monument of natural heritage and is located in the Škėvonys Geomorphological Reserve which main feature is unique erosional Škėvonys ridge formed by Nemunas River.

Stop 12

BALBIERIŠKIS OUTCROP

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Balbieriškis Outcrop is located on the left bank of the Nemunas River, about 0.5 km north of Balbieriškis town at an elevation of 92 m a.s.l. The relative height is about 40 m (Karmaza, Baltrūnas, 2001).

Topmost part (0–8.2 m) of the outcrop is composed of laminated clay. The studies of the glaciolacustrine laminated sediments were carried out by several researches (Mikaila, 1958, 1959; Gudelis, Mikaila, 1960; Kazakauskas, Gaigalas, 2000, 2004; Gaigalas, Uchman, 2004; Uchman et al., 2008).

Laminated clay bed (0–8.2 m) was formed in proglacial lake dammed near the margin of the receding ice sheet of the Baltija (Pomeranian) stage of the Last Glaciation (Nemunas, Weichselian). According to the lithology and character of lamination the profile can be subdivided into four units of laminated varved sediments (Kazakauskas, Gaigalas, 2004).

Glaciolacustrine clay of unit I is above the lodgement till (Fig. 1) at a depth of 8.3–6.3 m. Varves are commonly 1.4–3.4 cm thick with prevailing winter layers composed of dark brown clay and summer layers composed of coarse calcareous silt with clasts of till material. Winter layers are 0.1–6.1 cm thick (with 0.8–2.9 cm dominating) and summer layers are 0.1–6.8 cm thick (0.2–0.5 cm dominating). The thickest winter layers are bedding in the lower part of this unit. Glaciolacustrine sediments in the upper part (at a depth of 7.3–6.3 m) are disturbed by cryogenic processes.

In the second unit (at a depth of 6.3–3.9 m, Fig. 1), varves become thicker and range up to 13 cm in places. Summer layers (up to 6.0 cm thick) are composed of light yellowish brown calcareous silt and sand (with till clasts in some places) and winter layers (up to 7.4 cm thick) are composed of brown clay. In the lower part of the unit (at a depth of 6.3–5.8 m) the laminated sediments are more clayey, but upwards become siltier. The varves' differentiation becomes more expressed, and subseasonal lamination is visible in both its summer and winter layers.

In the third (III) unit (at a depth of 3.9–1.9 m) the clay becomes more homogeneous. In the lower part of the unit (at a depth of 3.9–3.4 m) varves are 0.1–4 cm thick with prevailing winter layers composed of dark brown clay and summer layers composed of yellowish brown calcareous silt. Winter layers are 0.1–4.1 cm thick and summer layers are 0.1–0.6 cm thick. The upper part of unit III (at a depth of 3.4–1.9 m) is represented by the thick (1.5 m) bed of dark brown homogeneous clay without visible lamination.

The fourth unit (IV) is represented by varved sediments with distinct lamination. Varves decrease in thickness upwards towards a bed of melt–out till (deposits at a depth of 0.5–0.3 m). In the lower part of unit IV (at a depth of 1.9–0.8 m) varves are commonly 1–3 cm thick but range up to 18 cm in places. Winter layers (0.2–17.9 cm thick) are composed of dark brown clay and summer layers (0.1–3.6 cm thick) are composed of yellowish brown calcareous silt. In the upper part (at a depth of 0.8–0.5 m) varves become thinner; they are generally 0.8–1 cm thick.

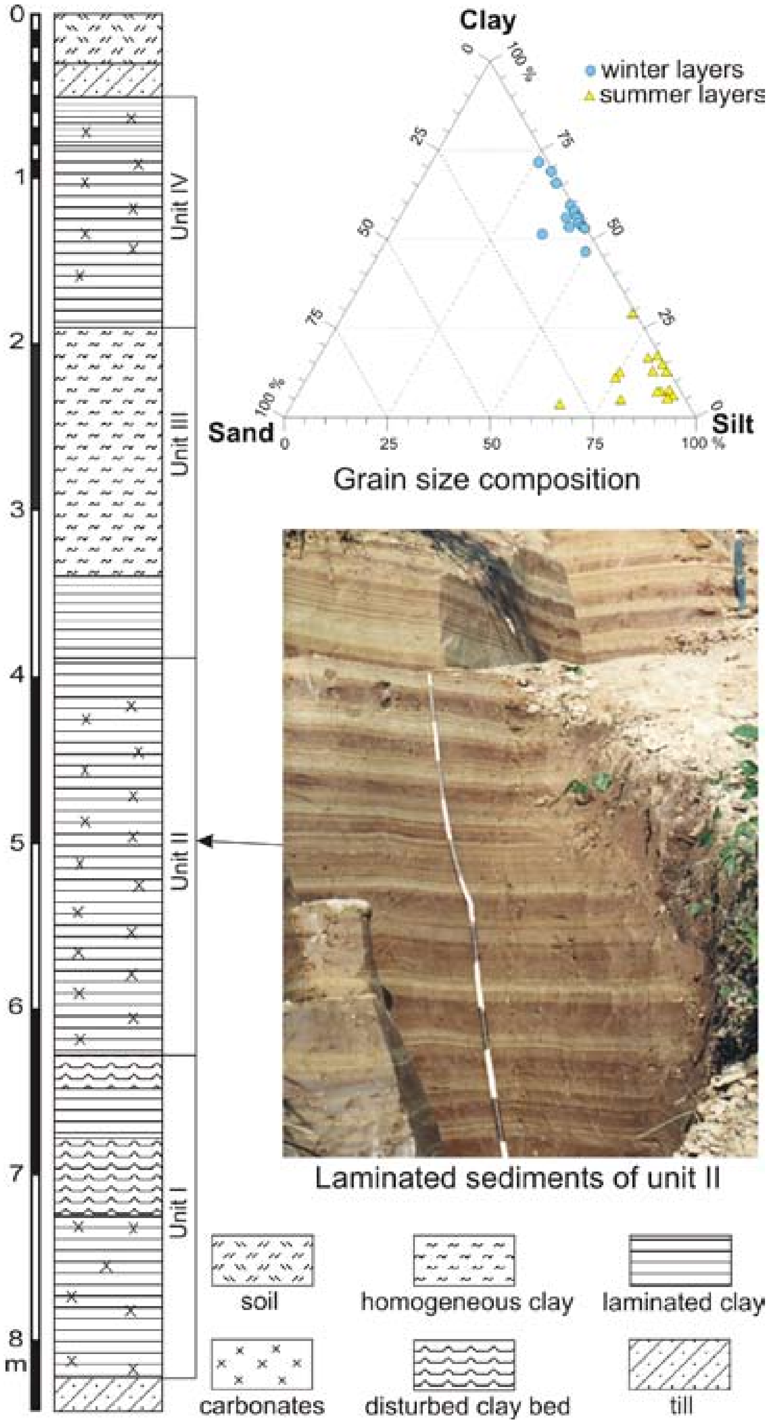

Fig. 1. Laminated clay section (0–8.2 m) of Balbieriškis Outcrop (after Kazakauskas, Gaigalas, 2004)

The differences between the summer and winter layer particle size composition of Balbieriškis section is shown in diagram (Fig. 1).

During the ichnological investigation of the section carried out in 2004 and 2008 (Gaigalas, Uchman, 2004; Uchman et al., 2008) the occurrences of trace fossils *Cochlichnus, Helminthoidichnites, Gordia, Glaciichnium* and curved ridges were found (in units I and II). Alteration of colonized (with trace fossils) and non-colonized packages of lamina indicates oscillations of ecological conditions, which can be related to the short-term climatic fluctuations. Laminated clay bearing trace fossils can indicate the warmer climatic periods related to the interphasials or interoscilations of the Baltija stage of the Nemunas Glaciation (Uchman et al., 2008).

The lowermost part of the outcrop was studied in the exposure located about 200 m to the south from the section described above. The brown, dark brown till (Fig. 2, depth 2.0–7.1 m) of the Baltija (Pomeranian) stage of the Late Nemunas (Weichselian, Würm) Glaciation lies below the laminated clay. The 5 m thick till bed is macroscopically homogeneous and contains relatively small amount of Permian limestone. The orientation and dip of the long axes of pebbles show vertical variations through the till section (Fig. 2). The preferred orientation of the long axes of pebbles in the lower part of the till bed (*ca.* 1 m thick) is dominantly E–W, although the dips may be to either E or W. The middle part of the till bed (1–2 m thick) is characterized by very weakly developed preferred, or random, orientation of the long axes. A well developed preferred orientation and dip to the S and SE was measured in the upper part of the till bed, although at the top of the till bed it again shows a more random character (Baltrūnas et al., 2005).

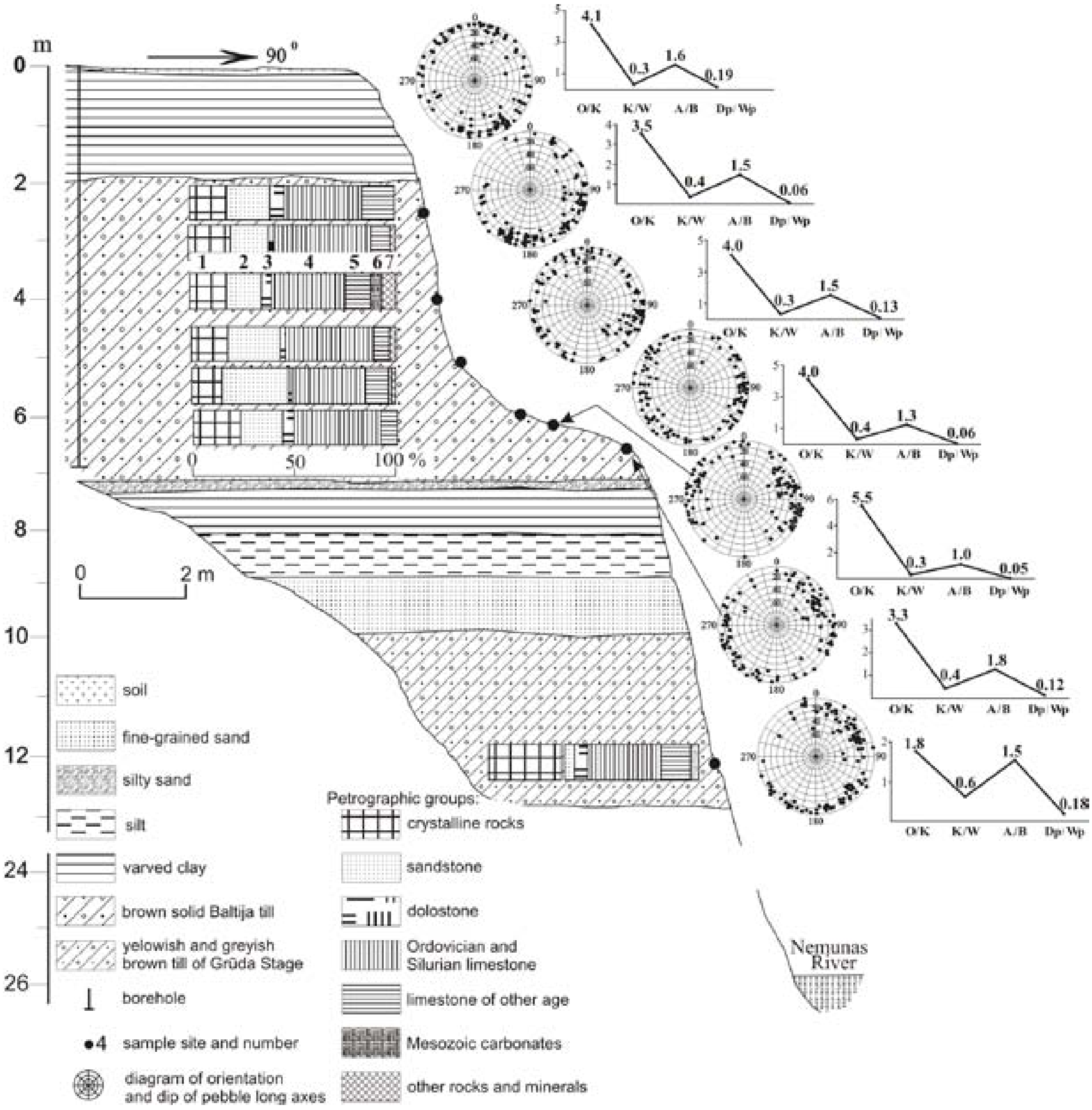

Fig. 2. Glacigenic deposit sequence in the Balbieriškis exposure (200 m to S from the section described in the Fig. 1). Petrographic coefficients: O/K – total of sedimentary rocks/total of crystalline rocks and northern quartz; K/W – total of crystalline rocks and northern quartz/total of limestones and dolomites; A/B – total of rocks non-resistant to destruction/total resistant rocks; Dp/Wp – dolomites/Ordovician and Silurian limestones (after Baltrūnas et al., 2005)

The petrographic composition of gravel and pebbles is generally uniform throughout the till bed, although it differs strongly from the underlying more weathered till of the Grūda (Brandenburg) Stage, the maximal stage of Nemunas (Weichselian) Glaciation (Baltrūnas et al., 2005).

Below the till (Fig. 2, depth 7.1–8.0 m) the layer of glaciolacustrine sediments – varved clay is observed. Varved clay consists of dark brown clay (winter) and grey silt (summer) layers. The thickness of clay layers is 4–5 cm and they prevail at the bottom of the interval. Silty layers are 8–10 cm thick and they prevail in the upper part. Varved clay turns to laminated sand (dark yellow and light yellow fine grained sand, lamina 3–5 cm thick) at the top of the interval. In this laminated clay section, only three parting surfaces of varves with ichnofossils (*Cochlichnus, Helminthoidichnites* and *Glaciichnium*) were found (Uchman et al., 2008).

At the 8.0–8.9 m depth (Fig. 2) grey, bluish grey silt occurs, which deposition is related to the proglacial lake existing during the interstadial. The silt is micro-laminated in the lower part of the layer.

The interval 8.9–10.0 m (Fig. 2) is composed of yellow, fine grained, wellsorted, cross bedded and wavy laminated sand, which was formed as a result of glaciofluvial processes of retreating ice.

The brownish-grey and greyish-brown till (Fig. 2, bellow the 10.0 m) were deposited during the Grūda (Brandenburg) stage of the Last Glaciation. Relatively small amount of dolostone and more significant amount of Ordovician and Silurian limestone pebbles is characteristic for this till. In most cases orientation of long axes of pebbles is NW-SE. It means that the ice advancing direction was NW-SE and limestone was probably brought from the Baltic Sea bottom. At the lower part of the till the numerous lenses (from 1–2 cm till 40 cm thickness) of yellow various grained sand have been found.

In the lowermost part of the outcrop the till of Medininkai (Saalian, Riss) Glaciation occur. The till is brown and contains 30–40 % pebbles of dolostone which were brought from the northern part of Lithuania, where Devonian dolostone occurs near the surface. North-south direction of the ice advance confirms orientation of long axes of pebbles.

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Stop 13

ALOVĖ OUTCROP

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The outcrop is approx. 23 m high. The outcrop is interesting due to occurrence of unique 4 m thick weathering crust formed during the Merkinė Interglacial (Fig. 1).

Fig. 1. Alovė Outcrop (photo V. Baltrūnas, 2009)

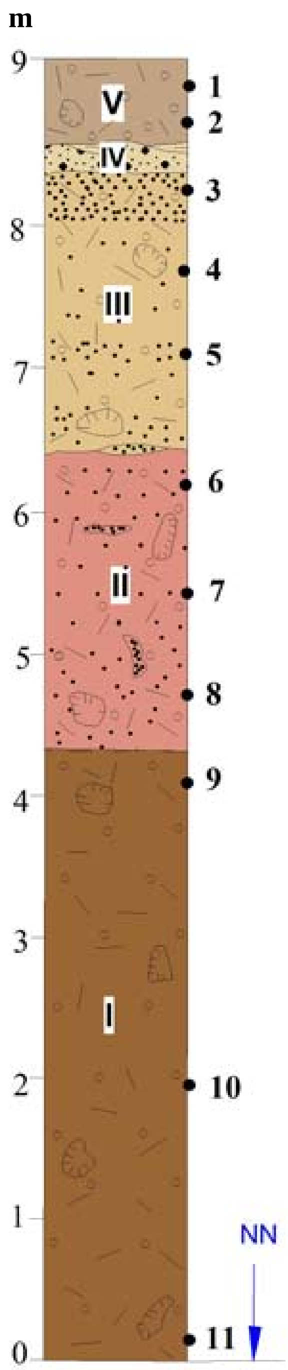

Fig. 2. Fragment of Alovė Outcrop section, showing the weathering crust (II) of the Merkinė Interglacial: I – Medininkai till, III, V – Late Nemunas tills, separated by thin layer of sandy gravel (IV). 1–11, samples sites (Baltrūnas, 2002)

According to A. Gaigalas, the crust occurs at depth of 10.9–14.9 m from top and is formed in the Medininkai till (hard brown clayey loam). The crust is covered by Upper Pleistocene till.

According to Baltrūnas (2002) the weathering crust occurs some 5 m above the water level in the Alovėlė rivulet (Fig. 2).

Table 1. Changes of microelement (g/t) in fraction less than 1 mm and of values of ratios in weathering crust profile of Merkinė Interglacial in Alovė Outcrop (Alytus district) (Baltrūnas, 2002)

No.of sample	Cu	Pb	Ti	Mn	Cr	Ni	V	Zr	B
1	24	22	3000	580	72	16	87	230	42
2	35	29	2600	850	78	19	100	230	52
3	12	13	1500	500	21	5	25	290	20
4	10	13	1500	560	22	4	28	290	30
5	14	13	1500	680	29	6	30	230	30
6	17	13	1800	700	35	7	45	230	35
7	18	13	1700	660	33	6	48	250	33
8	11	11	1600	600	28	5	40	210	40
9	8	8	1500	470	19	4	33	190	42
10	12	11	1400	700	24	6	35	230	40
11	8	15	1800	900	35	7	45	210	34

No. of sample	Yb	Sc	Mn/Cu	Mn/V	Zr/Cu	Cr/B	Ti/Zr	Mn/N	Zr/Ni
1	2.1	12	24	6.6	9.6	5.5	13	36	14.4
2	2.0	15	24	8.5	6.6	4.4	11.3	45	12.1
3	1.2	7	42	20	24.1	14.5	5.2	100	58
4	4.0	7	56	20	29	9.6	5.2	140	72
5	1.5	14	49	22.6	16.4	7.6	6.5	113	38
6	1.2	11	41	15.5	13.5	6.6	7.8	100	33
7	1.5	12	36	13.3	13.9	7.6	6.8	110	42
8	1.2	10	54	15	19.1	5.2	7.6	120	42
9	1.0	10	59	14.2	23.7	4.5	7.9	117	47
10	1.5	13	58	20	19.1	5.7	6.1	116	38
11	1.5	12	112	20	26.2	6.2	8.6	129	30

Stop 14

PUNIA HILL FORT

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Hill forts or strongholds are the most fascinating and visually best known archaeological monuments in Lithuania. The hill forts originated in Europe at the Bronze and the general knowledge about Lithuanian hill forts gives understanding that these fortified hills were used as the society dwelling place since the beginning of the Late Bronze Age as well. The importance of these sites especially increased in the 1st millennium AD, and they didn't lose their importance till the end of the 14th c. when mostly of them were burned down during fights with Livonian and Teutonic Orders, or just abandoned due to the changing political and economical situation. Though the total number of hill forts representing the different stages of the Iron Age and later intervals approaches 993 in the territory of Lithuania, however more or less extensive archaeological excavations were conducted at 184 hill-forts until 2005. The single Šeiminiškėliai hill fort (eastern Lithuania) was fully investigated.

Fig. 1. Punia hill fort

The Punia hill fort (Fig. 1), also named Margio Kalnas, with a high-powered fortification system and foot settlement is one of the most spectacular strongholds in southern Lithuania. Situated in Alytus district (54°30′43″N 24°05′25″E) this archaeological monument is surrounded by Nemunas and Punelė rivers from three sides. The plateau of Punia hill-fort is east-west orientated, three angular-shaped reaching a size of about 155 by 85 metres and covering an area of about 1 ha. Even now, the main eastern rampart of the hill fort is 75 metres long, 6 metres high and 30 metres wide at its base. The stronghold has an external ditch over the eastern rampart. The height difference between the hill fort plateau and it's basement varies from 36 to 44 m, the slopes are still steep. Both Nemunas and Punelė rivers used to flow fairly close to the plateau base and the big part of the hill fort was eroded due to this reason. Situated eastward from the hill fort the foot settlement covers an area of about 3 ha.

Archaeological data i.e. pottery shards with smooth surface suggests the initial population of the hill fort and surroundings during the first millennium BC. Both the archaeological information and the historical documents, including written sources, suggest three stages in the history of the Punia stronghold: the end of the 13th c. – 14th c., 15th c. – beginning of 16th c. and the end of 16th c. – 17th c. AD. Construction of the hill fort started in the second half of 13th c. when wooden castle surrounded by powerful rampart-trench system was build. Punia stronghold have played an important role as military centre during the Teutonic onslaughts as during the 13th – 15th c. Livonian and Teutonic Orders directed a series of military campaigns against The Great Duchy of Lithuania with the aim of expansion of Christianity in the region. In 1382 AD surroundings of Punia (terra Punow) were referred in the written sources for the first time. At the same time region and castle were attacked and devastated by the Teutonic army. Whereas archaeological and palaeobotanical data suggest the earliest attacks of this castle taken place in the first half of 14th c. even. After everyone attack Punia castle was rebuild and being situated in the eastern outskirts of the The Great Duchy of Lithuania became on of the most important and strongest forepost during the Teutonic onslaughts. In 1387 and 1414 AD Punia castle was mentioned in historical documents as estate of Lithuanian Grand Duke. Obviously, military importance of this site was also accompanied by trading and other economic activities as remains of luxury articles i.e. coins of Roman Empire have been discovered during the archaeological excavations. Beside that Punia was important religious centre in this part of the state as the first church was erected here between 1425–1430 AD.

After 1410 AD, when the military might of the Order was destroyed at Battle of Žalgiris (Battle of Tannenberg or Grunwald), Punia became important manor of Lithuanian sovereigns. Not latter then in the first half of the 16th c. former castle was re-arranged to comfortable palace which was often visited by the Grand Duke and state nobility, foreign quests. Notability of this place had positively influenced the development of the Punia township i.e. city rights was ensured for Punia in 1503 AD. Also, according to the historical sources, Punia was multinationational township as together with the Lithuanians and the Polish, Jews and Tatars settled here. In 1513 AD the parish school was opened in Punia. If 17th c. could be identified as a time of Punia prospering, in 18th c. remarkable decline of the site started. During the Great Northern War (1700 – 1721 AD) palace and township were plundered and burned down. Later the bubonic plaque started…. In 1738 AD only 38 families were indicated as living in the site. Punia's glory was gone.

Stop 15

THE NETIESOS OUTCROP: EEMIAN-WEICHSELIAN SEQUENCE

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The Netiesos Outcrop is situated in southern Lithuania on the right bank of the Nemunas River approximately 6 km downstream from the town of Merkinė (Fig. 1). Quaternary sediments of Saalian (Medininkai), Eemian (Merkinė) and Weichselian (Nemunas) age are represented in the outcrop and reach more than 20 m thick (Fig. 2).

Quaternary deposits of the Netiesos environ at 20–40 m a.s.l. lye on the Upper Cretaceous chalk formation and their thickness reaches 60–70 m. The interglacial palaeolake sediments were found in the palaeoincision filled by glaciolacustrine sediments from the depression in the middle Pleistocene Medininkai till and are shaped like a lens with varying thickness up to 6 m. Sediments are rich in organic matter and covered by lower and middle Weichselian glaciolacustrine and upper Weichselian glaciofluvial layers of very fine sands (Fig. 3).

Sections representing uninterrupted sedimentation during the last interglacial-glacial cycle are rare, so they are of great significance for studies of environment changes during the late Pleistocene. Recently the new geochemical, palaeontological (plant macro-remain, diatom, fishbones), geochronological and magnetic susceptibility investigations of the section have been carried out (Baltrūnas et al., 2013).

Palaeobotanical investigations. According to the palaeobotanical (pollen, plant macro-remain, diatom) studies development of the lake began in the late glacial phase and continued up to the end of the optimal phase of the Merkinė interglacial. Most likely the sedimentation occurred in the sublittoral zone of the lake (Kondratienė, 1996; Velichkevich et al., 1999; Baltrūnas et al., 2013).

The silt at the lowermost part of the section is predominated by aquatic plants with temperate and cold-resistant species. Terrestrial vegetation was mosaic with forest islands in the tundra environment. Among trees coniferous species, mostly *Pinus*, and *Betula* are dominant. This floristic complex is typical of the late glacial time that preceded the Merkinė interglacial (Md; N1 zones).

The transition from the late glacial complex to the interglacial is clearly fixed, as recorded by the change in the flora composition. The presence of thermophilic plants indicates the starting process of the eutrophication of palaeobasin and well-developed shore vegetation. A pollen spectrum of this interval is more diverse in species composition. *Picea* is replaced by *Pinus* and *Betula*, where *Pinus* constitute up to 70%. *Betula nana* vanished from the territory (M1, 2; N1, 2 zones).

The most favourable conditions for vegetation evolution appear during the accumulation of gyttja and peat layers. According to pollen composition three subzones of the climatic optimum of the interglacial are identified. The first one is characterised by spread of *Quercus* (58%) and *Ulmus* forests. At the beginning of the zone *Pinus* was numerous and makes approximately 30% from the trees and

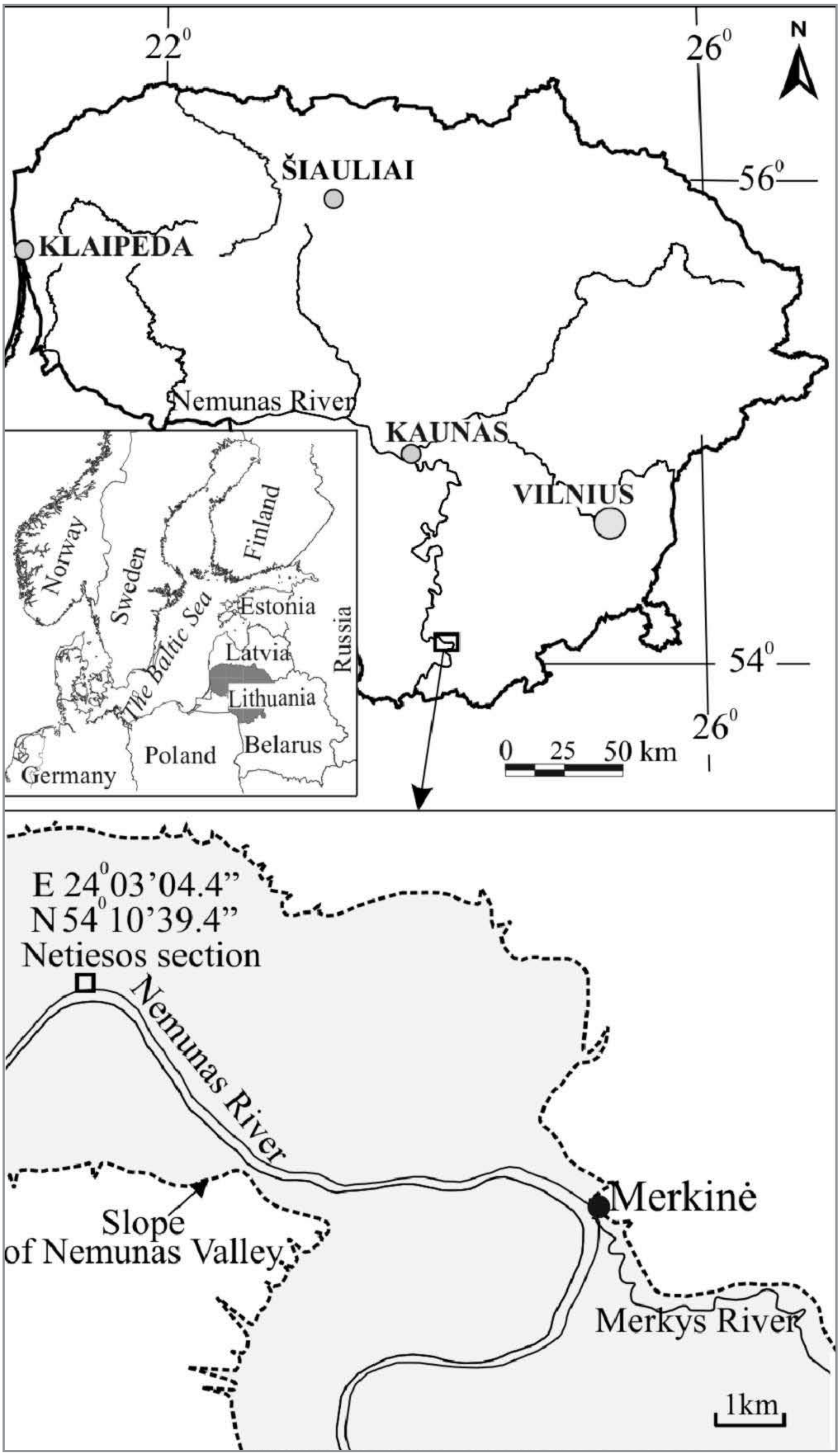

Fig. 1. Location of the investigated site

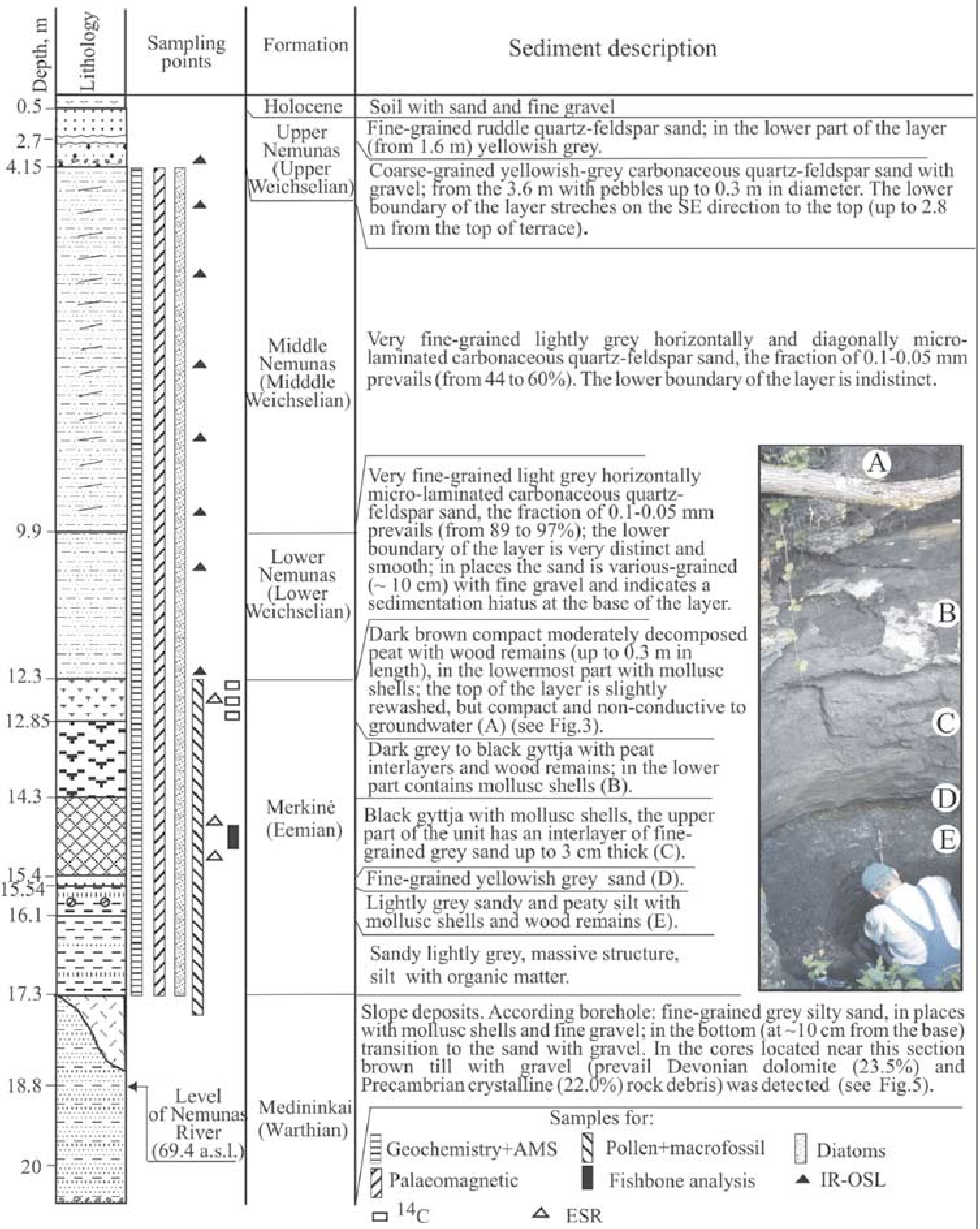

Fig. 2. Lithological description of the Netiesos section

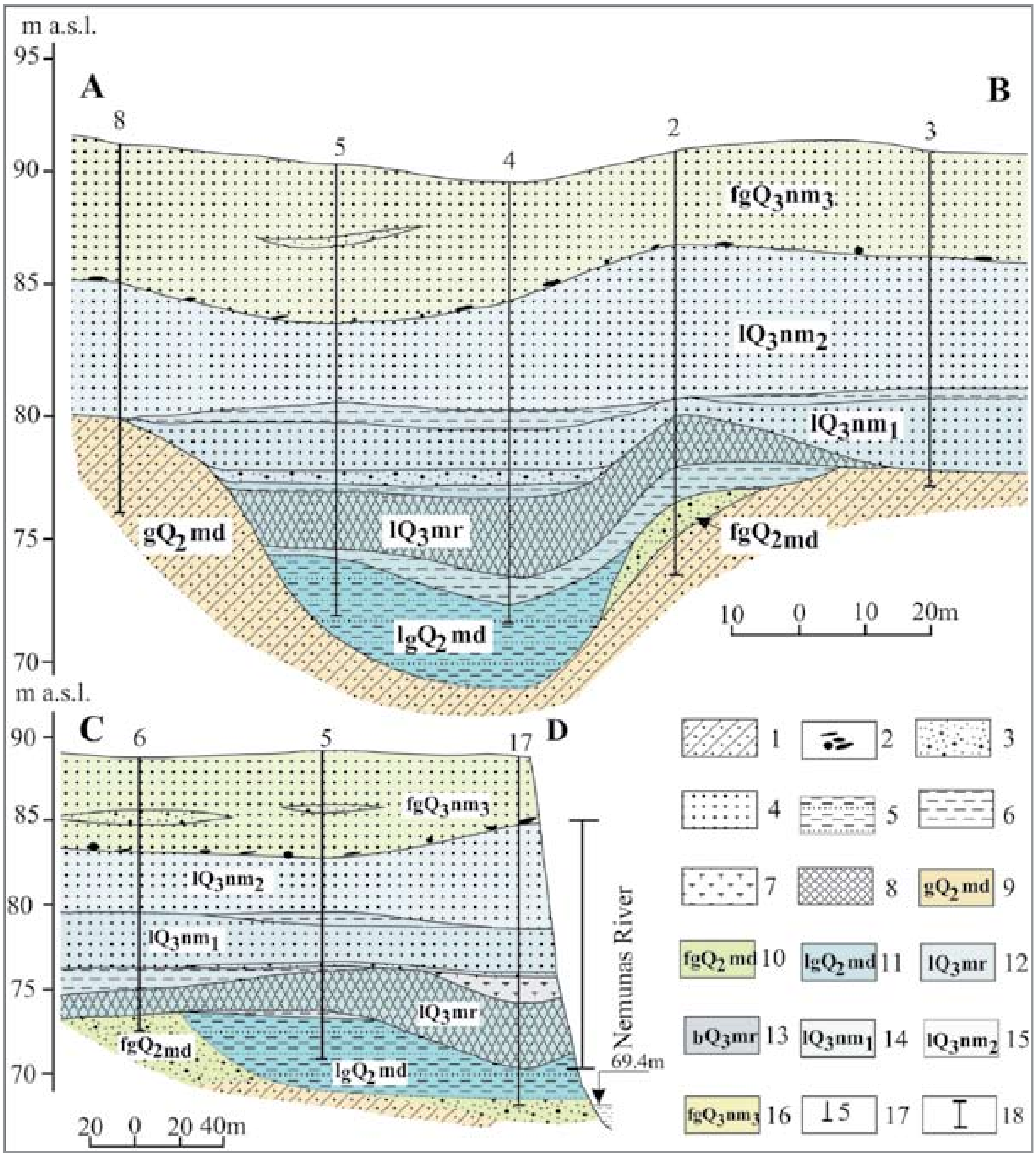

Fig. 3. Cross-section of the upper part of the late Pleistocene thickness in the Netiesos environs

1 – till;
2 – gravel and pebble;
3 – various sand;
4 – very fine-grained sand;
5 – sandy silt;
6 – silt;
7 – peat;
8 – gyttja;
9 – Medininkai till;
10 – glaciofluvial sediments of Medininkai age;
11 – glaciolacustrine sediments of Medininkai age;
12 – Merkinė interglacial lacustrine sediments;
13 – Merkinė interglacial bog sediments;
14 – Lower Nemunas lacustrine sediments;
15 – Middle Nemunas lacustrine sediments;
16 – glaciofluvial sediments of Upper Nemunas age;
17 – borehole;
18 – investigated part of Netiesos section

on the second its half *Corylus* and *Alnus* underwood was common. Deciduous forests with a *Tilia* up to 33% occupied the territory during the second subzone. *Alnus*, *Corylus*, *Quercus* and *Acer* are also presented. The third subzone is described as a spread of *Carpinus* up to 50% and *Picea* forests. *Alnus* was abundant as well (M3a-c zones).

Numerous thermophilic water and terrestrial plant species were present in plant macro-remain composition. The first subzone is characterised by the occurrence of *Tilia tomentosa* and *Vitis vinifera*. The finds of *Tilia platyphyllos*, *Carpinus betulus* and *Cornus sanguinea* characterise the second one. In the third subzone dramatically increased thermophilic plants, especially broad-leaved trees and aquatic ferns (*Salvinia natans*), are present (N3a-c zones). The existence of optimum conditions is proved by flourishing warm water eutrophic diatom species such as *Aulacoseira granulata*, S*tephanodiscus rotula*, *Cymbella ehrenbergii* and others.

The uppermost part of the interglacial sediments is dominated by xeromesophytes (*Urtica, Polygonum, Mentha*) and wetland plants (*Ranunculus, Lysimachia, Lycopus*). The remains of aquatic species decreased. Pollen composition shows the occurrence of *Picea* forests with an admixture of *Carpinus* and *Alnus*, those gradualy were replaced by *Pinus*. This zone also should be attributed to optimal phase of interglacial because of the presences of thermophilic flora plant macro-remains (*Quercus, Corylus, Acer, Tilia, Frangula, Brasenia, Stratiote*) (M4; N4 zones).

Compositional changes of the flora during final stages of the palaeobasin development indicated the lowering of water level and transformation of the eutrophic lake into the bog. It is confirmed by changes in the sediment lithology of the, as well. Deposits from the end of the interglacial may have been destroyed.

Fishbone investigation. The five recorded fish species were not very valuable for the late Pleistocene palaeoecological environmental reconstruction. *Esox, Perca* and *Rutilus* are present in many Central European Eemian assemblages and also in the beds from the transitional glacial periods. They distribution was not strongly influenced by smaller climatic changes. Evidence for this may be the record of these species in the late Weichelian sediments. In contrast, the more thermophilic *Tinca* is an indicator of mid-Eemian climate because it has occurred in Eemian's northern Central Europe contemporaneously with thermophilic European pond turtle *Emys orbicularis*. Furthermore, there is evidence of a late immigration of *Tinca* into northern Central and Eastern Europe during Holocene (Baltrūnas et al., 2013).

The rodent faunal remains were found only in the lowermost part of the Netiesos section and indicate a cold environment (Kalinovski, 1981). The **malacological** investigations of the lower part of the section between lower sand and upper peat revealed a transition from the periglacial mollusc fauna, corresponding to the late glacial stage of the penultimate Medininkai (MIS 6) glaciation, to the faunal composition characteristic of the optimum of the following Merkinė (Eemian) interglacial (Sanko, Gaigalas, 2007).

Parallel geomagnetic and ESR geochronological research capacitates to identify the palaeomagnetic Blake Event in the gyttja at a depth from 15.15 to 15.45 m ESR dated at about 112 ka and could be correlated with the beginning of the thermophilous deciduous forests phase of the last interglacial period (spread of *Quercus,Ulmus, Corylus, Pinus*) (Fig. 4).

Comparison of the magnitudes and distribution pattern of the scores of minerogenic (allogenic), authigenic and biogenic factors determined according to **geochemical data** from 29 chemical elements enabled the distinguishing of 14 depth-related geochemical units (U1–U14), reflecting changes of sedimentation environment from the inherited glaciolacustrine up to eutrophic lake with considerable water level changes (Fig. 5). Geochemical units fit well with depositional episodes revealed by

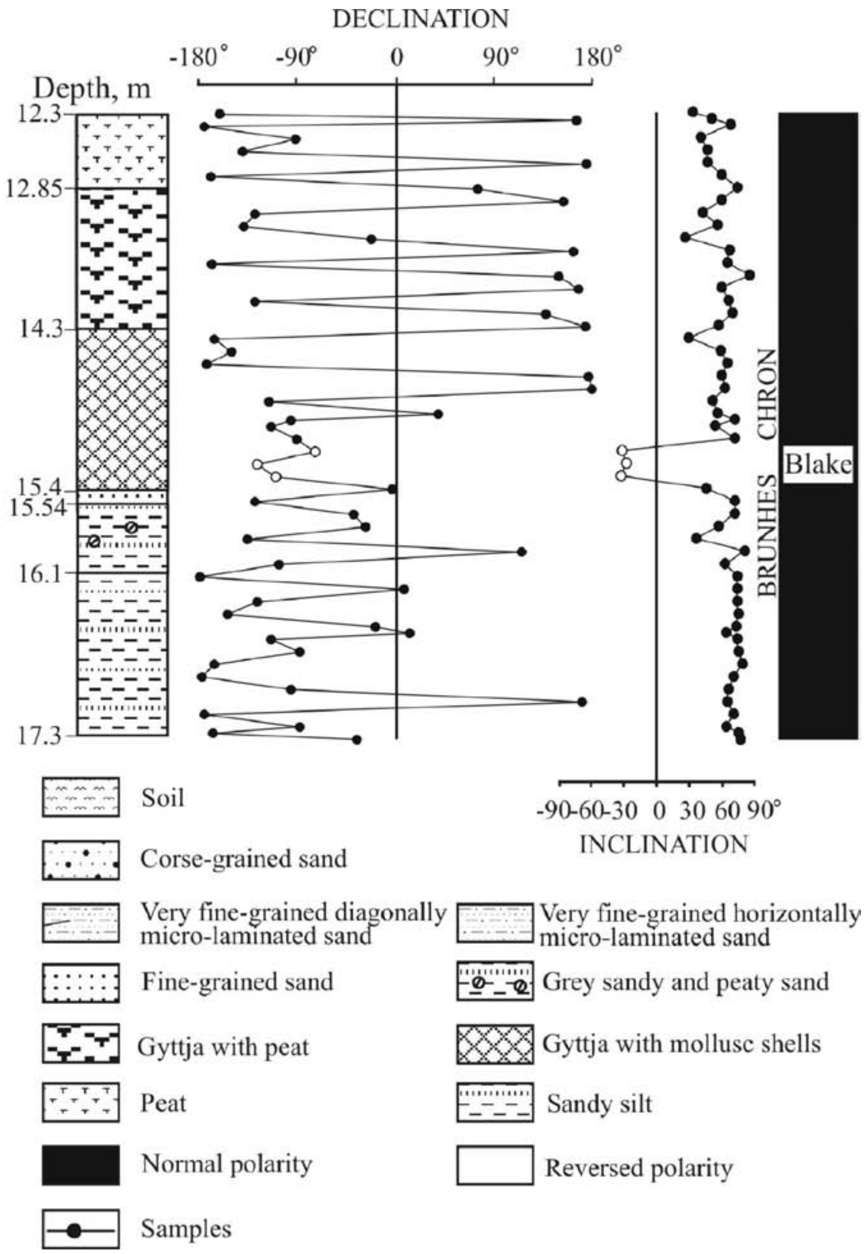

Fig. 4. Magnetic polarity scale from Netiesos section including inclination and declination data

investigation of **magnetic susceptibility** and its **anisotropy.** The boundaries between these units and episodes often coincided with the lithological and palaeobotanical zone boundaries.

The main period of the deposition of authigenic elements was during U1–U3 formation, with the tendency of decrease up to the middle of U8. It could be related to the feeding of palaeolake by hidrocarbonate groundwater which role was decreasing as well. Highly fluctuating during the U2–U11 formation the biogenic elements reached their highest values during the U5–U9 formation. Meanwhile, for the minerogenic elements the main period was during the units UI3–U14 formation (Fig. 4). During the U12 after the decrease of biogenic sedimentation and sharp increase of palaeolake water level, considerably increased the allogenic (minerogenic) sedimentation, meanwhile, during the U13 frac-

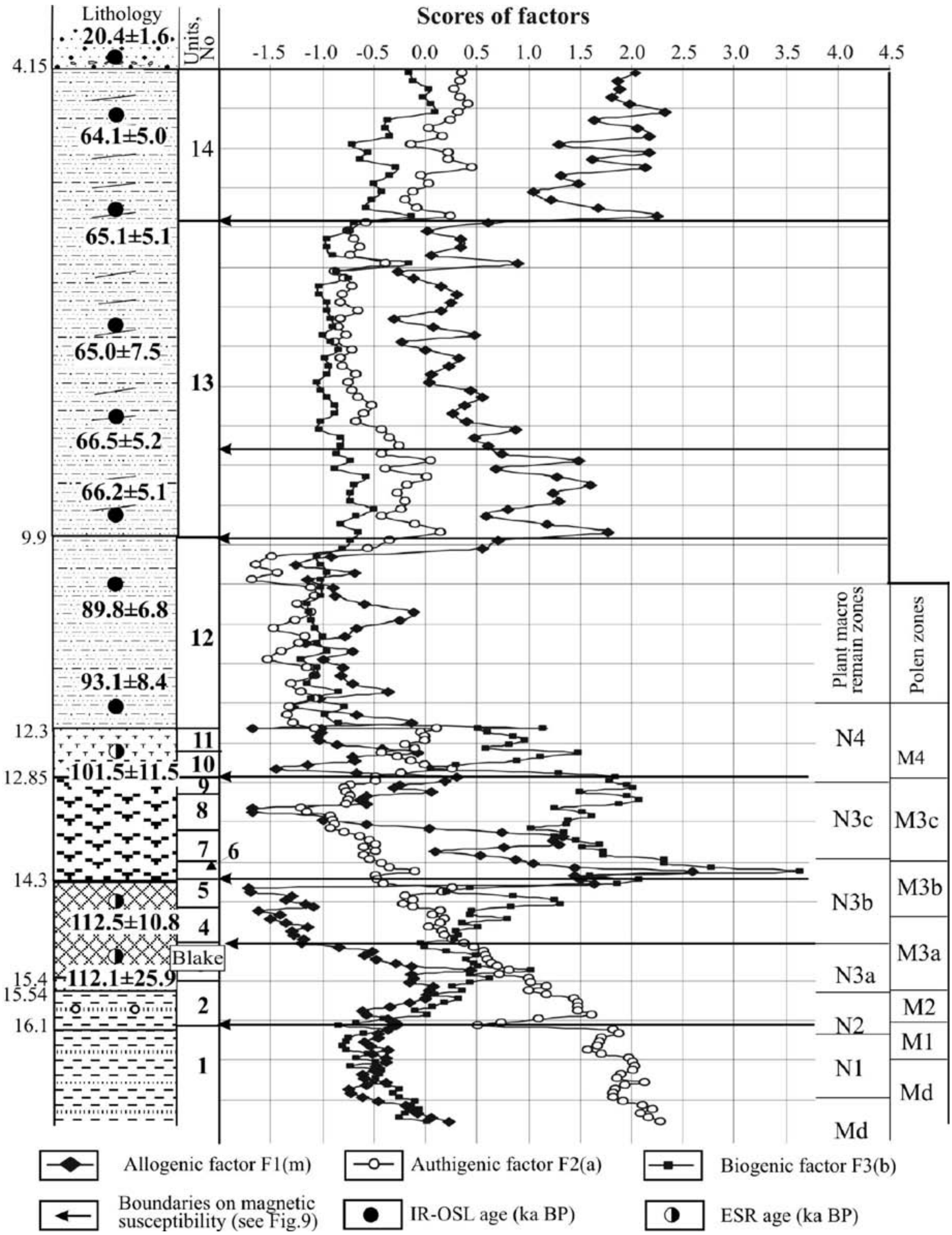

Fig. 5. Summary chart of palaeoenvironmental changes, based on complex data

tionally increased the amount of authigenic material. The primary source of allogenic (minerogenic) and authigenic material could be caused by the rise of the weathering from the Eemian weathering crust because of the cooling of the climate and degradation of the vegetation cover (Baltrūnas, 1995). Those processes intensified since the beginning of U14.

Development of the Netiesos palaeolake began in the late Medininkai glacial (~MIS 6) and continued until the end of deciduous forests phase of the Merkinė interglacial. Sedimentation in this period occurred in the sublittoral zone of the eutrophic lake, which gradually overgrows. Plant macro-remain data obtained demonstrate the development of the terrestrial vegetation from open tundra with coniferous islands typical of the late glacial to broadleaved forests of interglacial times. The palaeoflora of the studied part of the Netiesos section is one of the richest floras of last interglacial period in the East Baltic region, and it contains a high amount of thermophilic species with such unique elements as *Pilea lithuanica* and *Vitis vinifera*.

Temporal position of the thermophilous deciduous forests phase in the second half of MIS 5 coincides with ESR/IR-OSL palaeoclimatic records derived between 145 and 70 ka mostly on directly ESR- and IR-OSL-dated warm climate-related deposits in the climatically highly sensitive Eurasian Arctic palaeo-shelf area.

The data obtained from the fish fauna clearly imply non-glacial conditions in the vicinity of Netiesos during MIS 5d, i.e., approximately 112 ka ago, as was derived from the ESR dating on freshwater mollusc shells from the same horizon. The overlying peat was ESR dated at approximately 102 ka. This result coincides closely with the ages of 108.8±8.7 and 105.7±10.0 ka of the peat that were obtained by U–Th method (Gaigalas el al., 2005a).

The layer of fine-grained sands overlying the peat is sequentially dated by IR-OSL from 93.1±8.4 ka to 89.8±6.8 ka. The upper limit of the sand layer at a depth of 10.2 m is estimated to be 86.7 ka in age. It implies that the layer was formed mainly during the MIS 5c and MIS 5b transition. The deposits from the final phase of MIS 5 are most likely destroyed in the Netiesos section.

According to IR-OSL data, the overlying horizon of fine-grained sands was deposited in the period from approximately 66 to 64 ka, i.e., during the cold MIS 4. No signs of glacigenic deposition were observed within this period in the Netiesos section. Deposits corresponding to initial and final phases of the MIS 4, as well as to the entire MIS 3, are missing in the Netiesos section.

A sample of coarse-grained sands with gravel and pebbles taken in the upper part of the section is IR-OSL dated at 20.4±1.6 ka and implies deposition during the earlier part of MIS 2.

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Stop 16

THE MERKINĖ ARCHAEOLOGICAL SITE AND TOWNSHIP

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The Merkinė archaeological site (54° 9′N, 24° 11′E), consisting of picturesque hill fort, lower castle and foot settlement (Fig. 1), is situated in the outskirts of Merkinė township, Varėna district, southern Lithuania. Mentioned archaeological site stretches at the confluence of Merkys and Nemunas rivers, on the left bank of small Stangė rivulet. Being important military, trade and religious centre of the Great Duchy of Lithuania during the Middle Ages (in Lithuania – end of 14th c. – beginning of 16th c.), presently this place serves as historical and cultural centre in the southern part of the country.

Fig. 1. Merkinė archaeological site

In general, surroundings of Merkinė contains especially rich archaeological heritage. Numerous archaeological sites dated back to the different periods of the Stone Age have been discovered and excavated in the surroundings of Merkinė township confirming colonization of the area during the earliest stages of the post-Glacial. Archaeological context discovered during the extensive excavations carried out in the territory suggests that people representing different Paleolithic cultures e.g. Hamburgian, Bromme-Lyngby, Swiderian, Baltic Magdalenian, Vilnius group, inhabited the territory during the particular intervals of the Lateglacial. All together more then 20 archaeological sites, situated on the terraces of rivers and lakes, have been investigated. Territory has attracted inhabitants during the earliest stages of the Holocene and subsequently artifacts of Mesolithic Kunda, Kudlajevka and Janislawice cultures have been discovered in numerous sites. Furthermore, in numerous sites discovered archaeological context included artifacts of both Palaeolithic and Mesolithic cultures suggesting continuous long-lasted population of the particular areas. Population density in the area decreased with the onset of the Neolithic. This shift may have been coursed both by the environmental changes and introduction of the new type of the subsistence economy, especially during the later stages of the Neolithic. Increasing intensity of the cattle breading and cultivation required rich soils and population moved away from the area under discussion where poor sandy deposits play the leading role in the soil formation. As evidenced by the archaeological data, surroundings of Merkinė were scarcely populated during the Bronze Age as well. Importance of this region as well as Merkinė itself started to increase with the onset of Iron Age. Numerous well-developed archaeological sites, including graveyards, hill forts accompanied by the foot settlements and etc., representing the different stages of the Iron Age and Historical Times, have been discovered and excavated.

Merkinė archaeological site is the most visually impressive stronghold in the region where quite a rich set of archaeological sites are known. Dated back to 14th c.–15th c. this place was one of the most important military centre in The Grand Duchy of Lithuania (Fig. 2). The area of archaeological site includes the oval-shaped hill fort, lower castle and two foot settlements. The part of the archaeological complex i.e. hill fort rises on the top of the hill which steep slopes overlook confluence of Merkys and Nemunas rivers. The height difference between the bottom of the valley and top of the hill reaches up to 12–30 m. Unfortunately in 1930 the biggest part of the hill fort was destroyed by the water of Stangė river. Originally the area of the hill fort plateau reached 1200 m2 and was surrounded by the impressive rampart. In 1962, remnants of brick – building were opened on the eastern slope of the hill fort. North-eastwards from the hill fort situated lower castle was excavated in 1997 and 1998 and cultural layer reaching up to 80 cm depth discovered. Excavated traces of the cultural activity included potsherds, iron ploughshare and etc. Two foot settlements, the southern and the western, all together covering an area of about 800 m2, were located next to foot of the hill fort. Here depth of the cultural formations reaches up to 2 m, and numerous archaeological artifacts dated back to the 16th c. – 17th c. suggest ongoing human activity. Archaeological complex is supplemented by the graveyard situated at about 200 m eastwards from the hill fort. Based on the archaeological information it was dated back to 14th c. – 15th c.

Discussing importance of Merkinė castle and this area for the development of Lithuanian state, few facts describing the political situation of the region at the time under discussion should be pointed out. Lithuania emerged as a state in the 13th c. Between 1219 – 1236 AD, many Lithuanian tribes united into a state under the leadership of Mindaugas (ca 1236 – 1263 AD) who was crowned King in 1253 AD. In the 12th c. – 13th c., the most significant political factor in the region, in addition to the rise of the Lithuanian state, was the arrival of armed missionary Knights in Livonia and Prussia. The Livonian Order of the Sword attempted to expand into Lithuanian lands but was stopped. The Order

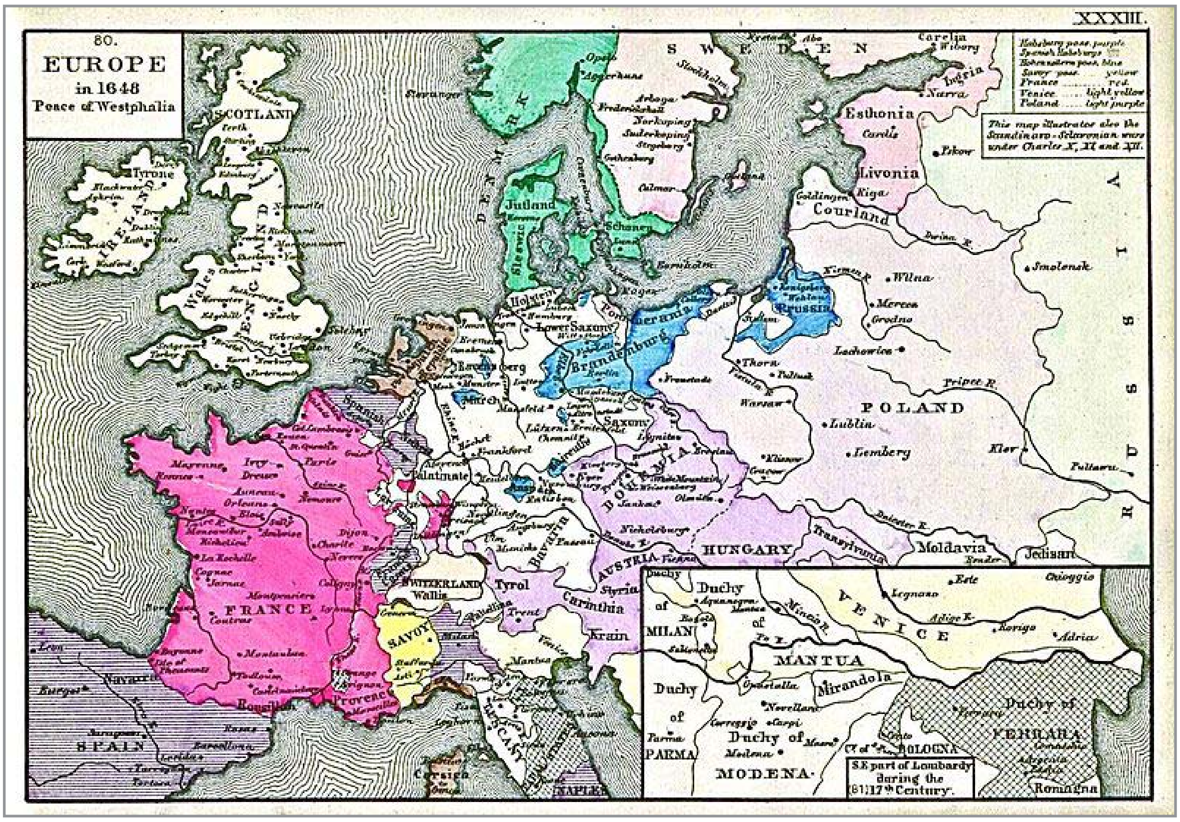

Fig. 2. Merkinė (Merecz) in the European map (1648 AD) ("An Historical Atlas containing a chronological series of one hundred and four maps, at successive periods, from the dawn of history to the present day", by Robert H. Labberton. Sixth Edition, 1884) (http://lt.wikipedia.org/wiki/Vaizdas:Europe_1648_westphal_1884.jpg)

of the Cross also came to the region about the same time. They were invited by the Mozurian Duke Konrad to help in the defense against the raids of the Prussians. Emperor Friedrich II the Hohenstauffen donated to the Order the territories of Courland, Lithuania, and Zemgallia. Pope Gregory IX gave the Order permission to establish its own state. After establishing itself in Prussia, in 1237 AD, the Order absorbed the Livonian Knights. Thus, by the middle of the XIII century most of the coastal land on the Eastern Baltic shores, all the way from Gdansk (Danzig) to Estonia, was controlled, or dominated by the German Order of the Knights of the Cross. The Knights sought to territorially unite these provinces by conquering Žemaitija (Samogitia) which lay between them. Alongside with these territorial questions the mission of the Knights of the Cross, approved by the Pope, was to Christianize the pagan Lithuanians. The Knights endeavored to achieve this by military means. This created an immediate danger to the integrity of the young Lithuanian state and did not disappear for almost two hundred years.

Talking about the prosperity of the Merkinė site we based our conclusions on the historical data, mainly. Available information suggests the construction of the Merkinė castle in the second half of XIII c. In 1359 AD castle, property of the Lithuanian Grand Duke, was referred in the Novgorod annuals for the first time. In 1377 AD, the chronicle of the Teutonic Order mentioned settlement named Merken or Merkenpil. Though the Castle was attacked by about twelve thousands of the Order's knights and solders it withstanded an attack. Merkinė castle became one of the most important parts of Nemunas defense line that included Vilnius-Kaunas-Merkinė, against Teutonic Order. In 1384, 1385 and 1387 AD castle was repeatedly mentioned in the chronicle of the Teutonic Order suggesting recurring campaigns to Lithuania. Alongside with the military actions numerous other events, important for the economic and social live of the state, took place in this castle. For example Grand duke of Lithuania and king of Poland Jogaila ensured city rights for Vilnius in 1387 and this document was signed in Merkinė castle. At the same time citizens of Merkinė settlement were christianized and the first church erected. After 1410 AD, when the military might of the Order was destroyed at Battle of Žalgiris (Battle of Tannenberg or Grunwald), Merkinė township started to grow becoming one of the biggest economical, confessional and cultural centre in this part of joint Lithuanian-Polish state. The second half of 16th c. – the first half of 17th c. could be identified as time of Merkinė prospering. In 1565 AD city was repeatedly granted the Magdeburg rights, more then 2000 farmsteads existed here. In 1605 AD Dominicans settled in Merkinė and a new stone church was sanctified in 1615 AD. After the arrival of Jesuits, who came here in 1676 AD, the first school was opened.

Decline in Merkinė history started after Lithuanian-Polish war with Russia, 1655 AD. During the Great Northern War (1700–21) Russian Tsar Peter the Great (Piotr I) visited Merkinė in 1707 and 1708 AD. The military actions and followed bubonic plague nearly destroyed the population of the site. Frequent fires decreased population number and importance of Merkinė township even more and all state institutions were moved to growing Alytus town in 1773–1775. Since that time Merkinė lives as small peripheral township with a great history.

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ŪLOS AKIS OUTCROP AS AN EXAMPLE OF PLEISTOCENE PROGLACIAL FLUVIAL SEDIMENTATION IN SE LITHUANIAN PLAIN

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Geomorphological research at the SE Lithuanian Outwash Plain was carried out by A. Basalykas, V. Dvareckas, L. Dicevičienė, V. Baltrūnas (Basalykas, 1955, 1965; Basalykas et al., 1984; Baltrūnas et al., 2007) as well as lithological and sediment structure investigations by A. Mikalauskas, A. Jurgaitis, N. Blažauskas, P. Šinkūnas (Mikalauskas, 1964, 1966; Mikalauskas, Jurgaitis, 1975; Blažauskas et al., 1998). Applied sedimentological methodology during the later studies (Jurgaitis et al., 2002; Blažauskas et al., 2007) of deposits well exposed in outcrops and quarries as well as analyzed geomorphological features led to the conclusion that proglacial fluvial facies are of the most importance in the development of SE Lithuanian Plain. The studied area probably is one of the major areas in Lithuania of intensive meltwater activity during the retreat of continental glaciers of Last Glaciation. Therefore deposits of various glaciofluvial facies can be studied and sedimentation peculiarities can be analyzed in this area of SE Lithuania where the northwestern side of SE Lithuanian Plain adjoins Baltija Uplands (Fig. 1). Due to the proximity to the Baltija Uplands – the zone of ice marginal formations the northeastern part of the Plain is rich in active quarries of sand and gravel whereas the southern part of the Plain is notable for the outcrops especially in Ūla River valley. Hydraulic parameters such as mean flow velocity, stream power and mean flow depth or bed shear stress were estimated using the methodology applied by T. Zielinski (1989 and 1992). For this most useful were cross bedded sediments, such us trough cross bedded sandy sets (the most common for all proglacial fluvial facies).

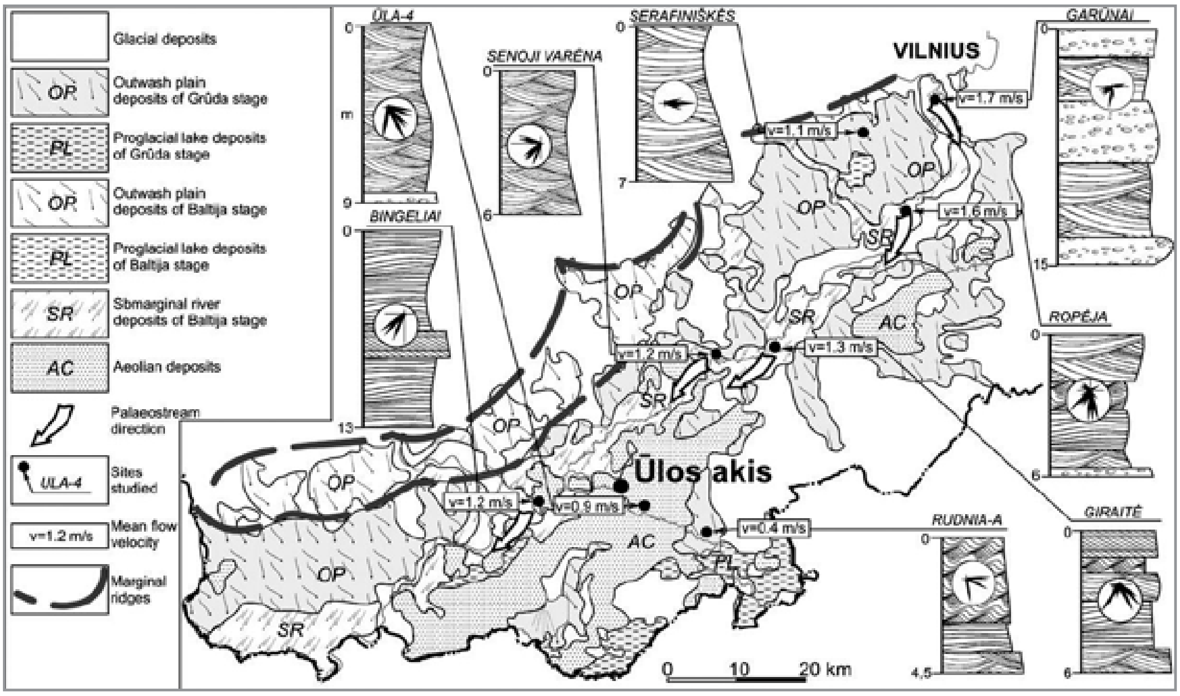

Fig. 1. Sedimentation pattern of the glacigenic sediments of the SE Lithuanian Plain. By Blažauskas et al., 2007

Lithocomplexes of aeolian deposits (I), lake sediments (II), ice-marginal river deposits (III), outwash plain deposits (IV, VI, VIII) in some places with coarse gravel with boulders at basal erosion surfaces (VI, VII) can be recognized in sediment sequences of SE Lithuanian Plain (Fig. 2).

Aeolian deposits (I) are frequently observed at the upper parts of the Ūla River Outcrop sediment sequences forming cover up to 10 m or thicker. The subhorizontal beds of fine- and medium-grained yellow coloured sand or large scale planar cross-beds depending on the sedimentation pattern in continental dunes or coversands cover palaeosol layers in some places. In cross-sections these aeolian deposits overlie the outwash-plain deposits, so that deflation of the latter seems to be the main source of these aeolian sediments.

Lake sediments (II) underlain by outwash-plain deposits and usually covered by aeolian ones are found in number of the Ūla River outcrops. Most often there are gyttja and underlying or overlying lacustrine sand, silt and clay. Sediments usually are horizontally bedded, sand of higher grain-size and mineral composition maturity and lighter coloured than underlying glaciofluvial or overlying aeolian one. The most frequent post-Glacial lacustrine sediment bed overall thickness is 1–2 m.

Ice-marginal river deposits (III) are spread in a typical (i.e. pradolina-type) icemarginal proglacial valley orientated along the ice margin. Coarse sand and gravel of large-scale tabular and trough cross-stratification as well as subhorizontally stratified sheet-like gravel beds are attributed to mid-channel bar deposits. Also side-channel bar deposits were distinguished represented by beds of large-scale tabular and trough cross-stratified sand and successions of subhorizontally stratified sands at some places followed by sands with current ripples and well expressed accretion surfaces in lenses on the inner edges of the ice-marginal channel characteristic of point-bar deposits in rivers of meandering character.

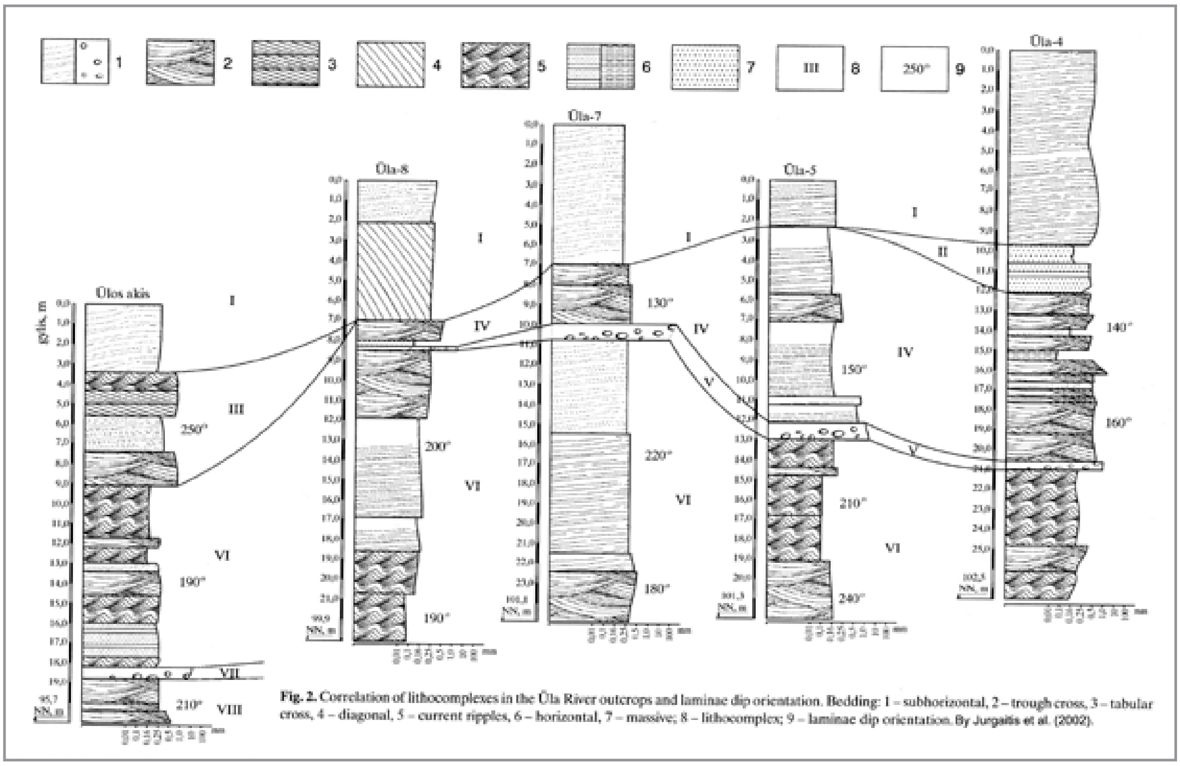

Fig. 2. Correlation of lithocomplexes in the Ūla River outcrops and laminae dip orientation. Bedding:

1 – subhorizontal,
2 – trough cross,
3 – tabular cross,
4 – diagonal,
5 – current ripples,
6 – horizontal,
7 – massive,
8 – lithocomplex,
9 – laminae dip orientation. By Jurgaitis et al., 2002

Outwash plain deposits (IV, VI, VIII) occur widespread over the entire SE Lithuanian Plain. The proximal, the middle and the distal facies assemblages are distinguished in the braidplain, depending on the distance from the front of past land-ice masses. Deposits of the proximal part of the sandur are badly sorted subhorizontally bedded gravel and trough cross-stratified sand and gravel represented by sets up to 1 m thick and 5–7 m long. Among the deposits of the middle part of the sandur the ripple-laminated fine sand, trough cross-stratified coarse sand and subhorizontally stratified gravel in cross-stratified beds of up to 30 cm thick and up to 2 m long prevail. The deposits of the distal part of the sandur are composed by fine sand and course silt with predominant current ripple lamination, whereas the small-scale trough cross-stratified sand beds up to 10 cm thick and subhorizontally stratified coarse sand beds are of the less importance.

Deposits at basal erosion surfaces (V, VII) in outwash plain deposit complexes are presented by coarse gravel with boulders and mark the sedimentation pattern shifts probably related to the fluctuation of glacial ice sheet margin related to climate change. At the initial stages the sandar were formed by glaciofluvial activity from the ice margin towards the South. Due to the repeated phases of intensive ablation the later braided-streams of south-eastern direction had accumulated deposit series studied in outcrops along the Ūla River. During the subsequent ice sheet retreat phase of Baltija Stage of Last Glaciation the intensive outflow of meltwater on the SE Lithuanian Plain has resulted in ice-marginal stream of perpendicular direction of the former braided streams, which has eroded the palaeovalley and deposited a glaciofluvial deposit successions.

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THE "ŪLOS AKIS" (ULA's EYE) SPRING

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The spring "Ūlos Akis" is situated on the left terrace of the Ūla River. The surface of the 300×100 m terrace is slightly undulating. The terrace is composed of medium grained sand. The spring is at distance of 8 m from the Ūla River channel. The water level of the Ūla River is 95.1 m above see level (a.s.l). The spring water level is 99.5 m a.s.l.

The spring's water is clear, hydrocarbonate, magnesium and calcium type. The temperature of the water is 8º C. It springs up from the inter-till aquifer. The Spring occurs in the 1,87 deep suffosian hollow. The yield of the spring is 2,1 l per second. The small stream flows into the Ūla River 22 m from the spring. The Spring is of ascending type.

People of the surrounding villages tell that The Spring water is used for curative needs.

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NEW MULTI-PROXY INVESTIGATIONS IN ZERVYNOS 1 OUTCROP – TYPICAL LATEGLACIAL SITE IN ŪLA RIVER VALLEY

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During the last decade Lateglacial environmental variations have been intensively studied in the south-eastern sector of the Late Weichselian Glaciation including Baltic region and adjacent territories (Makhnach et al., 2004; Šeirienė et al., 2006; Wohlfarth et al., 2007; Rinterknecht et al., 2006; Stančikaitė et al., 2008, 2009; Heikkilä et al., 2009; Bitinas, 2011; Amon, 2011; Veski et al., 2012; Balakauskas et al., 2013). A variety of environmental shifts including numerous climate oscillations has been identified on a basis of palaeobotanical data, isotope investigations, lithological information and many other proxies. However despite the broad knowledge of the Lateglacial environmental history some unsolved problems still exist talking about the earliest stages of the investigated interval especially.

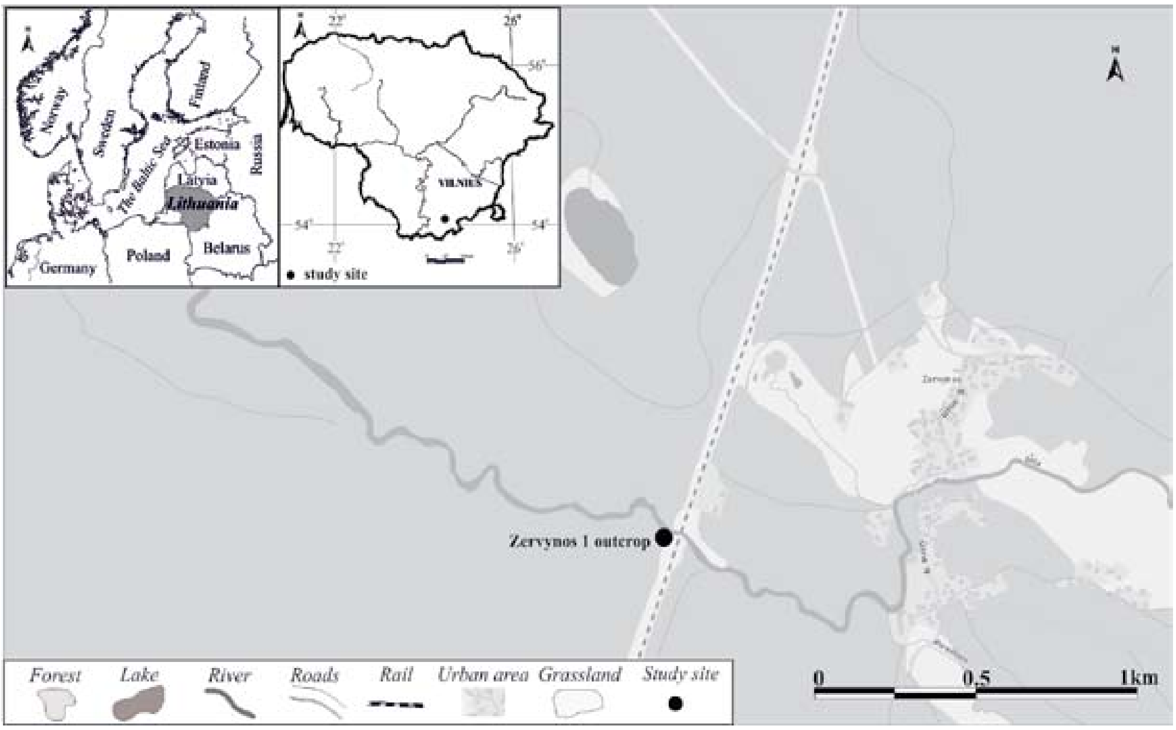

Fig. 1. Location of the Zervynos 1 Outcrop

The numerous outcrops containing organic–enriched sediments of the Lateglacial age have been known and investigated in Ūla river valley for more that forty years (Blažauskas et al., 1998). Therefore searching for the oldest post-Glacial sediment beds we concentrated in this region (Fig. 1). Detailed multi-proxy investigations i.e. pollen, diatom, plant macrofossil survey, $\delta^{18}O$, $\delta^{13}C$, ^{14}C (AMS), loss-on-ignition (*LOI*) and grain-size measurements alongside with the survey of magnetic susceptibility, were applied with high temporal resolution in Zervynos 1 (54°06´30,6´´N; 24°29´08,4´´E) Outcrop. The purpose of the conducted investigations was to reconstruct the vegetation dynamics, sedimentation regime and climatic variations during the earliest stages of the Lateglacial.

The results of AMS dating show that the formation of the bottom-most part of the investigated gyttja (83–155 cm) containing negligible portion of $CaCO_3$ and organic matter took place at about 13950–14650 cal yr BP (Poz-51807) (Fig. 2) that could roughly be correlated with the earliest stages of the Lateglacial Interstadial i.e. Bölling warming or GI-1e event according to Lowe et al. (2008). Underlying bed consisting of well-sorted sand with negligible amount of silt and clay particles (155–165 cm) was deposited during the initial sedimentation phase when intensive transportation of terrigenous mineral matter into the lake took place. Very few palaeobotanical remains i.e. *Typha latofolia* and *Potamogeton* sp. have been recorded in this interval so far suggesting harsh climate and unstable environmental regime predominated in the region. Presence of *Chara* sp. macroremains suggests existence of oxygen-rich, alkaline water basin with a high content of dissolved mineral salts and calcium. Whereas deposition of above mentioned gyttja marks the change of sedimentation regime and environmental situation with the onset of GI-1e event. First of all the indicated proxies, including lithological ones, suggest the stabilization of sedimentation regime in the basin as the sand particles were changed with increased amount of clay and silt and organic constituent together with $CaCO_3$ *pro rata*. Simultaneously the micro and macro remains of *Pinus* (pollen, stomata, needle and epidermis) and *Betula* (seed) were recorded in sediments indicating formation of the vegetation cover with the presence of pine and birch alongside with different NAP species. Whereas drop in the $\delta^{18}O$ values to more negative ones (from -9.09 to -10.86‰) was recorded simultaneously that contradicts to the GRIP ice core record of GI-1e event (Lowe et al., 2008). Similar changes of oxygen isotope curve indicating more negative values with the onset of warm Interstadial were described from Belarus (Makhnach et al., 2004), Germany (Böttger et al., 1998) and Denmark (Hammarlund, Buchard, 1996) where “contrary to general expectations, the oxygen-isotope values tend to be more positive in the cooler periods than in warmer”. Possible explanations for these recorded changes is an increase in the evaporation regulated by changes in air humidity, determinated by climatic changes, respectively, or an increase in the relative portion of detrital carbonate in the sediments (Böttger et al., 1998; Hammarlund, Buchard, 1996). As the amount of $CaCO_3$ stays rather low in investigated sediments, the climatic instability and change of evaporation rate, respectively, might have played leading role in above mentioned process.

Further analysis of collected data confirms short-lasted deterioration of environmental situation recorded at the depth of 142–149 cm. Palaeobotanical data i.e. increasing representation of NAP including *Artemisia*, Chenopodiaceae and Poaceae, and higher proportion of sand in the sediment bed as well as changing amount of organic and $CaCO_3$ constituents in the sediments suggest the instability of environmental regime that could be attributed to GI-1d event or Older Dryas cooling.

Starting from the depth of 143 cm (interval 143–100 cm), considerable changes recorded in the $\delta^{18}O$ curve, as well as those seen in pollen, *LO*I, grain-size and magnetic susceptibility records indicate climatic, hydrological and vegetation shifts had taken place in the region. Drop in sand input and increase of organic constituent suggests the stabilization of the surface. Simultaneous rise of magnetic susceptibility suggests higher representation of magnetic-rich minerals in the basin. Often these changes are related with high water level (Kirby et al., 2004). Predominance of AP pollen in spectra indicates the formation of open forest where pine played a leading role as pollen values >50% indicate local dominance of this tree (Huntley, Birks, 1983). Meanwhile birch was represented rather sporadically as only pollen values over 25% can indicate local birch dominated woodland (Huntley, Birks, 1983). Subsequently, supply of allochthonous material from the catchment decreased and the increased value of recorded $CaCO_3$ must have originated from the lake itself as a result, suggesting increasing productivity of the basin. Presence of *Typha latofolia* and *Menyanthes trifoliata* mac-

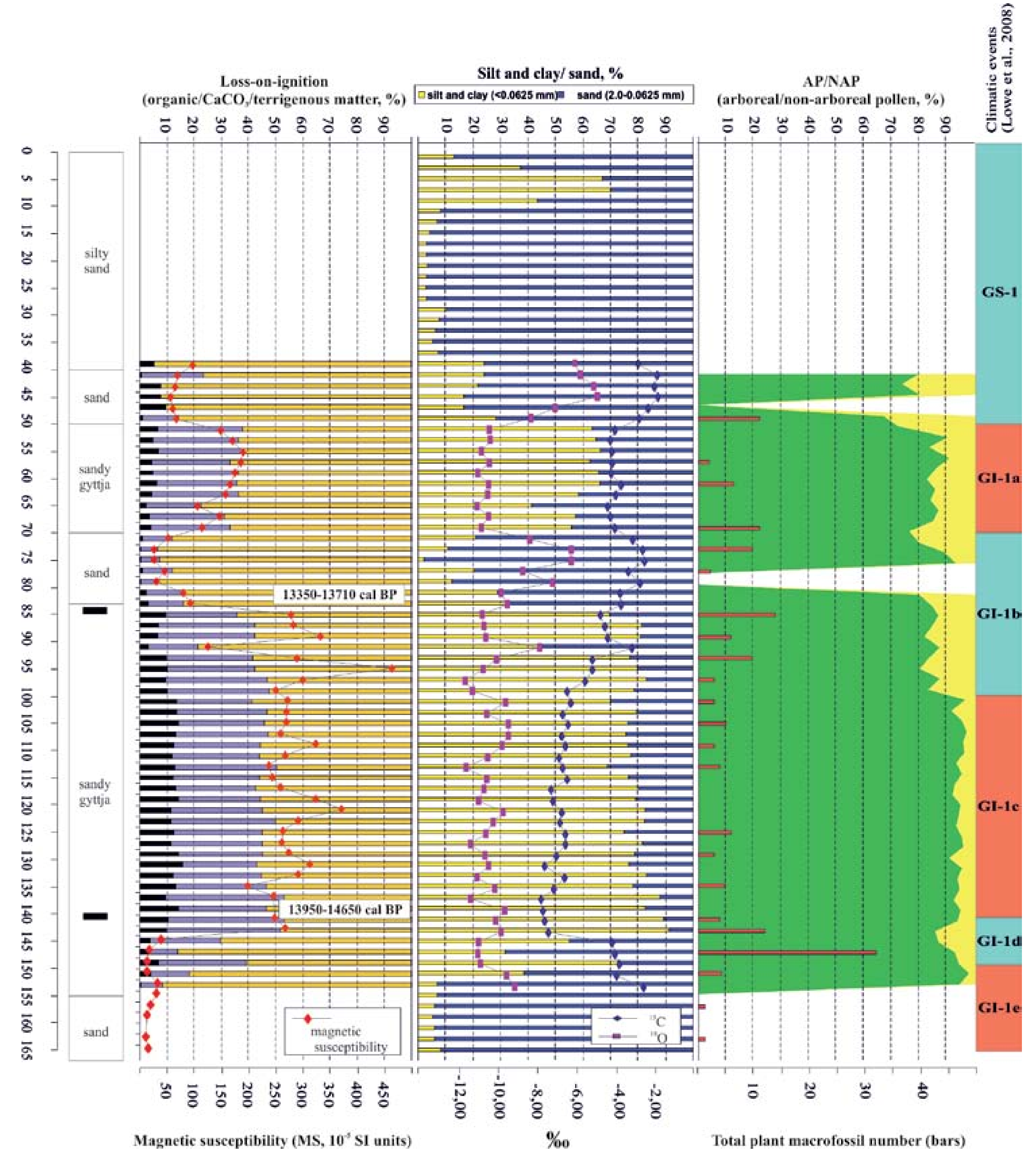

Fig. 2. Summary graphs from Zervynos 1 Outcrop compared to climatic events scheme developed by Lowe and co-authors (2008)

roremains suggests the earliest signs of eutrophication. A drop in the $\delta^{18}O$ curve to more negative values recorded at the onset of the interval may indicate a rise in the evaporation rate likely caused by higher mean temperature, a probability that is in a positive correlation with palaeobotanical data. In turn the described shifts point to the climatic amelioration that could be correlated with the onset of Alleröd warming or GI-1c event (Lowe et al., 2008) dated back to 13700 cal BP in the territory of Lithuania.

Approaching the upper part of the gyttja bed, at the depth of 100 cm, the changing trends of the pollen curves indicate some thinning of the vegetation cover and opening of the landscape subsequently. In the vegetation structure representation of pine decreased as pollen number in spectra is lower in comparison with the previous interval. Macroremains of pine vanished from spectra and trees are represented by *Betula* sect *Albae* only. Number of NAP pollen increased indicating formation of open grasslands with high number of light-demanding *Juniperus*. Simultaneous gradual rise of the $\delta^{18}O$ curve suggests some deterioration of the climatic regime including increasing aridity that is in agreement with palaeobotanical record i.e. occurrence of *Potamogeton filiformi*s and *Selaginella selaginoides*. Rising input of terrigenous matter and drop in $CaCO_3$ representation could be related with intensive erosion processes, destruction of the soil cover and decreasing productivity of the lake itself. Culmination of the above mentioned processes might have been related with the formation of sand interlayer (interval 83–70 cm). Deposition of the gyttja was interrupted at about 13350–13710 cal yr BP (Poz-51806). Similar changes in biota structure and oxygen isotope composition have been correlated with the Gerzensee oscillation or GI-1b event in Europe (Lotter et al., 1992).

Deposition of the sandy gyttja (70–50 cm) indicates some stabilization of sedimentary environment. However facts i.e. low organic content and rather intensive input of the sand into basin point to high erosion rates. As the portion of mineral matter in the sediments increases, suggesting high supply of allochthonous material from the catchment, the increasing representation of recorded $CaCO_3$ must have originated from this source mainly. Simultaneous changes recorded in the pollen signal suggest formation of a new vegetation type in area. First of all previously presented pine decreased in number or even vanished from the area according pollen and plant macrofossil data. Only macroremains of *Betula* sect. *Albae* were recorded. On the one part vegetation became sparse as numerous light-demanding species i.e. *Juniperus, Hippophaë*, etc. were recorded, on the other part occurrence of new tree taxa i.e. *Picea* points to the formation of dense vegetation structure. Increasing representation of spruce in pollen record indicates occurrence of this tree on a local scale as the 1–5% pollen threshold was chosen to trace local expansion of the spruce (Giesecke, Bennett, 2004; Latalowa, van der Knaap, 2006). Lateglacial immigration of this taxa into the SE Lithuania was proved by occurrence of plant macrofossils as well (Stančikaitė et al., 2008). Both $\delta^{18}O$ and palaeobotanical records show some climatic amelioration and increasing evaporation though temperature was lower in comparison with GI-1c event. Described interval of the Lateglacial environmental history might be correlated with the second half of the Alleröd warming or GI-1a event (Lowe et al., 2008).

Sand overlaying the bed of sandy gyttja was deposited in rather severe climatic conditions as it is suggested by $\delta^{18}O$ record. Prominent climatic deterioration is also seen in pollen data as number of AP pollen declines and NAP increases in number. Terrigenous matter became the predominating type of the material deposited suggesting intensive erosion processes.

Collected multi-proxy data obtained from the Zervynos 1 Outcrop enabled us to make a detailed environmental reconstruction of the Late Weichselian Interstadial in SE Lithuania. Formation of the investigated gyttja bed started during the earliest stages of the Interstadial (GI-1e event) whereas the first instability of the environmental regime could be correlated with the Older Dryas cooling (GI-1d event). Climatic and environmental fluctuations provoked by the Gerzensee oscillation or GI-1b event caused the first basin infill. It is evident that these processes had started earlier than it was concluded during former estimations. Further development of the environmental proxies suggests gradual changes of the environmental regime and vegetation structure during the GI-1a event.

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Stratigraphical Scheme for the Quaternary of Lithuania, Officially Assignet for State Geological Investigation (2009)

Stratigraphic units						
System	Division	Subdivision		Step Formation	Stadial Subformation	Phasial Member
Quaternary	Holocene					
Quaternary	Pleistocene	Upper	Nemunas (Weichselian)	Viršutinis Nemunas (Upper Weichselian)	Baltija Grūda	Šiaurės Lietuvos (North Lithuanian) Vidurio Lietuvos (Middle Lithuanian) Pietų Lietuvos (South Lithuanian)
				Vidurinis Nemunas (Middle Weichselian)	Mickūnai 4 (thermomer) Nemunas 3e (cryomer) Mickūnai 3 (thermomer) Nemunas 2d (cryomer) Mickūnai 2 (thermomer) Nemunas 2c (cryomer) Mickūnai 1 (thermomer) Nemunas 2b (cryomer) Jonionys 3 (thermomer) Nemunas 2a (cryomer)	
				Apatinis Nemunas (Lower Weichselian)	Jonionys 2 (thermomer) Nemunas 1b (cryomer) Jonionys 1 (thermomer) Nemunas 1a (cryomer)	
			Merkinė (Eemian) Interglacial			
		Middle	Žeimena Glacial		Pamarys (Medininkai Late Glacial) (thermomer) Medininkai (Warthian) (cryomer) Vikiškės (thermomer) Žemaitija (Saalian) (cryomer)	
			Būtėnai (Holsteinian) Interglacial			
			Dainava (Elsterian 2) Glacial			
			Turgeliai Interglacial			
		Lower	Dzūkija (Elsterian 1) Glacial			
			Vindžūnai Interglacial			
			Kalviai Glacial			
	Prepleistocene	Daumantai Preglacial				

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