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Eemian-Weichselian palaeoenvironmental record from the Mickūnai glacial depression (Eastern Lithuania)

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An extensive area of distribution of palaeolacustrine sediments (sand, silt with humus and interlayers of gyttja), occurring above the Eemian (Merkinė) Interglacial deposits and below the relief forming the Upper Weichselian till, was determined in the Mickūnai glaciodepression (in the vicinities of Vilnius, East Lithuania).

These sediments were interpreted as being formed in a shallow palaeolake or lacustrine system, which occupied the depression during the Early-Middle Weichselian.

Four boreholes were drilled in the central part of the Mickūnai depression and their sections were studied using lithostratigraphic and pollen analyses and datings by the optically stimulated luminescence (OSL) method.

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

The Mickūnai sequence reflects presence of nonglacial palaeoenvironments from the end of the Eemian Interglacial to the Late Weichselian ice advance.

Key words: Early-Middle Weichselian, pollen, Late Pleistocene, East Lithuania, palaeolacustrine sediments

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INTRODUCTION

Knowledge on climato-stratigraphic events of the Early-Middle Weichselian in the Baltic Region is rather limited. The Early Weichselian interstadials identified in Fennoscandia and the Baltic Region mainly through comparison with the sites farther to the south can be correlated with either the Brörup or Odderade interstadials (Lagerbäck, Robertsson, 1988; Mangerud, 1991; Helmens et al., 2000, 2007; Roman, Balwierz, 2010; Kalnina et al., 2011; Nenonen, 1995; Donner, 1996; Lunkka et al., 2004; Väliranta et al., 2009).

The Middle Weichselian (OIS 4–3) and the transition from the Early to Middle Weichselian are the most problematic and disputed time intervals of the Late Pleistocene. Especially contentious are the extent of glacial advances during the Middle Weichselian (Mangerud, 2004; Kalm, 2006; Marks, 2012; Lunkka et al., 2001) and the character of palaeoenvironmental changes in the transition from OIS 5 to OIS 4. Glacial deposits attributed to the Middle Weichselian were reported from Estonia (Liivrand, 1991), southern Finland (Nenonen, 1995), Poland (Marks, 2004; 2012) and Denmark (Houmark-Nielsen, 2004; 2011).

The early Middle Weichselian glacial event (OIS 4) is recorded in the central part of the Fennoscandian Ice Sheet (Hitura pit, Ostrobothnia), which began here after the entirely ice-free Early Weichselian 79 kyr ago and was followed by a deglaciation between 62 and 55 kyr ago (Salonen et al., 2008). The sediment succession of Ruunaa (eastern Finland) indicates a Middle Weichselian glacial event which took place prior to 52 kyr ago and was followed by an ice-free period around 50–25 kyr ago (Lunkka et al., 2008). Based on glaciological modeling, Zelčs and Markots (2004) proposed a possible early Middle Weichselian glaciation in western Latvia (so-called Talsi Stadial) between 74 and 59 kyr BP, however, no direct evidence was reported. Recently the Talsi stadial was placed between 68–54 kyr and this interval was followed by the Lejasciems interstadial between 54 and 24 kyr (Zelčs et al., 2011).

On the basis of IR-OSL datings of inter-till deposits from the Lithuanian Maritime Region, covering the time span of 114–76 kyr (Molodkov et al., 2010), the tills from Klaipėda and vicinities were interpreted as having been formed during the early Middle Weichselian glacial advance.

Kalm (2006), summarizing published ^{14}C and OSL data, indicated that Estonia was ice-free at least between 43.2–26.8 kyr BP and assumed that the time period for a possible early Middle Weichselian glaciation in Estonia could be between 68–44 kyr (Kalm et al., 2011). However, this approach is challenged by recent data, which suggest ice-free and warm conditions in major parts of eastern Fennoscandia in early MIS 3 around 53 kyr (Helmens, Engels, 2010). Radiocarbon dates suggest that there was larger ice-free area in Fennoscandia during Middle Weichselian from ca. 44 to ca. 22.5 kyr BP than previously assumed (Ukkonen et al., 1999; 2007).

According to Houmark-Nielsen (2004; 2011) ice sheets may have reached Denmark at the Ristinge (54–51 kyr) and Klintholm (35–32 kyr) advances during the Middle Weichselian. The OIS 3 in Denmark ended with ameliorated interstadial environments characterized by shrub tundra and boreo-arctic seas (Houmark-Nielsen, 2004).

Keeping in mind a variety of interpretations, investigations of the Early and Middle Weichselian sequences in the Baltic Region are of great importance for assessing the extent of the early Middle Weichselian glaciation and palaeogeography of the terminal OIS 5, OIS 4, and OIS 3. Furthermore, Middle Weichselian palaeoenvironmental and chronostratigraphical investigations are essential for determining the timing of the initiation of the Late Weichselian glaciation. For example, Zelčs and Markots (2004) proposed an early date for the onset of the Late Weichselian glaciation in neighbouring Latvia at ca. 33 kyr BP, which contradicts the evidence from Estonia where it is placed at around 22–20 kyr BP (Kalm, 2006) or even northern Finland (about 25–22 kyr ago) (Sarala et al., 2010).

It is noteworthy that occurrence of till (up to 5.5 m thick) offshore Šventoji (located on the Baltic coast of Lithuania) in between two marine sandy complexes dated by OSL at 48.8 ± 6.2 kyr – 43.7 ± 4.0 kyr (overlaying) and 113.1 ± 8.5–83.6 ± 6.7 kyr (underlying) was recently reported (Damušytė et al., 2011). This glacial event could be correlated with the Schalkholz (Nemunas 2a) stadial geochronologically located in the interval 74–59 kyr BP.

To address the problem of climatostratigraphy of the Early-Middle Weichselian, the investigations of the sections drilled in the Mickūnai depression (Fig. 1) were carried out in order to determine the palaeogeographic conditions and stratigraphic position of the palaeolacustrine sediments.

GEOLOGICAL SETTING OF THE MICKŪNAI GLACIAL DEPRESSION

The Mickūnai glacial depression occupies the lowland between the river valleys of Neris and its tributary Vilnia (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 in the upper part of Quaternary deposits.

Merkinė (Eemian) Interglacial deposits in the Mickūnai glacial depression were earlier known only from two localities – Mickūnai and Bezdonys, where they have been discovered in boreholes (Kondratienė, Vonsavičiūtė, 1986).

Fig. 1. Location map of the study area
1 pav. Tyrimų plotas

In the vicinity of Mickūnai the Merkinė Interglacial deposits were found in sections of the boreholes Mickūnai-9, Mickūnai-7 and Gaidūnai-5. The presence of two interstadials occurring on the top of the Eemian Interglacial has been revealed only in the borehole Gaidūnai-5, near the village Mickūnai (Kondratienė, Vonsavičiūtė, 1986). These two interstadials were interpreted as Jonionys 1 and Jonionys 2, and assumed to be of the Early Weichselian age.

In the course of geological mapping a continuous occurrence of Merkinė Interglacial deposits has been documented in the Vilnia-Neris depression (Satkūnas, 1993). It was established that in the area of 200 km^2 the interglacial deposits are situated at the same altitude – 102 (bottom)–120 (top) m above the present sea level. The interglacial deposits are represented by lacustrine silt, silty sand, sand with abundant mollusc shells and lacustrine marl. 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 the 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 $CaCO_3$. 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 mostly fine-grained sand. This indicates that at the end of the Interglacial the lake became shallower and was finally filled by sediments.

The Merkinė Interglacial deposits of the Mickūnai basin are covered by deposits of the Nemunas (Weichselian) age.

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 the diluvial 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. Nevertheless, the origin of the sediments shows that after the Eemian Interglacial peat land with small lakes existed in this depression at least during part of the Early Weichselian.

Above the Lower Weichselian organic-bearing sediments a regular presence of lacustrine sand and silt has been revealed continuously distributed over the central part of the Vilnia-Neris depression. These sediments were interpreted as being formed in a large palaeolake or palaelacustrine system, which occupied the depression during the Middle Weichselian.

The Upper Weichselian in this area is represented by glacial, glaciofluvial and glaciolacustrine sediments accumulated during the maximum extension of the last glaciation. The uppermost part of the Quaternary cover in the Vilnia-Neris glacial depression is composed of eolian sand formed during the Late Glacial and Holocene (Satkūnas, 1993).

MATERIALS AND METHODS

In 1996–1998, in the 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 were drilled in the Vilnia River valley in order to get more data on the stratigraphy of the Upper Pleistocene (Fig. 1).

The boreholes were drilled using a screw-auger drilling rig. Sections of sediments were examined macroscopically. Their lithological determination was given on the basis of grain size analysis. Results of this analysis are presented in the report "The Geochronology and Stratigraphic Correlation of Upper Pleistocene in the Baltic Region" stored at the Archive of the Lithuanian Geological Survey.

In the course of lithostratigraphic determination presence of organic matter, e. g. gyttja with fragments of mollusc shells or organic detritus were used as an indicator of climatically more favourable conditions as compared with coarse sand or gravel without any organic matter.

For the setting of the age, the sediments from the boreholes Popierinė and Rokantai were dated by the OSL method in the Institute of Geology at the Tallinn University of Technology (by Galina Hütt).

400 samples for pollen and spores analyses were taken from all boreholes.

For pollen analyses all samples were first boiled in 10% KOH for 5 min. Those samples that contained carbonates were subsequently treated with 10% HCl. Coarse mineral particles were removed by decanting and macroscopic plant remains by sieving through a 0.25 mm mesh sieve. Fine mineral particles were separated according to the Grichuk's method (Grichuk, Zaklinskaya, 1948) using the heavy liquids KJ and CdJ_2 (density 2.22 mg/cm^3). The organic fraction was treated by the standard acetolysis method (Erdtman, 1960). The material was mounted in glycerine and a minimum of 300 arboreal pollen grains per sample were counted. Pollen percentage values were calculated as percentages of the total sum of terrestrial plants (trees, shrubs and herbs). The percentages of aquatic plants and pteridophyta (X) were calculated on the pollen sum + X for each separate component.

On the basis of the lithological composition and pollen and spores data the studied sections were tentatively subdivided into thermomers and cryomers.

RESULTS OF POLLEN ANALYSIS

Mickūnai 184P

The section could be subdivided into 11 local Pollen Assemblage Zones (LPAZ) (Fig. 2):

Zone I (30.6–29.0 m) Pinus-Picea LPAZ: Frequency of pollen is high. AP constitutes 95–98% of the total sum. Pollen of *Pinus* prevails. The curve of *Picea* pollen reaches up to 20%. Broad-leaved pollen is represented by low frequency.

Zone II (29.0–28.3 m) Pinus LPAZ: *Picea* pollen decreases. *Pinus* pollen shows a clear maximum forming up to 80% of the total. The value of Cyperaceae pollen increases.

Zone III (28.3–27.3 m) Pinus-Betula: Trees pollen decreases up to 86%. *Picea* pollen also decreases. *Pinus* pollen prevails. Values of herbaceous plant with Cyperaceae, Poaceae, *Artemisia* increase. Pre-Quaternary spores are noted. Broad-leaved pollen and part of AP are possibly redeposited (then not only broad-leaved).

Zone IV (27.3–25.3 m) Pinus-Picea: Pollen of coniferous trees prevails. *Pinus* pollen constitutes 70%, *Picea* pollen 20%. Cyperaceae are dominant among herbs.

Zone V (22.1–20.5 m) AP-Cyperaceae: Frequency of pollen is low. Pollen of *Betula* and *Alnus* reaches up to 20% in the lower part of the zone. Values of *Pinus* and *Picea* pollen increase in the upper part of the zone. Ericaceae with their maximum are noted. Herb pollen is dominated by Cyperaceae. Pollen of QM and *Corylus* are reworked from older sediments.

Zone VI (20.5–19.5 m) Cyperaceae-Poaceae: Value of trees pollen decreases to 45%. Herbaceous plant communities constitute mainly Cyperaceae with 40% and Poaceae with 10%. Pollen of Helianthemum was noted.

Zone VII (19.5–18.2 m) Betula-Cyperaceae: Amount of *Betula* pollen increases. Curve of Cyperaceae reaches 30%. *Artemisia* accounts for 10%.

Zone VIII (18.2–16.0 m) Cyperaceae: Frequency of pollen is very low. Very few pollen grains were noted in some spectrum and percentage value was not calculated. Cyperaceae value varies between 30 and 60%.

Zone IX (16.0–14.9 m) Artemisia-Cyperaceae: Relatively high AP percentages. Pollen from herbs, mostly *Artemisia* and Cyperaceae, constitutes 30%.

Zone X (10.5–10.3 m) Cyperaceae: Dominated by *Pinus* and Cyperaceae.

Zone XI (10.5–8.5 m) NAP: Frequency of pollen is very low. Redeposited pollen was identified.

Gaidūnai

The section could be subdivided into 13 local Pollen Assemblage Zones (LPAZ) (Fig. 3):

Zone I (33.0–28.6 m) AP-Picea-Carpinus: Trees pollen reaches up to 90%. *Pinus* pollen prevails. Values of *Picea* and *Carpinus* pollen increase in the upper part of this zone. A few Pre-Quaternary spores and spores of *Osmunda* and *Selaginella selaginoides* are noted.

Zone II (28.6–27.5 m) Pinus: The curve of *Pinus* pollen slightly rises. Among *Betula* pollen some of *Betula nana* is identified.

Zone III (27.5–25.5 m) Pinus-Picea: Pollen from coniferous trees dominates: *Pinus* (55%), *Picea* (35%).

Zone IV (25.5–24.7 m) Pinus-Cyperaceae: Value of trees pollen decreases to 65%. *Pinus* pollen is dominating among trees pollen. Amount of Cyperaceae pollen increases up to 30%.

Zone V (24.7–23.2 m) Pinus-Alnus: Percentage value of *Pinus* pollen is similar as in the preceding zone. *Alnus* pollen percentage increases.

Zone VI (23.2–22.1 m) Cyperaceae-Betula: Cyperaceae with 30%, *Artemisia* and Poaceae are dominant among herbaceous plant. *Betula* reaches its highest pollen value in this zone.

Zone VII (22.1–20.9 m) Alnus-Betula: Trees pollen reaches up to 90%. *Alnus* and *Betula* pollen prevail.

Zone VIII (20.9–17.5 m) Cyperacea-Poaceae: Frequency of pollen is low. Cyperaceae constitute 20%, Poaceae are increased. Caryophyllaceae with their 3% maximum are noted.

Zone IX (17.5–14.3 m) Pinus-Alnus: Trees pollen values vary between 55 and 90%. The clear *Alnus* maximum is noted in the lower part of the zone. *Pinus* pollen dominates.

Zone X (14.3–12.0 m) Artemisia-Cyperaceae-Poaceae: Herb pollen constitutes 60–85%. A peak (up to 12%) of *Artemisia* is noted. Cyperaceae gradually increase to 70%, Poaceae rise to 25%.

Zone XI (12.0–11.5 m) AP-Artemisia: This zone is dominated by *Pinus*, *Betula*, *Alnus* and *Artemisia* pollen.

Zone XII (11.5–7.5 m) NAP: The pollen frequency is very low. Herbs are represented by *Artemisia*, Chenopodiaceae, Cyperaceae and Poaceae.

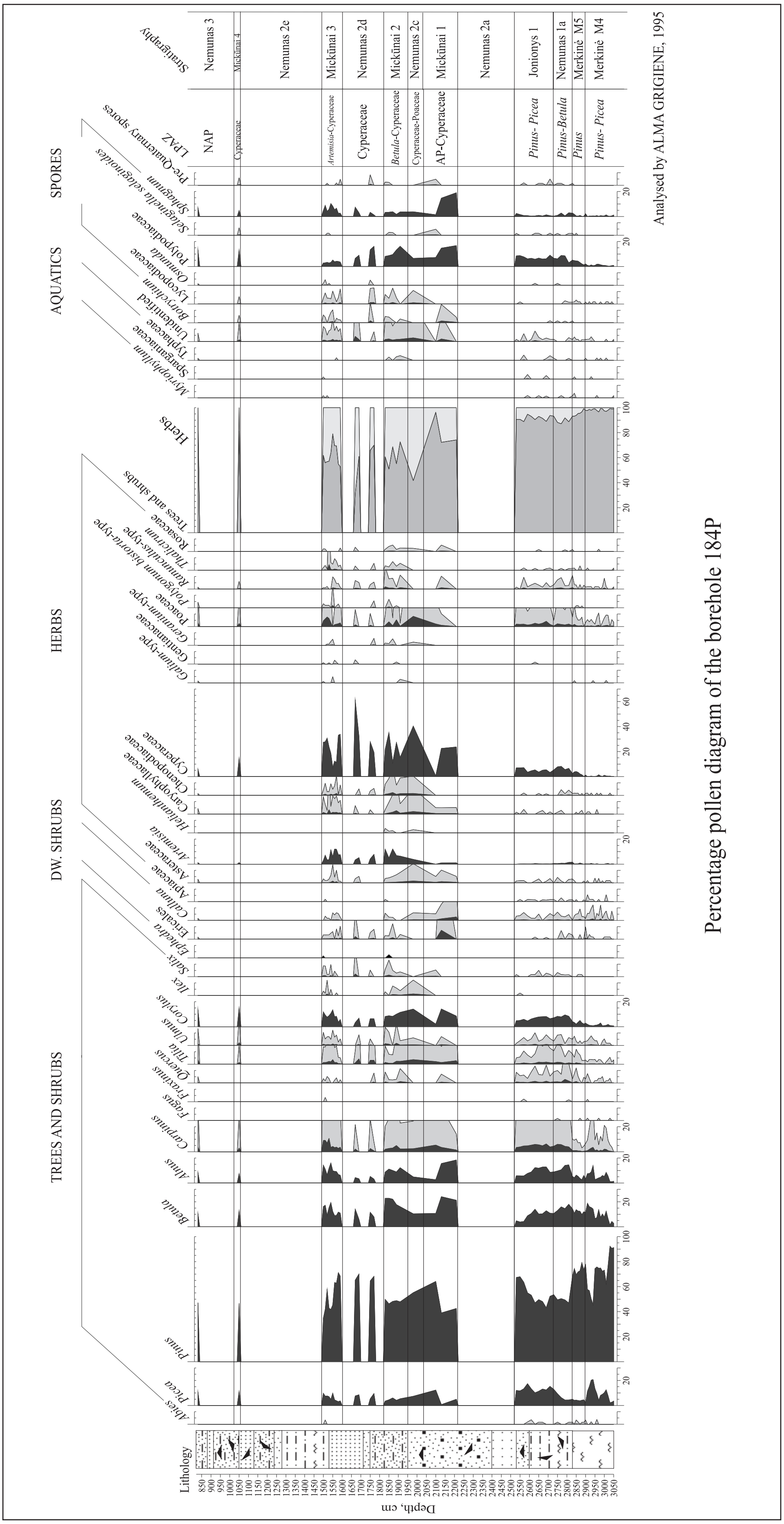

Fig. 2. The pollen percentage diagram of the borehole Mickūnai 184P
2 pav. Procentinė žiedadulkių diagrama, Mickūnų 184P gręžinys

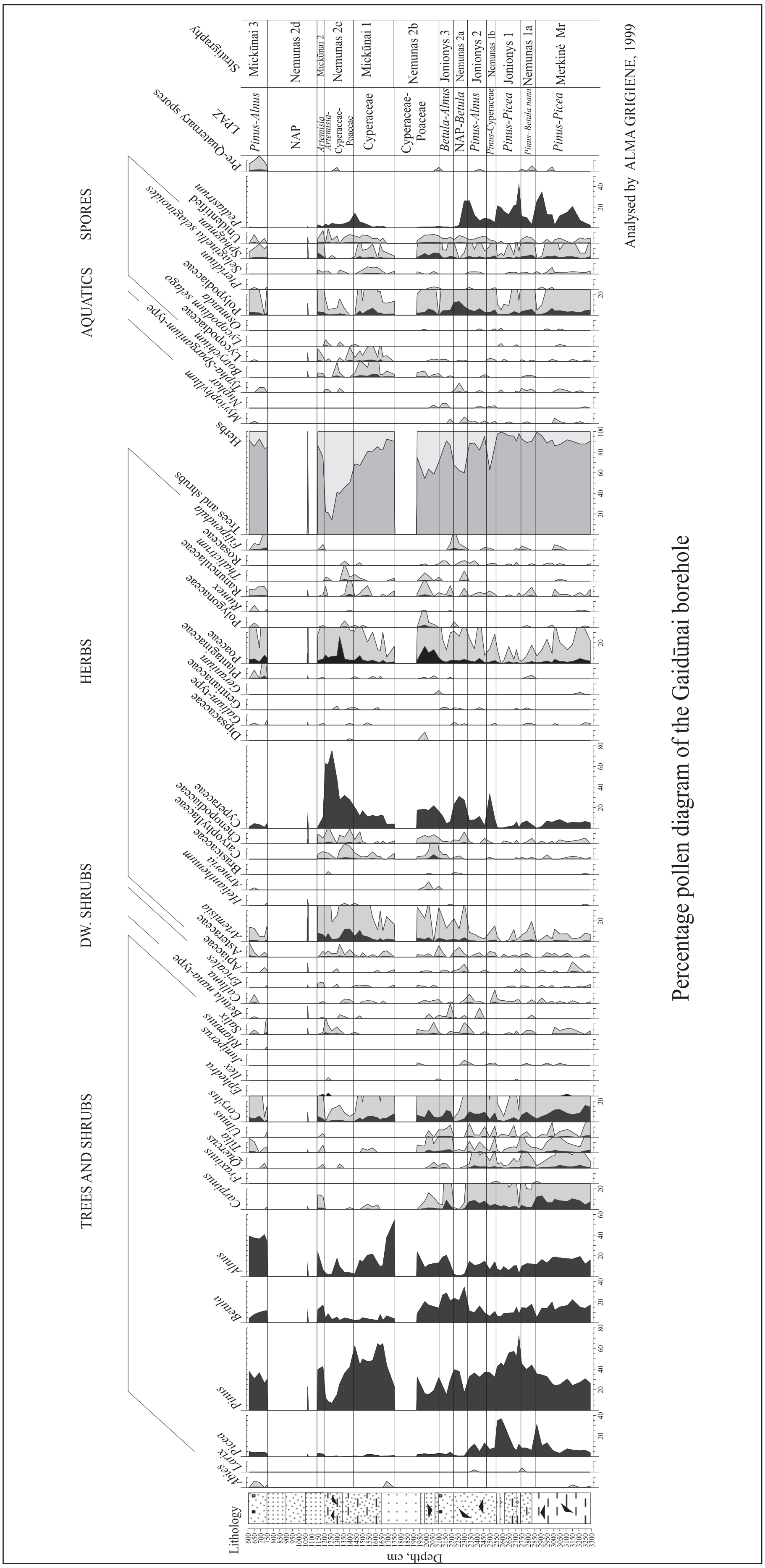

Fig. 3. The pollen percentage diagram of the borehole Gaidūnai
3 pav. Procentinė žiedadulkių diagrama, Gaidūnų gręžinys

Zone XIII (7.5–6.0 m) *Pinus-Alnus*: *Alnus* and *Pinus* are dominant. The value of herbaceous pollen is considerably low.

Rokantai

The pollen diagram has been divided into ten local Pollen Assemblage Zones (LPAZ) (Fig. 4):

Zone I (26.7–24.3 m) *Pinus*-Cyperaceae: *Pinus* pollen with 50% prevails. *Picea* reaches to 10%. Pollen of Cyperaceae is dominant among herbs.

Zone II (24.3–23.4 m) NAP: The pollen frequency is low in this zone. Cyperaceae predominate.

Zone III (23.4–22.1 m) *Betula-Alnus*: Value of *Pinus* pollen decreases. Amounts of *Betula* and *Alnus* increase. Herbs are represented mainly by *Artemisia*, Cyperaceae and Poaceae.

Zone IV (22.1–21.5 m) AP-Cyperaceae: Value of trees pollen slightly increases. Cyperaceae and *Artemisia* represent herbs.

Zone V (21.5–19.3 m) Cyperaceae-*Artmisia*: Cyperaceae (up to 60%) prevail. *Artemisia* reaches its highest value (20%) in this zone. A small peak of *Ranunculus*-type is noted. Pollen from light-demanding plants, e. g. *Ephedra*, *Helianthemum*, Chenopodiaceae, was identified.

Zone VI (19.3–16.0 m) Cyperaceae: Cyperaceae (50%) is still dominated. *Artemisia* pollen percentage decreases. *Pinus* increases.

Zone VII (16.0–13.2 m) *Artemisia*-Cyperaceae-Poaceae: The pollen frequency is low. Poaceae (45%), Cyperaceae (40%) and *Artemisia* (15%) dominate.

Zone VIII (13.2–10.2 m) *Betula*: Amount of *Betula* pollen reaches 75%. *Betula nana* and *Alnus* slightly increase.

Zone IX (10.2–9.5 m) NAP: The pollen frequency is very low. Asteraceae, *Artemisia*, Chenopodiaceae represent herbs. A few pollen of *Alnus* and *Betula nana* are noted.

Zone X (9.5–7.0 m) *Betula-Betula nana*-type: *Betula* dominates among the arboreal pollen. *Betula nana* increases to 18%. *Artemisia* and Cyperaceae are most common among herbs.

Popierinė

The section could be subdivided into 6 local Pollen Assemblage Zones (LPAZ) (Fig. 5):

Zone I (21.0–19.8 m) *Betula*-Cyperaceae: Value of trees pollen increases in the upper part of the zone. *Betula*, *Pinus* and *Alnus* dominate. Cyperaceae are present in large numbers.

Zone II (19.8–15.1 m) Cyperaceae: Trees pollen decreases to 20%. Cyperaceae pollen shows a clear maximum forming up to 80% of the total.

Zone III (15.1–13.0 m) *Pinus*-NAP: *Pinus* pollen prevails. A small peak of *Picea* is noted. Value of *Betula* and *Alnus* slightly increases. Asteraceae, *Artemisia*, Chenopodiaceae and Cyperaceae represent herbs.

Zone IV (13.0–11.8 m) NAP: The pollen frequency is low. NAP with Poaceae dominate and increase up to 75%.

Zone V (11.8–8.8 m) *Betula*-NAP: Trees pollen is represented by *Betula* and *Alnus*. The value of *Artemisia* rises up to 15% in the upper part of the zone. Cyperaceae account for 20%.

Zone VI (8.8–7.5 m) *Betula nana*-NAP: The frequency of pollen is very low. *Betula nana*, *Artemisia* and Cyperaceae predominate.

DISCUSSION

The main part of the examined Mickūnai site section is composed of sandy-silty sediments with different admixtures of organic matter and gravel, organic remains, interlayers of gyttja (Fig. 6). Geneticaly these sediments are interpreted as lacustrine with prevailing shallow facies. As the sediments genesis is defined only on the base of the lithological composition, without textural examination (due to screw-auger drilling) for coarser beds, alluvial genesis is also possible. The upper part of the section is composed of till (clayey loam with pebbles) and overlaying coarse gravelly sand is presumably of glaciofluvial genesis.

The integrated stratigraphic interpretation of Mickūnai sections is given in the cross-section (Fig. 6).

The studied sections of the Mickūnai depression demonstrate climatostratigraphic events – cryomers alternating with thermomers, however, minor climatic fluctuations are reflected in both palynologic and lithostratigraphic records, except the Merkinė Interglacial (Eemian) (e. g. LPAZ I, II in Mickūnai 184P section, LPAZ I in Gaidūnai section). Vegetation cover with Cyperaceae and *Artemisia* expansion shows the climatic deterioration during Early and Middle Weichselian cryomers.

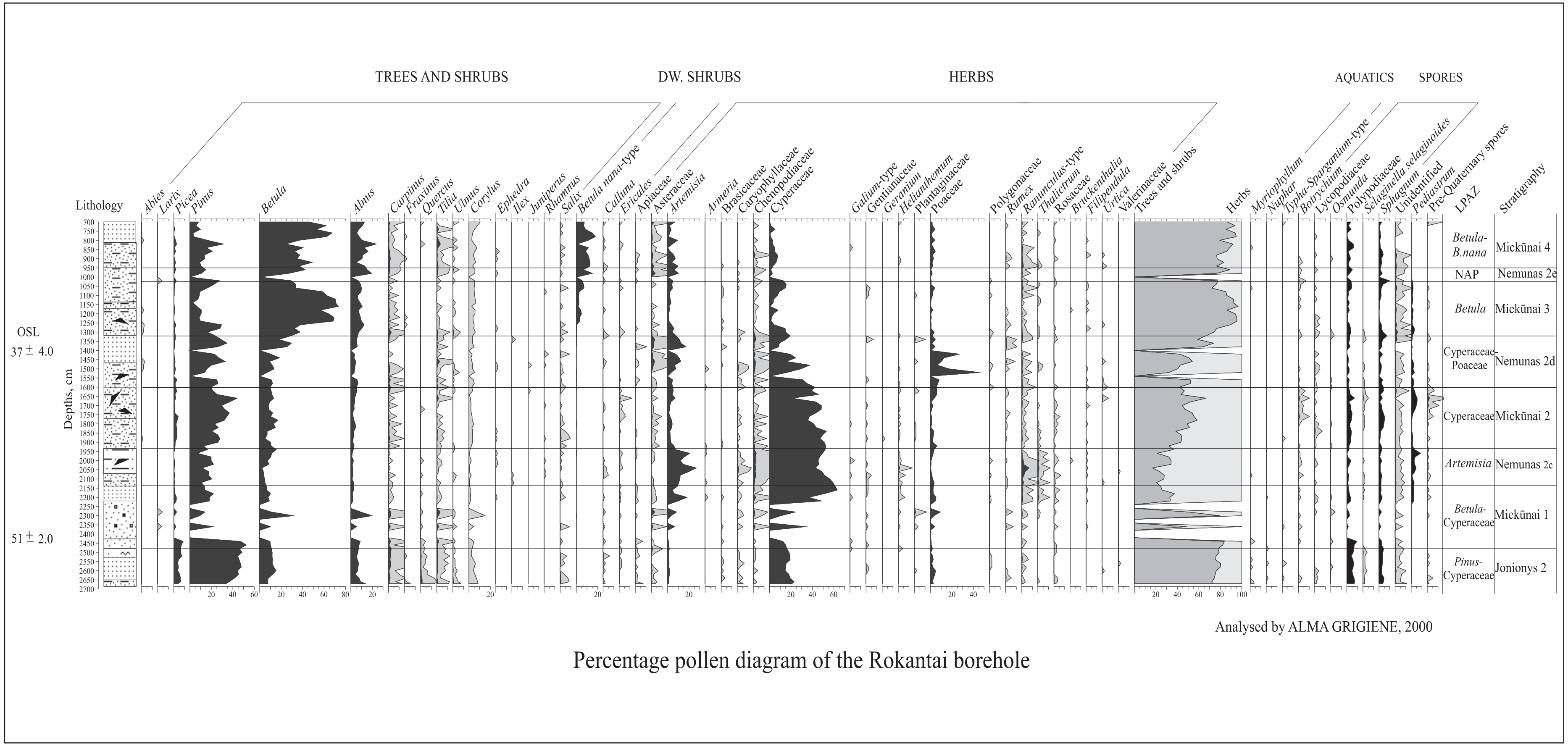

Fig. 4. The pollen percentage diagram of the borehole Rokantai
4 pav. Procentinė žiedadulkių diagrama, Rokantų gręžinys

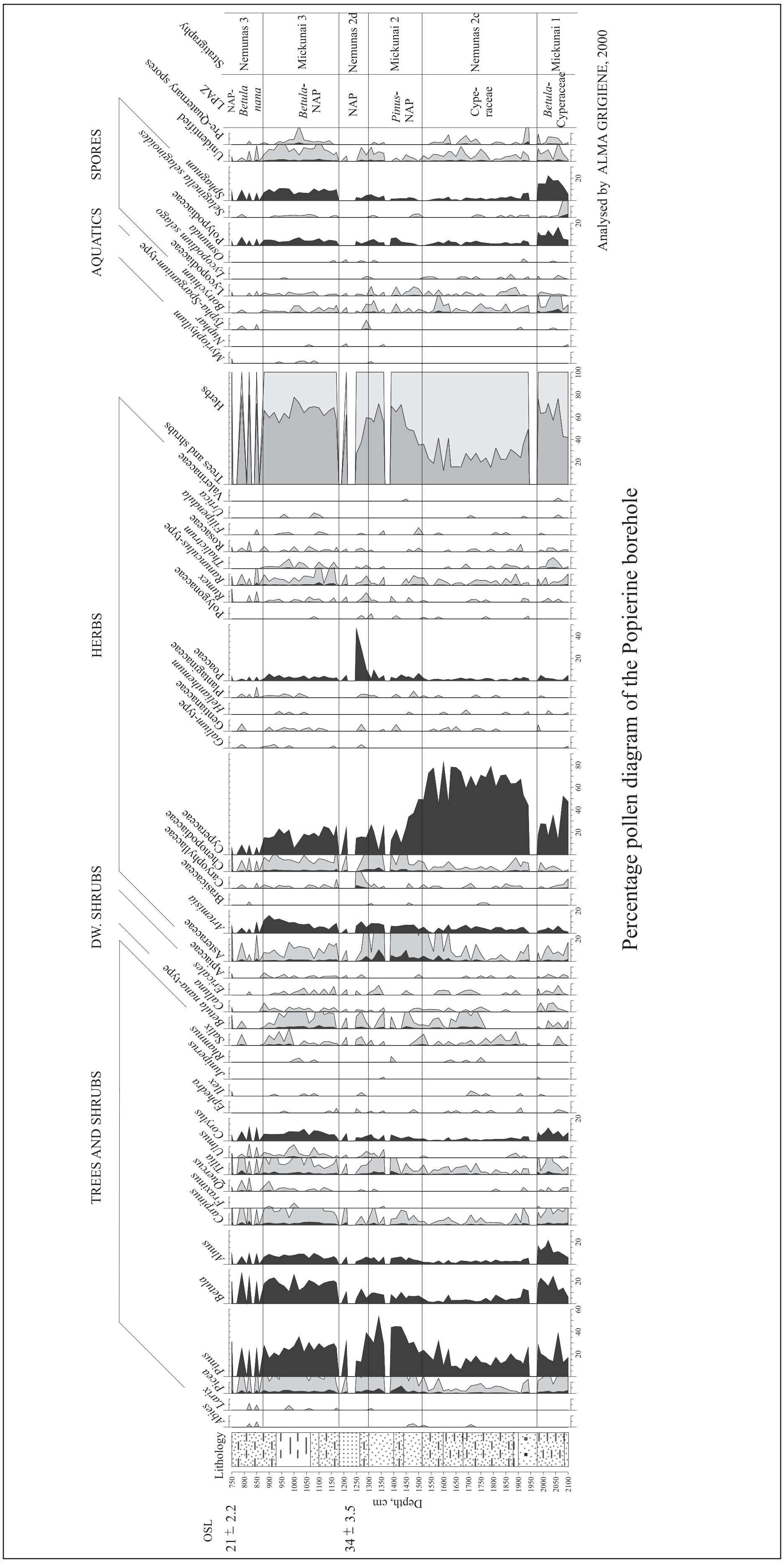

Fig. 5. The pollen percentage diagram of the borehole Popierinė
5 pav. Procentinė žiedadulkių diagrama, Popierinės gręžinys

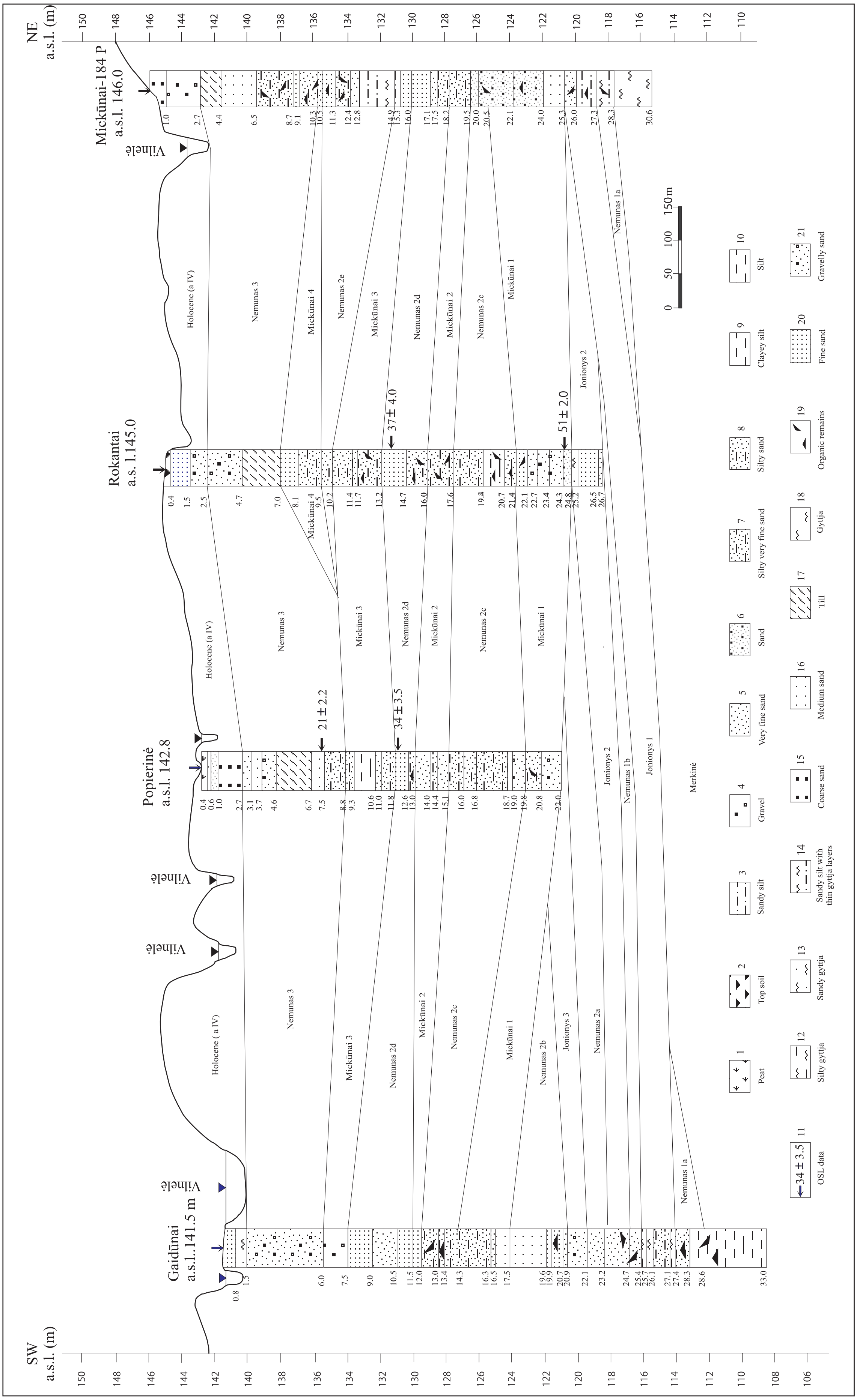

Fig. 6. Stratigraphical interpretation of the Mickūnai site cross-section. For location of the cross-section see Fig. 1
6 pav. Mickūnų ploto geologinio pjūvio stratigrafinė interpretacija. Vieta parodyta 1 pav.

Generalised pollen characteristics of Eemian-Weichselian events are presented below in Tables 1 and 2.

The Merkinė Interglacial and Early Weichselian thermomers are characterised by forest environments. The environmental history of the Merkinė (Eemian) Interglacial (130–117 kyr BP) in Lithuania is well documented (Gaigalas et al., 1994; Baltrūnas, 1995; Gaigalas, Hütt, 1996; Kondratienė, 1996). Data from the Mickūnai site well correspond to Eemian reference sections and imply a continuous forest cover.

The results from the Jonionys site (South Lithuania) (Kondratienė, 1996) clearly demonstrate the

Table 1. **Generalised pollen characteristics of the Eemian–Weichselian events from the Mickūnai palaeolake**
1 lentelė. **Mickūnų paleoežero Emio–Veichselio įvykių apibendrintos žiedadulkių charakteristikos**

Merkinė (Eemian) Interglacial: it is characterized by changes in the vegetation from coniferous forest to broad-leaved forest and back to coniferous forest (spruce, pine). The broad-leaved forest was formed of oak, lime-trees, nut-trees and hornbeam with admixture of alder. The sediments accumulated at the end of Merkinė Interglacial were studied in the area. The spruce and pine pollen are dominant. The herbaceous pollen and spores of *Osmunda* were noted.
Nemunas 1a Stadial: the values of herbs pollen (Cyperaceae, *Artemisia*, Chenopodiaceae) and ericaceous shrubs increase.
Jonionys 1 Interstadial: reflecting pronounced changes in the local vegetation cover. Birch prevails in the beginning of the interstadial and it is replaced by pine in the end of the interstadial. Spruce with some *Picea obovata* spread in the area.
Nemunas 1b Stadial: this stadial is characterized by a decrease in tree pollen and an increase in herbaceous pollen. Among tree pollen *Pinus* and *Betula* are dominant. Cyperaceae reach high values.
Jonionys 2 Interstadial: the values of tree pollen increase up to 95%. The pollen of *Pinus* prevails. *Alnus* is also represented by high frequencies. The pollen of larch (*Larix*) and *Calluna* and spores of *Selaginella selaginoides* are noted.
Nemunas 2a Stadial: tree pollen decreases and constitutes some 60%. *Betula* and *Pinus* predominate among tree pollen. Cyperaceae are dominant among herbaceous pollen.
Jonionys 3 Interstadial: the spectrum of sediments of this interstadial is characterized by increase in tree pollen (up to 90%). *Betula* and *Alnus* are dominant. Herb pollen consists of Cyperaceae, Poaceae, *Artemisia* and Chenopodiacea.
Nemunas 2b Stadial: the percentage values of tree pollen are 60%. *Pinus*, *Betula* and *Alnus* predominate. Cyperaceae and Poaceae represent herbs. Pollen from light-demanding plants, e. g. Caryophyllaceae, *Artemisia*, *Armeria,* Plantaginaceae and spores of *Botrychium* were noted.
Mickūnai 1 Interstadial: *Alnus* is represented by high frequencies in the beginning of the interstadial. *Pinus* values vary between 30 and 60%. The number of *Betula* is low. Cyperaceae and *Artemisia* are dominant among herbaceous pollen. North-boreal mesophytes are present by *Selaginella selaginoides* and *Botrychium boreale*.
Nemunas 2c Stadial: non-tree pollen constitutes 80%. Cyperaceae dominate the taxa. Percentage values of *Artemisia*, Ranunculaceae, Chenopodiaceae, *Helianthemum* increase and indicate an open landscape.
Mickūnai 2 Interstadial: the percentage values of tree pollen slightly increase. *Pinus* and Cyperaceae are dominant among the pollen flora.
Nemunas 2d Stadial: the pollen frequency is very low. NAP is predominant. Poaceae are prevailing. Cyperaceae and *Artemisia* also present large numbers.
Mickūnai 3 Interstadial: *Betula* predominates. The value of herbaceous pollen is considerably low.
Nemunas 2e Stadial: the pollen frequency is low. *Betula* and *Alnus* predominate among tree pollen. Asteraceae, *Artemisia*, Chenopodiaceae represent herbs.
Mickūnai 4 Interstadial: *Betula* is dominant among the tree pollen. This interstadial is marked by increase in *Betula nana* pollen (up to 18%). Herbs pollen consists of Cyperaceae, Poaceae and *Artemisia*

Table 2. **Comparison of Pollen Assemblage Zones (LPAZ) of the studied sections**

2 lentelė. **Žiedadulkių asociacijų zonų palyginimas tarp tirtų gręžinių**

		Gaidūnai	**Popierinė**	**Rokantai**	**Mickūnai-184P**
			Local PAZ		
Merkinė (Eemian)	M4	*Pinus-Picea*			*Pinus-Picea*
	M5	*Pinus*			*Pinus*
Nemunas 1a					*Pinus-Betula*
Jonionys 1		*Pinus-Picea*			*Pinus-Picea*
Nemunas 1b		*Pinus*-Cyperaceae			
Jonionys 2		*Pinus-Alnus*		*Pinus*-Cyperaceae	
Nemunas 2a		NAP-*Betula*		NAP	
Jonionys 3		*Betula-Alnus*			
Nemunas 2b		Cyperaceae-Poaceae			
Mickūnai 1		Cyperaceae	*Betula*-Cyperaceae	*Pinus*-Cyperaceae-*Artemisia*	AP-Cyperaceae
Nemunas 2c		*Artemisia*-Cyperaceae-Poaceae	Cyperaceae	*Artemisia*	Cyperaceae-Poaceae
Mickūnai 2		*Artemisia*	Pinus-NAP	Cyperaceae	*Betula*-Cyperaceae
Nemunas 2d		NAP	NAP	Cyperaceae-Poaceae	Cyperaceae
Mickūnai 3		*Pinus-Alnus*	*Betula*-NAP	*Betula*	*Artemisia*-Cyperaceae
Nemunas 2e				NAP	
Mickūnai 4				*Betula-Betula nana*	Cyperaceae
Nemunas 3			NAP-*Betula nana*		NAP

presence of two thermomers younger than the Eemian (Merkinė) Interglacial. The first two, Jonionys 1 and Jonionys 2, correlate with Brörup and Odderade, respectively. They are rather widely represented in Lithuania and have been identified at several sites – Medininkai, Dysnai, and Smalvos (Satkūnas et al., 1997; 1998). Jonionys 1 and Jonionys 2 interstadials are characterized by forested birch-pine-spruce-larch landscapes with a mild and humid climate.

Interstadials Jonionys 1 and Jonionys 2, however, are represented rather fragmentically at the Mickūnai site, as sedimentation conditions probably were not favourable. The sandy sediments with organic matter were attributed to the Jonionys 1 interstadial in the sections Mickūnai 184P and Gaidūnai. As determined from these sections, the vegetation during the Jonionys 1 interstadial consisted of a coniferous forest, including pine and spruce.

The sandy sediments of Jonionys 2 interstadial are proposed in the sections Rokantai and Gadūnai. Not understandable! This interpretation is based on high values of tree pollen (*Pinus* prevails, *Alnus* is also represented by high frequencies, *Larix* is noted).

The remainder of the Middle Weichselian (Pleniglacial) is much more complicated from the point of view of subdivision into distinct climatostratigraphic events.

The composition and the changes in the pollen flora at the Mickūnai site indicate an open shrubby and herbaceous vegetation with the presence of tree birches, scattered pine and spruces during succeeding Middle Weichselian (Middle Nemunas) cryomers. *Betula nana* was an important component of the plant communities. The reworked pollen grains from the Eemian Interglacial were noted in the sediments. Part of pine pollen could be long-distance transported from south regions.

The Jonionys 3 interstadial is very tentatively determined in the section Gaidūnai and is characterised by *Betula-Alnus* LPAZ. The Jonionys 3 interstadial, originally identified at the Jonionys paleolacustrine site (Satkūnas et al., 1998), was characterized by a dwarf birch forest / tundra palaeoenvironment, that rather well corresponds with the palaeoenvironment recorded in the Gaidūnai section. However, sandy sediments in the latter section must be noted and that could imply unfavourable conditions of pollen accumulation. Nevertheless, the thermomer Jonionys 3, correlating with the Oerel interstadial, can be identified over a much broader region, e. g. in Poland (Roman, Balwierz, 2010) and even in Finnish Lappland (Helmens et al., 2007; Bos et al., 2009).

Interpretation of the Mickūnai 1 thermomer is proposed in all boreholes. The sandy sediments are characterised by Cyperaceae, *Betula*-Cyperaceae, *Pinus*-Cyperaceae-*Artemisia* LPAZ, indicating open surrounding palaeoenvironments.

The OSL datings give rather valuable information on the geochronology, however, interpretation of the datings has to be carried out in the context of the pollen data and broader correlation. The OSL date of the Mickūnai 1 cryomer in the section Rokantai gives an age of the sand 51 ± 2.0 kyr and this date well corresponds to the geochronological framework of MIS 3 (Behre, 1989). It is noteworthy that the marine sandy complex offshore Šventoji (located on the Baltic coast of Lithuania) dated by OSL at 48.8 ± 6.2 kyr – 43.7 ± 4.0 (Damušytė et al., 2011) is of similar age. In broader context, the sediment succession of Ruunaa (eastern Finland) indicates an ice-free period around 50–25 kyr ago (Lunkka et al., 2008). A shallow fresh water basin was mapped and dated 52–24 kyr in western Latvia (Saks et al., 2012).

Similarly, the Mickūnai 2 thermomer is proposed in all studied boreholes and this interpretation is based on the pollen data, indicating slight paleoenvironmental amelioration. Similar interval dated by U/Th to ca. 42 kyr BP was identified in the Medininkai 117P section (located in distance of some 20 km to the east from the Mickūnai site) and correlated with the Hengelo Interstadial (Satkūnas et al., 2003). This interstadial represents only a minor climatic amelioration with formation of shrub tundra (Behre, 1989). Possibly, the Mickūnai 3 thermomer can be correlated with the interval of ice-free lacustrine conditions between 44 and 37 kyr ago that were reported from the Arumetsa quarry (south-west Estonia) (Rattas et al., 2010).

The Mickūnai 3 thermomer is also recorded in all sections on the basis of the pollen data (*Pinus-Alnus, Betula*-NAP *Betula* and *Artemisia*-Cyperaceae LPAZ). This interpretation is supported by OSL dates of underlying sand that was dated to 37 ± 4.0 kyr (Rokantai) and 34 ± 3.5 kyr (Popierinė). Thus the Mickūnai 3 thermomer, being younger than the underlying dated sandy interval, is close to the Denekamp Interstadial which is described from a number of sites in the Netherlands and Germany and is characterised by treeless, shrub tundra landscapes (Kolstrup, Wijmstra, 1977; Behre, 1989; Bos et al., 2001).

In the regional context, an interval similar to the Mickūnai 3 thermomer, as recorded in the Mickūnai site, according to the pollen and spores data was identified in the Medininkai 117P section (Satkūnas et al., 2003). Lacustrine sediments from the Purviai outcrop (located in the north-west Lithuania) were radiocarbon dated to ca. 34 kyr BP and that section was interpreted as the Mickūnai 3 thermomer and tentatively correlated with the Middle Weichselian Denekamp Interstadial (Satkūnas et al., 2009). Furthermore, palaeoenvironmental data from the north-eastern Estonia (Voka outcrop) characterising the time span 35–32 kyr (IR-OSL datings) evidence that periglacial tundra palaeoenvironment stayed in this region (Molodkov et al., 2006).

The Mickūnai 4 thermomer is tentatively proposed in the sections Rokantai and the Mickūnai 184P as slight palaeoenvironmental amelioration according to the pollen data.

The dated sand of 21 ± 2.2 kyr ago in the section of the borehole Popierinė below the till of the Late Weichselian well corresponds to lithostratigraphical interpretation.

CONCLUSIONS

The climatostratigraphic subdivision and palaeogeographic interpretation of the Middle Weichselian (Middle Nemunas) are very disputable all over Europe. Due to the erosion impact during the Late Weichselian glaciation the Middle Weichselian sediments are very limited or missing. Therefore each site with Middle Weichselian sediments is very important for the reconstruction of climatostratigraphy of this time interval.

An extensive area of distribution of palaeolacustrine sediments (sand, silt with humus and interlayers of gyttja), occurring above the Eemian (Merkinė) Interglacial deposits and under the relief forming the Upper Weichselian till, is mapped in the Mickūnai glaciodepression.

These sediments were interpreted as being formed in a shallow palaeolake or lacustrine system, which occupied the depression during the Early-Middle Weichselian.

On the basis of the lithological composition and pollen and spores, the studied sections were tentatively subdivided into thermomers (time periods with relatively warmer climate) and cryomers (time intervals with colder periods). In the Mickūnai site there 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 that reached East Lithuania most probably not earlier than ca. 21 kyr BP.

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EMIO–VEICHSELIO PALEOAPLINKOS TYRIMAI MICKŪNŲ LEDYNINĖJE ĮDUBOJE (RYTŲ LIETUVA)

Santrauka

Mickūnų įduboje plačiai paplitusios senosios ežerinės nuogulos (smėlis, aleuritas su humusu ir gitijos tarpsluoksniais) glūdi tarp Emio (Merkinės) tarpledynmečio sluoksnio (apačioje) ir reljefą formuojančių viršutinio Veichselio (Nemuno) morenų (viršuje) Vilniaus apylinkėse (Rytų Lietuva).

Šios nuogulos susiklostė sekliame paleoežere ar ežerų sistemoje, kuri susiformavo vidurinio–viršutinio Veichselio įduboje.

Mickūnų įdubos viduryje buvo išgręžti keturi gręžiniai. Nuosėdos ištirtos panaudojant litostratigrafinę ir žiedadulkių analizę, o datuotos stimuliuotos liuminescencijos (OSL) metodu.

Remiantis litologine sudėtimi bei žiedadulkių ir sporų tyrimais, pjūvyje buvo išskirti šiltesnio (termomerai) ir šaltesnio klimato laikotarpiai (kriomerai). Mickūnų plote virš Emio tarpledynmečio uolienų buvo išskirti septyni termomerai ir aštuoni kriomerai. Vidurinio Veichselio termomerai buvo nustatyti tik pagal nedidelius klimato pokyčius bendrame klimato atvėsimo fone.

Mickūnų pjūviai atskleidė neledyninę paleoaplinką nuo Emio tarpledynmečio iki viršutinio Veichselio ledyno atslinkimo.

Raktažodžiai: ankstyvasis–vidurinis Veichselis, žiedadulkės, vėlyvasis pleistocenas, Rytų Lietuva, paleoežerinės nuogulos