Palaeoenvironmental changes in the environs of Žadeikiai Bog, NW Lithuania, during the Late Glacial and the Holocene according to palaeobotanical and ^{14}C data

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Palaeoenvironmental studies combining pollen records, survey of plant macrofossils, diatom investigations and conventional radiocarbon dates (^{14}C) were applied in the Žadeikiai bog. The sediments found at the bottom of the sequence, which consists of organic and clastic material, were redeposited before the Younger Dryas and the rest part of the section cover all the Holocene chronozones. Since 7200 BP *Picea* became an important component of the forest successions. Periods of the lake bogging (Preboreal–Boreal, the second half of the Late Subboreal and the second half of the Subatlantic) were changed by the high water level (Atlantic and Early Subatlantic). The palaeobasin with eutrophic signs, which existed during the Younger Dryas, became of oligotrophic–mezotrophic type at the beginning of the Holocene and acquired eutrophic features at its end.

Keywords: pollen and plant macrofossils, diatoms, palaeoenvironment, Late Glacial and Holocene, NW Lithuania

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INTRODUCTION

Complex investigations of the post-glacial sediments in the Žadeikiai bog provided new data on the Late Glacial and Holocene environmental history of Northwest Lithuania. Earlier palinological investigations were mainly applied to stratigraphical research of the interglacial sediments here (Kondratienė, 1998). Most of pollen diagrams of the Post-Glacial were published a few decades ago and presented a general overview of the vegetation history without the ^{14}C dates (Sudnikavičienė, 1963–1964; Vaičvilienė, 1976). Recent palaeobotanical investigations applied in parallel with the archaeological survey have provided new data explaining vegetation development and human activity in the surroundings of hillforts (Risberg et al., *in preparation*).

Geological mapping at a scale of 1:50000 in Ylakiai area (Damušytė ir kt., 2002) provided an excellent possibility to expand our knowledge of the environmental changes in this part of Lithuania throughout the Late Glacial and the Holocene.

THE STUDY AREA

The Žadeikiai bog with the study section (56°10'14" N, 21°58'45" E) (Fig. 1) is situated in Northwest Lithuania at the transition zone between the Middle Žemaičių and west Kurzeme Highlands (Basalykas, 1965). Rinas and valleys filled with sand, silt, gyttja and peat adds variety to the gently undulating landscape formed by the glacigenic deposits of the Upper Nemunas (Late Weichselian) age. In the territory glacigenic deposits predominate, while sediments of

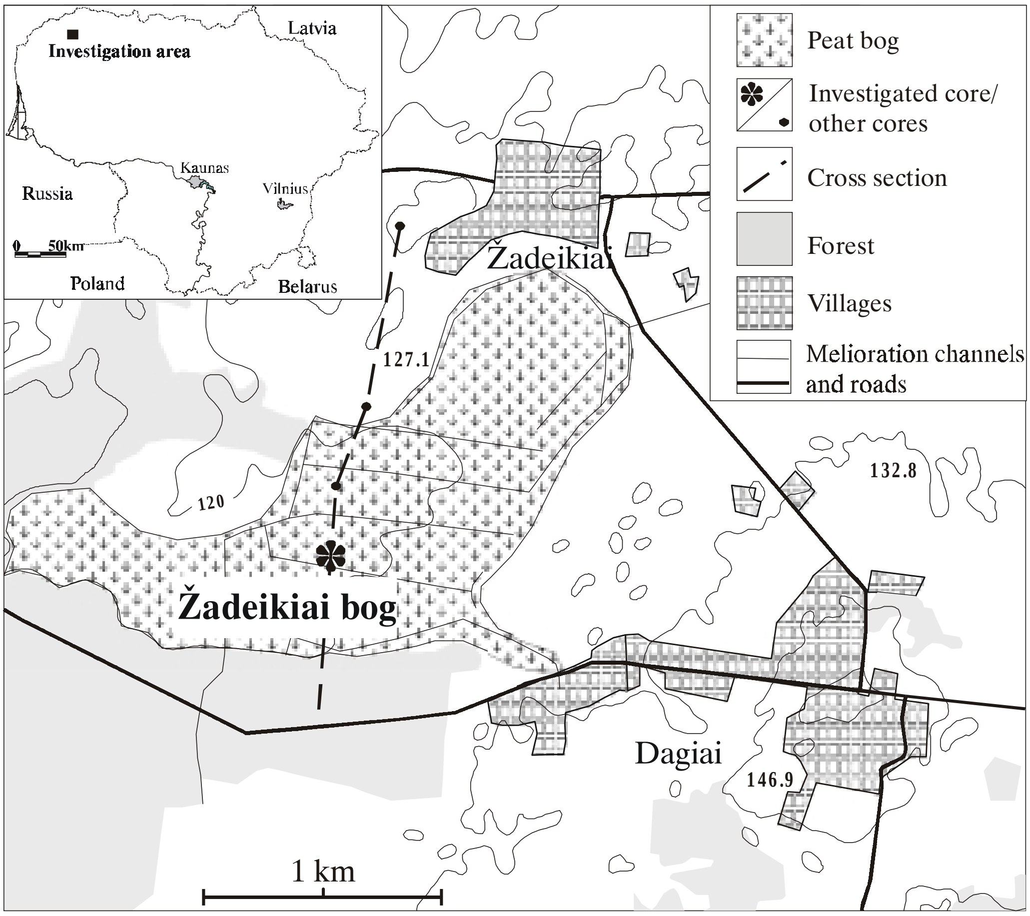

Fig. 1. Situational scheme of Žadeikiai bog
1 pav. Situacinė schema

glaciolacustrine origin as well as the glaciofluvial ones are common in the lowerings (Damušytė ir kt., 2002). Well expressed slopes of the valleys or lakes are covered with deluvium.

The altitude of the Žadeikiai bog is 118–120 m, it covers about 192 ha and the biggest depth of the organic sediment reaches 9 m (Lietuvos durpynų kadastras, 1995). In the seventh decade of the last century the bog was ameliorated, and vast areas of meadows and agricultural fields appeared. Surrounded by spruce and pine forest, a bog is overgrown with alder, willow and birch in wet places. Over the last years the intensity of agriculture reduced and areas formerly used for pastures and agriculture began to overgrow.

METHODS

Coring and sampling

Sediments of the Žadeikiai bog were cored using a Russian corer, and samples from the 6 m sequence (Fig. 2) were collected for microbotanical investigations. One sample covers a 5-cm interval. The parallel sediment core was sub-sampled at 10 cm intervals for plant macrofossil survey and ^{14}C dating.

Pollen analysis

Chemical preparation followed the standard way described by V. P. Grichiuk (1940) and G. Erdtman (1936) with modifications suggested by J. Stockmarr (1971). More than 1000 terrestrial pollen grains were counted per sample, and the sum of arboreal (AP) and non-arboreal (NAP) taxa was used to calculate the percentage of the spectra. Chronostratigraphical zonation of the pollen diagram is based on available ^{14}C dates (uncalibrated BP) and changes of the local pollen assemblage zones (LPAZ). Microscopic charcoal particles were counted in parallel with pollen. The identification of pollen and spores was based on K. Fægri and J. Iversen (1989), P. D. Moore, J. A. Webb and M. E. Collinson (1991) and D. Moe (1974).

All the spreadsheets and diagrams were plotted with TILIA (version 2) and Tilia GRAPH (version 2.0 b.5) (Grimm, 1990).

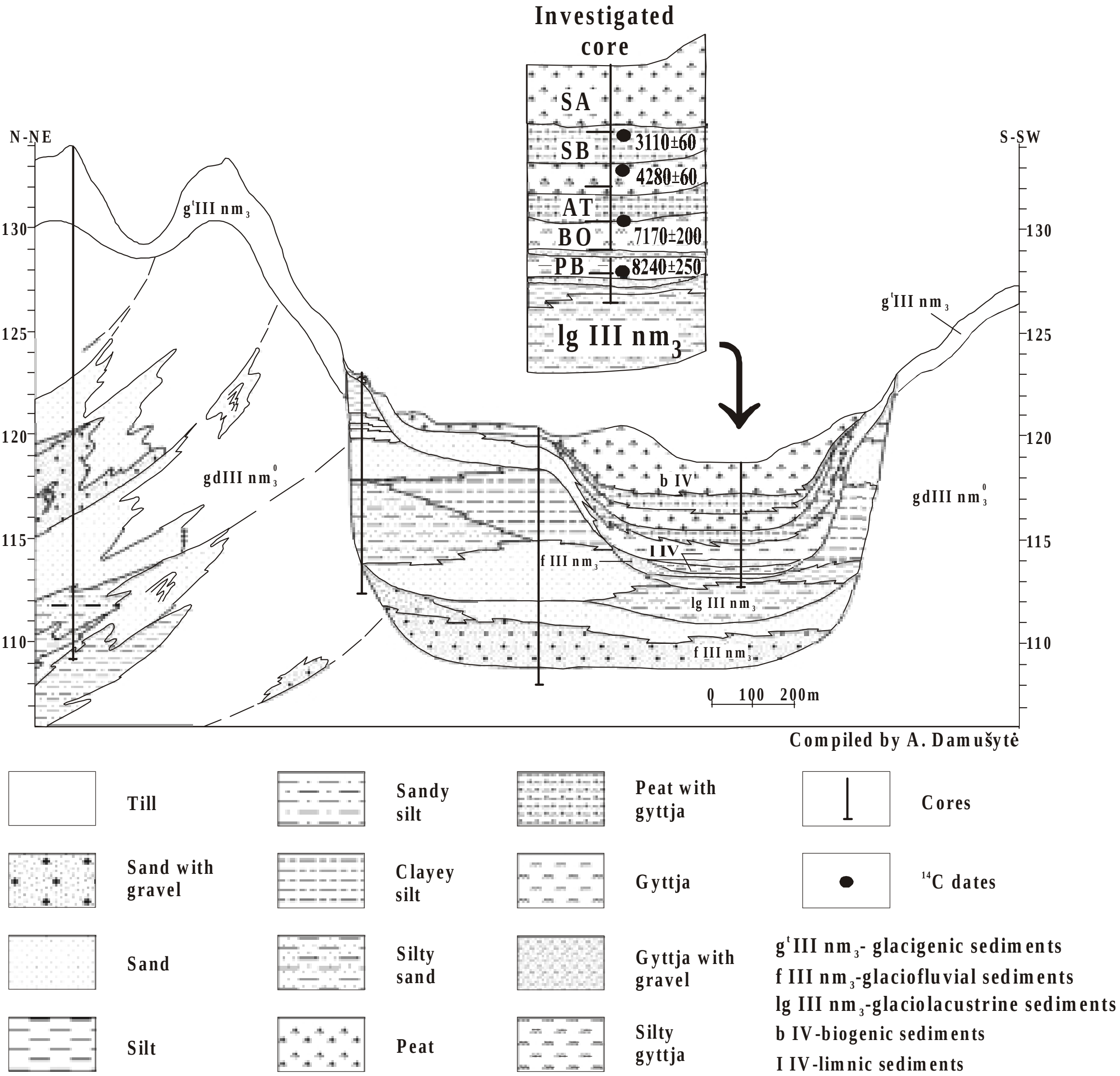

Fig. 2. Geological cross-section of Žadeikiai bog (compiled by A. Damušytė)
2 pav. Geologinis Žadeikių pelkės nuosėdų pjūvis (sudarė A. Damušytė)

Plant macrofossil investigations

Samples for plant macrofossil analysis were taken from the core 550 cm deep. Alltogether, 0.5-litre 22 samples covering 10 cm each (with 20 cm gaps) were investigated. Samples were sieved through screens, mesh size 0.25 mm. Macroscopic plant remains were picked from the resulting residues using a low-power binocular microscope. Identification of plant macrofossils was based on W. Beijerinck (1947), A. Grigas (1986), F. J. Velichkevich (1973) and P. J. Dorofejev (1986) in combination with the plant macrofossil collection of the Institute of Geology and Geography and a seed collection of modern plants belonging to author. The results are presented in Table (absolute quantity of macrofossils). Taxa have been sorted into habitat classifications to aid interpretation and reconstruction of the past vegetation and palaeoenvironment. Analysis of the flora composition served as a basis for stratigraphical interpretation of the data. The evolution of the phytocoenoses and the peculiarities of the sedimentary basins as well as the impact of geological and palaeogeographical factors on flora were studied.

Diatom analysis

Diatoms were extracted from the sediments in the conventional manner (Battarbee, 1986). Besides, to remove mineral matter, flotation in heavy liquids was employed. The samples were centrifuged in S. G. 2.4 solution (potassium iodide (KI) and cadmium iodide (CdI_2)) for about 10 min at 1.000–1.500 rpm. The supernatant containing the diatoms was decanted and collected. The diatoms then were recovered by diluting the supernatant with distilled water and mounted into the Naphrax Liquid. The diatoms were examined under an MBI-6 light microscope (LM) with an oil immersion objective at a magnification of 1000. A total of 500 frustules were counted in the central part of each slide. Identification to species was based on the K. Krammer and H. Lange-Bertalot (1988; 1991 a, b; 1997) as well as N. Hustedt (1991).

Diatoms react sensitively to changes in environmental conditions – basin depth, water salinity, acid and alkali balance (pH). Separate ecological diatom groups were examined upon the taxa composition.

Three groups were identified in the areas populated by the diatoms: plankton-, overgrowth-, and benthic-type diatoms; the percentage of each group was also calculated.

The following groups of diatoms were identified according to their reaction to the palaeobasin water acidity (pH value): alkaliphilous (favouring pH>7), alkalibiontic (living under pH>7 only), indifferent (living independently of the pH value), acidophilous (favouring pH<5.5, but able to live under pH<7 as well) (Lowe and Walker, 1997).

The following groups were identified according to the fresh-water diatom salt favourability: halophilous (salt-favouring diatoms), neutrophilous (living both in salty and fresh water) and halophobic (living in fresh water only).

Identification of separate ecological diatom groups was a basis for defining the local diatom zones. The obtained taxon composition results were of significant value for the restoration of the palaeoecological conditions of the former lake in the Žadeikiai bog, water level fluctuations of the lake in the course of time, eutrophication, both natural and anthropogenic, and pollution. The percentage pollen diagram and ^{14}C data is the basis for the chronostratigraphic division of the section.

RESULTS

Lithology

The sequence studied consists of clastic, limnic and biogenic material. The detailed lithology of the cores is shown in Table 1 and accompanies all the diagrams.

Table 1. **Lithology of the Žadeikiai core**
1 lentelė. **Žadeikių pjūvio litologinė sudėtis**

Depth, cm	Lithology
0–150	Brown *Sphagnum* peat
150–245	Dark brown peat with gyttja
245–333	Black peat
333–393	Dark brown peat with gyttja
393–475	Black gyttja
475–484	Black gyttja with gravel
484–545	Greyish silty gyttja
545–551	Coarse grained sand
551–581	Greyish silt
581–600	Silty fine grained sand

Chronology

The chronostratigraphical subdivision of the section was supported by four conventional ^{14}C dates (Table 2). Samples were dated in the Radioisotope Studies Laboratory of Institute of Geology and Geography, Vilnius. The dating was focused on the natural evidence, such as changes in sedimentation conditions (520–530 cm, 8240 ± 250 ^{14}C BP), the rational limit of the *Picea* curve (390–400 cm, 7170 ± ± 200 ^{14}C BP) and establishing new vegetation successions (180–190 cm, 3110 ± 60 ^{14}C BP). Sediments with apophytic taxa were studied (270–280 cm, 4280 ± 60 ^{14}C BP).

In the text, uncalibrated ^{14}C age (BP) is used.

Table 2. **^{14}C (BP) and calibrated (cal AD/cal BC) dates of the Žadeikiai profile**
2 lentelė. **Nekalibruotos ^{14}C (BP) ir kalibruotos (cal AD/cal BC) Žadeikių pjūvio datos**

Depth, cm	Uncalibrated ^{14}C, years BP	Calibrated time (1σ range)	Laboratory code	Dated material	Dating object
180–190	3110 ± 60	BC 1427–1298	Vs-1287	Peat with gyttja	New vegetation type
270–280	4280 ± 60	BC 2926–2868	Vs-1283	Peat	Rise of the apophytic taxa
390–400	7170 ± 200	BC 6179–5792	Vs-1288	Peat with gyttja	Earliest *Picea* peak
520–530	8240 ± 250	BC 7508–6996	Vs-1302	Gyttja	Changes in sediment type

Pollen stratigraphy

The pollen material has been described in terms of local pollen assemblage zones (LPAZ) and correlated with the pollen zones determined for the territory and chronozones of Lithuania (Mangerud et al., 1974; Kabailienė, 1998). The pollen diagram from the Žadeikiai succession is divided into 8 LPAZs (Fig. 3).

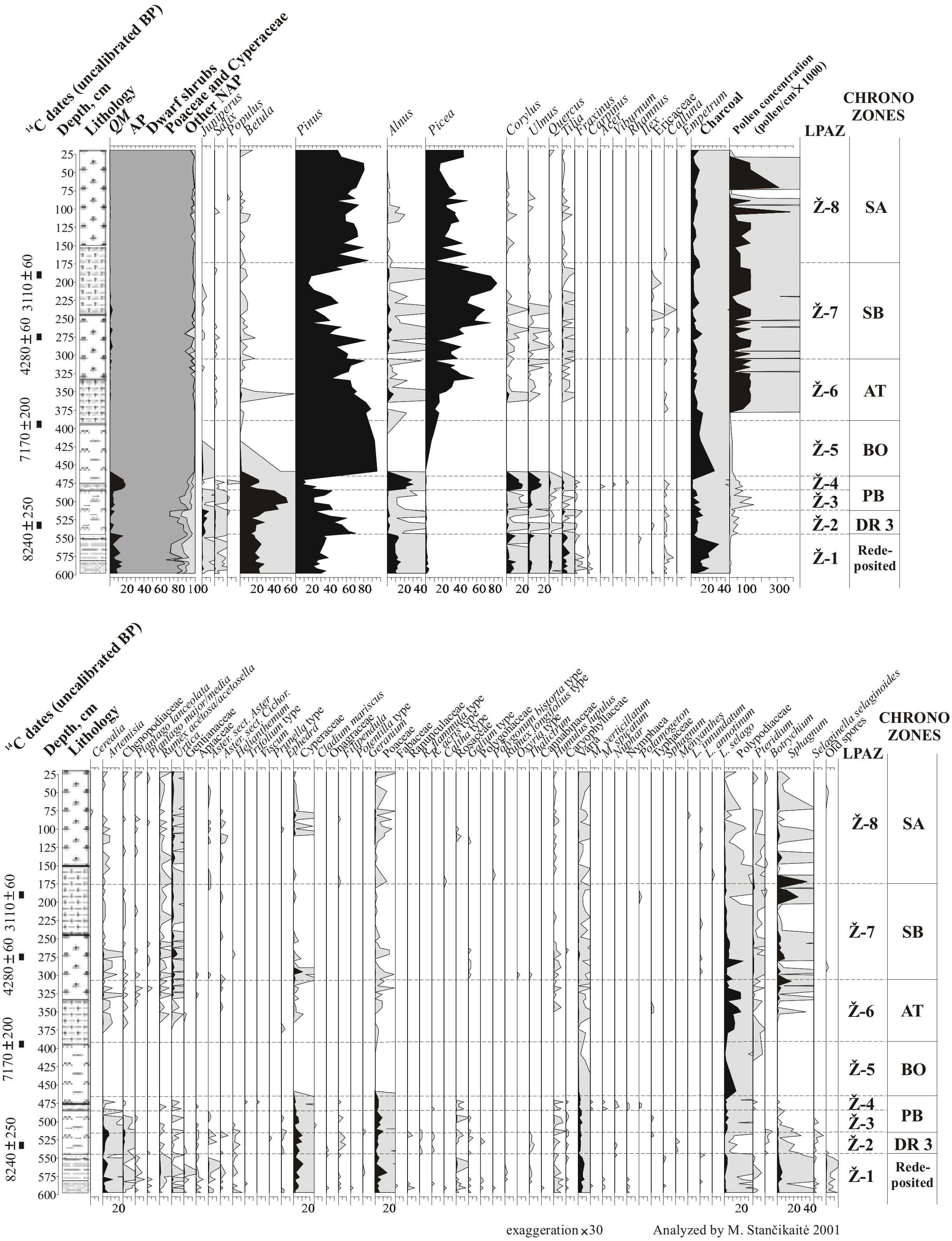

Fig. 3. Percentage pollen diagram, Žadeikiai bog (for lithological explanations, see Fig. 2)
3 pav. Procentinė Žadeikių pelkės nuosėdų sporų ir žiedadulkių diagrama (litologinė nuosėdų sudėtis nurodyta 2 pav.)

Ž–1 LPAZ (*QM–Alnus*; 600–545 cm), redeposited interval – Late Glacial?

The high frequency of *QM* (up to 15%) characterized this zone. *Tilia* (9%) is best represented among the thermophylous species. *Alnus* reaches 15.8%, and a continuous *Corylus* curve occurred. Cyperaceae and Poaceae are best represented among non-arboreal (15%) taxa. Heliophytic taxa (*Artemisia*, Chenopodiaceae, *Rumex acetosa/acetosella* and *Urtica*) are continuously represented throughout this zone. Polypodiaceae, *Sphagnum* and pre-Quaternary spores have their rational limits in this zone. Charcoal representation reaches 32.5%, which is an absolute maximum. Pollen concentration is very low (max. 52.6 × 10^3 pollen/cm^3).

Ž–2 LPAZ (*Pinus–Juniperus–Artemisia*; 545–520 cm), Younger Dryas

The increasing value of the *Pinus* (up to 70.9%) is the main feature characterizing the pollen spectra of this zone. *QM* nearly disappeared from the spectra, as *Alnus* and *Corylus* did. Light-demanding *Juniperus* (6%), *Salix* (1%) and *Calluna* increased in representation. The total NAP value dropped down at the beginning of the zone, but a certain rise appears, reaching the upper limit. The diversity of the non-arboreal species increases considerably, and *Artemisia*, Poaceae as well as Cyperaceae are best represented. *Nuphar* and Typhaceae pollen grains were found. *Selaginella selaginoides* and *Botrychium* occurred, but other spores decreased in number. Pollen concentration increased up to 202 × 10^3 pollen/ /cm^3.

Ž–3 LPAZ (*Betula*; 520–478 cm), Preboreal

Betula culmination (55.9%) characterized this zone. Some regeneration was registered in *QM* representation where *Ulmus* shows 15%. The diversity and representation of NAP decreased, especially in the second half of the zone. Simultaneously, the number of aquatic taxa increased and pollen grains of *M. verticillatum*, *M. spicatum*, *Nuphar*, Nymphaea, *Potamogeton* and *Typha* were found. The number of charcoal pieces decreased. Pollen concentration reaches 508 × 10^3 pollen/cm^3 in the first half of the zone and gradually decreases.

Ž–4 LPAZ (*Alnus–Corylus–Ulmus*; 478–473 cm), Preboreal

A rise in deciduous tree representation is characteristic of this zone. *Alnus* reaches 30.4%, *Corylus* 18.6% and *Ulmus* 15.8%. The increasing numbers of *Betula*, *Quercus* and *Tilia* curves have been registered. The amount of *Pinus* pollen (8.8%) is the lowest throughout the whole diagram. The number and diversity of NAP decrease in this zone. An especially low spore count was registered, and the same is true for charcoal representation. Pollen concentration is similar to that registered in the previous zone.

Ž–5 LPAZ (*Pinus*; 473–406 cm), Boreal

Pinus culminates (96%) in this zone. *Juniperus* shows 1.6% and *Betula* reaches 22.1%. A gradually rising *Picea* curve is registered. NAP representation is imperceptible and Polypodiaceae are best represented in spores. Pollen concentration is low in this zone (min. 40 × 10^3 pollen/cm^3).

Ž–6 LPAZ (*Picea–Pinus*; 406–306 cm), Atlantic

A rising *Picea* curve, which reaches the rational limit at a depth of 328 cm is the main component of the pollen spectra. *Pinus* representation gradually decreases, and the number of deciduous trees (*Alnus*, *Betula*, *Ulmus* and *Tilia*) is very low. NAP increases: *Artemisia*, *Rumex acetosa/acetosella* and *Urtica* are common in the spectra. The rest species are represented sporadically. Polypodiaceae, *Sphagnum* and *Pteridium* are best represented. The charcoal value varies from 2.3% to 13.9%. Pollen concentration reaches 13181 × 10^3 pollen/cm^3.

Ž–7 LPAZ (*Picea*; 306–175 cm), Subboreal

Picea culminates in this LPAZ (83.8%). The rest trees, both deciduous and coniferous species, nearly diminish from the spectra. NAP shows 12.2%, and *Urtica* is the best represented species. Scattered pollen grains of aquatic plants occurred. *Sphagnum* and Polypodiaceae predominate among spores. The charcoal value is low (max. 12.9%), and the pollen concentration similar to that registered in the previous zone.

Ž–8 LPAZ (*Pinus*; 175–19.5 cm), Subatlantic

Pinus (85.4%) plays the dominant role in spectra. *Picea* representation decreases and shows 49.4%. A minor representation of NAP (max. 5.8%) is registered. Charcoal representation is equal throughout this zone. Pollen concentration culminates in the second half of the zone (37884 × 10^3 pollen/cm^3).

Plant macrofossils

In total, 34 plant taxa are recorded and 22 identified to species level (Table 3). Many of the plant macrofossils are well preserved. The concentration of plant macrofossils varies throughout the core, but is the highest in the upper part.

In the gyttja layer (540–330 cm) the concentration of plant macrofossils is low. Only macrofossils of aquatic plants (8 taxa) were recorded here (Table 3, Fig. 4). Some of the taxa (*Najas marina* L., *Nymphaea alba* L. and *Potamogeton perfoliatus* L.) suggest that water could have been about 3 m deep (Preston and Croft, 1997), although there are species as *Potamogeton filiformis* Pers. growing in shallow habitats, so the depth of the basin most probably was about 1–2 m. The finds of *Chara* oosporangia indicate that water conditions were calcareous and the presence of taxa such as *Nuphar lutea* L., *Nym-*

Table 3. **Macrofossils found in sediments of Žadeikiai section**
3 lentelė. **Augalų makroliekanų lentelė**

Groups	Taxa	Type of remains	Depth, cm															***Sum***
			00–10	20–30	50–60	80–90	110–120	140–150	200–210	230–240	260–270	320–330	350–360	380–390	470–480	530–540	540–550	
Woodland & scrubland	*Picea* sp.	Needles	1	1		2	10											***14***
		Seeds	1			1	1		1									***4***
	Betula pendula Roth	Squama				1												***1***
	Betula sect. *Albae*	Seeds	12	7	15	33	13	2	1		1	1						***85***
	Alnus glutinosa (L.) Gaertn.	Friut									1							***1***
	cf. Salix	Leaves										3						***3***
	Tilia sp.	Fruit								1								***1***
	Sum of remains		***14***	***8***	***15***	***37***	***24***	***2***	***2***	***1***	***2***	***4***						***109***
	Sum of taxa		***2***	***2***	***1***	***3***	***2***	***1***	***2***	***1***	***2***	***2***						***18***
Aquatic	*Chara* sp.	Oospores														13	1	***14***
	Nymphaea alba L.	Seed										1						***1***
	Nuphar lutea Sm.	Seeds												2				***2***
	Hippuris vulgaris L.	Fruit											1					***1***
	Potamogeton filiformis Pers.	Endocarps													2	2		***4***
	Potamogeton perfoliatus L.	Endocarps													2			***2***
	Potamogeton vaginatus Turtcz.	Endocarps														2		***2***
	Najas marina L.	Seed													1			***1***
	Sum of remains										***1***	***1***	***2***	***5***	***17***	***1***	***27***	
	Sum of taxa										***1***	***1***	***1***	***3***	***3***	***1***	***8***	
Plant of wetlands and shores	*Bryales* gen.	Branches					1											***1***
	Equisetum	Stems		2														***2***
	Ranunculus sp.	Fruit			1													***1***
	Rumex aquaticus L.	Fruit		1														***1***
	Andromeda polifolia L.	Fruits							3	32	7							***42***
		Leaves									4							***4***
	Chamaedaphne caliculata (L.) Moench	Seeds					5											***5***
	Comarum palustre L.	Seeds	2				2					3	1					***8***
	Cicuta virosa L.	Fruits				1						2						***3***
	Lycopus europaea L.	Fruits										5						***5***
	Menyantes trifoliata L.	Seeds	1					2							1			***4***
	ef. *Pedicularis palustris*		1	1														***2***
	Carex cf. *elongata* L.	Fruits				1	2					10						***13***
	Carex diandra Schrank	Fruits	30	29	17	31	5											***112***
	Carex pseudocyperus L.	Fruits										16						***16***
	Carex sp. div.	Fruits	9	3	4	1	1	1	1			23						***43***
	Sum of remains		***43***	***36***	***22***	***34***	***16***	***3***	***4***	***32***	***11***	***59***	***1***		***1***			***262***
	Sum of taxa		***5***	***5***	***3***	***4***	***6***	***2***	***2***	***1***	***2***	***6***	***1***		***1***			***15***
Unclassified	*Stellaria graminea* L.	Seed		7		7												***14***
	Fragaria vesca L.	Fruit	1															***1***
	Potentilla sp.	Fruit										1						***1***
	Poaceae	Fruit			1													***1***
	Indeterminate	Fruits	4															***4***
	Sum of remais		***5***	***7***	***1***	***7***						***1***						***21***
	Sum of taxa		***1***	***1***	***1***	***1***						***1***						***5***
Total sum of remains			***62***	***51***	***38***	***78***	***40***	***5***	***6***	***33***	***13***	***65***	***2***	***2***	***6***	***17***	***1***	***419***
Total sum of taxa			***8***	***8***	***5***	***8***	***8***	***3***	***4***	***2***	***4***	***10***	***2***	***1***	***4***	***3***	***1***	***71***

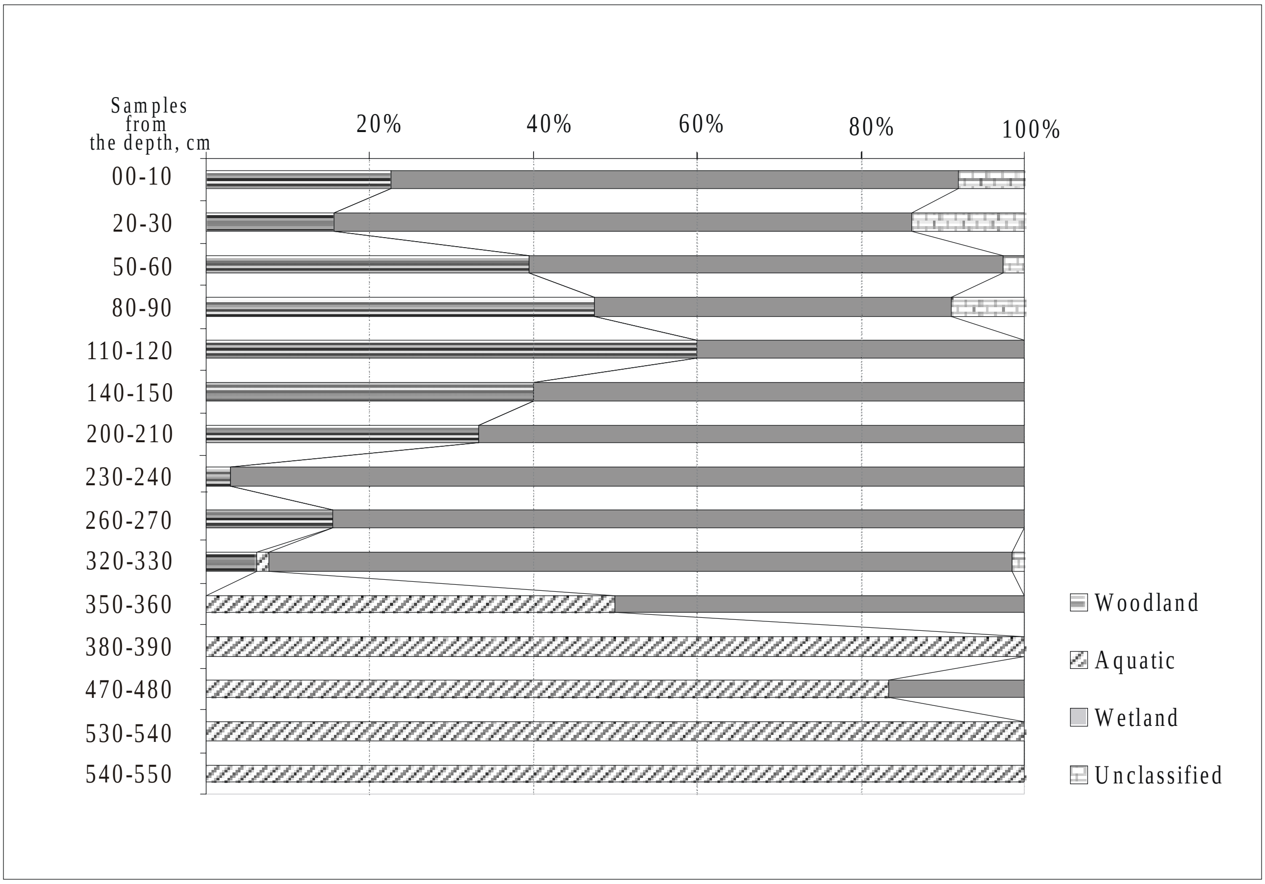

Fig. 4. Plant macrofossils diagram
4 pav. Augalų makroliekanų diagrama

phaea alba L. and *Potamogeton perfoliatus* L., suggest an eutrophic water status (Keen et al., 1999) at a depth of 480–320 cm. *Potamogeton vaginatus* Turtcz. is represented by endocarps appearing at a depth of 530–540 cm. According to the present distribution of this plant in Scandinavia and East Siberia, it is possible to suggest that climate was colder in the Lithuanian territory when the sediments were depositing. Macrobotanical assemblages discovered in the upper part of the interval (320–480 cm) suggest improvement of the climatic conditions at the time of the bed formation.

Further up the core, the 140–320 cm interval is characterised by appearance of deciduous trees (*Tilia* sp., *Alnus glutinosa* (L.) Gaertn and *Betula* sect. *Albae*) and remains of a typical bog plant (*Andromeda polifolia* L.). No macrofossils of aquatic taxa were found above 320 cm (Fig. 4). That could be related to a wider distribution of trees, which occupied the new habitats close to the sampling point. Most probably it was abrupt water changes and the subsequent formation of a peat bog that initiated these fluctuations.

The highest concentration of plant macrofossils (especially remnants from woodland and wetland plant taxa) occurred in the interval above 140 cm (Table 3, Fig. 4). Here *Picea* sp. together with *Betula* sect. *Albae* are well represented, suggesting that the conditions were especially favourable for these trees. Therefore remains of wetland and shore plants are most common in these sediments. *Carex* predominates in this group. The purely shore plants *Cicuta virosa* L., *Comarum palustre* L., *Rumex aquaticus* L. and the uliginous plants *Menyanthes trifoliata* L. together with *Chamaedaphne caliculata* (L.) Moench are recorded here. *Fragaria vesca* L. and *Stellaria graminea* L. belong to the natural vegetation of sunny, open, or shadowed forest slopes. Macrofossils of these plants are found in the upper part of the core (0–90 cm).

Diatom stratigraphy

The diatom diagram (Fig. 5a, 5b) was based on the percentage diatom structure, which defines nine local diatom assemblage zones (LDAZ) upon the ecological diatom groups. In the lower part of the section, between 520–600 cm, either no diatom or just several shell fractures were found. In the upper part of the section, *i.e.* between 18–515 cm, the diatom flora is

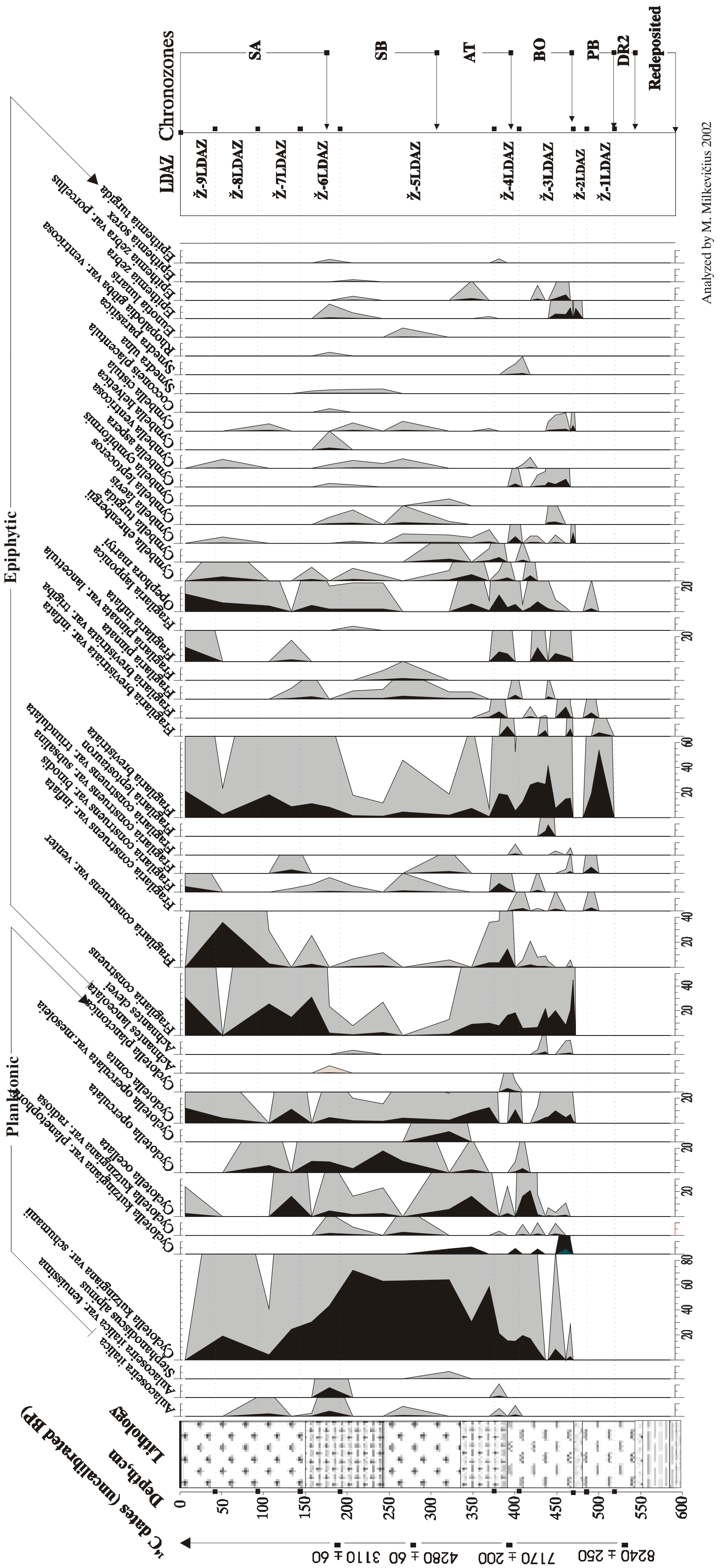

Fig. 5a. Diatom diagram, the first part (for lithological explanations, see Fig. 2)
5a pav. Diatomėjų diagrama, pirma dalis (litologinė nuosėdų sudėtis nurodyta 2 pav.)

abundant. A very high abundance and variety was identified in the interval 375–425 cm. In total, 81 types and subtypes of diatoms were defined.

Ž–1 LDAZ (520–495 cm)

At this period of low water level, lake benthic and overgrowing type diatoms prevailed *(Fragiliaria brevistriata, Navicula laterostrata, Amphora ovalis* and *Gomphonema capitatum)*. This zone can be characterised by a vast abundance of the next-to-coast zone genera *Fragilaria*.

Ž–2 LDAZ (495–470 cm)

This diatom zone is related to the prevalence of special types of the benthic diatoms. This interval is characterised by the abundance of the following diatoms: *Navicula scutelloides, Navicula ajajensis, Navicula anglica, Navicula gastrum, Navicula radiosa, Amphora ovalis* et var. *gracilis,* var. *libyca* and *Diploneis domblittensis* et var. *subconstricta*. The *Anomoeoneis sphaerophora* variety diatoms were of especial prevalence related to a vast increase of the nutritious substances (phosphates, nitrates, and various salts). It was a low-water-level lake period. Absence of the overgrowth and planktonic species as well as the lithology indicate a very significant increase in the flow-through of the lake during that time.

Ž–3 LDAZ (470–425 cm)

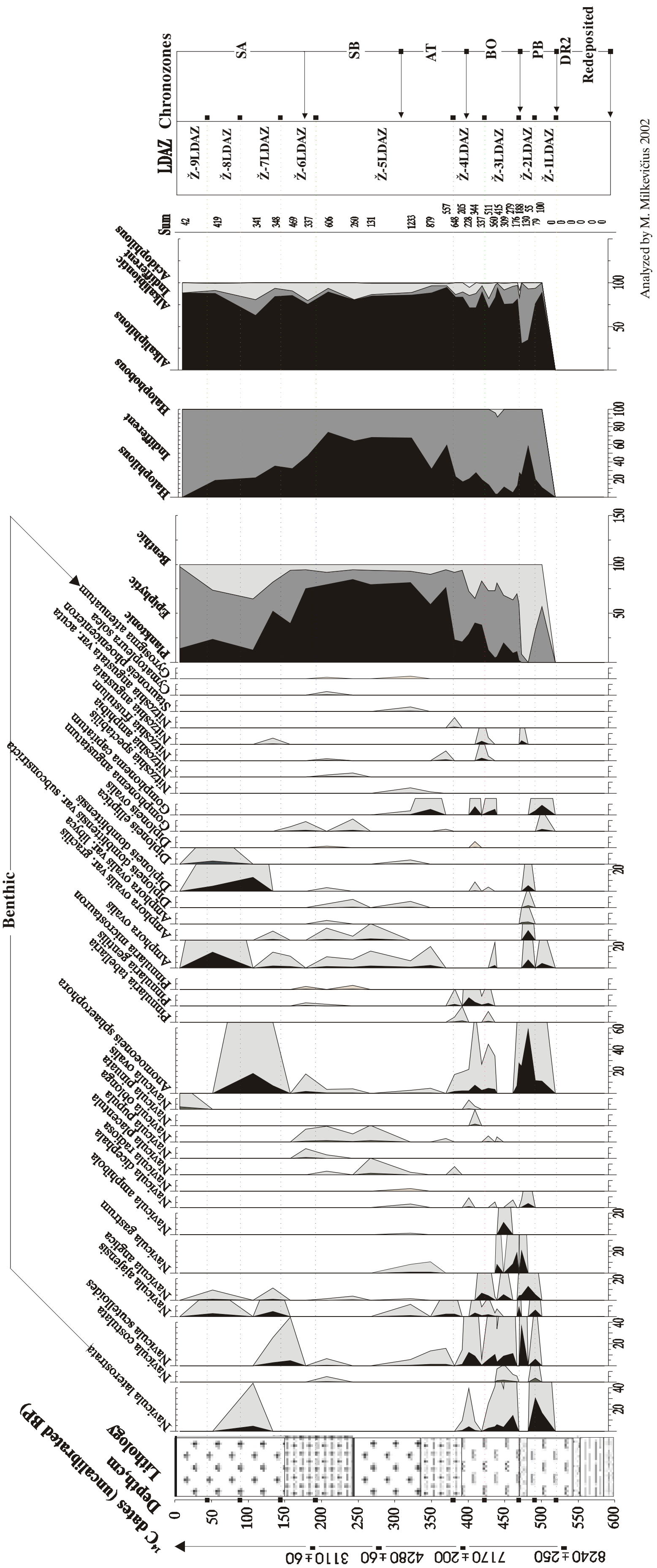

Fig. 5b. Diatom diagram, the second part (for lithological explanations, see Fig. 2)
5b pav. Diatomėjų diagrama, antra dalis (litologinė nuosėdų sudėtis nurodyta 2 pav.)

Here, the benthic diatoms from the genus *Navicula* (such as *N. scutelloides, N. laterostrata, N. anglica* and *N. amphibola*) as well as the overgrowth diatoms from the *Fragilaria* genus (*F. construens, F. brevistriata* and *F. inflata*) prevail. The prevalence of those genera indicates a low water level. Here, at the place of the boring, was a littoral boggy lake zone (Kabailienė, 1990). An additionally proof is *Epithemia* and *Gomphonema* genera diatom prevalence.

Ž–4 LDAZ (425–380 cm)

This local diatom zone can be characterised according to an increased number of planktonic diatoms (*Cyclotella kützingiana var. shumanii, C. ocellata* and *C. comta*) indicating a rise of the lake water level. From the epiphytic species, *Fragilaria construens* and *Fragilaria brevistriata* diatom varieties prevail in the zone. The lower part of the zone is characterised by prevailing *Gomphonema capitatum* variety diatoms and a quite abundant *Navicula scutelloides* variety diatoms ascribed to the benthic diatoms.

Ž–5 LDAZ (380–195 cm)

This zone, covering peat and gyttja peat layers, is characterised by a special abundance of the diatom flora. The planktonic diatom varieties, predominate especially (up to 80%) the *Cyclotella* genus diatoms (*Cyclotella kützingiana* var. *schumanii* (up to 70%), *C. comta, C. ocellata* and *C. operculata* et var. *mesoleia*), indicating a formerly high water level in the lake.

Ž–6 LDAZ (195–145 cm)

This zone shows an abundance of planktonic diatoms with the predomination of the genus *Cyclotella* diatoms. There was quite a low quantity of plankton *Aulacoseira italica* et var. *tenuissima* variety diatoms, indicating that the palaeobasin attained a eutrophic character. The upper part of the zone indicates an increase of the number of epiphytic *Fragilaria* (*F. construens* and *F. brevistriata*) diatoms overgrowing the foreshore plants. These diatoms are characteristic of a littoral bogging zone. At that time the water level of the lake slightly decreased, but still remained high.

Ž–7 LDAZ (145–90 cm)

It is the period of a low water level, with the predominance of overgrowth (*Fragilaria construens* and *F. brevistriata*) and benthic (*Anomoeoneis sphaerophora, Diploneis domblittensis* and *Navicula laterostrata*) diatoms.

Ž–8 LDAZ (90–45 cm)

This zone can be characterised by a vast prevalence of epiphytic *Fragilaria construens* var. *venter* and quite an abundance of *Amphora ovalis* (up to 15%). The diatom variety characteristic of the next-to-shore zone indicates a low water level of the lake.

Ž–9 LDAZ (45–0 cm)

In this diatom zone prevail the epiphytic overgrowth diatom varieties such as *Fragilaria construens* et var. *venter, F. brevistriata, F. inflata* and *Opephora martyi.* These varieties are typical of the bogging next-to-shore zone. The diatom flora is not abundant in this zone. It indicates the period of a low-water-level overgrowing lake.

Alkaliphilous species were most abundant (25–85%), favoured by pH>7 medium. Somewhat lower numbers were found in the 90–145 cm interval (about 55%) and a radical decrease in the 470–495 cm interval (about 25%). The latter interval can be characterised by widespread alkabiontic diatoms prevalent only at pH>7 (up to 70%). The general prevalence of diatoms in the remaining part of the section is not significant and varies in the scope of 1–10%. The distribution of the indifferent diatoms (prevailing at pH 7) is more or less even (about 20%) throughout all the section. Acidophilous (prevailing at pH<7) are rare, most of them (up to 2%) are found in the lower part of the section.

VEGETATION HISTORY

The lower part of the section contains numerous pollen and spores from the different habitats (Fig. 3). Both thermophylous and heliophytic taxa are well represented in the spectra. The high representation of *QM* pollen (*Tilia* and *Ulmus*) as well as other deciduous trees (*Corylus*, *Alnus* and *Betula*) coincides with the flourishing of herb species typical of the pioneer vegetation (*Artemisia*, Chenopodiaceae and *Rumex acetosa/acetosella*). The pollen spectrum is accompanied by a high frequency of old, pre-Quaternary spores. A major part of these pollen grains and spores must have been redeposited. The unknown amount of secondary pollen complicates interpretation of the pollen spectra in terms of vegetation history. The formation of these layers could be attributed to the first half of the Late Glacial when open herb predominating vegetation with some admixture of pine and birch existed in the biggest part of the present Lithuania (Kabailienė, 1998) and intensive erosion influenced the landscape.

Abrupt lithological changes fixed at a depth of 545 cm coincide with the development of the Younger Dryas vegetation. Open vegetation with a great number of light-demanding taxa predominated in the area. Birch and pine were tree species whose presence may be considered during the Younger Dryas. Junipers and different herbs that flourished on the banks of Lake Žadeikiai covered light habitats. Severe climatic conditions favoured the spread of *Sellaginella selaginoides* and *Potamogeton vaginatus* (Fig. 4). In our days the habitats of these plants are situated northwards, in Scandinavia and East Siberia (Meusel et al., 1965).

The transition from the Younger Dryas to Preboreal vegetation was sudden and the new vegetation type with the predominance of birch woods developed very fast. The rise of elm and hazel representation suggests the immigration of these trees into the area. The number and diversity of herb species decreased, suggesting the lack of the favourable habitats. Wood communities ousted herbs and other light-demanding taxa from the area. Remarkable fluctuations in pollen spectra fixed at the end of the Preboreal coincide with the changes in sediment lithology. An obvious rise in the broad-leaved (*Quercus*, *Tilia* and *Ulmus*), alder and hazel representation is restricted by the appearance and disappearance of a sandy gyttja layer. A reliable explanation of these changes, both lithological and palynological, is a short-lasting redeposition of material that included pollen and spores.

Vegetation that developed in the Boreal is characterised by the flourishing of the pine (Kabailienė, 1990). Reaching up to the 96% of the pollen spectra, pine was the main constituent of the forest developed on the dry sandy soils. The emphiric limit of the spruce curve denotes the presence of this tree in forest successions at the end of the period. The spruce prefers wet clayey soils common around the sedimentary basin. The various topography and changing soil composition provided suitable places for the expansion of deciduous trees including broad-leaved species in Northwestern Lithuania throughout the Atlantic (Stančikaitė and Guobytė, 1996). However, the amount of these pollen grains is negligible in the sediments studied, possibly because of unfavourable sedimentation conditions and intensive destruction of pollen grains by sedimentation processes. The same is true for the non-arboreal pollen representation.

Gradual expansion of the spruce that became an important component of the vegetation since 7200 BP onwards and an increasing importance of deciduous trees are the main features that are peculiar to the Atlantic vegetation. However, the number of broad-leaved tree pollen is negligible in the Žadeikiai section. This could be related to the sedimentation environment. The local topography and moister conditions determine a rise in alder representation: *Alnus* prefers wet boggy habitats usually developed along the water bodies. Spread of the herbs (*Artemisia*, *Urtica*, *Rumex acetosa/acetosella*, etc.) is relevant to the development of the forest-free areas. Appearance of the *Cerealia* pollen in sediments dated back to the Atlantic period could be related to the flourishing of the non-cultivated grasses with the pollen morphology similar to cereal (Poska and Saarse, 1999).

In the Subboreal, especially during its second half, the spruce was the main component of forest successions around the Žadeikiai bog. *Picea* culminated at about 3200 BP. Fruits and seeds of *Betula* sect. *Albae*, *Alnus glutinosa* and *Tilia* sp. confirm the growing of these trees in the area. The representation of the deciduous species is low, and the obvious reason for the general regression of broad-leaved trees is the interaction of climatic conditions and human activity confirmed by the appearance of the *Plantago lanceolata* and other apophytic herbs. The increasing representation of the non-arboreal taxa was also related to the development of the bog vegetation represented by *Andromeda polifolia* and different *Carex* species.

The beginning of the Subatlantic coincides with remarkable changes in the vegetation. Pine became the predominant component of the forest successions. The amount of trees other than birch and spruce was minor. Numerous needles and seeds of *Picea* sp. and a high representation of *Betula* sect. *Albae* seeds confirm the presence of these species in the habitat. Appearance of *Cerealia*, the increasing number of *Artemisia* and other ruderals could be related with the increasing levels of human activities and the subsequent fluctuations in landscape composition. Deforestation of the territory and formation of open land suitable for agriculture and pastures were the main features of the Subatlantic environment.

DEVELOPMENT OF THE ŽADEIKIAI BOG

The Žadeikiai bog is lying in a lowering the bottom of which was formed by a glaciolacustrine basin of the Upper Nemunas (Late Weichselian) age (Damušytė ir kt., 2002). After the final retreating of the ice sheet sedimentation went on, but the composition of the pollen spectra suggests an intensive water flow and a possible redeposition of the material during the earliest stages of the Late Glacial. The lower part of the section (silty sand, silt, sand and lower part of the gyttja) deposited during the Younger Dryas and before it contains no diatoms. The appearance of the diatoms coincides with the beginning of the Holocene. The first diatom finds, Ž–1 and Ž–2 diatom zones, correspond to the Preboreal (Fig. 5a, 5b). The organic-substance-saturated gyttja layer occurring on late glacial period silt, silty sand and coursed-sand strata was formed at that time. The water level in the palaeobasin was low during that time, overgrowth and benthic diatom varieties predominated. Thin strata of the gyttja with gravel, corresponding to the second diatom zone, is predominated by the benthic type diatoms; the number of overgrowth diatoms decreased. This indicates a significant increase of the lake flow-through during that time. The Boreal period corresponds to Ž–3 and the greater part of Ž–4 diatom zone when a gyttja bed was formed. It was a low-water-level period. The epiphytic and water-plant-overgrowing diatom varieties indicate an active lake overgrowth and bogging, especially during the first half of the Boreal. During the period of formation of peat with gyttja occurring in the depth of 390–340 cm, peat strata (340–245 cm), and peat with gyttja strata above them (245–195 cm), the palaeobasin water level increased. The Ž–5 diatom zone correlates the Atlantic and the Subboreal periods. This diatom zone can be characterised by a very rich abundance of diatoms, especially planktonic (predomination of *Cyclotella* diatoms), indicating a high water level (Kabailienė, 1998). The rise of the water level started about 6500 years BP according to the estimated time scale, while about 4300–4200 years BP some water lowering occurred. Prevalence of *Eunotia, Epithemia* and *Gomphonema* diatoms during the second half of the Subboreal period indicates the bogging process of the lake. The Ž–6 – Ž–9 local diatom zones correlate to the Subatlantic period. Diatom composition indicates that the water level during the first half of the Subatlantic was higher, while during the second half of the period also planktonic diatom varieties were widespread. The second half of the Subatlantic period is characterised by the prevalence of epiphytic *Fragilaria* diatoms indicating a lowering water level;

the lake attained a eutrophic character. According to the estimated time, water lowering took place about 2000 years BP.

Appearance of the *Nuphar lutea* L., *Nymphaea alba* L. and *Potamogeton perfoliatus* L., macroremains suggests a eutrophic water status in the basin during the Late Boreal–Atlantic. The diatom structure found though all the Holocene part of the section indicates that the palaeobasin trophism was low – the *Cyclotella* genus varieties prevail among the plankton-living diatoms. The quantity of *Aulacoseira* and *Stephanodiscus* representatives is insignificant. The number of the latter varieties increases a little at a depth of 150–190 cm, implying a possible eutrophisation of the basin. Thus, at the beginning of the Holocene the palaeobasin was of oligotrophic–mezotrophic type and attained well pronounced eutrophic features only at the end of its existence.

CONCLUSIONS

The development of the palaeobasin, later transformed into the Žadeikiai bog, started before the Younger Dryas cooling, when beds of clastic material with the microbotanical remains were formed. The type of the pollen spectra suggests redeposition of the sediments most probably from the interglacial or interstadial sequence.

The appearance of the palaeobasin in the Younger Dryas was accompanied by the formation of forest tundra vegetation with a high representation of light-demanding taxa. The Holocene vegetation cover was determined by early (about 7200 BP) immigration of *Picea* into the region.

Throughout the Holocene the oligotrophic–mezotrophic sedimentation basin survived a few bogging periods: Preboreal–Boreal, the second half of the Subboreal (at about 4200–4000 years BP) and the second half of the Subatlantic (2000 years BP onwards). Remarkable changes in the water regime took place at about 6500 years BP when the basin reached the highest altitude. At the end of the Holocene the basin became of eutrophic type, while its eutrophication had started earlier (Late Boreal–Atlantic) in some parts.

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ŽADEIKIŲ PELKĖS IR APYPELKIO (ŠV LIETUVA) RAIDA VĖLYVAJAME LEDYNMETYJE IR HOLOCENE PALEOBOTANINIŲ BEI ¹⁴C TYRIMŲ DUOMENIMIS

S a n t r a u k a

Žadeikių pelkėje (ŠV Lietuva) atlikti kompleksiniai paleobotaniniai (sporų ir žiedadulkių, diatominių dumblių bei augalų makroliekanų) ir nuosėdų absoliutaus amžiaus tyrimai (^{14}C) leido nustatyti pelkės formavimąsi bei apypelkio augalijos raidą poledynmečiu. Tirtoji storymė slūgso viršutinio Nemuno glacigeninio reljefo pažemėjime, kuriame ledynui traukiantis telkšojo limnoglacialinis baseinas. Nuosėdos čia pradėjo klostytis vėlyvojo ledynmečio pirmojoje pusėje, kai intensyviai plūdęs srautas perklostė terigenines nuosėdas, praturtintas šilumą mėgstančių augalų žiedadulkėmis. Pastarosios, matyt, buvo eroduojamos iš tarpledynmečio ar tarpstadijinės storymės. Vėlyvajame driase prasidėjusi ežerinė sedimentacija tęsėsi visą holoceną. Augalijos raidai būdingas ankstyvas eglių plitimas, prasidėjęs prieš 7200 metų. Sedimentaciniame baseine išryškėja keli žemo vandens lygio laikotarpiai (preborealyje–borealyje ir prieš 4200–4000 bei 2000 metų). Prieš 6500 metų vandens lygis sedimentaciniame baseine buvo aukščiausias. Augalų makroliekanų tyrimai leidžia teigti, kad atskirose ežero dalyse borealio pabaigoje – atlantyje prasidėjo eutrofikacijos procesai, o visas baseinas iš oligotrofinės–mezotrofinės stadijos perėjo į eutrofinę tik holoceno pabaigoje.

Мигле Станчикайте, Мартинас Милкевичюс, Даля Киселене

РАЗВИТИЕ БОЛОТА ЖАДЕЙКЯЙ (СЗ ЛИТВА) В ПОЗДНЕЛЕДНИКОВЬЕ И ГОЛОЦЕНЕ, СОГЛАСНО ПАЛЕОБОТАНИЧЕСКИМ И ¹⁴C ДАННЫМ

Р е з ю м е

Проведенные в болоте Жадейкяй комплексные палеоботанические (спорово-пыльцевой, диатомовый и анализ макроостатков растений) и радиоуглеродные (^{14}C) исследования позволили установить условия формирования болота и развитие растительности в позднеледниковье и голоцене. Исследуемая толща лежит в понижении гляцигенного рельефа, где при отступлении ледника простирался лимногляциальный бассейн. Осадки здесь начали скапливаться в первой половине позднеледниковья, когда интенсивно текущий поток переотложил терригенный материал, обогащенный пыльцой теплолюбивых растений. Последние, по-видимому, были эродированы из межледниковой или межстадиальной толщи. Озерная седиментация, начавшаяся во время позднего дриаса, продолжалась на протяжении всего голоцена. Для развития растительности характерно раннее распространение ели, начавшееся 7200 лет тому назад. В седиментационном бассейне установлено несколько периодов со значительным понижением уровня воды.