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Radiocarbon dating of Late Glacial sediments of Lake Miłkowskie by accelerator mass spectrometry

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ABSTRACT. This paper presents results of ^{14}C dating of Late Glacial sediments from Lake Miłkowskie, NE Poland. This sediments reveal annual lamination, biogenic in the upper part and minerogenic at the bottom, however, the lamination is not continuous over the profile. Along the Late Glacial part of sediments 6 individual laminated sequences were distinguished. The youngest analysed laminated sequence corresponds to Allerød/Younger Dryas and ^{14}C dates of this part of sediments fit ^{14}C calibration curve quite well. In the deeper part, at a transition from biogenic to minerogenic lamination a period of birch tree development is documented on pollen diagram. By calibration of ^{14}C dates from this transition, the development of birch has been dated to 12 500±60 ^{14}C BP against INTCAL04. In the lowermost sediments (with clastic lamination) plant macroremains from different environments (terrestrial, aquatic and intermediate) were found. ^{14}C dates of all these macroremains are similar to each other, claiming for their reliability, and confirming that this fragment of sediments covered quite short period of time. Altogether ^{14}C dating at the Late Glacial part of Lake Miłkowskie sediments indicated that pollen diagram drawn in relationship to age has quite different proportions from that present at a depth scale. This show that pollen analysis of Late Glacial sediments, made without careful study of their chronology, may give a wrong picture of the vegetation dynamics.

KEY WORDS: radiocarbon, AMS dating, lake sediments, chronology, macrofossils

INTRODUCTION

Analysis of sediments has been used for a long time in many fields of palaeoscience like palaeontology, geophysics, sedimentology and palaeoclimatology. From the chronological point of view the most attractive are sediments with differentiable annual laminae (Goslar 1995a, b). The most extensive study of such sediments in Poland was made on Lake Gościąż under the leadership of M. Ralska-Jasiewiczowa (Ralska-Jasiewiczowa et al. 1998). ^{14}C dates of the Late Glacial part of the lake Gościąż sediments have been used for supplementing the calibration curve beyond the dendrochronological scale (Goslar 1995a, Goslar et al. 2000), till the time when the annually laminated sediments from the Cariaco Basin were dated (Hughen et al. 2000). Another laminated sediment extensively dated with ^{14}C (Goslar et al. 2000) was that of Lake Perespilno and together with Lake Gościąż, it became a key site for establishing calendar chronology of vegetational changes during the Late Glacial in Poland (Ralska-Jasiewiczowa et al. 1999).

This paper presents results of ^{14}C dating of Late Glacial part of sediments of Lake Miłkowskie, NE Poland. This sediment also show lamination, which however, is not continuous. A set of ^{14}C dates presented here enabled reconstruction of calendar chronology of the sediment. This work is a part of Ph.D. thesis made in Department of Radioisotopes, Institute of Physics, Silesian University of Technology in Gliwice.

MATERIAL AND METHODS

The material dated were the remains of terrestrial plants. Because of small sample masses ^{14}C dating was made with the AMS technique. In the AMS method concentration of ^{14}C is measured in a graphite target prepared from the material of the sample to be studied (Goslar & Czernik 2000, Czernik & Goslar 2001). The samples were subjected to the AAA (Acid-Alkali-Acid) procedure in order to remove any carbonate and organic contamination. Because of small masses of the samples, utmost care was taken not to introduce any contamination in the preparation procedures. After the AAA treatment, the sample was placed in a quartz tube containing copper oxide (CuO) and silver wool (Ag), sealed and cut off under a vacuum and combusted in a furnace at 900°C. The products of combustion are carbon dioxide, water vapour and other compounds – contaminants which partly remain on the silver. Graphite is then formed as a result of CO_2 reduction. After the reduction, the Fe-C mixture was pressed into a target in an aluminium holder. The targets were stored in the argon atmosphere and sent to the Laboratory in Kiel, Germany for the ^{14}C AMS measurements.

^{14}C DATING OF SEDIMENTS FROM LAKE MIŁKOWSKIE

Lake Miłkowskie (53°56′N, 21°50′E) is situated in the Miłki village, ca. 15 km southeast of Giżycko near the southern end of Lake Wojnowo (Fig. 1). The lake area is 23.7 ha and its maximum depth is 15 m; it is supplied by two water courses and by shallow underground water. The water from Lake Miłkowskie outflows to Lake Wojnowo. The shoreline of Lake Miłkowskie is poorly developed. Its banks are very steep, on the eastern part of lower hill-like elevation. It is surrounded by arable fields and meadows, except the eastern side occupied by the village of Miłki.

The cores from Lake Miłkowskie sediments (Fig. 1) were collected in 1998 (30.05.1998–2.06.1998) from the water depth of 15 m. Four cores (M1, M2, M3, M4) were collected in sections 1 m long. The cores cover the whole profile of the sediment from the time of lake formation to the present. For the purpose of

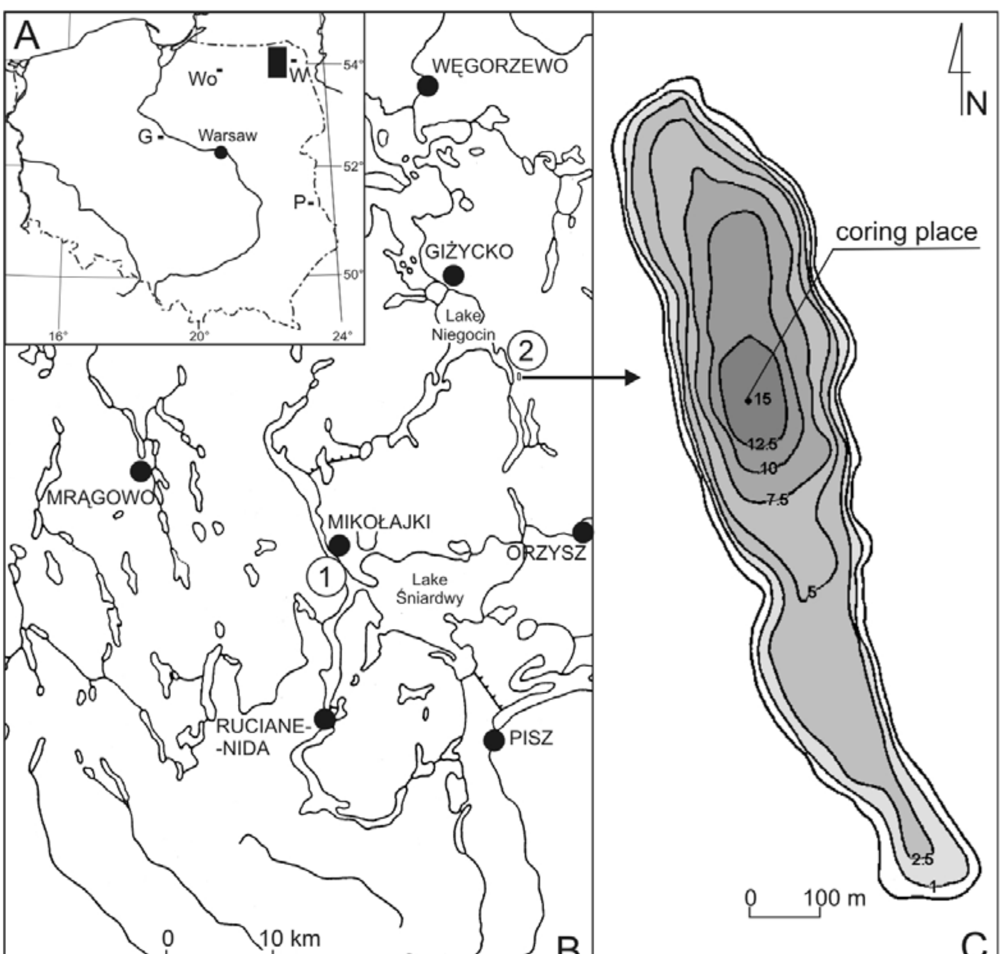

Fig. 1. Location of Lake Miłkowskie in Poland showing where cores were collected for analyses

this study the deepest parts of the M3 and M4 cores covering the Late Glacial period were only used.

The sediment from Lake Miłkowskie was subjected to pollen analysis by A. Wacnik at the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków. Between the depth of 36.40–35.40 m a marked decrease in the concentration of tree pollen is noted (Fig. 2). This section is dated as the Younger Dryas (Ralska-Jasiewiczowa et al. 1998, Björck et al. 1998, Brauer et al. 1999a, b, Goslar et al. 1999, Litt et al. 2001), the last cold period before the Holocene. In the lower part there is a significant increase in the amount of birch pollen at a depth of about 37.50 m. A similar increase in birch pollen was noted earlier in the sediments collected from Lake Mikołajki (Ralska-Jasiewiczowa et al. 1999), Witów (Wasylikowa 1978), Lake Łukcze (Bałaga 1982, 1990) or Lake Perespilno (Goslar et al. 1999) and in the sediments from the German lakes Meerfelder Maar (Stebich 1999, Brauer et al. 2000a, b, Litt et al. 2001) and Hämelsee (Merkt & Müller 1999).

The Late Glacial and early Holocene sections of the cores M3 and M4 were exactly correlated with each other basing on visible lamination (Fig. 3). In the higher parts the sediment's lamination is biogenic (Fig. 4), in the middle parts biogenic lamination occurs along with minerogenic (clastic) lamination and the deepest part has purely clastic lamination. In the biogenic part of the profile light laminae contain diatoms and Chrysophyceae cysts, and from Younger Dryas, also diatoms and carbonates, which suggests that the laminae were formed in spring and summer. The laminae formed in autumn and winter contain additionally organic matter and are darker in colour. Below the interface of minerogenic and biogenic layers, the sediment becomes more uniform in colour with marked thick annual increments. In this fragment the sediment contains mineral grains coming from outside the lake. Seasonal changes are marked by the size of the grains: they are finer in winter and larger in spring and summer. Differences in the type of sediment are reflected in the thickness of the laminas (Fig. 4). Above the minerogenic/biogenic interface the mean thickness is 1.5–3.0 mm/year, while in the minerogenic sediment it reaches 4–6 mm/year. Unfortunately microscopic analysis of the microsections (T. Goslar, pers. comm.) show number of discontinuities of lamination related to bioturbations or redeposition of the sediment. Therefore, in the analysed fragment of profile, six individual varved sequences were distinguished, and they have been numbered as I through VI.

The plant remains separated from the sediments were subjected to ^{14}C dating. To separate the plant remains, the cores collected were cut into sections 2–5 cm thick. Of great importance for dating of plant macroremains is the state of their preservation allowing identification of the material and means of sample collection and storage. Also important is the way of sample preparation for ^{14}C dating and the time of storage (Wohlfarth et al. 1998). The plant macroremains suitable for ^{14}C dating were selected under a microscope with the use of fine paint brushes. Exemplary plant macroremains separated from the sediment were identified at W. Szafer Institute of Botany in Kraków by A. Wacnik. From a few hundred inspected samples an amount of material sufficient for ^{14}C dating was found only in 30 of them (Tab. 1). From these 30 samples only a part was selected for further analysis, basing on information obtained from the pollen diagram (Fig. 2). Where the types of macrofossils, most commonly used in the previous studies (Goslar et al. 2000), were not available, another type of material was forwarded for dating. Description and identification of the macroremains of plant remains selected for dating are given in Table 1. Most samples were prepared at the Gliwice Radiocarbon Laboratory and measured with AMS at the Leibniz Labor für Altersbeschtimmung in Kiel. And additional sample, needed to establish more sufficient date of birch growth phase, was dated in Poznań Radiocarbon Laboratory. The results are presented in Table 2 and illustrated in Figure 5.

^{14}C ages of the samples were calculated at the Kiel Laboratory assuming the same background level for all samples. However, the mass of the combusted and later graphitised sample affects the background level measured in the AMS spectrometer. For the samples smaller than 1 mg prepared at the Laboratory in Gliwice, the relation between the background level and the mass of the sample combusted was established (Czernik & Goslar 2001). On the basis of this relationship ^{14}C ages were corrected for sample mass (Tab. 2).

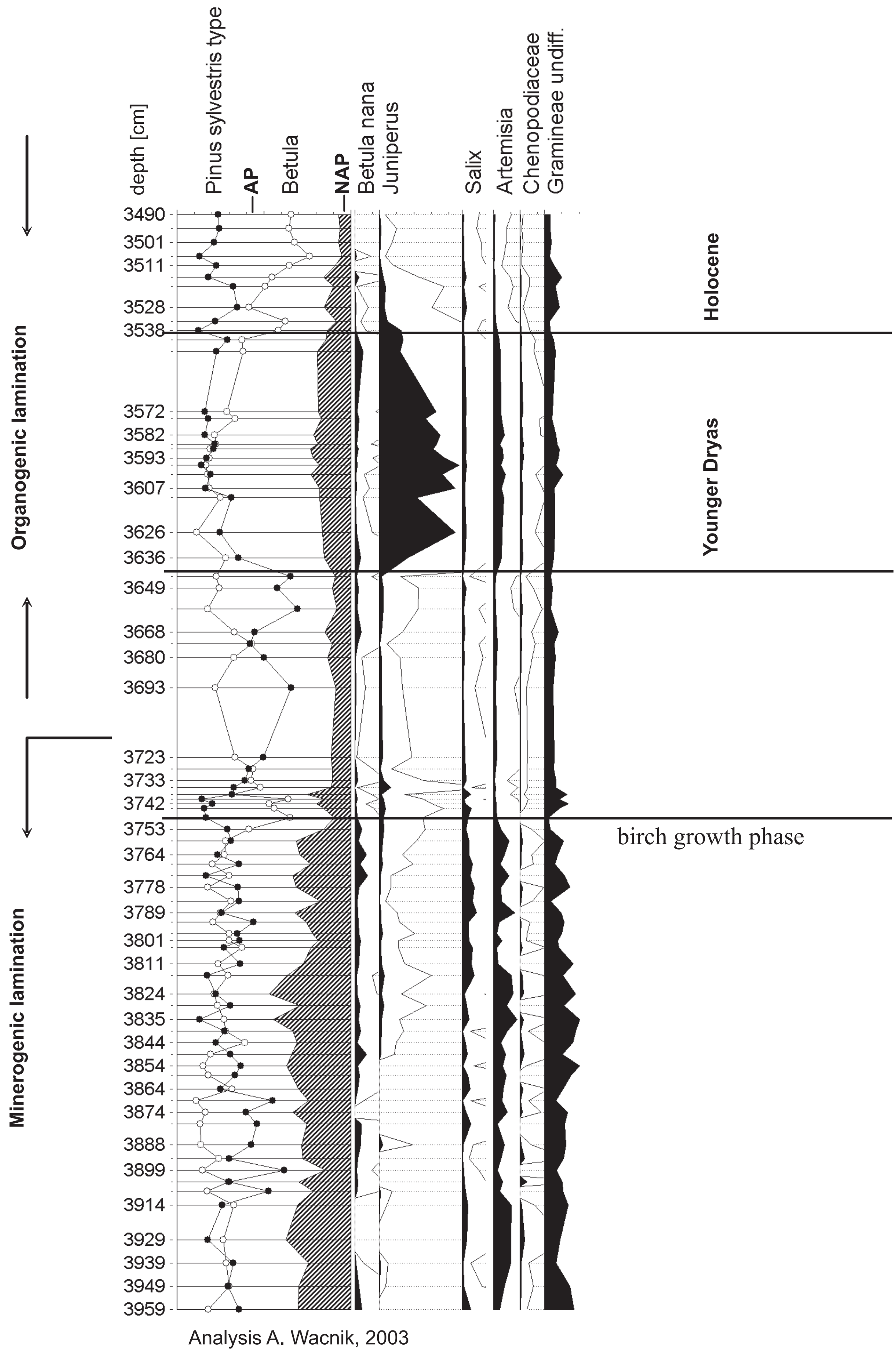

Fig. 2. Pollen diagram of Lake Miłkowskie sediment (core M4) with selected taxa only (Wacnik 2003). AP – arboreal plants, NAP – non-arboreal plants

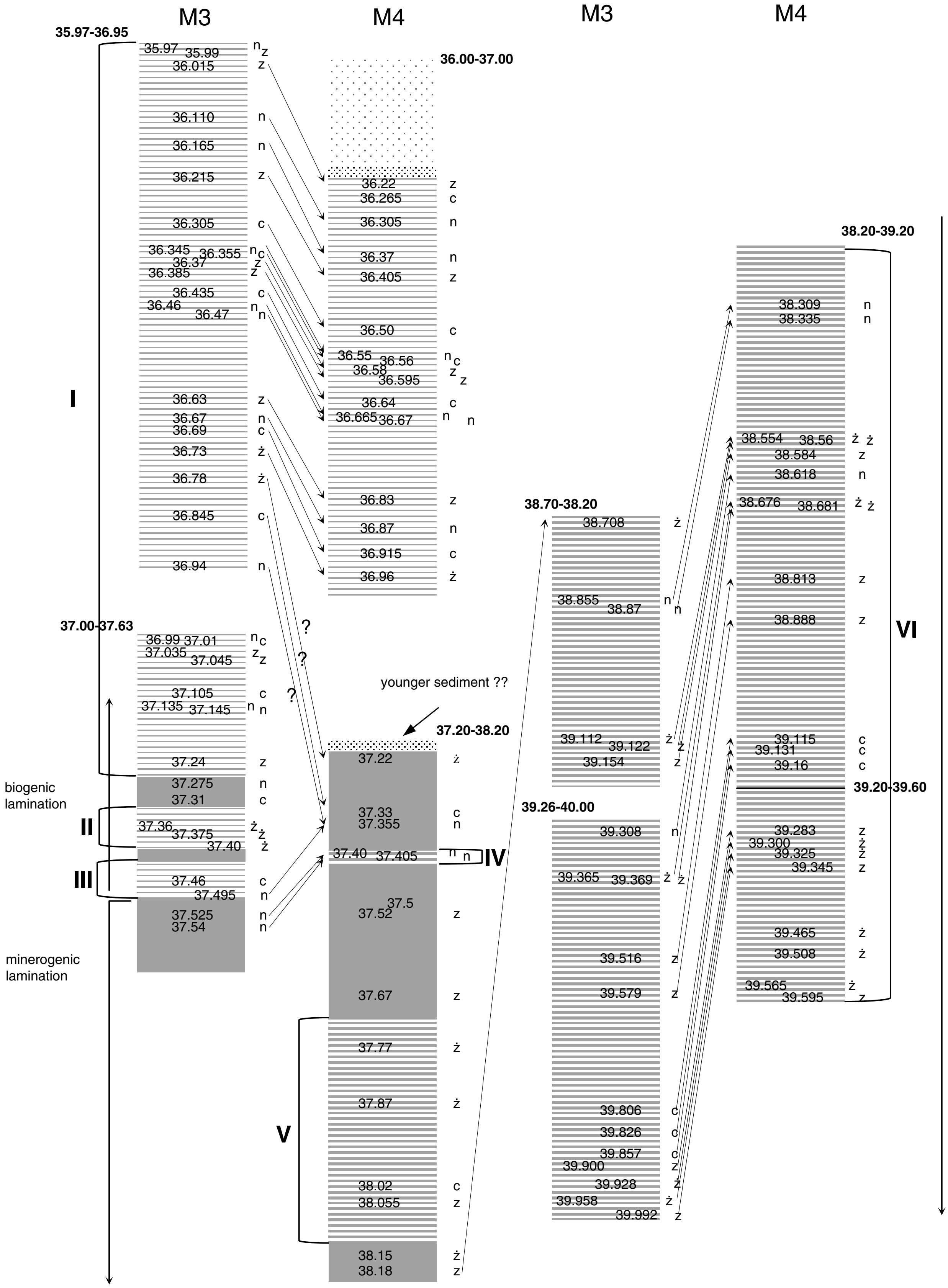

Fig. 3. Detected correlation of M3 and M4 cores from Lake Miłkowskie sediment. Numbers indicates depth read during sampling the cores. Horizontal lines indicate laminated sections, thin lines – biogenic lamination, thick lines – minerogenic lamination. Individual varved sequences are denoted with roman figures (I-VI)

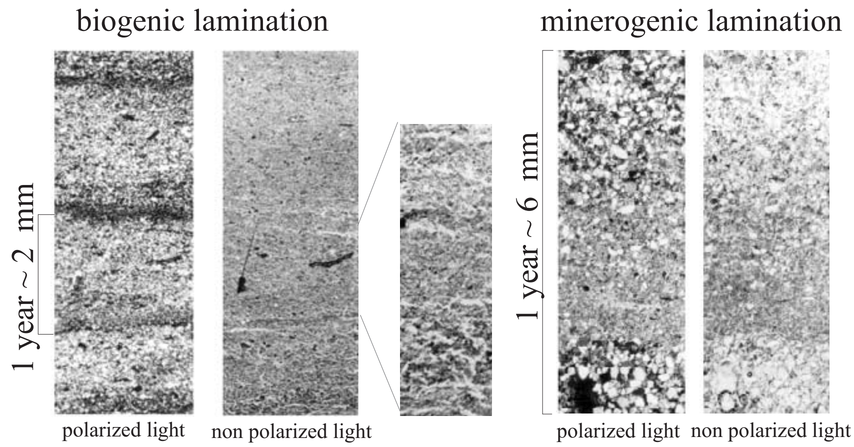

Fig. 4. Ilustration of the lamination found in biogenic and minerogenic sediment in polarized and non polarized light

Table 1. Data on samples selected from Lake Miłkowskie sediment intended for AMS ^{14}C dating

Sample name (core no_depth)	Depth (m) in M3 core	Type of remains	Composition of sample
M4/98 36.47–36.49	36.275–36.295	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed
M4/98 36.64–36.68	36.435–36.475	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed, needle, periderm)
M4/98 36.82–36.86	37.105–37.145	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed, needle, periderm
M4/98 37.22–37.28	37.40–37.46	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale *Pinus sylvestris* seed, needle, periderm
M4/98 37.28–37.32	37.46–37.49	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed, needle, periderm, *Carex* sp. fruit
M4/98 37.36–37.40	37.50–37.54	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed, *Carex* sp. fruit
M4/98 37.40–37.42	37.54–37.56	terrestrial plants	*Betula* sect. *Albae* fruit, *Carex* sp., epicarp
M4/98 37.80–37.85M	lack of correlation	terrestrial/aquatic plants	moss stems and leaf
M4/98 37.95–38.05	lack of correlation	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Pinus sylvestris* seed, needle, periderm
M4/98 38.00–38.05E	37.56–37.61	terrestrial plants	*Equisetum* rhizomes
M4/98 38.00–38.10M	37.56–37.66	terrestrial/aquatic plants	moss stems and leaves
M4/98 38.23–38.34	38.78–38.88	terrestrial plants	*Betula* sect. *Albae* fruit, fruit scale, *Carex* sp. fruit, epicarp
M4/98 38.29–38.34M	38.835–38.885	terrestrial/aquatic plants	moss stems and leaves
M4/98 38.38–38.48C	38.92–39.02	aquatic plants	Characeae oogonia
M4/98 38.53–38.57	39.09–39.13	aquatic plants	Characeae oogonia
M4/98 38.53–38.58C	39.09–39.14	aquatic plants	Characeae oogonia
M4/98 38.58–38.63C	39.15–39.20	aquatic plants	Characeae oogonia
M4/98 38.58–38.63	39.15–39.20	aquatic plants	Characeae oogonia
M4/98 38.58–38.63M	39.15–39.20	terrestrial/aquatic plants	moss stems
M4/98 39.08–39.13C	39.77–39.82	aquatic plants	Characeae oogonia
M4/98 39.14–39.17C	39.83–39.86	aquatic plants	Characeae oogonia
M4/98 39.23–39.33C	39.85–39.95	aquatic plants	Characeae oogonia
Sample dated in 2009			
M4/98 37.50–37.52		terrestrial/aquatic plants	Seeds, moss stems, *Equisetum* rhizomes, Characeae oogonia

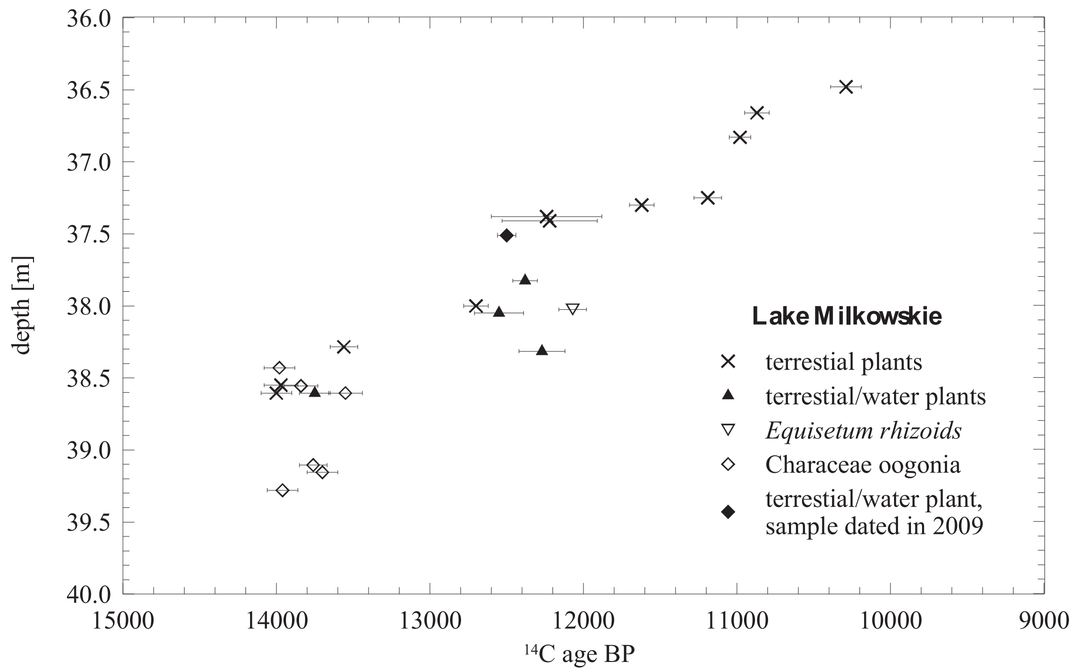

Fig. 5. Results of AMS ^{14}C dating of samples from Lake Miłkowskie sediments in relation to depth. The presented ^{14}C dates were not corrected for sample mass oogonia

Table 2. ^{14}C dates of plant remains separated from Lake Miłkowskie sediment. Individual segments of varve chronology are denoted with Roman figures

Sample ID	Sample name	Sample mass [mg]	PMC	^{14}C age BP	δ^{13}C (‰)	^{14}C age BP with correction for sample mass	Varve no	
GdA-103	M4/98 36.47–36.49	0.26	27.78±0.34	10 290±100	–42.98±1.96	10 500±250	178	I
GdA-104	M4/98 36.64–36.68	0.79	25.84±0.25	10 870±80	–30.88±0.19	10 890±200	268	I
GdA-105	M4/98 36.82–36.86	1.02	25.51±0.22	10 980±70	–23.82±0.08		328	I
GdA-106	M4/98 37.22–37.28	1.04	24.84±0.29	11 190±90	–34.18±1.53		31	III
GdA-107	M4/98 37.28–37.32	1.05	23.53±0.23	11 620±80	–26.14±0.18		57	III
GdA-109	M4/98 37.36–37.40	0.38	21.80±0.96	12 240+360/-350	–49.96±0.43	12 370±410	not laminated	
GdA-110	M4/98 37.40–37.42	0.28	21.84±0.83	12 220+310/-300	–46.96±0.68	12 470±410	0	IV
GdA-113	M4/98 37.80–37.85M	0.68	21.41±0.22	12 380±80	–27.57±0.09	12 400±230	19	V
GdA-112	M4/98 37.95–38.05	1.05	20.57±0.21	12 700±80	–20.32±0.13		51	V
GdA-115	M4/98 38.00–38.05E	0.73	22.26±0.25	12 070±90	–32.45±0.14	12 090±230	60	V
GdA-114	M4/98 38.00–38.10M	0.26	20.96±0.41	12 550±160	–48.82±0.29	12 810±350	67	V
GdA-123	M4/98 38.23–38.34	0.98	18.48±0.22	13 560±90	–14.35±0.17		7	VI
GdA-130	M4/98 38.29–38.34M	0.23	21.72±0.41	12 270±150	–53.62±0.47	12 550±340	10	VI
GdA-120	M4/98 38.38–38.48C	1.10	17.54±0.21	13 980±100	–20.47±0.09		20	VI
GdA-124	M4/98 38.53–38.57	1.00	17.58±0.23	13 970+110/–100	–13.62±0.07		66	VI
GdA-121	M4/98 38.53–38.58C	1.00	17.86±0.24	13 840±110	–17.25±0.23		67	VI
GdA-122	M4/98 38.58–38.63C	0.98	18.51±0.25	13 550±110	–29.72±0.15		75	VI
GdA-125	M4/98 38.58–38.63	1.00	17.51±0.22	14 000±100	–13.54±0.09		75	VI
GdA-132	M4/98 38.58–38.63M	0.98	18.05±0.21	13 750+100/–90	–32.67±0.04		75	VI
GdA-135	M4/98 39.08–39.13C	1.06	18.04±0.21	13 760±90	–17.68±0.21		173	VI
GdA-136	M4/98 39.14–39.17C	1.00	18.17±0.22	13 700±100	–19.14±0.14		183	VI
GdA-137	M4/98 39.23–39.33C	0.99	17.59±0.21	13 960±100	–15.95±0.19		193	VI
				Sample dated in 2009				
Poz-28540	M4/98 37.50–37.52	2.20	21.09±0.15	12 500±60	–23.01±0.34		not laminated	

CALENDAR CHRONOLOGY OF LAKE MIŁKOWSKIE SEDIMENTS

Pollen analysis of Lake Miłkowskie (Fig. 2) suggests that the studied section covers the time from the end of the Oldest Dryas to Holocene, namely about 3000 years. Comparison of thickness of the part dated to the Younger Dryas (82 cm) with that of the sediment below (319 cm) knowing the duration of the Younger Dryas (1140 years, Ralska-Jasiewiczowa et al. 1998), suggests that if sedimentation rate was constant, the whole section studied would cover over 4000 years. On the other hand, the total number of varves counted in the laminated sections is only 876, and assuming a similar rate of sedimentation in the non-laminated sections, they would cover only 250 years (Figs 3, 4).

This contradiction means that either the counting of varves was erroneous or there are severe discontinuities in sedimentation between the laminated sections. The later seems confirmed by clustering of the ^{14}C dates in the three intervals ~11 000 ^{14}C BP, 12 000–12 800 ^{14}C BP, 13 600–14 000 ^{14}C BP (Fig. 5). A detailed analysis of the calendar age of particular sections is given in the next sections.

CHRONOLOGY OF BIOGENIC LAMINATION

The shallowest part of the dated sediment encompasses varved sequence I between 35.99 m and 37.26 m in M3, and about 36.20–36.83 m in M4 (Fig. 3). Between 37.26 m and 37.33 m the sediment is not laminated and near the depth of 37.42 m the varves could not be counted either. According to the pollen analysis (Wacnik 2003 and in this volume Fig. 2), the Allerød/Younger Dryas boundary occurs at the depth of 36.215 m in M3. The calendar age of the varved sequence I was then estimated by synchronization of the Allerød/Younger Dryas interfaces determined by palynological studies in the sediments of Miłkowskie and Gościąż lakes (Ralska-Jasiewiczowa et al. 1998). Taking into regard the corrected pine chronology

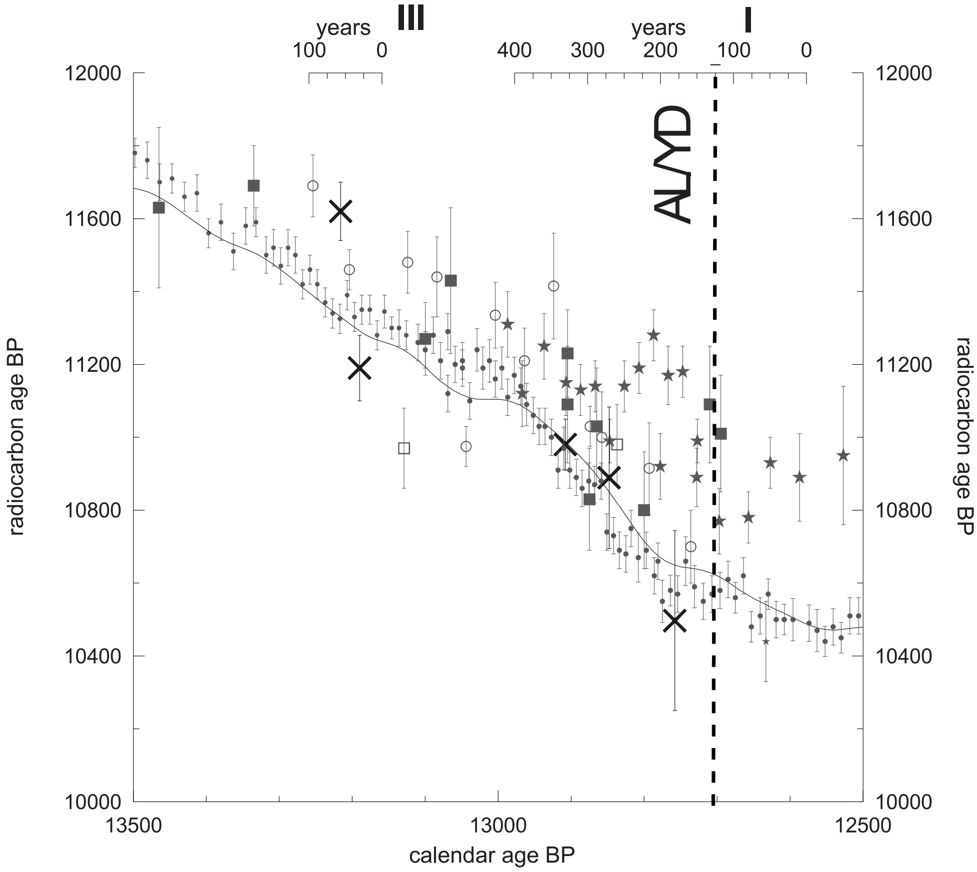

Fig. 6. ^{14}C ages of samples from biogenic sediments of Lake Miłkowskie plotted on the background of calibration ^{14}C data. In the upper part of drawing are marked calendar scales of individual laminated sequences. Symbols mean respectively: × – land plants from Lake Miłkowskie; — – calibration curve INTCAL04 (Reimer et al. 2004), ● – Cariaco Basin (Hughen et al. 2000, 2004), □ – corals (Edwards 1993), ■ – corals (Bard et al. 1990a, b, 1993, 1998a, b); ○ – Lake Suigetsu (Kitagawa & van der Plicht 2000); ★ – Lake Gościąż (Goslar et al. 2000)

(Friedrich et al. 1999, 2000) the Allerød/Younger Dryas interface in the Lake Gościąż sediments occurs at 12 710 cal BP. ^{14}C dates of so dated sequence I (Fig. 6) are generally consistent with the ^{14}C calibration data. The age of the deeper laminated fragment of the biogenic sediment (III) was estimated assuming a constant rate of sedimentation between sequences I, II and III. The quality of match between the ^{14}C data and the calibration data (Kitagawa & van der Plicht 2000, Edwards et al. 1993, Bard 1998, Bard et al. 1990a, b, 1992, 1993, 1998) does not contradict this assumption.

CHRONOLOGY OF THE INTERFACE OF MINEROGENIC AND BIOGENIC DEPOSITS; THE BIRCH DEVELOPMENT PHASE

^{14}C dates of the laminated sequence V (Fig. 7) correspond to those of the oldest part of the sediments from the Cariaco Basin (Hughen et al. 2004). The ^{14}C dates are similar to each other, except of that for the *Equisetum* rhizomes sample collected at the depth of 38.00–38.05 m (M4), which appeared significantly younger than the other dates including those of 3 samples from the overlying non-laminated section (Fig. 7). Disregarding the sample 38.00–38.05 (probably contaminated with modern carbon) the other dates (Fig. 8) were calibrated against the INTCAL04 (Reimer et al. 2004). In this calibration were taken into account known differences of calendar dates of the samples from the varved sequence V, and assumed that chronological orded of the overlying samples agreed with stratigraphy. Situation of the obtained ^{14}C dates on the background of ^{14}C calibration data is shown in Figure 7.

At the depth of about 37.50 m in M3 (37.42 m in M4) there is the interface between the minerogenic sediment and biogenic sediment. Starting from this interface (37.50 m in M4 core) the evidence of the birch tree development is found in the sediment (Wacnik 2003). The change in the type of lamination from minerogenic to biogenic suggests a change in

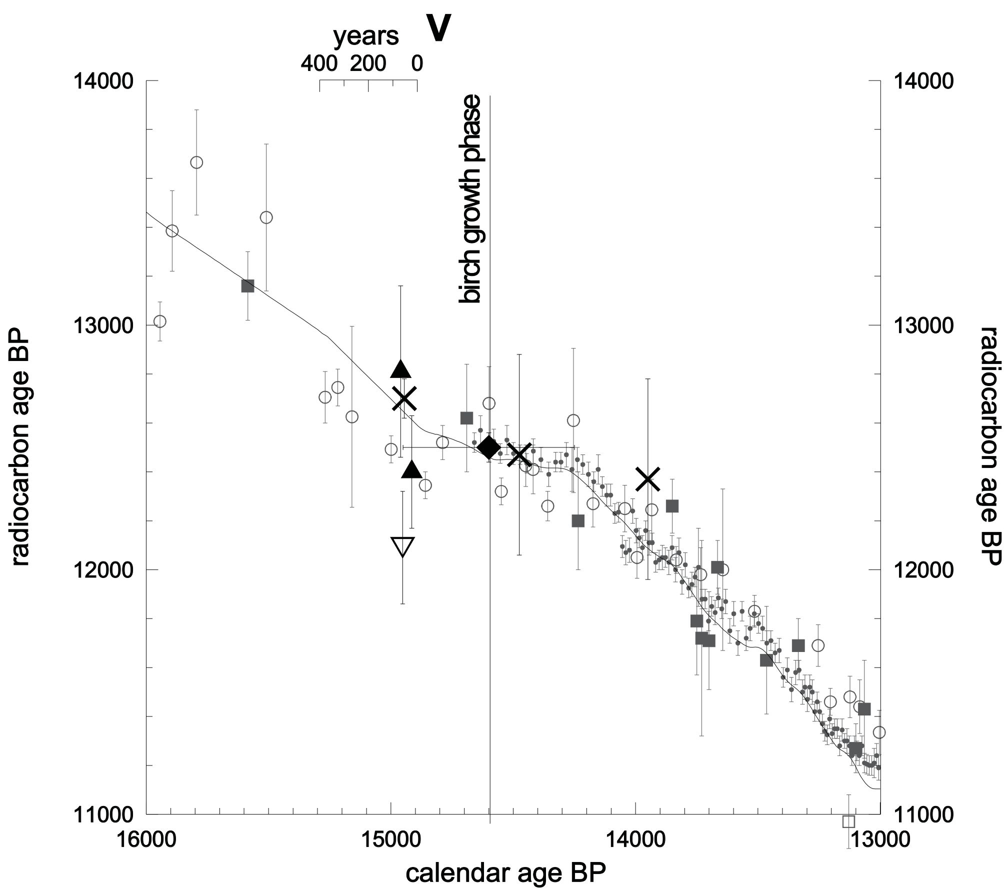

Fig. 7. ^{14}C dates of the birch growth phase in the Lake Miłkowskie sediment. In upper part of the drawing is marked calendar scale of the laminated sequence V. Calendar ages of the samples from Lake Miłkowskie were determined by calibration of ^{14}C dates with respect to INTCAL04 (Fig. 8). Symbols mean respectively: × – land plants; ▲ – moss, ∇ – Equisetum, ♦ – sample dated in 2009; — – calibration curve INTCAL04 (Reimer et al. 2004), ● – Cariaco Basin (Hughen et al. 2000, 2004), □ – corals (Edwards 1993), ■ – corals (Bard et al. 1990a, b, 1993, 1998a, b); ○ – Lake Suigetsu (Kitagawa & van der Plicht 2000)

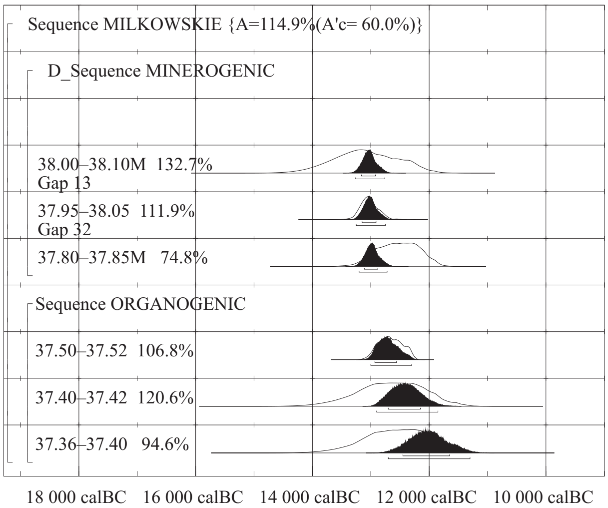

Fig. 8. Calibrated ^{14}C dates from Lake Miłkowskie from around the birch growth phase

climate, probably warming, which is consistent with an increased concentration of birch pollen in the sediment.

The sample 37.50–37.52 taken just from the beginning of the birch development phase was dated at 12 500±60 ^{14}C BP. The birch tree development prior to the Younger Dryas is also marked in the sediments from other Polish sites. The pollen profile from Witów (Wasylikowa 1978) shows the birch development phase dated by one sample at 12 260±230 ^{14}C BP. Similar date for this phase (12 330±160 ^{14}C BP) was obtained at Lake Łukcze (Bałaga 1982, 1990). On the other hand in the sediments from Lake Mikołajki the birch development phase is marked near the level dated to 12 000±130 ^{14}C BP (Ralska-Jasiewiczowa 1966). However, all these dates were made on bulk organic fraction of the sediment and none of these sediments was laminated.

The Polish best dated sediment from this period seems the laminated sediment of Lake Perespilno (Goslar et al. 2000). The calendar age of the birch development phase in Perespilno and Łukcze is about 14 450 cal BP. Basing on chronology of these sediments Ralska-Jasiewiczowa et al. (1999) have made an attempt at making a calendar chronology for the earlier studied Late Glacial profiles. According to their results, the birch development phase marked in the profile collected from Witów would be synchronized with the ages established from the sediments of Lakes Perespilno and Łukcze, while this phase marked in the sediment of Lake Mikołajki should be dated much later, to about 13 100 cal BP (Fig. 9). The older age is in accordance with the result obtained from the ^{14}C dating of Lake Miłkowskie taking into regard the large error in calendar dating of the Lake Miłkowskie sediments.

The simplified pollen spectra from the birch tree development phase determined in the sediment from lakes Miłkowskie and Mikołajskie look very similar (Fig. 9), which – in view of close distance between the two sites – would claim for synchronism of these phases. In fact only one sample from the Lake Mikołajskie sediment was dated by ^{14}C. Moreover, it cannot be excluded that the profile in Lake Mikołajki had discontinuities as severe as those documented in Lake Miłkowskie, so the birch development phase in Mikołajki might be much older than assumed hitherto and synchronous with that marked in the sediment of Lake Miłkowskie. Anyway one still can allow that in the period between the birch development phase and the beginning of the Younger Dryas marked in the sediment of Lake Miłkowskie, there was another phase of birch development, not marked in the sediment because of its discontinuity.

A significant increase in the birch pollen before the Younger Dryas has been also found in Germany in the sediments from Meerfelder Maar and Hämelsee (Stebich 1999, Litt et al. 2001). The sediment from Meerfelder Maar is laminated almost through the whole profile and it has a calendar chronology. The chronology of the sediment from Hämelsee is based on a correlation of the volcanic levels UMT and LST (Ulmenermaar tephra, Laacher See tephra) and the pollen diagrams from both sediments (Brauer et al. 1999a, b, 2000a, b, Friedrich et al. 1999, Litt et al. 2003). The phase of the greatest birch development marked in the sediments of these lakes has been dated to about 13 600–13 700 cal BP (Stebich 1999, Merkt & Müller 1999, Litt et al. 2001), which is later than that dated from the sediments from Lake Miłkowskie (Fig. 10). The varve chronology of the sediment from Meerfelder Maar (and the chronology of the sediment from Hämelsee made on its basis), covering a wide time range, does not lack discontinuities (Brauer et al. 2000a, b, Litt et al. 2001). For example the discontinuity found above the phase of the maximum birch development in the sediment from Meerfelder Maar (about 110 years, Brauer et al. 2000b), has shifted the calendar age of this phase closer to the calendar age of

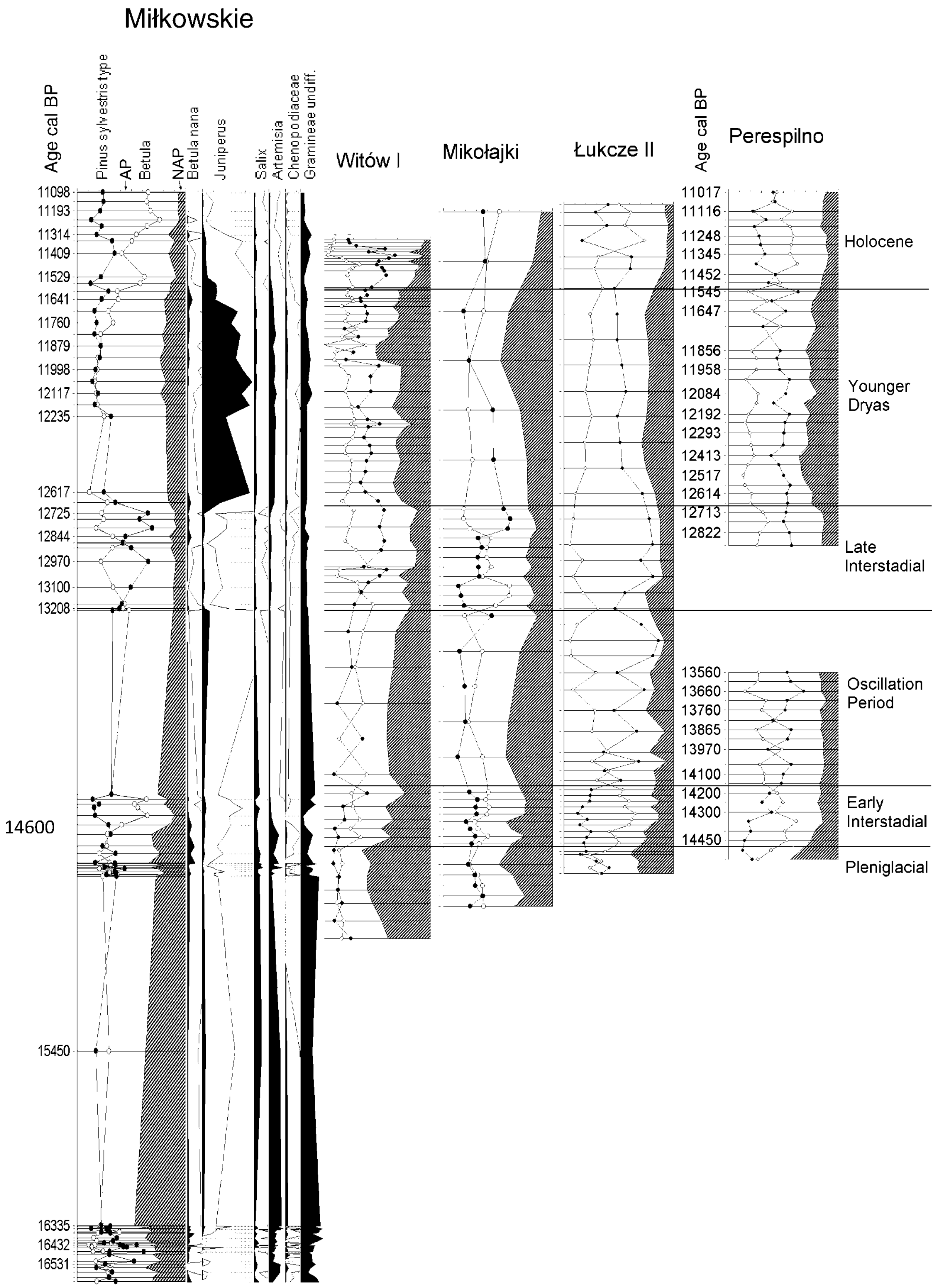

Fig. 9. Comparison of pollen diagram of Lake Miłkowskie with the pollen diagrams of sediments from Witów, Mikołajki, Łukcze and Perespilno (Ralska-Jasiewiczowa et al. 1999). AP – arboreal plants, NAP – non arboreal plants

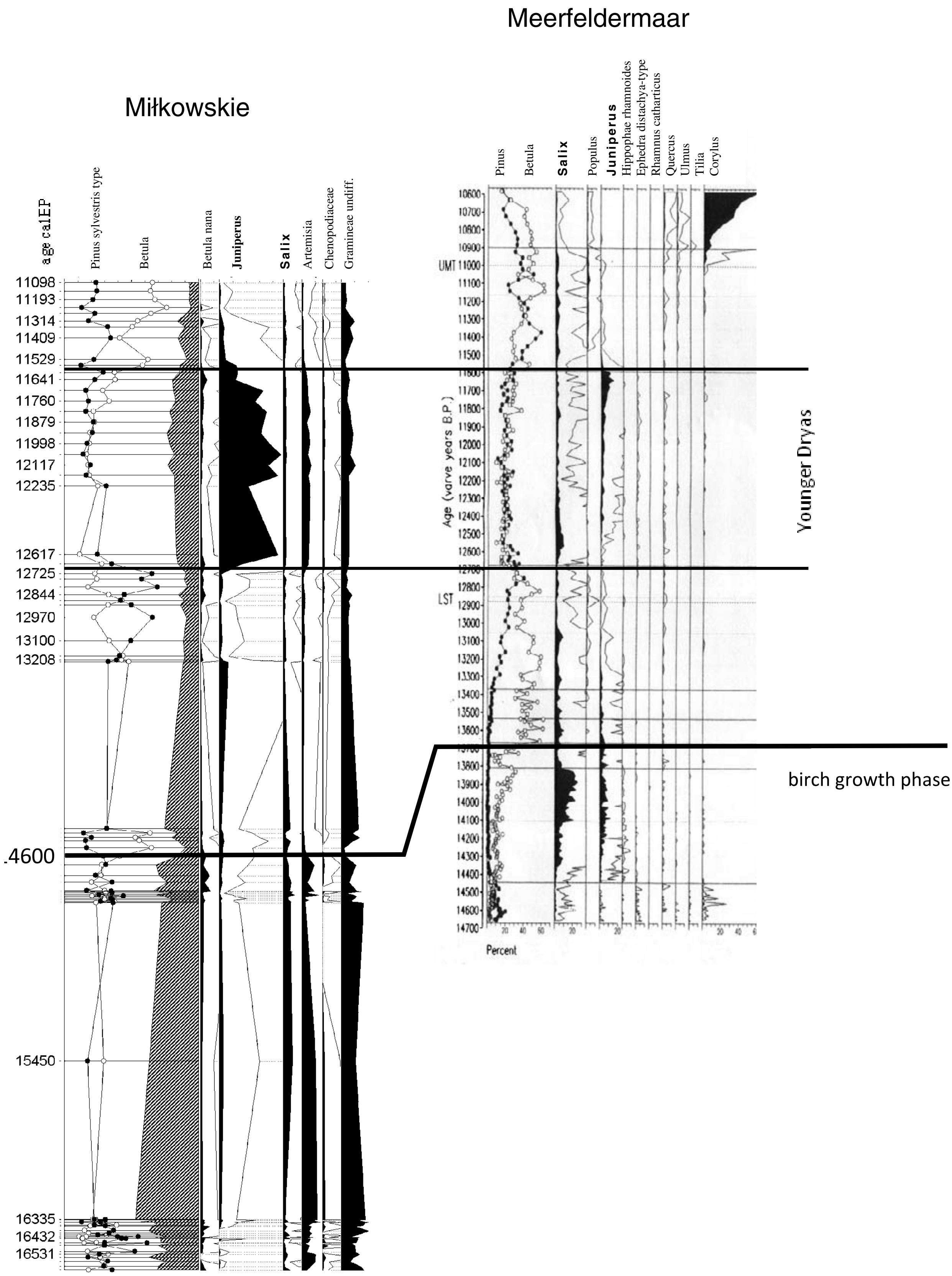

Fig. 10. Comparison of pollen diagram from Lake Miłkowskie (Wacnik 2003) and Meerfeldermaar (Stebich 1999, Litt et al. 2001)

this phase determined from Miłkowskie and Perespilno sediments. Nevertheless, the difference in the age of the birch development determined from sediments of the Polish and German lakes remains to be of about 500 years. It could suggest that the phase of birch development in the eastern and north-eastern Poland took place earlier than in Germany. Perhaps this phase in Poland is synchronous with the Meiendorf phase distinguished in the German studies (Brauer et al. 2000a, b, Litt et al. 2001, Merkt & Müller 1999). However, it cannot be excluded that the sediment from Meerfelder Maar has other discontinuities and the phases of birch development could indeed be synchronous.

CHRONOLOGY OF THE MINEROGENIC SEDIMENT; REPRESENTATIVENESS OF ^{14}C DATES OF DIFFERENT TYPES OF MACROREMAINS

The macroremains of terrestrial plants had been used for ^{14}C dating of varved clays in Scandinavia, however a considerable number of these dates are either underestimated or overestimated (Wohlfarth et al. 1993). The incorrect results of dating of the Scandinavian sediments challenged the reliability of ^{14}C dating of such sediments. These sediments are characterized by the classical clastic lamination caused by the seasonal changes in the rate of the glacier melting. The Lake Miłkowskie sediments in the lower part also show such lamination and the macroremains found in them were used for testing the representativeness of ^{14}C dates of this sediment.

The ^{14}C dating was made on different types of macroremains: terrestrial plants (birch), aquatic plants (Characeae oogonia) and plants from intermediate habitats (moss). Comparison between ^{14}C dates of the material typically used in dating lacustrine sediments (terrestrial plants) with those obtained for the samples of intermediate and water environments (Tab. 2) seems to demonstrate suitability of the latter for ^{14}C dating. The ^{14}C dates of the remains of aquatic and intermediate plants (Characeae oogonia and moss) do not differ much from the ^{14}C dates of terrestrial plants, and in general, all the dates cover rather narrow time interval.

The ^{14}C age of one moss sample (Fig. 11) strongly differs from the other ^{14}C dates. This moss sample had the smallest mass, which probably influenced the AMS measurement (Tab. 2). According to the experience of the

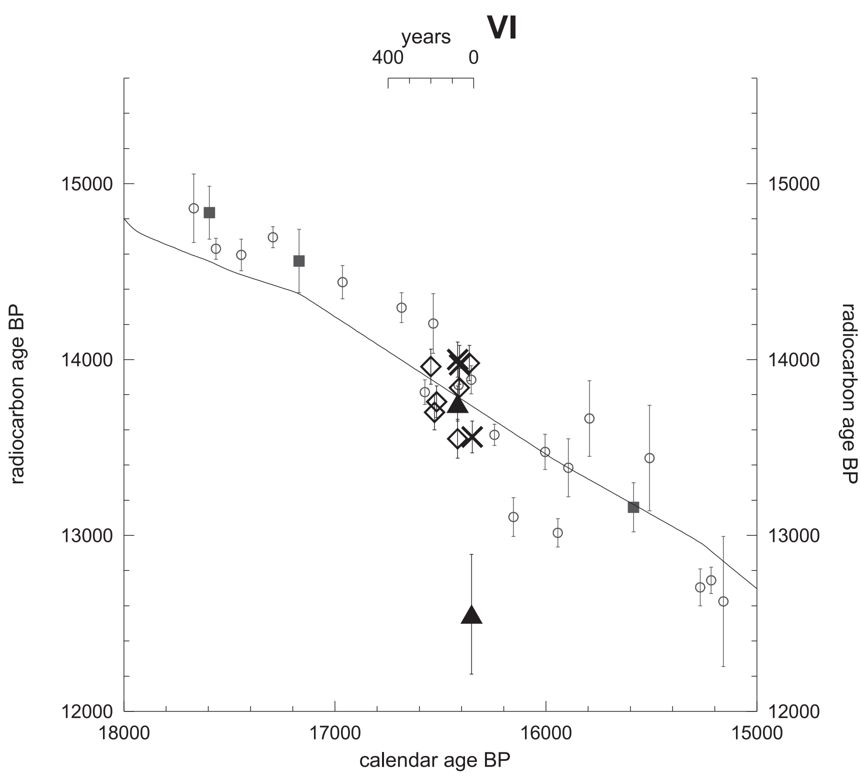

Fig. 11. ^{14}C dates of samples from oldest laminated sediment in Lake Miłkowskie. Symbols mean respectively: × – land plants; ▲ – moss, ◊ – Chara,; – calibration curve INTCAL04 (Reimer et al. 2004), ■ – corals (Bard 1998, Bard et al. 1990a, b, 1993, 1998); ○ – Lake Suigetsu (Kitagawa & van der Plicht 2000)

Radiocarbon Laboratory in Poznań, when the $\delta^{13}C$ values obtained from AMS measurement are very low (<-35‰), application of the correction for fractionation leads to overestimation of the corrected $^{14}C/^{12}C$ ratio and underestimation of the ^{14}C age. It has been confirmed by the results of measurements of the isotope ratios during the long-lasting sample sputtering in the AMS spectrometer (Goslar, pers. comm.). For example, when $\delta^{13}C$=-50‰ (such a value was measured by AMS for this moss sample) the underestimation of the age can reach even 250 years. As the construction of the AMS spectrometer used at the Laboratory in Kiel is different, it cannot be sure if the magnitude and direction of the age falsification at very low $\delta^{13}C$ is in Kiel the same as in Poznań Laboratory. Therefore, it should be only concluded that the error of the age of the critical moss sample can be much greater than that given in Table 2 and Figure 11.

The annual increments of the minerogenic sediment from Lake Miłkowskie are many times thicker than those in the biogenic part. Taking into account the result of varve counting from this part of the sediment substantially changes the proportions of the pollen diagram. The original pollen diagram (Wacnik 2003) drawn on the scale of sediment depth would suggest that the section VI covers >1500 years, whereas the analysis of laminae suggests only 279 years. The ^{14}C dates of the section VI confirm that this part of the profile covered a short period of time. In the age interval of interest, the calibration curve INTCAL04 (Reimer et al. 2004) is based mainly on ^{14}C dates of corals (Bard 1998, Bard et al. 1998), which are practically absent in the section of the sediment considered. Therefore the calendar chronology of this part of the sediment from Lake Miłkowskie, has been determined by matching to the ^{14}C dates from Lake Suigetsu (Kitagawa & van der Plicht 2000). The calendar age determined in this way is close to 16 500 years BP (Fig. 11).

CONCLUSION

The aim of the present study were to establish chronology of the Late Glacial sediments of Lake Miłkowskie, determination of the age of the phase of birch tree developmental in Late Glacial in northern Poland and testing the representativeness of ^{14}C dates of plant remains from the section of clastic lamination.

Microscopic analysis of the Lake Miłkowskie sediments showed that this sediment had short laminated fragments with large discontinuities, confirmed by the results of ^{14}C age determinations. In its younger part the sediment reveals has biogenic lamination, suggesting that it grew in the period of increased biological productivity of the lake and its vicinity. The older sediment deposited in the colder period as indicated by the clastic type of lamination.

The youngest laminated fragment of the analysed sediment was formed at the turn of the Allerød and the Younger Dryas. The calendar age of the sediment was matched to the transition of Allerød/Younger Dryas which was well dated in the sediment of Lake Gościąż. Assuming this calendar age, ^{14}C dates of the samples from Lake Miłkowskie, are in good agreement with the ^{14}C calibration data.

The calendar ages of the lower laminated sections were determined by matching the groups of the ^{14}C dates to the ^{14}C calibration data. The age of the birch tree development phase, reflected at the interface between clastic and biogenic laminations, seems to be synchronous with the birch development phase found in sediments from a few other Polish lakes. The correlation between the birch development phase in Lake Miłkowskie and that one found in the sediments of lakes Merfeldermaar and Hämelsee, suggest that in Germany the birch development occurred later than in Poland. However, we cannot exclude this apparent time lag could still be an artefact of not-detected discontinuities in the sediment from Merfelder Maar.

The oldest fragment of Lake Miłkowskie has clastic lamination. Comparison of ^{14}C dates of the various plant remains has confirmed their usefulness for ^{14}C dating of the sediment, and also indicated that the oldest fragment of the sediment was formed in a rather short time period. Taking into account the results of ^{14}C dating of the individual varve sequences of Lake Miłkowskie sediment, the proportions of the pollen diagram change substantially. This individual study demonstrates that reconstruction of history of vegetation on the basis of the pollen diagrams drawn solely on the depth scale is risky and may lead to incorrect conclusions. The enrichment of the pollen studies by the dense ^{14}C dating of plant macroremains, permits a more reliable reconstruction of changes in the vegetation over time.

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