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RADIOCARBON CHRONOLOGY OF LATE GLACIAL AND HOLOCENE SEDIMENTATION AND WATER-LEVEL CHANGES IN THE AREA OF THE GOŚCIĄŻ LAKE BASIN

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ABSTRACT. We obtained ^{14}C ages on samples of lake marl and other sediments from cores taken in Gościąż Lake and its environs. Comparison of ^{14}C dates of bulk samples of laminated sediment with varve chronology and available AMS dates of terrestrial macrofossils indicates a reservoir correction of 2000 ± 120 yr for the basal series of lake sediments. ^{14}C dates obtained on peat layers underlying the oldest lacustrine sediments in Gościąż and other lakes consistently locate the beginning of organogenic sedimentation in this area at *ca.* 13 ka BP. We distinguished three periods of lacustrine gyttja sedimentation in cores taken in Gościąż and adjacent lakes: 11.8–10.2 ka, 8–7 ka and 2.7–2.1 ka BP. From the ^{14}C dates of lithological boundaries in these cores, we reconstruct a pattern of lake-level changes during the last 12 ka, remarkably similar to Swedish lakes and generally agreeing with available records from European and American lakes. The behavior of Gościąż Lake during the last 12 ka fairly well reflects global climate changes in the temperate zone during the Late Glacial and Holocene periods.

INTRODUCTION

Gościąż Lake, situated in the Płock Basin (Fig. 1), is the largest and the deepest in the system of the four "Na Jazach" lakes drained by the small Ruda Creek. The significance of this lake was recognized immediately after discovery of its laminated sediment in 1985. Over 18 m of Gościąż Lake's basal sediments consist of carbonaceous-sulphuric gyttja with a large amount of iron and other elements, accumulated in a superaqueous environment dominated by reduction processes. The sediment reveals distinct lamination, consisting of *ca.* 12,500 laminae couplets, extending back from the present to the Allerød interstadial. Goslar *et al.* (1993) used varve chronology and AMS dates on macrofossils from Gościąż Lake to determine the duration of the Younger Dryas.

DESCRIPTION OF THE STUDY AREA

The Płock Basin is located in a glaciated area near the maximum southern advance of the Vistulian ice sheet, among the > 60 lakes of the Gostynin Lakeland. The region's mean annual temperature is 7.9°C; January and July mean temperatures are –1.6°C and 18.7°C, respectively. Annual precipitation is *ca.* 520 mm and evaporation *ca.* 412 mm; dominating winds are westerly (Sierżęga and Narwojsz 1988).

Quaternary sediments of the Płock Basin were formed mostly during the last glaciation. Glacial tills, kame and ooze sands occur in the eastern part of the Płock Basin; sands and gravels dominate in the vicinity of Gościąż Lake. Most of the Płock Basin is covered with glaciofluvial sands and gravels deposited at the decline of the Poznań phase and before the beginning of the Pomeranian phase of the Vistulian glaciation. The surface of glaciofluvial sediments is marked by numerous subglacial troughs and melt-out basins, some forming present-day lakes. The initial glacial relief of the region is hidden by dunes of Late Glacial age.

Underlying the Quaternary sediments are Pliocene clays with layers of silts, silty/clayey sands and Miocene sands, clays and silts with layers of brown coal up to 5 m thick. Siderite concretions and

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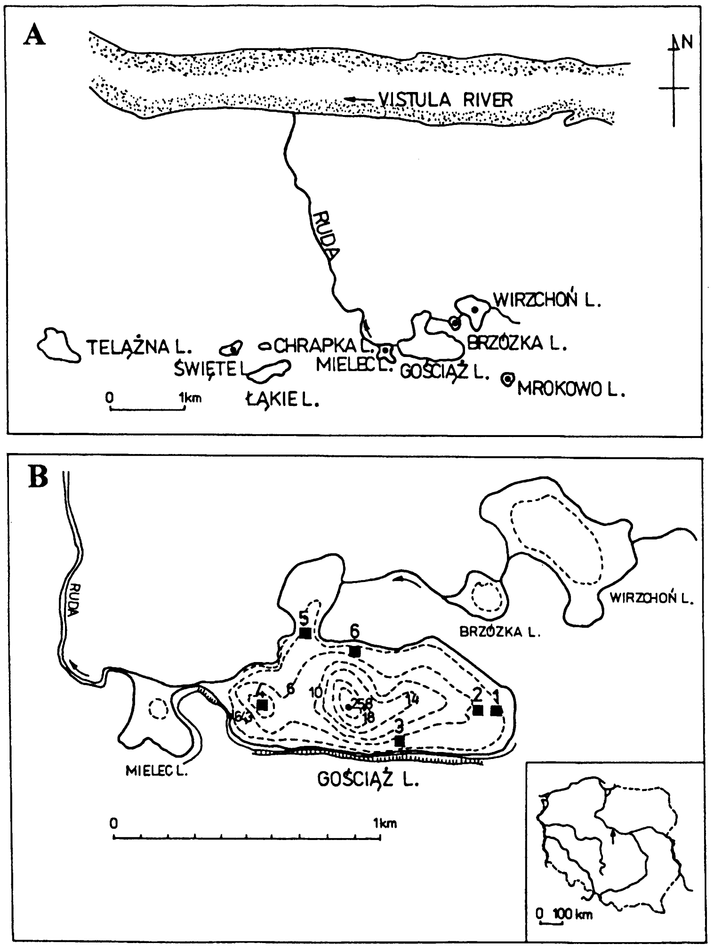

Fig. 1. Map of the study area. A. Environs of Gościąż Lake; • = cores from other lakes. B. Simplified bathymetric chart of the Na Jazach lake system. ■ = coring locations in Gościąż Lake; numbers = profiles shown in Fig. 2. Note: cores of laminated sediment from the central depression at water depth 25.8 m are not explicitly shown.

pyrite can be found in the Pliocene clays. The varied surface of Tertiary sediments exhibits denivellations of up to 130 m, caused by erosion, evorsion and glaciotectonic processes (Skompski 1971; Madeyska 1993).

Gościąż Lake forms an intermediate stage of a system of four lakes drained by Ruda Creek (Fig. 1). The input to the system is on the eastern side of Wirzchoń Lake at the mouth of a small stream that drains several peaty and boggy depressions; output is from the western part of Mielec Lake. The four lakes form a cascade system dropping from Wirzchoń Lake, 64.4 m asl. This lake, which captures most of the allochthonous material, is presently *ca.* 2.6 m deep, and its basal sediments are 12.5 m thick.

The distinct chemical characteristics of groundwater in the drainage basin of the lake system indicate that Gościąż Lake is supplied by surface water from recent precipitation and by underground seepage from water-bearing Pleistocene sands and much deeper Pliocene/Miocene beds (Wicik and Więckowski 1991). The present surface area of Gościąż Lake is 0.45 km^2. It has two distinct basal depressions: a central one with a maximum depth of 25.8 m, in the form of an elliptical cone extending SE-NW for *ca.* 300 m (Więckowski 1993), and a western one of similar shape and dimension, slightly > 12 m deep. A third shallow depression in the eastern lake basin is not marked on the bathymetric chart of the lake. The lacustrine sediments vary in thickness from *ca.* 7 m to *ca.* 18 m in the depressions. In both eastern and western depressions, the lacustrine sediments overlie a thin peaty layer showing pollen spectra typical for the Allerød period (Ralska-Jasiewiczowa, Wicik and Więckowski 1987). Close examination of other cores shows that lacustrine sediments were deposited directly on sands with fragments of lignite. In the core taken *ca.* 350 m east of the central depression, below a series of sandy sediments of Pleistocene age, a level of gravels directly overlies Pliocene silts.

Methods

We collected samples for ^{14}C dating from core segments 5 or 10 cm thick. Cores of laminated sediment were analyzed at the Institute of Botany, Polish Academy of Sciences, Krakow, by T. Goslar; other cores were analyzed at the Institute of Geography, Warsaw University, by A. Pazdur and B. Wicik. Samples of laminated sediment were pretreated with 0.5 N HCl; evolved CO_2 was trapped and, after purification, was used for ^{14}C activity measurements. Insoluble residue was washed until neutral reaction, dried and combusted in an oxygen stream. ^{14}C activity was measured using proportional counters filled with pure CO_2. We collected small aliquots of CO_2 for $\delta^{13}C$ determinations just before filling the proportional counters. All $\delta^{13}C$ analyses were made on an MI1305 mass spectrometer at the Institute of Physics, Maria Curie Skłodowska University, Lublin.

Samples from other cores were treated with 0.5 N HCl to remove carbonates and, after washing and drying, were combusted to CO_2 and counted. We used only the organic fraction for ^{14}C determinations on most samples. Both old and new oxalic acid standards were used as modern reference samples. Ages were calculated according to the recommendations of Stuiver and Polach (1977). Plant fragments for accelerator mass spectrometry (AMS) dating were separated from 10-yr segments of core by Z. Tomczynska-Moskwa, and terrestrial macrofossils were identified and selected by M. Ralska-Jasiewiczowa at the Institute of Botany, Krakow. Because of the very low mass obtained, individual samples separated from adjacent 10-yr segments of core were combined at the Centre des Faibles Radioactivités, Gif sur Yvette, to obtain enough carbon for AMS dating (Arnold *et al.* 1987).

Radiocarbon chronology of Gościąż lake sediments

Beginning with the first coring in 1985, which yielded the first long laminated sequence (Pazdur *et al.* 1987a,b; Ralska-Jasiewiczowa, Wicik and Więckowski 1987), four other cores of laminated sediment were collected from the central depression at water depth 25.8 m (*cf.* Fig. 1B). These cores were used to establish a detailed varve chronology (Goslar 1993) as well as for isotopic and paleoecologic studies (Różański *et al.* 1992; Goslar *et al.* 1992). Bulk samples of laminated sediment from cores G1/85, G1/87, G2/87 and G1/90 were used for ^{14}C age determinations on both carbonate and total organic matter fractions. Preliminary results were reported elsewhere (Pazdur *et al.* 1987a,b; Goslar *et al.* 1989) and were also used for tentative reconstruction of lake-level changes (Pazdur and Starkel 1989). Table 1 lists ^{14}C age determinations of all laminated sediment samples. Pazdur *et al.* (ms. in preparation) will discuss in detail the significance of isotopic data obtained from long cores of laminated sediment.

The size of the reservoir effect estimated by comparing varve chronology and ^{14}C dates obtained on bulk samples of laminated sediment varies with time and ranges from 900 to 3100 yr. ^{14}C content of dissolved inorganic carbon (DIC) of groundwater supplying the lake ranges from 63.4 to 70.0 pMC and in lake water equals 82.5 ± 1.7 pMC. Table 2 lists the results of AMS-dated terrestrial macrofossils separated from well-defined levels of laminated-sediment cores G1/97 and G2/97, obtained at the Gif

TABLE 1. ^{14}C Dates Obtained on Samples of Laminated Sediment From Cores Taken in the Central Depression of Gościąż Lake, Water Depth 25.8 m

Lab no. (Gd-)	Sample, depth	^{14}C age (BP)	$\delta^{13}C$ (‰)
2583	G1/85/1.5–1.6m/C*	2100 ± 90	−0.99
4066	G1/85/1.5–1.6m/O†	1730 ± 100	−30.24
3230	G1/85/2.65–2.75m/C	2200 ± 40	1.20
2649	G1/85/2.65–2.75m/O	2340 ± 80	−29.30
5008	G1/85/3.05–3.15m/C	3660 ± 50	0.00
2571	G1/85/3.05–3.15m/O	2730 ± 120	−30.36
5082	G1/85/3.9–4.0m/C	3880 ± 70	1.26
2620	G1/85/3.9–4.0m/O	3050 ± 80	−28.55
2618	G1/85/4.9–5.0m/C	4680 ± 120	1.61
2621	G1/85/4.9–5.0m/O	3800 ± 90	−30.17
3277	G1/85/6.1–6.2m/C	5350 ± 50	−1.20
2527	G1/85/6.1–6.2m/O	4230 ± 120	−31.52
5086	G1/85/6.9–7.0m/C	5690 ± 80	0.49
2623	G1/85/6.9–7.0m/O	5040 ± 110	−30.67
5094	G1/85/7.9–8.0m/C	6280 ± 80	0.35
2626	G1/85/7.9–8.0m/O	5530 ± 100	−30.63
5088	G1/85/8.9–9.0m/C	7390 ± 190	−0.04
4100	G1/85/8.9–9.0m/O	6320 ± 120	−31.37
1992	G1/85/9.60–9.65m/C	7930 ± 70	−1.05
2564	G1/85/9.60–9.65m/O	6840 ± 390	−32.00
5091	G1/85/10.0–10.1m/C	8190 ± 100	−0.49
5372	G1/85/10.0–10.1m/O	7630 ± 120	−31.23
5095	G1/85/10.45–10.55m/C	8420 ± 90	−2.16
4105	G1/85/10.45–10.55m/O	7880 ± 150	−31.59
5096	G1/85/11.0–11.1m/C	8800 ± 70	−1.80
3231	G1/85/11.45–11.50m/C	9160 ± 50	−4.54
2476	G1/85/11.45–11.50m/O	8960 ± 120	−32.00
5098	G1/85/12.0–12.1m/C	10,230 ± 90	−6.05
2627	G1/85/12.5–12.6m/C	10,710 ± 150	−6.38
4103	G1/85/12.5–12.6m/O	10,240 ± 250	−34.08
5099	G1/85/13.0–13.1m/C	10,830 ± 80	−6.58
4104	G1/85/13.0–13.1m/O	10,790 ± 220	−34.34
3225	G1/85/13.5–13.55m/C	10,640 ± 60	−8.29
2464	G1/85/13.5–13.55m/O	10,640 ± 100	−35.44
3223	G1/85/14.45–14.50m/C	12,100 ± 90	−6.96
4067	G1/85/14.45–14.50m/O	11,270 ± 350	−34.23
4007	G1/85/15.0–15.05m/C	12,570 ± 130	−7.82
4013	G1/85/15.0–15.05m/O	11,980 ± 430	−33.00
2584	G1/85/15.4–15.5m/O	12,650 ± 140	−33.19
5048	G1/85/15.40–15.50m/C	13,480 ± 120	−8.02
5444	G1/87/4.01–4.10m/C	3850 ± 70	0.75
5442	G1/87/4.31–4.40m/C	3720 ± 70	1.38
5441	G1/87/5.02–5.11m/C	3610 ± 60	1.85
5377	G1/87/6.15–6.25m/C	4520 ± 50	0.48
5376	G1/87/7.00–7.10m/C	4540 ± 70	0.56
5375	G1/87/7.90–8.00m/C	5430 ± 60	0.64
5374	G1/87/9.02–9.10m/C	6130 ± 60	0.02

TABLE 1. (Continued)

Lab no. (Gd-)	Sample, depth	^{14}C age (BP)	$\delta^{13}C$ (‰)
2888	G1/87/9.42–9.52m/C	5270 ± 90	0.04
2889	G1/87/10.66–10.72m/C	7350 ± 120	−0.78
5373	G1/87/10.93–11.0m/C	7620 ± 60	−0.92
5372	G1/87/11.33–11.40m/C	7800 ± 70	−1.35
5242	G1/87/16.92–16.98m/C	13,240 ± 120	−10.20
2771	G1/87/16.92–16.98m/O	13,780 ± 200	−34.00
6371	G2/87/16.02–16.10m/C	11,980 ± 170	−8.37
5853	G2/87/16.10–16.20m/C	11,700 ± 120	−4.12
4676	G2/87/16.10–16.20m/O	10,470 ± 180	−30.00‡
6355	G1/90/14.89–14.92/O1	11,970 ± 130	−29.46
4669	G1/90/14.89–14.92/O2	12,350 ± 260	−25.00

*C = carbonate fraction
†O = organic fraction
‡Assumed value

sur Yvette AMS facility. Różański *et al.* (1992) and Goslar *et al.* (1992) discussed the significance of these results for extending the calibration of the ^{14}C time scale to the Late Glacial period.

For this study, we used the data listed in Tables 1 and 2 to evaluate the magnitude of the reservoir correction ("hard-water effect"). One may compare two independent time scales with the ^{14}C dates of bulk samples of lake marl to derive the reservoir correction: the varve chronology elaborated by Goslar (1993), and the AMS dates listed in Table 2. The first approach yields a reservoir correction value of 2070 ± 120 yr, whereas the second approach yields a value of 1900 ± 120 yr. In both cases, we compared ten pairs of dates covering the Late Glacial segment of laminated sediment. From this comparison, we conclude that the reservoir correction for the basal sediments of Gościąż Lake is 2000 ± 120 yr. The observed scatter of individual differences in both cases is similar, with a standard deviation of $s_1 = 360$ yr.

TABLE 2. AMS Dates of Terrestrial Macrofossils from Core G2/87, Gościąż Lake

Sample	Varves	Sample material	^{14}C age (BP)
G201M	354–362	*Pinus* seedling, wood	10,030 ± 250
G202M	363–371	*Pinus* needle, *Betula* nutlet	10,450 ± 140
G223M			
+G224M			
+G225M	637–666	*Betula* nutlet, seed, scales	9600 ± 280
G233M	754–763	Bark	9950 ± 150
G236M			
+G237M	794–813	*Betula* nutlets, scales	9870 ± 150
G238M	824–833	*Betula* nutlets, scales	9870 ± 330
G244M			
+G245M			
+G245AM	886–910	Bud scales	10,040 ± 240
G252M			
+G255M	973–1020	*Pinus* seedlings, *Betula* nutlets	10,360 ± 160
G264M	1121–1130	Plant detritus	9750 ± 210
G268M	1171–1180	*Pinus* needles	10,050 ± 120

As a supplement to this study, we sampled a series of 12 cores along two lines in a W–E direction, to determine the thickness and stratigraphy of the lake sediments; we ^{14}C-dated six cores. Figure 1B shows core locations. Figure 2 shows the profiles of the cores and Table 3 lists the results.

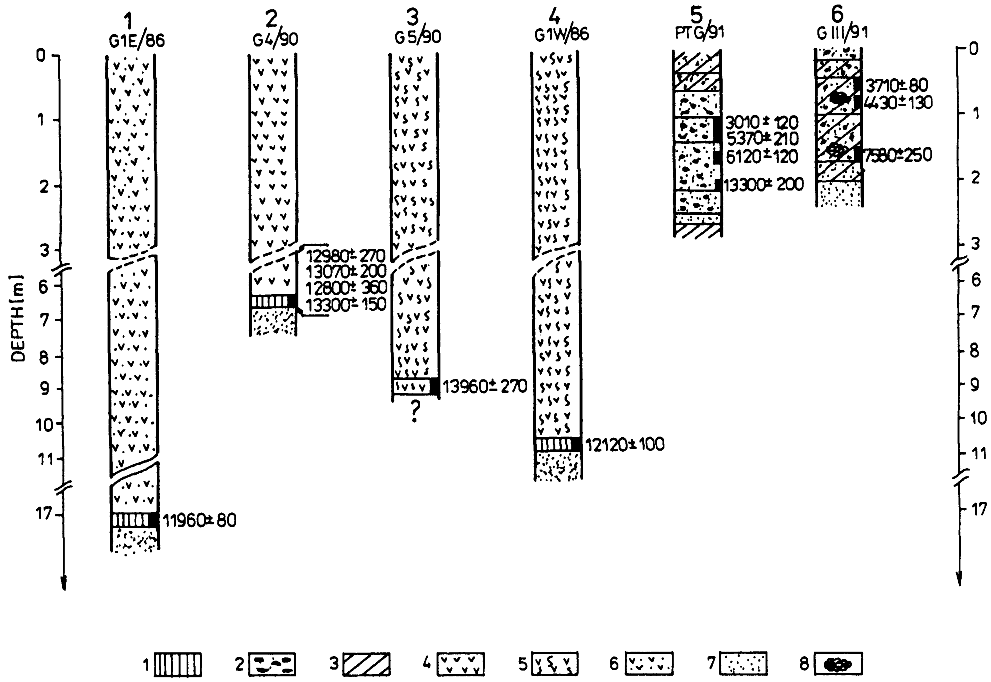

Fig. 2. Lithological profiles of sediment cores from Gościąż Lake. Key: 1. peat; 2. macroscopic plant remains (bark, twigs, charcoal); 3. fine detrital gyttja; 4. algal gyttja; 5. sulphuric-calcareous gyttja; 6. calcareous gyttja; 7. sand; 8. cone of *Picea* spp.

These results enable reliable and relatively precise dating of the beginning of organogenic sedimentation in the Gościąż Lake basin. The date of 13,300 ± 150 BP obtained on the deepest segment of the basal layer of peat underlying the lacustrine series in profile G4/90 (Fig. 2) determines the beginning of organic sedimentation in the eastern part of the lake. Taking into account the mean value of two dates obtained on the middle peat layer (6.6–6.7 m depth), 13,010 ± 170 BP, we obtain for the basal peat layer a series of three dates in good stratigraphic order. Because of relatively large dating errors, it seems reasonable to attribute to this peat layer the mean value of the whole set of four dates, 13,150 ± 110 BP. This result coincides well with the date, 13,300 ± 200 BP, which determines the beginning of organic sedimentation in the profile PTG/91 (Core 5 in Fig. 1, taken at the boundary between Gościąż Lake and Tobyłka Bay), obtained on coarse-detrital gyttja.

Almost identical early dates were obtained on thin peat layers underlying lacustrine sediments in cores G3/92 and G20/92 (13,020 ± 160 BP and 13,240 ± 150 BP, respectively), taken in peaty depressions of Ruda Creek valley at the eastern part of the study area (sampling points 11 and 13, Fig. 3). Similar dates were obtained on layers of peat and peaty detritus from basal sediment of Mielec and Wirzchoń Lakes (*cf.* Figs. 1 and 6 and Table 5).

TABLE 3. ^{14}C dates of Cores Taken From Gościąż Lake

Lab no. (Gd-)	Sample, depth	Sample material	^{14}C age (BP)
3305	G1E/86/17m	Peaty gyttja	11,960 ± 80
4683	G4/90/6.55–6.60m	Peat	12,980 ± 270
6386	G4/90/6.6–6.65m	Peat	13,070 ± 200
4691	G4/90/6.6–6.7m	Peat	12,800 ± 360
5857	G4/90/6.71–6.78m	Peat	13,300 ± 150
4688	G5/90/9.04m	Calcareous gyttja	13,960 ± 270
4733	GIII/91/0.45–0.60m	Detrital gyttja	3710 ± 80
4732	GIII/91/0.70–0.90m	Detrital gyttja	4430 ± 130
4731	GIII/91/1.50–1.70m	Detrital gyttja	7580 ± 250
4788	PTG/91/1.00–1.34m	Charcoal	3010 ± 120
4790	PTG/91/1.46–1.64m	Charcoal	5370 ± 210
4789	PTG/91/1.94–2.12m	Wood and charcoal	6120 ± 120
4791	PTG/91/2.67–2.69m	Coarse detrital gyttja	13,300 ± 200
5049	G1W/86/11m	Peaty detrital gyttja	12,120 ± 110

CHRONOLOGY OF SEDIMENTATION IN THE AREA OF GOŚCIĄŻ LAKE

Lithofacially differentiated sediments from the area of the lake contain important information about the development of the lake system and changes of its hydrological regime, including changing water levels during the last 13 ka BP. We conducted field work on these sediments for three seasons: in 1989, we sampled eight cores (Fig. 3); in 1992, we collected a second series of long cores reaching depths of *ca.* 8 m (Fig. 3); and we took 15 short cores along the southeast shore to determine the structure of subfossil lake terraces. From this series of corings, four samples were available for dating (LT-E1/92, LT-G3/92, LT-E5/92 and LT-J3/92 (Fig. 3); in 1993, we took two cores at the north shore of the lake (21 and 22 in Fig. 3). Figures 4 and 5 show detailed stratigraphy of some of these cores; Table 4 lists the ^{14}C results.

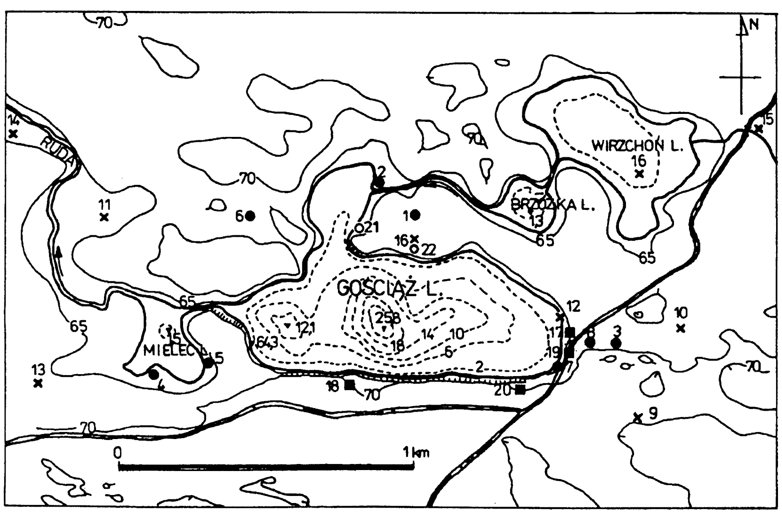

Fig. 3. Locations of cores and trenches around Gościąż Lake. • (1–8) = cores taken along the lakeshore in 1989; Fig. 4 shows lithological profiles. × (9–16) = cores taken in 1992; Fig. 5 shows lithological profiles (except core 16). ■ (17–20) = trenches made in 1992 to determine the structure of lake terraces; profiles are not shown. o (21–22) = cores taken in 1993.

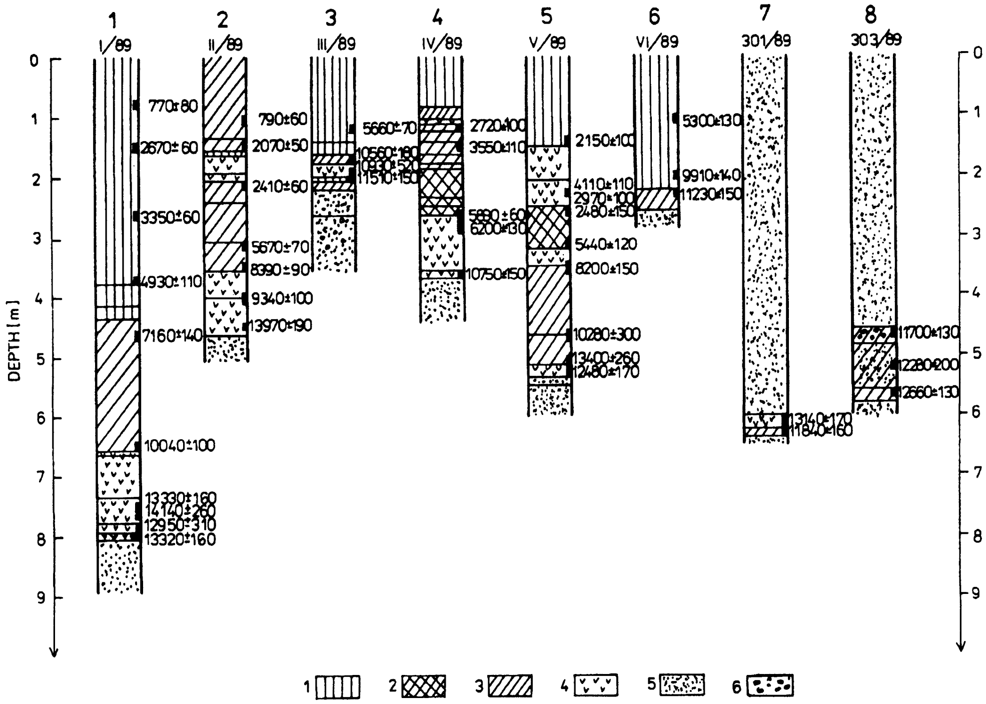

Fig. 4. Cores taken in 1989 around Gościąż and Mielec Lakes (• in Fig. 3): 1. peat; 2. decayed organic matter; 3. amorphous organic matter and humus sand; 4. lake marl (gyttja); 5. sand. Horizontal lines mark minor lithological boundaries.

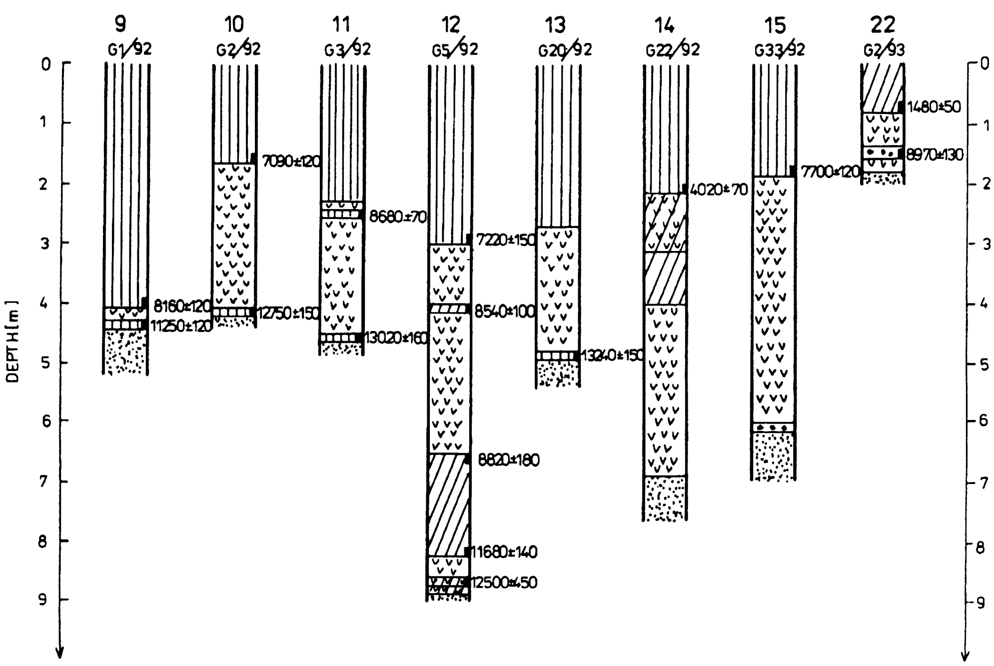

Fig. 5. Cores taken in 1992 and 1993; Fig. 3 shows locations. Key to lithological symbols is in Fig. 4.

TABLE 4. ^{14}C Dates From Cores Taken in the Vicinity Of Gościąż Lake

Lab no. (Gd-)	Sample, depth	Sample material	^{14}C age (BP)
6171	GTOI/89/0.7–0.8m	Peat	770 ± 80
5656	GTOI/89/1.6–1.7m	Peat	2670 ± 60
5657	GTOI/89/2.6–2.7m	Peat	3350 ± 60
6174	GTOI/89/3.6–3.7m	Peat	4930 ± 110
6176	GTOI/89/4.6–4.7m	Peat	7160 ± 140
5659	GTOI/89/6.4–6.5m	Amorphous organic matter	10,040 ± 100
6219	GTOI/89/7.6–7.7m	Calcareous gyttja	13,330 ± 160
6192	GTOI/89/7.7–7.8m	Calcareous gyttja	14,140 ± 260
4549	GTOI/89/7.8–7.93m	Calcareous gyttja	12,950 ± 310
4559	GTOI/89/7.8–7.93m	Calcareous gyttja	13,320 ± 160
5678	GTOII/89/1.00–1.15m	Amorphous organic matter	790 ± 60
5669	GTOII/89/1.37–1.59m	Amorphous organic matter	2070 ± 50
5670	GTOII/89/2.13–2.30m	Amorphous organic matter	2410 ± 60
5679	GTOII/89/3.00–3.18m	Amorphous organic matter	5670 ± 70
5677	GTOII/89/3.51–3.61m	Amorphous organic matter	8390 ± 90
5676	GTOII/89/3.90–4.12m	Calcareous gyttja	9340 ± 100
6194	GTOII/89/4.50–4.69m	Calcareous gyttja	13,970 ± 190
5681	GTOIII/89/1.05–1.25m	Wooden peat	5660 ± 70
6200	GTOIII/89/1.55–1.71m	Amorphous organic matter	10,560 ± 180
4522	GTOIII/89/1.84m	Amorphous organic matter	10,930 ± 520
6201	GTOIII/89/1.94–2.05m	Peat	11,510 ± 150
4521	GTOIV/89/1.22–1.37m	Amorphous organic matter	2720 ± 100
4542	GTOIV/89/1.44–1.55m	Amorphous organic matter	3550 ± 110
5703	GTOIV/89/2.77–2.90m	Calcareous gyttja	5890 ± 60
6202	GTOIV/89/2.94–3.15m	Calcareous gyttja	6200 ± 130
6203	GTOIV/89/3.60–3.70m	Calcareous gyttja	10,750 ± 150
6205	GTOV/89/1.42–1.52m	Peat	2150 ± 100
6209	GTOV/89/2.18–2.35m	Calcareous gyttja	4110 ± 110
6221	GTOV/89/2.48–2.60m	Organic detritus	2970 ± 100
4564	GTOV/89/2.48–2.60m	Charcoal	2480 ± 150
4557	GTOV/89/3.00–3.12m	Detrital gyttja	5440 ± 120
6210	GTOV/89/3.32–3.42m	Calcareous gyttja	8200 ± 150
4565	GTOV/89/4.60–4.70m	Amorphous organic matter	10,280 ± 300
4558	GTOV/89/5.30–5.45m	Sand with organic matter	13,400 ± 260
6215	GTOV/89/5.57–5.77m	Calcareous gyttja	12,480 ± 170
6212	GTOVI/89/1.0–1.1m	Moss peat	5300 ± 130
6214	GTOVI/89/2.0–2.1m	Moss peat	9910 ± 140
6217	GTOVI/89/2.2–2.3m	Amorphous organic matter	11,230 ± 150
5696	GTO301/89/6.0–6.3m	Calcareous gyttja	13,140 ± 170
6220	GTO301/89/6.30–6.35m	Amorphous organic matter	11,840 ± 160
5789	GTO303/89/4.5–4.7m	Gyttja with organic detritus	11,700 ± 130
6297	GTO303/89/5.3–5.4m	Calcareous gyttja	12,280 ± 200
5778	GTO303/89/5.6–5.8m	Calcareous gyttja	12,660 ± 130
6753	G1/92/4.0–4.1m	Peat	8160 ± 120
6764	G1/92/4.27–4.33m	Peat	11,250 ± 120
6754	G2/92/1.50–1.59m	Peat	7090 ± 120
6759	G2/92/4.12–4.31m	Peat	12,750 ± 150
7227	G3/92/2.34–2.38m	Peat	8680 ± 70
6783	G3/92/4.53–4.60m	Peat	13,020 ± 160

TABLE 4. (Continued)

Lab no. (Gd-)	Sample, depth	Sample material	^{14}C age (BP)
4932	G5/92/2.83–3.0m	Peat	7220 ± 150
4933	G5/92/3.98–4.02	Calcareous gyttja	8540 ± 100
4934	G5/92/6.45–6.55m	Calcareous gyttja	8820 ± 180
6762	G5/92/8.1–8.13m	Calcareous gyttja	11,680 ± 140
4924	G5/92/8.7–8.8m	Calcareous gyttja	12,500 ± 450
4936	G20/92/4.80–4.85	Peat	13,240 ± 150
4935	G22/92/2.0–2.12m	Peat	4020 ± 70
4937	G33/92/1.8–1.9m	Peat	7700 ± 120
7187	GM43/92/0.65–0.67	Tufa	7730 ± 60
7258	G56/92	Lignite	>43,000
7364	G1/93WD/7.6m	Lignite	34,300 ± 700
7363	G2/93/0.60–0.80m	Soil	1480 ± 50
7353	G2/93/0.98–1.02m	Calcareous gyttja	12,120 ± 70
7352	G2/93/1.50–1.55m/C	Calcareous gyttja	12,720 ± 100
6900	G2/93/1.50–1.55m/O	Calcareous gyttja	8970 ± 130
8053	E5/92/0.65–0.75m	Fossil soil	3650 ± 170
8054	A1/92/2.95–3.0m	Organic silt	8100 ± 200
8054	G3/92/1.9–1.96m	Sand with organic layers	4400 ± 160
8055	J3/92/0.4–0.45m	Peat	2330 ± 180

Cores GTO/89

In all GTO cores, except GTO301/89 and GTO303/89, lacustrine marls of different thickness topped by peat overlie a basal sand layer. In cores GTOII/89, GTOIV/89 and GTOV/89, which show direct hydrological relations with the Gościąż Lake basin, layers of decayed organic sediments and sandy humus separate a series of lacustrine sediments that formed when the water table in the lake was *ca.* 2.5 m lower than at present. This may be regarded as an indicator of an exceptionally dry period.

The scatter of ^{14}C dates obtained on lacustrine gyttja, observed in the bottom of profile GTOI/89 (Fig. 4), does not significantly exceed the limits predicted from comparative analysis of ^{14}C dates obtained on bulk samples of laminated sediment and the corresponding varve dates or AMS dates of macrofossils. Four dates on the organic fractions of lake marl samples at depths ranging from 7.8 m to 7.93 m yield a mean value of 13,440 ± 250 BP. Given a reservoir correction of 2000 ± 120 yr, the beginning of lacustrine sedimentation in profile GTOI/89 may be dated to several centuries before 11,440 ± 300 BP.

Markedly similar sequences can be observed in profiles GTOIV/89 and GTOV/89, from the Mielec Lake shore (4 and 5 in Fig. 3). Decayed organic matter directly overlies lacustrine gyttja in profile GTOIV/89, indicating a break in sedimentation and the beginning of a dry episode and low water level. ^{14}C dates on the organic fractions of the basal and top layers of the lacustrine series are 10,750 ± 150 BP (obtained on gyttja) and 5890 ± 60 BP, respectively. In profile GTOV/89, lacustrine gyttja accumulation is delimited by two ^{14}C dates, 8200 ± 150 BP, obtained on amorphous organic matter, and 5440 ± 120 BP, obtained on mursh, from under- and overlying lacustrine series, respectively. Because the two profiles were taken from proximate sites in similar geomorphological settings, we assume that deposition of amorphous organic matter and mursh in both profiles was approximately synchronous. If so, the beginning of lacustrine accumulation in profile GTOIV may be dated to 8750 BP, after applying the reservoir correction of 2000 yr.

Cores G/92

We sampled cores from sites 17–20 (Fig. 3) from low peat bogs during several seasons of field work. According to geomorphological and geological data, these cores should reflect hydrological changes in the lake basin. We selected ^{14}C-dated samples from these cores to supplement the determinations made earlier on cores GTO/89, which had few peaty organic horizons. Figure 5 shows the stratigraphy of the sediments; Table 4 lists the ^{14}C results.

Lake Terraces

We collected four samples from lake terraces identified in the morphology of the southeastern lake shore (sites 17–20 in Fig. 3). Sample LT-J3/92 was taken from a peat layer in the spring terrace (site 18 in Fig. 3). Other samples were dispersed organic dust from lake sands of the beach facies.

Radiocarbon chronology of sediments in neighboring lakes

We dated cores from three other lakes forming the Na Jazach lake complex and from Mrokowo and Święte Lakes (Fig. 1; Table 5). This system of lakes and peaty depressions has no common drainage; Ruda Creek drains the eastern area and the Zuzanka River drains the western area. Mrokowo and Święte Lakes are not drained.

TABLE 5. ^{14}C Dates From Cores Taken in the Na Jazach Lake System

Lab no. (Gd-)	Sample, depth	Sample material	^{14}C age (BP)
6369	Wirzchoń/86/12.4–12.5m	Peat (?)	13,770 ± 150
4763	Brzózka/91/6.75–6.84m	Algal gyttja	4510 ± 80
6589	Brzózka/91/11.35–11.45m	Calcareous gyttja	11,340 ± 150
4679	Mielec 3/90/13.90–13.95m	Calcareous gyttja	14,380 ± 270
6370	Mielec 3/90/13.95–14.0m	Calcareous gyttja	12,590 ± 190
4692	Mielec 3/90/15m	Peat	13,280 ± 320
6491	Święte/91/4.0–4.1m	Algal gyttja	2840 ± 100
6485	Święte/91/8.05–8.14m	Algal gyttja	4510 ± 110
5948	Święte/91/9.65–9.75m	Calcareous gyttja	7010 ± 90
6487	Święte/91/11.86–11.88m	Bark fragments	10,060 ± 140
6467	Święte/91/12.22–12.27m	Peat	12,410 ± 170
6553	Święte/91/13.16–13.18m	Organic detritus	11,030 ± 170
6684	Mrokowo/91/7.9–8.0m	Gyttja	7760 ± 110
6685	Mrokowo/91/11.9–12.0m	Gyttja	8530 ± 110
6720	Mrokowo/91/12.9–13.0m	Rotten peat	9480 ± 120
6721	Mrokowo/91/14.0–14.1m	Peat	12,030 ± 130

Wirzchoń Lake was cored in 1986; other cores were taken in 1990 and 1991. Figure 6 shows the stratigraphy of all the cores used in this study. The sediments of the Wirzchoń and Mielec Lakes begin with a thin peat layer at the base, overlain by an almost uniform series of calcareous gyttjas. The profile obtained from Brzózka Lake is more differentiated, showing distinct irregular lamination at its base (between *ca.* 6.5 and 11.5 m); the core taken from this lake probably did not reach the bottom of the sediment. For dating, we used the basal segment of the core, consisting of algal gyttja with sand admixture.

Sediments from two lakes west of the Na Jazach lake complex begin with a layer of mursh (Mrokowo/91) or sandy peat (Święte/91) (Fig. 6). In the latter profile, sand with some macrofossils

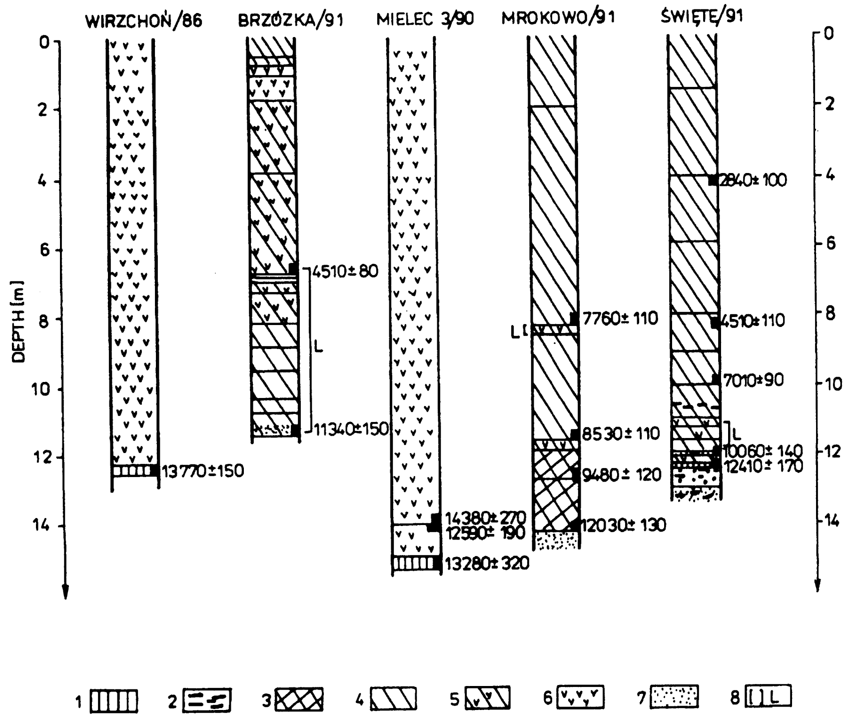

Fig. 6. Cores taken from other lakes in the study area. Coring location are • in Fig. 1A. Key: 1. peat; 2. macroscopic plant remains; 3. decayed organic matter; 4. algal gyttja; 5. algal-calcareous gyttja; 6. calcareous gyttja; 7. sand; 8. core segments with laminated sediment. Horizontal lines mark minor lithological boundaries.

overlies the organic level. Although both profiles consist mainly of non-calcareous algal gyttja, we found relatively thin layers of laminated algal-calcareous gyttja in each (Fig. 6). ^{14}C dates obtained on basal peat layers from Wirzchoń and Mielec Lakes, respectively 13,770 ± 150 and 13,280 ± 320 BP, indicate very early lacustrine sedimentation. These dates correlate well with the results obtained on basal peaty layers in Gościąż Lake (13,300 ± 200 BP, core PTG/91, and 13,150 ± 110 BP, the mean of four dates on basal peat from core G4/90). Dates obtained on basal organic levels in profiles from Mrokowo and Święte Lakes (Fig. 6) indicate that the lacustrine sedimentation began almost synchronously in both lakes, but *ca.* 1 ka later than in the Na Jazach lake complex.

WATER-LEVEL CHANGES

Detailed and accurate reconstruction of water-level changes in Gościąż Lake from ^{14}C-dated facial and lithological changes observed in sediment cores taken from its shore and environs is complex. Differentiation of sediments is controlled by both local geomorphology in the beach zone and by short-term water-level changes resulting from seasonal variation in precipitation. Despite these limitations, one can distinguish periods of high water level related to accumulating lacustrine gyttja. One may assume that lacustrine gyttja accumulation records high water levels in more than one profile. On the other hand, low water levels are recorded by layers of organic sediments such as peat and amorphous organic matter. Layers of mursh or decayed organic matter indicate arid periods with very low lake levels.

Cores GTO/89 and G/92 provide records of three periods of lacustrine gyttja accumulation, indicating high water levels. The oldest period lasted from *ca.* 11.8 to 10.2 ka BP, and the youngest from 2.5 to 2.1 ka BP. The duration of the middle period, which is not well documented in Figure 7, may be estimated at 8.2 to 7.0 ka BP. Almost all GTO/89 profiles (GTO I, II, III, V and 301) record the older episode of high water. Determining the beginning of calcareous gyttja accumulation in profiles GTO II, IV and V is problematic because corresponding dates are based on organic fractions of lacustrine sediment and may be subject to inaccuracy in the applied reservoir correction. Assuming a correction of 2000 yr, calcareous gyttja accumulation in profiles GTOI/89 and GTOII/89 begins *ca.* 12 ka BP. If this is the case, gyttja accumulation begins synchronously in profiles GTO I, II, III and 301 in the interval between 11.8 and 10.2 ka BP. The short episode of lacustrine accumulation, marked by a thin gyttja layer in profile GTO V (dated to 12,480 ± 170 BP), coincides, after reservoir correction, with the end of that period. Relatively precise timing of younger episodes of lacustrine sedimentation is possible from ^{14}C dates obtained on peat, mursh or amorphous organic matter. ^{14}C dates determining the beginning and end of lacustrine sedimentation obtained from peat layers in profiles G/92 correlate quite well with dates obtained on lithological boundaries of profiles GTO/89.

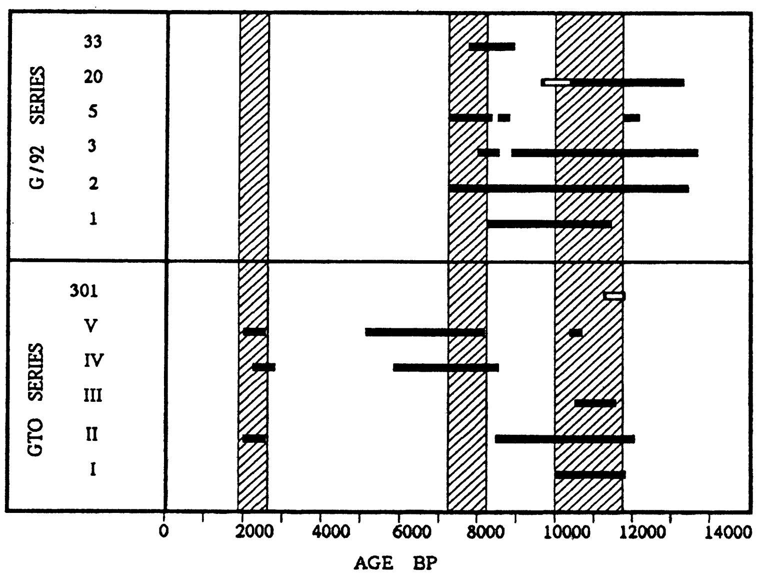

Fig. 7. Periods of lacustrine gyttja sedimentation near Gościąż Lake

We recorded no lacustrine sediments between 5.4 and 2.7 ka BP, which may indicate an extremely low lake level during this period. With the water level in Gościąż Lake at 62 m asl, Tobylka Bay was probably a shallow boggy basin. Figure 8 shows a reconstruction of water-level changes in Gościąż Lake from ^{14}C-dated lithological boundaries of sediments around the lake, based on the above-mentioned assumptions.

We distinguished a rapid rise in the Gościąż Lake level *ca.* 11.8 ka BP by observing a disturbance at the eastern lake shore associated with a landslide on the sandy bank. A thick series of fine-grained sands overlying lacustrine sediment in profile GTO301/89 records this event. Perhaps the sandy layer at the bottom of profile G1/87 was deposited at the same time (Wicik and Więckowski 1991). Similar trends in water-level changes between 8100 and 2300 BP may be deduced from ^{14}C dating

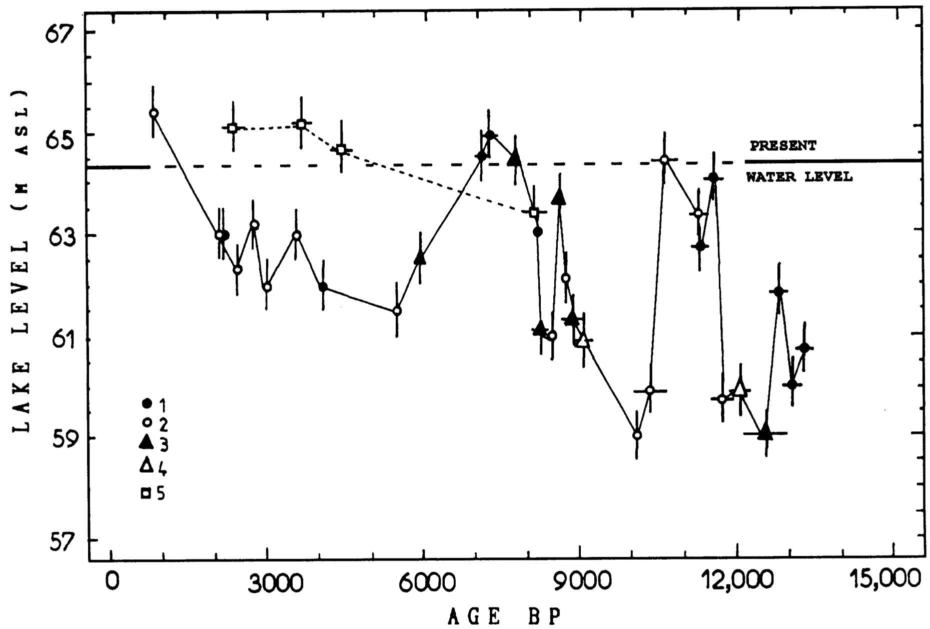

Fig. 8. Changes of water levels in Gościąż Lake from the Late Glacial to the present, expressed as changes in the elevation of the water table (m asl) estimated from lithological studies and ^{14}C-dating of cores around the lake. Key: 1. peat; 2. mursh; 3. detrital gyttja; 4. lake marl (T_R = 2 ka); 5. lake terraces.

of lake terraces. A water-level rise of *ca.* 1.5 m during this period corresponds to the formation of a terrace dated *ca.* 2300 BP at altitude *ca.* 1.5 m higher than that of the terrace at 8100 BP.

Conclusions

Lithological boundaries between lacustrine gyttja and non-lacustrine sediments reflect changes in the water level in Gościąż Lake. Correlating these locations with the ^{14}C dates enables us to reconstruct fluctuations in the lake's water table during the last 13 ka BP. Thus, the highest and lowest water levels of Gościąż Lake (Fig. 8) should correspond to other records of temperate-zone lake-level changes during the Late Glacial and Holocene. Holocene lake-level fluctuations recorded in southern Sweden by Digerfeldt (1988:173, Fig. 11) indicate the first distinct, rapid lake-level decline at 9.7–9.5 ka BP, and the second long period of a low lake level between 6.5 and 3.5 ka BP. Further, each of the nine lakes studied shows low levels between 2.7 and 2.0 ka BP. We have almost exactly replicated these findings with our data (Figs. 7 and 8).

The record of Holocene lake-level fluctuations in Jurassian and French subalpine lakes, obtained by Magny (1992, 1993) shows distinct similarities to the Gościąż Lake record. The two oldest transitions from transgression to regression, noted at 9.5–8.0 ka and 7.5–6.0 ka BP in French lakes, are also visible in the trend of Gościąż lake-level changes. No such distinct similarities occur in the late Holocene, but both records agree fairly well.

Gościąż lake-level changes also correlate to regional patterns of high and low lake levels obtained from statistical analyses of lakes in eastern North America (Harrison 1989) and Europe (Harrison, Prentice and Guiot 1993). Thus, we conclude that the behavior of Gościąż Lake during the last 12 ka fairly accurately reflects global climate changes in the temperate zone during the Late Glacial and Holocene.

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