

# INFLUENCE OF THE BOMB-PRODUCED $^{14}\text{C}$ ON THE RADIOCARBON CONCENTRATION IN THE YOUNGEST SEDIMENTS OF LAKE GOŚCIAŻ, CENTRAL POLAND

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**ABSTRACT.** This work is a study of changes of the radiocarbon concentration in the youngest part of Lake Gościąż sediments in the calendar time scale during the last 150 years. This period includes the time of the nuclear weapons tests performed in the upper atmosphere in the 1950s and the 1960s, which caused large release of  $^{14}\text{C}$  and  $^{137}\text{Cs}$  into the environment. On the basis of this study, the isotope dilution factor for  $^{14}\text{C}$  and the exchange time of carbon between the atmosphere and Lake Gościąż was estimated. The chronology of the upper part of the sediments was constructed using many interdisciplinary investigations. Among them, measurements of  $^{137}\text{Cs}$  in the sediment were used. An unexpected discrepancy between the previously constructed time scale and that suggested by  $^{137}\text{Cs}$  is observed in one of the cases.

## INTRODUCTION

Nuclear weapons tests performed in the upper atmosphere in the 1950s and 1960s caused large changes in the radiocarbon concentration of the atmosphere and release of  $^{137}\text{Cs}$  into the environment. It was evident that such large changes in the  $^{14}\text{C}$  concentration could be used to investigate many geochemical processes. One of them is the investigation of lake processes.

The organic and dissolved inorganic carbon present in a lake reservoir come from many sources with various  $^{14}\text{C}$  concentrations (Broecker and Walton 1959; Pazdur et al. 1995). The changes of  $^{14}\text{C}$  concentration in the atmosphere influence the  $^{14}\text{C}$  concentration in lake sediments. The investigation of the  $^{14}\text{C}$  concentration can provide information about carbon cycle in lake ecosystems.

Lake Gościąż (Figure 1) is perfectly suitable for such a study. Many interdisciplinary studies have been carried out on the ecosystem of the lake (Ralska-Jasiewiczowa et al. 1998). It is the largest and deepest in a system of four lakes, "Na Jazach", drained by the small creek Ruda. It has formed a nearly perfect continuous yearly lamination throughout its sediment profile from the Late Glacial until the present. More than 18-m-thick basal sediments of Lake Gościąż consist of carbonaceous-sulfuring gyttja with large amounts of iron and other elements, accumulated in an overlying aqueous environment with predominantly reducing conditions (Więckowski 1998). The fundamental deposits filling Lake Gościąż are gray-olive carbonate gyttjas of the type common in lakes formed in the the last glaciation. The specific sulfide-carbonate gyttjas are found only in the central and western depths. The upper 2.5 m or so of the deposits are soft, amorphous, and jelly-like, while the middle and lower parts are increasingly compact. In the whole profile, numerous tiny blue spots or thin layers of vivianite of up to 1 mm of thick are visible. Sands are lacking. The content of organic matter ranges from 10 to 18% of dry matter, and the smallest amount occurs in the middle 4–11 m of the sequence, where the content of  $\text{CaCO}_3$  reaches 75% of dry matter. A drastic decrease in the proportion of  $\text{CaCO}_3$  in the top layers covering no more than a few last centuries is supposed to be associ-

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ated with human activity, i.e. forest clearing and the development of agriculture. These activities caused the increase in deflation and supply of carbonates to the lake.

The chemical characteristics of groundwater in the lake system “Na Jazach” indicate that the water supply to Lake Gościąg is provided by surface water from recent precipitation and by underground seepage from Pleistocene and Pliocene/Miocene beds. Mean annual temperature of the region is +7.9 °C, with mean temperatures in January and July being –1.6 °C and +17.8 °C, respectively. Annual precipitation is about 410 mm and westerly winds dominate. Lake Gościąg is located at an altitude of 64.3 m above sea level (asl), which is about 14 m above the present-day level of the Vistula River, as the consequence of construction of the Włocławek artificial retention basin.

The morphometric parameters of Lake Gościąg are (Giziński et al. 1998): mean water depth 5 m, maximum depth 24 m, area 41.7 ha, and volume  $2.1 \cdot 10^6 \text{ m}^3$ . The total biomass of phytoplankton estimated for 1993 reached maximum of  $3.1 \text{ mg/dm}^3$  in July and a minimum of  $0.2 \text{ mg/dm}^3$  in November of that year (Giziński et al. 1998). The mean residence time of water in Lake Gościąg is estimated at 1–2 years (Wachniew and Róžański 1998).



Figure 1 Map of Europe with the location of Lake Gościąg

## METHODS

Cores from the upper 2.5 m of sediment were retrieved by the freezing-in-situ method (Walanus 1998). Cores were retrieved in the central depth with an overlaying water column of 24 m. The cores were then dried at a temperature of about –18 °C for a few months. During the period between 1989 and 1996, 44 cores of sediments were taken from Lake Gościąg and seven of them were sampled for isotopic investigations. Table 1 shows the results of the isotopic measurements. The names of all investigated cores are used as first part of names of the samples.

### Varve and $^{137}\text{Cs}$ Chronology of the Youngest Sediments

Photographic documentation was made for all cores. Laminated sequence of cores was replicated following the tape-peel method. However, the quality of lamination in the youngest part of the sediments was poor. There were only few clearly visible layers. The varves were clearly visible only for sediment depths larger than 1 m. The chronology of the upper part of the sediments was established using charcoal seen at the depth of 0.71 m and the  $^{137}\text{Cs}$  profile of core G21f. The results of  $^{137}\text{Cs}$  measurements in the core G43f (see Table 2) were not used for the chronology construction (they were used only to confirm the correlation of the core G43f with the previously constructed chronology). The charcoal was attributed to a large forest fire, which took place in the spring of 1946 and was well documented historically. The varves seen at depths below 1 m in the investigated cores were dated by correlation with the previously constructed varve chronology (Goslar 1998). Those varves and the extrapolated rate of sedimentation were used to correlate cores G43f and G1/96 with the chronology of the upper part of Lake Gościąg sediment (Figure 2). After correlation of the investigated cores with the varve chronology, samples with a resolution of 2–7 years were obtained. The calendar year of each sample was calculated using the relationship between the depth and the varve chronology as shown on Figure 2. For interpolation purposes, the square polynomial equation plotted on Figure 2 was used,

$$T_{\text{cal}} = -23.7x^2 - 42.8x + 1989, \quad (1)$$

where  $T_{\text{cal}}$  is calendar year and  $x$  is relative sediment depth.

Table 1 Isotopic composition of carbon:  $^{14}\text{C}$  concentration (normalized for isotopic fractionation) and  $\delta^{13}\text{C}$  in the youngest part of Lake Gościąg sediments.<sup>a</sup>

Lab nr	Core name, depth	Fraction <sup>b</sup>	$^{14}\text{a}_{\text{N,S}}$ (%)	$^{14}\text{C}$ age (BP)	$\delta^{13}\text{C}$ (‰, PDB)
Gds-49	G43f, 0–0.04 m	O	81.7 ± 1.5	1620 ± 150	–35.29
Gds-60	G43f, 0.04–0.08 m	C	78.0 ± 0.9	2000 ± 90	–1.8 <sup>c</sup>
Gds-50	G43f, 0.04–0.08 m	O	83.4 ± 1.2	1460 ± 120	–35.31
Gds-61	G43f, 0.08–0.12 m	C	79.8 ± 1.3	1810 ± 130	–1.82
Gds-51	G43f, 0.08–0.12 m	O	81.5 ± 1.2	1640 ± 120	–35.46
	G43f, 0.12–0.15 m	C			–2.06
Gds-52	G43f, 0.12–0.15 m	O	88.0 ± 1.1	1030 ± 100	–35.57
Gds-62	G43f, 0.15–0.185 m	C	78.4 ± 0.9	1960 ± 90	–2.1
Gds-53	G43f, 0.15–0.185 m	O	81.2 ± 1.2	1670 ± 120	–35.29
Gds-63	G43f, 0.185–0.22 m	C	78.7 ± 0.9	1920 ± 100	–1.78
Gds-54	G43f, 0.185–0.22 m	O	85.9 ± 1.0	1230 ± 100	–35.84
Gds-64	G43f, 0.22–0.28 m	C	78.1 ± 1.0	1980 ± 110	–2.17
Gds-55	G43f, 0.22–0.28 m	O	84.6 ± 0.9	1340 ± 80	–35.23
Gds-65	G43f, 0.28–0.34 m	C	79.3 ± 0.9	1860 ± 90	–2.28
Gds-56	G43f, 0.28–0.34 m	O	84.8 ± 1.0	1330 ± 90	–35.26
Gds-66	G43f, 0.34–0.375 m	C	80.8 ± 0.9	1710 ± 90	–2.34
Gds-57	G43f, 0.34–0.375 m	O	85.1 ± 1.3	1290 ± 120	–35.18
Gds-67	G43f, 0.375–0.41 m	C	75.5 ± 1.5	2260 ± 160	–2.33
Gds-58	G43f, 0.375–0.41 m	O	83.7 ± 1.4	1430 ± 140	–35.27
	G43f, 0.41–0.44 m	C			–2.37
Gds-59	G43f, 0.41–0.44 m	O	86.2 ± 1.2	1190 ± 110	–33.74
Gds-68	G43f, 0.44–0.47 m	C	81.0 ± 0.8	1700 ± 80	–2.52
	G1/96, 0.53–0.56 m	C			–2.14
Gd-16025	G1/96, 0.47–0.50 m	C	77.32 ± 1.5	2070 ± 150	–2.14
Gd-12219	G1/96, 0.50–0.53 m	C	81.46 ± 0.7	1650 ± 60	–2.66
Gd-17027	G1/96, 0.50–0.53 m	O	76.76 ± 1.8	2130 ± 190	–30.33
	G1/96, 0.56–0.59 m	C			–2.29
Gd-17025	G1/96, 0.56–0.59 m	O	78.86 ± 1.2	1910 ± 120	–30.5 <sup>c</sup>
	G1/96, 0.59–0.62 m	C			–2.00
Gd-16024	G1/96, 0.59–0.62 m	O	84.33 ± 1.4	1370 ± 130	–30.66
Gd-16017	G1/96, 0.62–0.66 m	O	89.95 ± 1.4	850 ± 120	–30.58
	G1/96, 0.72–0.75 m	C			–2.43

Table 1 Isotopic composition of carbon:  $^{14}\text{C}$  concentration (normalized for isotopic fractionation) and  $\delta^{13}\text{C}$  in the youngest part of Lake Gościąg sediments.<sup>a</sup> (Continued)

Lab nr	Core name, depth	Fraction <sup>b</sup>	$^{14}\text{a}_{\text{N,S}}$ (%)	$^{14}\text{C}$ age (BP)	$\delta^{13}\text{C}$ (‰, PDB)
Gd-16018	G1/96, 0.72–0.75 m	O	61.32 ± 1.4	3930 ± 180	–30.76
	G1/96, 0.75–0.84 m	C			–1.15
Gd-4787	G13f/15f, 0.93–0.98 m	C	82.0 ± 0.8	1590 ± 100	–1.8 <sup>c</sup>
Gd-4792	G13f/15f, 0.93–0.98 m	O	75.7 ± 1.0	2240 ± 100	–28.8*
Gd-4786	G13f/15f, 0.98–1.04 m	C	73.0 ± 1.0	2530 ± 120	–1.7 <sup>c</sup>
Gd-4793	G13f/15f, 0.98–1.04 m	O	77.1 ± 1.0	2090 ± 120	–28.2 <sup>c</sup>
Gd-4781	G13f/15f, 1.04–1.09 m	C	71.8 ± 0.9	2660 ± 100	–1.7 <sup>c</sup>
Gd-4795	G13f/15f, 1.04–1.09 m	O	76.6 ± 1.2	2130 ± 130	–28.4 <sup>c</sup>
	G4f/5f, 1.04–1.14 m	C			–2.28
Gd-4517	G4f/5f, 1.04–1.14 m	O	76.0 ± 1.4	2200 ± 150	–28.6 <sup>c</sup>
Gd-4779	G15f, 1.09–1.14 m	C	78.2 ± 1.0	1980 ± 110	–1.2 <sup>c</sup>
Gd-4794	G15f, 1.09–1.14 m	O	74.8 ± 1.3	2330 ± 140	–28.8 <sup>c</sup>
Gd-4782	G15f, 1.14–1.2 m	C	74.2 ± 0.9	2400 ± 90	–1.2 <sup>c</sup>
Gd-4796	G15f, 1.14–1.2 m	O	77.0 ± 0.8	2070 ± 80	–28.2 <sup>c</sup>
Gd-4503	G4f/5f, 1.14–1.25 m	C	72.1 ± 0.9	2630 ± 100	–1.91
Gd-4516	G4f/5f, 1.14–1.25 m	O	76.6 ± 0.9	2140 ± 90	–30.67
Gd-4780	G15f, 1.2–1.25 m	C	77.1 ± 0.9	2090 ± 80	–1.3 <sup>c</sup>
Gd-4797	G15f, 1.2–1.25 m	O	79.2 ± 1.0	1870 ± 120	–28.8 <sup>c</sup>
Gd-6184	G4f/5f, 1.25–1.38 m	C	74.1 ± 0.9	2410 ± 100	–1.11
Gd-6185	G4f/5f, 1.25–1.38 m	O	79.3 ± 0.9	1860 ± 90	–28.39
Gd-5668	G4f/5f, 1.38–1.48 m	C	76.1 ± 0.6	2190 ± 60	–0.76
Gd-6188	G4f/5f, 1.38–1.48 m	O	79.5 ± 1.0	1840 ± 100	–29.89
Gd-6193	G4f/5f, 1.48–1.6 m	C	72.7 ± 0.9	2560 ± 100	–0.17
Gd-6186	G4f/5f, 1.48–1.6 m	O	81.7 ± 0.7	1620 ± 70	–28.87
Gd-5667	G4f/5f, 1.6–1.72 m	C	73.5 ± 0.4	2470 ± 40	0.87
Gd-6183	G4f/5f, 1.6–1.72 m	O	71.6 ± 1.0	2680 ± 110	–29.86

<sup>a</sup> $^{14}\text{C}$  age (normalized, in BP) is conventional  $^{14}\text{C}$  age of the sample in the moment of sedimentation, calculated according to Stuiver and Polach (1977) and means so-called “reservoir age” or “apparent age” (Pazdur et al. 1995). Cores G4f and G5f were collected in May 1989, G13f and G15f in May 1990, G43f in May 1993 and G1/96 in March 1996.

<sup>b</sup>C=carbonate, O=organic fraction of the samples.

<sup>c</sup>For calculation of  $^{14}\text{a}_{\text{N,S}}$  (%) and  $^{14}\text{C}$  age (BP) estimated values of  $\delta^{13}\text{C}$  (on the basis of measurements in other cores) were used.

Table 2 Results of  $^{137}\text{Cs}$  measurements (in Bq/g of dry sample mass) in core G43f.

Core name, depth	$^{137}\text{Cs}$ (Bq/g)
G43f, 0–0.04 m	0.0430 ± 0.0032
G43f, 0.04–0.08 m	0.0503 ± 0.0025
G43f, 0.08–0.12 m	0.0513 ± 0.0025
G43f, 0.12–0.15 m	0.0531 ± 0.0025
G43f, 0.15–0.185 m	0.0519 ± 0.0031
G43f, 0.185–0.22 m	0.0533 ± 0.0025
G43f, 0.22–0.28 m	0.0821 ± 0.0029
G43f, 0.28–0.34 m	0.0600 ± 0.0027
G43f, 0.34–0.375 m	0.0546 ± 0.0026
G43f, 0.375–0.41 m	0.0450 ± 0.0025
G43f, 0.41–0.44 m	0.0367 ± 0.0024
G43f, 0.44–0.47 m	0.0363 ± 0.0024

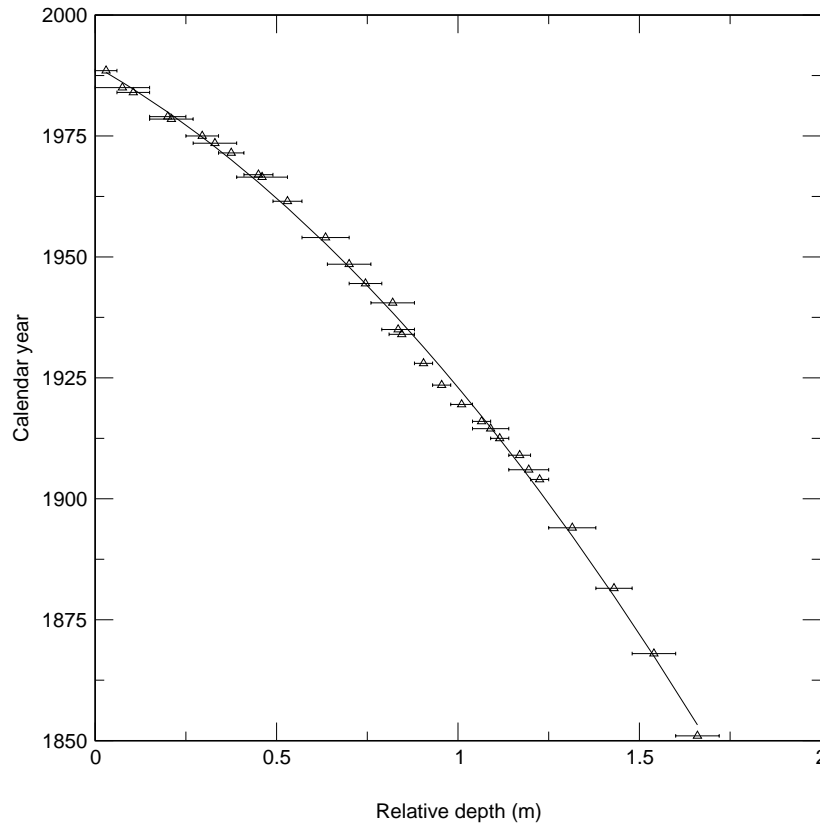


Figure 2 Calendar age versus relative depth of the youngest sediments for all the cores used for construction of the varve chronology in Goslar (1998). The drawn line is a second-order polynomial fit.

### Isotopic Measurements

Each sample was dried at approximately 50 °C and homogenized. An attempt was made to confirm the correlation of our cores with the chronology of that part of sediments in which measurements of  $^{137}\text{Cs}$  concentration were performed. Measurements of  $^{137}\text{Cs}$  were done on all samples corresponding to the depth from 0 to 1 m. Measurements of  $^{137}\text{Cs}$  were done on about 16.5 grams of dried sample, using a high-resolution germanium gamma spectrometer. The  $^{14}\text{C}$  concentration and  $^{13}\text{C}$  were measured separately in the organic and carbonate fractions. Small, proportional counters (GPC) of 0.3 dm<sup>3</sup> volume filled with CO<sub>2</sub> (Pazdur and Pazdur 1986) were used for the measurements of  $^{14}\text{C}$  concentration of samples with the Gd laboratory code prefix, while the measurements for the samples with Gds laboratory code prefix were carried out using a Quantulus 1220<sup>TM</sup> liquid scintillation beta spectrometer (LSC) (Pawlyta et al. 1998). For the latter measurements, 0.8 cm<sup>3</sup> PTFE vials were used. The CO<sub>2</sub> produced during benzene preparation was purified in a vacuum rig designed for preparation of the gas samples for GPC systems. All  $^{14}\text{C}$  measurement results (Table 1), were normalized according to Stuiver and Polach's (1977) procedure. The  $\delta^{13}\text{C}$  of the organic fraction used for normalization was measured using the CO<sub>2</sub> produced for  $^{14}\text{C}$  measurements. The  $\delta^{13}\text{C}$  in the carbonate fraction was measured using the CO<sub>2</sub> obtained in the vacuum rig, which was directly connected to the mass spectrometer. All  $\delta^{13}\text{C}$  results are given in respect to the PDB standard.

Conventional  $^{14}\text{C}$  ages were calculated using the normalized  $^{14}\text{C}$  values. They are “apparent ages” or “reservoir ages” (Pazdur et al. 1995) for both, the organic and the carbonate fractions of the sediment samples.

For both fractions of the samples, the isotopic dilution factor was calculated as defined by Pazdur et al. (1995)

$$q_L = \frac{{}^{14}a_{N,S}}{{}^{14}a_{N,CA}}, \quad (2)$$

where  ${}^{14}a_{N,S}$  and  ${}^{14}a_{N,CA}$  are the normalized  $^{14}\text{C}$  concentrations (Mook and van der Plicht 1999) in the sample and in the atmospheric  $\text{CO}_2$  at the time of the sediment deposition, respectively.

Changes of  $^{14}\text{C}$  concentration,  $q_L$  and  $\delta^{13}\text{C}$  for the sediment deposited in Lake Gościąg during last 13,000 years were discussed by Pazdur et al. (1995).

## RESULTS

Results of the  $^{14}\text{C}$  concentration measurements after normalization (in %) and  $^{137}\text{Cs}$  (in Bq/g of dry sample) measurements are shown in Tables 1 and 2. “O” denotes the organic fraction, while “C” denotes the carbonate fraction (Table 1). The right part of the sample name indicates the ranges of depths relative to the sediment–water interface on 1993. The results of the  $^{14}\text{C}$  and  $^{137}\text{Cs}$  measurements are presented in Figure 3 as a function of the calendar time scale. The calendar year of each sample was calculated using the relationship between calendar years and the relative depths given by Equation (1).

Figure 4 shows the changes of the  $\delta^{13}\text{C}$  values for the organic and carbonate fractions with time. The  $\delta^{13}\text{C}$  in organic fraction for G43f core for the depth range 0–0.47 m changes from  $-35.6\text{‰}$  to  $-33.7\text{‰}$  (Table 1). The  $\delta^{13}\text{C}$  values for G43f core are significantly different from the  $\delta^{13}\text{C}$  measured in the sediment taken from depth 0.93–1.72 m, which vary in the range of  $-30.67$  to  $-28.2\text{‰}$ . The  $\delta^{13}\text{C}$  in the carbonate fraction decreases with depth in the G43f core from  $-1.82$  to  $-2.52\text{‰}$  and increases with depth for deeper sediments (from approximately  $-1.8$  to  $+0.87\text{‰}$ ).

On the upper graph of Figure 5, the  $^{14}\text{C}$  concentration in the atmospheric  $\text{CO}_2$  measured on Nordcap by Nydal and Lövseth (1996) is shown. On this graph, the triangles with horizontal error bars represent the average values of  $^{14}\text{C}$  concentration in the atmosphere, calculated for the time of each sample accumulation. An exponential function was fitted to these average values (the solid line on the graph). This function is described by the formula:

$${}^{14}\text{C}(T) = a \cdot e^{-b(T-1963)} + c, \quad (3)$$

where  $T$  is given in calendar years. The exponential function was fitted to data beginning from the arbitrarily chosen calendar year 1963 in which the  $^{14}\text{C}$  concentration in the atmosphere reached maximum as a result of nuclear weapons tests. The parameter  $b$  may be interpreted as reciprocal of time constant for decrease of  $^{14}\text{C}$  concentration in the atmospheric  $\text{CO}_2$  for central Europe.

The bottom graph of Figure 5 shows the isotopic dilution factor  $q_L$  calculated according to Equation (2) as a function of the calendar year  $T$ . To calculate  $q_L$  we used the contemporary atmosphere level of  $^{14}\text{C}$  at the time of the sedimentation of the sample— ${}^{14}a_{N,CA}$ . The  ${}^{14}a_{N,CA}$  was obtained for each sample separately and denotes the average value of  $^{14}\text{C}$  concentration calculated for the

period of sample sedimentation, on the basis of  $^{14}\text{C}$  measurements in Nordcap atmosphere (Nydal and Lövseth 1996). The solid line represents a fitted exponential function of the form:

$$q_L(T) = k \cdot e^{-l(T-1963)} + m, \tag{4}$$

where  $T$  is calendar year. The parameter  $l$  may be interpreted as a reciprocal of the time constant of the return of  $q_l$  to the pre-thermonuclear era value.

Both exponential functions ([3] and [4]) were fitted using a nonlinear least squares method. The fitted parameters of both functions are shown in Table 3.

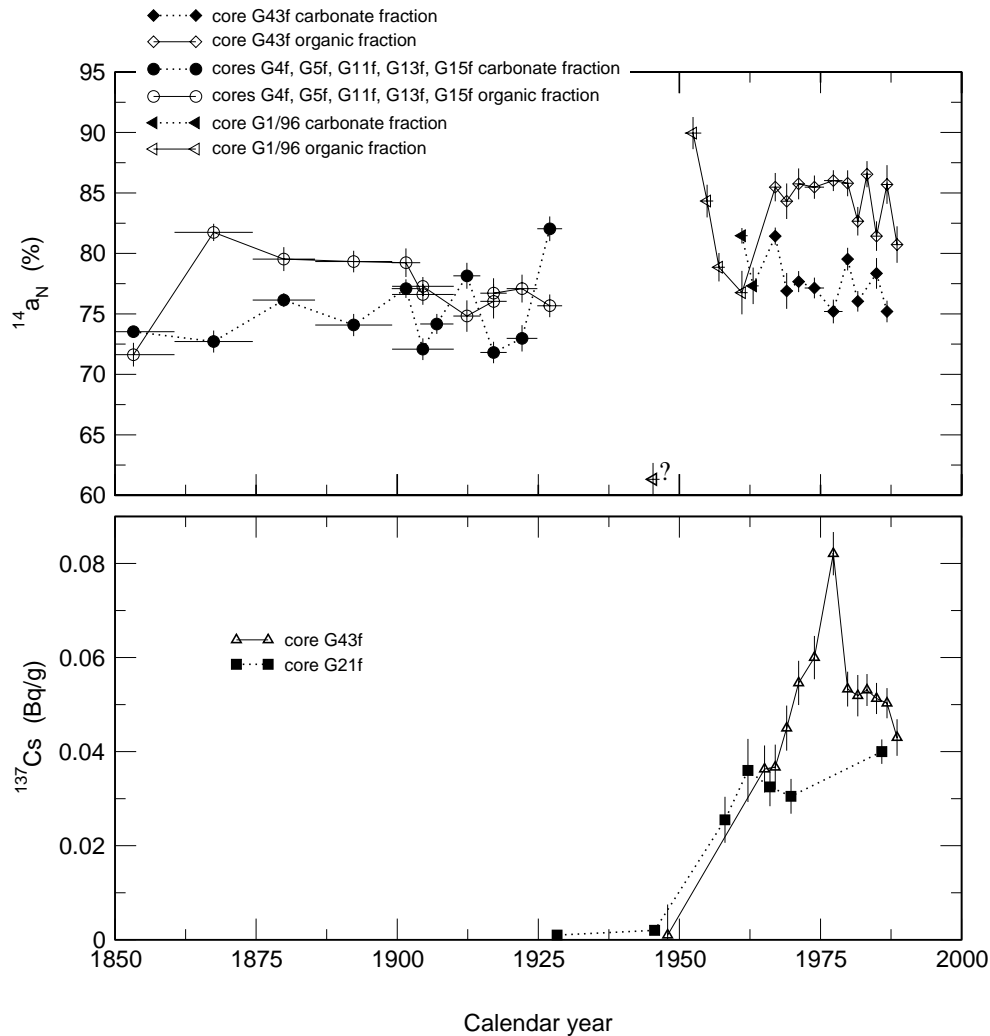


Figure 3 Measurements of  $^{14}\text{a}_\text{N}$  (in %) in organic and carbonate fraction of the samples, upper part of the figure. The names of the investigated cores are shown in the figure. Lower part of the figure:  $^{137}\text{Cs}$  measurements (in Bq per g of dry sample) in cores G21f (Reiss, unpublished) and G43F. It should be noted that cores with sediments deposited between approximately 1930–1950 years were not available. In core G1/96, at 0,75 m depth the organic fraction has an unexpected low value of  $^{14}\text{a}_\text{N}$  which is difficult to explain.

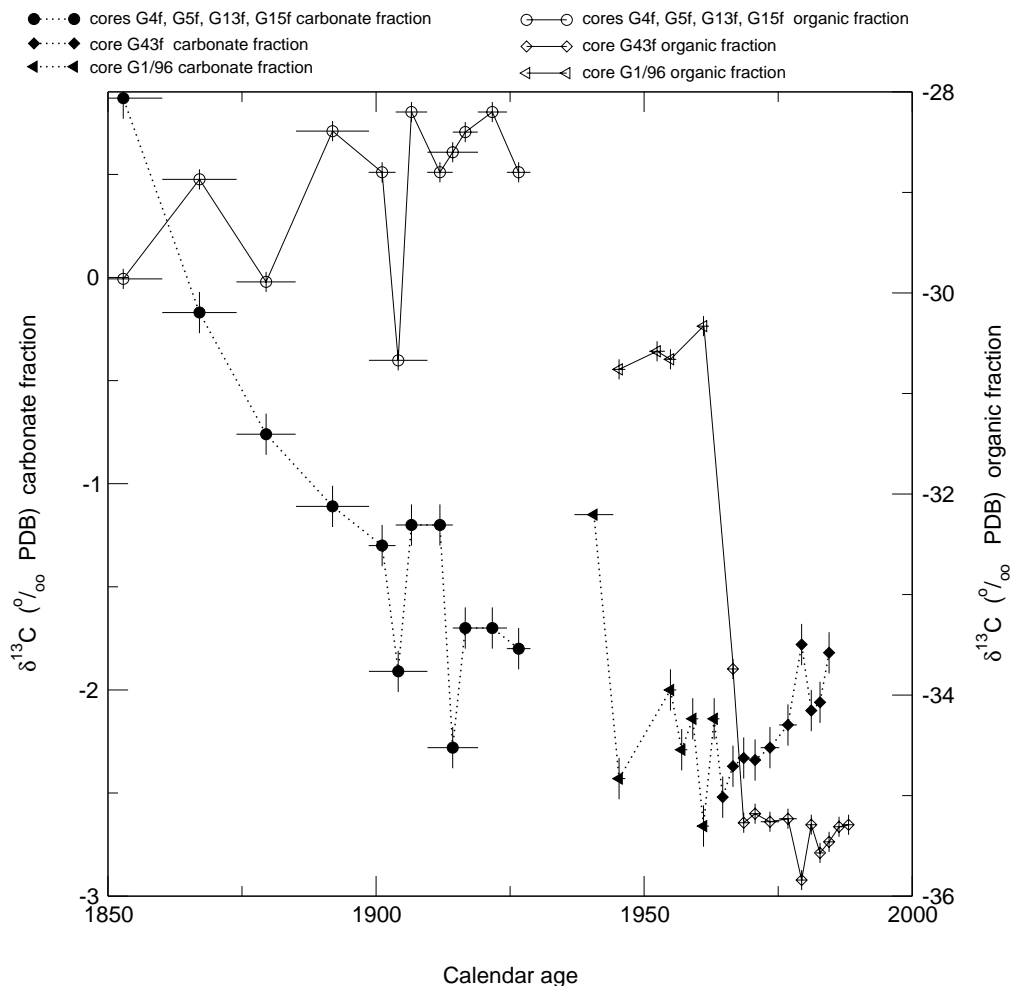


Figure 4 Changes with time of  $\delta^{13}\text{C}$  in organic and carbonate fractions of the youngest Lake Gościąg sediments. The names of the investigated cores are shown at the top. As in Figure 3,  $\delta^{13}\text{C}$  values are lacking in the same time/depth range as for  $^{14}\text{a}_\text{N}$ .

## DISCUSSION AND CONCLUSIONS

It is evident that the difference between  $^{14}\text{C}$  concentration in organic and carbonate fractions is larger in the youngest sediments from core G43f than in the older samples from deeper parts of sediments.

The isotopic dilution factor  $q_L$ , for the organic sediment fraction, calculated relatively to the  $^{14}\text{C}$  activity in atmospheric  $\text{CO}_2$ , shows that all of its change may be due to the change of  $^{14}\text{C}$  activity in the atmospheric  $\text{CO}_2$  only. This is evident because the coefficients  $b$  and  $l$  in Equations (3) and (4) shown in Figure 5 and Table 3 are similar and determine similar time constants of  $1/b = 14.71 \pm 0.31$  yr for the decrease of  $^{14}\text{C}$  in atmospheric  $\text{CO}_2$  and  $1/l = 19.6 \pm 8.9$  yr, for the increase of  $q_L$  calculated for the organic fraction of sediment. It means that the ecosystem of Lake Gościąg is very inert as carbon reservoir and because of that, very quick changes in  $^{14}\text{C}$  in the atmosphere and biosphere, with time constant similar as estimated above, caused by humans (nuclear weapons tests) were not clearly vis-



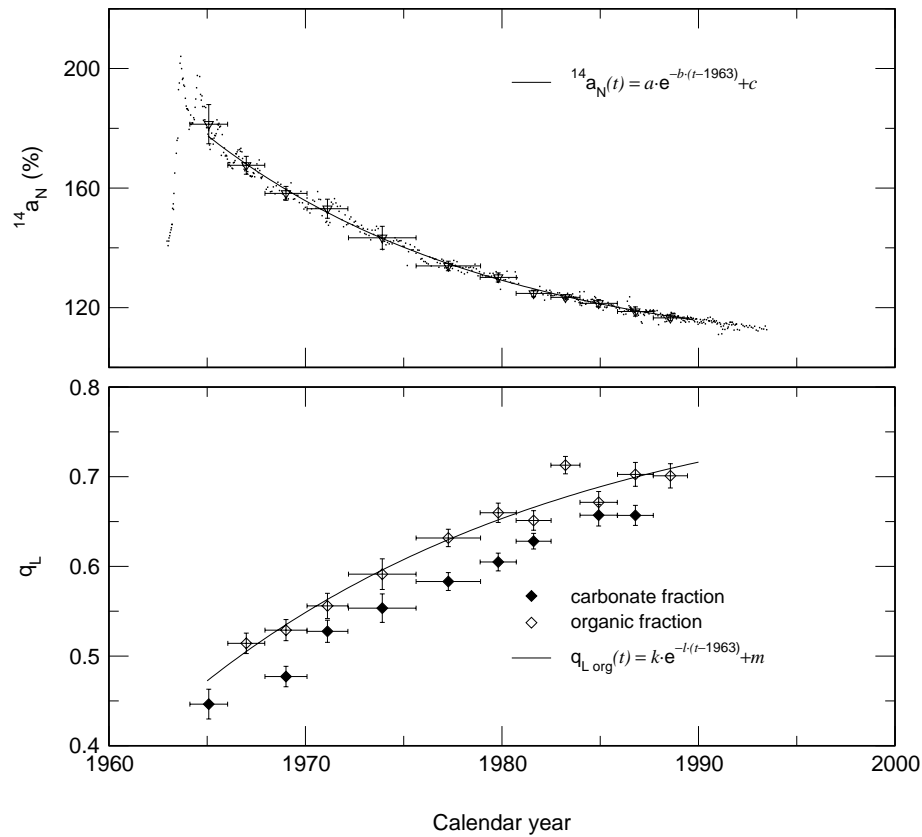


Figure 5 The  $^{14}\text{C}$  concentration in the atmospheric  $\text{CO}_2$   $^{14}\text{a}_\text{N}$  sampled on the Nordcap (Nydal and Lövsseth 1996) are seen as black dots on the upper graph. Triangles are mean values of these  $^{14}\text{C}$  concentrations during the periods that correspond to the time of sedimentation of the G43f samples. The solid line is a function (typed on graph legend) fitted to the mean values. The bottom graph shows changes of isotopic dilution factor  $q_\text{L}$  in the calendar time scale.

Table 3 Parameters of the fitted exponentials to the experimental results according to Equations (3) and (4) describing changes of  $^{14}\text{C}$  in atmospheric  $\text{CO}_2$  and isotope  $^{14}\text{C}$  dilution factor in the youngest lake sediments

Parameter	Value	
a	$86.86 \pm 0.047$	%
b	$0.06806 \pm 0.0014$	1/yr
c	$101.836 \pm 0.66$	%
k	$-0.3756 \pm 0.063$	
l	$0.0516 \pm 0.023$	1/yr
m	$0.826 \pm 0.09$	

ible in lake sediments. The  $q_L$  value calculated for the sediment deposited during last 10,000 years (including XIX Century) fluctuated around 0.82 (Pazdur et al. 1995).

The  $\delta^{13}\text{C}$  values in organic and carbonate fraction change with the calendar years but the character of these changes is different. Almost monotonic decrease of  $\delta^{13}\text{C}$  is observed in the carbonate fraction during the first 110 years, i.e. between 1852 and 1964 AD. Between 1964 and 1985 AD, an increase of  $\delta^{13}\text{C}$  in carbonates is observed. The carbon isotope ratios in the carbonates reflect changes of  $\delta^{13}\text{C}$  in the dissolved inorganic carbon (DIC). The variations of  $\delta^{13}\text{C}$  in the calcite of the sedimentary record might be interpreted as result of changes in the affected lake system, which affect its carbon budget (Wachniew and Róžański 1997).

For  $\delta^{13}\text{C}$  in organic fractions a slow increase of about 2‰ is observed from 1852 to 1922 AD. After this time, the  $\delta^{13}\text{C}$  rapidly decreases by about 10‰ to reach a constant value of about  $-35.4\text{‰}$  in 1966. This effect is probably caused by the change in lake productivity. Further studies are needed to test this hypothesis.

According to the chronology of the upper part of the youngest Lake Gościąż sediments, the peak of  $^{137}\text{Cs}$  concentration observed in the G43f core corresponds to the year 1977. However, it would be expected that the peak correspond to either 1963 or 1986. The year 1963 was the peak of nuclear fallout deposition from weapon tests performed in the atmosphere and 1986 was the year of the accident in the nuclear power plant in Chernobyl—in these two years large quantities of the  $^{137}\text{Cs}$  were released to the atmosphere. It is now impossible to decide which single year should be correlated to the observed maximum of  $^{137}\text{Cs}$  profile and how to correct the correlation of core G43f with the Lake Gościąż chronology.

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#### REFERENCES

- Broecker WS, Walton A. 1959. The geochemistry of  $^{14}\text{C}$  in freshwater system. *Geochimica et Cosmochimica Acta* 16:15–38.
- Giziński A, Kentzer A, Mieszczankin A, Żbikowski J, Żytkowicz R. 1998. Hydrobiological characteristics and modern sedimentation of Lake Gościąż. In: Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąż, central Poland, a Monographic Study*. Part 1. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. p 49–61.
- Goslar T. 1998. Chronological base and reconstruction of yearly cycles in the Lake Gościąż youngest sediments. In: Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąż, central Poland, a Monographic Study*. Part 1. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. p 301–10.
- Mook WG, van der Plicht J. 1999. Reporting  $^{14}\text{C}$  activities and concentrations. *Radiocarbon* 41(3): 227–39.
- Nydal R, Lövseth K. 1996. Carbon-14 Measurements in Atmospheric  $\text{CO}_2$  from Northern and Southern Hemisphere Sites, 1962–1993. ORNL/CDIAC-93, NDP-057. Oak Ridge, Tennessee: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.
- Pawlyta J, Rakowski AZ, Pazdur A, Miller BF, Harknes DD. 1998. Commissioning of a Quantulus 1220 liquid scintillation beta spectrometer for the measurement of  $^{14}\text{C}$  and  $^3\text{H}$  at natural abundance level. *Radiocarbon* 40(1):201–8.
- Pazdur A, Fontugne MR, Goslar T, Pazdur MF. 1995. Lateglacial and Holocene water-level changes of the Gościąż Lake, Central Poland, derived from carbon isotope studies of laminated sediment. *Quaternary Science Review* 14:125–35.
- Pazdur A, Pazdur MF. 1986. Aparatura pomiarowa Laboratorium  $^{14}\text{C}$  w Gliwicach. Doświadczenia konstrukcyjne i eksploatacyjne [The measuring equipment of the Gliwice Radiocarbon Laboratory. Experience gathered in the construction and exploitation]. *Zeszyty Naukowe Politechniki Śląskiej, Seria Matematyka-Fizyka*, Z. 46, *Geochronometria* 1:55–69. In Polish.
- Ralska-Jasiewiczowa M, Goslar T, Madeyska T, Starkel

- L., editors. 1998. *Lake Gościąg, central Poland a monographic study*. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. 340 p.
- Stuiver M, Polach HA. 1977. Discussion: reporting of  $^{14}\text{C}$  data. *Radiocarbon* 19(3):355–65.
- Wachniew P, Róžański K. 1997. Carbon budget of a mid-latitude, groundwater controlled lake: isotopic evidence for the importance of DIC recycling. *Geochimica et Cosmochimica Acta* 61:2453–65.
- Wachniew P, Róžański K. 1998. Isotopic composition of calcite deposited in Lake Gościąg under present climatic conditions. In: Ralska–Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąg, central Poland, a monographic study*. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. p 61–6.
- Walanus A. 1998. Sediment freezing *in situ*. In: Ralska–Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąg, central Poland, a monographic study*. Part 1. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. p 73–4.
- Więckowski K. 1998. Sediments of Lake Gościąg. In: Ralska–Jasiewiczowa M, Goslar T, Madeyska T, Starkel L, editors. *Lake Gościąg, central Poland, a monographic study*. Part 1. Kraków: W Szafer Institute of Botany, Polish Academy of Sciences. p 85–9.