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NEW APPROACH TO EXPLANATION OF CHANGES IN THE VOLUME AND WATER LEVEL OF THE GOŚCIĄŻ LAKE

Summary: The article presents first attempt of evaluation of changes of mean water depth of the Lake Gościąż during the last 11 500 BP. Presented estimates are based on results of measured ^{14}C activities of carbonate fraction of 20 samples of lake sediments, according to the geochemical model developed by Broecker and Walton (1959). The results of model calculations are compared with other available evidence for the surrounding regions, particularly those concerning changes in humidity reconstructed on the base of lake level changes, vegetation history and fluvial activity during the Late Glacial and Holocene. Detailed discussion of obtained curve of fluctuations of the Gościąż Lake level leads to the conclusions that predicted changes of lake level are probably partly caused by climatic changes in the past, and in part are influenced by changes of hydrological regime of the whole catchment basin to which belongs the investigated lake. Because accurate values of the parameters of geochemical model used in this study are not known, the results obtained should be regarded as tentative estimates indicating new potential possibilities of the ^{14}C method applied to paleohydrological investigation.

1. INTRODUCTION

Gościąż Lake with its laminated sediments discovered by K. Więckowski, is now an object of detailed studies due to existence of annual layers representing at least the last 12,600 years BP (Ralska-Jasiewiczowa et al, 1987; Pazdur et al, 1987a, 1987b). The statement of connection of ^{14}C concentration to the relation between volume and area of the lake in the case of the western part of the USA (Benson, 1978; Peng et al, 1978) help in the reconstruction of the mean lake water depth and indirectly of fluctuations of the lake water level. Introduction of this method for the Gościąż Lake is presented below. Its results are controversial in comparison to our knowledge about the variations of lake water levels in Poland (cf. Ralska-Jasiewiczowa, 1986). Therefore we try to compare our results with other evidence concerning the water level fluctuations in individual lakes and mires, changes in the fluvial regime, vegetation and $CaCO_3$ production during the Late Glacial and Holocene.

2. POSITION AND HYDROLOGY OF THE LAKE BASIN

The Gościąż Lake is located at the elevation of 26 m a. s. l. (after other sources 64.4 m), on the terrace plain developed during the ice sheet recession and transformed by dunes. Lake surface is elevated by ca 14 m above the Vistula water level. This lake together with other smaller ones (Mielec, Brzózka i Wirzchoń) form a complex which is drained by the Ruda creek with a gradient 1.36 %. On that creek some dozens years ago existed two mills with small barrages. The bathymetry of the lake system was well recognized by Lencewicz (1929). Other hydrological research in this region was continued by Głazik (1978). The joined surface of all mentioned lake reached 101.4 ha in 1921-1928 years and later in 1960-ties decreased to 88 ha due to water melioration. The total volume of those lakes reached earlier 466 100 m^3, what indicate a mean water depth extending 4.6 m. All other lakes besides Gościąż (45 ha) are smaller and shallow (max. depth does not exceed 2 m). Only in the Gościąż Lake there are hollows reaching 25.8 m, what means that their bottom go down 12 m below mean water level in the Vistula river (before construction of the Włocławek reservoir), Fig. 1. In the catchment basin of 53 km^2 with the flat relief and sandy grounds this 1 km^2 of lake surface play an important role in the regulation of outflow.

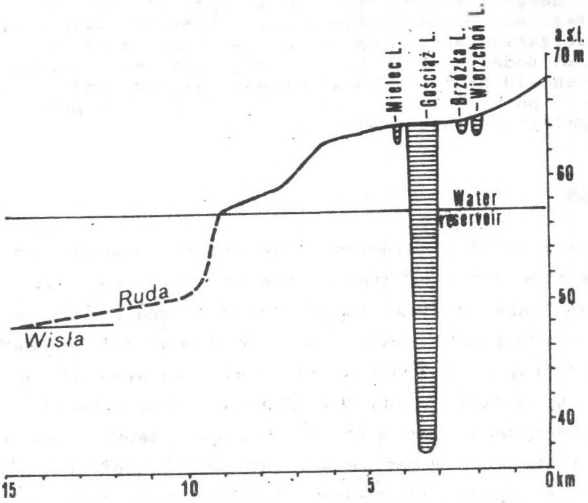

Fig. 1. Location of the lake basin.

Rys. 1. Położenie basenu Jeziora Gościąż

To imagine the scale of vertical water level changes in the lakes we tried to calculate an effect of 40 years changes taking as an example small Mielec lake, with the area equal to 6.9 ha, which during 40 years decreased to 3.5 ha. Taking for calculation a simplified round shape of Mielec lake with maximum depth 1.5 m we found that due to this decrease the lake volume diminished by 66% and mean lake depth changed from 50-55 cm to about 35 cm. Considering similar parallel drop of lake level of whole connected system we calculate a mean lake depth drop as equal to ca 4.4 m, associated with simultaneous decrease of water retention by 17%. This analysis shows how quickly can follow the disapearance of shallow lake basins as well as how well basins would be preserved (cf. Lake Gościąż).

Simultaneous measurements of thickness of lake deposits in the Gościąż Lake (reaching 16 m) and the Wirzchoń Lake indicate that in the Late Glacial the volumes of lake basins were by mean double. Therefore the relations between volume and surface of those basins change in time. The deeper depression slowly react in their lake level fluctuations on the various climatic changes as well as on outflow changes by incision or overgrowing of the creek channel. It can not be excluded that the perennial outflow was performed after creation of an impermeable blanket of calcareous gyttja at the bottom of all lakes. Otherwards our reconstructions of volumes and mean lake depth can not be used for explanation of lake level changes. Even more, probably the lakes show a continuous rising trend of water level through ages. In such a case, all documented below droppings down of the mean water depth and volume in the Gościąż Lake should be caused by changes in the hydrological regime.

3. ^{14}C MEASUREMENTS IN THE GOŚCIĄŻ LAKE SEDIMENTS

Radiocarbon datings were performed on organic and carbonate fractions of 21 samples collected from different depths of the core G0 (Pazdur et al, 1987a; Pazdur et al, 1987b). The correlation between the number of varves estimated in core G0 by Więckowski (Ralska-Jasiewiczowa et al, 1987) and calibrated radiocarbon ages indicated that continuous sedimentation in the lake has been started before the Allerød interstadial and proved one-to-one correspondence between number of varves and calibrated ^{14}C years. Recent studies of cores G1 and G2 (collected in late winter, 1987) comprising exact counting of number of varves and accurate measurements of varve thickeness led to construction of floating varve chronology, covering ca 10 000 years (Goslar et al, 1988). Comparison of this chronology with the varve thickness record of core G0 enables more accurate estimation of the number of varves corresponding to individual radiocarbon dated samples, and, in consequence, exact determination of their ages in term of astronomic time scale. It is therefore posible to determine the values of apparent age of carbonate fraction of all dated samples with errors approximately equal to laboratory errors of ^{14}C age measurements.

The dilution factor of the ^{14}C isotope in the carbonate sediment, which value can be derived from the apparent age (Pazdur, 1987) is an important parameter in the model describing the contribution of various sources of natural ^{14}C to total amount of carbon contained in the lake water (Broecker and Walton, 1959). This model was used by Benson (1978) and Peng et al (1978) to estimate apparent ages of carbonate sediments when dated by the radiocarbon dating method. Another important parameter of this model is the ratio of the lake volume to its area. It seems that the accurate values of dilution factors of the ^{14}C in the Gościąż Lake sediments allow to estimate the relative changes of the ratio of lake volume to its area (i. e. the mean depth of the lake) and therefore to reconstruct the oscillations of the water level in the lake during the Late Glacial and Holocene.

4. GEOCHEMICAL MODEL OF THE CARBON CYCLE IN THE LAKE WATER

Inorganic carbon in the lake water occurs in the form of HCO_3^- and CO_3^{2-} ions and gaseous CO_2 dissolved in the water. There are two primary sources of CO_2 dissolved in the lake water - first is atmospheric CO_2 with ^{14}C activity equal to ^{14}C activity of contemporary biosphere, the second source is biogenic CO_2 of similar ^{14}C activity, contained in soil cover. HCO_3^- and CO_3^{2-} ions contain both inactive old carbon and modern carbon with high ^{14}C content in the proportions which are determined by geochemical processes and the isotopic fractionation in the natural isotopic carbon cycle. The total actual amount of carbon dissolved in the lake water depends on: the CO_2 exchange rate between atmosphere and the surface layer of lake water, the evaporation rate, the concentration of carbon in water supplying the lake, losses of carbon through sedimentation and radioactive decay and, finally on the geometry of the lake.

The mass balance equations describing the amount of carbon and the ^{14}C content in the lake can be written (Broecker and Walton, 1959; Benson, 1978; Peng et al, 1978) as follows:

for total carbon

$$\underset{\text{(input)}}{RA_L + l_E A_L k_R} = \underset{\text{(loss)}}{S + R'A_L}, \qquad (1)$$

and for ^{14}C isotope

$$C_A R A_L + l_E A_L k_R = (S + R'A_L + V_L k_L \lambda) C_L \qquad (2)$$

where: R and R' - rates at which CO_2 enters and leaves the lake surface, respectively, l_E - the linear evaporation rate from the lake surface, k_R - the concentration of the total carbon entering the lake, S - the rate of loss of carbon from the lake through sedimentation of $CaCO_3$; C_A, C_R and C_L

- the actual concentrations of ^{14}C in the atmospheric CO_2, in HCO_3^- ions in the water entering the lake and in HCO_3^- ions in the lake water, respectively, k_L - the concentration of the total carbon in the lake, λ-the decay constant of ^{14}C, A_L - the area of lake surface and V_L - the lake volume.

If we denote the dilution factors of the ^{14}C isotope in water entering the lake and in lake water itself respectively by q_R and q_L ($q_R = C_R/C_A$, $q_L = C_L/C_A$) then from equations (1) and (2) we obtain

$$q_L = \frac{R + l_E k_R q_R}{R + l_E k_R + k_L \lambda V_L / A_L} \qquad (3)$$

This expression was used to estimate the value of the dilution factor q_L in the paper of Benson (1978) dealing with radiocarbon dating of algal tufas, gastropods and calcite-cemented sands marking fluctuations of the level of pluvial Lake Lahontan (Nevada, USA) during the last 40,000 years. The estimates made by Benson were based on the assumption of constant values of the model parameters (R, l_E, k_R, k_L) in the whole time span of dated samples. As the numerical values of these parameters the author took the values for the year 1957 either measured or estimated by Broecker and Walton (1959) on the basis of data available for North-American lakes (Pyramid, Walker, Mono, and Great Salt Lake) and verified by him. The value of V_L/A_L for **high** stands of the lake was estimated to be by 30 % greater than the value observed in 1957. The numerical values for inland lakes and rivers (before the bomb-effect) are: R=2-15 mol/m^2/y, l_E=1.1-1.5m/y, k_R=2.5-6.2 mol/m^3, k_L=2.8-19 mol/m^3, q_R=0.75-0.90. Benson assumed that the present isotopic cycle of carbon is representative for the past ca 40,000 years and that the initial concentration of the ^{14}C in sediments is the same as in the lake water.

5. FLUCTUATIONS OF THE WATER LEVEL OF THE GOŚCIĄŻ LAKE

Already established chronology of core G1 (Goslar et al, 1989) and correlation with core G0 used in ^{14}C dating, enables relatively accurate estimation of real ages of all dated samples, i. e. the ages expressed in terms of calibrated radiocarbon dates and the dilution factors q_L of inorganic matter fractions in samples can be estimated accurately.

The dilution factor is defined as

$$q_L = A_{co}/A_{sc}. \qquad (4)$$

The ^{14}C activity A_{co} of the lake carbonate in the moment of sedimentation is

$$A_{co} = A_c \exp(N/\tau) \qquad (5)$$

and ^{14}C activity A_{so} of the atmospheric CO_2 in this moment is

$$A_{so} = A_{ox}\exp(D/\tau). \qquad (6)$$

In the last expressions A_c denote the measured ^{14}C activity of the carbonate fraction and NBS oxalic acid standard in the present, τ is the mean life-time of the ^{14}C isotope (τ = 1.03x8033 y) and D = N-T is the dendrochronological correction to the conventional radiocarbon age T_k corresponding to varve N. It can be obtained from these equations that

$$q_L = (A_c/A_{ox})\exp(T_k/8274). \qquad (7)$$

If the conventional radiocarbon age T_c of the inorganic matter fraction of the sample corresponding to the varve N is known, then

$$A_c/A_{ox} = \exp(-T_c/8033) \qquad (8)$$

and

$$q_L = \exp(-T_{app}/8033)\ \exp(-0.03T_k/8274), \qquad (9)$$

where $T_{app} = T_c - T_k$ denotes the apparent age of the carbonate fraction of the sample. The values of N, T_k, T_c, T_{app} and q_L are listed in Table 1.

Assuming that 1) the inflow of groundwaters did not cause significantly the supply of dead carbonates which influence the values of the ^{14}C dilution factor, and 2) the carbon cycle in the Gościąż Lake is described by the model developed by Broecker and Walton, then the equations (3) and (9) give estimate of the value V_L/A_L = H for the known value of q_L corresponding to the given value of T_k

$$H = \frac{R + l_E k_R q_R}{q_L k_L \lambda} - \frac{R + l_E\ k_R}{k_L \lambda} \qquad (10)$$

Denoting by A and B the combinations of the model parameters

$$A = R + l_E k_R q_R \qquad (11)$$

$$B = R + l_E k_R \qquad (12)$$

the eq. (10) can be rewritten as follows

$$H = \frac{A/q_L - B}{k_L \lambda} \qquad (13)$$

The calculations of the value of H requires knowledge of numerical values of parameters R, l_E, k_R, k_L and q_R. Less dependent on the above parameters are the relative changes of the H value, calculated with respect to arbitrary chosen H_o value assuming $k_L = k_{LO}$, $A = A_o$ and $B = B_o$, i.e.

$$H/H_o = \frac{q_{LO}}{q_L} \cdot \frac{A - Bq_L}{A - Bq_{LO}} \qquad (14)$$

Numerical calculations were performed taking the q_{LO} value for the varve N=150. The calendar age of this sample covers years 1830-1850 AD and assures the absence of the "bomb-effect" in this sediment layer.

Table 1

Values of the varve number (N), conventional radiocarbon age (T_k), ages of carbonate fraction (T_c), apparent ages (T_{app}) and dilution factors (q_L) of samples from the Gościąż Lake. The values of T_k were calculated from calibration curves of Pearson and Stuiver (1986), Pearson et al (1986), Stuiver et al (1986) and Stuiver and Pearson (1986).

N	T_k	T_c	T_{app}	q_L
150	193	2100 ± 90	1907	0.789
700	805	2200 ± 40	1395	0.841
900	961	3660 ± 50	2699	0.715
1500	1598	3880 ± 70	2282	0.753
2100	2122	4680 ± 120	2558	0.727
2900	2794	5350 ± 50	2344	0.747
3850	3570	5690 ± 80	2120	0.768
4885	4327	6280 ± 80	1953	0.784
6135	5375	7390 ± 190	2015	0.778
6585	5780	7930 ± 70	2150	0.765
6940	6093	8190 ± 100	2097	0.770
7570	6800	8420 ± 90	1620	0.817
8390	7580	8800 ± 70	1220	0.859
8940	7985	9160 ± 50	1175	0.864
9685	8500	10 230 ± 90	1730	0.806
10 120	9000	10 710 ± 150	1710	0.808
10 620	9500	10 830 ± 80	1330	0.847
10 030	9950	10 640 ± 60	690	0.918
12 005	10 950	12 100 ± 90	1150	0.867
12 555	11 500	12 570 ± 130	1070	0.875

The coefficients A and B in the equation (14) defined by eqs. (11)-(12) differ by the presence of factor q_R. The ratio A/B depends on q_R and other model parameters but more less then absolute values of A and B. Extreme values of R were estimated by Peng et al (1978) for inland lakes to 5-7 mol/m^2/y. According to Schmuck (1953) the value of l_E in the Płock Basin is actually close to 0.75 m/y, and possible changes may be estimated as ranging from 0.5 to 1 m/y. Measured values of of CO_2 and HCO_3^- concentration in several rivers in southern Poland (Szulc, 1984) lead to conclusion that the value of k_R in almost all investigated rivers is equal to ca 6 mol/m^3 in the near-spring zone and decreases after distance of dozen hundreds meters to ca 2 mol/m^3. The q_R values are taken as equal to 0.7 because they should be not higher then q values. The family of curves

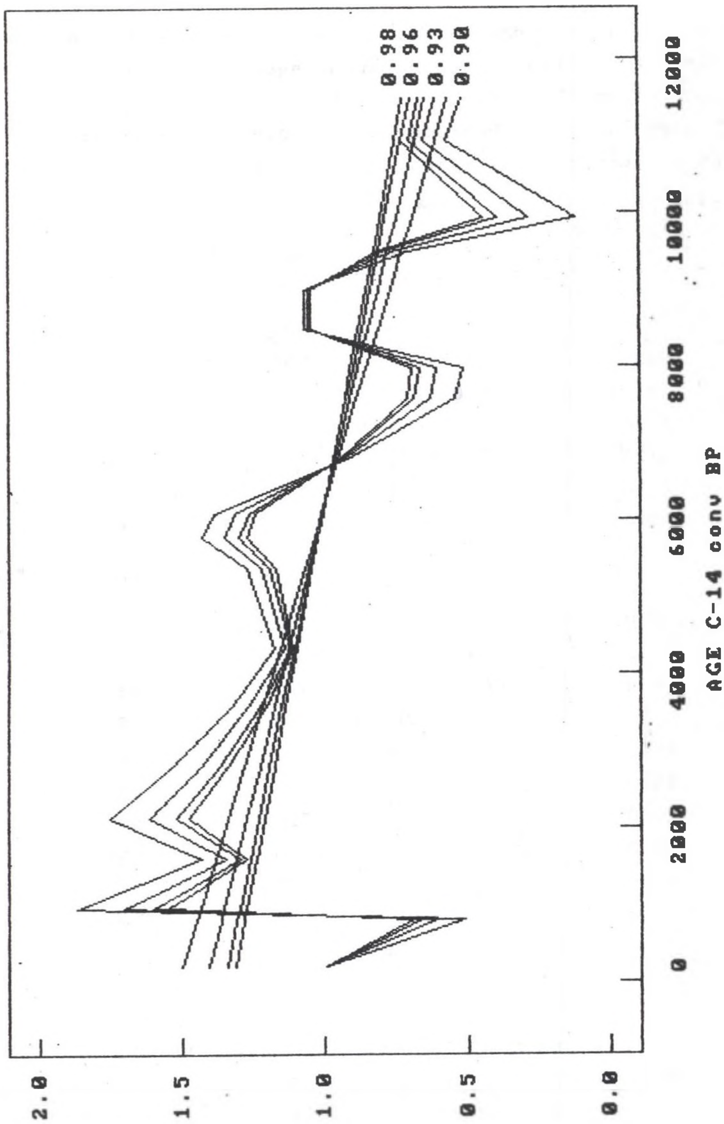

Fig. 2. Changes of H/H_0 as function of T_k for different values of ratio A/B.

Rys. 2. Zmiany stosunku H/H_0 w funkcji wieku konwencjonalnego T_k przy różnych wartościach stosunku A/B.

H/H_o as function of T_k for selected values of the ratio A/B is shown in Fig. 2. Under assumption that $R=6$ mol/m^2/yr, $k_R = 2-4$ mol/m^3, $q_R > 0.7$ and $l_E = 0.5-1.0$ m/yr, the values of the ratio A/B are greater than 0.90 providing positive values of the ratio H/H_o in the whole considered interval of time. Higher values of the linear evaporation rate l_E correspond to lower values of the ratio A/B.

The oscillations are seen with amplitudes depending the values of A/B superimposed on approximately linear trends of the changes H/H_o. Straight lines in Fig. 2 represent the least squares lines for the trends described by A/B=0.90, 0.93, 0.96 and 0.98. The oscillations of H/H_o obtained after subtraction of the linear trend described by least squares lines are given in Fig. 3.

6. AN ATTEMPT TO CORRELATE THE CURVE OF MEAN WATER DEPTH OF THE GOŚCIĄŻ LAKE WITH REFLECTION OF CLIMATE AND HYDROLOGICAL CHANGES IN OTHER DEPOSITS AND PHENOMENA

In Fig. 3 we find the distinct phases of higher and lower depths. Even the number of dated horizons is not to high, in the last 11.5 ka BP can be identified 5 phases of higher depth (above 11 ka, 9.0-8.5, 6.2-5.5, above 2.1 and ca 1 ka BP), separated by phases of low water depth (ca 10 ka, 8-7.5, 5-4, ca 1.6 and 0.8 ka BP). But, simultaneously, the curves are composed of segments with rising and lowering water depth. Taking this into account we may distinguish relatively longer phases of rising tendency (10-9 ka, 7-6.2, 4-2.2, 1.5-1 and since 0.8 ka BP) and droppings (11-10 ka, 8.5-8, 5.7-4.4, 2.2-1.6 and 1-0.8 ka BP).

The fluctuations of lake water levels were generalized by Ralska-Jasiewiczowa (1987) for the Polish Lowland on the base of detailed recognition of various parameters. She distinguished the following lowerings interpreted as decreases of annual rainfall and rises of evaporation: 10-9.5 ka, 9.2-8.5, 6.5-6, 4-3, 2.5-2 and after 1 ka BP separated by more wet phases. But the records compiled by her show that the course of water level fluctuations was not synchroneous. Hjelmross-Ericson (1981) for the closed depression of the Wielkie Gacno Lake considered phases of water lowerings diachroneous with the previous ones, just opposite to many other informations (see Fig. 4). It seems that either the criteria used for distinguishing of those phases were not precised enough or the causes of changes must be considered individually. Even earlier Korolec (1968) and Kondracki (1969) in the Masurian Lake Distinct expressed the opinion about lowerings in Boreal (9-8 ka BP), at the close of Atlantic and during Subboreal and about risings after 8 ka and between 3 and 2 ka BP.

Some marker horizons are visible in other records. Ralska-Jasiewiczowa (1987) after statistical elaboration of many pollen diagrams considered short phases of rapid vegetational changes caused by change in temperature

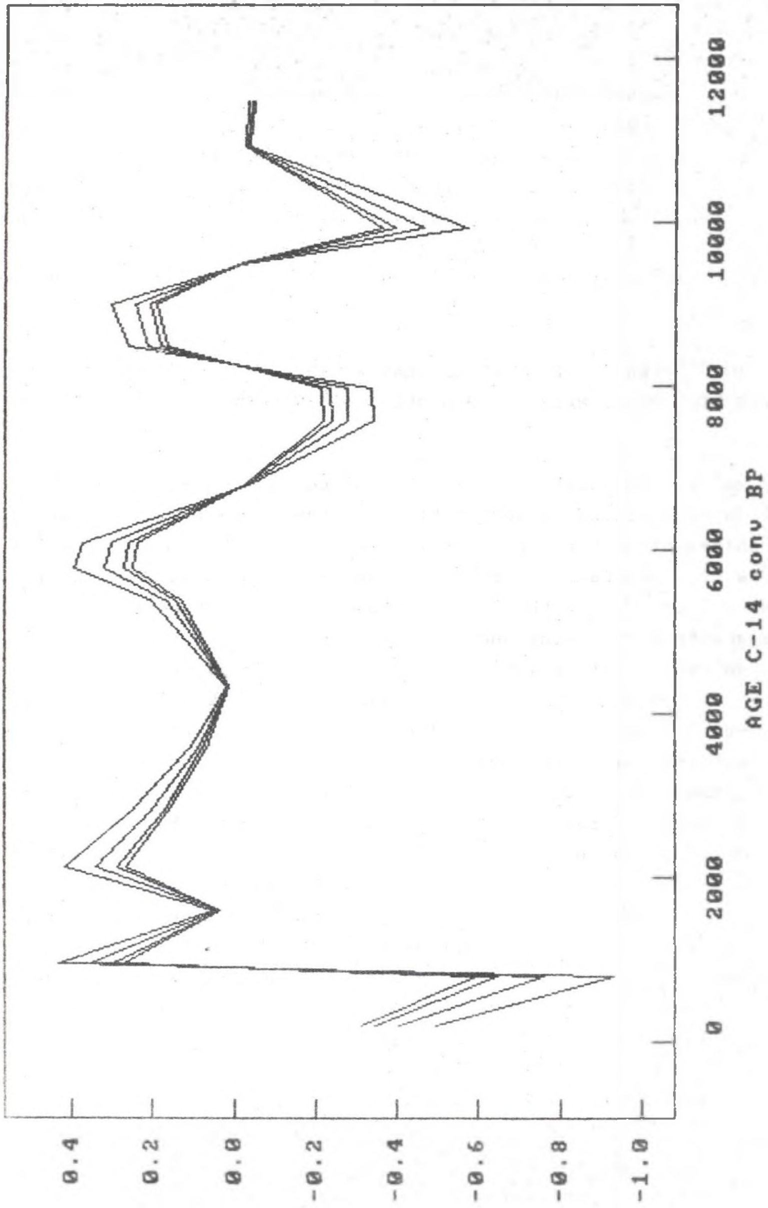

Fig. 3. Oscillations of H/H_0 obtained after subtraction of linear trend described by least squares lines.

Rys. 3. Oscylacje stosunku H/H_0 otrzymane po odjęciu liniowego trendu wyznaczonego przez proste najmniejszych kwadratów.

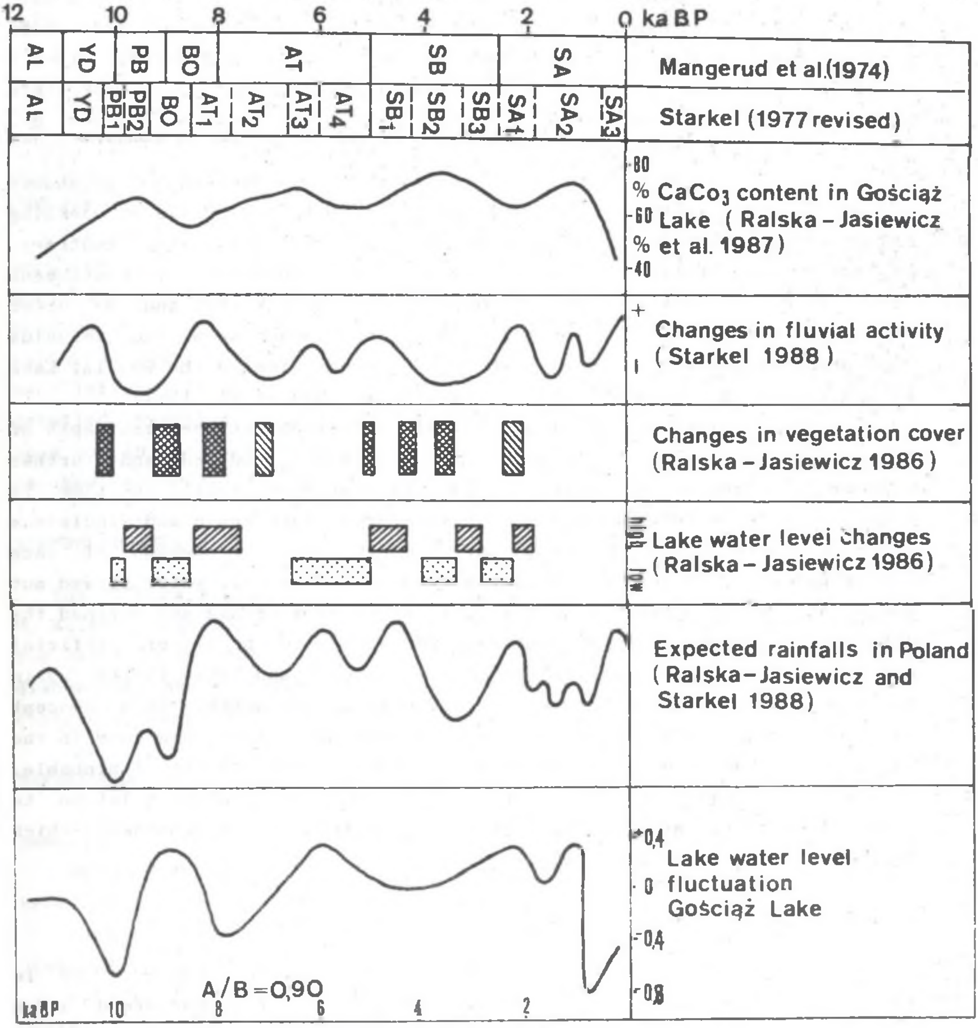

Fig. 4. Comparison of the oscillation of mean water depth with climate and hydrological changes and other evidence.

Rys. 4. Porównanie oscylacji średniego poziomu wody ze znanymi zapisami zmian klimatycznych, hydrologicznych oraz innymi danymi.

and humidity. The most distinct horizons were dated to 9.4-8.7, 8.2-7.7, 5.1-4.9, 4.4-4.1, 3.7-3.4 and less visible to 7.3-6.9 and 2.3-2.0 ka BP. In the fluvial environment of southern Poland as well as in the middle Europe as a whole few phases of increased fluvial activity and flood frequency can be distinguished (Starkel, 1983): 8.5-7.7, 5.0-4.5, 2.5-1.8 ka BP and in X-XIIc. and XVII-XIX c. These last mentioned phases correlate quite well with fluctuations of climatic vegetation vertical zones and glaciers in the European mountains (cf. Starkel, 1985).

Comparing all these informations on relatively wetter and drier phases during the Holocene we have not good relation with our curve presenting changes of the mean lake depth of the Gościąż Lake. But, on the contrary, the wetter phases show distinct agreement with periods of continuous lowerings of lake depth curve (cf. 8.5-8 and 5.5-4.4 ka BP) and the drier ones with curve rises. The top positions of our curve seems to coincide with probably warmer phases of higher $CaCO_3$ deposition in the Gościąż Lake (9.5-9.0 and 6.5-6.0 ka BP; cf. Ralska-Jasiewiczowa et al, 1987).

Therefore a distinct shift of rhythmic variations of the mean depth of the Gościąż Lake should be in future explained and cdemand further explorations. The one probable hypotesis is that this shift in time is connected with periodic events of overflowing of lake basin and incisions of the Ruda creek, draining this lake complex. At the beginn of each wetter phase (eg. 8.5 ka BP) followed rise of lake level, water flowed out across the swampy depression and then flowing creek eroded and drained the lake system. On the contrary the drier phase caused break of surficial outflow, supported palludification of valley floor and lake shores again and at least led to continuous rise of the mean lake depth. This concept should be supported by detailed investigations of sediment sequence in the littoral zone as well as in the bottom of the Ruda valley. It is probable, too, that the down-cuttings of the Ruda creek are in close relation to phases of rising and lowering of the Vistula river channel, which formsbasal level for small tributaries.

7. DISCUSSION

Evaluation of relative changes of mean depth of the Gościąż Lake in the time interval from 11 500 BP to the present was performed under assumption of constant values of parameters included in the Broecker-Walton model, i. e. R, k_R, q_R and l_E. Numeric values of those parameters were estimated in geographical regions which significantly differ from the region of the Gostynin Lake district. Actual values of those parameters for the Gościąż Lake itself were not yet measured. It seems that the determination of the relationship between lake waters and groundwaters supplying them is of even greater importance. As an argument against the greater supply of the carbonate rich groundwaters it may be quated the preliminary curve of $CaCO_3$ content in the core. The plot given by Ralska-Jasiewiczowa et al (1987) shows lowerings of the $CaCO_3$ content during the humid phases (Fig. 4) and rises which coincide with warmer and drier periods discovered in the Central and Northern Europe (Mörner and Wallin, 1977; Pazdur et al, 1988; Różański, 1988). It should be also noted, that listed parameters may change their values during the geological history of the lake. It is therefore difficult to select the most appropriate curve which should resonable real changes of mean water level, from the family of curves shown in Fig. 2. It should be expected that the value of linear evaporation rate may reveal the most distinct changes in function of time.

For correct estimation of numeric values of H/H_o, as well as more accurate evaluation of amplitudes of oscillations shown in Fig. 3, it is necessary to determine the actual values of model parameters for the Gościąż Lake. Moreover, further datings of appropriate number of samples collected from cores G1 and G2 are also needed in order to confirm if the oscillations of the mean water depth are in fact significant. Finally, detailed investigations of sediment sequences occuring in the littoral zone and in the Ruda valley are necessary for the verification of the geochemical model used in this study.

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REFERENCES

Benson L. V., 1978, Fluctuation in the level of pluvial Lake Lahontan during the last 40,000 years; Quaternary Research, vol. 9, p. 300-318.

Broecker W. S. Walton A., 1959, The geochemistry of ^{14}C in fresh water systems; Geochim. Cosmochim. Acta, vol. 16, p. 15-38.

Głazik R., 1978, Wpływ zbiornika wodnego na Wiśle we Włocławku na zmianę stosunków wodnych w dolinie; Dokument. Geogr. IG i PZ PAN, 2-3.

Goslar T., Pazdur M. F., Walanus A., 1989, Chronology of annually laminated sediments of the Gościąż Lake (lower part); Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., Zesz. 57, Geochronometria, No. 5, p. 11-20.

Hjelmross-Ericson M., 1981, Holocene development of Lake Wielkie Gacno area northwestern Poland; A contribution to IGCP Project 158 B, Thesis 10, Lund 1981.

Kondracki J., 1970, Changements du mireau des lacs comme resultat de oscillations du climat pendant l'Holocene (sur example du NE de la Pologne); Geographia Polonica, vol. 17.

Korolec H., 1968, Procesy brzegowe i zmiany linii brzegowej Jeziora Mikołajskiego; Prace Geograficzne IG i PZ PAN, Nr. 114.

Lencewicz D., 1929, Jeziora Gostynińskie; Przegl. Geogr., vol. 9.

Mörner N. A., Wallin B., 1977, A 10 000-year temperature record from Gotland, Sweden; Palaeogeogr. Palaeoclimat. Palaeoecol., vol. 21, p. 113-138.

Pazdur A., 1987, Skład izotopowy węgla i tlenu holoceńskich martwic wapiennych (Isotopic composition of carbon and oxygen in Holocene calcareous tufa); Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., Z. 54, Geochronometria No. 3.

Pazdur A., Pazdur M. F., Wicik B., Więckowski K., 1987, Radiocarbon chronology of annually laminated sediments from the Gościąż Lake; Bull. Polish Acad. Sci, Earth Sci., vol. 35, p. 139-145.

Pazdur M. F., Awsiuk R., Goslar T., Pazdur A., Walanus A., Wicik B., Więckowski, 1987, Calibrated radiocarbon chronology of annually laminated sediments from the Gościąż Lake; Zesz. Nauk. Pol. Śl., Seria Mat.-Fiz., Z. 56, Geochronometria No. 4, p. 69-83.

Pazdur A., Pazdur M. F., Starkel L., Szulc J., 1988, Stable isotopes of the Holocene calcareous tufa in southern Poland as paleoclimatic indicators; Quaternary Research, vol. 30, p. 177-189.

Pearson G. W., Stuiver M., 1986, High-precision calibration of the radiocarbon time scale, 500-2500 BC; Radiocarbon, vol. 28, p. 839-862.

Pearson G. W., Pilcher J. L., Baillie M. G. L., Corbett D. M., Qua F., 1986, High-precision ^{14}C measurements of Irish oaks to show the natural ^{14}C variations from AD 1840-5210 BC; Radiocarbon, vol. 28, p. 911-934.

Stuiver M., Kromer B., Becker B., Ferguson C. W., 1986, Radiocarbon age calibration back to 13,300 years BP and ^{14}C age matching of the German oak and US bristlecone pine chronologies; Radiocarbon, vol. 28, p. 969-979.

Peng T.-H., Goddard J. G., Broecker W. S., 1978, A direct comparison of ^{14}C and ^{230}Th ages at Searles Lake, California; Quaternary Research, vol. 9, p. 319-329.

Ralska-Jasiewiczowa M., 1987, Poland: vegetational, hydrological and climatic changes inferred from IGCP-158 B studies; IGCP-158 Symposium, Abstracts of lectures and posters, Lund, p. 35-38.

Ralska-Jasiewiczowa M., Starkel L., 1988, Record of the hydrological changes during the Holocene in the lake mire and fluvial deposits of Poland; Folia Quaternaria, vol. xx, in print.

Ralska-Jasiewiczowa M., Wicik B., Więckowski K., 1987, LakeGościąż - a site of annually laminated sediments covering 12 000 years; Bull. Polish Acad. Sci., Earth Sci., vol. 35, p. 139-145.

Różański K., 1987, The ^{18}O and ^{13}C C isotope investigations in carbonate sediments from the Lake Strażym, Acta Paleobotanica, vol.27, Z. 1, p. 277-282.

Schmuck A., 1953, Parowanie z wolnej powierzchni wodnej w Polsce; Spraw. Wrocł. Tow. Nauk., vol. 8.

Starkel L., 1983, The reflection of hydrologic changes in the fluvial environment of the temperate zone during the last 15 000 years; [In:] Gregory K. J., Wiley J., Eds., Background to Palaeohydrology: A Perspective, vol. 2, p. 3-235.

Starkel L., 1985, The reflection of the Holocene climatic variations in the slope and fluvial deposits and forms in the European mountains; Ecologia Mediterranea, vol. 11, p. 91-97.

Stuiver M., Pearson G. W., 1986, High-precision calibration of the radiocarbon time scale, AD 1950-500 BC; Radiocarbon, vol. 28, p. 805-838.

Szulc J., 1984, Sedymentacja czwartorzędowych martwic wapiennych Polski Południowej; Praca dokt., ING PAN, Kraków.

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ZMIANY OBJETOŚCI I POZIOMU WODY JEZIORA GOŚCIAŻ

Streszczenie

Autorzy podjęli próbę oszacowania zmian średniej głębokości Jeziora Gościąż na przestrzeni ostatnich 11 500 lat BP. Oszacowania wykonano na podstawie pomiarów koncentracji ^{14}C we frakcji węglanowej próbek pobranych z rdzenia laminowanych osadów wypełniających jezioro, według modelu Broeckera i Waltona (1959). Wyniki obliczeń zarówno zmian średniej głębokości, jak również oscylacji tej głębokości wskazują, że możliwe przyczyny tych zmian są spowodowane nie tylko wpływem klimatu lecz również zmianami w reżimie hydrologicznym całego kompleksu jezior do którego należy Jezioro Gościąż. Brak dokładnych wartości parametrów stosowanego modelu powoduje, że na tym etapie badań obliczenia należy traktować jako wskazanie pewnych potencjalnych możliwości interpretacyjnych wyników pomiarów uzyskanych metodą radiowęglową.

ИЗМЕНЕНИЯ ОБЬЕМА И УРОВНЯ ВОДЫ В ОЗЕРЕ ГОСЦИОНЖ

Резюме

В докладе представлена попытка оценки изменений среднего уровня воды в озере Госционж за время последних 11 500 лет. Оценки базируются на основе результатов измерений активности радиоуглерода в карбонатах из 20 образцов озерных отложений. Соответствующие вычисления были проведены согласно

геохимической модели Брекера-Вальтона (1959). Результаты вычислений сравнивались с доступными данными изменения температуры, количества осадков и речной активности за время позднего гляциала и голоцена. Анализ полученных кривых приводит к заключению, что некоторые изменения уровня озера вызваны климатическими факторами, в то время как другие связаны с изменениями гидрологического режима озерной системы к которой принадлежит озеро Госционж. Так как точные значения параметров геохимической модели пока неизвестны, полученные результаты следует считать предварительными оценками, дающими новые возможности приложения радиоуглеродного метода для исследования годично расслоенных озерных осадков.