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HOLOCENE CLIMATIC CHANGES IN THE LIGHT OF STATISTICAL ANALYSIS OF LAMINATED SEDIMENTS FROM THE GOŚCIĄŻ LAKE

Summary: The Lake Gościąż, situated in the Płock Basin, is the deepest one in the system of four lakes connected by the Ruda creek. Lake basin is developed within the Miocene series below the level of the Vistula river. Lake sediments, ca 16m thick, reveal distinct regular microlamination in the whole profile. Statistical analysis was performed on results of 10-year increments, accounting 1230 values obtained on core G0 below 2m depth. Results of thickness measurements were fitted by the sine functions with given value of period. The presence of cyclical patterns of sedimentation rate in laminated sediments was searched by changing this value in the interval from 10 to 15000 yr. Performed analysis indicate presence of cycles with 20 different values of period; application of the Fisher-Snedecor test leads to the conclusion that 13 values may be regarded significant. Eight of detected cycles are similiar to those found in changes of accummulation of organic matter in sediments of the Wikaryjskie Lake. Some cycles are close to well-known cycles of solar activity. Extreme values of sedimentation rate of laminated sediments in the Gościąż Lake coincide with coolings and warmings recorded in Europe and North America.

1. SITE DESCRIPTION

Gościąż Lake is located in the Płock Basin at elevation 64.4 m a.s.l., and belongs to the system of four natural water reservoirs connected by the Ruda Creek. Two upper steps of the system, situated at its eastern part, are formed by lakes Jazy (called also Wirzchoń) and Brzózka, and two lower by Lakes Gościąż and Mielec. In the vicinity of lakes occur fluvial and fluvioglacial sands with admixture of gravels and stones, associated with the youngest Pleistocene glaciation. South of lake occur dunes of late Pleistocene age. At depth of ca 15 m sandy sediments are separated with a level of stones of diameter exceeding 25 cm. At the same depth occur also flat surfaces inside the lake basin. Total thickness of Pleistocene deposits in that region reaches 20-40 m (Skompski, 1968). Pleistocene deposits are underlain by local lobes of clays and fine-grained Pliocene sands and series of Miocene sands and clays with laminations of brown coals. Top of Tertiary deposits is developed in form of a series of synclinal and antyclinal structures of NW-SE direction. The basins of Lake Gościąż and other lakes are situated within the synclinal structure at top of Tertiary deposits. Pieces of brown coal were found in fine-grained sands underlying the lacustrine series of the Gościąż Lake. Thick layer of brown coal was found under vari-grained sands at elevation 40 m a.s.l. in core situated ca 1.2 km NE of lake shore. Light-grey Cretaceous limestones were found in this region at depth ca 30 m below sea level. Results of geological survey suggest that significant part of the basin of Lake Gościąż is situated within the Miocene series and is below the level of Vistula river. Primary bottom of the lake basin in its deepest part was at depth ca 25 m a.s.l. Due to such hydrological conditions, slightly alkaline and oxygen-poor environment of lake basin is favourable for sedimentation of carbonates with significant contribution of sulphides (mostly Fe).

2. DESCRIPTION OF THE CORE

The core GO, taken at the deepest part of the lake basin (at depth 22.5 m) was chosen for preliminary studies. The core consists of 15.6 m thick series of organogenic deposits and 25 cm thick layer of underlying sands. Calcareous gyttja, which forms the organogenic series, is the dominating sediment in lakes of the Polish Lowland. However, the sediments of the Gościąż Lake reveal distinct specific features. Dominating macroscopic feature of these sediments is their black color with no significant changes in the whole profile, caused by high content of hydrotroillite. After oxidation the color changes to various shades of rotten green with more or less intensive rusty coating and microlamination of the sediment becames more clearly visible.

Chemical composition of the sediment seems also interesting. Organic matter constitutes 12-18% of dry mass of sediment. The lowest content of organic matter was found at the central part of core, from 4 to 11 m. This part has the highest content of carbonates (more than 70% of $CaCO_3$). The lowest content of carbonate in the basal part of the sediment is a normal feature, while rapid decrease of $CaCO_3$ content in the uppermost part is probably caused by anthropogenic changes of surrounding vegetation. Resulting increase of deflation caused enrichment of sediments with mineral substances. Fe_2O_3 content in investigated core is especially high as compared with sediments of other lakes; in the lower part of core at depths from 11 to 15 m it is equal to 5-8% of dry mass.

The most unusual feature of those sediments is distinct regular microlamination, occuring in whole vertical profile. Undoubtly the couplets of light and dark layers are associated with annual cycle of accumulation. Clearly visible are also 9-11 year cycles of accumulation connected with fundamental cycles of solar radiation. The core GO is the first core in Poland where the microlamination occurs during the whole time from the very beginning of sedimentation till the present day.

Due to presence of microlamination in the whole profile it was possible for the first time to establish the age of the lake in a direct way analogical to varve chronology or dendrochronology by counting the number of couplets in the profile. The number of couplets counted in core GO was equal to 12,600; the thickness of individual couplets ranges from 0.2 mm to 0.8 mm. The thickest couplets occur in the uppermost part of profile. Accounting for factors which may influence the acuracy of the result of counting we estimate the error of the total number of couplets as equal to ± 600. This first preliminary result is in good agreement with results of ^{14}C dating (Pazdur et al, 1987; Ralska-Jasiewiczowa et al, 1987) and with data available from other lakes.

Thicknesses of individual couplets and their differentiation in the studied profile gives also an excellent indicator of changes of acumulation rate in the whole time starting from the beginning of sedimentation in the lake basin. Differences of thicknesses of individual couplets undoubtely reflect all changes and fluctuations of environmental condition in the vicinity of lake, mostly thermal regime and biochemistry of lake and its trophy.

3. METHOD OF ANALYSIS

The periodicity of accumulation of sediments in the Lake Gościąż was e. total thicknesses of 10 couplets. Statistical analysis was performed on set of n=1230 experimental results, excluding the uppermost 2 m of core as well as disturbed parts of core. Periods of accumulation were estimated by the least squares method fitting of the sine function of the form

$$y = a + b\sin\left(\frac{2\Pi t}{T} + c\right), \tag{1}$$

where: a, b and c are unknown parameters (b - amplitude, c - phase shift), and T denotes period of sine function, to experimentally measured increments y1, ..., yn corresponding to time t=1, 2, ..., n. The value of T was changed from T=1 to T=1500. The condition of the minimum of residual variance

$$\varepsilon^2 = \frac{1}{n}\sum_{i=1}^{n}\left[y_i - a - b\sin\left(\frac{2\Pi t_i}{T} + c\right)\right]^2 \tag{2}$$

Table 1

Results of statistical analysis of the periodicity of sediment accumulation rate in the Gościąż Lake

	Period yr	Amplitude mm/10 yr	Phase	Value of Fisher-Snedecor statistics
1	110	0.187	1.780	1.14
2	180	0.164	0.142	0.90
3	300	0.282	1.125	2.47
4	370	0.308	-2.732	2.93
5	440	0.279	-0.714	2.42
6	490	0.228	-1.646	1.64
7	540	0.254	-1.052	1.99
8	560	0.484	-0.916	7.07
9	630	0.388	-0.318	4.56
10	660	0.365	-0.363	4.04
11	750	0.365	-0.307	4.04
12	870	0.793	-0.136	19.05
13	970	0.365	0.004	4.03
14	1070	0.596	-0.048	10.73
15	1280	0.463	-0.050	6.41
16	1430	0.812	0.147	19.97
17	1680	1.057	0.346	35.41
18	2310	0.902	0.427	25.53
19	2970	1.107	0.646	39.05
20	4470	1.425	0.581	70.14

leads to the regression equation

$$y = a + \alpha \sin \frac{2\Pi t}{T} + \cos \frac{2\Pi t}{T}, \tag{3}$$

where $b = \sqrt{\alpha^2 + \beta^2}$; $\mathrm{tg}c = \frac{\beta}{\alpha}$. Local minima of residual variance ε^2, corresponding to maximum values of correlation coefficient R

$$R^2 = 1 - \frac{\varepsilon^2}{s^2} \tag{4}$$

(s - standard deviation of y) are regarded as denoting real periods of sediment accumulation. Their significance was verified using the Fisher-Snedecor test

$$F = \frac{(n-3)R^2}{2(1-R^2)}. \tag{5}$$

Time dependence of decadal accumulation rate $y=f(t)$ was obtained by superposition of cycles which were significant at the significance level 5%

$$y = a_o + \sum_{j=1}^{k} b_j \sin\left(\frac{2\Pi t}{T_j} + c_j\right) \quad (6)$$

providing minimum of the residual variance

$$\varepsilon^2 = \frac{1}{n}\sum_{i=1}^{n}\left[y_i - a_o - \sum_{j=1}^{k} b_j \sin\left(\frac{2\Pi t_i}{T_j} + c_j\right)\right]^2 = \min. \quad (7)$$

4. RESULTS OF ANALYSIS

Performed analysis has revealed the presence of 20 values of the period of sediment accumulation rate in the Gościąż Lake, with 13 values which are significant at 95 significance level according to the Fisher-Snedecor test. All relevant data are listed in Table 1. The time trend $y = f(t)$ defined by Eq. (6) has the form

$$\begin{aligned} y = 10.88 &+ 0.3002\sin\left(\frac{2\Pi t}{37} - 2.788\right) + 0.4098\sin\left(\frac{2\Pi t}{56} - 0.752\right) + \\ &0.2969\sin\left(\frac{2\Pi t}{63} - 0.331\right) + 0.2694\sin\left(\frac{2\Pi t}{75} - 0.576\right) + \\ &0.7728\sin\left(\frac{2\Pi t}{87} - 0.533\right) + 0.2160\sin\left(\frac{2\Pi t}{97} - 0.437\right) + \\ &0.5715\sin\left(\frac{2\Pi t}{107} - 0.146\right) + 0.3490\sin\left(\frac{2\Pi t}{128} - 0.104\right) + \\ &0.6284\sin\left(\frac{2\Pi t}{143} + 0.305\right) + 0.8761\sin\left(\frac{2\Pi t}{168} + 0.274\right) + \\ &0.7528\sin\left(\frac{2\Pi t}{231} + 0.545\right) + 0.8549\sin\left(\frac{2\Pi t}{297} + 0.837\right) + \\ &0.1503\sin\left(\frac{2\Pi t}{448} + 0.242\right) \end{aligned} \quad (8)$$

Accuracy of this approximation is relatively good; coefficient of multiple correlation $R = 0.574$, calculated value of the Fisher-Snedecor statistics $F = 22.68$ (critical value for $n_1=26$, $n_2=1203$, is equal to $F_{cr}=1.50$), standard deviation $\delta = 2.68$ mm. As follows from analysis of numerical data listed in Table 2, the residuals $\varepsilon_i = y_i - f(t_i)$ are approximately normally distributed. We may therefore conclude that the hypothetical trend of accumulation rate is enclosed within the confidence band $f(t)\pm3\delta$ with the probability 0.997. The plot of function $y=f(t)$ given by Eq. (8) is shown in Fig. 1 in whole time range $(0<t<1230)$ with indicated mean value $\bar{y}=11.09$ mm.

Table 2

Frequency distribution of residuals

Relative deviation	Range of ε mm/10 yr	Observed number	Frequency
<-3	<-7.94	0	0
-3 – -2	-7.94 – -5.92	2	0.002
-2 – -1	-5.29 – -2.65	174	0.141
-1 – 0	-2.65 – 0	509	0.414
0 – 1	0 – 2.65	353	0.287
1 – 2	2.65 – 5.29	143	0.116
2 – 3	5.29 – 7.94	38	0.031
>3	>7.94	11	0.009

5. COMPARISONS WITH RESULTS FROM THE WIKARYJSKIE LAKE AND SOLAR DATA

As is shown in Table 3, eight cycles found in the laminated sequence from the Gościąż Lake coincide with cycles of accumulation of organic matter in sediments of the Wikaryjskie Lake (Boryczka, Wicik, 1984). Some cycles of sediment accumulation rate in the Gościąż Lake coincide with periods of solar activity. Detailed comparison is presented in Table 4. There is a correlation between the temperature of air and the activity of Sun, measured with the Wolf sunspot numbers. Solar activity in the interval of time ranging from AD 1700 to AD 1978 reveals cyclicity with three periods: 11.4 yr, 94 yr, and 179 yr, while mean air temperature in Warsaw shows cyclicity with periods 11.1 yr, 89 yr and 217 yr (Boryczka, 1984). Minimum values of temperature in the 89-yr cycle occur in: AD 1635, AD 1724, AD 1813, AD 1902 (and predicted AD 1991, AD 2080), while minima of solar activity in the 94-yr cycle were observed in: AD 1622, AD 1717, AD 1812, AD 1907 (and are predicted to occur in AD 2002 and AD 2097). Minimum values of mean annual air temperature in the 217 yr cycle occur at AD 1610 and AD 1827. Those dates coincide with well-known dates of the Maunder Minimum of sunspot number. It is interesting to note that the absolute minimum of observed trend of mean annual air temperature in Warsaw (AD 1812) occurs at the beginning of the weakest period (AD 1812–1823) of the 11yr cycle of solar activity. Absolute maximum of mean annual air temperature in the time interval from AD 1779 to AD 1979, occuring in AD 1950, slightly overtakes the strongest period of the 11 yr cycle (AD 1955–1964) with the absolute maximum of the Wolf number (AD 1957).

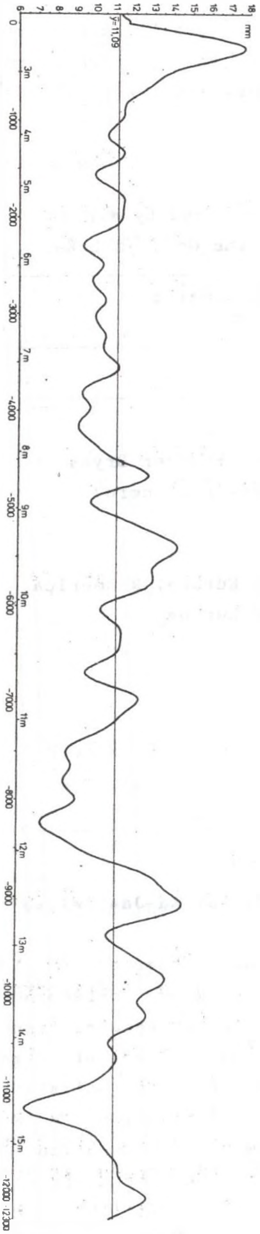

Fig. 1. Plot of function y=f(t)
Rys. 1. Wykres funkcji y=f(t)

Table 3

Periods of sediment accumulation rate in the Gościąż Lake and Wikaryjskie Lake

Gościąż L.	Wikaryjskie L.
370	300
560	550
870	850
970	950
1070	1150
1680	1600
2310	2350
2960	3300

Table 4

Comparison of periods revealed in sequence of laminated sediments of the Gosciąż Lake with periods of solar activity (after Kuklin, 1982)

Gościąż L.	Solar activity
110	91
180	179
300	350
370	400
560	600
750	700
870	900
970	10[illegible]0
1680	1700

6. COMPARISON WITH PALAEOCLIMATIC DATA

Maxima and minima of the obtained trend function y=f(t) are compared in Tables 5 and 6 with corresponding maxima and minima of organic matter content in sediments of the Wikaryjskie Lake (Boryczka, Wicik, 1984)

Table 5

Main deteriorations of climate in Poland revealed by minima of smoothed trend of accumulation rate in the Gościąż Lake

Gościąż Lake		Dates of main climatic cooling
t_{min}	y_{min}	
-12,700	7.6[a]	Kary
-11,150	6.5	-10,000 Mancato (Younger Dryas at 14.8m in GO core)
-8,250	7.2	-8,500 Europe
-5,000	9.8	
-4,150	9.1	-3,900 - -3,600 Europe, N America
-2,300	9.6	-2,500 - -1,900 Europe
-1,550	9.9	-1,400 Europe
-1,150	10.6	
+400	7.7	
+1,100	8.3	
+1,800	9.2	
+4,600	9.7	

a)- extrapolation of trend function, b)- prediction

c)- estimate from preliminary pollen analysis by M. Ralska-Jasiewiczowa

and with dates of warmings and coolings of climate, . observed in North America and in Europe. It may be noted fairly good correspondence between coolings and warmings estimated from obtained general trend of sediment accumulation rate in the Gościąż Lake and changes of organic matter content in the Wikaryjskie Lake, as well as satisfactory agreement with coolings of the Wisconsinian glaciation in North America. For example, the main minima of of sediment accumulation rate (both observed and predicted from extrapolation of the trend function, Eq. (8)), occuring in -16,300, -12,700 and -11,150 years correspond to well known coolings (Keree, Kary, Mancato).

Table 6

Main ameliorations of climate in Poland revealed by maxima of smoothed trend of accumulation rate in the Gościąż Lake

Gościąż Lake		Dates of main climatic warmings
t_{max}	y_{max}	
-12,100	12.8	-11,400+_350 Two Creeks -10,800+_580 Allerod -12,000 (Allerod at depth 15.45m in core GO)
-9,000	14.5	
-7,700	12.3	-7,000 (Atlantic optimum at depth 10.8m in GO core)
-5,400	14.3	
-4.700	12.8	-4,000 Thermal max. N America
-3,650	11.1	
-1,900	11.3	
-250	17.7	
+2,700	13.0[b]	
+4,150	13.3[b]	

a)- extrapolation of trend function, b)- prediction

c)- estimate from preliminary pollen analysis by M. Ralska-Jasiewiczowa

Similarly, main maxima of sediment accumulation rate in the Gościąż Lake, occuring at -12,100, -9800, and -5400 years are comparable with warmings observed in North America (Two Creeks) and Europe (Allerod, climatic optimum of the Holocene).

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HOLOCEŃSKIE WAHANIA KLIMATU W ŚWIETLE ANALIZY STATYSTYCZNEJ OSADÓW LAMINOWANYCH Z JEZIORA GOŚCIĄŻ

Streszczenie

Jezioro Gościąż zlokalizowane w Kotlinie Płockiej jest najgłębszym z systemu czterech jezior połączonych ciekiem Ruda. Misa jeziora Gościąż usytuowana jest w znacznym stopniu w obrębie utworów miocenu i znajduje się poniżej poziomu Wisły. Osady denne jeziora Gościąż, o miąższości blisko 16 m charakteryzują się występowaniem regularnej mikrolaminacji w całym profilu. Analizie statystycznej poddano wyniki pomiarów dziesięcioletnich przyrostów osadu, uwzględniając 1230 wartości obejmujących część rdzenia G0 począwszy od głębokości 2 m. Do wyników pomiarów dopasowywano metodą najmniejszych kwadratów funkcje sinusoidalne o zadanej wartości okresu sinusoidy zmieniającej się od 10 do 15000 lat. Stwierdzono występowanie cykliczności przyrostu osadu o 20 wartościach okresu, z czego na podstawie testu Fishera-Snedecora za istotne uznano 13 wartości okresu. Osiem spośród wykrytych cykli jest zbliżonych do okresów akumulacji substancji organicznej w osadach Jeziora Wikaryjskiego. Niektóre z wykrytych cykli mają długość zbliżoną do okresów aktywności Słońca. Stwierdzono także dobrą zgodność ekstremów trendu czasowego szybkości akumulacji osadów w Jeziorze Gościąż z datami ochłodzeń i ociepleń klimatycznych w Europie i Ameryce Północnej.

ГОЛОЦЕНОВЫЕ ИЗМЕНЕНИЯ КЛИМАТА В СВЕТЕ СТАТИСТИЧЕСКОГО АНАЛИЗА РАССЛОЕННЫХ ОСАДКОВ ИЗ ОЗЕРА ГОСЦИОНЖ

Резюме

Озеро Госционж расположенное в Плоцком бассейне является самым глубоким из системы четырех озер соединенных ручьем Руда. Развитие бассейна озера Госционж происходило в значительной степени в миоценовых

осадках. Донные осадки толщиной в 16m находящиеся ниже среднего уровня реки Вислы проявляют регулярное расслоение во всем разрезе. В докладе представлены результаты статистического анализа толщины десятилетних участков из колонки G0 на основе 1230 значений ниже 2m. Результаты измерений были аппроксимированы периодическими функциями на основе метода наименьших квадратов. Изменяя значение периода функции синуса в пределах от 10 до 15000 лет доказано присутствие циклических изменений толщины десятилетних приращений осадка. Обнаружено 20 разных значений периода, используя статистику Фишера - Снедекора доказано, что 13 значений периода можно считать статистически существенными. Восемь из обнаруженых циклов имеют значения периода приблизительно равно периоду накопления органического вещества в донных осадках озера Викарийского. Некоторые из обнаруженых циклов совпадают с известными циклами солнечиой активности. Показана также хорошая сходимость между экстремальными значениями временного тренда изменений скорости осадконакопления в озере Госционж и возрастом похолоданий и потеплений в Европе и северной Америке.