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RECORD OF HOLOCENE CLIMATIC CYCLES IN LAKE SEDIMENTS IN CENTRAL POLAND

INTRODUCTION

The purpose of the paper is to identify astronomical causes of Holocene climatic fluctuations. Analogous cycles — lasting several hundred or several thousand years — of contents of organic substance in lacustrine sediments and of the parameters of the Solar System were ascertained.

The statistical analysis of chronological sequences of accumulation of bottom sediments in the following lakes was made: Wikaryjskie, Gościąż and Święte, situated in the Gostyń — Włocławek Lake District in Poland.

A cylinder-shaped sample of the sediment 3.80 m in length was collected from Lake Wikaryjskie, and the content of organic substance (in percent) in 20-mm small layers ($n = 195$) was determined. Below the sediment layer peat was found which was dated to $10,360 \pm 200$ years by use of the radiocarbon method (Boryczka, Wicik 1983; Fig.1A).

The bottom sediments of Lake Gościąż are laminated and the annual increments are well seen. In a cylinder-shaped sample of 16 m in length (core GO) $n = 1230$ ten-year increments were calculated. In this case determination of absolute calendar time calculation was not difficult (Boryczka, Wicik 1989; Fig.1B).

From Lake Święte a sediment sample of 13.20 m in thickness was collected and the percent content of organic substance every 6 cm ($n = 221$) and of density of sediments (g/cm^3) every 3 cm ($n = 422$) was determined. The axis of time was drawn on the basis of five datings by the radiocarbon method: 4.0 – 4.1 m — 2840 ± 100 years, 8.05 – 8.14 — 4510 ± 110 years, 9.65 – 9.75 m — 7010 ± 90 years, 11.86 – 11.88m — $10,060 \pm 140$ years and 12.22 – 12.27m — $12,400 \pm 170$ years, taking into account variable compression of sediments (Figs.1C, 1D).

Changes occurring in the Solar System 20,000 years ago were shown by defining the following parameters:

G — resultant gravitational force of planets:
$$\vec{G} = \sum_i \frac{m_i}{r_i^3} \vec{r}_i$$

Fig.1. Chronological sequences of accumulation of bottom sediments in Polish lakes: Wikaryjskie, Gosciąż, Święte (organic substance, 10-year increments, density)

ΔG — resultant of tidal force on the Sun (towards the direction of the mass centre): $\Delta \vec{G} = \frac{\vec{s}}{s} \cdot \sum_i \frac{m_i}{r_i^4} \vec{r}_i$

J — total momentum of planets: $\vec{J} = \sum m_i \frac{d\vec{r}_i}{dt} \times \vec{r}_i$, AU^2 / month

$\cos \Gamma$ — cosine of angle between vector radii of the mass centre $\vec{s}$ and geometrical centre $\vec{S}$ of the Solar System,

$\vec{s} \approx \frac{1}{M} \sum_i m_i \vec{r}_i$, $\vec{S} = \frac{1}{9} \sum_i \vec{r}_i$ (M — mass of Solar System),

where m_i , $\vec{r}_i$ — mass and vector radius of the i th planet.

Heliocentric ecliptic coordinates from before 20,000 years were determined taking into account secular changes of parameters of their orbits, i.e. polynomials published by A.P.Reznikov (1982).

The true cycles (spectra of oscillation) were established by the Boryczka method of "regression sinusoids"

$$y = a + b \sin \left(\frac{2\pi}{\Theta} t + c \right) \quad (1)$$

changing period Θ every 1 or prescribing its values $\Theta_1, \dots, \Theta_n$

Forecasts of climatic changes were made on the basis of the function of time trend

$$y = a_o + \sum_j b_j \sin\left(\frac{2\pi}{\Theta_j} t + c_j\right), \quad (2)$$

where Θ_j are discovered periods in the spectrum of oscillation

True cycles Θ_j are local maxima of the spectrum of oscillation $b_1, \dots, b_n$. Amplitudes $b_1, \dots, b_k$ were verified by the Fisher-Snedecor test of $n_1 = 2$ and $n_2 = n - 3$ degrees of freedom.

SYNCHRONIC CHARACTER OF CYCLES OF ORGANIC SUBSTANCE AND OF PARAMETERS OF THE SOLAR SYSTEM

The spectra of oscillation of sedimentological and astronomical variables were shown in Figures 2 and 3. The true cycles of sedimentological variables in Lake Świąte are as follows:

organic substance (%)				density of sediments (g/cm ³)			
Θ	b	c	R	Θ	b	c	R
120	5.87	-2.58	0.167	60	0.069	0.65	0.081
190	3.27	-2.91	0.167	270	0.032	2.91	0.061
370	3.67	-1.21	0.105	360	0.031	-2..25	0.064
530	1.54	-2.15	0.044	540	0.037	-2.59	0.077
560	1.36	-0.43	0.039	590	0.041	-2.44	0.087
690	2.21	-0.26	0.062	710	0.054	-1.46	0.113
770	2.24	0.83	0.063	760	0.061	0.71	0.128
870	2.51	2.38	0.071	820	0.083	2.60	0.174
1050	2.61	1.53	0.074	1010	0.085	2.90	0.178
1190	2.39	-0.78	0.067	1110	0.058	-2.19	0.122
1310	4.05	-0.40	0.116	1340	0.036	-2.31	0.075
1600	3.70	-0.98	0.105	1590	0.054	-0.66	0.113
2020	4.99	0.48	0.145	1920	0.059	1.72	0.121
2450	4.60	-0.05	0.134	2250	0.122	1.41	0.255
2940	4.18	0.80	0.118	2780	0.162	2.58	0.324
4020	14.00	2.47	0.393	3620	0.248	-2.57	0.534
7350	11.60	-0.50	0.306	5500	0.168	-1.37	0.325
				7860	0.123	-2.98	0.240

where R is the coefficient of multiple correlation ($R_{0.05} = 0.144$, $R_{0.10} = 0.104$).

Statistically significant cycles at the level of confidence 90% and slightly lower are underlined. This testifies to the reliability of the measurements, dating as well as statistical analyses.

Fig.2. Spectra of oscillation of sedimentological (Lakes Wikaryjskie and Gościąg) and astronomical variables (total momentum of planets J , $\cos \Gamma$)

Of great cognitive value for the explanation of causes of Holocene climatic variations is the discovery of astronomical variables in the spectra of oscillation: resultant gravitational force of planets (G), resultant of tidal force on the Sun (ΔG), total momentum of planets (J), and $\cos \Gamma$ of the same cycles as those found in the spectra of oscillation of sedimentological variables: Lake Święte 1 — organic substance, Lake Święte 2 — density of sediments, Lake Wikaryjskie — organic substance, Lake Gościąg — 10-year increments of thickness of sediments. Similarity of the spectra of oscillation implies the hypothesis about the astronomical causes of Holocene climatic variations. This testifies to the effect of changes occurring in the Solar Sys-

tem on accumulation of organic substance in lake sediments, which are correlated with climate (air temperature and precipitation).

Here is the comparison of the true cycles of sedimentological and astronomical variables:

Św.1	Św.2	Wik.	Goś.	<i>G</i>	ΔG	<i>J</i>	$\cos \Gamma$
120	.	200	.	180	170	80	170
370	360	300	300	380	310	.	250
530	590	550	560	480	510	530	570
870	820	850	870	940	930	.	800
1050	1010	950	970	1010	1120	110	1050
1310	1110	1150	1280	1370	1480	1410	1400
<u>1600/2020</u>	<u>1590</u>	<u>1600</u>	<u>1680</u>	<u>1650</u>	<u>1670</u>	<u>1560</u>	<u>1600</u>
<u>2450</u>	<u>2250</u>	<u>2350</u>	<u>2310</u>	<u>2520</u>	<u>2280</u>	<u>2290</u>	<u>2350</u>
2940	2780	3300	2970	3040	2960	3270	.
4020	3620	.	.	3780	4000	4220	3940
.	5500	6150	4600	5060	.	6040	5920
7350	7860	.	.	7750	7730	.	.

Cycles of accumulation of organic substance in sediments of Lake Świąte of the highest amplitudes are: 2020, 2450, 4020 and 7350 years. The two latter (unknown so far) are strongest (4020 years — $R = 0.39$, 7350 years — $R = 0.31$).

Two cycles (among Św.1): 370 and 2450 years occur in the set of 4 cycles of climatic changes: 78, 180, 400, 2400 years, determined by the oxygen isotope ^{18}O (Johnsen et al., 1970).

The cycle of 2450 (according to the oxygen isotope ^{18}O — 2400 years) approximates the strongest cycle of the resultant of the effect of gravitational force of planets on the Sun of 2280 years. In all the spectra there occurs the Peterson cycle of 1600 years (of location of planets), whereas the cycle of glacial large-scale climatic processes of 1850 years (Maksimov 1972) — of volcanic activity — does not occur in the spectra of sedimentological variables or the Johnson set. There is a cycle of accumulation of organic substance in the sediments of Lake Świąte which is slightly longer (2020 years).

FORECAST OF CLIMATIC CHANGES ACCORDING TO ACCUMULATION OF ORGANIC SUBSTANCE IN LAKE SEDIMENTS

Knowing the spectra of oscillation (true cycles) of contents of organic substance (in percent) in the bottom sediments of Lake Świąte and density of sediments (in g/cm^3), time trends were determined ($y = f(t)$). For example, the time trend of organic substance (y) in sediments of that lake, taking into account 15 strongest cycles, is expressed by the following formula:

$$\begin{aligned}
 y = & 64.47 + 4.007 \sin (0.5236t - 2.496) + 2.996 \sin (0.3306t - 2.816) + \\
 & + 3.318 \sin (0.1696t - 1.176) + 0.763 \sin (0.0966t - 1.728) + \\
 & + 2.037 \sin (0.0816t + 1.417) + 3.489 \sin (0.0722t - 1.819) + \\
 & + 3.740 \sin (0.0598t + 1.197) + 2.542 \sin (0.0528t + 0.361) + \\
 & + 5.337 \sin (0.0478t - 0.083) + 4.342 \sin (0.0392t - 1.212) + \\
 & + 7.254 \sin (0.0312t + 0.427) + 5.378 \sin (0.0256t - 0.280) + \\
 & + 4.778 \sin (0.0214t - 1.433) + 14.150 \sin (0.0156t + 2.661) + \\
 & + 12.160 \sin (0.086t - 1.401)
 \end{aligned} \quad (3)$$

which is characterized by quite a high precision: correlation coefficient $R = 0.607$, the Fisher-Snedecor test $F = 3.693$ (critical value $F_{0.10} = 2.0$, arith-

Fig.3. Spectra of oscillation of sedimentological (Lake Święte) and astronomical variables (resultant of the gravitational force of planets G , tidal force on the Sun ΔG)

metric mean $\bar{y} = 66.97\%$, standard deviation $s = 24.77\%$, and standard error $\delta = 21.23\%$.

Curves in Figure 4 show the function of time trends of organic substance (in percent) and density of sediments (g/cm^3). The curves consist of three parts: RECONSTRUCTION, APPROXIMATION and FORECAST (negative time). Forecasts (predicted future) in the calendar time calculation are shown in Figures 4C and 4D.

The minima of organic substance in Lake Świąte (Fig.4A) correspond to Holocene cooling of climate, while maxima — to warming up. Secular extreme values of the curve (minima and maxima) were compared with the results of investigations in Lake Wikaryjskie and Lake Gościąg (Boryczka, Wicik 1983,1989), as well as with the cooling and warming of climate in Europe and North America (Lake Wisconsin) known from literature:

COOLING OF CLIMATE (dates):

L.Świąte	L.Wikaryjskie	L.Gościąg	acc.to others
-18,500			
-17,300		-17,000, Keree	
-14,000	-14,700	-12,700	
-11,450	-11,750	-11,150	
	-10,200		-10,000, Mancato, Kary
-9,000	-8,000	-8,250	8,500, Europa
-4930	-5200	-5000	
-3600	-3400	-4150	-3900
	-2450	-2300	-2500, Europa
-1200	-1200	-1950	-1000
360			forecast
	1400	1100	forecast
2630- 3000	4700	4600	forecast

WARMING OF CLIMATE (dates):

L.Świąte	L.Wikaryjskie	L.Gościąg	acc.to others
-18,350			
-15,700			
-14,830	-13,700	.	
-12,200	.	-12,100	-11,400 $\pm$ 350, Two Creeks
-10,300	-11,000	-9,000	-10,800 $\pm$ 580, Alleröd
-8300	-9500	-7,700	
-4400	-6300,-4100	-5400,-4700	-4000 optimum of climate
-2400	-2900,-1650	-3650,-1900	(absolute maximum in North America)
1000	600,2600	2700	forecast
4600	.	4150	forecast

Fig.4. Reconstruction-approximation-forecast of accumulation of organic substance in sediments of Lake Świąte: 20,000 years ago and in 5,000 years. Curves C,D — according to the calendar time calculation

The warming of -6300 and -5400 years ago coincides with the minimum of seismic activity which occurred 5800 years ago.

According to the content of organic substance in sediments of Lake Świąte, the nearest cooling of climate will occur in 360 years, and the subsequent one in 2630 years. These are only extremal values of the curves of the air temperature changes from before 20,000 years and in 5000 years (zero of the time axis t occurred in the year 1990 in which a sediment sample was collected below the bottom of Lake Świąte).

The curve predicting the contents of organic substance in sediments of Lake Świąte in the years 1980-2500 is below the mean $\bar{y} = 66.97\%$. Thus, we may predict a considerable cooling of climate in the coming 500 years (the greatest one is likely to occur between 2300 and 2400; see Fig.4D).

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