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COMPARISON OF VARIABILITY OF STABLE ISOTOPES ^{18}O AND ^{13}C AND VARVE THICKNESS IN BASAL PART OF LAMINATED SEDIMENTS OF THE GOŚCIĄŻ LAKE

Summary: Results of thickness measurements of annual layers and values of $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ content in two sequences from basal part of laminated sediments from the Gościąż Lake are subjected to detailed statistical analysis in order to reveal phenomenological relations between measured variables. Sedimentation of analysed sequences of annual couplets was interrupted by deposition of 0.5m thick layer of sands. Both sequences show similar relations between $\delta^{18}O$ and $\delta^{13}C$ and between $\delta^{18}O$ and $CaCO_3$ content. Relatively low correlation was found between thicknesses of annual increments and values of $\delta^{18}O$, mostly because in the older sequence this relation was disturbed by sedimentation of sandy layer and in the younger sequence the values of $\delta^{18}O$ cover very narrow interval. Distinct correlation was found between thicknesses of light (summer) and dark (winter) layers.

1. INTRODUCTION

Since the early work of Stuiver (1970), the records of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios in authigenic freshwater carbonates are widely used as climatic indicators. Critical review of limitations and possibilities of climatic interpretation of those records with a number of examples from several sites in Switzerland and France, is given by Siegenthaler and Eicher (1985). In Poland the method of stable isotopes was applied jointly with pollen analysis in studies of calcareous gyttja profiles from selected North Polish Lakes (Różański, 1988, Różański et al, 1985).

Laminated sediments of the Gościąż Lake provide an exact time scale for studying changes of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios in the whole Holocene and Late Glacial (Goslar et al, 1989, this volume), and, moreover, may be probably used as independent indicators of past climatic changes, as is

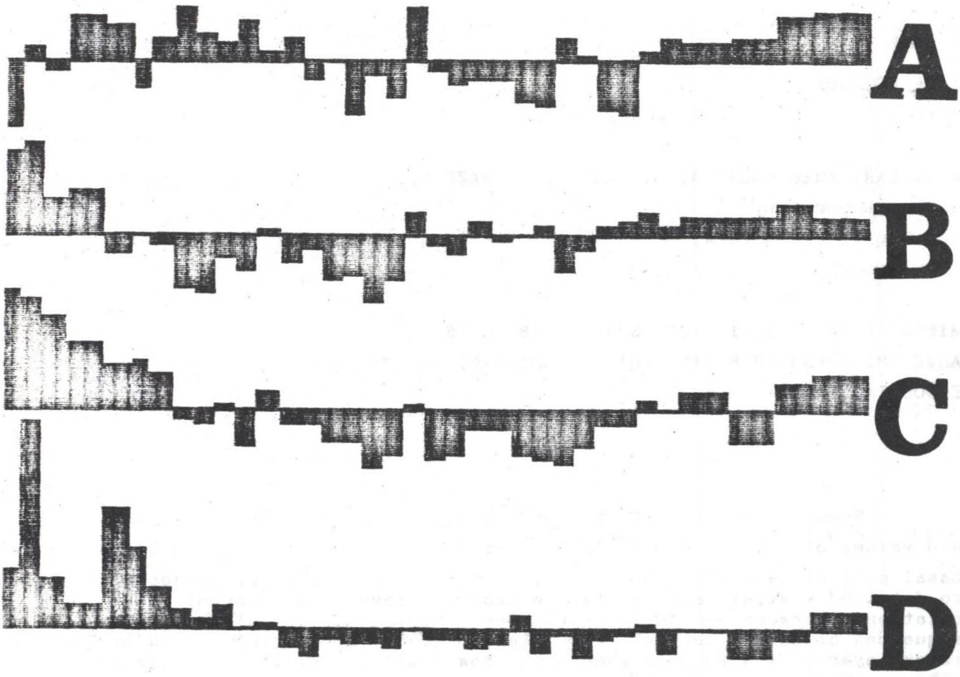

Fig. 1 Time variations observed in sequence of 244 couplets. Plots show: A - $CaCO_3$ content, B - $\delta^{18}O$, C - $\delta^{13}C$, D - mean varve thickness, E - time spans of individual samples. Note inversion of scale of $\delta^{13}C$ values. The content of $CaCO_3$ was not measured in 12 lowermost samples.

Rys. 1. Zmienność czasowa mierzonych wartości w serii 35 próbek z najstarszej sekwencji obejmującej 244 pary lamin. A - zawartość $CaCO_3$, B - $\delta^{18}O$, C - $\delta^{13}C$, D - średnie grubości rocznych przyrostów, E - odcinki czasu pokrywane poszczególnymi próbkami. Zawartość $CaCO_3$ w serii 12 najniżej leżących próbek nie była mierzona. Uwaga: skala wartości $\delta^{13}C$ jest odwrócona w porównaniu ze skalą $\delta^{18}O$.

suggested by preliminary results of Goslar (1989, this volume), and by studies of other authors. An attempt was therefore made to examine the relations between variations of $\delta^{18}O$, $\delta^{13}C$, $CaCO_3$ content (which may also be used as climate indicator) and varve thickness.

This preliminary note presents the results of analysis of data obtained on two short sequences from basal part of core G1, which jointly contain ca 550 couplets. They cover therefore only ca 4% of whole sequence of laminated sediments of the Gościąż Lake. It should not be expected that the results of measurements on such a short interval of time will enable

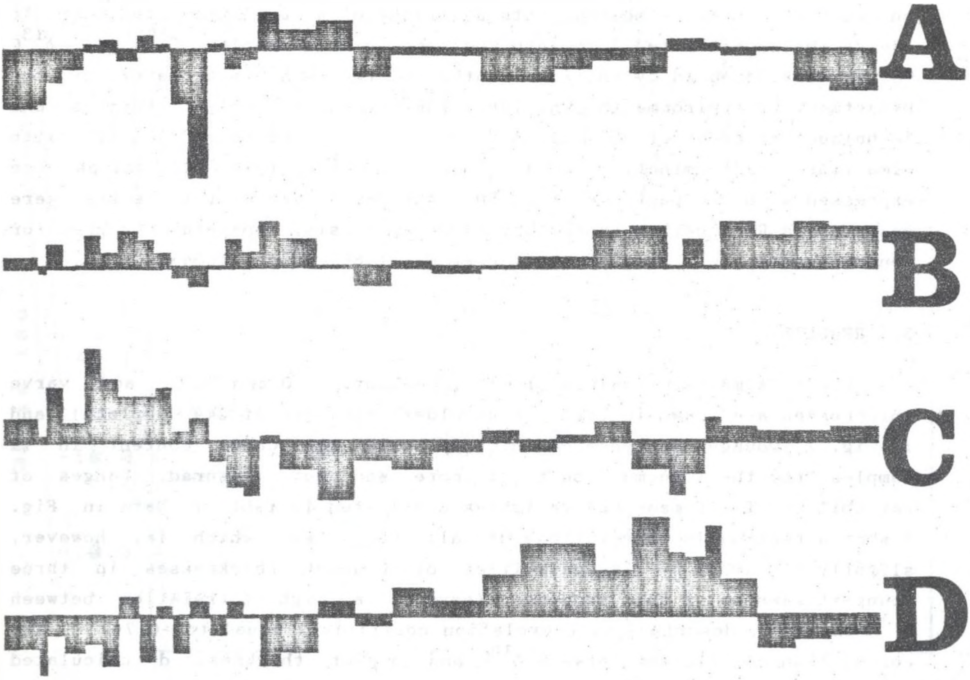

Fig. 2. Results obtained on series of 33 samples from the younger sequence of 301 couplets. Explanations as in Fig. 1.

Rys. 2. Wyniki otrzymane z serii 33 próbek z młodszej sekwencji obejmującej 301 par lamin. Objaśnienia jak na rys. 1.

definite palaeoclimatic or environmental conclusions, mainly because the environmental conditions may be regarded relatively steadily changing over a time scale of few centuries. In spite of this, it seems worthwhile to undertake detailed investigation of phenomenological relations between measured physical and chemical parameters of laminated sediment. We expect that detailed insight into the relations describing short-term behavior of isotopic and physicochemical data will be highly useful in future attempts of interpretation of characteristic patterns revealed by the long-term records in term of climatic and environmental changes.

2. MATERIAL AND METHODS

About 80 samples were taken for preliminary studies from ca 2 m long basal part of core G1, with 35 samples from the lowermost segment comprising 244 couplets and 32 samples from the overlying sequence of 301 couplets. Time span of individual samples ranges from 3 to 20 years; most samples cover time span of 6 years. Sampling intervals were chosen basing on results of precise measurements of widths of annual layers in order to divide the investigated core into the most uniform samples. $\delta^{18}O$ and $\delta^{13}C$ values were measured by the first author on the mass spectrometer at the Department of Environmental Physics, Institute of Nuclear Physics and Techniques, Academy of Mining and Metallurgy, Cracow, jointly with simultaneous determination of $CaCO_3$ content. $\delta^{18}O$ and $\delta^{13}C$ values are expressed with respect to the PDB standard. Varve thicknesses were measured in Radiocarbon Laboratory in Gliwice using apparatus designed for dendrochronological studies (Goslar et al, 1989, this volume).

3. RESULTS

Plots of measured values of $CaCO_3$ content, δ O and δ C, and varve thicknesses are shown in Fig. 1 (the oldest sequence of 244 couplets) and in Fig. 2 (younger sequence of 301 couplets). The $CaCO_3$ content in 12 samples from the lowermost part of core was not measured. Ranges of variability of all measured variables are listed in Table 1. Data in Fig. 1 show a reasonable correlation of all variables, which is, however, slightly disturbed by irregularities of couplet thicknesses in three youngest samples of this sequence. There is a high correlation between $\delta^{13}C$ and $\delta^{18}O$, described by correlation coefficient equal to -0.74. The correlation coefficient between $\delta^{18}O$ and couplet thickness d calculated after rejection of 3 uppermost samples is equal to 0.46; this value is significant at the significance level 0.01. Even higher correlation (r=0.56) was found between $\delta^{18}O$ and thicknesses of dark (=winter) layers. It is interesting to note the clearly outlying results obtained on sample No. 17 (in the middle of this sequence), which has especially thin couplets and remarkably high value of $\delta^{13}C$.

In the younger sequence of 301 couplets, shown in Fig. 2, no distinct correlation can be found. Only the correlation between $\delta^{13}C$ and varve thickness d (r=0.32) may be regarded as significant, but at relatively low significance level.

Another method of searching for some regularities which may become important in palaeoclimatic interpretation is presented in Figures 3-6, which include data from both sequences. Figure 3 shows relation between $\delta^{18}O$ value and $CaCO_3$ content in both sequences. It should be noted that the results obtained on six samples adjacent to the nonlaminated sandy layer (marked by circles) have relatively low $CaCO_3$ content. Three of them (marked by r) were not included in calculation of the equation of the least squares lines, shown as straight lines in Fig. 3. The relation between $\delta^{18}O$ and $CaCO_3$ content in older sequence (with 2 samples rejected) is described by the equation

$$\delta^{18}O = (-12.53\pm0.66) + (6.90\pm1.12)*10^{-2}*C, \qquad (1)$$

(correlation coefficient r = 0.82, number of data points N=21, residual dispersion s = 0.32), C denotes the $CaCO_3$ content. Corresponding

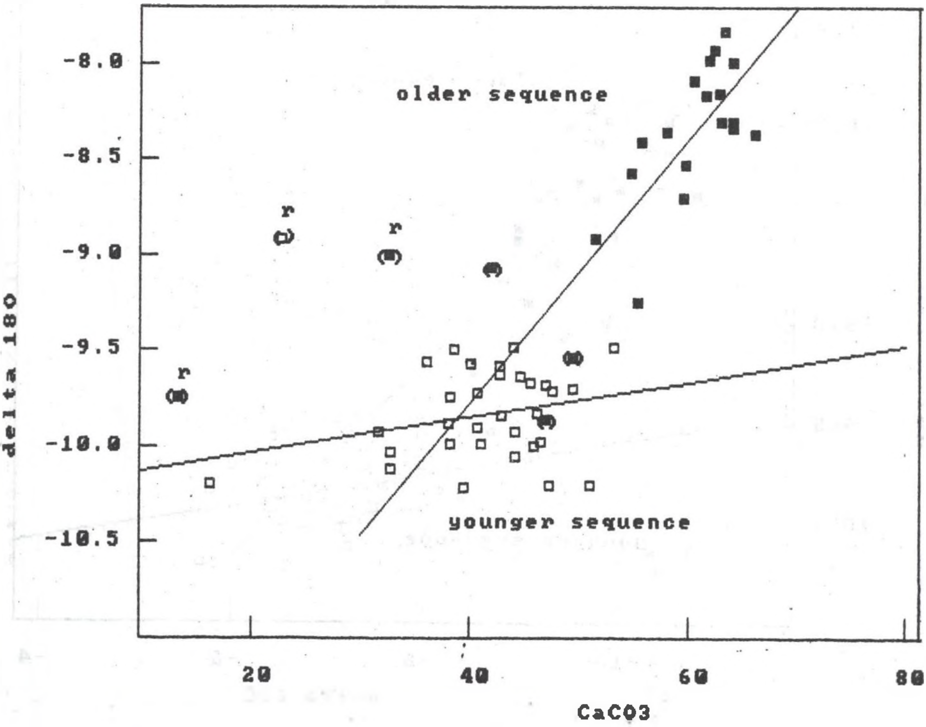

Fig. 3. Plot of $\delta^{18}O$ values in function of $CaCO_3$ content. Results from 5 uppermost samples in the older sequence and 1 lowermost sample from the younger sequence are marked by circles. Data marked with (r) are not included in calculation of the least squares lines.

Rys. 3. Zależność wartości $\delta^{18}O$ od zawartości $CaCO_3$ w próbkach z obu analizowanych sekwencji. W kółkach zaznaczono wyniki uzyskane z 5 najwyżej leżących próbek starszej sekwencji i najniższej próbki młodszej sekwencji. Dane oznaczone literą (r) nie zostały uwzględnione w obliczeniach prostej najmniejszych kwadratów.

relation in the younger sequence (with 1 sample rejected) is given by equation

$$\delta^{18}O = (-10.22\pm0.24)+(0.93\pm0.57)*10^{-2}*C \qquad (2)$$

(r=0.29, N=32, s=0.22). As may be concluded from quoted values of correlation coefficient the relation between $\delta^{18}O$ and $CaCO_3$ content in the older sequence is highly significant, while this observed in the younger sequence cannot be regarded significant. This may be explained by relatively narrow interval of $\delta^{18}O$ values in samples from the younger sequence. Moreover, it is easy to see that data from the younger sequence

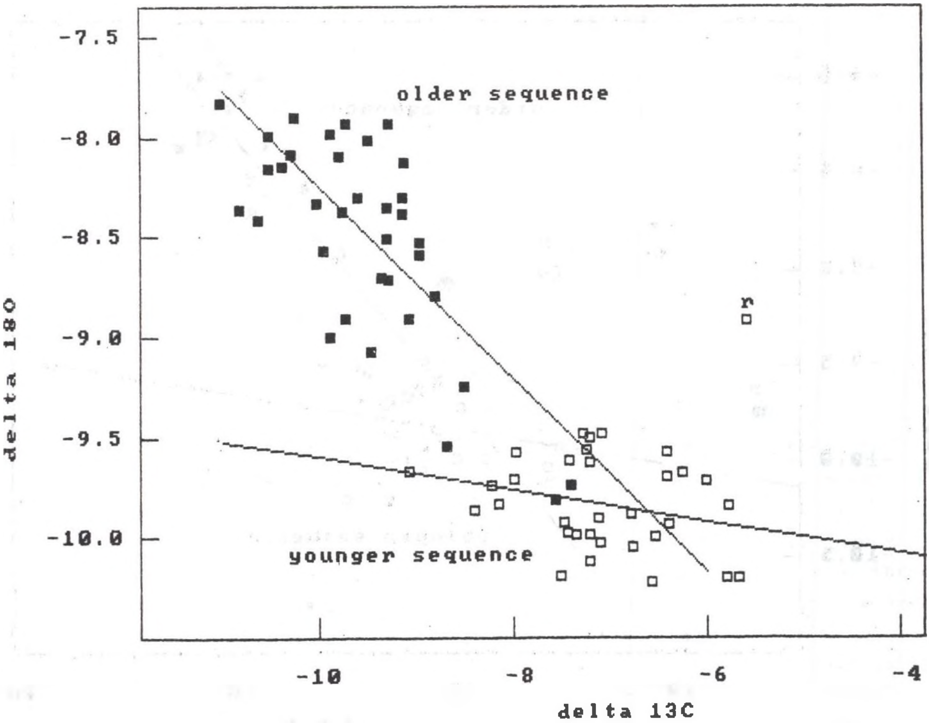

Fig. 4. Plot of $\delta^{18}O$ versus $\delta^{13}C$ in samples of both sequences.

Rys. 4. Zależność $\delta^{18}O$ od $\delta^{13}C$ w próbkach z obu sekwencji.

fit relatively well to the line describing the relation between $\delta^{18}O$ and $CaCO_3$ in the older sequence. The least squares line calculated using data from both sequences has the equation

$$\delta^{18}O = (-12.22\pm0.27)+(6.03\pm0.54)*10^{-2}*C \qquad (3)$$

(r=0.84, N=53, s=0.41), which, within the limits of errors is identical with that obtained on data from the older sequence.

The relation between $\delta^{18}O$ and $\delta^{13}C$ values in both sequences is shown in Fig. 4. In the older sequence the relation is highly significant; the corresponding least squares line has the equation

$$\delta^{18}O = (-13.05\pm0.73) + (-0.48\pm0.08)*\delta^{13}C \qquad (4)$$

(r=-0.74, N=35, s=0.36); the corresponding equation for the younger sequence (after rejecting of clearly outlying result) has the form

$$\delta^{18}O = (-10.40\pm0.35) + (-0.08\pm0.05)*\delta^{13}C. \qquad (5)$$

Value of correlation coefficient, equal to -0.28, indicate that this relation is not significant. However, similarly as in Fig. 3, it is easy

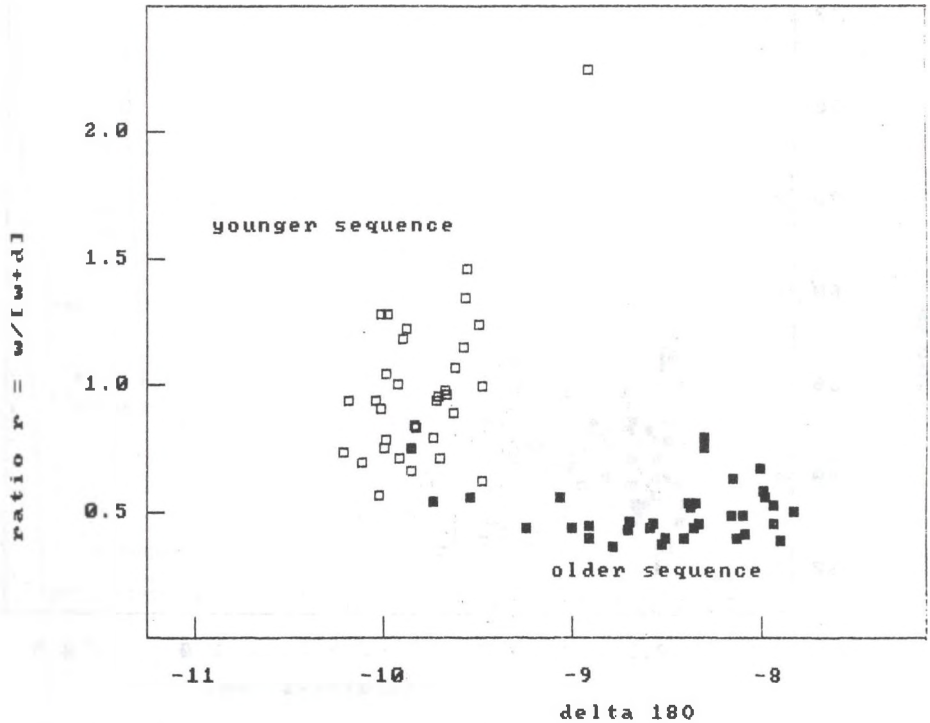

Fig. 5. Average thicknesses of couplets versus $\delta^{18}O$ in both sequences.

Rys. 5. Wartości średnie grubości rocznych przyrostów w funkcji $\delta^{18}O$ w obu sekwencjach.

to see that both groups of data fit relatively well the line obtained from the older sequence. The equation obtained using data of both sequences has the form

$$\delta^{18}O = (-13.07\pm0.27) + (-.047\pm0.03)*\delta^{13}C \qquad (6)$$

(r=-0.88, N=65, s=0.38).

It may be therefore concluded that, in spite of differences in correlation and regression coefficients describing the relations between $\delta^{18}O$, $\delta^{13}C$ and $CaCO_3$ content within each data group, data from both sequences can be regarded as belonging to same population described by Equations (3) and (6).

In Fig. 5 are shown average values of couplet thickness in function of $\delta^{18}O$ in both sequences. As stated above, there is a positive correlation between $\delta^{18}O$ and couplet thickness in the older sequence (after rejecting of 3 uppermost samples from this sequence). Data from younger sequence also show a slight positive correlation. It should be

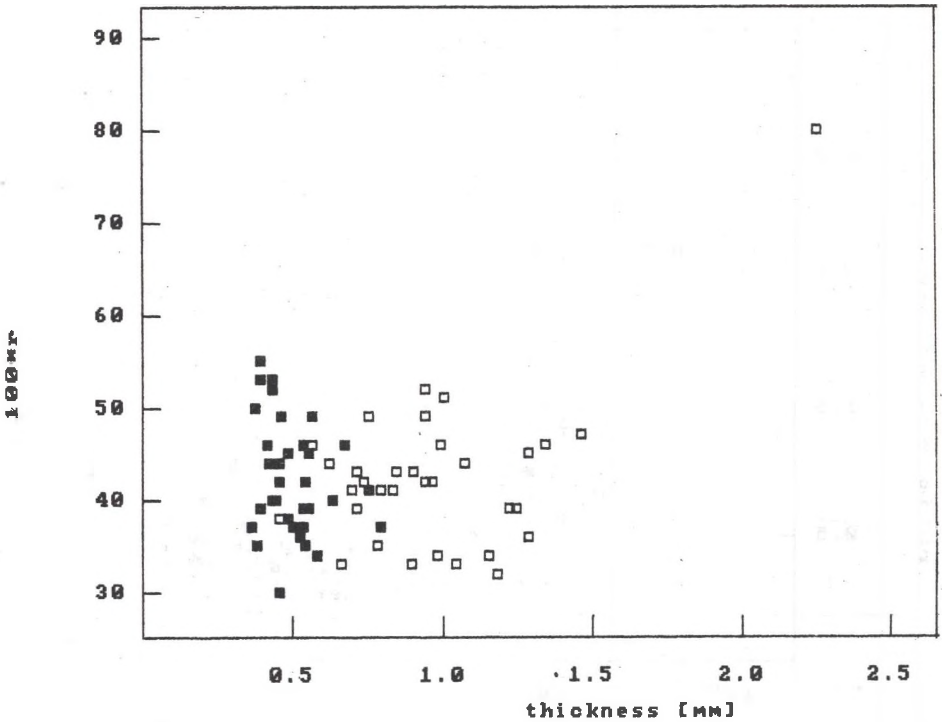

Fig. 6. Average values of ratio of light layer to total couplet thickness in function of mean couplet thickness.

Rys. 6. Wartości średnie stosunku grubości warstwy jasnej do całkowitej grubości rocznego przyrostu w funkcji grubości warstw rocznych.

noted, however, that both groups of data points reveal quite different behavior. The most characteristic pattern is a long and narrow band covered by data from the older sequence. It seems that the very low values of annual increments and their low variability in the older sequence are caused by postdepositional pressure of overlying 0.5m thick sandy layer.

Similar conclusions may be drawn from Fig. 6, which presents relation between ratio of light (summer) layer to the total couplet thickness in function of mean couplet thickness. No distinct correlation can be noted in data of older sequence, while results from the younger sequence reveal some correlation, which, however, has very low significance level.

An attempt to reveal the dependence between $\delta^{18}O$ and varve thicknesses, based on the concept of sequential analysis, is presented in Table 2, where signs of changes of both variables from sample to sample are plotted against sample number. Plus signs (+) denotes that absolute value of $\delta^{18}O$ (or d) in the sample is greater than in the preceding

Table 1

Ranges of variability of measured parameters in two analysed sequences of laminated sediments

Variable	Range in older sequence	Range in younger sequence
CaCO [%]	66.0 ÷ 13.2	46.8 ÷ 31.6
$\delta^{18}O$ [permille]	-7.8 ÷ -9.9	-9.5 ÷ -10.2
$\delta^{13}C$ [permille]	-11.0 ÷ -7.6	-9.1 ÷ -5.8
varve thickness [mm][a]	0.39 ÷ 0.79	0.56 ÷ 1.46[b]

a) average values;
b) maximum thickness of single varve was equal to2.25 mm.

Table 2

Values of sign of successive differences in sequences of absolute values of $\delta^{18}O$ and couplet thickness

Older sequence

$\lvert\delta^{18}O\rvert$	--+-+----++++--+--+++-+-+-+++-++++
d	+++-++---+--++--+-+-+-+-+--++--+-+

Younger sequence

$\lvert\delta^{18}O\rvert$	+-+-+-++++--+-+++-+--+--+-+-+-+--+
d	-+-+-+-+-+-+-+++-+-+++-+--+--++--+

sample. Black squares below mark pairs of samples with the same signs of changes of both variables. In the older sequence simultaneous increase (or decrease) of absolute values of $\delta^{18}O$ and d occurs in 22 samples of total 35. This result may be regarded significant, but at relatively low significance level, equal to 0.1. It should be noted that the result of sequential analysis leads to conclusion that the decrease of $\delta^{18}O$ value occurs simultaneously with increase of mean couplet thickness. This implies negative "differential" correlation between $\delta^{18}O$ and varve thickness - the result which is opposite to positive global correlation of those variables (r=0.46; cf Fig. 5).

At the beginning of the younger sequence of 301 couplets occurs a characterictic interval with periodic variations of couplet thicknesses (with period T = 12 yr). The same feature was found in values of $\delta^{18}O$. This periodicity occurs, however, on a shorter interval, but, in spite of this, we may conclude that within this short interval higher values of $\delta^{18}O$ are associated with more thick couplets.

4. CONCLUSIONS

The results obtained on both sequences are not consistent. This implies that the conditions of sedimentation were slightly different in both periods. According to results of chronological studies (Goslar et al, 1989, this volume) the younger series starts at ca 13,300 sidereal years BP (i.e. ca 12,200 BP in conventional radiocarbon years). The time gap corresponding to sedimentation of nonlaminated sandy layer is difficult to estimate; so it is not possible to place in time the oldest sequence and therefore to explain the differences observed in both sequences in term of differences of some definite climatic or environmental factors. It should be noted also that the two analysed sequences are relatively short, regarding both absolute time span covered by lamination (244 and 301 years, respectively) and number of samples included in analysis (35 and 33, respectively). It may be concluded, therefore, that the intervals of time covered by the analysed sequences are too short to record significant changes of measured parameters, and, moreover, the noise associated with unknown influences of a variety of environmental factors exceeds the real changes. This effect seems to be responsible for very low correlation between $CaCO_3$ content and $\delta^{18}O$ in the younger sequence, where the observed range of $\delta^{18}O$ values is equal to 0.7 permille (see Table 1). Besides of noise there is of course a catastrophic event of deposition of a thick sandy layer, probably responsible for disturbance of the regularity of annual layer thickness in the topmost part of older sequence (cf Fig. 1), as well as for very low range of variability of couplet thickness in this sequence.

COMMENT

by Leszek STARKEL

Detailed analysis of two basal sequences of laminated sediments separated with sandy layer suggest several possible interpretations of changes of sedimentational conditions and climate during considered period of time. In the older sequence of laminated sediment below the sandy layer is observed distinct decrease of $CaCO_3$ content and $\delta^{18}O$ values, characteristic for cooling of climate. Then occurs deposition of 0.5 m thick sandy layer; this episode consists of several separate events. The series of sandy sediments needs detailed sedimentologic investigation in order to determine whether it was deposited by solifluction from the slope of dune, or by surface flow, or, finally, by eolian transport (sandy storms). We do not know how long was duration of this episode (several yeras or several scores years?). Younger sequence of laminated sediments indicate return to equilibrium conditions, however, corresponding to cooler climate, as is indicated by lower $CaCO_3$ content and more negative values of $\delta^{18}O$. Therefore the sandy layer may mark teh beginning of cooling. However, it seems also probable that it corresponds to the phase of warming (Allerod?), associated with melting of dead ice blocks. Lake water becames cooler and the unstable slopes of lake basin were favorable for sandy solifluction.

It may be expected that detailed analysis of both laminated sequences in annual time scale will enable to distinguish the strictly local causes (disturbances of sedimentation) from regional or global climatic trends, which, however, may also reeal the presence of abrupt changes, suggested by Flohn (1984) and other climatologists.

ACKNOWLEDGEMENTS

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REFERENCES

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

Różański K., 1988, The ^{18}O and ^{13}C isotope investigations of carbonate sediments from the Lake Strażym; Acta Palaeobot., vol. 27, p. 277-282.

Różański K., Harmata K., Noryśkiewicz B., Ralska-Jasiewiczowa M., Wcisło D., 1985, Palynological and isotope studies on carbonate sediments from some Polish lakes - Preliminary results; [In:] Internatl Symp. "Swiss lake, mire and river history", 24 June - 1 July 1985, Bern.

Siegenthaler U., Eicher U., 1985, Stable oxygen and carbon isotope analyses; [In:] Berglund B., Ed., Handbook of Holocene Palaeoecology and Palaeohydrology, Wiley, London, p. 407-422.

Stuiver M., 1970, Oxygen and carbon isotope ratios of fresh-water carbonates as climatic indicators; Journ. Geophys. Res., vol. 75, p. 5247-5257.

Recenzent: Prof. dr S. W. Alexandrowicz

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PORÓWNANIE ZMIENNOŚCI ZAWARTOŚCI IZOTOPÓW STABILNYCH ^{18}O I ^{13}C ORAZ GRUBOŚCI ROCZNYCH PRZYROSTÓW W SPĄGOWEJ CZĘŚCI OSADÓW LAMINOWANYCH Z JEZIORA GOŚCIĄŻ

Streszczenie

Wyniki pomiarów grubości rocznych przyrostów oraz wartości $\delta^{18}O$, $\delta^{13}C$ i zawartości $CaCO_3$ w dwóch ciągach próbek ze spągowej części osadów laminowanych z Jez. Gościąż poddano szczegółowej analizie statystycznej w celu znalezienia fenomenologicznych związków pomiędzy tymi zmiennymi, zachodzących w skali czasowej 10-100 lat. Sedymentację warstw rocznych obu badanych sekwencji rozdziela ektremalne zdarzenie depozycji warstwy piaszczystej o półmetrowej miąższości. Wyniki uzyskane z obu sekwencji laminowanych wykazują podobne relacje między wartościami $\delta^{18}O$ i $\delta^{13}C$ oraz $\delta^{18}O$ i zawartością $CaCO_3$. Stwierdzono słabą korelację pomiędzy grubościami rocznych przyrostów a wartościami $\delta^{18}O$, co wydaje się być efektem kompakcji starsze sekwencji osadu laminowanego wskutek nacisku mechanicznego wywartego nadległą warstwą piaszczystą, oraz bardzo małym zakresem zmienności wartości $\delta^{18}O$ w młodszej sekwencji. Istotną korelację wykryto pomiędzy grubościami warstw jasnych (letnich) i ciemnych (zimowych).

СРАВНЕНИЕ ИЗМЕНЧИВОСТИ СОДЕРЖАНИЯ СТАБИЛЬНЫХ ИЗОТОПОВ ^{18}O И ^{13}C И ТОЛЩИНЫ ГОДИЧНЫХ СЛОЕВ В ПРИОСНОВНОЙ ЧАСТИ РАССЛОЕННЫХ ОСАДКОВ ИЗ ОЗЕРА ГОСЦИОНЖ

Резюме

Результаты измерений толщины годичных слоев значений $\delta^{18}O$ и $\delta^{13}C$ и содержания $CaCO_3$ в двух участках слоистых осадков из озера Госционж подвергают детальному статистическому анализу с целью обнаружения феноменологических зависимостей между измеряемыми величинами. Оба исследованных участка проявляют сходные виды взаимосвязи как между $\delta^{18}O$ и $\delta^{13}C$ так и между $\delta^{18}O$ и содержанием $CaCO_3$. Сравнительно низкая корреляция проявляется между толщиной годичных слоев и значениями $\delta^{18}O$.