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A PRELIMINARY STUDY OF PERIODICITIES IN PERCENTAGE CURVES DATED BY POLLEN DENSITY

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SUMMARY

The refined dating technique based on both pollen density and radio-carbon dating proposed by MIDDELDORP (1982) was applied to five curves of a pollen- and macro-remain diagram from a peat section from the Engbertsdijksveen (Vriezeveen, The Netherlands). Percentages curves of *Alnus, Quercus, Corylus,* alkaline soluble humic acids and coarse fraction of peat were then subjected to time series analysis by means of Periodic Regression (BRISKIN et al. 1980). In this way periodicities of approximately 1450, 1000, 800, 600, 500, 350, 200, 145, 85, 40 and possible 22 years could be established with reasonable confidence. Several of these periods seem to correspond to known sunspot cycles (22, 40, 80, 150, 200 and possibly 1000 years).

1. INTRODUCTION

Recently a method was developed in our laboratory, to use pollen density in addition to ^{14}C analysis for the purpose of much more precise dating (MIDDELDORP 1982). The efforts that were put in the development of this method were guided by the possibilities we saw to extract quantitative data of hitherto unachieved type and exactness from the very detailed total analysis of peat bog sections (micro- and macro-remains) at closed 1 or 0.5 cm intervals, realised by VAN GEEL (1972, 1978), VAN GEEL et al. (1980), BAKKER & SMEERDIJK (1981), MIDDELDORP (1984), HOEKSTRA (in prep.) and DUPONT (in prep.). In the meantime the interpretation of Deuterium and $^{16}O/^{18}O$ analysis carried out on these types of peat-sections with the same closed sample intervals, would also gain considerably from such a dating method.

The first application of the new dating method was that of the estimation of average annual net organic production (2 to 50 years averages), over intervals of thousands of years (MIDDELDORP 1982), or of average annual Nitrogen accumulation, etc. (MIDDELDORP 1984).

In the present publication a first attempt is made to apply the dating method to the analysis of possible periodicities or cycles in percentage curves of the above mentioned detailed diagrams (of pollen, spores, macro-remains etc.), with closed 1 cm sample intervals. The importance of this possibility will be evident, as it would enable us to recognize short-term periods or cycles, most probably to be interpreted in terms of climate, that might be of direct importance to recent climatology and meteorology.

2. THE DATA SET USED

For the first attempt five percentage curves were selected from a diagram of the section Engbertsdijksveen Ib (Vriezeveen, prov. Overijssel, The Netherlands), to be published in the near future (HOEKSTRA, in prep.). A closed continuous sample interval of 1 cm was used (samples continuous and 1 cm thick), and pollen densities were established for each sample. The section was ^{14}C dated, and the curve (function) of the relation of pollen density and calender years (according to MIDDELDORP 1982, 1984) calculated, with a polynomial regression. This on its turn enabled us to calculate the number of years each 1 cm sample represented, and the age of any sample of the section.

The percentage curves used are those of *Alnus, Quercus, Corylus*, alkaline soluble humic acids (the last product of decomposition) and the coarse fraction. While the first three curves depend on each other by way of the percentage calculation, the last two are completely independent of the first. The original curves (with the depth of the samples on the vertical axis) are given in *fig. 1*, together with the pollen density curve. Afterwards, with the Middeldorp method, for each 1 cm curves were redrawn converting the vertical axis to represent time in "calendarial years", the distance between the mid-sample points now being determined by the number of calendarial years each sample represents (*fig. 2*).

These data represent approximately 2000 years, covering the time between 940 BC and 960 AD (HOEKSTRA, in prep.).

For the time series analysis, the percentage data of the taxa or fractions were used, together with the above mentioned time distances of all samples (99 data planes).

3. THE TIME SERIES ANALYSIS

The data set represents a series of observations on a variable unequally spaced in time. The standard approaches to time series analyses – classical Fourier analyses and truncated autocovariance functions developed by BLACKMAN & TUKEY (1958) – are incapable of resolving all periodic components actually present in such type of data. Because these methods were developed for series of data that are sampled at equally spaced observations, another approach to time series analysis must be used. The method used in this paper is that of Periodic Regression (see BRISKIN et al. 1980). The results of periodic regression are depicted in a line spectrum comparable to the periodogram of Schuster. In periodic regression, estimates of any discrete wave-form present in a time series are obtained where the observation interval may be non-uniform. The various associated wave forms will sum to the original variance of the time series; and the wave forms, when combined, will be practically undistinguishable from Fourier series representation of a continuous record. So a time series is decomposed into a set of sinusoidal wave forms that have non integer frequencies and which correspond to the actual periodic components which are present in the data.

In this way the time series can be decomposed as follows. Suppose we have

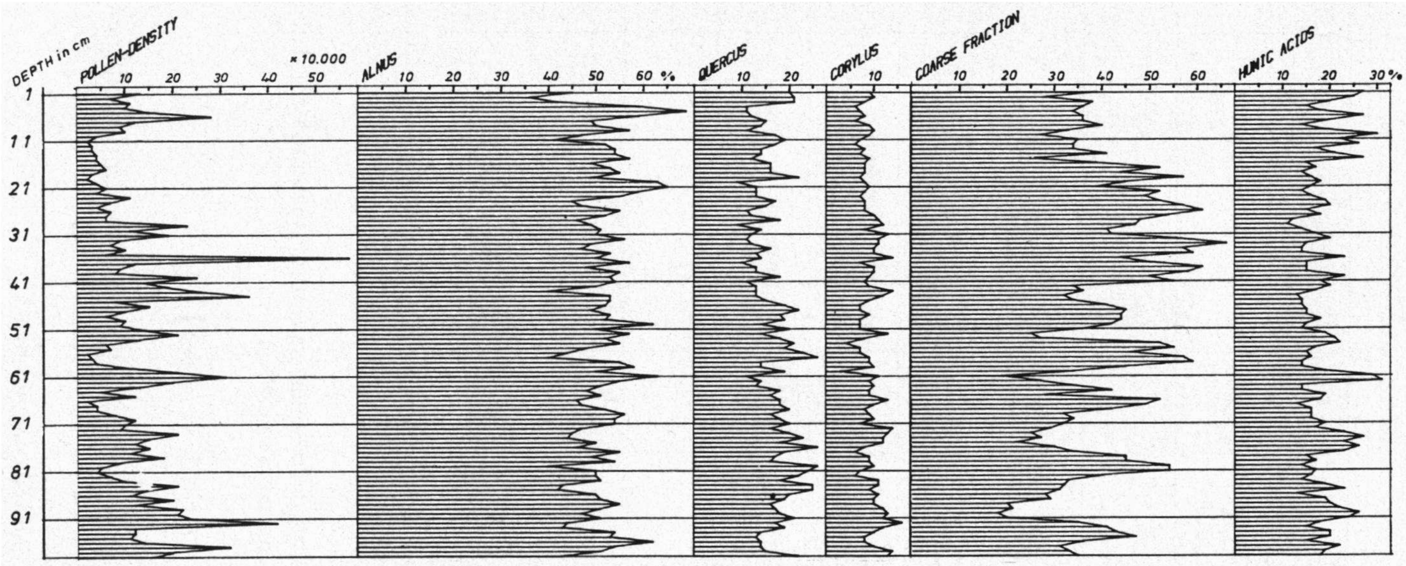

Fig. 1. Original percentage curves (vertical scale in cm) of tree pollen density, *Alnus*, *Quercus*, *Corylus*, coarse fraction (macro-remains) and alkaline soluble humic acids of diagram Engbertsdijksveen 1b, covering the period 940 BC–960 AD (anal. S. Hoekstra).

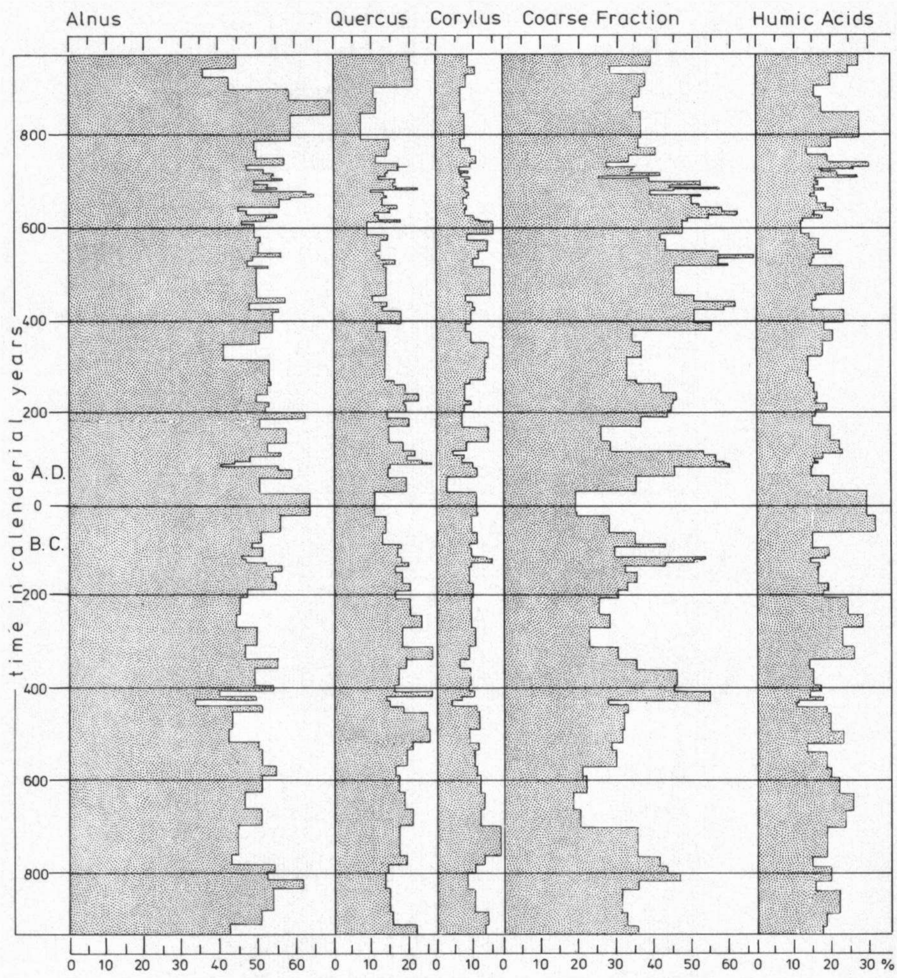

Fig. 2. Curves of *fig. 1*, but vertical scale represents time in calendarial years (calculated according to the Middeldorp dating method).

a number of decomposed sinusoidal wave forms present in our data set. Wave form Y_i can be represented as follows.

$$Y_i = \bar{Y} - A\bar{c} + A\cos\left(\frac{f\,2\pi t(i)}{T} - P\right)$$

where Y_i = the value of Y, the dependent variable, corresponding to the ith. value of time.

$\bar{Y}$ = mean of all Y's

A = amplitude of sinusoid i, in units of Y

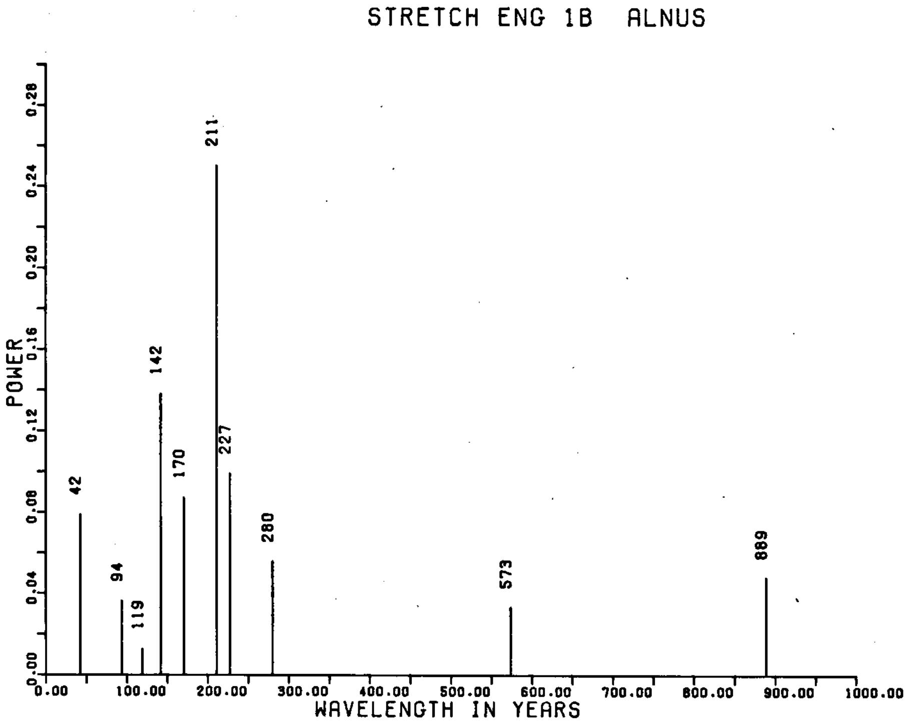

Fig. 3. Periodic regression analysis spectrum of the percentage curve of *Alnus*.

$\bar{c}$ = average value of cos term
f = frequency
P = lateral of set of the sinusoid in units of time
t(i) = the ith value of time, in units of time (i = 1 → N)
T = total length of records in units of time
N = number of paired observations

With the identity K cos (u − v) = K cos(v)cos(u) + K sin(v)sin(u) Y can be rewritten as

$$Y_i = \bar{Y} - A\bar{c} + A \cos P \cos \left(\frac{f2\pi t(i)}{T}\right) + A \sin (P) \sin \left(\frac{f2\pi t(i)}{T}\right)$$

Let $\alpha = A \cos P$, $\beta = A \sin P$ and $I = \bar{Y} - A\bar{c}$

then

$$Y_i = I + \alpha \cos \left(\frac{f2\pi t(i)}{T}\right) + \beta \sin \left(\frac{f2\pi t(i)}{T}\right) \quad (2)$$

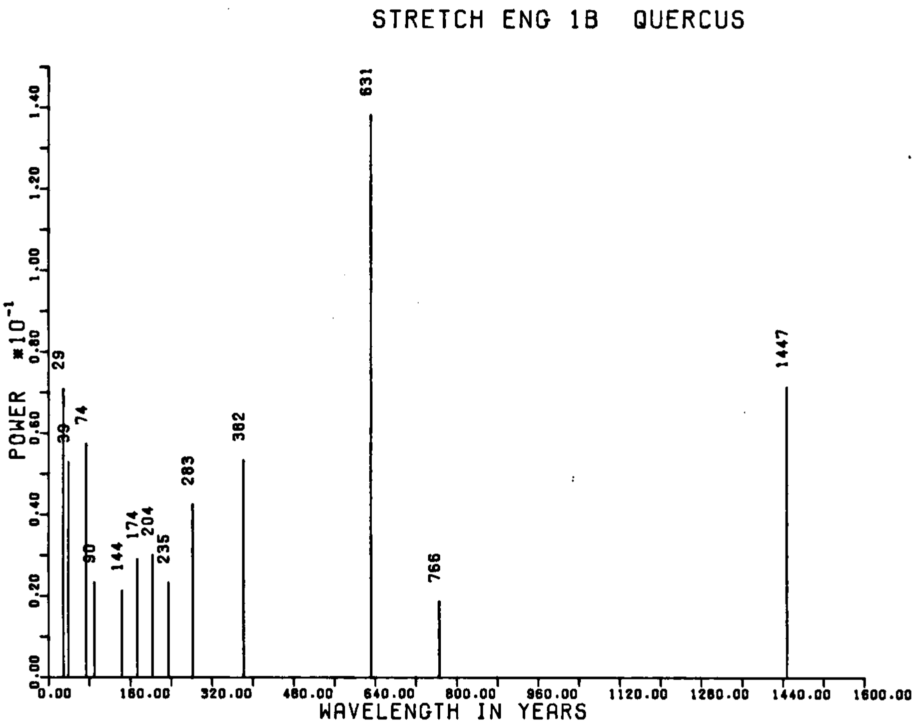

Fig. 4. Periodic regression analysis spectrum of the percentage curve of *Quercus*.

From equation 2 we can now define the regression model

$$Y_i = I_j + \alpha_j \cos\left(\frac{f(j)2\pi t(i)}{T}\right) + \beta \sin\left(\frac{f(j)2\pi t(i)}{T}\right) + \varepsilon$$

when α_j and β_j are the regression coefficient, I_j = intercept term corresponding to the j th. frequency, f_j; Y_i is the value for the i th. term and ε is the residual term. This equation can be solved by multiple regression technique, by least square techniques criteria. In matrix notation the I, α, β, can be solved as follows

$$\begin{bmatrix} I \\ \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} N & \Sigma(c) & \Sigma(s) \\ \Sigma(c) & \Sigma(c^2) & \Sigma(sc) \\ \Sigma(s) & \Sigma(sc) & \Sigma(s^2) \end{bmatrix}^{-1} \cdot \begin{bmatrix} \Sigma(y) \\ \Sigma(yc) \\ \Sigma(ys) \end{bmatrix}$$

The portion of the total variance $s^2(Y)$ of Y_i accounted for by the curve with frequence f_j and corresponding wave length T/f_j is equal to the coefficient of determination R^2_j = the power of frequency f_j. For the analysis of the data sets a program Madi developed by BRISKIN & HERRELL (1980) was used impli-

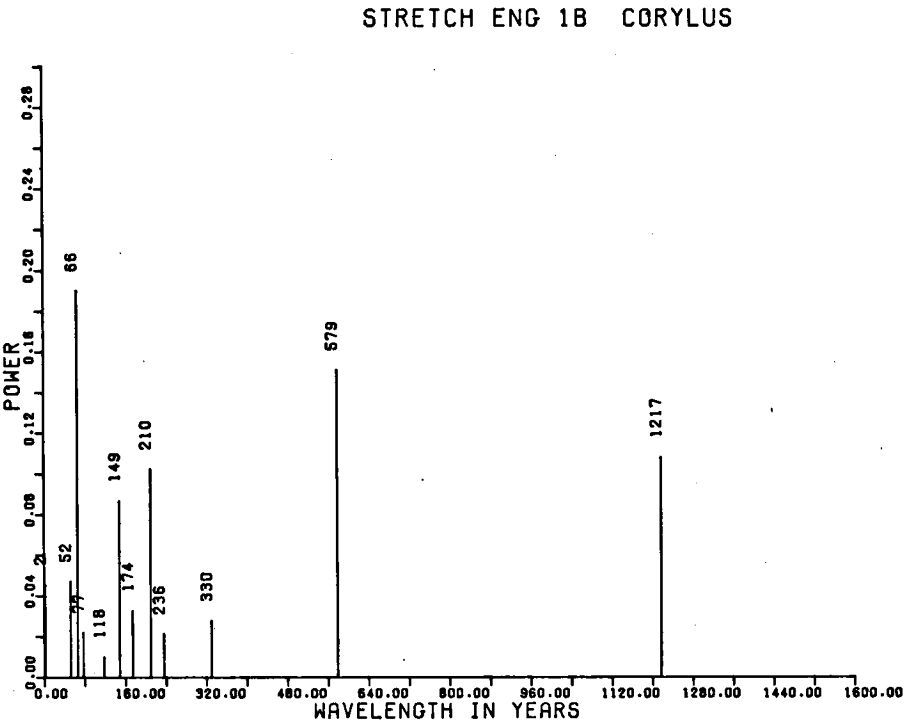

Fig. 5. Periodic regression analysis spectrum of the percentage curve of *Corylus*.

mented for a CDC Cyber 170-750 computer.

The results of the power spectra *figs. 3, 4, 5, 6* and *7* showed a dominating approximately 205 year period in the *Alnus* curve (211), also present in the *Corylus* curve (210), the alkaline soluble humic acids curve (203) and the coarse fraction curve (203). A period of about 145 year is also present in the *Alnus* (142), *Corylus* (149), humic acids (143) and coarse fraction (150) curves. A circa 85 year period is represented in the humic acids (87) and also found in the power spectrum of the pollen density (85; not represented here). A circa 40 year wave length is present in the *Quercus* curve (39) and in the coarse fraction (macroremains) (38). A 22 year period was found in the humic acids curve. Amongst the longer periods a circa 240 year one was found in the humic acid curve (243) and the curve of the coarse fraction (255). A circa 380 year one was noticed in the *Quercus* (382) and a 458 year one in the coarse fraction curve. A period near 600 years was found to be dominating in the *Quercus* curve (621) and the *Corylus* curve (579) and present in the humic acid curve (582). A circa 780 year period is present in the curve of the coarse fraction, a circa 1000 years period in the humic acid curve (1030), and a circa 1450 year period in the *Quercus* (1447), coarse fraction (1361) and humic acids (1469).

The *Quercus* curve shows a strongest power in the 631 year period, *Alnus*

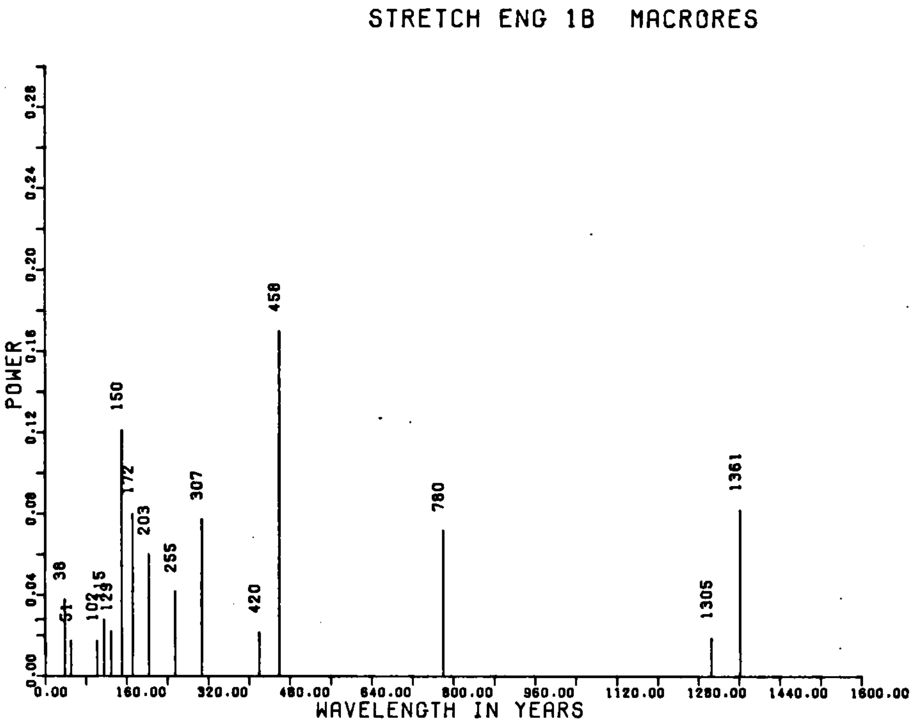

Fig. 6. Periodic regression analysis spectrum of the percentage curve of the coarse fraction (macro-remains) of the peat.

in the 211 year period. *Corylus* in the 66, coarse fraction in the 458 and alkaline soluble humic acids in the 353 year period. In *fig. 8* a histogram is drawn for all wavelengths found in the curves of *Alnus, Quercus, Corylus*, macro-remains and humic acids. This frequency distribution shows maxima at a wavelength in the class intervals between 45–90, 135–225, 315–360, 450–495, 630–675 and 1395–1485.

Taking into account that small differences in time may occur as errors, the following sequence of periods seems to be reasonably represented (approximate numbers): 1450, 1000, 800, 600, 500, 350, 200, 145, 85, 40. Some indication of a circa 22 year wavelength is present in the periodic regression of the humic acid curve. Other periods than those mentioned are present in the power spectra, but they have not been mentioned here when the power in all or most of the spectra was lower than 30%, making an exception for the 22 year period.

4. DISCUSSION AND CONCLUSIONS

The periodicities found in the curves analysed may indicate both periodic increase or decrease in abundance of the taxon, or periodic increase or decrease

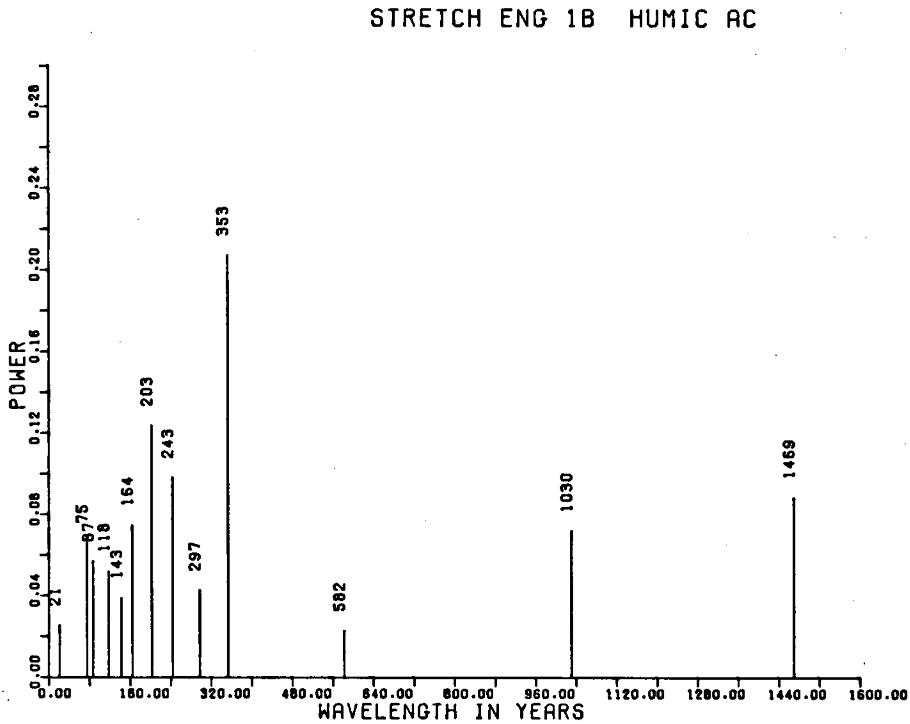

Fig. 7. Periodic regression analysis spectrum of the curve of the alkaline soluble humic acids fraction of the peat.

of pollen production only. The last mentioned possiblity might especially become important in the case of short-term cycles where time becomes very short for replacement, especially in the case of climax-tree like *Quercus*. The known internally determined periodicity in flowering and pollen production of some species, all very short (mostly 2 or 3 years), are left out of consideration here.

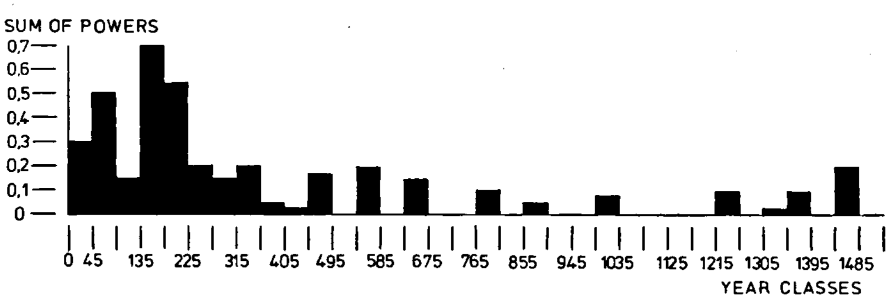

Fig. 8. Bar chart representing distribution of wavelengths found by periodic regression of the interval 0–1500 years. X axis = time divided in intervals of 45 years; Y axis = sum of power per class interval.

It seems, however, most likely that these phenomena, whatever be the case, are caused by changing climatic factors. This seems to be confirmed by the periodicities found in the completely independent coarse fraction curve. The fluctuations of this curve indicate mainly differences in decomposition of the organic material, dependent on humidity of the local bog surface (degree of humidity and annual distribution of humidity, ground water level), that for a good deal should be climatically induced (changes of effective rainfall, determined by precipitation and temperature). From all the above we may conclude that most probably the periodicities of our curves are climatically induced and should therefore reflect mainly climatic periodicites.

A review of existing literature on sunspot cycles (e.g. GLEISBERG 1958; DEWEY 1960; SCHOVE 1967, 1983; EDDY 1976) reveals a sequence of numbers that is very similar to part of that found in our five curves. Sunspot cycles are reported to be c. 11.1, 22, 45, 80, 150, 200, 500 and roughly 1000 years. These numbers are, however, averages over long periods, and shorter periods may give somewhat different averages. SCHOVE (1967) mentions for the 80 year cycle individual numbers between 65 and 90 years and reports that it has an average over 90 for the last 250 years. As the relative length of the observation becomes shorter for the longer cycles, these numbers are increasingly uncertain.

EDDY (1976, 1977) found a close correlation between Maunders sunspot minimum (circa 1650–1700 AD), a maximum of the ^{14}C content of the atmosphere and the winter severety index (taking into account the 40 years necessary to distribute the ^{14}C formed under the influence of solar radiation in the outer atmosphere). Using the fluctuations of ^{14}C content of the atmosphere established by the analysis of tree rings, he estimated the possible fluctuations of solar activity back to 3000 BC. A clear correlation was then found in the winter severety index and temperatures back to approximately 1100 AD and with alpine ice advances in the period 1500 BC to 1000 AD. It is also most obvious that the two sunspot minima/^{14}C maxima correspond nicely with the coldest part of the little ice age (see also CRAWLEY 1983). EDDY came to the conclusion that changes in world climate coincide with long term variations in the activity of the sun. Although this idea was put forward many times on earlier occasions, the coincidence he gives is very clear. STUIVER (1980) documented 120- and 240-year cycles in ^{14}C production rates and further analysis may show the existence of longer ones.

Although further analysis of curves dated by pollen density and of e.g. ^{14}C curves is necessary, we may conclude, for the time being, that the first results sofar obtained are very encouraging, showing periodicities partly coinciding with or very near to the known sunsport cycles: 22, 45, 80, 200, 500 and 1000 years and one possibly with one of the Stuivers ^{14}C cycles. It may be mentioned here that WIJMSTRA et al. (1971) suggested already, that a 80 year period seemed to be present in an *Alnus* curve of the Wietmarscher Moor and VAN GEEL (1978) supposed the presence of a 150–200 year cycle in the *Corylus* curve in his diagram. The results of the present analysis made possibly by the Middeldorp dating method, seems to open a whole new area for future palaeoecological-palaeoclimatological research, that may become of considerable importance for meteorology and long term weather forcasting. For this purpose the translation of the periodicities in climatic parameters seems to be the next goal; we hope that the work on Deuterium analysis of organic matter in relation to peat bog vegetation and climate that is now being carried out by DUPONT (in prep.) and studies on the changes of the humidity in peat bogs and peat bog sections will give the clue to this translation.

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