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HIGH-RESOLUTION ^{14}C DATING OF ORGANIC DEPOSITS USING NATURAL ATMOSPHERIC ^{14}C VARIATIONS

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ABSTRACT. The occurrence of atmospheric ^{14}C variations complicates calibration, *ie*, the translation of ^{14}C ages into real calendar ages. The procedure of wiggle matching, however, allows very precise calibration, by matching known ^{14}C variations with wiggles in the floating chronology. In principle, wiggle matching can also be applied to a series of ^{14}C dates from organic (peat) deposits. Where, in general, ^{14}C ages are required at short distances and on small samples, dating by ^{14}C accelerator mass spectrometry (AMS) is required.

INTRODUCTION

Variations in the $^{14}C/^{12}C$ ratio of CO_2 in the atmosphere are well established. Possible causes for the fluctuations were mentioned by Damon, Lerman & Long (1978). Medium-term atmospheric variations are evident from measurements of tree rings (Suess, 1970; de Jong, 1981; Klein *et al,* 1982; Becker, 1983). The so-called Suess wiggles are evident when conventional ^{14}C ages of tree rings are plotted *vs* tree-ring number (each tree ring representing one year). Pronounced wiggles may amount to changes in conventional ^{14}C ages of 120–180 yr within a historical period of 40–50 yr.

Presently, computer programs exist to transfer individual conventional ^{14}C ages into real calendar ages, using the known calibration curves. However, because of the irregular shape of these curves, the Gaussian distribution of an individual date of organic material ofter corresponds to a rather irregular real calendar age probability distribution, which in some cases encompasses a relatively long period (van der Plicht, Mook & Hasper, 1987). By using a series of ^{14}C ages of stratigraphically consecutive samples, we can, however, obtain a much better age assignment of a profile.

Overlapping chronologies can be matched using the method of wiggle matching (Ferguson, Huber & Suess, 1966) because separate wiggles often show particular and individual features. For curve matching, both sets must contain sufficient dates. In order to avoid ambiguity in the wiggle match, the peat section must be long enough to cover more than merely one wiggle. The matching procedure can in principle be done by computer.

The European Hohenheim master chronology is extended back to 7237 BC (Becker & Schmidt, in press) and the North American bristlecone pine chronology is extended back to 6700 BC (Ferguson & Graybill, 1983).

WIGGLE MATCHING IN ORGANIC DEPOSITS

The variations of atmospheric ^{14}C of the past that are reflected in the wiggles of the tree-ring calibration curves will certainly also be present in the organic material of lake sediments and bog deposits. Bioturbation, contamination and reservoir effect (Olsson, 1986) may have smoothed or disturbed the original fluctuations, but in most sites selected for detailed palynological studies, these phenomena will not have played an important role.

In raised bog deposits (*Sphagnum* bogs) or other deposits with similar high accumulation rates (Aaby, 1986), high-resolution dating combined with wiggle matching may be successful. The application of tandem accelerators used as ^{14}C mass spectrometers allows ^{14}C dating of very small samples so that (non-aquatic) plant remains such as mosses, fruits and seeds can be selected at very short vertical distances (*eg*, a sample in every 2 or 3mm of sediment). In that way, contamination by (younger) roots can be totally avoided and an optimal correspondence of the date with the pollen spectrum can be achieved.

Following this strategy, the uncertainties of separate ^{14}C dates due to the natural atmospheric variations can be avoided and the disadvantage of these variations can be turned into an advantage: a more exact orientation in calendar ages of a stratigraphic sequence becomes possible. Application of "pollen density dating" (Middeldorp, 1982) in the same sediment sequence can provide an extra check on changes in the sediment accumulation rate.

Carbonate of relatively old age in lake deposits can be excluded from the sample by using fossil pollen for ^{14}C dating (preparation according to Faegri & Iversen (1975) using noncontaminating chemicals and ending the procedure with pollen in distilled water). In Holocene lake deposits, this pollen often is almost completely of non-aquatic origin (trees and herbaceous plants of upland sites). The application of ultrasonic filtration (Caratini, 1980; Tomlinson, 1984) on a 10μm sieve can be useful in eliminating fine organic particles from the pollen samples.

In the same way, pollen of subsequent layers in soils can be used for dating to avoid contamination by decomposed younger roots and fine vertically transported organic material. ^{14}C wiggle reconstruction cannot be used in soil studies because of the low time resolution and mixing as a consequence of the mobility of the various chemical fractions, and of activities of the soil fauna. The method outlined here may be useful to pinpoint with high precision floating chronologies in annually laminated sediments (Saarnisto, 1986; Ralska-Jasiewiczowa, Wicik & Wieckowski, 1987), especially when pollen can be used for dating. Even the possible presence of hiatuses may be studied (wiggles or part of one wiggle may be missing). In case of laminated sediments with questionable annual lamination, the present technique may also be of practical value.

DISCUSSION

The possibilities for the proposed high-resolution dating (recognition of Suess wiggles in sediments and curve matching with the dendro-calibration curve) depend on sediment accumulation rates. Apart from the demands related to little mixing during the formation of the deposit, there is also the need for minimal time resolution for each ^{14}C sample in a continuous series. In order to recognize separate Suess wiggles with individual characteristics, each sediment or peat sample should represent $\leq$ca 25 yr.

Peat accumulation rates in NW European bogs were calculated by Aaby and Tauber (1975). The mean rates vary between ca 0.2 and 0.9mm/yr, with a tendency for younger peat layers to higher accumulation rates (up to 1.8mm/yr) as a consequence of diminished autocompaction in the upper layers. Thus, for a successful application of wiggle matching, we should aim for ^{14}C dating 5–10mm of peat.

For matching a "floating" peat chronology with the calibration curve, wiggles are not always required. If the conventional ^{14}C age period is limited to a steep part of the calibration curve, matching is straightforward and requires 3–4 stratigraphically consecutive samples. An example is shown in Figure 1. Assuming constant peat growth, *ie,* a linear relation between sample depth and time, a series of ^{14}C ages (four in our example) may be stretched and shifted in real time (horizontally) to match the calibration curve.

If, however, the ^{14}C age range obtained coincides with a relatively horizontal part of the calibration curves, or extends over a long period of which only part of the calibration curve is steep—which is generally the case—we depend entirely on the occurrence of wiggles in this part. In these cases, more ^{14}C age determinations over a longer time period are required. At present, computer programs exist for determining the best (wiggle) match between the calibration data and a floating tree-ring chronology (Pearson,

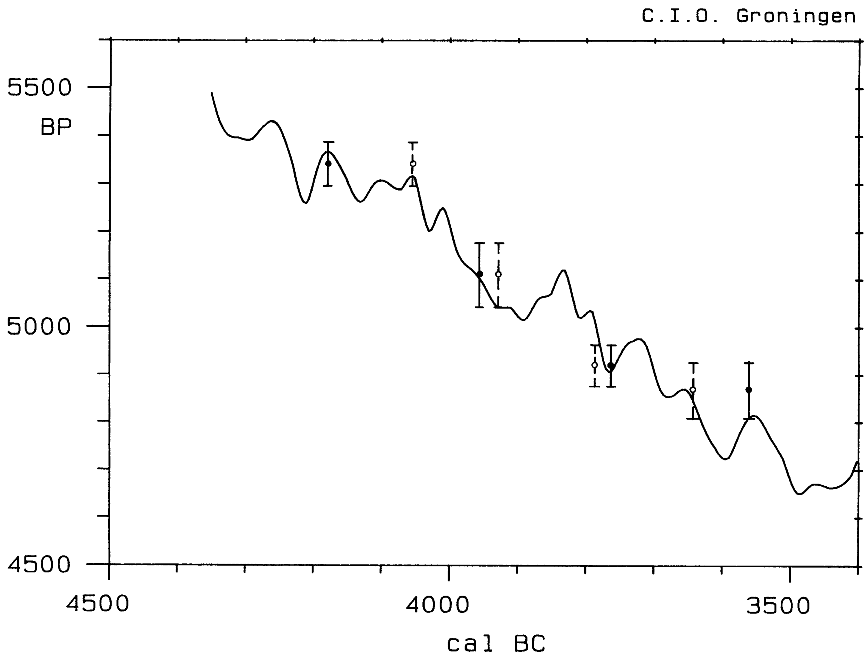

Fig 1. Part of the calibration curve based on the data of Pearson *et al* (1986). A series of ^{14}C ages from a peat section (subm by M O'Connell, Univ College, Galway, Ireland) from Loch Sheeauns is fitted for two different (constant) growth rates: filled circles refer to small peat accumulation. The relative position on the horizontal scale is proportional to sample depth.

1986), in which case, however, the growth period is known. In dating peat or lake deposits of unknown accumulation rates, this method cannot be applied simply.

There is one additional complication in wiggle matching organic deposits as compared to tree rings, for which the year-to-year true-age distribution is known, although absolute ages are not (floating chronology). For organic deposits, the sedimentation rate is unknown. Thus, computer matching should also make the proper adjustment for this. With constant accumulation rate, the real-age *vs* depth relationship is proportional, however, with an unknown proportionality constant. This amounts to stretching the calendar age chronology of the stratigraphical sequence until a best fit is obtained (Fig 1). This option will be inserted in the Groningen fitting program. With varying rates, matching becomes more complicated and additional information is required, *eg,* from variations in pollen concentration (Middeldorp, 1982).

The large number of dates (several wiggles have to be recorded) makes the method very expensive so that careful selection of deposits is necessary. In combination with high-resolution pollen analysis and the study of macrofossils, the estimation of the approximate duration (in calendar years) of the recorded vegetational and climatic changes can be improved.

The combination of detailed studies of raised bog and lake deposits with the above-mentioned high-resolution dating may lead to detecting a direct relationship between ^{14}C variations and short-term climatic fluctuations caused by solar and/or geomagnetic variations recorded in lake or bog ecosystems. Fluctuations in the concentrations of ^{14}C may help explain the very palaeoclimatic events to which ^{14}C dating has been applied. Using this dating strategy, it will be possible to compare, with maximal precision, the detailed palaeoecological and partly palaeoclimatic reconstructions based on raised bog studies (Middeldorp, 1982; Aaby, 1975; Barber, 1981; van Geel, 1978; Dupont, 1986) and densitometric and isotope (dendro) climatic reconstructions (Dupont & Mook, 1987; Bradley, 1985). Even cyclic climatic effects related to the causes of the ^{14}C wiggles may be recorded and subsequently interpreted in organic deposits.

For the application of the present idea, it would be useful to identify each wiggle in the tree-ring calibration curve by an identification number (*cf* the stages in the isotope curves from oceanic records (Emiliani, 1955)).

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