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FREQUENCY DISTRIBUTION OF ^{14}C DATES FROM POLAND IN THE TIME INTERVAL 12-45 KYR BP AND ITS PALEOGEOGRAPHICAL IMPLICATIONS

Summary: Analysis of the frequency of ^{14}C dates from the territory of Poland in the time interval from 45 to 12 kyr BP is based on a set of 193 samples. Two main chronostratigraphic boundaries can be distinguished in the considered period of time in the obtained histogram of ^{14}C dates, namely at 21 and 15 kyr BP. Time period betwen 21 and 15 kyr BP may be characterized as highly unfavourable for vegetation, though with remarkable differentiation in both space and time. Some second order features are also discussed and compared with other evidence.

1. INTRODUCTION

An analysis of the frequency distribution of ^{14}C-dated samples in a time scale has been carried out in recent years for several selected geographic regions (Geyh, 1969; 1971; Geyh, Rhode, 1972; Geyh, Jäkel, 1974). Distinct correlation was noted between observed frequency of ^{14}C dates and variations of specific geological features controlled by climatic changes. The ^{14}C dating method, which was primarily used simply to determine the absolute age of sediment containing dated samples, becames therefore an important source of information on the course of some geologic processes in the past.

For Poland such a study was performed in a relatively small time interval of the Late Glacial (Pazdur, Pazdur, 1966). The set of ^{14}C dates older than 12,000 yr BP gathered till now consists of more than 200 and is, in our opinion, sufficiently large and representative to justify an attempt to ascertain some general regularities of the resulting frequency distribution of those dates. Conclusions which may be drawn are of general character. It could be expected, however, that with increasing number of dated samples in this time interval also the second order variations in the frequency distribution will become significant and will lead therefore to more detailed conclusions.

2. ASSUMPTIONS

An interpretation of the frequency distribution of ^{14}C dates is based on two fundamental assumptions:

1. The number of ^{14}C-dated samples is proportional to the total amount of organic matter in sediments deposited in considered time interval,
2. Total amount of organic matter deposited in a given interval of time depends on paleogeographical conditions, with dominating influence of climatic conditions during this period. Significant changes in the amount of deposited organic matter occurs at time boundaries marking distinct amelioration or deterioration of climatic conditions. It should be noted that transition from favourable to unfavourable conditions may be caused by appropriate change of one of two fundamental climatic factors: either temperature or humidity.

The above assumptions, which are in general agreement with those made by Geyh and Rhode (1972), enable us to interpret the observed changes in the frequency distribution in terms related to the evolution of paleoclimate in strictly determined time intervals.

The accuracy of climatic interpretation of the fréquency distribution of ^{14}C dates is limited by a number of factors of various origin, which, in general, may be grouped in two classes.

1. Factors connected with nature of dated organic matter

A. Depletion of initial radiocarbon concentration

Deposited organic matter may have lower mean ^{14}C concentration than corresponding ^{14}C concentration in land vegetation and atmospheric CO_2 because of:

a) admixture of older organic remnants (for example presence of wind-blown organic dust)

b) presence of ^{14}C-free old carbonates.

Both factors lead to erroneously older ^{14}C dates, but for ^{14}C dates older ca 20 kyr BP those effects seem to be insignificant.

B. Contamination with younger organic matter

Organic deposits may be contaminated with younger (Holocene) carbon by infiltration of water containing dissolved organic compounds of high ^{14}C activity or by penetraton of rootlets or small animals. Though contamination with old carbon is also possible, the admixture of younger carbon seems to be the main source of erroneous ^{14}C dates, especially for dates older than 30-40 kyr BP.

C. Destruction of organic deposits

Intensive erosion in some periods may lead to destruction of fossil or subsynchroneous organic layer.

D. Technical reasons

Older ^{14}C dates are subjected to greater dating errors because of purely statistical reasons. This causes serious differences in the shape of resulting histogram; in the time interval 15-20 kyr BP dating errors are of order of several hundreds years, while for samples older than 30-40 kyr BP errors are commonly greater than 1-2 kyr.

2. Factors connected with sampling

A. Decreasing availability of older deposits

Younger deposits, which as a rule lie near the present surface, are more frequently met in field studies than the older ones, which are less frequently found in outcrops and also in boreholes. This leads to obvious tendency of decreasing frequency of ^{14}C dates with increasing age, which should be taken into account.

B. Subjective causes

a) Samples for ^{14}C dating are frequently collected only from selected horizons (or beds) which are of special interest from the point of view of investigator, or from levels of questionable or doubtful age. This practice seems to be a general rule in studies of outcrops or cores rich in organic deposits; because of economic reasons (limited funds for dating) only very limited number of organic layers can be dated.

b) Frequently field studies are focused on a specific small regions or even single sites. This may cause serious distorsion of obtained frequency distribution because of dominating presence of local effects.

3. FREQUENCY DISTRIBUTION OF ^{14}C DATES

3.1. Analyzed material

Present analysis is based on a set of all ^{14}C dates older than 12 kyr BP from the territory of Poland, gathered till the end of 1986. "Infinite" dates, i.e. those reported in form "age greater than ..." are not included. In practice this means that the considered time interval ranges from 12 to 45 kyr BP. Total number of such ^{14}C dates is equal to 198; five dates were rejected before further processing because of their obvious rejuvenation. Two of them were obtained on peaty muds from

Cracow-Nowa Huta site (Mamakowa, Środoń, 1977) and were questioned by several authors (cf Mojski, 1985), one was obtained on organic mud from site Smerek III (Ralska-Jasiewiczowa, 1980), and the last two were from outermost part of mollusc shells (Gliwice Radiocarbon Laboratory, unpublished data).

There are in general three main sources of information on ^{14}C dates: 1) Gliwice Radiocarbon Laboratory data bank (only dates from this laboratory); 2) published date lists from Łódź Radiocarbon Laboratory (Kanwiszer, Trzeciak, 1981), supplemented by personal communication to the first author; 3) published register of ^{14}C dates from southern Poland (Gradowski, Nalepka, 1984a,b; 1985). The first two sources are reliable and complete; this means that all dates produced by ^{14}C laboratories in Łódź and Gliwice are included in the analysed set. The third source seems to be incomplete because it does not contain unpublished ^{14}C dates, and, moreover, it is restricted to relatively small part of southern Poland. Therefore, to make the analysed set of dates more complete and representative, the authors have attempted to search through available sources, including interviews with numerous persons engaged in Quaternary studies in Poland.

Table 1

Distribution of ^{14}C dates versus dating laboratory

Laboratory	Lab. code	Number of samples	o/o
Gliwice	Gd	128	64.65
Łódź	Lod	26	13.13
Hannover	Hv	23	11.62
Groningen	GrN	4	2.02
Lyon	Ly	9	4.55
Lund	Lu	2	1.01
Louvain	Lv	2	1.01
Birmingham	Birm	2	1.01
Kopenhagen	K	1	0.50
Waterloo	WAT	1	0.50

The distribution of analysed set versus ^{14}C dating laboratory is shown in Table 1. Detailed list of ^{14}C dates is not included; the readers should refer to published date lists and other references quoted above. Analysed set of dates has been subdivided into 10 groups according to type of dated organic material. The groups are listed in Table 2 with corresponding numbers of samples in each group. The most numerous group includes 91 samples of peat; it should be noted that in this group were included also samples designated by the submitters as "peaty silts" or "peaty muds". In the groups of "muds" are included samples designated as

Table 2

Distribution of ^{14}C dates versus dated organic material

Type of dated organic material	Number of samples	0/0
wood	21	10.88
peat	91	47.15
mud	37	19.17
bone	16	8.29
humus	8	4.15
charcoal	8	4.15
detritus	4	2.07
gyttja	4	2.07
shell	2	1.04
speleothem	2	1.04

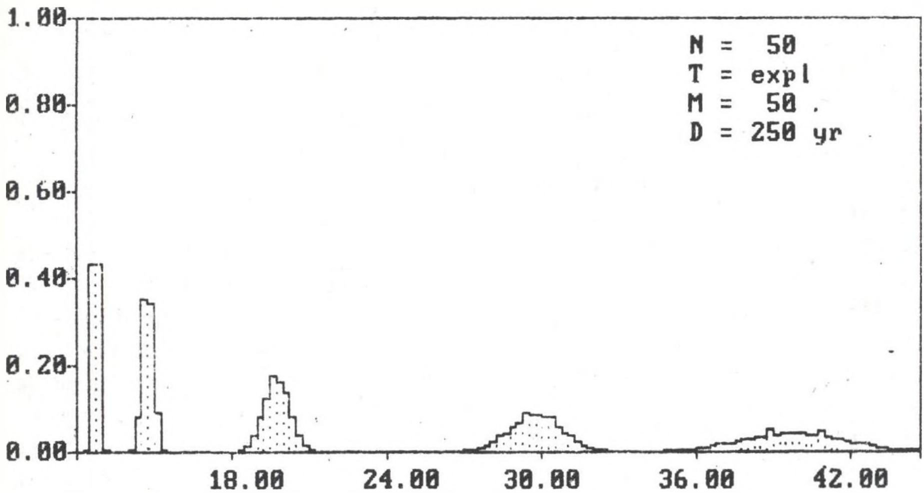

Fig. 1. An illustration of the method of construction of the frequency distribution of ^{14}C dates. Each peak represents 10 identical ^{14}C dates. Horizontal and vertical scales are the same as in Figs. 2, 3 and 4. A - 13,000±100; B - 15,000±200; C - 20,000±500; D - 30,000±1,000; E - 40,000±2,000

Rys. 1. Ilustracja metody tworzenia rozkładu częstości dat ^{14}C. Każde z maksimów przedstawia wynik złożenia 10 identycznych dat. Skale pionowa i pozioma są identyczne jak na rysunkach 2, 3 i 4. A - 13,000±100; B - 15,000±200; C - 20,000±500; D - 30,000±1,000; E - 40,000±2,000 "organic muds" of various origin.

3.2. Methods

In order to obtain final distribution of the frequency of ^{14}C dates each individual date was represented in form of histogram in time intervals equal to 250 yr. The height of single-date histogram was calculated by numerical integration of the initial Gaussian probability distribution N(T, ΔT) in the time interval from T-4ΔT to T+4ΔT. Resulting final histogram was then obtained by summing the heights of individual histograms of all considered dates obtained on samples of given selected type. All histograms were finally normalized and are presented in the same scale. An illustrative example is presented in Fig. 1, where five "individual" histograms representing ^{14}C dates with dating errors typical for considered time intervals are shown. Each "single date" histogram in Fig. 1 represents 10 identical ^{14}C dates, equal respectively to: 13,000±100; 15,000±200; 20,000±500; 30,000±1,000; and 40,000±2,000 yr BP. The readers should note distinct smoothing of presented histograms with increasing age.

4. RESULTS AND DISCUSSION

Resulting histogram, representing frequency distribution of all ^{14}C dates is shown in Fig. 2. Maximum height of this histogram was used to normalize all other histograms, shown in Figs 1, 3 and 4. Obtained distribution in the whole time interval from 45 to 12 kyr BP reveals distinct general trend of increasing frequency of dated samples towards the present day, continued in the next time interval, i.e. from 12 to 10 kyr BP (Pazdur, Pazdur, 1986). This tendency is caused by factors discussed above (section 2, causes 1d and 2a), but, in spite of this, in the last several thousands years of the considered time interval (from 15 to 12 kyr BP) it is obviously correlated with main trend of climatic changes. At the oldest part of histogram (45-35 kyr BP) deviations of the observed frequency from the general trend may be regarded insignificant. This smoothing, however, cannot be interpreted as the lack of distinct climatic fluctuations during this time interval because of two reasons of purely technical nature: 1) low accuracy of ^{14}C dates in this time interval causes broadening of single-date histograms (see Fig. 1), and 2) it should be expected that some dates from this time interval were reported in form of "infinite" ^{14}C dates, and in consequence are not included in histogram. Moreover, the total number of samples from this period of time seems to bo too low to show such fluctuations.

4.1. General features

Considering distinct differentiation of the histogram shown in Fig. 2 we are able to distinguish three main intervals with quite different

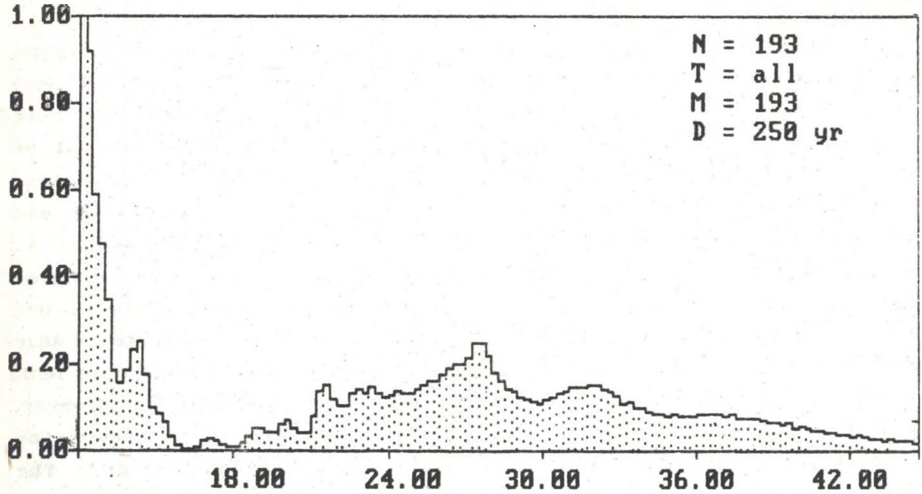

Fig. 2. Frequency distribution of all ^{14}C dates from Poland (only "finite" dates are included). N - total number of dates (193); T - type of dated organic material; M - number of dates of type T included in histogram; D - time step of histogram

Rys. 2. Rozkład częstości dat ^{14}C z uwzględnieniem wszystkich datowanych próbek z terenu Polski. N - całkowita liczebność analizowanego zbioru (193); T - typ datowanego materiału organicznego; M - liczba próbek typu T uwzględniona przy konstrukcji histogramu; D - skok histogramu

features. First interval, ranging from 45 to ca 21 kyr BP, is characterized by long periods when observed frequency approximately coincides with the general trend and relatively short periods with distinctly increased frequency of ^{14}C dates. It may be therefore concluded that climatic conditions during this time interval were approximately same with slight periodical ameliorations. Second interval, ranging from ca 21 to 15 kyr BP, can be characterized by distinct decrease of the frequency of dated samples, especially in shorter interval (20-15 kyr BP), where the observed frequency is close to zero. Rapid increase of the frequency of dated samples is a dominating feature of the third interval. This trend is continued in the following period of time (10-12 kyr BP; Pazdur, Pazdur, 1986). Detailed discussion of those main periond of time is presented in the following sections.

4.2. 45-21 kyr BP

This period, except of its younger part, coincides with the classical chronostratigraphic unit distinguished by van der Hammen et al (1967) as Middle Pleniglacial (interpleniglacial). Boundary between this unit and the following one (Upper Pleniglacial) coincides with the end of Denekamp Interstadial, dated by mentioned authors to ca 29 kyr BP. Subdivision proposed by van der Hammen et al (1967) twenty years before was accepted by most European authors. It should be remembered, however, that in the opinion of mentioned Dutch authors the period of Upper Pleniglacial corresponds to especially severe climatic condition of frosty desert. Consequently, their decision to set up the boundary between Middle and Upper Pleniglacial at 29 kyr BP has been justified by complete lack of organic deposits in time interval between 26 and 13 kyr BP. However, recent studies (i.e. Kolstrup, 1980; Vanderberghe, 1981) have proved the occurence of organic deposits of this age in Belgium and Netherlands. The arguments of van der Hammen et al (1967) are not valid in light of present day evidence. As can be easily seen from the histogram presented in Fig. 2, an abrupt fall of the frequency of dated samples occurs in Poland at ca 21 kyr BP. Similar analysis of ^{14}C dates from West and Middle Europe, performed by Geyh and Rhode (1972), has led those authors to the conclusion that the lower boundary of the coolest period should be placed at ca 20 kyr BP. It should be pointed out that most datings from Poland were not included in this study. Actually available set of ^{14}C dates close to 20-22 kyr BP is sufficiently large to confirm this conclusion. Moreover, most of these dates were obtained on organic deposits directly related to the marginal zone of the maximum extent of Vistulian ice sheet (cf Cepek, 1965; Krasnov, 1978; Pazdur et al, 1980). Also the evidence presented by Berglund and Lagerlund (1981) indicates that Scania was not covered with ice sheet before 21 kyr BP. All these arguments lead us to the conclusion that the boundary at 21 kyr BP seems to be of primary importance in chronostratigraphic subdivision of the Central European Pleniglacial.

Three peaks can be seen in the frequency distribution of ^{14}C dates (Fig. 2) in the considered interval of time, with especially prominent peak at ca 27,500 yr BP and two less pronounced peaks at ca 32 kyr BP and at ca 22 kyr BP. First peak (32 kyr BP) coincides with the beginning of Denekamp Interstadial, while the second one is younger than the corresponding closing date of this interstadial. Better analogy with the chronostratigraphic subdivision of considered part of Vistulian can be found on diagram of Geyh and Rhode (1972), where two distinct peaks occur at 31 and 29.5 kyr BP, i.e. within the time limits of Denekamp Interstadial. It should be noted, however, that a less pronounced peak can also be seen in this diagram at ca 26.5 kyr BP. Because in the construction of diagram of

Geyh and Rhode (1972) only ^{14}C dates of wood and peat were included, direct comparison should be made with corresponding histogram from Poland, shown in Fig. 3. Both compared histograms show distinct peaks at ca 22 kyr BP, which may be connected with slight amelioration of climatic conditions immediately preceding the period of the most severe climate in

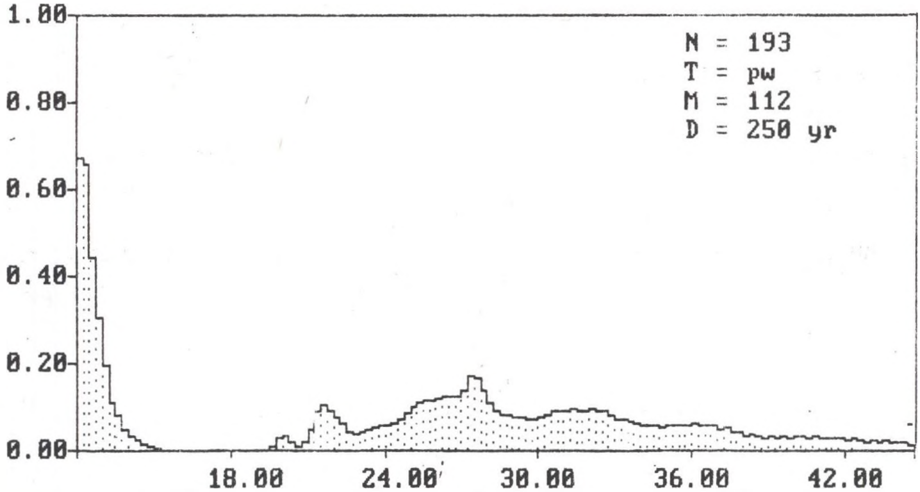

Fig. 3. Frequency distribution of ^{14}C dates obtained on samples of peat and wood

Rys. 3. Rozkład częstości dat ^{14}C uzyskanych dla próbek drewna i torfu

the whole Vistulian. In the opinion of J. K. Kozłowski (priv. comm.), this peak should correspond to the Tursac Interstadial, represented in Poland by the site Cracow-Spadzista (cf Kozłowski, 1977, Table I). Comparison of histograms from Poland and Central Europe reveals some distinct similarities with minor differences, which, in our opinion, reflect regional differentiation of climatic conditions.

4.3. 21-15 kyr BP

This interval is characterized by very low number of dated samples, as may be seen in Fig. 2. However, if only ^{14}C dates of peat samples are considered, the resulting picture is even more clear, as the histogram shown in Fig. 4 does not contain ^{14}C dates in this time interval. Numerous well exposed profiles of this age do not contain organic levels, even in valleys, where the conditions for preservation of organic matter are usually more favourable. Alluvial deposits of that age in Poland are

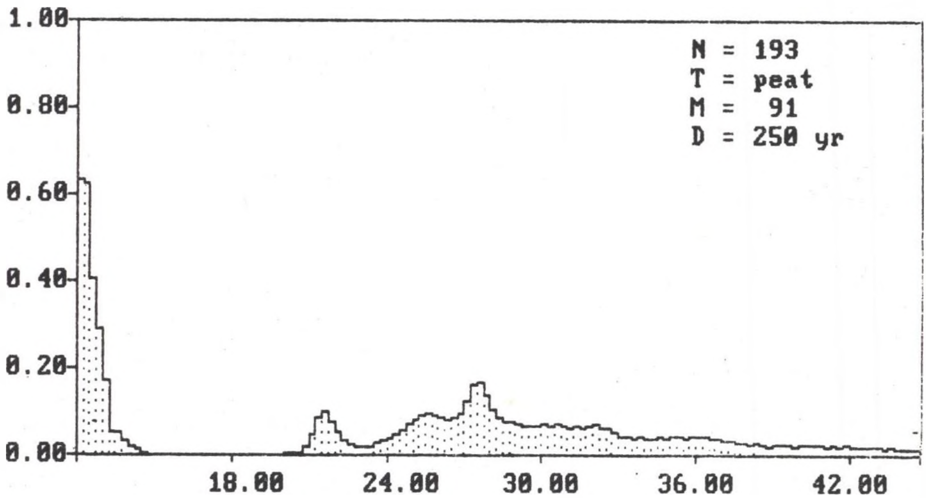

Fig. 4. Frequency distribution of ^{14}C dates of peat samples
Rys. 4. Rozkład częstości dat ^{14}C dla próbek torfu

up to 20 m thick and in some profiles are under- and overlain by well dated organic horizons. In lacustrine basins, where organic muds have been deposited during interpleniglacial, in the considered time period either break of deposition or accumulation of mineral series without organic matter is observed. At the surface were formed ice wedges with syngenetic filling, characteristic for regions of especially dry and cold climate (Goździk, 1986). Structures of same type, developed during advance of the continental ice sheet in Jutland were described by Kolstrup (1986). In Poland there is also evidence of intensive eolian activity in regions not covered with the ice sheet.

In addition to very low frequency of ^{14}C-dated samples in this period it should be pointed out that also the nature of dated samples is exceptional. Almost 40⁰/o of samples dated are bones, while abundance of bones in total set of analyzed samples amounts to 8.3⁰/o.

The course of geological processes in considered time interval was highly differentiated in both space and time. In the northern Poland all processes were dominated by the advance of continental ice sheet and following deglaciation, while on the other part periglacial conditions were prevailing, though with obvious differentiation in the latitudinal direction. The question therefore arises if this differentiation is expressed in the disposal of dated samples corresponding to the maximum advance of ice sheet and, moreover, if there are any differences o-

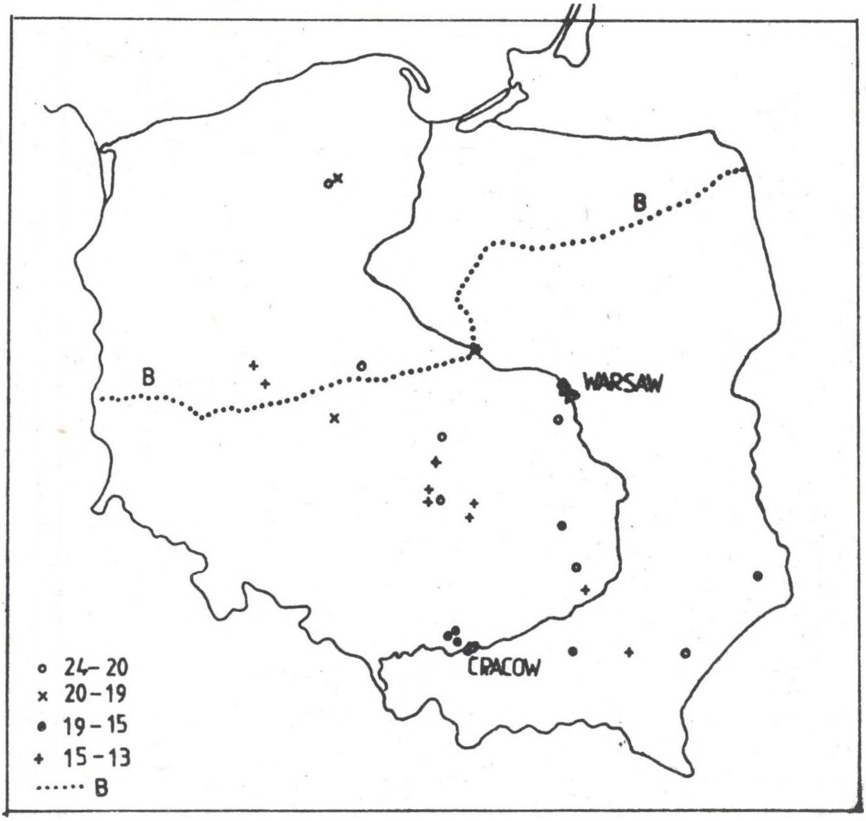

Fig. 5. Spatial distribution of sites with ^{14}C dates belonging to time interval from 24 to 13 kyr BP. Dashed line shows maximum extent of the last glaciation

Rys. 5. Rozmieszczenie przestrzenne stanowisk, z których pochodzą próbki o datach ^{14}C z przedziału 24-13 kyr BP. Linia przerywana oznacza maksymalny zasięg ostatniego zlodowacenia

disposal patterns in periods immediately before and after the maximum advance of the ice sheet? The answer is presented in Fig. 5, where all dated sites are denoted and classified into four age intervals: 24-21 kyr BP, 21-20 kyr BP, 20-15 kyr BP and 15-13 kyr BP.

Samples belonging to the oldest distinguished age interval are approximately uniformly scattered in the latitudinal direction and are also found in area covered by the last glaciation. In the next period (21-20 kyr BP) this situation does not essentially change though only two sites of this age are indicated in Fig. 5. On the other hand, all sites belonging to the third group are located in southern Poland. Samples of the last group (15-13 kyr BP) are again scattered over significant part of central Poland.

It may be concluded that in period of the most severe climatic conditions, i.e. between 20 and 15 kyr BP, climatic conditions in southern Poland, especially in basins, were locally moderately suitable for vegetation. Results of archeological investigations indicate that in the considered period those locally favourable conditions were too severe for human habitation as there are no traces of settlements in the whole considered period of time. Archeological evidence indicates migration of human groups in the eastward direction (Kozłowski, 1977).

4.4. 15-12 kyr BP

This part of frequency histogram (Fig. 2) may be subdivided into two intervals. In the first one, ranging from 15 to 13.5 kyr BP, the course of frequency changes seems to be similar to that observed before 21 kyr BP. Second interval is dominated by rapid increase of the frequency of dated samples with decreasing age.

The number of ^{14}C dates in the first interval is low, but in spite of this a peak at ca 14-14.5 kyr BP is clearly expressed as well as the following minimum at ca 13.5 kyr BP. Most of dates are obtained on organic muds with low carbon content with significant contribution of dates on bone samples. As it follows from both published and unpublished data (information provided by persons submitting samples for dating) almost all samples were collected from thin organic levels, which are difficult for palynological interpretation because of low pollen frequency and their poor preservation. Obviously climatic conditions in this time interval were more favourable for vegetation than those in the preceding period, but because of insufficient paleobotanical evidence they cannot be accurately recognized. It is worthwhile to note strict correspondence of this peak and the lithostratigraphic unit Epe, distinguished in the Netherlands by E. Kolstrup (1980), and dated to 14,000±150 BP (GrN-8509). In description of this profile E. Kolstrup points out that her conclusions are tentative and states (on page 228) that: "The pollen diagram represents a vegetation type almost totally dominated by herbs, most of which are heliophilous".

The following minimum of the frequency diagram at 13.5 kyr BP suggests slight deterioration of climate, which may be undoubtly connected with the Oldest Dryas phase. In the opinion of S. Kozarski (1981) the presence of a separate cold phase corresponding to the Oldest Dryas is problematic because warmer episode preceding such phase remains unrecognized in Poland. Results of our study seem to indicate the presence of slight warming and successive cooling just before the Bolling Interphase. Of course further investigations, first of all paleobotanical, are necessary to obtain definite answer to the question if there was in Poland a warmer period preceding the Oldest Dryas phase. On the other hand, irrespectively of the results of future paleobotanical studies, the evidence presented by frequency histograms in this paper (Figs 2, 3 and 4) and from recent paper (Pazdur, Pazdur, 1986) confirm the opinion (Kozarski, 1981) that the lower boundary of the Bolling Interphase should be placed before 13 kyr BP.

5. CONCLUSIONS

1. Analysis of the set of ^{14}C dates from Poland, ranging from 45 to 12 kyr BP, has led us to only general conclusions, some of which are tentative. In our opinion significantly larger set of ^{14}C dates is necessary to draw more detailed conclusions. It would be also advisable to extend the area of this study in order to arrive at more complete conclusions.

2. The conclusions drawn from analysis of the frequency distribution of ^{14}C dates reveal good agreement with those drawn from geological, paleobotanical, geomorphological and archeological evidence and may be useful in reconstructions of paleoclimate.

3. Analysed distribution of the frequency of ^{14}C dates is clearly tripartite; the most distinct time boundaries should be set at 21 and 15 kyr BP. The lowest frequency of ^{14}C dates is observed in the period of most severe climatic conditions (between 21 and 15 kyr BP).

4. Almost total disappearance of dated samples is observed at about 21 kyr BP. On the other hand, as is pointed in numerous papers, at this moment threshold values of many processes in nature have been overstepped. In our opinion the major rank of this boundary is not reflected in recent chronostratigraphic subdivisions of the Vistulian. Similar remarks, though of minor importance, arise in relation to the second boundary at 15 kyr BP.

5. Two distinct second-order features of the analysed frequency distribution of ^{14}C dates include:

a) the most distinct peak in the whole time period before 21 kyr BP occurs at ca 27.5 kyr BP, i.e. after the end of Denekamp Interstadial,

b) slight but significant increase of the frequency of ^{14}C dates at ca 14.5-14 kyr BP, which is probably connected with slight amelioration of climate and can be regarded as an interlude between the most severe period of Vistulian and rapid amelioration of climatic conditions during the Late Glacial.

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ROZKŁAD CZĘSTOSCI DAT ^{14}C Z TERENU POLSKI W PRZEDZIALE CZASU 12-45 TYSIĘCY LAT BP I JEGO KONSEKWENCJE PALEOGEOGRAFICZNE

Streszczenie

W analizie częstości dat ^{14}C z terenu Polski w przedziale czasu od 45 do 12 tysięcy lat BP wykorzystano zbiór 193 datowanych próbek. Na podstawie otrzymanego histogramu częstości stwierdzono występowanie dwóch głównych granic chronostratygraficznych w rozważanym przedziale czasu, odpowiadających datom 21 i 15 tysięcy lat BP. Przedział czasu pomiędzy 21 a 15 tysięcy lat BP charakteryzuje się maksymalnie niekorzystnymi warunkami dla rozwoju świata roślinnego, jednakże ze znacznym zróżnicowaniem przestrzennym i czasowym. Dyskutowane są również niektóre zjawiska drugiego rzędu widoczne w rozkładzie częstości oraz ich relacja z innymi znanymi faktami.

РАССПРЕДЕЛЕНИЕ ЧАСТОТЫ РАДИОУГЛЕРОДНЫХ ДАТИРОВОК ИЗ ПОЛЬШИ В ИНТЕРВАЛЕ ВРЕМЕНИ 12-45 ТЫС. ЛЕТ И ЕГО ПАЛЕОГЕОГРАФИЧЕСКИЕ СЛЕДСТВИЯ

Резюме

В докладе представлено результаты анализа частоты выступления радиоуглеродных дат в интервале времени от 45 до 12 тыс. лет тому назад, используя набор 193 датированных образцов из Польши. Обнаружено существование двых особенно важных хроностратиграфических границ в рассматриваемом интервале времени. Границы эти ответствуют радиоуглеродным датам равным приблизительно 21 и 15 тыс. лет. Промежуток времени между 21 и 15 тыс. лет характеризуется исключительно неприятными условиями для развития растительности, но все таки пространственно и временно неоднородными. Рассмотрено также некоторые характерные особенности второго ранга и их связь с другими данными, в том числе геоморфологическими и археологическими.