PALEOCLIMATIC IMPLICATIONS OF RADIOCARBON DATING OF SPELEOTHEMS FROM THE CRACOW-WIELUŃ UPLAND, SOUTHERN POLAND

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ABSTRACT. We report preliminary results of a long-term systematic study intended to gather paleoclimatic records from precisely dated speleothems. The research project is limited to speleothems deposited in caves of the Cracow-Wieluń Upland, the largest and best-explored karst region in Poland, covering *ca.* 2900 km^2 with >1000 caves. Speleothem samples were selected from collections of the Geological Museum of the Academy of Mining and Metallurgy in Cracow. Radiocarbon dates of these samples from *ca.* 45–20 ka BP almost exactly coincide with age range of the Interplenivistulian. A break in speleothem formation between *ca.* 20 and 10 ka BP may be interpreted as a result of serious climatic deterioration associated with the maximum extent of the last glaciation. We observed differences among ^{14}C, U/Th and AAR dating results. Changes of δ^{13}C and δ^{18}O in speleothems that grew between *ca.* 30 and 20 ka BP may be interpreted as changes of paleoclimatic conditions.

INTRODUCTION

It is well known that speleothems formed during relatively warm and humid periods, their growth seriously stunted during the glacial periods (Baker, Smart and Ford 1993; Dorale *et al.* 1992; Geyh and Hennig 1986; Geyh and Schleicher 1990; Hennig, Grün and Brunnacker 1983). Thus, the presence or absence of speleothems of a certain age is an important indicator of paleoclimatic conditions. Detailed studies of isotopic changes recorded in appropriately selected speleothems are an effective tool for reconstructing subtle climate changes in the moderate zone (Gascoyne 1992; Geyh and Hennig 1986; Harmon *et al.* 1978). Speleothem growth rate depends on the intensity of water inflow during precipitation and because of this depends on humidity (Dreybrodt 1988; Duliński and Różański 1990).

We present here preliminary results from the first stage of our long-term systematic study of isotopic data gathered from speleothem records precisely dated by radiocarbon (^{14}C) and other dating methods, including uranium/thorium (U/Th) and thermoluminescence/electron spin resonance (TL/ESR). The main aim of this preliminary stage was to gather the necessary introductory information concerning the age of speleothems deposited in caves of southern Poland.

STUDY AREA

For this project, we chose to study speleothems deposited in caves of the Cracow-Wieluń Upland, the largest and best-explored karst region in Poland, extending from Cracow in the south to Wieluń, *ca.* 160 km north of Cracow. The Cracow-Wieluń Upland consists of Upper Jurassic limestones and covers *ca.* 2900 km^2. More than 1000 caves are located in this area. Most of the caves are relatively small; only two are longer than 500 m and 66 longer than 100 m (Szelerewicz and Górny 1986; Wiśniewski 1981). Many caves were inhabited during the Middle and Upper Paleolithic (Madeyska 1982) and then during the Mesolithic and Neolithic. Figure 1 shows the localities of some of the most important caves in the Cracow-Wieluń Upland.

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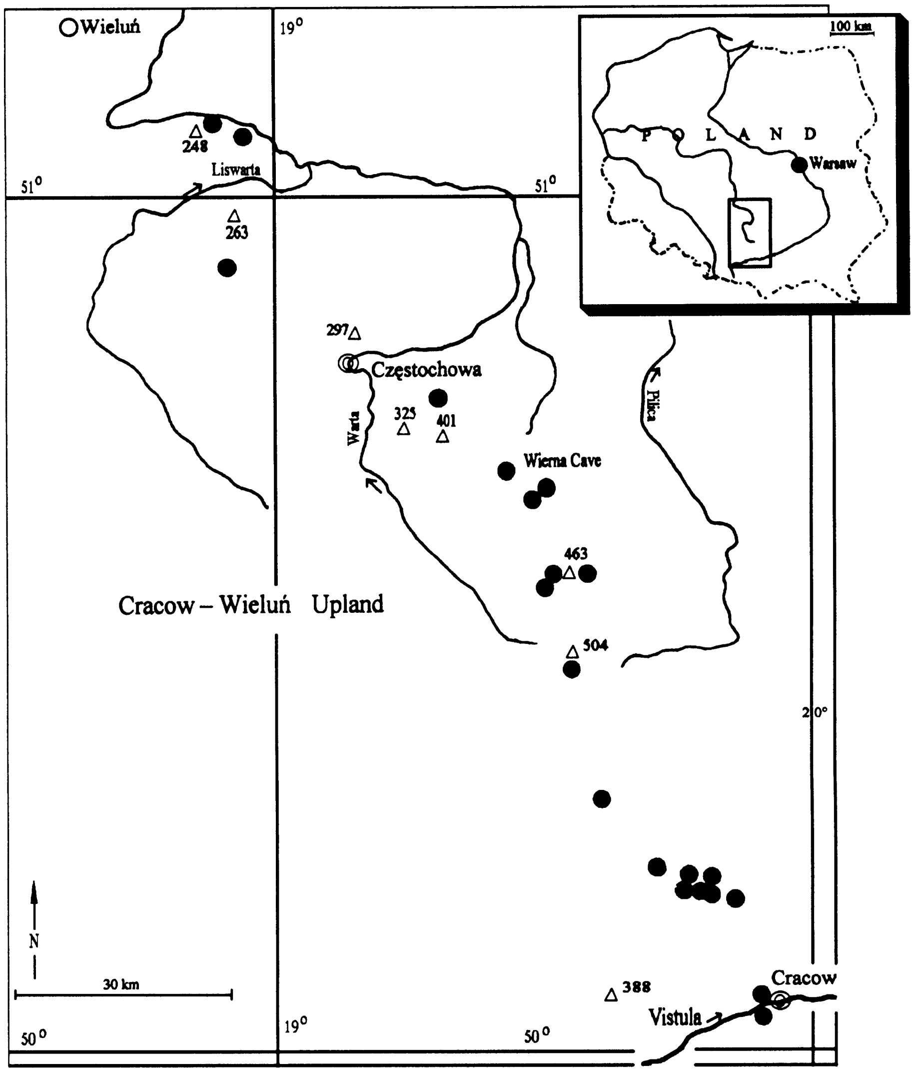

Fig. 1. Map of the Cracow-Wieluń Upland with locations of the largest caves included in this study. ● = locations of the largest caves; ◎ = important cities; △ = major hills (figures denote elevation in meters above sea level (asl)).

Methods

The speleothems and flowstones used in our study were relatively small. Oblong speleothems measured <20–30 cm and transversal dimensions were <15 cm. The largest stalagmite, JWi2 from Wierna Cave, shown in Figure 2, is 30 cm long, with a basal diameter *ca.* 10 cm; the largest flowstone was *ca.* 20 x 30 cm.

Speleothems were subdivided according to lithological features; the main indicators for separating samples for dating were surfaces indicating a break in calcite deposition. As a rule, the outermost layers were dated to determine termination of calcite deposition. If appropriate, the oldest layers were used for ^{14}C dating.

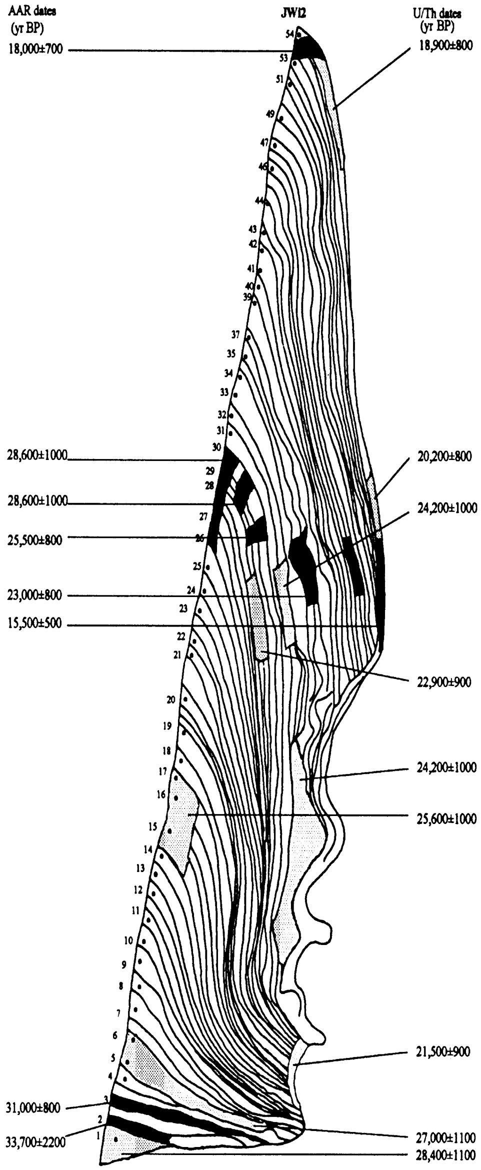

Fig. 2. Cross-section through stalagmite JWi2 from Wierna Cave, showing sampling points for stable carbon and oxygen isotope measurements (numbered dots along the growth axis) and results of U/Th (▩)and AAR (■) dating.

Calcite was treated with hydrochloric acid, and evolved CO_2 was purified, stored in glass reservoirs for at least one month to allow for complete decay of ^{222}Rn and then counted in proportional counters filled with pure CO_2 (Pazdur and Pazdur 1986). Small aliquots of CO_2 were used for mass-spectrometric determinations of δ^{13}C and δ^{18}O. We investigated 89 speleothems from 41 caves and obtained 170 ^{14}C dates; 45 of these samples yielded infinite dates.

Speleothem JWi2 (Fig. 2) underwent U/Th and amino acid racemization (AAR) dating at the Institute of Geochemistry and Physics of Minerals of the Ukrainian Academy of Sciences in Kiev. AAR results were based on experimentally determined relations between stable and unstable amino acids, Thr/Leu and Thr/Glu.

Samples for stable oxygen and carbon isotope (δ^{18}O and δ^{13}C) analysis were taken by drilling 2-mm apertures of 10-mm long along a growth line as shown in Figure 2. The weight of each sample was *ca.* 30 mg. The stable isotope analyses were performed in Kiev.

RESULTS

Age Distribution of Speleothems from the Study Area

The large number of dating results obtained by different methods enables us to interpret results using probabilistic methods (Baker, Smart and Ford 1993; Geyh 1970; Smart and Richards 1992; Srdoč *et al.* 1983). Frequency distributions of dates may be compared with results of investigations obtained by other methods, such as changes in temperature and precipitation in the past reconstructed from pollen analyses of peat-bog profiles and lake sediments of unglaciated areas, and with paleoclimatic records from deep sea cores (Guiot *et al.* 1989; Martinson *et al.* 1987; Shackleton 1969).

Our first results enable us to draw some preliminary conclusions about climate changes in the study area during the last glacial-interglacial cycle (Pazdur *et al.* 1994). Figures 3 and 4 show the main set of ^{14}C results as probability distributions. The ^{14}C dates reported here are conventional ages calcu-

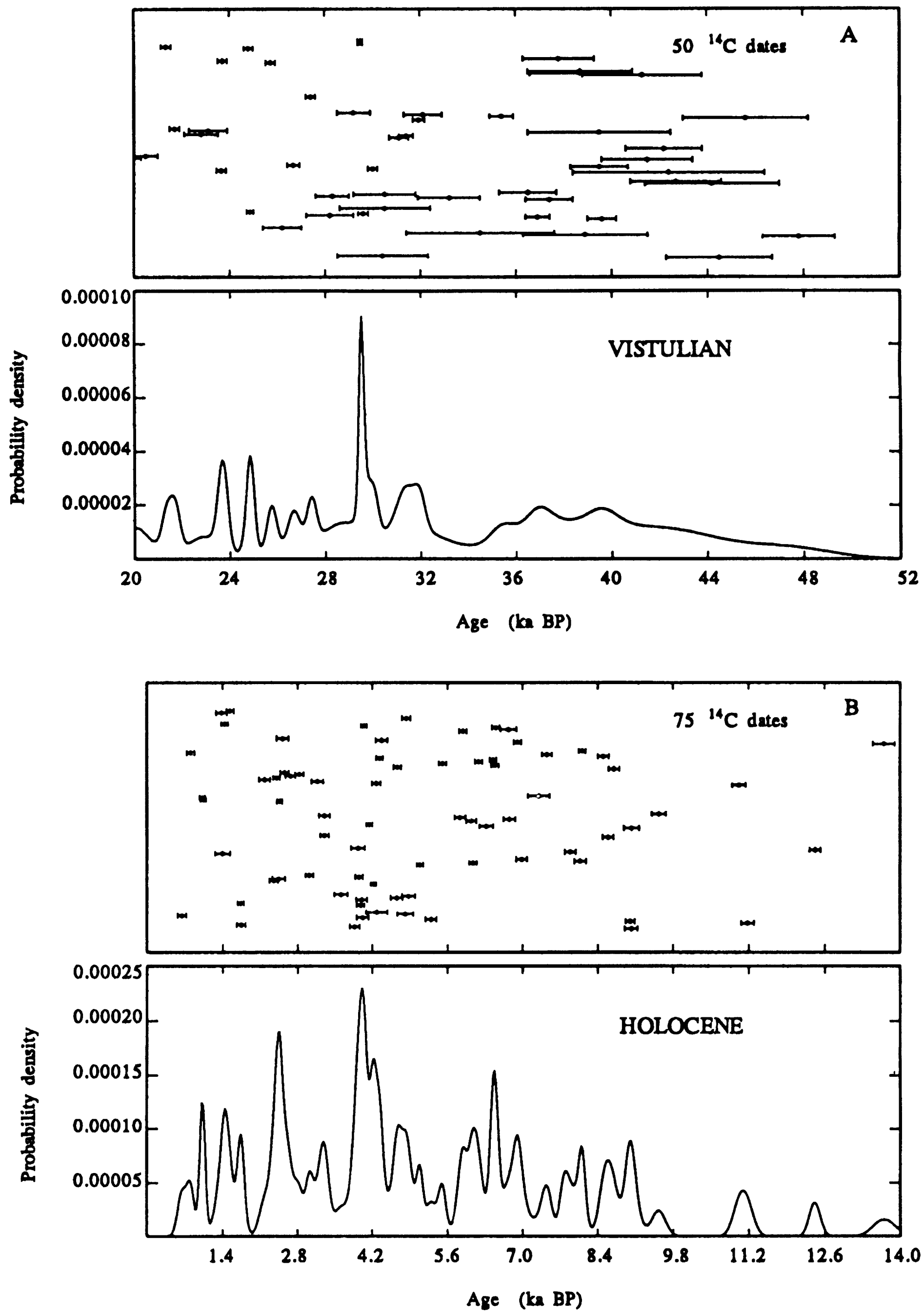

Fig. 3. Conventional ^{14}C dates of speleothems (uncorrected for reservoir effect). A. Vistulian; B. Holocene.

lated according to Stuiver and Polach (1977). We did not calculate the reservoir age correction, which we assume to be 1500 yr, because the ^{14}C ages seem to be 1500 yr too old (Geyh 1970; Geyh and Hennig 1986).

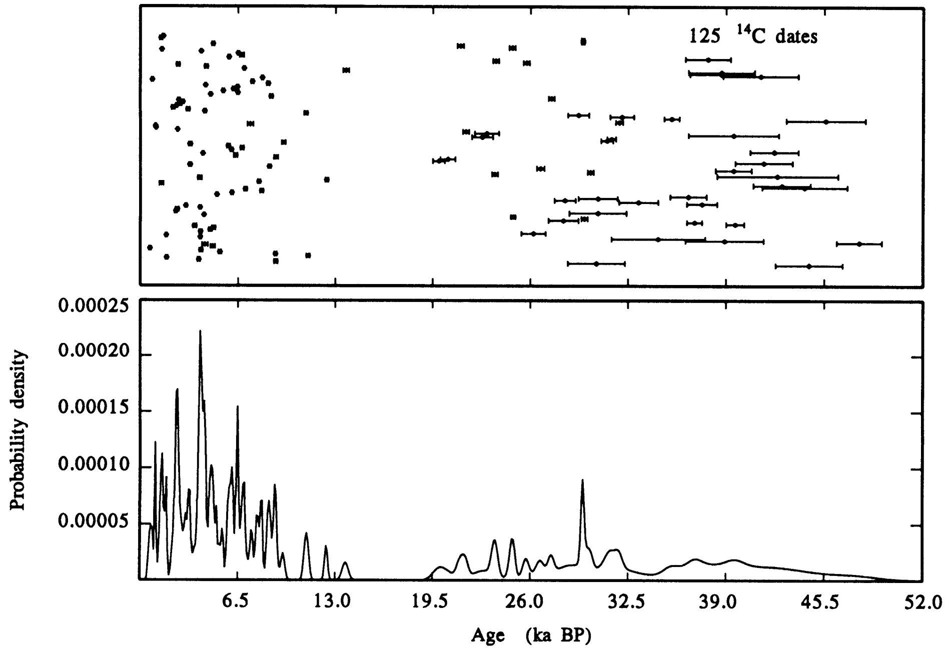

Fig. 4. Conventional ^{14}C dates of all dated speleothem samples (uncorrected for reservoir effect).

The group of older dates range from 48 to 20 ka BP (Fig. 3B). These boundaries, determined by the presence of speleothems, coincide almost exactly with the Interplenivistulian climatostratigraphic unit, determined from paleogeographical studies in the foothills of the Carpathian Mountains (Starkel 1980). This period approximately parallels the duration of the Jerzmanowice culture, discovered at numerous sites in the Jerzmanowice area (Madeyska 1982). Unfortunately, the contamination effect is important for samples with ages of >30 ka (Srdoč *et al.* 1986), and it is possible that many samples attributed to the Interplenivistulian have ages far beyond the limits of ^{14}C dating.

Our results also show an interruption in speleothem formation between 20 and 10 ka BP, which may be interpreted as serious climatic deterioration associated with the maximum extent of the last glaciation (Younger Plenivistulian, incorporating the Late Glacial period). A single date, 13,700 ± 200 BP, (Gd-6435), obtained from the thin outermost layer of flowstone collected in the Wierzchowska Górna Cave, may suggest that a relatively warm climate, suitable for speleothem formation in southern Poland, occurred before the beginning of the Holocene, probably during the Bølling/Allerød interstadial. Of course, a single result must be confirmed by dates from other caves in the study area before conclusions can be drawn.

The principal period of speleothem deposition falls within the Holocene (Fig. 3B). The oldest dates of this group, at 9000 BP, were obtained on speleothems from the Ciemna and Straszykowa Caves. In particular, the maximum peak of the date density plots (Figs. 3B and 4) approximately fit the climatic optimum of the Holocene, *i.e.*, the Atlantic period.

Age of Speleothem JWi2

Almost identical U/Th (18,900 ± 800 BP) and AAR dates (18,000 ± 700 BP) of the outermost layer of stalagmite JWi2 (Fig. 2) indicate that deposition ceased just before the last glacial maximum, the so-called Leszno phase, dated in other records from Poland to *ca.* 18 ka BP (Kozarski 1980; Mojski 1992;

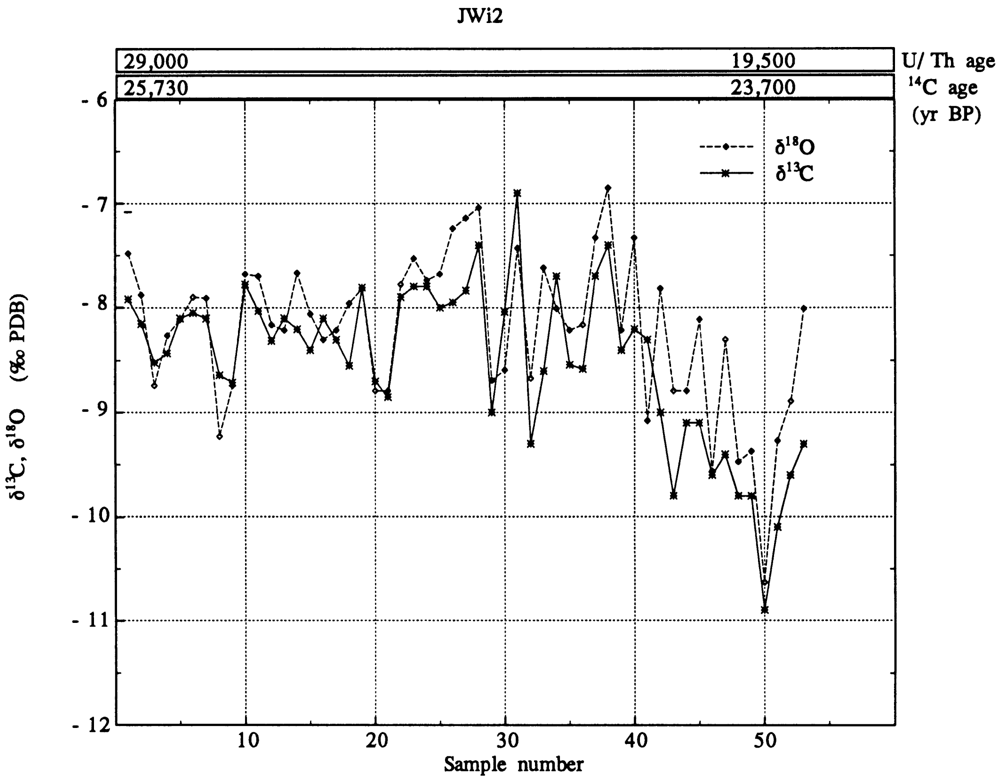

Fig. 5. Stable carbon and oxygen isotope measurements in stalagmite JWi2 along its growth line. U/Th dates were obtained independently from dates listed in Figure 2.

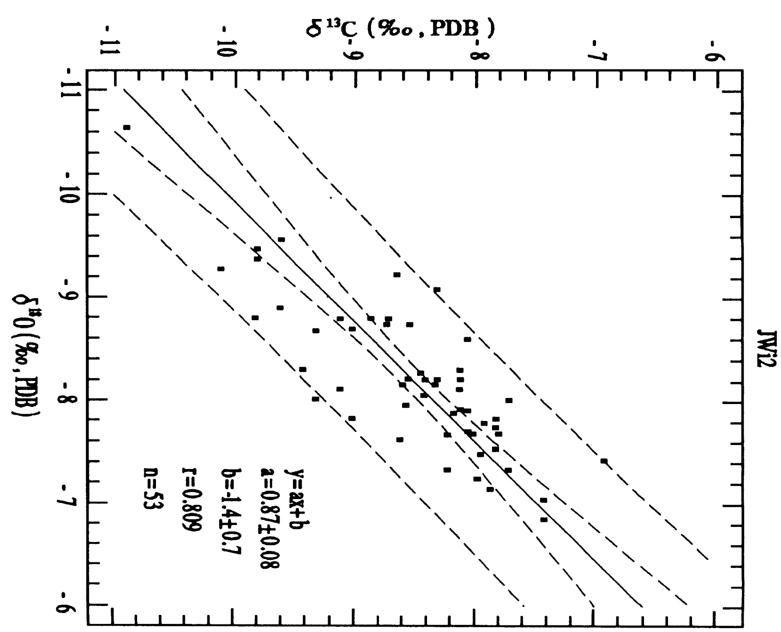

Fig. 6. Correlation between δ^{13}C and δ^{18}O measured along the growth axis of stalagmite JWi2. – – – =1- and 2-σ ranges of approximation uncertainties.

Starkel 1988). A conventional ^{14}C date obtained for the outermost layer is much older (23,700 ± 200 BP). The three methods of dating have yielded different results for the beginning of stalagmite's growth. U/Th (28,400 ± 1100 BP) and AAR (33,700 ± 2200 BP) dates are much older than the corresponding ^{14}C date (25,730 ± 200 BP). Because the study has not been completed, however, it is difficult to be definitive about the discrepancies. Diagenetic processes may be the major source of age differences (Geyh and Henning 1986; Chen and Polach 1986; Yates 1986; Fontes *et al.* 1992).

Stable Isotope Analysis of Speleothem JWi2

Figure 5 shows the results of $\delta^{13}C$ and $\delta^{18}O$ measurements on JWi2. The rapid decline of both curves at the end of speleothem formation (before *ca.* 18,000 BP) may relate to the rapid cooling before the last glaciation in Central Europe observed in different paleoclimatic records (Mojski 1992). It is interesting to note more negative values of both $\delta^{13}C$ and $\delta^{18}O$ when the temperature falls. Figure 6 shows a strong positive correlation between $\delta^{13}C$ and $\delta^{18}O$ values: the correlation coefficient $r = 0.809$ ($n = 53$ points). Of the $\delta^{13}C$ and $\delta^{18}O$ values that we measured along five layers, we observed positive, negative and near-zero correlation coefficients. It seems that speleothem was deposited under conditions of kinetic isotope fractionation.

Conclusion

A group of older ^{14}C dates, obtained on speleothem samples from 18 caves, range from 45 to 20 ka BP. This time frame, determined by the presence of speleothems, coincides almost exactly with the interval of the Interplenivistulian. An interruption occurred in speleothem formation between 20 and 10 ka BP, caused by serious climatic deterioration associated with the last glacial maximum. The younger dates span the Holocene, the broad maximum falling within the Atlantic phase.

^{14}C, U/Th and AAR dates were obtained on a single speleothem from Wierna Cave (JWi2). These, accompanied by $\delta^{13}C$ and $\delta^{18}O$ values obtained along its growth line, indicate a rapid cooling before speleothem JWi2 stopped growing (*ca.* 18 ka BP).

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