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# $^{14}C$ VARIATIONS DURING THE UPPER PLEISTOCENE

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ABSTRACT. Parallel determinations of $^{14}C$ and ionium dates on a stalagmite from the Cango Caves provide evidence of variations in the $^{14}C$ content of the atmosphere beyond the range of the California tree-ring sequence. During the Holocene growth period the $^{230}Th$ dates are compatible with the tree-ring calibrated $^{14}C$ dates. At 18,000 BP and between 30,000 and 40,000 BP the $^{14}C$ ages are markedly younger than the $^{230}Th$ ages, suggesting that the $^{14}C$ level of the atmosphere was considerably higher at these times. Between the $^{230}Th$ ages of 35,000 and 29,000 BP the $^{14}C$ ages remain nearly constant at 29,500 BP, indicating that $^{14}C$ production must have been drastically reduced during this period. The $^{14}C$ fluctuation is greater than that predicted by Barbetti (1980) but it may be explained by postulating a substantial increase in the geomagnetic dipole field, for which there is mounting evidence.

## INTRODUCTION

Several attempts have been made to establish the constancy of the $^{14}C$ content of the atmosphere in the period beyond the current range of the California tree-ring sequence, without thus far producing conclusive results. $^{14}C$ dates in the range of 23,000 to 32,000 BP were compared with ionium (uranium series) dates in the same sedimentary sequence, but no discrepancy could be detected (Peng, Goddard, and Broecker, 1978; Stuiver, 1978). However, some indication of considerable deviations between 17,000 and 40,000 BP were reported (Vogel, 1980), and Barbetti and Flude (1979) and Barbetti (1980) showed that the available paleomagnetic data may point to substantial fluctuations in the dipole field of the earth. These, in turn, would have produced significant distortions in $^{14}C$ dates during this period

In order to investigate this possibility further, a stalagmite, 2.8m high, was secured from the Cango Caves near Oudtshoorn in the Cape Province of South Africa. It stood some 1000m from the mouth of the cave, and since water still dripped onto it at times, we thought it could still be growing. The stalagmite consists of large calcite crystals and is virtually impervious and nearly transparent. Thus, it is ideally suited for both ionium and $^{14}C$ dating, since it is unlikely that either uranium or $^{14}C$ could have been adsorbed from percolating water after initial precipitation of the calcium carbonate, or that the uranium could have been leached out at a later stage. The surface shows no signs of re-solution so that it was probably never submerged under the groundwater table.

CALIBRATION

At ca 95cm from the top of the stalagmite, a discontinuity could be discerned, in that the lower part is slightly yellow-brown, while the upper 95cm are completely colorless. In the event there was a break of some 10,000 years in the growth of the speleothem at this point, the purer calcite accumulating during the past 6000 years. Both the $^{14}C$ and ionium age measurements for the upper section are shown in figure 1.

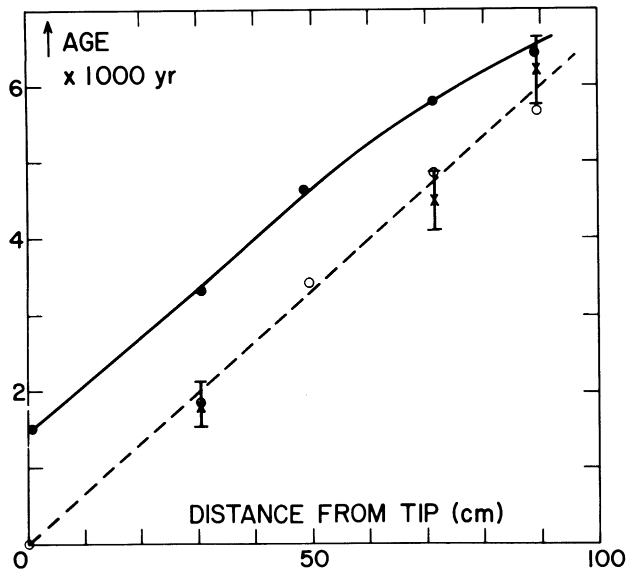


Fig 1. Growth curve for the upper 97cm of the stalagmite
● apparent $^{14}C$ ages of the samples
o ages after correction for the apparent initial age (-1500 yr) and calibration for variation in the atmospheric $^{14}C$ content
x associated ionium ages

As expected, the apparent $^{14}C$ ages are higher than the ionium ages due to the apparent age of the groundwater dripping into the cave. Excellent conformity of the two sets of data is obtained if the apparent initial age of the calcite is taken to be 1500 years and if the ages thus deduced are calibrated according to the curve of Suess (1970). As far as the ionium ages are concerned, all the samples reported on in this paper contained very little or no $^{232}Th$. Where measurable amounts were present, the ages were adjusted for initial $^{230}Th$, assuming a $^{230}Th/^{232}Th$ ratio of (1 ± 0.5). The maximum correction was 230 years, which is well within the uncertainty of the measurements. Both the ionium dates and the corrected $^{14}C$ dates show a uniform rate of growth of 15mm/century over the past 6000 years.

UPPER PLEISTOCENE PERIOD

With initial relative $^{14}C$ content of the speleothem established, an appropriate adjustment (1500 yr) can be made to the $^{14}C$ ages of the older sections. In addition to the correction for the apparent initial age, the $^{14}C$ dates are calculated using the more correct half-life of 5730 yr. The results are shown in figure 2 together with the ionium ages obtained for the same samples. The correction of 1500 yr need not necessarily apply to the older section, but an error in this figure would not change the conclusions presented below.

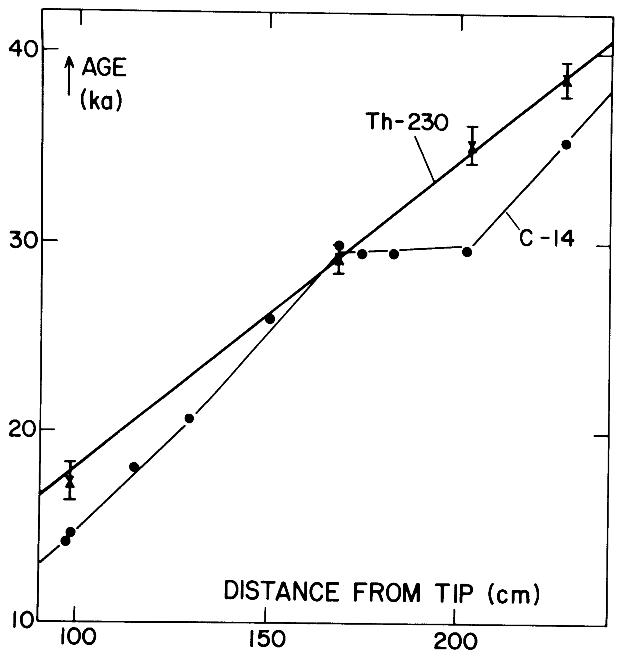


Fig 2. Growth curve for the lower section of the stalagmite. The ionium dates (x) show a linear rate of growth. The $^{14}C$ ages (●) are corrected for apparent initial age by subtracting 1500 yr and calculated using a half-life of 5730 yr for $^{14}C$.

The first point to note is the abrupt jump in age between 90cm from the tip (6000 BP, fig 1) and 97cm (ca 16,000 BP, fig 2). This discontinuity represents a period during which the stalagmite did not grow at all, possibly because there was insufficient seepage at this time.

The ionium dates for the section 230cm to 97cm from the tip indicate a practically constant growth rate of 6.2mm/century between 39,000 BP and 18,000 BP. The $^{14}C$ dates, on the other hand, are substantially younger for much of the period, excepting those for the section between 205 and 166cm which remain virtually constant at ca 29,500 BP.

The discrepancy between the $^{14}C$ and ionium dates at 19,000, 35,000, and 39,000 BP (ionium ages) may most logically be interpreted to mean that the $^{14}C$ level in the atmosphere was then significantly higher than it is today. The alternative explanation that the accepted half-life of $^{230}Th$ (75,200 yr) is at least 10% too great, seems less likely at this stage. The observed discrepancy further confirms the previously reported suspicion of deviating $^{14}C$ ages at these dates (Vogel, 1980).

The second feature revealed in figure 2 is the substantial kink in the $^{14}C$ growth curve at ca 29,500 yr BP. This can be explained in two ways: either the growth rate of the stalagmite was at least 10 times greater during this period (60mm/century) <u>and</u> one or both the ionium dates at 167cm and 204cm are in error, or the rate of $^{14}C$ production in the atmosphere was drastically decreased for about 6000 yr after 35,000 BP. The second possibility seems more probable, especially in view of the very high paleomagnetic field strengths at ca 29,500 $^{14}C$ yr BP reported by Barbetti and McElhinny (1976) for the Lake Mungo site in Australia. If these magnetic field intensities represent an increase in the geomagnetic dipole moment, they would indicate that the dipole strength changed from as little as 2 to nearly $50 \times 10^{22} AM^2$ between 32,000 and 29,500 $^{14}C$ yr BP. This, in turn, could have reduced the production rate of $^{14}C$ by a factor of 5 (Barbetti, 1980; Lingenfelter and Ramaty, 1970). If such high values of the dipole field of the earth were maintained for several thousand years, it would have had the effect that apparent $^{14}C$ ages changed very slowly throughout the period. It appears, therefore, that the constancy of the $^{14}C$ ages observed between 165 and 205cm in the stalagmite could be explained by changes of the strength of the geomagnetic dipole alone.

The atmospheric $^{14}C$ concentration derived from the four pairs of $^{14}C$ and $^{230}Th$ dates are plotted in figure 3.

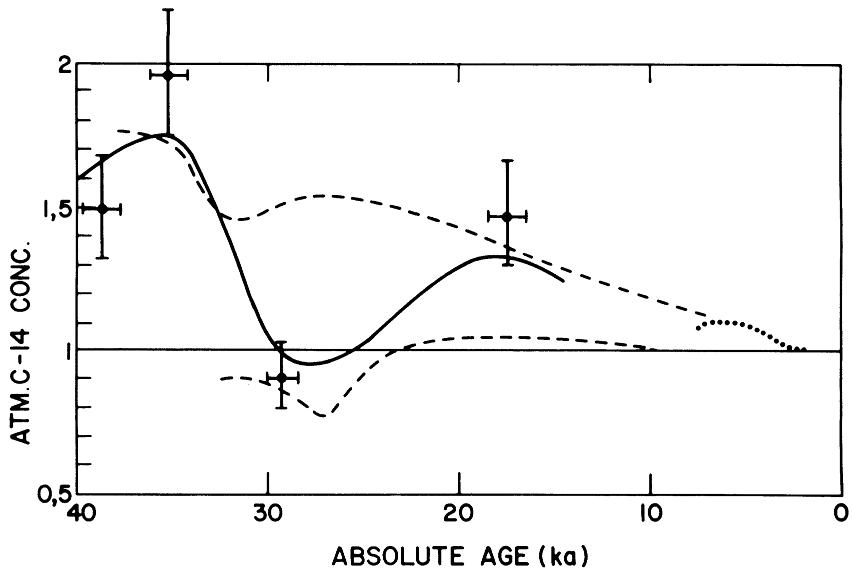


Fig 3. Relative atmospheric $^{14}C$ content deduced from the differences between the $^{14}C$ and $^{230}Th$ ages of the samples dated by both methods. The dashed lines are the extreme possible values calculated by Barbetti (1980) from geomagnetic data. The dotted line is the variation derived from dendrochronology.

The values lie within the limits calculated by Barbetti (1980) from the known data on magnetic field intensities (dashed lines). The results reported here are not at variance with other published pairs of dates summarized by Barbetti (1980), although the uncertainties associated with the existing measurements between 30,000 and 40,000 BP are too large to permit a meaningful comparison.

## CONCLUSIONS

Evidence is presented that $^{14}C$ ages may be several thousand years too young at some stages during the Upper Pleniglacial and that they remain nearly constant between 29,000 and 35,000 BP. The latter finding suggests that the production of $^{14}C$ in the atmosphere was drastically decreased during this period. These observations need to be substantiated by further precise measurements on other samples from different regions before they can be accepted with confidence. The main problems in this regard are those of obtaining datable material in the relevant age range and of attaining sufficient accuracy in the ionium measurements.

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