Accurate dating with radiocarbon from the atom bomb tests

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THE ARTIFICIAL RADIOCARBON PRODUCED by the thermonuclear bomb tests in the 1950s and 1960s significantly increased the level of ^{14}C in the environment. A detailed record of the subsequent changes in the ^{14}C concentration of the atmosphere can be used to date plant and animal material accurately over the past half century. Examples of this application are given.

Naturally occurring radiocarbon has proved remarkably successful in providing absolute dates over the past 40–50 thousand years. The nuclear fusion bomb tests conducted above ground level by the U.S.A. and the U.S.S.R. between 1954 and 1962 introduced large amounts of radioactive carbon into the atmosphere and thereby substantially increased the level of ^{14}C in the environment. This created the additional possibility of accurate short-term dating.

In 1963, the ^{14}C content of atmospheric carbon dioxide in mid-northern latitudes reached a level double that of the natural value.[1] Because the tests were carried out in the north, the southern hemisphere lagged behind and a maximum of 65% above normal was reached only in 1965.[2–5] Subsequently, the level has gradually declined as the excess ^{14}C became absorbed into the ocean. The later tests conducted by various nations did not have a noticeable effect on the ^{14}C levels.

Much of the radioactive debris from the explosions was injected directly into the stratosphere and tended to mix down into the troposphere as the tropopause rose during the next few spring seasons, to be followed, each time, by a slight decrease as the excess ^{14}C became distributed through the exchangeable carbon system. This caused the ^{14}C content at ground level initially to show marked seasonal fluctuations. To a lesser extent, these variations have persisted, but the lower values in winter are mainly due to the dilution caused by increased combustion of fossil fuel during the cold months.

The complete data set for the southern hemisphere is shown in Fig. 1. The values prior to mid-1959 are based on dated plant and animal material from South Africa.[2,6] In 1959, arrangements were made for the direct collection of atmospheric carbon dioxide at the CSIR in Pretoria. Until September 1962, the samples were measured in Heidelberg,[1] Germany, and thereafter in Holland in the Groningen laboratory until March 1965, when sampling ceased.[4] For the period from 1966 to August 1968, the data were supplemented with air samples collected at Bariloche, Argentina.[7] In October 1968, collection was resumed at the CSIR, Pretoria, and since then the analyses were performed in the Pretoria laboratory.

The samples were measured relative to the value of the international reference standard (NBS oxalic acid) at the time of measurement and were corrected for variations in isotope fractionation. They are expressed as parts per thousand (‰) above the standardized value for AD1950. The 1σ uncertainty usually lay between ± 5 and 8‰ except for the samples analysed since 1995, when the errors are 2–3‰. The actual data are available on our website.[8]

In what follows, some examples will be given of the accurate dating of samples in the period since 1955. When plant and animal material is to be dated, only the atmospheric values recorded in the summer growing season are to be used; the winter readings, which are affected by pollution, can be ignored. Our best estimate of the annual summer values are plotted in Fig. 2.[8] The data are again given in ‰ above the standardized value. The uncertainty is estimated to be 2–3 ‰ and, together with the error attached to a sample measurement, the derived date is typically accurate to ± 1 year. Usually, a ^{14}C value will translate to either of two possible dates, depending on whether it corresponds to the upward arm of the curve before 1965 or the downward arm thereafter. If no additional information is available, a further adjacent sample needs to be analysed in order to decide which date applies. Trees that show secondary thickening can be dated by counting the annual rings in the trunk and this has often been done to compare with the atmospheric data, to establish the extent of local pollution by fossil fuel combustion or to evaluate the contamination from nearby nuclear power plants. Certain other plants can, however, also be dated without actually damaging the plant.

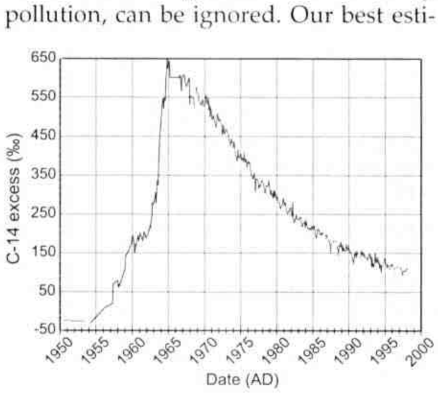

Fig. 1. The elevated ^{14}C levels in mid-southern latitudes caused by testing nuclear weapons in the atmosphere. The measurements were mainly made on carbon dioxide collected at the CSIR on the eastern side of Pretoria. The data are expressed as parts per thousand (‰) above the standardized (unpolluted) value for 1950. Regional and local pollution by fossil fuel consumption is mainly responsible for the depressed values during the winter months.

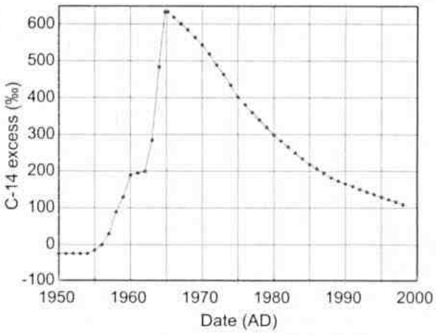

Fig. 2. The average annual summer-month values of the ^{14}C excess in mid-southern latitudes derived from Fig. 1 for use in dating post-1954 samples.

Dating examples

Palm trees

The bases of dead leaves of palms often remain attached to the stem, so that the bottommost leaf base can be used to determine when the stem started to develop. To demonstrate this, the basal leaf of a palm planted in the Menlo Park suburb of Pretoria in 1964 was analysed in 1994 with the result: Pta-6422, dead leaf base at ground level, 373 ± 3‰

Comparison with Fig. 2 shows that the leaf dates to 1963/4 or 1976/7. In this case the first date obviously applies.

Tree aloes

Dead leaves from the stem of a *c*. 2-m-tall *Aloe marlothi* that germinated in 1972 and was planted in a garden in Menlo Park, Pretoria, in 1974 and sampled in May and August 1992 gave the following results: Pta-5909, dead leaf base, 0.3 m above ground, 321 ± 8‰; Pta-6024, dead

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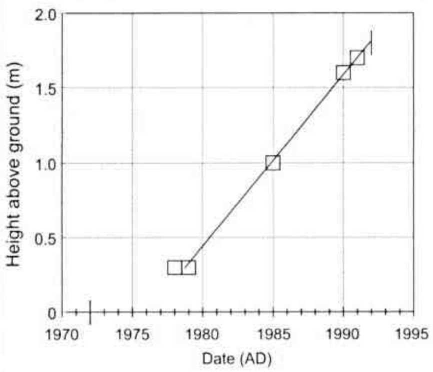

Fig. 3. The derived dating of the growth of an *Aloe marlothi* that germinated in 1972.

leaf, 1.0 m above ground, 210 ± 5‰; Pta-5914, youngest dead leaf, 1.6 m above ground, 158 ± 2‰; Pta-6042, newly dead leaf 3 months later, 1.7 m above ground, 157 ± 5‰; Pta-6043, newly dead leaf 3 months later, 1.7 m above ground, 158 ± 7‰.

The dates derived from Fig. 2 are plotted against the height above ground of the leaves in Fig. 3. (The alternative dates in the 1960s do not apply here.) It apparently took the seedling seven years to grow a stem 0.3 m tall; after that a steady growth rate of 110 mm/yr was maintained. A 6-m-tall *A. marlothi* standing on the northern side of the Magaliesburg, but whose germination date is unknown, similarly showed a constant growth rate of 150 mm/yr and was thus somewhat more than 41 years old.

Cycads

Initially, it was thought that the basal leaf scales that cover the stem of a cycad would provide the age of the plant. It was, found, however, that younger tissue is deposited in these scales,[9] so that only dead leaf bases can be used to determine growth rate. Samples were collected in September 1995 from two specimens of *Encephalartos eugene-maraisii* growing at the Entabeni Game Lodge, 30 km west of Potgietersrus: Pta-6984, (a) bottommost dry leaf, 0.3 m from top of 1.5 m stem, 433 ± 3‰; Pta-7004, (b) youngest leaf of broken-off 2.1-m slanting stem, 198 ± 2‰; Pta-7050, oldest leaf bases of same, 0.3 m from top, 45 ± 6‰.

The date deduced for the leaf on Plant (a) can be either 1964 or 1974, which means that the top 0.3 m grew at a rate of 10 or 15 mm/yr. Assuming constant growth in the past, this would make the 1.5-m stem either 150 or 100 years old. The top leaf of the broken stem of Plant (b) dates to either 1962 or 1987, while the leaf bases 0.3 m lower down date to 1957. On the basis of the latter date, 1962 can be rejected for the top and a growth rate of 10 mm/yr is implied. Again assuming a linear growth rate, the 2.1-m stem would thus have been about 210 years old. Based on this evidence, the 'Waterberg' cycad grows at about 10 mm a year in that environment.

Welwitschia

The stunted stem of the desert plant, *Welwitschia mirabilis*, in the Namib pushes out only two leaves. A 4-m leaf from a medium-sized plant growing east of Swakopmund was sampled in 1977 and analysed to determine its growth rate.[10] The result was: Pta-2155, section of leaf at 3.7 m from stem, 251 ± 5‰.

This gives a date of 1962/3 and an age of 15 years in 1977. The average growth rate is therefore 250 mm/yr, although it may not be uniform.

Elephant tusks

The tusk of an elephant grows out from the base so that the bottom of the tusk can be used to date when the animal died. To demonstrate this, some tusks of elephants from the Kruger National Park, of which the date of death is known, were analysed. The organic collagen of the samples was used for the analysis. At the same time pieces of rib bone were processed to determine the regeneration rate of the collagen in the bone. The results are as follows:

1) Pta-5175, base of tusk of young bull, died June 1989, 176 ± 7‰; Pta-5154, rib bone of same, 205 ± 6‰.

The date for the tusk base is 1998/9 and the average age of the collagen in the rib is 3 years.

2) Pta-5122, base of tusk of young bull, died July 1989, 165 ± 5‰; Pta-5154, rib bone of same, 221 ± 6‰.

The date for the tusk base is 1990 and the average age of the collagen in the rib is 4/5 years.

3) Pta-5121, base of tusk of 45-yr-old bull, died June 1989, 193 ± 5‰; Pta-5154, rib bone of same, 341 ± 7‰.

The date for the tusk base is 1987 and the average age of the collagen in the rib is 11 years.

4) Pta-5121, base of tusk of old bull, died January 1988, 208 ± 6‰; Pta-5154, rib bone of same, 354 ± 7‰.

The date for the tusk base is 1986 and the average age of the collagen in the rib is 11 years.

5) Pta-5121, base of tusk of old animal, died in 1983, 262 ± 5‰.

The date for the tusk base is 1982.

The evidence presented here indicates that the base of the tusk generally dates to the year before the animal dies. The growth of the tusks may also slow down slightly in old age, while the regeneration of collagen in the rib bones decreases markedly.

Rhinoceros horn

The horn of a rhinoceros also grows continuously from the base up, so that a slice of the bottom of a horn will date to a time shortly before the death of the animal. One example of this can be given: Pta-6015, basal slice off a horn 410 mm long, 580 ± 10‰

The result places the death of the animal between 1964 and 1969.

Liquor

The age of matured liquor can be verified with this technique. A bottle of mature brandy was purchased from a local bottle-store in May 1995. The analysis gave: Pta-6890, eight-year-old matured Oude Molen brandy, 264 ± 7‰.

The derived date for the alcohol in the brandy is 1982, indicating that the fruit from which it was made grew 13 years before purchase. How long it was on the shelf is, of course, unknown, but the claim of eight years can be accepted.

Conclusion

The record of the ^{14}C, produced by thermonuclear bombs, in mid-southern latitudes allows the dating of plants and animals that lived after 1954 to an accuracy of ±1 year. The examples given here show that there are various instances where useful information can be obtained in this regard.

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