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RADIOCARBON FLUCTUATIONS DURING THE THIRD MILLENNIUM BC

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ABSTRACT. Precision ^{14}C analyses have been performed on samples comprising 1 to 4 annual rings from the south-central European dendrochronologic sequence of sub-fossil oak wood covering the period 1930 to 3100 BC. Apart from a major deviation in the 29th century BC, the ^{14}C fluctuations have amplitudes of ca 10‰ and a possible periodicity of 90 years. A ^{14}C peak at 2190 BC has a rise- and decay-time of <20 years indicating rather abrupt changes in the production rate of ^{14}C. The ^{14}C calibration curve derived from these data can be used for precise dating of the Early Bronze Age in the Near East.

The 3rd millennium BC is that early historic period to which ^{14}C dating can make a positive contribution. It covers, roughly, the time from Dynasty I to the beginning of Dynasty XII in Egypt and the Dynasties of Sumer and Akkad in Mesopotamia, *viz*, a period during which absolute historic dates are by no means secure. Precision ^{14}C dating, properly applied to archaeologic sites and events in the Near East, could thus be used to refine the historical time scale for this Early Bronze Age period.

With this objective in mind, a high-precision calibration curve for ^{14}C dates is being constructed for the time span 1930 to 3100 BC. From a geophysical point of view, this period (1900–2800 BC) is also of interest because it has been reported as showing no large fluctuations in ^{14}C (Suess, 1980; Pearson, Pilcher & Baillie, 1983). By analyzing individual annual tree rings from a dendrochronologically-dated sequence, it was hoped to gain more insight into the nature of such a "quiet" period of ^{14}C production.

The samples investigated were annual rings taken from the south-central European sub-fossil oak sequence (Becker, 1979) which has recently been dated absolutely by cross-calibration with a similar Irish oak series (Pilcher *et al*, 1984). In cases where the rings were narrow, 2 to 4 rings were combined for a sample; otherwise single annual rings were used. The spacing between samples was 10 or 20 years, but several intermediate samples were also measured to define the trends with greater precision. For the purpose of constructing a calibration curve for ^{14}C dates, the use of integrated samples of, say, 20 annual rings may be more appropriate (eg, Pearson & Baillie, 1983), but since details of short-term variations in ^{14}C would thus be lost, individual rings were preferred.

The samples were reduced to matchstick-size pieces and purified by the de Vries method, *viz*, they were extracted respectively with 2% HCl, 2% NaOH, and 2% HCl at 70°C overnight. The weight loss was normally ca 50%. Tests showed that only ca 1% by weight could be removed by additional extraction with ethanol/benzene and ethanol in a soxlett. Since it has repeatedly been shown that this organically soluble matter cannot influence the results noticeably (eg, Tans, de Jong & Mook, 1978), the procedure was not applied to the bulk of the samples.

The purified wood was converted to carbon dioxide which, after purification, was measured in a gas proportional counter for at least two periods of 3 or 4 days. The ^{13}C content of the counter gas was determined before and after counting. The statistical uncertainty of the ^{14}C analyses was in the order of 2‰, while the combined error in the determination of gas volume and the uncertainty in the corrections for differences in purity of the gas is estimated to be ca 0.7‰. This latter error thus contributes only 1 or 2 years to the inaccuracy of the derived age. At present, the count rate of the NBS oxalic acid standard is known within ±0.5‰, while the ratio to the Heidelberg enriched standard, $A_{Hdb}/.95A_{ox} = 10.1994 \pm .006$. The ratio between the old and new NBS oxalic acid, both normalized to $\delta^{13}C = -19‰$, as measured in this counter is 1.2884 ± .0009, which compares well with the average obtained by nine different laboratories, *viz*, 1.2893 ± .0004 (Mann, 1983).

An error in the estimate of the activity of the NBS oxalic acid as well as an error in the background value can cause a systematic difference between analyses done in different counters and especially in different laboratories. The intercalibration of laboratories remains a problem and systematic differences of 20 to 30 years are probably not unusual.

The results obtained thus far are listed in Table 1. In Figure 1, the conventional ^{14}C age is plotted against the dendrochronologic date of the wood samples. Between 2800 and 2900 BC a relatively large deviation in the ^{14}C content occurs, but for the rest of the millennium (1900–2800 BC) the amplitude of the ^{14}C fluctuations is small. In Figure 2, the deviations from the average trend in ^{14}C are plotted to reveal the nature of these medium-term variations. Some of the scatter in the curve will be due to the analytical uncertainty of ca 2‰ for the individual points, but in those cases where deviations from the mean are substantiated by several measurements, the "wiggles" must be accepted as real. Except for the major fluctuation during the 29th century BC, the amplitudes are ca 10‰.

To investigate whether distinct periodicities occur, the series was subjected to Fourier analysis. The limited number of points and their unequal spacing, however, complicates the analysis and the results are influenced by the specific procedure adopted. Nevertheless, a predominant period of ca 90 years does seem to emerge for our data covering the 3rd millennium BC. This is in contrast with the times during which larger fluctuations occur, eg, in the 2nd millennium AD when amplitudes of 20‰ and a period of ca 200 years are obvious (de Vries, 1958; Stuiver, 1982) or during the 1st millennium AD and the 4th millennium BC when a periodicity of 150–180 years has been observed (Bruns, Münnich & Becker, 1980; de Jong & Mook, 1980). Using his own data Suess (1980) found a predominant period of 202 years for the whole time span since 6000 BC. The recurrence period of 90 years during most of the 3rd millennium BC seems to suggest that the smaller amplitudes of 10‰ are not the result of damping of two nearly similar periodicities in the region of 200 years.

Of special interest is the rapidity with which some of the maxima decay. In Figure 3, the two "wiggles" between 2140 and 2320 BC are shown in detail. The second peak at 2190 BC has both a rise and a decay time of <20 years, suggesting that the production rate of ^{14}C must have changed even faster than this. In fact, the decay time is similar to that of the atom bomb ^{14}C in the atmosphere, the production of which was abruptly discontinued in 1962 (Levin *et al*, 1985). A more gradual change in the natural production rate would inevitably increase the rate at which the ^{14}C concentration decreases. It thus seems that in this instance at least we are observing a rather abrupt event. The question arises as to how common such rapid changes have been and further detailed measurement of other "wiggles" in the sequence would undoubtedly increase our understanding of the nature of their underlying causes. Such measurements need to be undertaken on a year-to-year basis since samples comprising, say, 20 annual rings will obscure the rapid changes that seem to be present.

In order to use the data presented here for the calibration of ^{14}C dates, it must be understood that most samples actually consist of a mixture of biogenic material covering several decades. Different calibration curves constructed from running averages over 20, 40, or 80 years, as the case may be, would thus provide the most accurate conversion date (de Jong, 1981). The optimal use of such curves will, however, require that much more care be taken in the selection of the sample material for dating.

In addition, account needs to be taken of the latitudinal gradient in the ^{14}C content of the atmosphere. The previous finding, that wood samples from 42°S Lat contain (4.5 ± 1)‰ less ^{14}C than synchronous wood grown at 42°N Lat (Lerman, Mook & Vogel, 1970), has been verified by comparing 6 pairs of annual rings from two trees grown in the Netherlands (53° N Lat) and Cape Town (34° S Lat), respectively. The results are shown in Table 2. The average difference between the ^{14}C content is (4.56 ± .85)‰, which amply confirms the earlier results. The implication of this is that apparent ^{14}C dates for mid-southern latitudes would all be ca 36 years younger than those for mid-northern latitudes. Since the dendrochronologic series on which calibration curves are based derive from the northern hemisphere, 36 years should be subtracted from southern hemisphere dates before conversion to the absolute (historic) time scale.

At present, the measurements are being extended to link up with the series analyzed by de Jong, which covers the years 3200 to 3900 BC (de Jong & Mook, 1980). Once this has been done, suitable integrated calibration curves spanning the time from the Late Chalcolithic to the beginning of the Middle Bronze Age in the ancient Near East can be constructed. Such curves could then be used for detailed dating of selected archaeologic sites in the region.

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TABLE 1

Conventional ^{14}C ages of samples from the south-central European oak sequence

Lab. No. Pta-	Dendroyear BC	^{14}C age BP	$\delta^{13}C$ ‰
Steinheim 7			
2745	1935-36	3575 ± 11	-25.4
2884	1942-45	3596 ± 17	-25.2
2738	1955-56	3616 ± 14	-25.9
3333	1964-65	3640 ± 20	-25.3
2734	1975-76	3609 ± 14	-26.4
3332	1982-83	3646 ± 16	-25.8
2726	1995-96	3644 ± 15	-26.1
Unterleiterbach 10			
3328	2005-06	3621 ± 19	-24.8
2751	2015-16	3635 ± 16	-25.8
3127	2025-26	3659 ± 18	-24.7
2787	2034-35	3688 ± 14	-25.8
2792	2056	3693 ± 15	-25.5
2799	2075-76	3707 ± 13	-25.4
Vohberg 19			
2856	2093	3705 ± 14	-25.2
3135	2105	3687 ± 20	-26.0
2892	2115	3680 ± 14	-25.5
3132	2124	3701 ± 18	-26.6
2900	2134-35	3707 ± 19	-24.9
3126	2145-46	3760 ± 21	-24.3
2928	2155	3797 ± 14	-24.4
3327	2165	3783 ± 16	-23.7
2983	2175	3779 ± 16	-24.5
3454	2180	3741 ± 16	-24.2
3321	2185	3735 ± 15	-23.5
3469	2190	3715 ± 25	-24.2
2996	2195	3750 ± 18	-25.2
3115	2205	3801 ± 17	-25.3
3006	2215	3855 ± 17	-23.9
Nersingen 40			
3014	2236	3839 ± 16	-25.2
3338	2245	3868 ± 17	-24.5
3016	2255-56	3833 ± 18	-25.3
3303	2265	3807 ± 20	-24.9
3120	2275	3795 ± 19	-26.0
3335	2284	3812 ± 18	-25.2
3123	2295	3855 ± 17	-24.4
Hochstadt-Staustufe 3			
3769	2280-82	3833 ± 20	-26.6
3846	2290-92	3836 ± 19	-26.9
Vohberg 34			
3503	2300-02	3888 ± 17	-26.6
3532	2320-22	3902 ± 21	-26.0
3496	2327-30	3859 ± 13	-26.2
3502	2337-40	3872 ± 14	-25.3
3541	2350-52	3926 ± 15	-25.3
3599	2370-72	3905 ± 15	-25.4
3606	2390-92	3904 ± 22	-26.0
Christiansworth 2			
3514	2407-10	3897 ± 19	-24.9
3519	2417-20	3890 ± 20	-24.6
3525	2427-30	3905 ± 16	-24.6
3539	2437-40	3931 ± 20	-25.6
3552	2447-50	3914 ± 17	-25.5
3568	2467-70	3941 ± 15	-25.6
3593	2490-92	4016 ± 17	-24.6
3613	2510-12	4047 ± 20	-24.5
3607	2510-12	4057 ± 21	-24.9
3619	2530-32	4060 ± 18	-25.6
Pettstadt 48			
3626	2550-52	4033 ± 19	-23.1
3630	2570-72	4053 ± 19	-23.6
3638	2590-92	4114 ± 15	-23.5
3751	2600-02	4119 ± 17	-23.8
3644	2610-12	4072 ± 18	-23.9
3776	2620-22	4116 ± 18	-24.1
3657•	2630-32	4063 ± 26	-23.2
Nersingen 51			
3670	2652-55	4124 ± 20	-25.2
3676	2672-75	4134 ± 18	-26.0
3681	2692-95	4151 ± 18	-25.9
3685	2712-15	4198 ± 18	-26.2
3740	2732-35	4126 ± 15	-25.8
3746	2752-55	4152 ± 21	-25.8
Blindheim 37			
4011	2711-14	4149 ± 18	-25.7
3909	2731-34	4146 ± 20	-26.7
3914	2751-54	4169 ± 20	-25.9
4024	2761-64	4197 ± 18	-25.7
Blindheim 57			
3920	2771-74	4168 ± 18	-26.2
3951	2791-94	4159 ± 21	-26.1
Blindheim 35			
3952	2811-14	4148 ± 16	-24.5
3953	2831-34	4124 ± 18	-24.4
3963	2841-44	4159 ± 15	-24.1
3850	2861-64	4182 ± 19	-24.9
3856	2881-84	4262 ± 21	-24.2
3854	2901-04	4281 ± 19	-25.3
Pettstadt 4			
3861	2921-24	4337 ± 21	-25.6
3878	2941-44	4347 ± 17	-25.6
3867	2961-64	4364 ± 19	-25.4
Bamberg 1			
3885	2981-84	4399 ± 25	-25.0
3888	3001-04	4375 ± 16	-24.7
3901	3021-24	4416 ± 19	-24.7
3904	3041-44	4451 ± 19	-24.9
3968	3061-64	4418 ± 19	-24.7
3979	3081-84	4427 ± 24	-25.1
3991	3096-99	4484 ± 19	-24.1

TABLE 2

Difference between ^{14}C contents of annual rings from an oak grown in northern Netherlands (53°N Lat) and a pine grown in Cape Town (34°S Lat).

Dendroyear AD	Dutch Oak $\Delta^{14}C$ ‰	Cape Town Pine $\Delta^{14}C$ ‰	Difference ‰
1840	-5.0 ± 1.7	- 8.6 ± 1.9	3.6 ± 2.6
1850	-4.2 ± 1.7	- 6.2 ± 1.4	2.0 ± 2.0
1860	-4.8 ± 1.7	- 8.9 ± 1.6	4.1 ± 2.3
1870	-2.8 ± 1.5	-12.3 ± 1.4	9.4 ± 2.1
1879-80	-5.5 ± 1.6	- 9.9 ± 0.9	4.4 ± 1.8
1890	-7.6 ± 1.6	-11.4 ± 1.1	3.9 ± 1.9
		Ave	4.56 ± 0.85

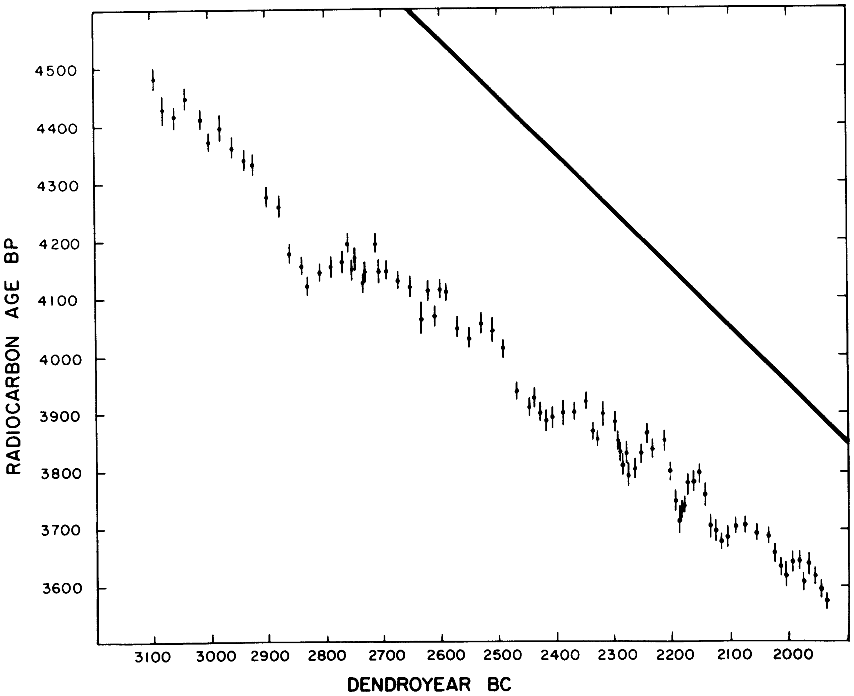

Fig 1. Conventional ^{14}C age plotted against the dendro-age of oak wood from southern Germany (48°N Lat).

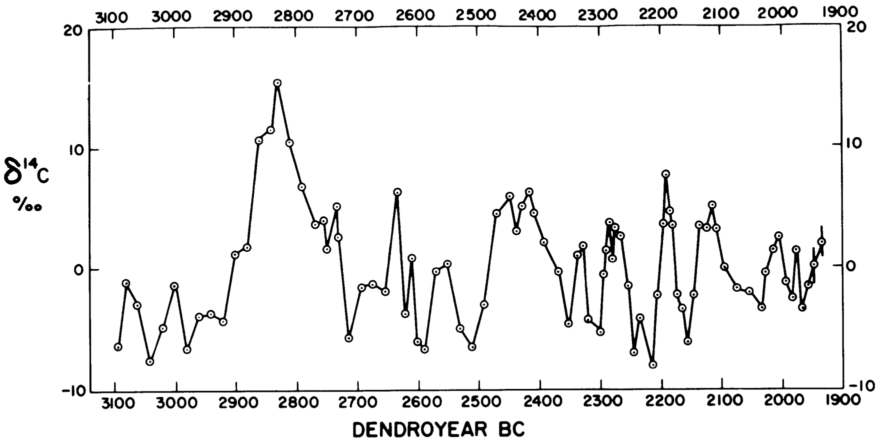

Fig 2. Deviations from the mean trend in the ^{14}C content between 1930 and 3100 BC

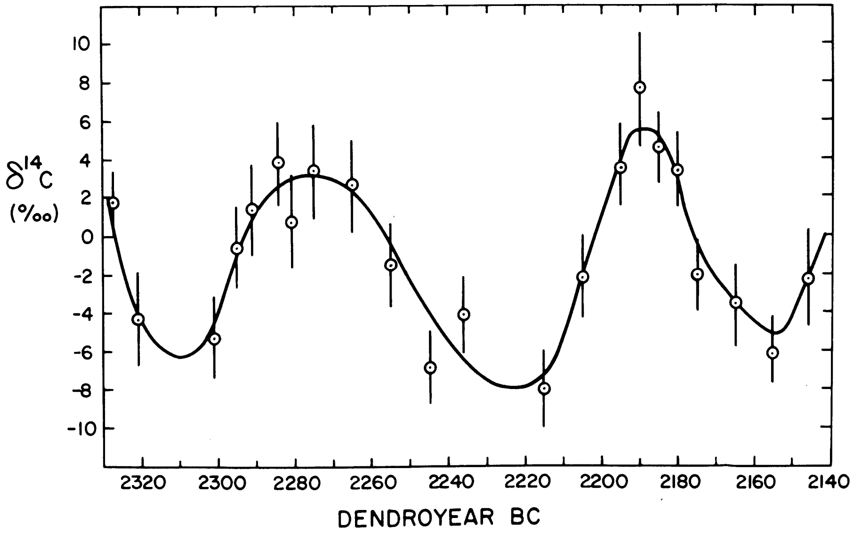

Fig 3. Fluctuations in the ^{14}C content between 2140 and 2320 BC