[RADIOCARBON, VOL. 35, NO. 1, 1993, P. 73–85]

PRETORIA CALIBRATION CURVE FOR SHORT-LIVED SAMPLES, 1930–3350 BC

J. C. VOGEL, ANNEMARIE FULS, EBBIE VISSER

Quaternary Dating Research Unit, CSIR, P.O. Box 395, Pretoria 0001, South Africa

and

BERND BECKER

Institut für Botanik, Universität Hohenheim, D-7000 Stuttgart 70 Germany

The high-precision radiocarbon calibration curve for short-lived samples (1–4 yr) of the early historical period (3rd millennium BC) presented previously (Vogel *et al.* 1986) has been further substantiated and extended to link with a similar curve produced by de Jong for part of the 4th millennium BC (de Jong & Mook 1980). The precise dendrochronological age of the sample set measured by de Jong has finally been fixed (de Jong, Mook & Becker 1989), so that the two sets now cover the period 1930–3900 BC, *i.e.*, the Early Bronze Age and Late Chalcolithic periods of the Middle East. The standard calibration curve for the two sets is presented by Vogel and van der Plicht (1993).

In all, we analyzed 173 samples of 1–4 annual tree rings of the south-central European subfossil oak sequence (Becker 1979). The method of pretreatment and measurement has remained the same, as Vogel *et al.* (1986) briefly described previously. Table 1 lists the results. Because we made certain retrospective adjustments to the 89 analyses presented in our previous paper (Vogel *et al.* 1986), we include them here. For the most part, the corrections are less than 4 yr, but in a few cases, re-evaluation has resulted in larger changes.

The construction of a calibration curve from these data requires some discussion. On the one hand, the individual data points, of necessity, have to scatter on both sides of the actual correlation curve to the degree prescribed by the uncertainty of the measurements. A line connecting successive points would thus show erratic variations that do not correspond to the actual changes in ^{14}C, and some smoothing is necessary. On the other hand, the smoothing procedure should not dampen or eliminate the real "wiggles" in the curve. We feel that the best compromise in this situation is to use a spline curve with "tightness", S = 1, *i.e.*, a curve that passes within 1 σ from 68% of all the data points, but smooths out unsubstantiated variations (Talma & Vogel 1993).

The resulting calibration curve is presented in Figure 1A–C. In Figure 2, the Groningen data (de Jong, Mook & Becker 1989) are added to the Pretoria measurements to show the compatibility of the two sets for the region of overlap. The combined data produce a continuous curve for the period, 1930 to 3900 BC, specifically for calibrating short-lived ^{14}C samples. We consider the 68% confidence level of the curve to be better than the 1 σ errors of individual points, because the adjacent measurements contribute to the estimate of the spline at each point. The validity of our data set has been checked in different ways:

1. We analyzed a set of 13 samples of the bristlecone pine dendrochronological series (Ferguson 1970) in the same counter to verify the tree-ring dating of our series. The samples were chosen from a period when the ^{14}C level was changing rapidly (2830–2960 BC) to achieve maximum sensitivity. Table 2 gives the results of the analyses. The comparison is made by determining the distance on the x axis that the eight samples on the steep part of the calibration curve between 2830 and 2930 BC deviate from the corresponding spline values

through our South German data points. The average deviation is 1.1±4.1 yr, so that we can safely accept that the South German tree-ring dates at 2900 BC correspond to those of the bristlecone pine chronology.

2. It is especially difficult to achieve precise intercalibration among laboratories, and systematic differences of 20–30 yr are probably not unusual between laboratories. With the present data set, we can make very accurate comparisons with other high-precision laboratories. First, we can assess the compatibility of the Groningen data set (de Jong, Mook & Becker 1989) with ours for the period of overlap between 3200 and 3350 BC. By comparing the 25 points of our set in this time range with the corresponding values of the spline through the Groningen data, we find an offset of −7.1 ± 6.4 yr. If the one apparent outlier of our set at 3342 BC is excluded, the difference reduces to −4.2 ± 6.0 yr, *i.e.*, our dates are, on average, 4.2 yr older than those of Groningen. The two sets are thus highly compatible and can be joined without reservation.

3. A similar comparison can be made with the newly adjusted and extended measurements of the Seattle laboratory (Stuiver & Becker 1993). If the 173 points of the Pretoria series are compared with the corresponding values of a spline (S = 1) through the Seattle data, we find an offset of 2.9 ± 1.8 yr, σ = 24.1 yr, indicating that our dates are, on average, 2.9 yr younger than those of Seattle. This means that the calibration of the two laboratories is nearly identical. The standard deviation of 24.1 yr shows that the fluctuations around the spline are of the size to be expected for a sample error of just under 20 yr and an error of ~15 yr in the spline.

We have made more analyses to quantify the difference in ^{14}C ages between the northern and southern hemispheres (Vogel *et al.* 1986). In all, we made 14 comparisons of 1–2 annual rings, covering the 19th century, of an oak grown in Norg, The Netherlands, and a pine grown in Cape Town, South Africa. Table 3 lists the results. The average difference in ^{14}C content between the two sets is 5.1 ±0.6 ‰, which translates to 41 ± 5 yr, a value slightly larger than that reported previously. This value is now used to create a calibration curve for midlatitudes in the southern hemisphere, using the data of Stuiver and Pearson (1993) for the northern hemisphere.

Finally, we measured more precisely the extent of the industrial dilution of ^{14}C (Suess effect) in southern Africa. For this, we secured two pine trees planted in the 1940s in state forests far removed from local city pollution. One tree, planted in 1942, derives from the Jonkershoek forest outside Stellenbosch (33°57′S, 18°57′E). The second, planted in 1947, is from the Mac Mac forest in the eastern Transvaal (25°05′S, 30°47′E). For these measurements, we prepared pure cellulose from the inner annual rings, according to the technique described by Tans, de Jong & Mook (1978), because of the presence of mobile organic substances of later years contaminated by atomic bomb ^{14}C. We also made two analyses on the horn of a Kudu antelope shot in the Erongo Mountains, Namibia (21°39′S, 15°45′E) in 1952. These samples of horn core and horn sheath from the base of the horn should accurately represent the ^{14}C level of vegetation grown in 1950–1952. The ^{14}C analyses of these samples are presented in Table 4. The average ^{14}C depletion, with respect to NBS oxalic acid Δ^{14}C, for the samples dating to 1950–1953, is Δ^{14}C = −24.7 ± 0.9 ‰. This is almost exactly equal to the value for annual tree rings of the years, 1950–1954, of a Douglas fir, reported by Stuiver & Quay (1981). Because ^{14}C in southern Africa during the 19th century was 5.1‰ lower than in the northern hemisphere (Table 3), the ^{14}C dilution in the southern hemisphere was only about 15‰ between 1860 and 1950, compared to the 20‰ obtained for the northern hemisphere by Stuiver and Quay (1981).

The high-precision calibration curves now available make it possible to produce remarkably accurate age determinations with ^{14}C. However, to obtain the maximum benefit from the technique, great care must be taken with the selection of samples. An accurate historic age can be obtained only if the sample consists of material that is undoubtedly contemporaneous with the event to be dated. This means that emphasis should be placed on short-lived organic matter, such as, *e.g.*, charred food remains associated with a specific destruction level. For the time being, the samples should also be large enough, at least 25 g, so that thorough chemical pretreatment can be undertaken. Such an approach, pursued with vigor, would lead to a new phase of ^{14}C dating in which the early and protohistoric periods could be provided with a more precise chronology.

ACKNOWLEDGMENTS

We thank Siep Talma for providing accurate ^{13}C analyses of all the samples, and especially for producing and debugging the computer programs used in the laboratory. We are indebted to D. Liebenberg, Forestek, CSIR, Stellenbosch and E. J. P. Malan, Department of Water Affairs and Forestry, Pretoria, for supplying disks of the Jonkershoek pine and the Mac Mac pine, respectively.

REFERENCES

Becker, B. 1979 Holocene tree-ring series from southern central Europe for archaeology dating, radiocarbon calibration, and stable isotope analysis. *In* Berger, R. and Suess, H. E., eds., *Radiocarbon Dating*, Proceedings of the 9th International ^{14}C Conference. Berkeley/Los Angeles, University of California Press: 554–565.

de Jong, A. F. M. and Mook, W. G. 1980 Medium-term atmospheric ^{14}C variations. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 10th International ^{14}C conference. *Radiocarbon* 22(2): 267–272.

de Jong, A. F. M., Mook, W. G. and Becker, B. 1989 Corrected calibration of the radiocarbon time scale, 3904–3203 cal BC. *Radiocarbon* 31(2): 201–210.

Ferguson, C. W. 1970 Dendrochronology of bristlecone pine, *Pinus aristata*: Establishment of a 7484-year chronology in the White Mountains of eastern-central California. *In* Olsson, I. U., ed., *Radiocarbon Variations and Absolute Chronology*, Proceedings of the 12th Nobel Symposium. New York, John Wiley & Sons: 237–245.

Stuiver, M. and Becker, B. 1993 High-precision decadal calibration of the radiocarbon time scale, AD 1950–6000 BC. *Radiocarbon*, this issue.

Stuiver, M. and Pearson, G. W. 1993 High-precision calibration of the radiocarbon time scale, AD 1950–500 BC and 2500–6000 BC. *Radiocarbon*, this issue.

Stuiver, M. and Quay, P. D. 1981 Atmospheric ^{14}C changes resulting from fossil fuel CO_2 release and cosmic ray flux variability. *Earth and Planetary Science Letters* 53: 349–362.

Talma, A. S. and Vogel, J. C. 1993 A simplified approach to the calibration of radiocarbon dates. *Radiocarbon*, in press.

Tans, P. P., de Jong, A. F. M. and Mook, W. G. 1978 Chemical pretreatment and radial flow of ^{14}C in tree rings. *Nature* 271: 234–235.

Vogel, J. C., Fuls, A., Visser, E. and Becker, B. 1986 Radiocarbon fluctuations during the third millennium BC. *In* Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2B): 935–938.

Vogel, J. C. and van der Plicht, J. 1993 Calibration curve for short-lived samples, 1900–3900 BC. *Radiocarbon*, this issue.

TABLE 1. Conventional ^{14}C ages and $\Delta^{14}C$ of tree-ring samples from the South German oak tree-ring sequence

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
Steinheim 7				
2745	1935–36	3580 ± 8	−25.3	+24.5 ± 0.9
2884	1942–45	3596 ± 18	−25.2	+23.5 ± 2.2
2738	1955–56	3618 ± 14	−25.9	+22.3 ± 1.7
3333	1964–65	3639 ± 20	−25.3	+20.7 ± 2.5
2734	1975–76	3608 ± 14	−26.4	+25.9 ± 1.7
3332	1982–83	3645 ± 17	−25.8	+22.2 ± 2.0
2726	1995–96	3644 ± 15	−26.1	+23.8 ± 1.9
Unterleiterbach 19				
3328	2005–06	3619 ± 19	−24.8	+28.2 ± 2.4
2751	2015–16	3636 ± 16	−25.8	+27.2 ± 2.0
3127	2025–26	3658 ± 18	−24.7	+25.8 ± 2.2
2787	2034–35	3689 ± 14	−25.8	+22.8 ± 1.7
4495	2044–45	3699 ± 27	−24.9	+22.9 ± 3.3
2792	2056	3694 ± 15	−25.5	+24.8 ± 1.9
4510	2065	3760 ± 21	−25.5	+17.7 ± 2.6
2799	2075–76	3707 ± 13	−25.4	+25.8 ± 1.6
4503	2085–86	3738 ± 20	−26.0	+23.0 ± 2.4
Vohberg 19				
2856	2093	3705 ± 14	−25.2	+28.2 ± 1.7
3135	2105	3686 ± 20	−26.0	+32.0 ± 2.5
2892	2115	3680 ± 14	−25.5	+34.0 ± 1.7
3132	2124	3698 ± 18	−26.6	+32.8 ± 2.2
2900	2134–35	3707 ± 19	−24.9	+33.1 ± 2.4
3126	2145–46	3760 ± 20	−24.3	+27.6 ± 2.6
4113	2149–50	3731 ± 18	−24.5	+31.8 ± 2.2
2928	2155	3797 ± 14	−24.4	+24.1 ± 1.8
4096	2159–60	3768 ± 19	−24.9	+28.5 ± 2.4
3327	2165	3782 ± 16	−23.7	+27.3 ± 1.9
2983	2175	3779 ± 16	−24.5	+28.8 ± 1.9
3454	2180	3739 ± 16	−24.2	+34.8 ± 1.9
3321	2185	3734 ± 15	−23.5	+35.8 ± 1.9
3469	2190	3713 ± 25	−24.2	+39.4 ± 3.0
2996	2195	3750 ± 18	−25.2	+35.2 ± 2.2
3115	2205	3801 ± 17	−25.3	+29.7 ± 2.1
3006	2215	3855 ± 17	−23.9	+24.2 ± 2.1
Nersingen 40				
4107	2220–21	3821 ± 18	−24.8	+29.1 ± 2.3
4101	2230–31	3832 ± 16	−25.6	+29.0 ± 2.1
3014	2236	3840 ± 16	−25.2	+28.7 ± 1.9
4147	2239	3806 ± 18	−25.4	+33.5 ± 2.3
3338	2245	3867 ± 17	−24.5	+26.4 ± 2.1
3016	2255–56	3834 ± 18	−25.3	+31.7 ± 2.3
3303	2265	3806 ± 20	−24.9	+36.7 ± 2.4
3120	2275	3808 ± 19	−26.0	+37.5 ± 2.4
Hochstadt–Staustufe 3				
3769	2280–82	3830 ± 20	−26.6	+35.5 ± 2.6
Nersingen 40				
3335	2284	3810 ± 18	−25.2	+38.5 ± 2.3

TABLE 1. (Continued)

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
Hochstadt–Staustufe 3				
3846	2290–92	3850 ± 19	−26.9	+34.2 ± 2.4
Nersingen 40				
3123	2295	3854 ± 17	−24.4	+34.2 ± 2.1
Hochstadt–Staustufe 3				
3503	2300–02	3886 ± 17	−26.6	+30.8 ± 2.1
4512	2310–12	3898 ± 18	−27.4	+30.5 ± 2.3
Vohberg 34				
3532	2320–22	3900 ± 21	−26.0	+31.4 ± 2.6
3496	2327–30	3857 ± 13	−26.2	+38.0 ± 1.6
3502	2337–40	3870 ± 14	−25.3	+37.5 ± 1.8
3541	2350–52	3924 ± 15	−25.3	+32.2 ± 1.8
4518	2360–62	3911 ± 24	−25.5	+35.0 ± 2.9
3599	2370–72	3905 ± 15	−25.4	+37.1 ± 2.0
4509	2380–82	3888 ± 19	−26.1	+40.7 ± 2.4
3606	2390–92	3902 ± 22	−26.0	+40.2 ± 2.8
Christiansworth 2				
3514	2407–10	3895 ± 19	−24.9	+43.1 ± 2.4
3519	2417–20	3888 ± 20	−24.6	+45.3 ± 2.4
3525	2427–30	3904 ± 16	−24.6	+44.5 ± 1.9
3539	2437–40	3929 ± 20	−25.6	+42.6 ± 2.4
3552	2447–50	3913 ± 17	−25.5	+45.9 ± 2.1
3568	2467–70	3939 ± 15	−25.6	+45.0 ± 1.8
4524	2480–82	3987 ± 20	−25.3	+40.4 ± 2.5
3593	2490–92	4014 ± 17	−24.6	+38.3 ± 2.1
4525	2500–02	4037 ± 18	−25.2	+36.5 ± 2.3
3607	2510–12	4055 ± 21	−24.9	+35.3 ± 2.6
3613	2510–12	4045 ± 20	−24.5	+36.8 ± 2.5
4533	2520–22	4040 ± 21	−25.6	+38.5 ± 2.6
3619	2530–32	4058 ± 18	−25.6	+37.5 ± 2.2
Pettstadt 48				
4540	2540–42	3995 ± 14	−24.2	+47.0 ± 1.8
3626	2550–52	4031 ± 19	−23.1	+43.6 ± 2.5
4545	2560–62	3982 ± 21	−23.9	+51.1 ± 2.6
3630	2570–72	4051 ± 19	−23.6	+43.5 ± 2.5
4360	2580–82	4107 ± 17	−23.7	+37.4 ± 2.2
3638	2590–92	4112 ± 15	−23.5	+37.9 ± 1.8
3751	2600–02	4116 ± 17	−23.8	+38.9 ± 2.2
3644	2610–12	4069 ± 18	−23.9	+46.1 ± 2.2
3776	2620–22	4113 ± 18	−24.1	+41.7 ± 2.3
3657	2630–32	4092 ± 19	−24.3	+45.8 ± 2.3
4338	2640–42	4142 ± 21	−24.0	+40.2 ± 2.7
Nersingen 51				
3670	2652–55	4121 ± 20	−25.2	+44.6 ± 2.5
4554	2662–65	4143 ± 15	−26.0	+43.2 ± 1.8
3676	2672–75	4131 ± 18	−26.0	+45.8 ± 2.2
4485	2682–85	4176 ± 14	−26.3	+41.4 ± 1.7
3681	2692–95	4148 ± 18	−25.9	+46.4 ± 2.4
4371	2702–05	4175 ± 16	−26.8	+44.1 ± 2.0
Blindheim 37				
4011	2711–14	4145 ± 18	−25.7	+49.1 ± 2.2

TABLE 1. (Continued)

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
Nersingen 51				
3685	2712–15	4195 ± 18	−26.2	+42.7 ± 2.4
Blindheim 37				
4244	2721–24	4153 ± 18	−26.9	+49.4 ± 2.2
3909	2731–34	4149 ± 20	−26.7	+51.1 ± 2.5
Nersingen 51				
3740	2732–35	4125 ± 15	−25.8	+54.3 ± 2.0
Blindheim 37				
4498	2741–44	4129 ± 27	−26.3	+55.1 ± 3.4
3914	2751–54	4170 ± 18	−25.9	+50.9 ± 2.2
Nersingen 51				
3746	2752–55	4149 ± 21	−25.8	+53.6 ± 2.5
Blindheim 37				
4024	2761–64	4193 ± 18	−25.7	+49.3 ± 2.2
3920	2771–74	4172 ± 22	−26.2	+53.2 ± 2.7
4031	2781–84	4214 ± 17	−25.9	+48.9 ± 2.0
4448	2786–89	4175 ± 18	−25.8	+54.8 ± 2.4
3951	2791–94	4165 ± 21	−26.1	+56.6 ± 2.5
4387	2801–04	4180 ± 14	−25.1	+56.1 ± 1.9
3952	2811–14	4146 ± 16	−24.5	+61.7 ± 2.0
4238	2821–24	4114 ± 18	−24.5	+67.4 ± 2.3
3953	2831–34	4124 ± 18	−24.4	+67.4 ± 2.3
4158	2836–39	4172 ± 18	−24.0	+61.3 ± 2.2
3963	2841–44	4163 ± 15	−24.1	+63.2 ± 1.8
4163	2851–54	4170 ± 17	−24.2	+63.7 ± 2.2
3850	2861–64	4202 ± 19	−24.9	+60.9 ± 2.4
4490	2866–69	4181 ± 15	−24.4	+64.1 ± 1.8
4460	2876–79	4222 ± 15	−25.3	+59.9 ± 1.9
3856	2881–84	4300 ± 21	−24.2	+50.3 ± 2.6
4294	2891–94	4284 ± 15	−24.6	+53.7 ± 1.9
3854	2901–04	4308 ± 20	−25.3	+51.9 ± 2.4
4397	2906–09	4342 ± 19	−24.3	+48.0 ± 2.2
4181	2911–14	4350 ± 17	−24.9	+47.7 ± 2.1
4561	2916–19	4358 ± 18	−25.4	+47.2 ± 2.2
Pettstadt 4				
3861	2921–24	4371 ± 21	−25.6	+46.1 ± 2.6
4175	2931–34	4377 ± 19	−25.7	+46.9 ± 2.4
3878	2941–44	4361 ± 18	−25.6	+50.1 ± 2.2
4130	2946–49	4383 ± 20	−24.7	+47.9 ± 2.6
4285	2956–59	4389 ± 16	−25.1	+48.4 ± 1.9
3867	2961–64	4393 ± 19	−25.4	+48.6 ± 2.2
4037	2971–74	4381 ± 19	−25.5	+51.2 ± 2.4
Bamberg 1				
3885	2981–84	4395 ± 25	−25.0	+50.6 ± 3.1
4456	2986–89	4394 ± 17	−24.7	+51.4 ± 2.1
4058	2991–94	4376 ± 20	−24.9	+54.4 ± 2.6
3888	3001–04	4382 ± 16	−24.7	+55.1 ± 2.1
4125	3011–14	4417 ± 20	−24.5	+51.8 ± 2.4
3901	3021–24	4423 ± 19	−24.7	+52.0 ± 2.4
4483	3026–29	4451 ± 19	−24.9	+49.2 ± 2.3

TABLE 1. (Continued)

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
Bamberg 1 (continued)				
4119	3031–34	4511 ± 20	–24.7	+42.0 ± 2.5
4415	3036–39	4451 ± 16	–25.0	+50.3 ± 2.1
3904	3041–44	4459 ± 19	–24.9	+50.0 ± 2.4
4069	3051–54	4424 ± 22	–24.7	+55.8 ± 2.8
3968	3061–64	4414 ± 19	–24.7	+58.4 ± 2.4
4073	3071–74	4407 ± 17	–24.9	+60.7 ± 2.1
3979	3081–84	4423 ± 24	–25.1	+59.8 ± 2.9
4089	3091–94	4439 ± 19	–24.6	+58.9 ± 2.3
3991	3096–99	4480 ± 19	–24.1	+54.3 ± 2.3
Pettstadt 123				
4836	3106–09	4492 ± 20	–25.6	+53.9 ± 2.5
4933	3116–19	4494 ± 19	–26.6	+55.1 ± 2.3
4830	3126–29	4521 ± 18	–25.5	+52.5 ± 2.3
4929	3136–39	4523 ± 19	–25.5	+53.6 ± 2.3
4825	3146–49	4528 ± 18	–25.0	+54.2 ± 2.3
4891	3156–59	4506 ± 19	–24.8	+58.6 ± 2.3
4820	3166–69	4487 ± 19	–25.3	+62.3 ± 2.4
4885	3176–79	4496 ± 16	–25.1	+62.4 ± 1.9
4787	3186–89	4505 ± 20	–25.7	+62.5 ± 2.5
4870	3196–99	4544 ± 19	–26.1	+58.5 ± 2.5
Pettstadt 123 & 127				
4934	3201–04	4527 ± 19	–26.2	+61.4 ± 2.3
4680	3206–09	4514 ± 19	–25.7	+63.8 ± 2.3
4963	3211–14	4511 ± 17	–26.1	+64.9 ± 2.1
Pettstadt 123				
4866	3216–19	4476 ± 18	–25.5	+70.1 ± 2.3
Pettstadt 123 & 127				
4966	3221–24	4481 ± 11	–26.7	+70.3 ± 1.4
Pettstadt 123 & Erlach 43				
4715	3226–29	4551 ± 21	–25.9	+61.5 ± 2.6
Erlach 43				
5125	3231–34	4496 ± 17	–24.8	+69.4 ± 2.1
4859	3236–39	4489 ± 20	–25.0	+71.2 ± 2.4
5130	3241–44	4474 ± 19	–25.3	+73.6 ± 2.4
5135	3246–49	4479 ± 17	–25.0	+73.4 ± 2.1
4709	3251–54	4471 ± 20	–25.7	+75.4 ± 2.4
5147	3256–59	4449 ± 19	–25.0	+78.9 ± 2.4
4853	3261–64	4425 ± 15	–25.0	+82.9 ± 1.9
5142	3266–69	4492 ± 18	–24.8	+74.5 ± 2.3
4691	3271–74	4528 ± 20	–25.1	+70.5 ± 2.5
4810	3276–79	4498 ± 17	–24.9	+75.0 ± 2.1
4848	3281–84	4482 ± 15	–24.7	+77.7 ± 1.9
5152	3286–89	4502 ± 16	–24.9	+75.8 ± 1.9
4702	3291–94	4539 ± 20	–25.2	+71.4 ± 2.5
4958	3296–99	4467 ± 14	–25.1	+81.9 ± 1.7
4781	3301–04	4495 ± 18	–25.2	+78.8 ± 2.3
4774	3311–14	4490 ± 20	–25.1	+80.6 ± 2.4
4840	3321–24	4490 ± 19	–25.1	+81.7 ± 2.4

TABLE 1. (Continued)

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
Erlach 43 (continued)				
4696	3331–34	4501 ± 19	−25.1	+81.7 ± 2.3
4797	3341–44	4591 ± 19	−24.6	+71.1 ± 2.3
4804	3346–49	4534 ± 20	−24.9	+79.3 ± 2.5

TABLE 2. Conventional ^{14}C ages and $\Delta^{14}C$ of decadal tree-ring samples from Stump TRL77-122 of the bristlecone pine tree-ring sequence, California, USA

Pta-no.	Cal BC	^{14}C age (yr BP)	$\delta^{13}C$ (‰)	$\Delta^{14}C$ (‰)
3410	2830–40	4172 ± 17	−20.7	61.0 ± 2.2
3812	2860–70	4198 ± 15	−20.7	61.6 ± 1.9
4216	2870–80	4210 ± 18	−20.9	61.2 ± 2.3
3826	2880–90	4232 ± 20	−20.6	59.5 ± 2.5
4295	2890–2900	4292 ± 15	−20.8	53.0 ± 1.9
3817	2900–10	4326 ± 20	−20.7	49.8 ± 2.4
4315	2910–20	4358 ± 14	−20.5	46.9 ± 1.7
3831	2920–30	4329 ± 25	−20.6	52.0 ± 3.1
4194	2930–40	4391 ± 16	−21.0	45.2 ± 2.0
4190	2940–45	4384 ± 17	−21.2	47.0 ± 2.1
3415	2940–50	4400 ± 18	−21.3	45.2 ± 2.3
4213	2950–60	4419 ± 15	−20.9	44.1 ± 1.9
3830	2960–70	4373 ± 23	−20.7	51.4 ± 2.8

TABLE 3. Comparison of the ^{14}C content of 19th-century wood grown in Norg, The Netherlands and Cape Town, South Africa

Dutch oak		Cape Town pine		
Dendroyear AD	$\Delta^{14}C$ (‰)	Dendroyear AD	$\Delta^{14}C$ (‰)	Difference (‰)
1835	2.4 ± 1.4	1835	−1.5 ± 1.7	3.9 ± 2.2
1840	−4.6 ± 1.7	1840	−9.0 ± 1.9	4.4 ± 2.6
1844–45	−2.7 ± 1.7	1845	−5.0 ± 1.9	2.3 ± 2.6
1850	−3.9 ± 1.7	1850	−7.2 ± 1.4	3.3 ± 2.2
1854–55	−1.7 ± 1.7	1855	−6.9 ± 1.3	5.2 ± 2.1
1860	−4.2 ± 1.8	1860	−9.3 ± 1.6	5.1 ± 2.4
1865	−3.8 ± 1.2	1864	−10.8 ± 1.7	7.0 ± 2.1
1870	−2.5 ± 1.5	1870	−12.7 ± 1.4	10.2 ± 2.1
1874–75	−3.9 ± 1.9	1874–75	−13.0 ± 1.4	9.1 ± 2.4
1880	−5.1 ± 1.6	1879	−10.2 ± 0.9	5.1 ± 1.8
1885	−4.4 ± 1.6	1885–86	−11.6 ± 1.8	7.2 ± 2.4
1890	−7.2 ± 1.6	1890	−11.8 ± 1.1	4.6 ± 1.9
1895	−3.9 ± 2.0	1895	−7.9 ± 1.6	4.0 ± 2.6
1900	−8.6 ± 1.3	1900	−9.1 ± 1.5	0.5 ± 2.0
			Average	5.14 ± 0.59
				(41 ± 5 yr)

TABLE 4. ^{14}C analysis of the industrial effect in southern Africa

Pta-no.	Sample	Date (AD)	^{14}C age (yr BP)	$\Delta^{14}C$ (‰)
5643	Mac Mac pine	1950	198 ± 21	−24.3 ± 2.6
5635	Jonkershoek pine	1950	201 ± 19	−24.8 ± 2.3
5639	Jonkershoek pine	1953	207 ± 21	−25.4 ± 2.6
5564	Erongo Kudu horn core	1951	213 ± 11	−26.1 ± 1.4
5556	Erongo Kudu horn sheath	1951	184 ± 13	−22.6 ± 1.6
		Average	201 ± 7	−24.7 ± 0.9

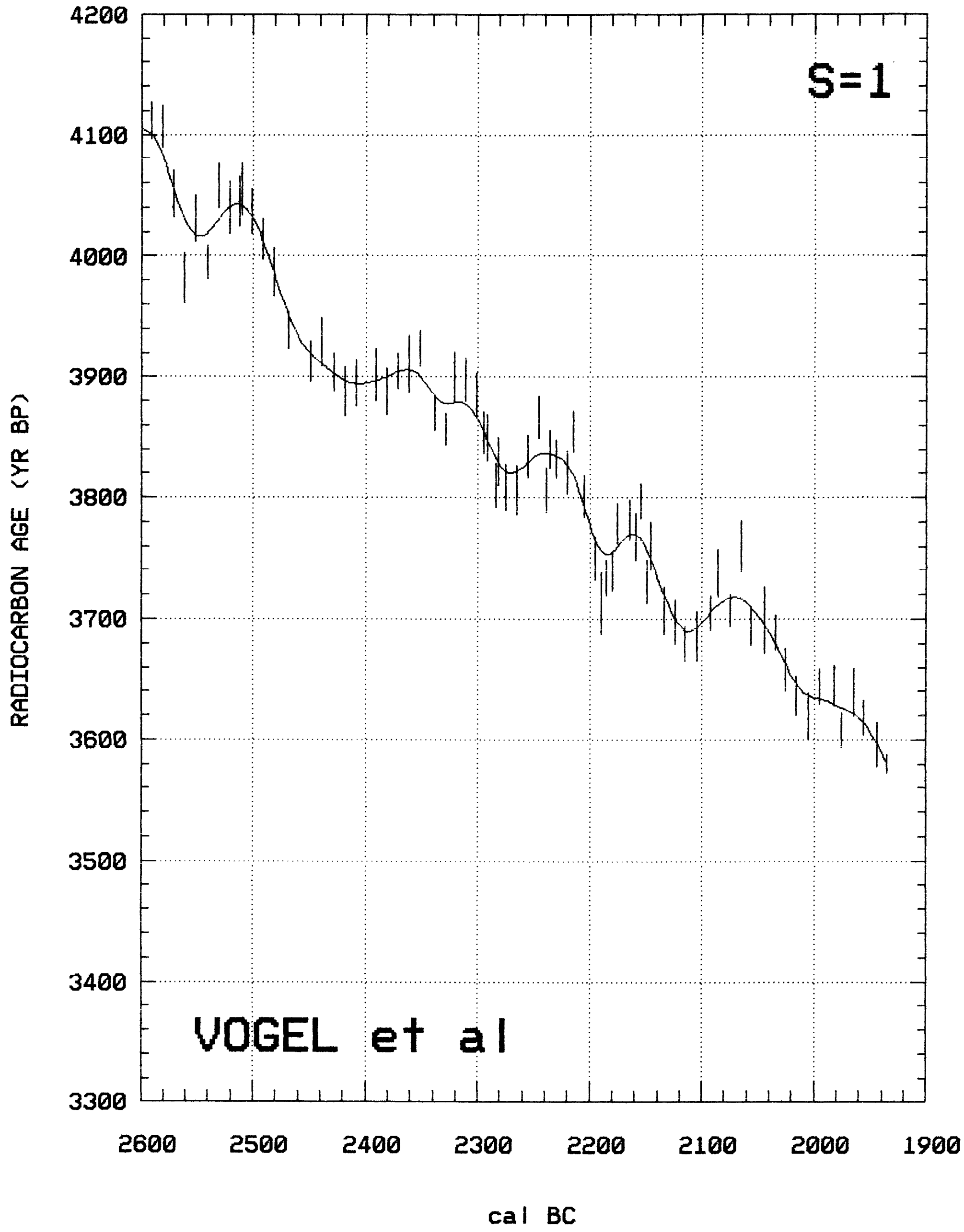

Fig. 1A–C. Pretoria radiocarbon measurements, 1930–3350 BC, with ± 1 σ error bars and a spline drawn through the points with a "tightness", S = 1

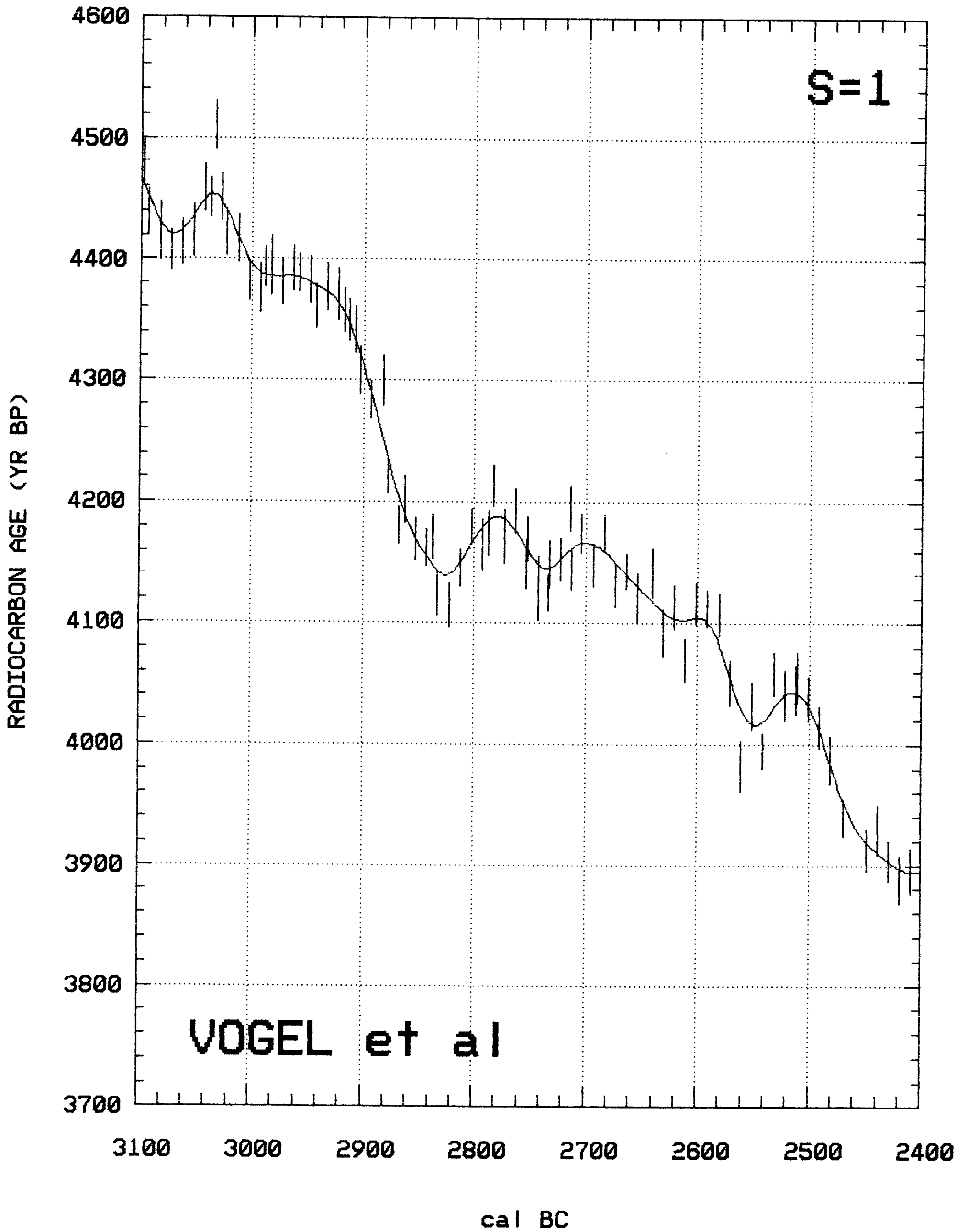
S=1
VOGEL et al
RADIOCARBON AGE (YR BP)
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3100
3000
2900
2800
2700
2600
2500
2400
cal BC

Fig. 1B

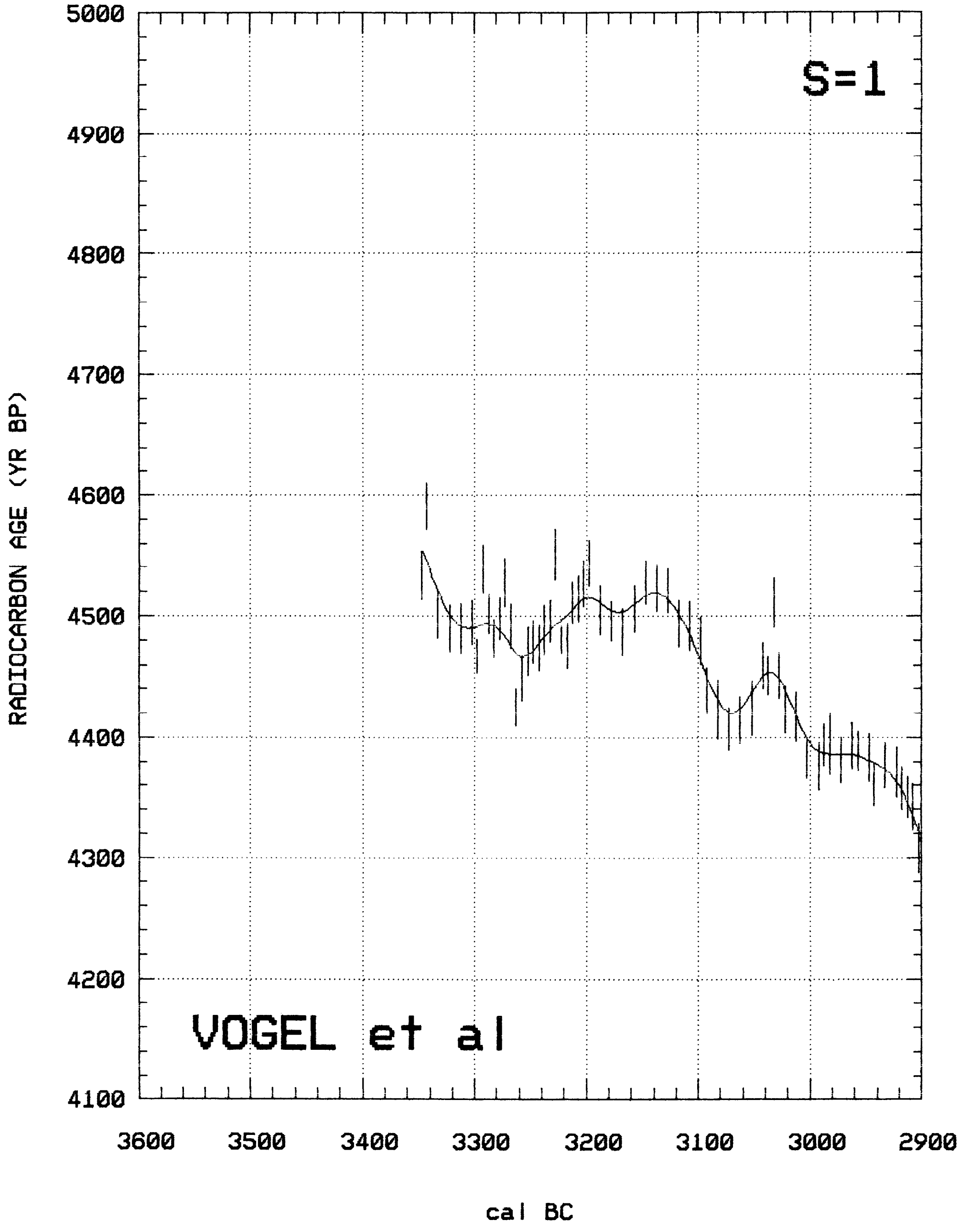
5000
4900
4800
4700
4600
4500
4400
4300
4200
4100
S=1
VOGEL et al
RADIOCARBON AGE (YR BP)
3600
3500
3400
3300
3200
3100
3000
2900
cal BC

Fig. 1C

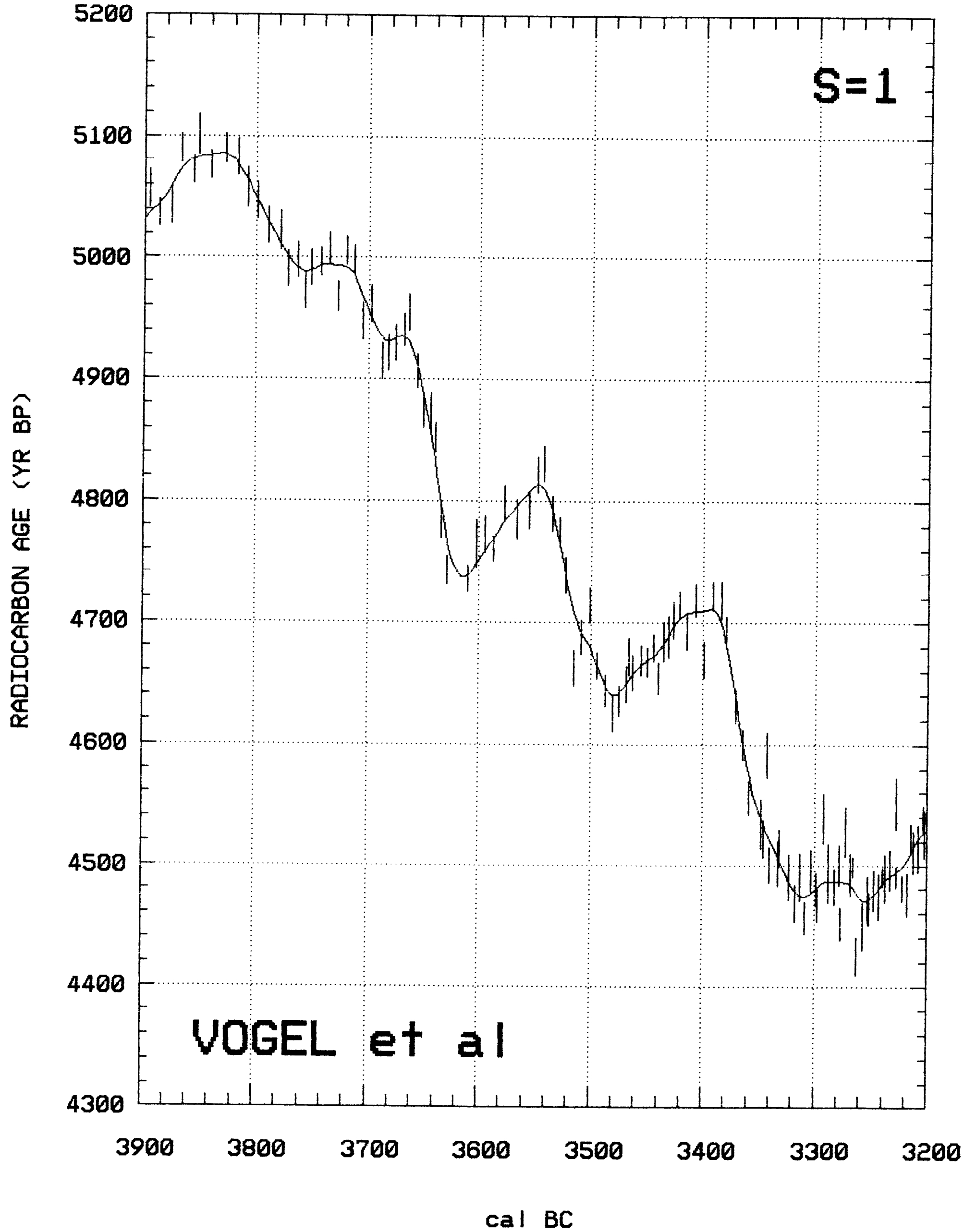

Fig. 2. Pretoria radiocarbon measurements, 3200–3350 BC, combined with those of Groningen for 3200–3900 BC. The smoothed curve through the points is the spline (S = 1) calculated for the entire data sets of Pretoria and Groningen, and differs only very slightly from that in Figure 1C for the overlap period.