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HIGH-PRECISION BIDECADAL CALIBRATION OF THE RADIOCARBON TIME SCALE, 500-2500 BC

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INTRODUCTION

The sole purpose of this paper is to present a previously published ^{14}C data set to which minor corrections have been applied. All basic information previously given is still applicable (Pearson & Stuiver 1986). The corrections are needed because ^{14}C count-rate influences (radon decay in Seattle, a re-evaluation of the corrections applied for efficiency variation with time previously unrecognized in Belfast) had to be accounted for in more detail. Information on the radon correction is given in Stuiver and Becker (1993). The Belfast corrections were necessary because the original correction for efficiency variations with time was calculated using two suspect standards (these were shown to be suspect by recent observations) that overweighted the correction. A re-evaluation (Pearson & Qua 1993) now shows it to be almost insignificant, and the corrected dates (using the new correction) became older by about 16 years.

Systematic ^{14}C age differences between the current Seattle and Belfast data sets are 9.9, 16.6 and 2.4 ^{14}C yr for, respectively, the 1-1000 BC, 1001-2000 BC and 2001-3000 BC intervals. Reproducibility can be expressed by an error multiplier, $K_{Seattle-Belfast}$, which is defined as the ratio of the actual standard deviation in the age differences and the average standard deviation of the differences calculated from the quoted errors in the ^{14}C determinations. K values for the above intervals are, respectively, 1.3, 1.4 and 1.8. A detailed discussion of the offsets and K values for the AD 1840-6000 BC interval is given in Stuiver and Pearson (1992, 1993). Here we note: 1) the Table 1 Seattle-Belfast bidecadal conventional (Stuiver & Polach 1977) ^{14}C age averages may be subject to systematic errors of 5-8 ^{14}C yr maximally; and 2) the standard deviations given with the bidecadal ^{14}C ages are based on quoted errors multiplied with $K_{Belfast}$ = 1.23 and $K_{Seattle}$ = 1.6, and thus account for 90-100% of the variance encountered in the Seattle-Belfast ^{14}C age differences. Details on K determinations can be found, *e.g.*, in Stuiver and Pearson (1986).

Seattle-Belfast bidecadal ^{14}C age averages for the AD 1840-500 BC and 2500-6000 BC interval are given in a twin paper (Stuiver & Pearson 1993).

CALIBRATION INSTRUCTIONS

We recommend that users of ^{14}C dates obtain additional information on reproducibility (and systematic error, if any) from the laboratory reporting the ^{14}C date. This information should lead to a realistic standard deviation in the reported age. A systematic error has to be deducted from, or added to, the reported ^{14}C age prior to age calibration.

Only the calibration curve is given in Figure 1; the one-sigma (1σ; standard deviation) uncertainty in the curve is not given. The actual standard deviation (averaging 12.9 ^{14}C yr for the nearly 8000 cal yr bidecadal calibration curve of Belfast-Seattle ^{14}C age averages) is tabulated in Table 1 for each bidecadal midpoint.

Cal BP ages are relative to the year AD 1950, with 0 cal BP equal to AD 1950. The relationship between cal AD/BC and cal BP ages is cal BP = 1950 − cal AD, and cal BP = 1949 + cal BC. The switch from 1950 to 1949 when converting BC ages is caused by the absence of the zero year in the AD/BC chronology.

The conversion of a ^{14}C age to a cal age is as follows: 1) draw line A parallel to the bottom axis through the ^{14}C age to be converted; 2) draw vertical line(s) through the intercept(s) of line A and the calibration curve. The cal AD/BC ages can be read at the bottom axis, the cal BP ages at the top.

To convert the standard error in the ^{14}C age into a range of cal AD/BC (BP) ages, determine the sample standard deviation, σ, by multiplying the quoted laboratory standard deviation by the "error multiplier". Unfortunately, information on error multipliers is often lacking. Here, the ^{14}C age user should refer to K values given in Stuiver and Pearson (1992, 1993) or Scott, Long & Kra (1990).

Once the sample σ is known, the curve σ should be read from Table 1. The curve σ and sample σ should then be used to calculate total $\sigma = ((\text{sample } \sigma)^2 + (\text{curve } \sigma)^2)^{1/2}$ (Stuiver 1982). Lines parallel to A should now be drawn through the ^{14}C age + total σ, and ^{14}C age − total σ value. The vertical lines drawn through the intercepts now yield the outer limits of possible cal AD/BC (cal BP) ages that are compatible with the sample standard deviation.

The conversion procedure yields 1) single or multiple cal AD/BC (BP) ages that are compatible with a certain ^{14}C age, and 2) the range(s) of cal ages that correspond(s) to the standard deviation in the ^{14}C age (and calibration curve). Here, the user determines the calibrated ages from the Figure 1 graphs by drawing lines, whereas an alternate approach would be to use the computerized calibration (CALIB) program discussed elsewhere in this issue (Stuiver & Reimer 1993).

The probability that a certain cal age is the actual sample age may be quite variable within the cal age range. Higher probabilities are encountered around the intercept ages. The non-linear transform of a Gaussian standard deviation around a ^{14}C age into cal AD/BC (cal BP) age is not a simple matter, and computer programs are needed to derive the complex probability distribution. The CALIB program incorporates such probability distributions.

The calibration data presented here are valid for northern hemispheric samples that were formed in equilibrium with atmospheric $^{14}CO_2$. Systematic age differences are possible for the southern hemisphere where ^{14}C ages of wood samples tend to be about 40 yr older (Vogel *et al.* 1993). Thus, ^{14}C ages of southern hemispheric samples preceding our era of fossil-fuel combustion should be reduced by 40 yr before being converted into cal AD/BC (BP) ages.

The Figure 1 calibration points are the midpoints of wood samples spanning 20 yr. Samples submitted for dating may cover shorter or longer intervals. The decadal calibration results of the Seattle laboratory (Stuiver & Becker 1993; Stuiver & Reimer 1993) provide a better time resolution, whereas the CALIB program also has an option to use Figure 1 moving averages (*e.g.*, a 5-point or 100-yr moving average of the bidecadal curve). The latter should be used for a sample grown over a 100-yr interval. Samples formed over intervals longer than a decade or bidecade are very desirable as the ^{14}C "wiggles" of the calibration curve have less influence on the (midpoint) cal age when a smoothed (moving average) calibration curve is used (Stuiver 1992).

The calibration curve is valid only for age conversion of samples that were formed in equilibrium with atmospheric CO_2. Conventional ^{14}C ages of materials not in equilibrium with atmospheric reservoirs do not take into account the offset in ^{14}C age that may occur (Stuiver & Polach 1977). This constant offset, or reservoir deficiency, must be deducted from the reported ^{14}C age before any attempt can be made to convert to cal AD/BC (BP) ages.

The reservoir deficiency is time dependent for the mixed (and deep) layer of the ocean. For the calibration of marine samples in this time domain, the reader is referred to Stuiver and Braziunas (1993) and, of course, the CALIB program.

Acknowledgments

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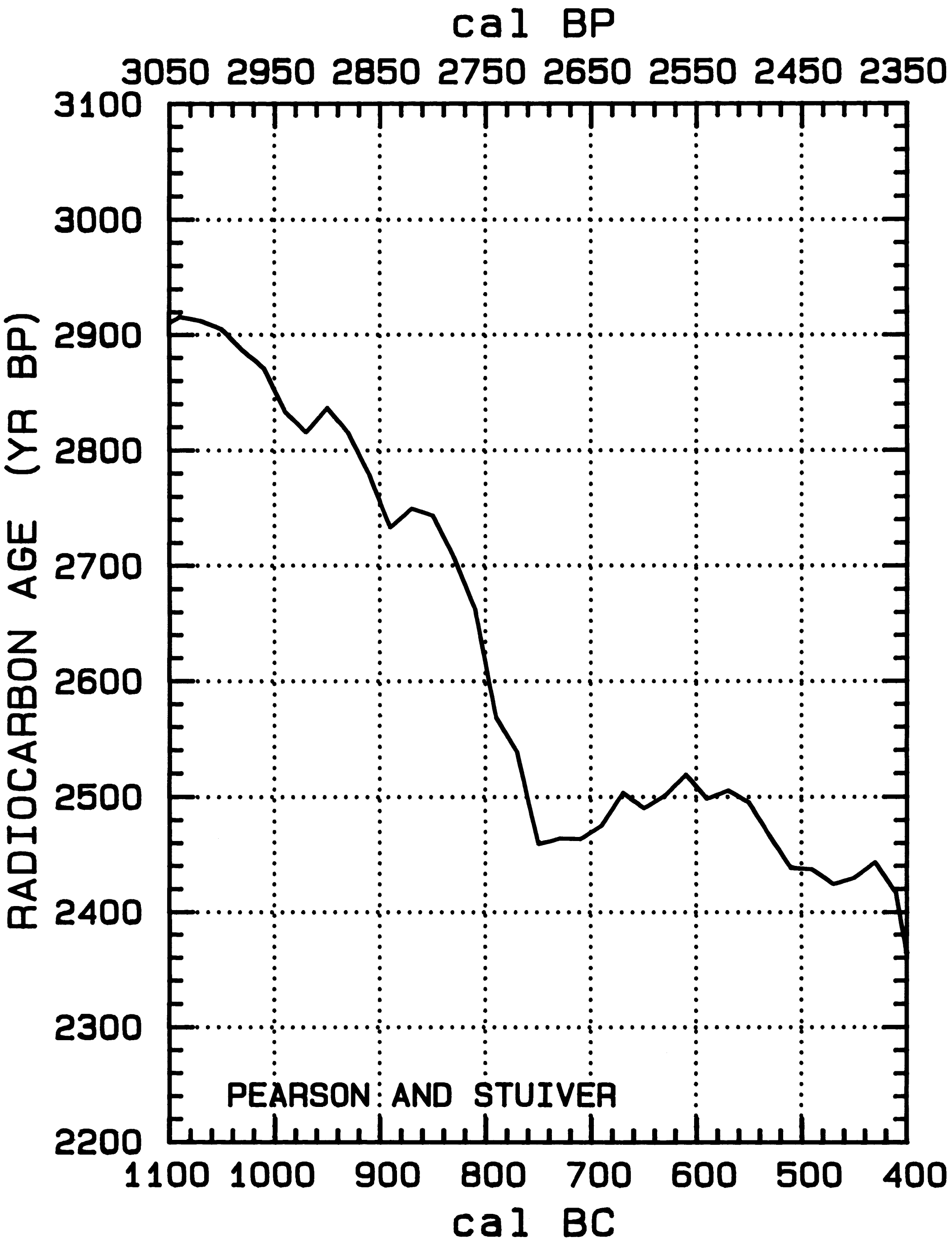

Fig. 1A–D. ^{14}C calibration curve derived from bidecadal samples

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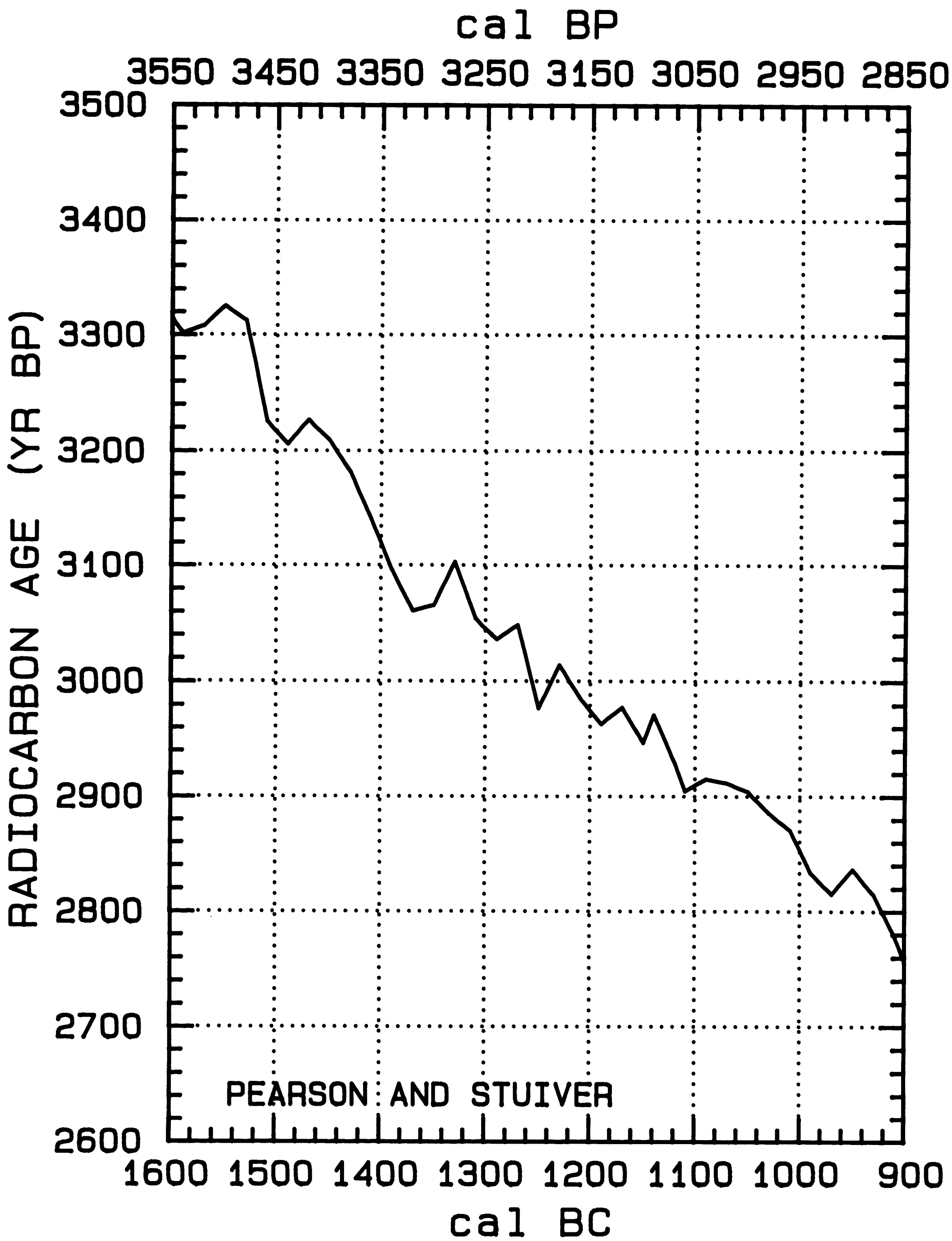

Fig. 1B

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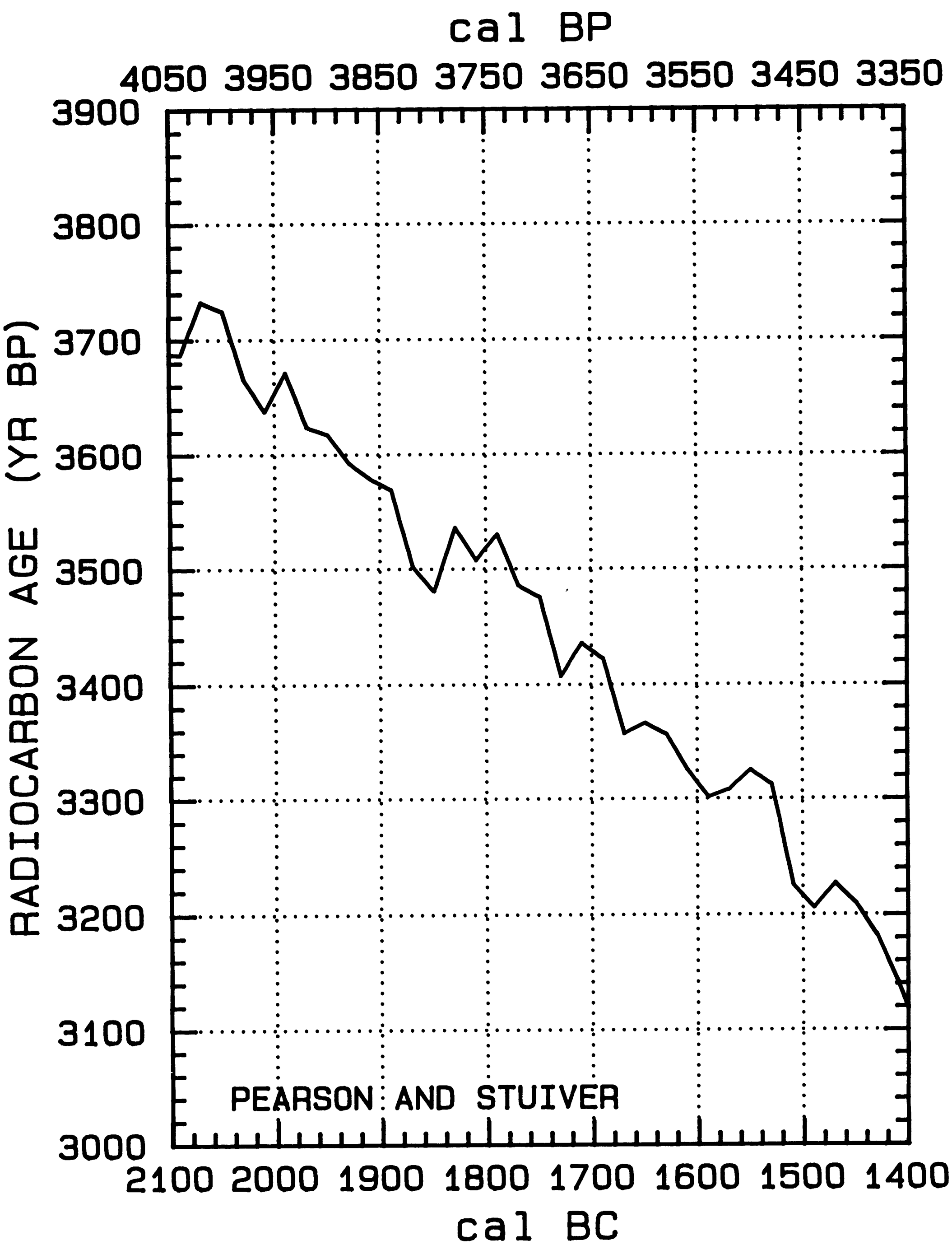

Fig. 1C

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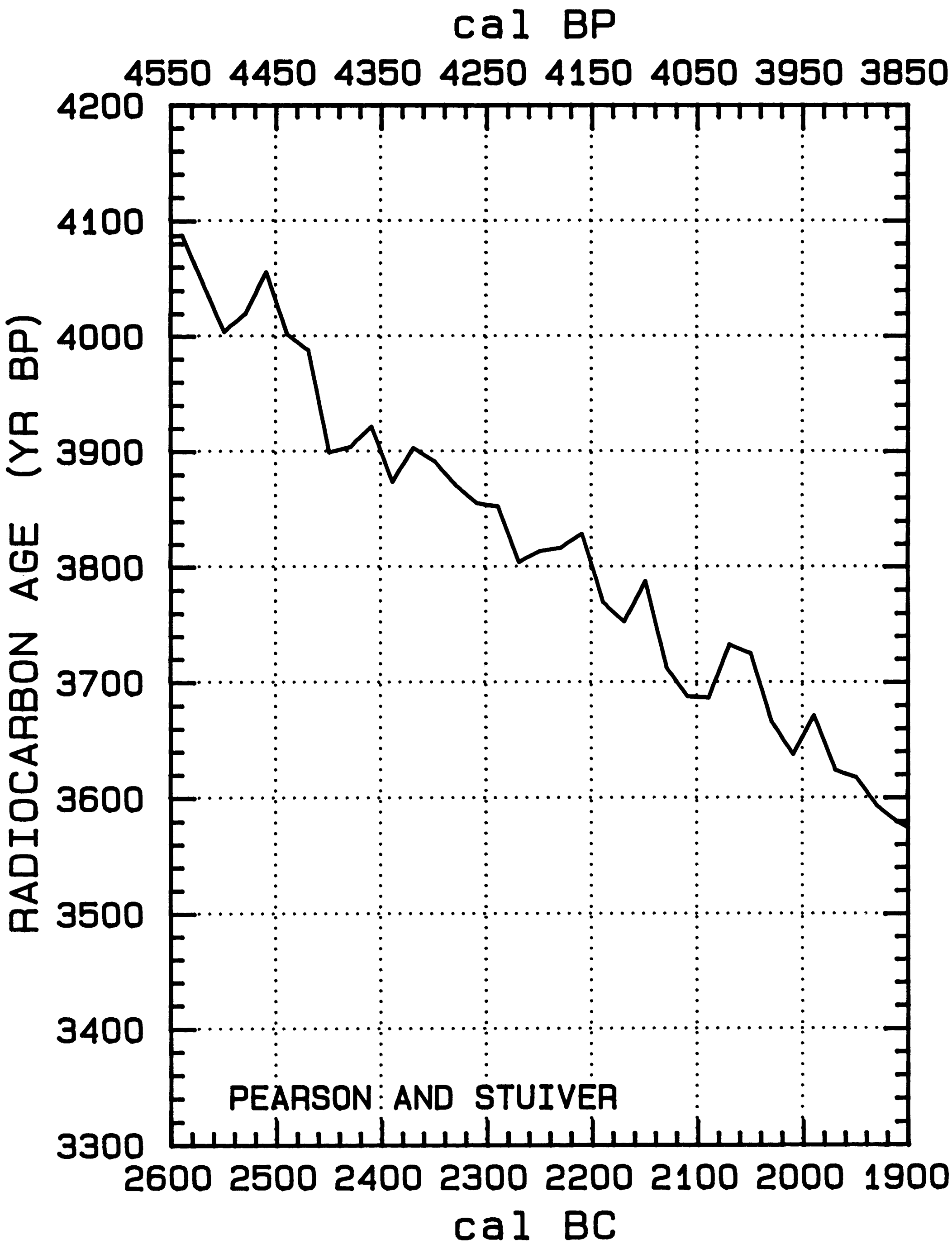

Fig. 1D

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TABLE 1. Weighted averages of University of Belfast and the University of Washington (Seattle) ^{14}C age determinations. The cal AD/BC (or cal BP) ages represent the midpoints of bidecadal wood sections, except as noted in the text. The standard deviation in the ages and $\Delta^{14}C$ (defined in Stuiver and Polach 1977) values includes lab error multipliers of 1.23 for Belfast and 1.6 for Seattle.

Cal AD/BC	$\Delta^{14}C$ ‰	^{14}C age (BP)	Cal BP	Cal AD/BC	$\Delta^{14}C$ ‰	^{14}C age (BP)	Cal BP
510 BC	−6.0 ± 1.2	2438 ± 10	BP 2459	1350 BC	17.6 ± 1.8	3066 ± 14	BP 3299
530 BC	−7.1 ± 1.1	2466 ± 9	BP 2479	1370 BC	20.7 ± 1.8	3061 ± 14	BP 3319
550 BC	−8.2 ± 1.0	2495 ± 8	BP 2499	1390 BC	18.7 ± 1.5	3096 ± 12	BP 3339
570 BC	−7.1 ± 1.3	2505 ± 11	BP 2519	1410 BC	15.4 ± 1.6	3141 ± 13	BP 3359
590 BC	−3.9 ± 1.3	2498 ± 11	BP 2539	1430 BC	12.7 ± 1.5	3182 ± 12	BP 3379
610 BC	−4.0 ± 1.2	2519 ± 10	BP 2559	1450 BC	11.7 ± 1.1	3210 ± 9	BP 3399
630 BC	0.6 ± 1.2	2501 ± 9	BP 2579	1470 BC	11.9 ± 1.4	3227 ± 11	BP 3419
650 BC	4.4 ± 1.3	2490 ± 10	BP 2599	1490 BC	17.1 ± 1.6	3206 ± 13	BP 3439
670 BC	5.2 ± 1.6	2503 ± 13	BP 2619	1510 BC	17.0 ± 1.7	3226 ± 14	BP 3459
690 BC	11.2 ± 1.8	2475 ± 14	BP 2639	1530 BC	8.5 ± 1.6	3313 ± 13	BP 3479
710 BC	15.1 ± 2.0	2464 ± 16	BP 2659	1550 BC	9.3 ± 1.8	3326 ± 15	BP 3499
730 BC	17.5 ± 1.5	2464 ± 12	BP 2679	1570 BC	14.0 ± 2.1	3308 ± 17	BP 3519
750 BC	20.6 ± 1.7	2459 ± 14	BP 2699	1590 BC	17.3 ± 1.5	3301 ± 12	BP 3539
770 BC	13.1 ± 2.0	2538 ± 16	BP 2719	1610 BC	16.7 ± 1.5	3326 ± 12	BP 3559
790 BC	11.7 ± 1.3	2568 ± 10	BP 2739	1630 BC	15.1 ± 1.6	3357 ± 12	BP 3579
810 BC	2.3 ± 1.6	2662 ± 13	BP 2759	1650 BC	16.3 ± 1.3	3367 ± 10	BP 3599
830 BC	−0.8 ± 1.5	2707 ± 12	BP 2779	1670 BC	20.0 ± 1.7	3357 ± 14	BP 3619
850 BC	−2.9 ± 1.6	2743 ± 13	BP 2799	1690 BC	14.2 ± 1.6	3423 ± 12	BP 3639
870 BC	−1.3 ± 1.6	2750 ± 13	BP 2819	1710 BC	15.0 ± 1.9	3436 ± 15	BP 3659
890 BC	3.2 ± 1.6	2733 ± 13	BP 2839	1730 BC	21.1 ± 1.6	3407 ± 12	BP 3679
910 BC	−0.1 ± 1.5	2779 ± 12	BP 2859	1750 BC	14.9 ± 1.6	3476 ± 12	BP 3699
930 BC	−2.1 ± 1.7	2815 ± 13	BP 2879	1770 BC	16.1 ± 1.4	3486 ± 11	BP 3719
950 BC	−2.4 ± 1.5	2837 ± 12	BP 2899	1790 BC	12.8 ± 1.4	3531 ± 11	BP 3739
970 BC	2.7 ± 1.3	2815 ± 10	BP 2919	1810 BC	18.2 ± 1.5	3508 ± 12	BP 3759
990 BC	2.8 ± 1.4	2833 ± 11	BP 2939	1830 BC	17.0 ± 1.9	3537 ± 15	BP 3779
1010 BC	0.5 ± 1.1	2871 ± 9	BP 2959	1850 BC	26.6 ± 1.7	3481 ± 13	BP 3799
1030 BC	1.1 ± 1.5	2886 ± 12	BP 2979	1870 BC	26.4 ± 1.5	3502 ± 12	BP 3819
1050 BC	1.2 ± 1.3	2905 ± 10	BP 2999	1890 BC	20.3 ± 1.6	3569 ± 12	BP 3839
1070 BC	2.7 ± 1.3	2912 ± 11	BP 3019	1910 BC	21.5 ± 1.9	3579 ± 15	BP 3859
1090 BC	4.7 ± 1.3	2916 ± 11	BP 3039	1930 BC	22.2 ± 1.5	3593 ± 12	BP 3879
1110 BC	8.4 ± 1.4	2905 ± 11	BP 3059	1950 BC	21.5 ± 1.6	3618 ± 13	BP 3899
1120 BC	6.6 ± 1.7	2930 ± 14	BP 3069	1970 BC	23.1 ± 1.8	3624 ± 14	BP 3919
1140 BC	3.8 ± 1.5	2972 ± 12	BP 3089	1990 BC	19.6 ± 1.4	3672 ± 11	BP 3939
1150 BC	8.1 ± 1.7	2947 ± 14	BP 3099	2010 BC	26.4 ± 1.7	3638 ± 13	BP 3959
1170 BC	6.6 ± 1.7	2978 ± 13	BP 3119	2030 BC	25.3 ± 1.5	3666 ± 12	BP 3979
1190 BC	10.9 ± 1.7	2963 ± 14	BP 3139	2050 BC	20.2 ± 1.4	3725 ± 11	BP 3999
1210 BC	10.5 ± 1.4	2986 ± 11	BP 3159	2070 BC	21.7 ± 1.6	3733 ± 13	BP 4019
1230 BC	9.4 ± 1.6	3014 ± 13	BP 3179	2090 BC	30.1 ± 1.7	3687 ± 13	BP 4039
1250 BC	16.5 ± 1.5	2977 ± 12	BP 3199	2110 BC	32.4 ± 1.6	3688 ± 13	BP 4059
1270 BC	9.9 ± 1.8	3049 ± 14	BP 3219	2130 BC	31.8 ± 1.9	3713 ± 15	BP 4079
1290 BC	14.0 ± 1.8	3036 ± 14	BP 3239	2150 BC	24.7 ± 1.3	3788 ± 10	BP 4099
1310 BC	14.1 ± 1.8	3054 ± 15	BP 3259	2170 BC	31.6 ± 1.6	3753 ± 13	BP 4119
1330 BC	10.4 ± 1.7	3103 ± 13	BP 3279	2190 BC	31.9 ± 1.2	3770 ± 9	BP 4139

TABLE 1. (Continued)

Cal AD/BC	$\Delta^{14}C$ ‰	^{14}C age (BP)	Cal BP	Cal AD/BC	$\Delta^{14}C$ ‰	^{14}C age (BP)	Cal BP
2210 BC	26.8 ± 1.4	3829 ± 11	BP 4159	2370 BC	37.2 ± 1.5	3903 ± 11	BP 4319
2230 BC	30.9 ± 1.5	3817 ± 12	BP 4179	2390 BC	43.6 ± 1.7	3874 ± 13	BP 4339
2250 BC	33.7 ± 1.4	3814 ± 11	BP 4199	2410 BC	39.9 ± 1.4	3922 ± 11	BP 4359
2270 BC	37.5 ± 1.9	3804 ± 15	BP 4219	2430 BC	44.7 ± 0.9	3904 ± 7	BP 4379
2290 BC	33.6 ± 1.6	3853 ± 12	BP 4239	2450 BC	48.0 ± 1.7	3899 ± 12	BP 4399
2310 BC	35.8 ± 1.8	3856 ± 14	BP 4259	2470 BC	38.8 ± 1.5	3988 ± 12	BP 4419
2330 BC	36.3 ± 1.5	3872 ± 11	BP 4279	2490 BC	39.5 ± 1.5	4002 ± 12	BP 4439
2350 BC	36.2 ± 1.6	3892 ± 13	BP 4299				

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