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# HIGH-PRECISION $^{14}C$ MEASUREMENT OF IRISH OAKS TO SHOW THE NATURAL $^{14}C$ VARIATIONS FROM AD 1840 TO 5210 BC

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ABSTRACT. High-precision measurement of dendrochronologically dated Irish oak at bi-decade/decade intervals has continued in the Belfast laboratory, extending the $^{14}C$ data base from ca AD 1840 to 5210 BC. The dendrochronology is now considered absolute (see Belfast dendrochronology this conference) (Brown *et al*, 1986) and a continuous detailed curve is presented, showing the natural variations in the atmospheric concentration of $^{14}C$ over >7000 years. Each data point has a precision of <2.5‰, and some 4500 years have now been compared with Seattle, giving excellent agreement. Discussion of this data base and the justification of the claimed accuracy is given together with a comparison of other chronologies. Some of the advantages and limitations of the above are discussed.

## INTRODUCTION

High-precision (ca ± 2‰) measurements of dendrochronologically dated wood have shown in detail the short-term variation of $^{14}C$ in atmospheric carbon. Some 6000 years of bi-decade measurements were presented by Pearson and Baillie (1983) and Pearson, Pilcher and Baillie (1983) but were not considered absolute dendrochronologically from ca 500 BC → ca 4000 BC. The natural variations illustrated here are shown against an absolute dendro-axis and the $^{14}C$ measurements are demonstrated to be accurate internally, giving consistent replication over the whole time period presented and externally by comparison with ca 4500 years of Seattle measurements (Stuiver & Pearson, 1986; Pearson & Stuiver, 1986).

The achievement of high precision in liquid scintillation counting was detailed in Pearson (1979, 1980), but an updating of the corrections used, together with their effect on accuracy when omitted are discussed below. Greater detail of the variables giving rise to the above corrections and the parameters monitored to ascertain the variation, are given in Pearson (1983).

## HIGH-PRECISION $^{14}C$ MEASUREMENT (BY LIQUID SCINTILLATION COUNTING OF BENZENE)

This method of analysis has been discussed in previous publications (Pearson, 1979, 1980, 1983; Pearson & Baillie, 1983). The fundamental requirements for high-precision analysis are 1) to have a pure uncontaminated sample, and 2) to measure this under stable standardized conditions. Rigorous pretreatment of samples (wood) (Dresser, 1970) and careful conversion to benzene can provide pure samples with relatively high conversion yields. To achieve stable standardized conditions of counting, many factors that influence both the efficiency of detection and the 'background' contribution to sample counts, determine the need for corrective measures. In high-precision counting, all variables that have a significance of >0.025% (Pearson, 1979, 1980) have to be resolved by correction or eliminated as variables. A list of those resolved by correction and the parameters monitored to derive the corrections is given in Table 1, together with the residual and estimated errors, if such a correction was ignored.

Potential variables such as 1) vial differences that may give inconsistent efficiencies and/or background, 2) plastic caps that do not allow accurate weighing because of their differential moisture absorption, dependent upon ambient conditions, 3) $^{222}Rn$ contamination from laboratory water supply, and 4) memory effects in the lithium reactor are eliminated. This is achieved for 1) by the selection of identical vials, 2) by the change of vial caps to a low radioactive lead alloy, 3) by specially selecting a water containing minimal amounts of $^{222}Rn$, then completely degassing by boiling and standing the sample benzene for at least a month before measurement, and finally, 4) the memory effects are reduced to an insignificant level by using 'clean-out' samples (samples of similar age to the one under analysis) which condition the reactor.

The above list shows that the variables and potential variables are many and it is expected that with very few exceptions these would apply to most liquid scintillation counting systems, although with differing emphasis. Some of the variables may be avoided by the quasi-simultaneous counting of identically prepared standards and background, although it is statistically advantageous to be able to take mean values of these over longer periods than normal sample measurements.

Only one value of standard count rate was used for the calculations presented here. The standard and samples were measured over a 10-year period, allowing a precise value for the standard to be obtained. The actual standard deviation based on 55 duplicate analyses was calculated using the relationship $\hat{\sigma} = SS/2n$ where SS = Sum of the (difference between duplicates)$^2$, n = No. of duplicated measurements, and $\hat{\sigma}$ is the derived average standard deviation which can then be compared to the mean standard deviation ($\bar{\sigma}$) quoted on the 110 individual measurements. The actual calculated standard deviation value was $\hat{\sigma} = \pm 19.0$ yr. The mean quoted error on the individual measurements was evaluated from $\bar{\sigma} = [\Sigma_{i=1}^{n} (\sigma_1)^2/n]^{1/2}$, and gave a value of $\bar{\sigma} = \pm 15.4$ yr, thus suggesting that the quoted error is underestimated by ca 23%, or an error multiplier of 1.23 is required.

## RADIOCARBON TIME-SCALE CALIBRATION

During the past decade high-precision techniques have been used to measure dendrochronologically dated wood samples to provide a record of the natural $^{14}C$ variations; this information has been used primarily for time-scale calibration with a quoted mean measurement error of $<\pm 20$ yr. The longest previously published high-precision BC calibration (Pearson, Pilcher & Baillie, 1983) was based on a provisional fixing of a Belfast floating dendrochronologic sequence; consequently, for this period, it was probably more prudent to use the lower precision measurements of absolutely dated samples such as the calibration presented by Klein *et al* (1982).

The $^{14}C$ measurements presented here are derived from decade/bi-decade contiguous samples of mainly Irish oak. The decade sample measurements were combined, and are presented with bi-decade measurements in Table 2 and also separately in Table 3. Since the announcement of the continuous European dendrochronologic sequence in 1984 (Pilcher *et al*, 1984), the entire sequence in the BC era has been re-worked and dendrochronologically checked and is totally internally consistent. The links with the German chronologies have further been confirmed by cross-dating, between established chronologies from North Germany, England, and Northern Ireland (Pilcher *et al*, 1984). There are >700 trees in the section of chronology from 116 BC to 5289 BC and over most of this time span the replication is very good. The justification for the chronology at the few remaining places where replication is weakest, is given (Baillie, Pilcher & Pearson, 1983; Brown *et al*, 1986).

Some 7000 years of Irish oak have now been measured as decade or bi-decade contiguous samples, providing the longest single high-precision calibration of the $^{14}C$ time scale and the results are illustrated in Figure 1. Although much of it has been published before, (Pearson & Baillie, 1983; Pearson, Pilcher & Baillie, 1983) all measurements have been recalculated using updated corrections to give improved accuracy. Duplicate analyses on many samples have allowed reduction in their quoted precision, although this was shown above to be possibly underestimated by ca 23%. Tables 2 and 3 give the laboratory number of the bi-decade/decade sample respectively, together with the center dendro-year and its $^{14}C$ age in years BP, based on the Libby half-life of 5568 years. Also included are the equivalent $\Delta$ values and one standard deviation error limits on both the $^{14}C$ age and $\Delta$ values; this is the estimated error and includes all correction errors together with the counting statistics; it does not include the error multiplier discussed above.

The international validity of any calibration can only be proved by the independent analysis of other absolutely dated wood samples from other parts of the world. If the agreement between two such data sets is within statistical expectation, then it seems reasonable that such a calibration would be more internationally acceptable. Such a comparison is possible over 4500 years of calibration between Belfast and Seattle. Some 214 measurements were compared and the resulting differences closely fit a Gaussian distribution with a standard deviation of 25.6 years (Stuiver & Pearson, 1986) and a mean difference of 0.6 years. This agreement shows that no significant bias exists. The replicate analyses as discussed above suggest an error multiplier of ca 1.23 for the Belfast data. A similar approach yields an overall error 1.6 times the standard deviation in combining statistics for the Seattle data (Stuiver & Pearson, 1986). Application of these error multipliers result in an average standard deviation of the 214 points of 22.9 years. Thus, the Seattle and Belfast overall laboratory precision accounts for nearly the entire variability found between both data sets.

## CONCLUSION

The fine detail of the natural $^{14}C$ variation curve will be of considerable interest to many workers in astrophysics, solar physics, geophysics, etc, but perhaps the most immediate use will be as a high-precision $^{14}C$ time-scale calibration.

It has been shown above that it is now possible by combining Seattle and Belfast data to provide an internationally acceptable calibration curve within a $1\sigma$ envelope of ca $\pm 14$ years, covering a time period of some 4500 years. The remaining Belfast curve from 2500–5210 BC would be valid using an error multiplier of 1.23 to give an average calibration band-width of $< \pm 20$ years.

The high-precision curve is essential for converting high-precision analysis and it has already proved useful in sorting out some archaeologic dating problems from the late Bronze age/early Iron age where the calibration curve is almost horizontal from 400–800 BC. Samples dated ca 2350 BP, eg, with precisions of ca $\pm 100$ years could not be converted to a calendar age band with any greater resolution than 480 years (750–270 BC). Using high-precision measurement ca $\pm 20$ years, this band width for the above sample can be reduced to almost 10 years. Single high-precision analysis of samples can give calendric band widths which are similar to the $^{14}C$ quoted error range over considerable portions of the calibration.

The use of 'wiggle matching' (Pearson, 1986) can give narrow calendric band widths for certain samples with a known deposition rate or growth period where wiggles would normally cause the reporting of large calendric band widths.

Thus, it can be concluded that high-precision analysis can provide fine calendric resolution to the archaeologic chronology, providing, of course, the samples submitted have the same credentials in terms of precise association and integrity, allowing for correct interpretation.

## ACKNOWLEDGMENTS

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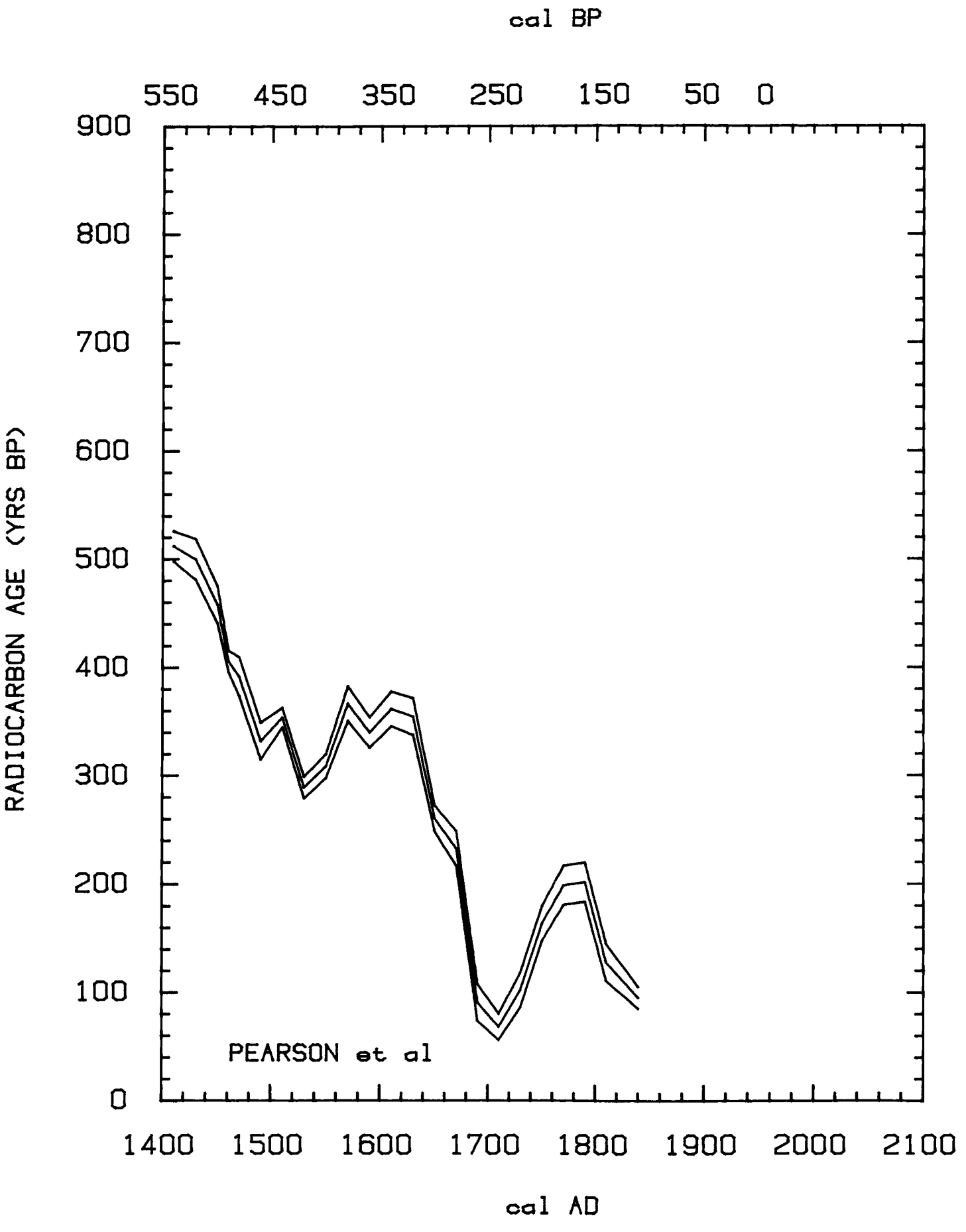
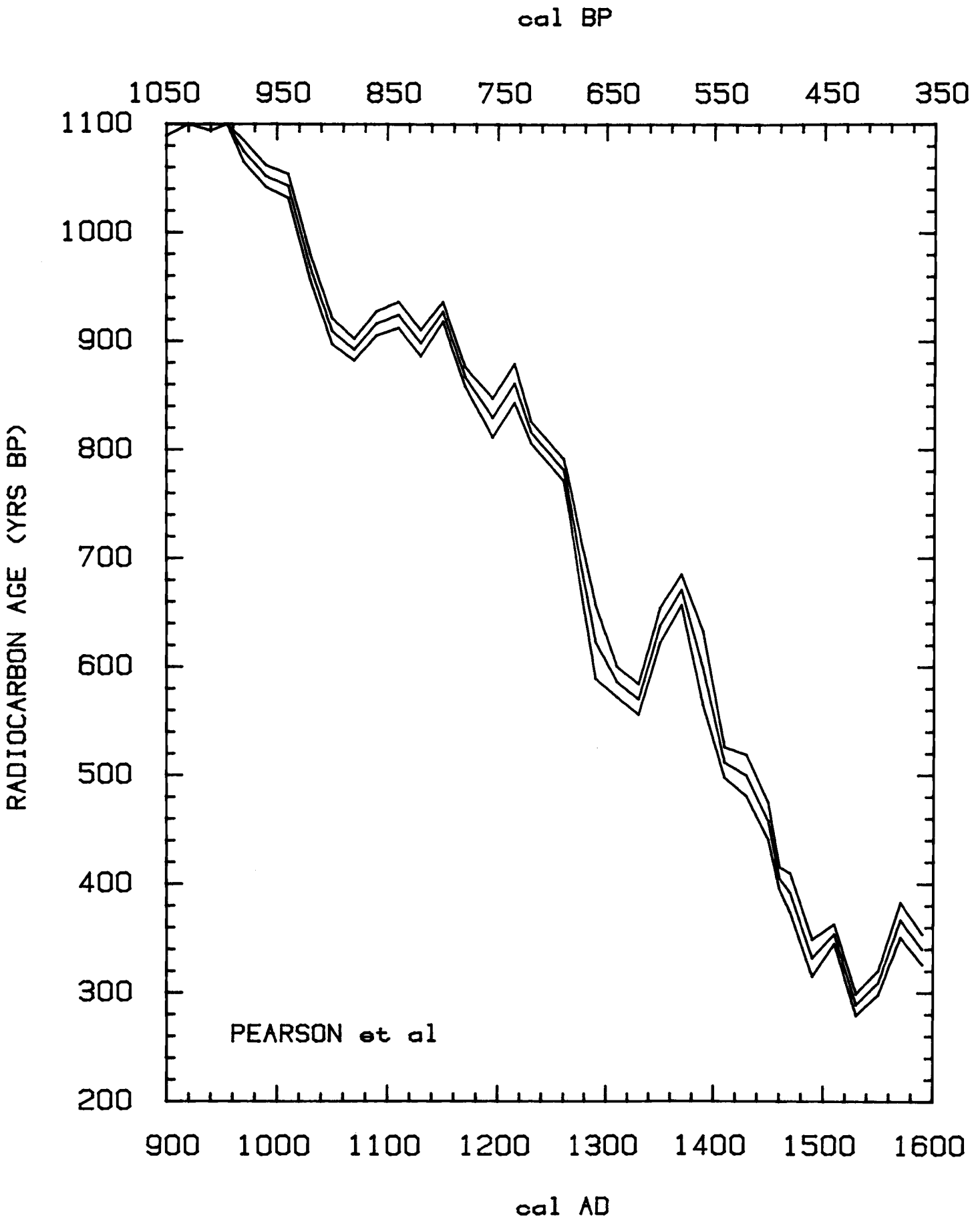



Fig 1A

Figs 1A–1O. Radiocarbon time-scale calibration from AD 1840 to 5210 BC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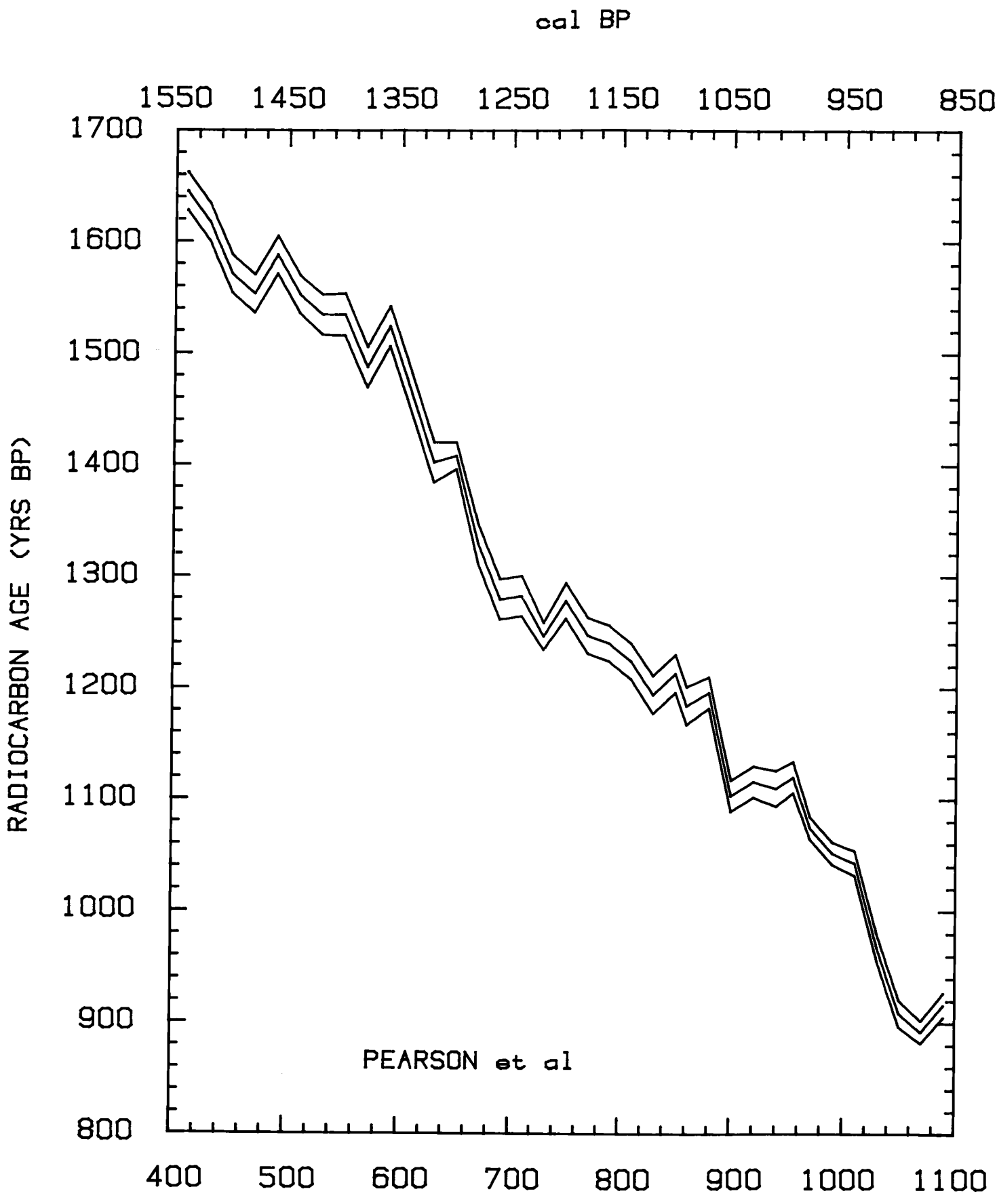
950
850
750
650
550
450
350
1100
1000
900
800
700
600
500
400
300
200
RADIOCARBON AGE (YRS BP)
PEARSON et al
900
1000
1100
1200
1300
1400
1500
1600
cal AD

Fig 1B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950
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1200
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1000
900
800
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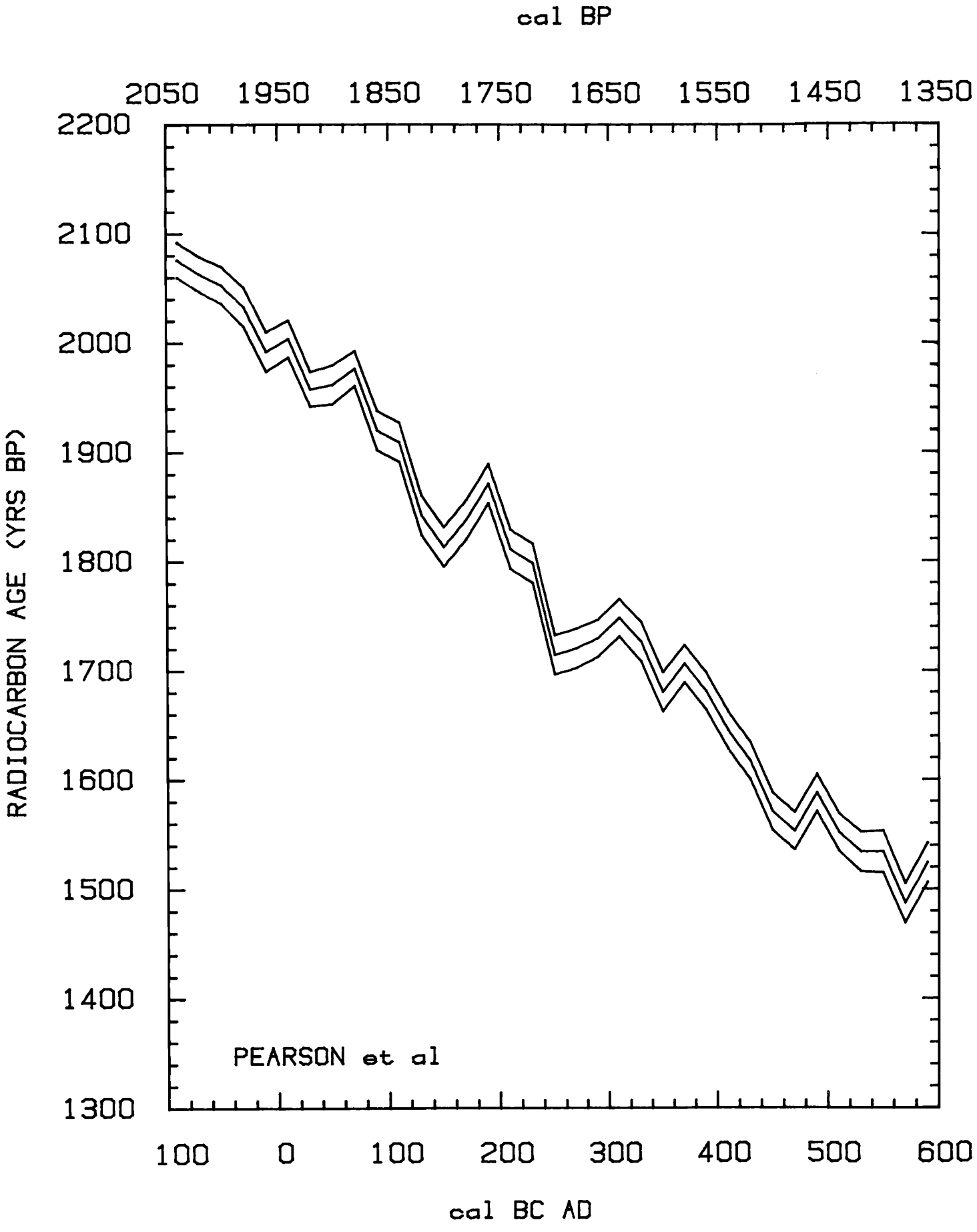
PEARSON et al
400
500
600
700
800
900
1000
1100
cal AD

Fig 1C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1850
1750
1650
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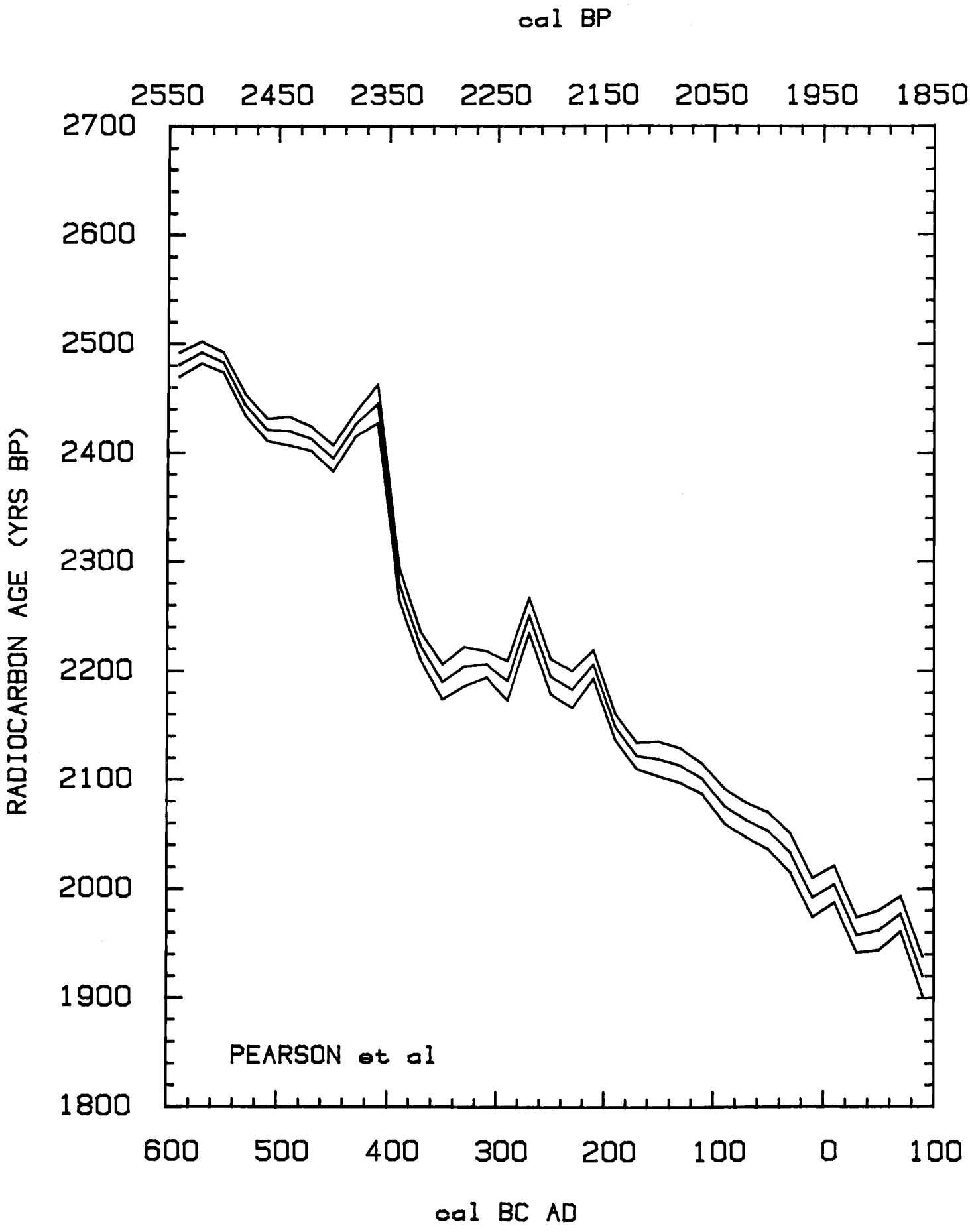
1450
1350
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
RADIOCARBON AGE (YRS BP)
PEARSON et al
100
0
100
200
300
400
500
600
cal BC AD

Fig 1D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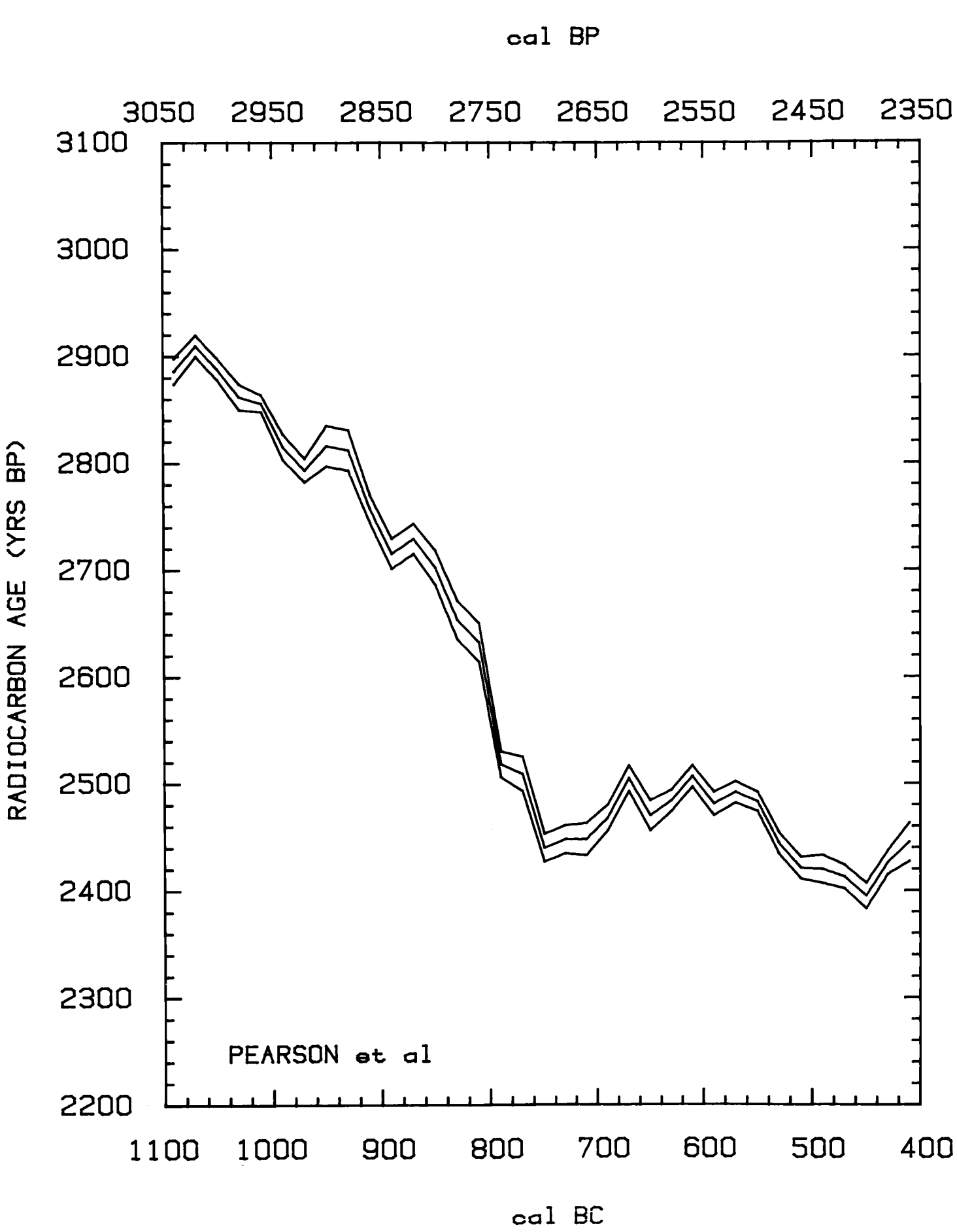
2050
1950
1850
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
RADIOCARBON AGE (YRS BP)
PEARSON et al
600
500
400
300
200
100
0
100
cal BC AD

Fig 1E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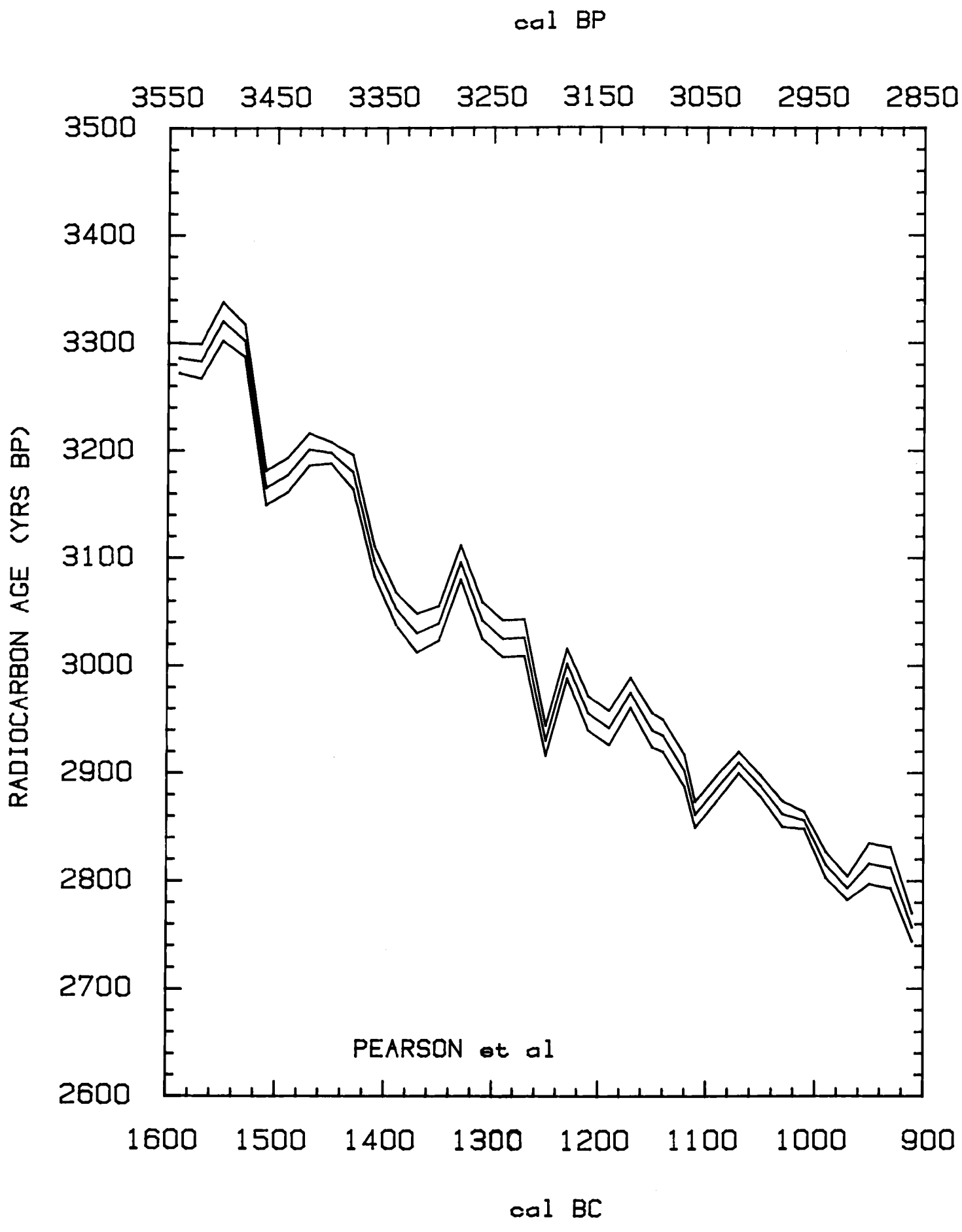
2750
2650
2550
2450
2350
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
RADIOCARBON AGE (YRS BP)
PEARSON et al
1100
1000
900
800
700
600
500
400
cal BC

Fig 1F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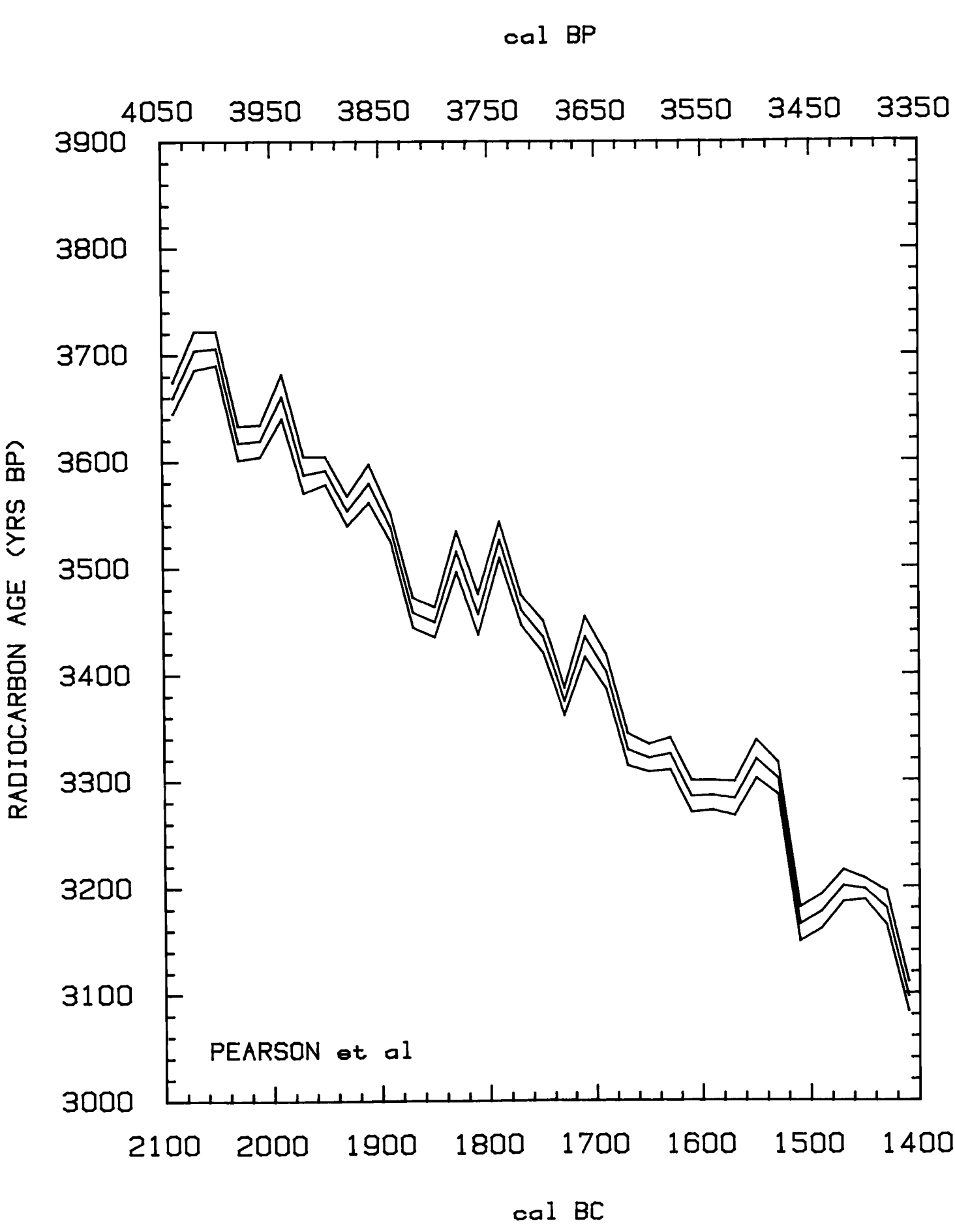
2900
2800
2700
2600
RADIOCARBON AGE (YRS BP)
PEARSON et al
1600
1500
1400
1300
1200
1100
1000
900
cal BC

Fig 1G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3300
3200
3100
3000
RADIOCARBON AGE (YRS BP)
PEARSON et al
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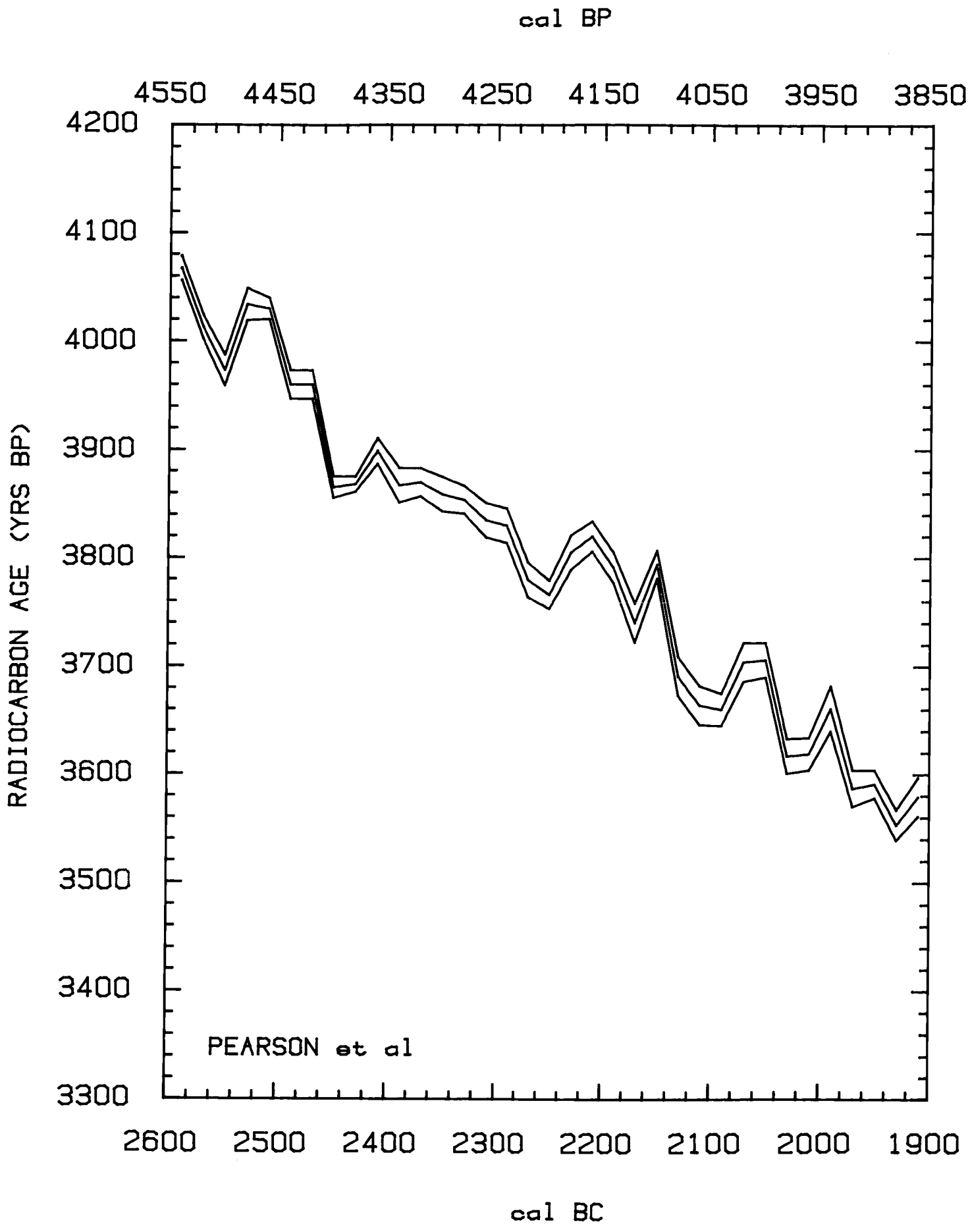
2000
1900
1800
1700
1600
1500
1400
cal BC

Fig 1H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3950
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4000
3900
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3600
3500
3400
3300
RADIOCARBON AGE (YRS BP)
PEARSON et al
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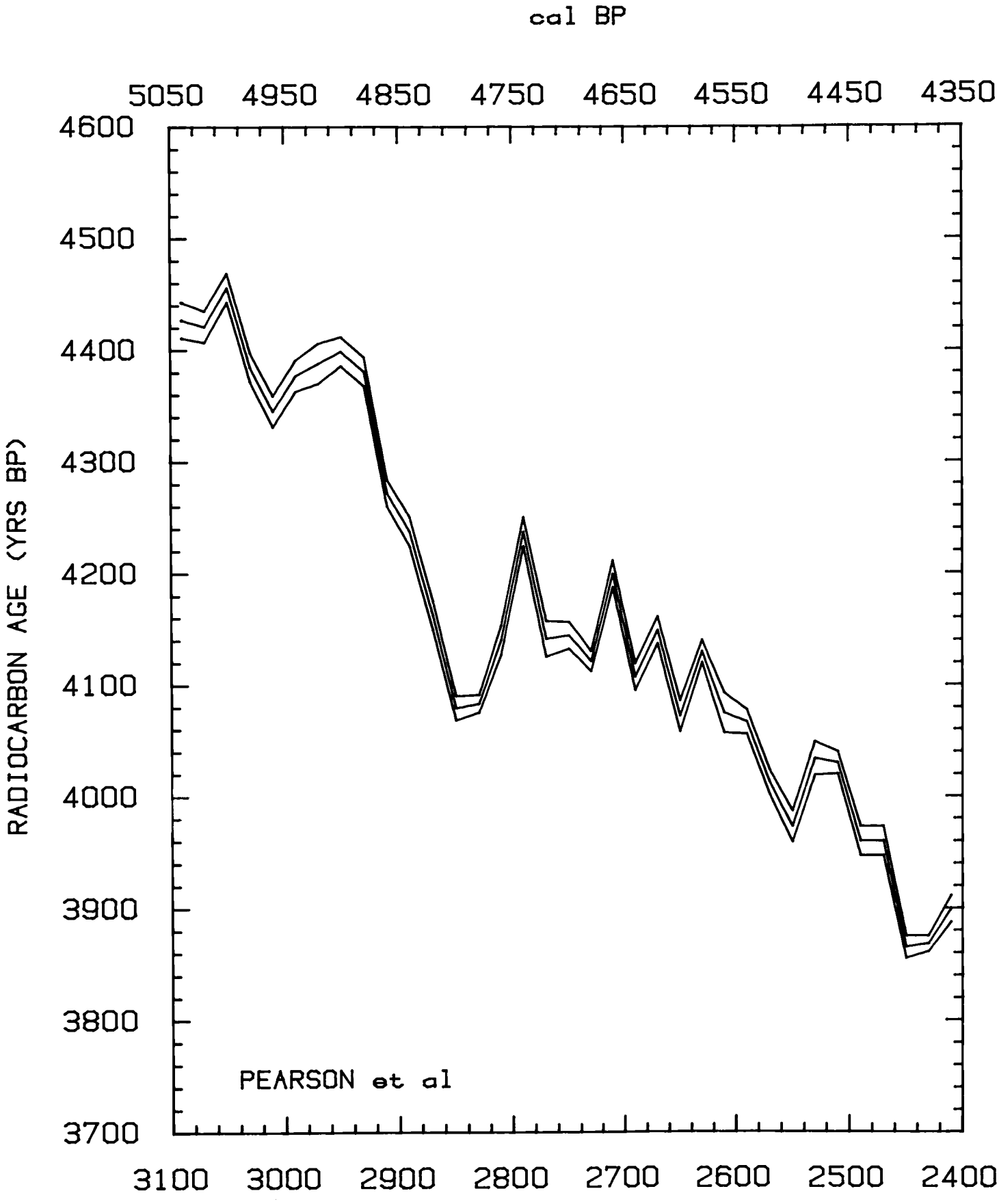
2500
2400
2300
2200
2100
2000
1900
cal BC

922

Fig 11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4000
3900
3800
3700
RADIOCARBON AGE (YRS BP)
PEARSON et al
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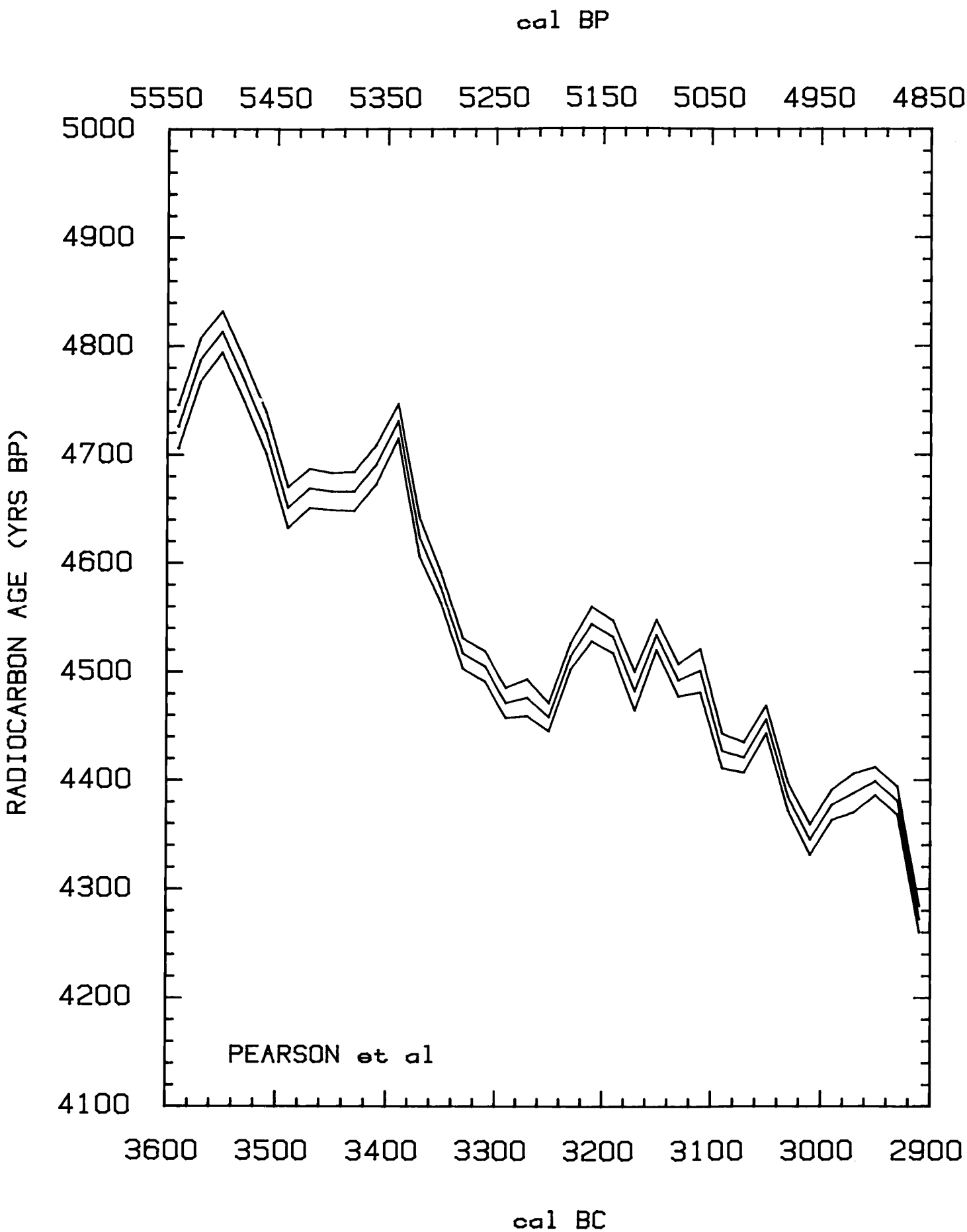
2500
2400
cal BC

923

Fig 1J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4300
4200
4100
RADIOCARBON AGE (YRS BP)
PEARSON et al
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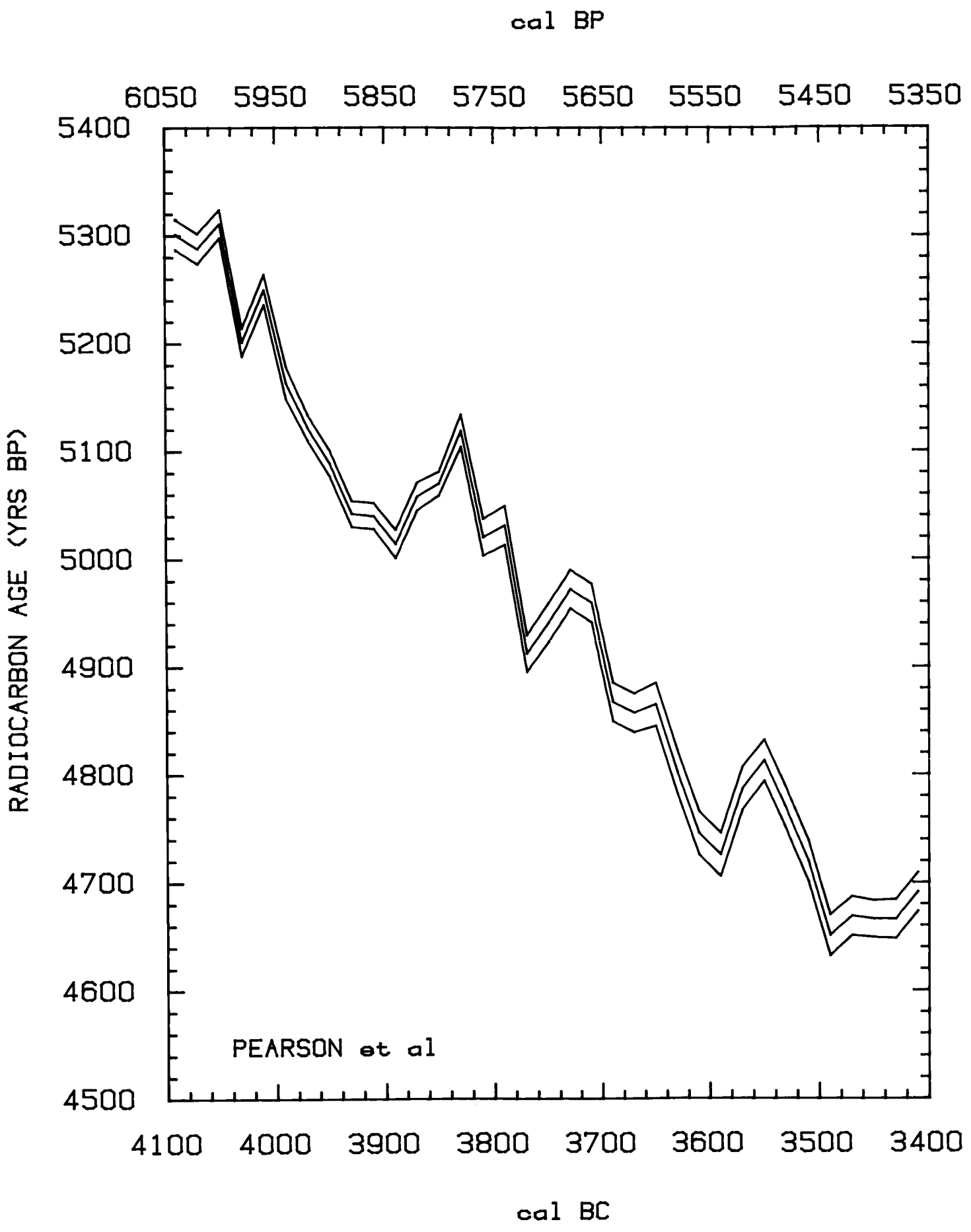
3300
3200
3100
3000
2900
cal BC

Fig 1K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4800
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RADIOCARBON AGE (YRS BP)
PEARSON et al
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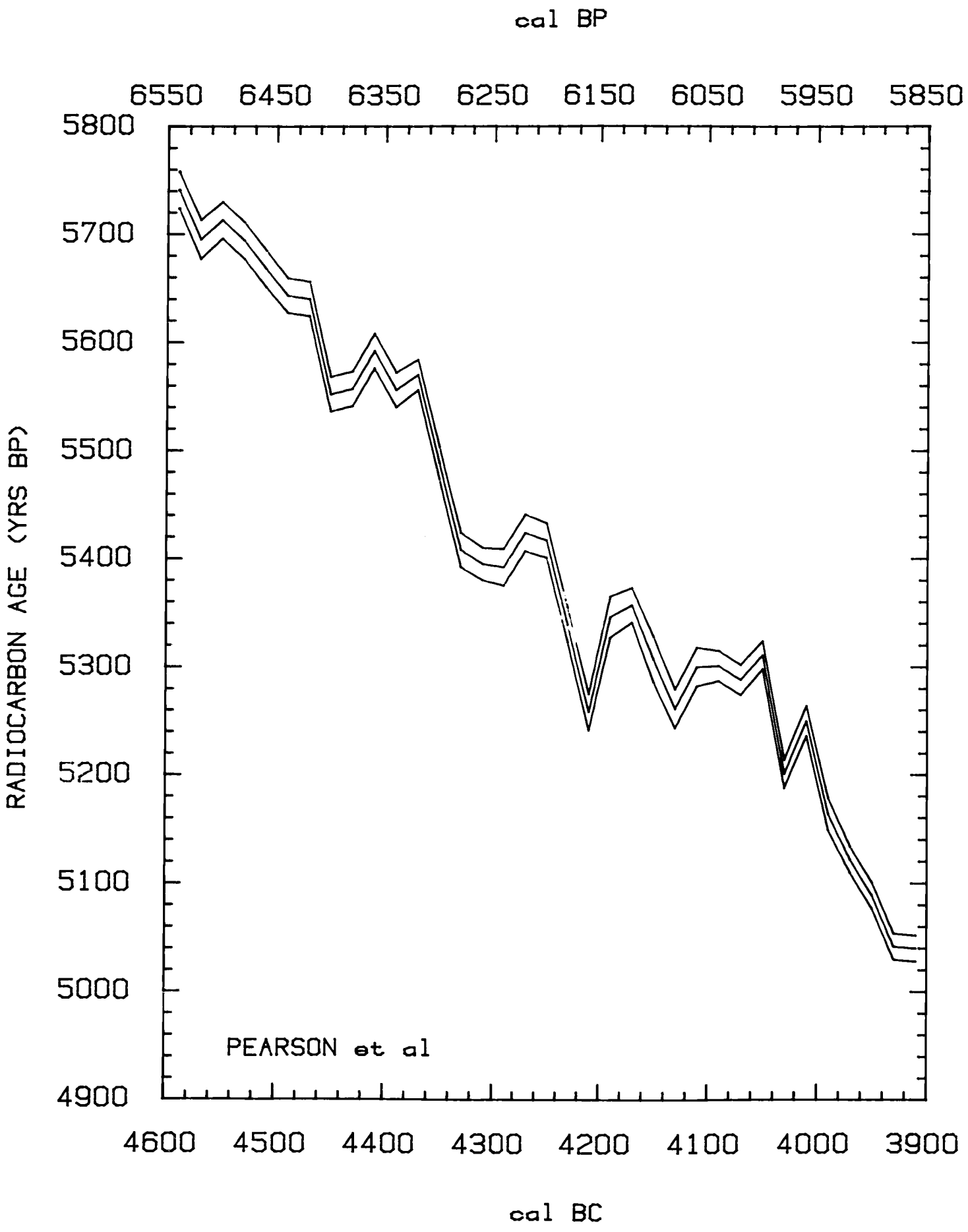
cal BC

925

Fig 1L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6350
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6150
6050
5950
5850
5800
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5400
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5200
5100
5000
4900
RADIOCARBON AGE (YRS BP)
PEARSON et al
4600
4500
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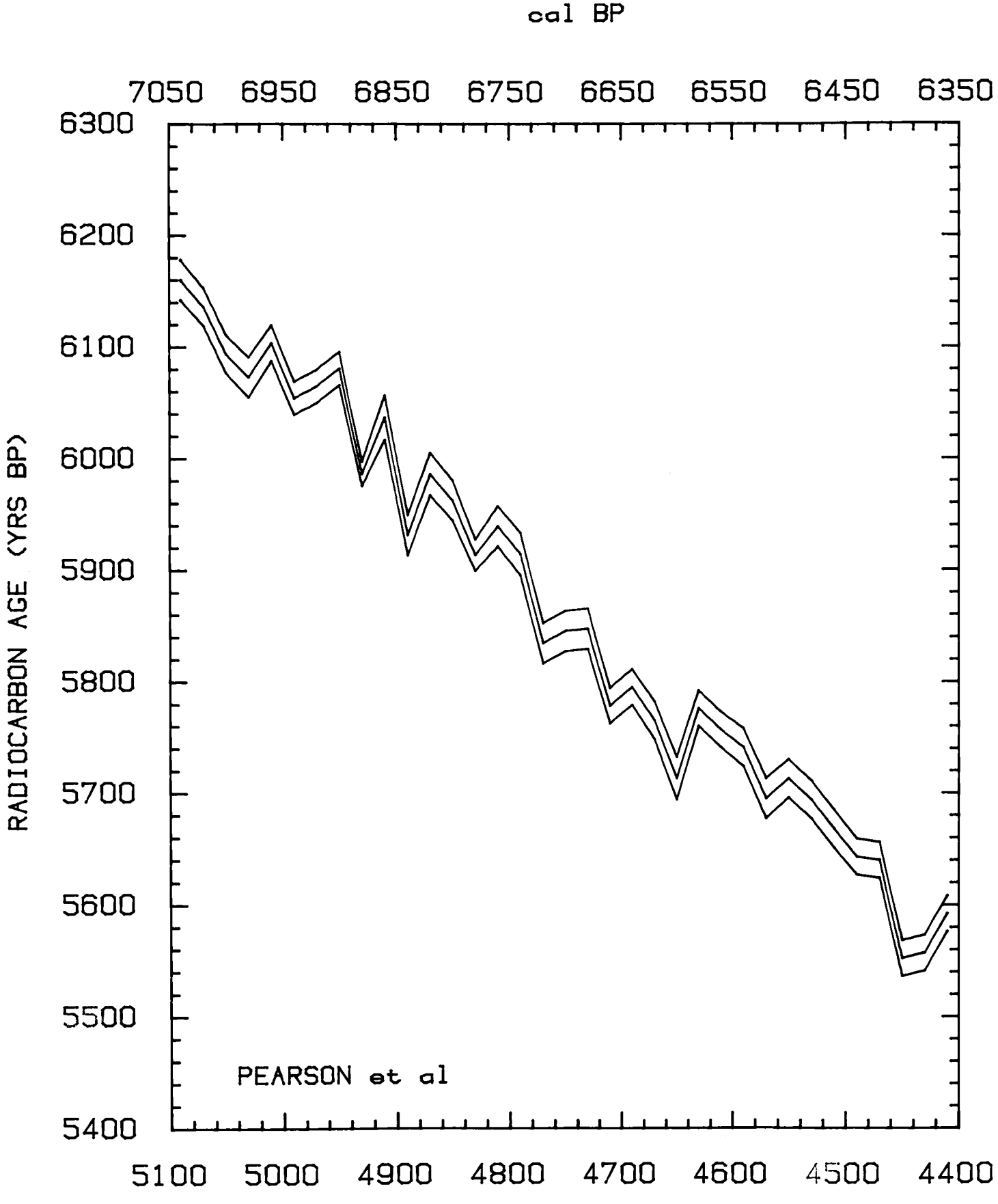
3900
cal BC



Fig 1M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6300
6200
6100
6000
5900
5800
5700
5600
5500
5400
RADIOCARBON AGE (YRS BP)
PEARSON et al
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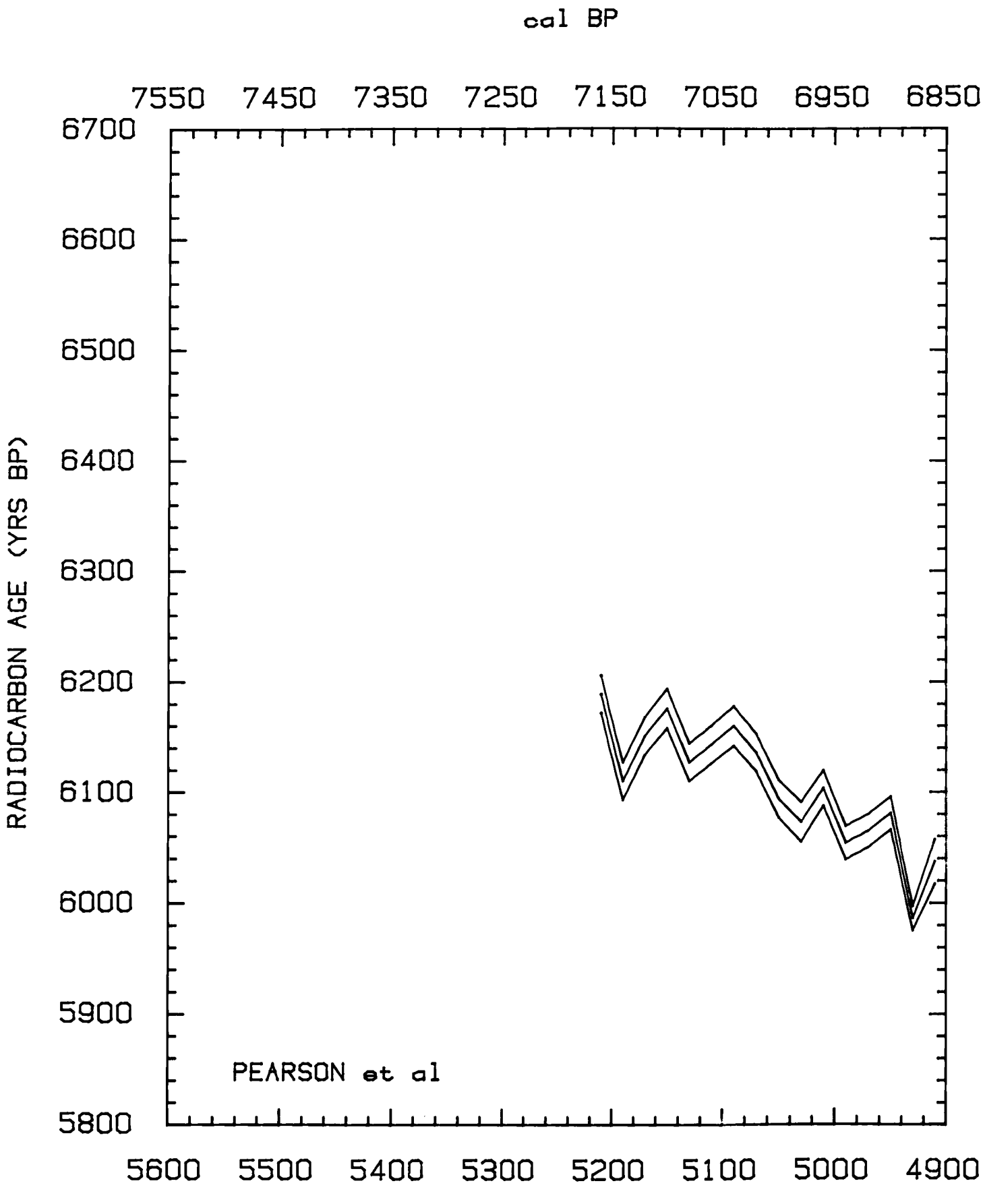
cal BC

Fig 1N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7450
7350
7250
7150
7050
6950
6850
6700
6600
6500
6400
6300
6200
6100
6000
5900
5800
RADIOCARBON AGE (YRS BP)
PEARSON et al
5600
5500
5400
5300
5200
5100
5000
4900
cal BC

Fig 10

## TABLE 1
## Corrections applied to scintillation counting results

| ERROR SOURCE | PARAMETER MONITORED | DERIVATION OF CORRECTION | NORMALISED VALUE | ERROR ESTIMATED ON SAMPLE COUNTS ONLY | |
|---|---|---|---|---|---|
| | | | | ESTIMATED RESIDUAL ERROR IN YEARS cf SAMPLE = $T^2$ NET SAMPLE = 60 CPM | ESTIMATED ERROR IN YEARS IF UNCORRECTED cf SAMPLE = $T^2$ NET SAMPLE = 60 CPM |
| Background variation with 'purity' | Channel ratio of external $^{133}Ba$ source | Correction is in two parts:- Constant component = 0.013 cpm Variable component = 0.008 cpm for each 0.01 rise in channels ratio | Channels ratio = 1.95 | Estimated at 0.03% cf $T^2$ ie ± 2.5 years | Channels ratio variation = ± 0.05 ≡ ± 0.1 cpm ie ± 13 years |
| Background variation with weight loss from vial | Vial weighing; average weight loss calculated | Background count rate variation with volume curve Slope = 0.289 cpm/g loss | Weight of standard contents=14.2666 g. 13.1325 g of C6H6 | Weighing error ± 1 mg ≡ ± 0.000289 cpm ie 0.04 years | Normal losses are about 1 mg per day. On a 14 day count this would give an error of ± 0.6 years. |
| Efficiency variation with weight loss from vial | Vial weighing; average weight loss calculated | Linear regression of efficiency on weight loss over a 1 g fall Slope = 0.0016%/mg fall in weight | Filling weight = 14.2666 g | Error in weighing = ± 1 mg ≡ ± 0.00096 cpm ie ± 0.13 years | Loss of 1 mg/day ≡ 0.013 cpm ie ≃ 2 years |
| Differential loss of benzene and toluene from counting mixture | as above | Experimentally derived 97.65% loss is benzene | Filling weight of benzene = 13.1325 g | Error in weighing = ± 1 mg Weight loss of sample = ± 0.98 mg ≡ ± 0.004 cpm ie ± 0.6 years | Loss of 1 mg/day ≡ 0.06 cpm ie ≃ 8 years This loss can be up to 10 mg/day |
| Background variation with atmospheric depth, solar radiation and neutron flux | Height of atmosphere at 100 mb pressure level. Solar radio transmission at 9500 Mlz. Neutron flux as monitored by Leeds University | Triple linear regression using the three parameters with BG corrected for BP Slopes: -0.0002 cpm/metre - 0.0007 cpm/unit flux 0.0233 cpm/unit flux | 100 mb pressure level height = 16019 metres. Solar radio transmission = 303.688 units Neutron flux = 92.778/Au | These estimates are based on the ability to read parameters at levels indicated 100 mb PLH ± 10 metres ≡ ± 0.002 cpm ie ± 0.25 years. SRT ± 4 units ≡ ± 0.0007 cpm ie ± 0.25 years Neutron flux ± 0.1 units ie ± 0.25 years | Range errors 100 mb PLH ± 500 m ≡ ±0.1 cpm ie ± 13 years SRT ± 40 units ≡ 0.028 cpm ie ± 4 yrs Neutron flux ± 4/Au ≡ ± 0.093 ie ± 13 years |
| Background variation with barometric pressure | Barometric pressure | Linear regression of BG count rate (sealed vial) on BP. Slope = -0.0127 cpm/mb increase in pressure | 1010 millibars | Barograph reading ± 0.05 mb ie ± 0.8 years | Pressure range ± 25 mb Error ≃ ± 0.32 cpm ie ± 42 years |
| Background variation with $^{133}Ba$ contribution | Known contribution $A = A' - \left(e^{-0.0077t}\right)0.35$ where A = corrected BG cpm A' = observed BG | The contribution was determined by source removal. There is a variation applied to this correction for 'purity' change (see correction below) | To zero contribution | Estimated at ± 0.02 cpm ie ≡ ± 2.5 years | Variable contribution 0.18 cpm ie ≡ 24 years although most of this would have been included in BG/Purity |
| Efficiency variation with gain 'purity' | Channels ratio of $^{133}Ba$ external source | The loss of counts is proportional to the increasing area of a triangle: the height varies as a function of the purity. The equation is:- $A = A_1(1+(\frac{x^2}{8})0.0015)$ where A = corrected cpm $A_1$ = observed cpm (previously corr) x = change in channels ratio x 100 | Channels ratio = 1.95 | Channels ratio ± 0.01 ≡ ± 0.019% ≡ ± 0.011 cpm ie ± 1.5 years | Channels ratio ±0.05 ≡ ± 0.46% ≡ ± 0.28 cpm ie ± 38 years |
| Efficiency variation with counting time | Continuous quality control | Exponential regression of corrected standard cpm with time | Mid point of counting time | None | Loss of standard counts ≃ 0.005 cpm per day ≡ 0.67 years per day difference between sample & standard counting time |

TABLE 2 A–G
Calibration table data (See legend, Table 2G)

TABLE 2A

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| AD 1840[1] | 1.5 ± 1.3 | 95 ± 10 |
| BP 110 | | |
| AD 1810 | 1.0 ± 2.1 | 128 ± 17 |
| BP 140 | | |
| AD 1790 | -5.8 ± 2.2 | 202 ± 18 |
| BP 160 | | |
| AD 1770 | -3.0 ± 2.2 | 199 ± 18 |
| BP 180 | | |
| AD 1750 | 3.8 ± 2.0 | 164 ± 16 |
| BP 200 | | |
| AD 1730 | 14.0 ± 2.0 | 102 ± 16 |
| BP 220 | | |
| AD 1710 | 20.8 ± 1.5 | 68 ± 12 |
| BP 240 | | |
| AD 1690 | 20.3 ± 2.2 | 91 ± 17 |
| BP 260 | | |
| AD 1670 | 4.9 ± 2.0 | 233 ± 16 |
| BP 280 | | |
| AD 1650 | 3.8 ± 1.5 | 261 ± 12 |
| BP 300 | | |
| AD 1630 | -5.5 ± 2.1 | 355 ± 17 |
| BP 320 | | |
| AD 1610 | -3.9 ± 2.0 | 362 ± 16 |
| BP 340 | | |
| AD 1590 | 1.2 ± 1.7 | 340 ± 14 |
| BP 360 | | |
| AD 1570 | 0.3 ± 2.0 | 367 ± 16 |
| BP 380 | | |
| AD 1550[1] | 10.0 ± 1.4 | 309 ± 11 |
| BP 400 | | |
| AD 1530[4] | 14.9 ± 1.3 | 289 ± 10 |
| BP 420 | | |
| AD 1510[4] | 9.2 ± 1.1 | 354 ± 9 |
| BP 440 | | |
| AD 1490 | 14.4 ± 2.2 | 332 ± 17 |
| BP 460 | | |
| AD 1470 | 9.3 ± 2.3 | 392 ± 18 |
| BP 480 | | |
| AD 1460[6] | 8.8 ± 1.3 | 406 ± 10 |
| BP 490 | | |
| AD 1450 | 3.5 ± 2.1 | 458 ± 17 |
| BP 500 | | |
| AD 1430 | 0.7 ± 2.4 | 500 ± 19 |
| BP 520 | | |
| AD 1410 | 1.6 ± 1.8 | 512 ± 14 |
| BP 540 | | |
| AD 1390 | -6.8 ± 4.2 | 599 ± 34 |
| BP 560 | | |
| AD 1370 | -13.3 ± 1.7 | 671 ± 14 |
| BP 580 | | |
| AD 1350 | -6.8 ± 2.0 | 638 ± 16 |
| BP 600 | | |
| AD 1330 | 4.1 ± 1.8 | 570 ± 14 |
| BP 620 | | |
| AD 1310 | 4.5 ± 1.8 | 586 ± 14 |
| BP 640 | | |
| AD 1290 | 2.3 ± 4.2 | 623 ± 34 |
| BP 660 | | |
| AD 1260[4] | -13.7 ± 1.2 | 781 ± 10 |
| BP 690 | | |
| AD 1230[3] | -14.4 ± 1.2 | 816 ± 10 |
| BP 720 | | |
| AD 1215[7] | -18.1 ± 2.2 | 861 ± 18 |
| BP 735 | | |
| AD 1195[7] | -11.8 ± 2.2 | 829 ± 18 |
| BP 755 | | |
| AD 1170[3] | -13.5 ± 1.1 | 867 ± 9 |
| BP 780 | | |
| AD 1150[3] | -18.5 ± 1.1 | 927 ± 9 |
| BP 800 | | |
| AD 1130[3] | -12.5 ± 1.5 | 898 ± 12 |
| BP 820 | | |
| AD 1110[3] | -13.3 ± 1.5 | 924 ± 12 |
| BP 840 | | |
| AD 1090[3] | -10.0 ± 1.4 | 916 ± 11 |
| BP 860 | | |
| AD 1070[3] | -4.6 ± 1.2 | 892 ± 10 |
| BP 880 | | |
| AD 1050[3] | -4.3 ± 1.5 | 909 ± 12 |
| BP 900 | | |
| AD 1030[3] | -9.2 ± 1.5 | 968 ± 12 |
| BP 920 | | |
| AD 1010[3] | -16.0 ± 1.4 | 1043 ± 11 |
| BP 940 | | |
| AD 990[3] | -17.1 ± 1.2 | 1052 ± 10 |
| BP 960 | | |
| AD 970[3] | -15.2 ± 1.2 | 1075 ± 10 |
| BP 980 | | |
| AD 955[7] | -18.9 ± 1.7 | 1120 ± 14 |
| BP 995 | | |
| AD 940 | -15.9 ± 2.0 | 1110 ± 16 |
| BP 1010 | | |
| AD 920 | -14.2 ± 1.7 | 1116 ± 14 |
| BP 1030 | | |
| AD 900 | -10.2 ± 1.7 | 1103 ± 14 |
| BP 1050 | | |
| AD 880 | -19.3 ± 1.7 | 1196 ± 14 |
| BP 1070 | | |
| AD 860 | -15.4 ± 2.1 | 1184 ± 17 |
| BP 1090 | | |
| AD 850 | -17.8 ± 2.1 | 1213 ± 17 |
| BP 1100 | | |
| AD 830 | -13.1 ± 2.1 | 1194 ± 17 |
| BP 1120 | | |
| AD 810 | -14.4 ± 2.0 | 1224 ± 16 |
| BP 1140 | | |
| AD 790 | -14.0 ± 2.0 | 1240 ± 16 |
| BP 1160 | | |
| AD 770 | -12.4 ± 2.0 | 1247 ± 16 |
| BP 1180 | | |
| AD 750 | -13.8 ± 2.0 | 1278 ± 16 |
| BP 1200 | | |

TABLE 2B

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| AD 730[1] | -7.5 ± 1.5 | 1246 ± 19 |
| BP 1220 | | |
| AD 710 | -9.6 ± 2.2 | 1282 ± |
| BP 1240 | | |
| AD 690 | -6.8 ± 2.2 | 1279 ± 18 |
| BP 1260 | | |
| AD 670 | -10.6 ± 2.2 | 1329 ± 18 |
| BP 1280 | | |
| AD 650[1] | -17.9 ± 1.5 | 1408 ± 12 |
| BP 1300 | | |
| AD 630 | -14.8 ± 2.2 | 1402 ± 18 |
| BP 1320 | | |
| AD 610 | -19.8 ± 2.2 | 1463 ± 18 |
| BP 1340 | | |
| AD 590 | -24.9 ± 2.2 | 1524 ± 18 |
| BP 1360 | | |
| AD 570 | -18.0 ± 2.2 | 1487 ± 18 |
| BP 1380 | | |
| AD 550 | -21.4 ± 2.3 | 1534 ± 19 |
| BP 1400 | | |
| AD 530 | -19.0 ± 2.2 | 1534 ± 18 |
| BP 1420 | | |
| AD 510 | -18.8 ± 2.1 | 1552 ± 17 |
| BP 1440 | | |
| AD 490 | -20.9 ± 2.1 | 1588 ± 17 |
| BP 1460 | | |
| AD 470 | -14.2 ± 2.1 | 1553 ± 17 |
| BP 1480 | | |
| AD 450 | -14.0 ± 2.1 | 1571 ± 17 |
| BP 1500 | | |
| AD 430 | -17.3 ± 2.1 | 1617 ± 17 |
| BP 1520 | | |
| AD 410 | -18.3 ± 2.1 | 1645 ± 17 |
| BP 1540 | | |
| AD 390 | -20.4 ± 2.1 | 1681 ± 17 |
| BP 1560 | | |
| AD 370 | -21.0 ± 2.1 | 1706 ± 17 |
| BP 1580 | | |
| AD 350 | -15.5 ± 2.2 | 1680 ± 18 |
| BP 1600 | | |
| AD 330 | -18.7 ± 2.2 | 1726 ± 18 |
| BP 1620 | | |
| AD 310 | -19.0 ± 2.1 | 1748 ± 17 |
| BP 1640 | | |
| AD 290 | -14.3 ± 2.1 | 1729 ± 17 |
| BP 1660 | | |
| AD 270 | -10.8 ± 2.2 | 1720 ± 18 |
| BP 1680 | | |
| AD 250 | -7.7 ± 2.2 | 1714 ± 18 |
| BP 1700 | | |
| AD 230 | -15.7 ± 2.2 | 1798 ± 18 |
| BP 1720 | | |
| AD 210 | -14.9 ± 2.2 | 1811 ± 18 |
| BP 1740 | | |
| AD 190 | -19.8 ± 2.2 | 1871 ± 18 |
| BP 1760 | | |
| AD 170 | -13.4 ± 2.2 | 1838 ± 18 |
| BP 1780 | | |
| AD 150 | -7.9 ± 2.2 | 1813 ± 18 |
| BP 1800 | | |
| AD 130 | -9.1 ± 2.2 | 1842 ± 18 |
| BP 1820 | | |
| AD 110 | -15.0 ± 2.2 | 1909 ± 18 |
| BP 1840 | | |
| AD 90 | -13.9 ± 2.2 | 1920 ± 18 |
| BP 1860 | | |
| AD 70 | -18.5 ± 2.0 | 1977 ± 16 |
| BP 1880 | | |
| AD 50 | -14.3 ± 2.2 | 1962 ± 18 |
| BP 1900 | | |
| AD 30 | -11.4 ± 2.0 | 1958 ± 16 |
| BP 1920 | | |
| AD 10 | -14.7 ± 2.1 | 2004 ± 17 |
| BP 1940 | | |
| BC 10 | -10.8 ± 2.2 | 1992 ± 18 |
| BP 1960 | | |
| BC 30 | -13.5 ± 2.2 | 2033 ± 18 |
| BP 1980 | | |
| BC 50 | -13.6 ± 2.1 | 2053 ± 17 |
| BP 2000 | | |
| BC 70 | -12.4 ± 2.0 | 2063 ± 16 |
| BP 2020 | | |
| BC 90 | -11.6 ± 2.0 | 2076 ± 16 |
| BP 2040 | | |
| BC 110 | -12.3 ± 1.7 | 2101 ± 14 |
| BP 2060 | | |
| BC 130 | -11.4 ± 2.0 | 2113 ± 16 |
| BP 2080 | | |
| BC 150 | -9.7 ± 2.0 | 2119 ± 16 |
| BP 2100 | | |
| BC 170[3] | -7.7 ± 1.5 | 2122 ± 12 |
| BP 2120 | | |
| BC 190[3] | -8.6 ± 1.5 | 2149 ± 12 |
| BP 2140 | | |
| BC 210[3] | -13.3 ± 1.6 | 2206 ± 13 |
| BP 2160 | | |
| BC 230 | -8.0 ± 2.1 | 2183 ± 17 |
| BP 2180 | | |
| BC 250 | -7.1 ± 2.0 | 2195 ± 16 |
| BP 2200 | | |
| BC 270 | -11.6 ± 2.0 | 2251 ± 16 |
| BP 2220 | | |
| BC 290 | -1.8 ± 2.2 | 2191 ± 18 |
| BP 2240 | | |
| BC 310[1] | -1.2 ± 1.6 | 2206 ± 13 |
| BP 2260 | | |
| BC 330 | 1.4 ± 2.2 | 2204 ± 18 |
| BP 2280 | | |
| BC 350 | 5.6 ± 2.0 | 2190 ± 16 |
| BP 2300 | | |
| BC 370 | 3.9 ± 1.6 | 2223 ± 13 |
| BP 2320 | | |

TABLE 2C

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| BC 390<br>BP 2340 | -0.8 ± 1.9 | 2280 ± 15 |
| BC 410<br>BP 2360 | -18.7 ± 2.2 | 2445 ± 18 |
| BC 430[4]<br>BP 2380 | -14.0 ± 1.4 | 2426 ± 11 |
| BC 450[4]<br>BP 2400 | -7.8 ± 1.5 | 2395 ± 12 |
| BC 470[4]<br>BP 2420 | -7.6 ± 1.4 | 2413 ± 11 |
| BC 490[4]<br>BP 2440 | -6.1 ± 1.6 | 2420 ± 13 |
| BC 510[4]<br>BP 2460 | -3.8 ± 1.2 | 2421 ± 10 |
| BC 530[4]<br>BP 2480 | -4.3 ± 1.2 | 2444 ± 10 |
| BC 550[4]<br>BP 2500 | -6.7 ± 1.1 | 2483 ± 9 |
| BC 570[4]<br>BP 2520 | -5.4 ± 1.2 | 2492 ± 10 |
| BC 590[4]<br>BP 2540 | -1.6 ± 1.4 | 2481 ± 11 |
| BC 610[4]<br>BP 2560 | -2.4 ± 1.2 | 2507 ± 10 |
| BC 630[4]<br>BP 2580 | 2.9 ± 1.3 | 2484 ± 10 |
| BC 650<br>BP 2600 | 7.1 ± 1.8 | 2470 ± 14 |
| BC 670[1]<br>BP 2620 | 5.1 ± 1.5 | 2505 ± 12 |
| BC 690[1]<br>BP 2640 | 12.2 ± 1.5 | 2468 ± 12 |
| BC 710<br>BP 2660 | 17.2 ± 1.9 | 2448 ± 15 |
| BC 730<br>BP 2680 | 19.6 ± 1.7 | 2448 ± 13 |
| BC 750<br>BP 2700 | 23.1 ± 1.7 | 2440 ± 13 |
| BC 770<br>BP 2720 | 16.8 ± 2.0 | 2509 ± 16 |
| BC 790[1]<br>BP 2740 | 18.1 ± 1.5 | 2518 ± 12 |
| BC 810<br>BP 2760 | 6.2 ± 2.3 | 2632 ± 18 |
| BC 830<br>BP 2780 | 6.0 ± 2.3 | 2653 ± 18 |
| BC 850<br>BP 2800 | 2.3 ± 2.0 | 2702 ± 16 |
| BC 870[1]<br>BP 2820 | 1.4 ± 1.8 | 2729 ± 14 |
| BC 890[1]<br>BP 2840 | 5.6 ± 1.8 | 2715 ± 14 |
| BC 910<br>BP 2860 | 2.8 ± 1.6 | 2757 ± 13 |
| BC 930<br>BP 2880 | -1.7 ± 2.4 | 2812 ± 19 |
| BC 950<br>BP 2900 | 0.2 ± 2.4 | 2816 ± 19 |
| BC 970[1]<br>BP 2920 | 5.5 ± 1.4 | 2793 ± 11 |
| BC 990[1]<br>BP 2940 | 5.2 ± 1.5 | 2815 ± 12 |
| BC 1010[2]<br>BP 2960 | 2.5 ± 1.0 | 2856 ± 8 |
| BC 1030[1]<br>BP 2980 | 4.2 ± 1.5 | 2862 ± 12 |
| BC 1050[1]<br>BP 3000 | 3.4 ± 1.3 | 2888 ± 10 |
| BC 1070[2]<br>BP 3020 | 3.1 ± 1.3 | 2910 ± 10 |
| BC 1090[1]<br>BP 3040 | 8.5 ± 1.5 | 2886 ± 12 |
| BC 1110[1]<br>BP 3060 | 14.1 ± 1.5 | 2861 ± 12 |
| BC 1120[3]<br>BP 3070 | 10.2 ± 1.9 | 2902 ± 15 |
| BC 1140[3]<br>BP 3090 | 8.4 ± 1.9 | 2935 ± 15 |
| BC 1150<br>BP 3100 | 9.0 ± 2.0 | 2940 ± 16 |
| BC 1170<br>BP 3120 | 7.1 ± 1.8 | 2975 ± 14 |
| BC 1190<br>BP 3140 | 13.7 ± 2.0 | 2942 ± 16 |
| BC 1210<br>BP 3160 | 14.4 ± 2.0 | 2956 ± 16 |
| BC 1230<br>BP 3180 | 11.0 ± 1.8 | 3002 ± 14 |
| BC 1250<br>BP 3200 | 22.6 ± 1.8 | 2930 ± 14 |
| BC 1270<br>BP 3220 | 12.9 ± 2.1 | 3026 ± 17 |
| BC 1290<br>BP 3240 | 15.5 ± 2.2 | 3025 ± 17 |
| BC 1310<br>BP 3260 | 15.8 ± 2.2 | 3042 ± 17 |
| BC 1330<br>BP 3280 | 11.4 ± 2.0 | 3096 ± 16 |
| BC 1350<br>BP 3300 | 21.1 ± 2.0 | 3039 ± 16 |
| BC 1370<br>BP 3320 | 24.7 ± 2.3 | 3030 ± 18 |
| BC 1390<br>BP 3240 | 24.3 ± 1.9 | 3053 ± 15 |
| BC 1410<br>BP 3360 | 21.1 ± 1.8 | 3097 ± 14 |
| BC 1430<br>BP 3380 | 13.1 ± 2.0 | 3180 ± 16 |
| BC 1450[1]<br>BP 3400 | 13.3 ± 1.3 | 3198 ± 10 |
| BC 1470<br>BP 3420 | 15.3 ± 1.9 | 3201 ± 15 |

TABLE 2D

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| BC 1490<br>BP 3440 | 20.8 ± 2.0 | 3177 ± 16 |
| BC 1510<br>BP 3460 | 24.8 ± 2.0 | 3165 ± 16 |
| BC 1530<br>BP 3480 | 10.0 ± 1.9 | 3302 ± 15 |
| BC 1550<br>BP 3500 | 10.1 ± 2.3 | 3320 ± 18 |
| BC 1570<br>BP 3520 | 17.3 ± 2.0 | 3283 ± 16 |
| BC 1590<br>BP 3540 | 19.3 ± 1.8 | 3286 ± 14 |
| BC 1610<br>BP 3560 | 21.9 ± 1.9 | 3285 ± 15 |
| BC 1630<br>BP 3580 | 19.3 ± 1.9 | 3325 ± 15 |
| BC 1650<br>BP 3600 | 22.3 ± 1.7 | 3321 ± 13 |
| BC 1670<br>BP 3620 | 23.8 ± 1.9 | 3329 ± 15 |
| BC 1690<br>BP 3640 | 16.9 ± 2.0 | 3402 ± 16 |
| BC 1710<br>BP 3660 | 15.2 ± 2.4 | 3435 ± 19 |
| BC 1730<br>BP 3680 | 25.4 ± 1.7 | 3374 ± 13 |
| BC 1750<br>BP 3700 | 20.2 ± 1.9 | 3435 ± 15 |
| BC 1770<br>BP 3720 | 19.5 ± 1.8 | 3460 ± 14 |
| BC 1790<br>BP 3740 | 13.6 ± 2.2 | 3526 ± 17 |
| BC 1810<br>BP 3760 | 24.9 ± 2.4 | 3456 ± 19 |
| BC 1830<br>BP 3780 | 19.9 ± 2.4 | 3515 ± 19 |
| BC 1850<br>BP 3800 | 30.8 ± 1.8 | 3449 ± 14 |
| BC 1870<br>BP 3820 | 32.1 ± 1.8 | 3458 ± 14 |
| BC 1890<br>BP 3840 | 24.5 ± 1.7 | 3537 ± 13 |
| BC 1910<br>BP 3860 | 21.6 ± 2.3 | 3579 ± 18 |
| BC 1930<br>BP 3880 | 27.4 ± 1.8 | 3553 ± 14 |
| BC 1950<br>BP 3900 | 25.0 ± 1.7 | 3591 ± 13 |
| BC 1970<br>BP 3920 | 28.0 ± 2.2 | 3587 ± 17 |
| BC 1990<br>BP 3940 | 21.1 ± 2.7 | 3661 ± 21 |
| BC 2010<br>BP 3960 | 28.9 ± 1.9 | 3619 ± 15 |
| BC 2030<br>BP 3980 | 31.7 ± 2.1 | 3617 ± 16 |
| BC 2050<br>BP 4000 | 22.8 ± 2.0 | 3706 ± 16 |
| BC 2070<br>BP 4020 | 25.5 ± 2.3 | 3704 ± 18 |
| BC 2090<br>BP 4040 | 33.6 ± 1.9 | 3660 ± 15 |
| BC 2110<br>BP 4060 | 35.6 ± 2.3 | 3664 ± 18 |
| BC 2130<br>BP 4080 | 34.6 ± 2.3 | 3691 ± 18 |
| BC 2150[1]<br>BP 4100 | 23.9 ± 1.7 | 3794 ± 13 |
| BC 2170<br>BP 4120 | 33.3 ± 2.3 | 3740 ± 18 |
| BC 2190<br>BP 4140 | 29.3 ± 1.8 | 3791 ± 14 |
| BC 2210<br>BP 4160 | 28.1 ± 1.8 | 3820 ± 14 |
| BC 2230<br>BP 4180 | 32.5 ± 2.1 | 3805 ± 16 |
| BC 2250<br>BP 4200 | 40.0 ± 1.7 | 3766 ± 13 |
| BC 2270<br>BP 4220 | 40.7 ± 2.1 | 3780 ± 16 |
| BC 2290<br>BP 4240 | 36.8 ± 2.1 | 3830 ± 16 |
| BC 2310<br>BP 4260 | 38.6 ± 2.1 | 3835 ± 16 |
| BC 2330<br>BP 4280 | 38.7 ± 1.7 | 3854 ± 13 |
| BC 2350<br>BP 4300 | 40.6 ± 2.1 | 3859 ± 16 |
| BC 2370<br>BP 4320 | 41.6 ± 1.7 | 3870 ± 13 |
| BC 2390<br>BP 4340 | 44.6 ± 2.1 | 3867 ± 16 |
| BC 2410<br>BP 4360 | 42.9 ± 1.6 | 3899 ± 12 |
| BC 2430[1&4]<br>BP 4380 | 49.5 ± 0.9 | 3868 ± 7 |
| BC 2450<br>BP 4400 | 52.4 ± 1.3 | 3865 ± 10 |
| BC 2470<br>BP 4420 | 42.6 ± 1.7 | 3960 ± 13 |
| BC 2490<br>BP 4440 | 45.1 ± 1.7 | 3960 ± 13 |
| BC 2510<br>BP 4460 | 38.5 ± 1.3 | 4030 ± 10 |
| BC 2530<br>BP 4480 | 40.5 ± 1.9 | 4034 ± 15 |
| BC 2550<br>BP 4500 | 51.0 ± 1.8 | 3973 ± 14 |

TABLE 2E

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| BC 2570<br>BP 4520 | 48.3 ± 1.4 | 4013 ± 11 |
| BC 2590[1]<br>BP 4540 | 43.8 ± 1.4 | 4067 ± 11 |
| BC 2610<br>BP 4560 | 45.3 ± 2.3 | 4075 ± 18 |
| BC 2630<br>BP 4580 | 40.7 ± 1.3 | 4130 ± 10 |
| BC 2650<br>BP 4600 | 50.8 ± 1.8 | 4072 ± 14 |
| BC 2670<br>BP 4620 | 43.3 ± 1.6 | 4149 ± 12 |
| BC 2690<br>BP 4640 | 51.3 ± 1.6 | 4107 ± 12 |
| BC 2710<br>BP 4660 | 41.8 ± 1.6 | 4199 ± 12 |
| BC 2730[1]<br>BP 4680 | 54.4 ± 1.2 | 4121 ± 9 |
| BC 2750<br>BP 4700 | 54.7 ± 1.6 | 4144 ± 12 |
| BC 2770<br>BP 4720 | 57.0 ± 2.1 | 4141 ± 16 |
| BC 2790<br>BP 4740 | 47.0 ± 1.7 | 4237 ± 13 |
| BC 2810<br>BP 4760 | 62.3 ± 1.7 | 4140 ± 13 |
| BC 2830[1&4]<br>BP 4780 | 72.4 ± 1.1 | 4083 ± 8 |
| BC 2850[4]<br>BP 4800 | 75.6 ± 1.5 | 4079 ± 11 |
| BC 2870[3]<br>BP 4820 | 67.1 ± 1.7 | 4162 ± 13 |
| BC 2890<br>BP 4840 | 59.7 ± 1.7 | 4237 ± 13 |
| BC 2910<br>BP 4860 | 57.7 ± 1.6 | 4272 ± 12 |
| BC 2930<br>BP 4880 | 46.0 ± 1.7 | 4381 ± 13 |
| BC 2950<br>BP 4900 | 46.1 ± 1.7 | 4399 ± 13 |
| BC 2970<br>BP 4920 | 50.1 ± 2.4 | 4388 ± 18 |
| BC 2990<br>BP 4940 | 54.1 ± 1.8 | 4377 ± 14 |
| BC 3010<br>BP 4960 | 60.9 ± 1.9 | 4345 ± 14 |
| BC 3030<br>BP 4980 | 58.2 ± 1.7 | 4385 ± 13 |
| BC 3050<br>BP 5000 | 51.4 ± 1.7 | 4456 ± 13 |
| BC 3070<br>BP 5020 | 58.5 ± 1.8 | 4421 ± 14 |
| BC 3090<br>BP 5040 | 60.3 ± 2.1 | 4427 ± 16 |
| BC 3110<br>BP 5060 | 53.1 ± 2.6 | 4501 ± 20 |
| BC 3130<br>BP 5080 | 56.9 ± 2.0 | 4492 ± 15 |
| BC 3150<br>BP 5100 | 53.9 ± 1.8 | 4534 ± 14 |
| BC 3170<br>BP 5120 | 63.3 ± 2.4 | 4482 ± 18 |
| BC 3190[1]<br>BP 5140 | 59.3 ± 2.0 | 4532 ± 15 |
| BC 3210<br>BP 5160 | 60.3 ± 2.1 | 4544 ± 16 |
| BC 3230[1]<br>BP 5180 | 66.8 ± 1.6 | 4514 ± 12 |
| BC 3250[1]<br>BP 5200 | 76.9 ± 1.7 | 4458 ± 13 |
| BC 3270<br>BP 5220 | 77.1 ± 2.3 | 4476 ± 17 |
| BC 3290<br>BP 5240 | 80.3 ± 1.9 | 4471 ± 14 |
| BC 3310<br>BP 5260 | 78.4 ± 1.9 | 4505 ± 14 |
| BC 3330<br>BP 5280 | 79.4 ± 1.9 | 4517 ± 14 |
| BC 3350<br>BP 5300 | 73.9 ± 1.9 | 4577 ± 14 |
| BC 3370<br>BP 5320 | 70.3 ± 2.4 | 4624 ± 18 |
| BC 3390<br>BP 5340 | 58.7 ± 2.1 | 4731 ± 16 |
| BC 3410<br>BP 5360 | 66.5 ± 2.4 | 4691 ± 18 |
| BC 3430<br>BP 5380 | 72.4 ± 2.4 | 4666 ± 18 |
| BC 3450<br>BP 5400 | 75.0 ± 2.3 | 4666 ± 17 |
| BC 3470<br>BP 5420 | 77.2 ± 2.4 | 4669 ± 18 |
| BC 3490<br>BP 5440 | 82.3 ± 2.6 | 4651 ± 19 |
| BC 3510<br>BP 5460 | 75.6 ± 2.5 | 4720 ± 19 |
| BC 3530<br>BP 5480 | 71.8 ± 2.5 | 4768 ± 19 |
| BC 3550<br>BP 5500 | 68.4 ± 2.5 | 4813 ± 19 |
| BC 3570<br>BP 5520 | 74.4 ± 2.7 | 4787 ± 20 |
| BC 3590<br>BP 5540 | 85.3 ± 2.7 | 4726 ± 20 |
| BC 3610<br>BP 5560 | 85.2 ± 2.7 | 4746 ± 20 |
| BC 3630<br>BP 5580 | 80.3 ± 2.7 | 4802 ± 20 |

TABLE 2F

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|
| BC 3650<br>BP 5600 | 74.4 ± 2.7 | 4865 ± 20 |
| BC 3670<br>BP 5620 | 78.1 ± 2.4 | 4857 ± 18 |
| BC 3690<br>BP 5640 | 79.4 ± 2.4 | 4867 ± 18 |
| BC 3710<br>BP 5660 | 69.6 ± 2.4 | 4959 ± 18 |
| BC 3730<br>BP 5680 | 70.5 ± 2.4 | 4972 ± 18 |
| BC 3750<br>BP 5700 | 77.2 ± 2.4 | 4941 ± 18 |
| BC 3770<br>BP 5720 | 83.8 ± 2.3 | 4912 ± 17 |
| BC 3790<br>BP 5740 | 70.4 ± 2.4 | 5031 ± 18 |
| BC 3810<br>BP 5760 | 74.5 ± 2.3 | 5020 ± 17 |
| BC 3830<br>BP 5780 | 63.9 ± 2.0 | 5119 ± 15 |
| BC 3850[5]<br>BP 5800 | 73.0 ± 1.5 | 5070 ± 11 |
| BC 3870[5]<br>BP 5820 | 77.2 ± 1.7 | 5058 ± 13 |
| BC 3890[5]<br>BP 5840 | 85.7 ± 1.8 | 5014 ± 13 |
| BC 3910[5]<br>BP 5860 | 84.9 ± 1.6 | 5040 ± 12 |
| BC 3930[5]<br>BP 5880 | 87.2 ± 1.6 | 5042 ± 12 |
| BC 3950[5]<br>BP 5900 | 83.5 ± 1.6 | 5089 ± 12 |
| BC 3970[5]<br>BP 5920 | 81.6 ± 1.6 | 5122 ± 12 |
| BC 3990<br>BP 5940 | 78.6 ± 2.0 | 5164 ± 15 |
| BC 4010<br>BP 5960 | 69.7 ± 1.9 | 5250 ± 14 |
| BC 4030<br>BP 5980 | 78.9 ± 1.8 | 5201 ± 13 |
| BC 4050<br>BP 6000 | 66.8 ± 1.7 | 5311 ± 13 |
| BC 4070<br>BP 6020 | 72.4 ± 1.9 | 5288 ± 14 |
| BC 4090<br>BP 6040 | 73.3 ± 1.9 | 5301 ± 14 |
| BC 4110<br>BP 6060 | 76.0 ± 2.4 | 5300 ± 18 |
| BC 4130<br>BP 6080 | 83.9 ± 2.4 | 5261 ± 18 |
| BC 4150<br>BP 6100 | 80.3 ± 2.8 | 5307 ± 21 |
| BC 4170<br>BP 6120 | 76.2 ± 2.1 | 5357 ± 16 |
| BC 4190<br>BP 6140 | 80.3 ± 2.6 | 5346 ± 19 |
| BC 4210<br>BP 6160 | 94.8 ± 2.3 | 5258 ± 17 |
| BC 4230<br>BP 6180 | 86.5 ± 2.2 | 5339 ± 16 |
| BC 4250<br>BP 6200 | 78.6 ± 2.2 | 5417 ± 16 |
| BC 4270<br>BP 6220 | 80.2 ± 2.3 | 5424 ± 17 |
| BC 4290<br>BP 6240 | 87.2 ± 2.3 | 5392 ± 17 |
| BC 4310<br>BP 6260 | 89.4 ± 2.0 | 5395 ± 15 |
| BC 4330<br>BP 6280 | 90.3 ± 2.2 | 5408 ± 16 |
| BC 4350<br>BP 6300 | 81.9 ± 2.0 | 5489 ± 15 |
| BC 4370<br>BP 6320 | 73.7 ± 1.9 | 5570 ± 14 |
| BC 4390<br>BP 6340 | 78.2 ± 2.2 | 5556 ± 16 |
| BC 4410<br>BP 6360 | 75.9 ± 2.1 | 5592 ± 16 |
| BC 4430<br>BP 6380 | 83.3 ± 2.2 | 5557 ± 16 |
| BC 4450<br>BP 6400 | 86.6 ± 2.2 | 5552 ± 16 |
| BC 4470<br>BP 6420 | 77.3 ± 2.2 | 5640 ± 16 |
| BC 4490<br>BP 6440 | 79.5 ± 2.2 | 5643 ± 16 |
| BC 4510<br>BP 6460 | 78.8 ± 2.3 | 5668 ± 17 |
| BC 4530<br>BP 6480 | 77.9 ± 2.3 | 5694 ± 17 |
| BC 4550<br>BP 6500 | 78.0 ± 2.3 | 5713 ± 17 |
| BC 4570<br>BP 6520 | 83.0 ± 2.4 | 5695 ± 18 |
| BC 4590<br>BP 6540 | 79.4 ± 2.3 | 5741 ± 17 |
| BC 4610<br>BP 6560 | 79.9 ± 2.2 | 5757 ± 16 |
| BC 4630<br>BP 6580 | 79.9 ± 2.2 | 5776 ± 16 |
| BC 4650<br>BP 6600 | 91.1 ± 2.6 | 5713 ± 19 |
| BC 4670<br>BP 6620 | 86.7 ± 2.3 | 5765 ± 17 |
| BC 4690<br>BP 6640 | 85.2 ± 2.2 | 5795 ± 16 |
| BC 4710<br>BP 6660 | 90.2 ± 2.2 | 5778 ± 16 |

TABLE 2G

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP | cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|---|---|---|
| BC 4730<br>BP 6680 | 83.5 ± 2.4 | 5847 ± 18 | BC 4990<br>BP 6940 | 89.6 ± 2.0 | 6054 ± 15 |
| BC 4750<br>BP 6700 | 86.4 ± 2.4 | 5845 ± 18 | BC 5010<br>BP 6960 | 85.5 ± 2.2 | 6104 ± 16 |
| BC 4770<br>BP 6720 | 90.5 ± 2.4 | 5834 ± 18 | BC 5030<br>BP 6980 | 92.3 ± 2.5 | 6073 ± 18 |
| BC 4790<br>BP 6740 | 82.2 ± 2.6 | 5914 ± 19 | BC 5050<br>BP 7000 | 92.1 ± 2.3 | 6094 ± 17 |
| BC 4810<br>BP 6760 | 81.6 ± 2.4 | 5939 ± 18 | BC 5070<br>BP 7020 | 89.1 ± 2.3 | 6136 ± 17 |
| BC 4830<br>BP 6780 | 87.7 ± 1.9 | 5913 ± 14 | BC 5090<br>BP 7040 | 88.4 ± 2.4 | 6160 ± 18 |
| BC 4850<br>BP 6800 | 83.7 ± 2.4 | 5962 ± 18 | BC 5110<br>BP 7060 | 93.4 ± 2.3 | 6143 ± 17 |
| BC 4870<br>BP 6820 | 83.1 ± 2.6 | 5986 ± 19 | BC 5130<br>BP 7080 | 98.2 ± 2.3 | 6127 ± 17 |
| BC4890<br>BP 6840 | 93.1 ± 2.6 | 5931 ± 18 | BC 5150<br>BP 7100 | 94.2 ± 2.5 | 6176 ± 18 |
| BC 4910<br>BP 6860 | 81.4 ± 2.7 | 6037 ± 20 | BC 5170<br>BP 7120 | 100.3 ± 2.3 | 6151 ± 17 |
| BC 4930[1]<br>BP 6880 | 91.0 ± 1.5 | 5986 ± 11 | BC 5190<br>BP 7140 | 108.6 ± 2.4 | 6110 ± 17 |
| BC 4950<br>BP 6900 | 80.7 ± 2.0 | 6081 ± 15 | BC 5210<br>BP 7160 | 100.4 ± 2.3 | 6189 ± 17 |
| BC 4970<br>BP 6920 | 85.5 ± 2.0 | 6065 ± 15 | | | |

Legend

cal AD/BC<br>cal BP : Mid-point of bi-decade sample unless otherwise stated

Superscript:

[1] A weighted mean of the bi-decade results of a complete duplicate analysis
[2] A weighted mean of the bi-decade results of a complete triplicate analysis
[3] A weighted mean of two decades to give a bi-decade value
[4] Two decades meaned to give a bi-decade value which is then meaned with a bi-decade measurement, appropriately weighted
[5] Overlapping bi-decade results combined to give a weighted mean bi-decade value
[6] A weighted mean of the bi-decade results of a complete duplicate analysis combined with overlapping bi-decade values, appropriately weighted
[7] Decade result only

$$\Delta^{14}C : \Delta = \left[\frac{A_{SN}e^{\lambda(y-x)}}{A_{ABS}} - 1\right] 1000‰$$

calculated using the mean $^{14}C$ age (where applicable) $\pm 1\sigma$
(Stuiver & Polach, 1977)

Radiocarbon age BP : Age of bi-decade sample unless otherwise stated (see superscript) $\pm 1\sigma$

TABLE 3 A–B

Decade samples only (either extracted from or additional to Table 2)
(See legend, Table 3B)

TABLE 3A

| cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP | cal AD/BC<br>cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|---|---|---|
| AD 1535<br>BP 415 | 11.2 ± 2.0 | 314 ± 16 | AD 1015<br>BP 935 | -13.8 ± 2.1 | 1020 ± 17 |
| AD 1525<br>BP 425 | 17.6 ± 1.8 | 273 ± 14 | AD 1005<br>BP 945 | -17.3 ± 1.7 | 1058 ± 14 |
| AD 1515<br>BP 435 | 9.7 ± 1.8 | 345 ± 14 | AD 995<br>BP 955 | -13.1 ± 1.7 | 1034 ± 14 |
| AD 1505<br>BP 445 | 6.8 ± 1.8 | 378 ± 14 | AD 985<br>BP 965 | -16.2 ± 1.7 | 1069 ± 14 |
| AD 1265<br>BP 685 | -12.5 ± 2.0 | 767 ± 16 | AD 975<br>BP 975 | -12.2 ± 1.7 | 1046 ± 14 |
| AD 1255<br>BP 695 | -15.3 ± 1.7 | 799 ± 14 | AD 965<br>BP 985 | -18.1 ± 1.7 | 1104 ± 14 |
| AD 1235<br>BP 715 | -11.2 ± 2.1 | 785 ± 17 | AD 955<br>BP 995 | -18.9 ± 1.7 | 1120 ± 14 |
| AD 1225<br>BP 725 | -15.6 ± 1.5 | 831 ± 12 | BC 165<br>BP 2115 | -8.4 ± 2.0 | 2123 ± 16 |
| AD 1215<br>BP 735 | -18.1 ± 2.2 | 861 ± 18 | BC 175<br>BP 2125 | -7.0 ± 2.1 | 2121 ± 17 |
| AD 1195<br>BP 755 | -11.8 ± 2.2 | 829 ± 18 | BC 185<br>BP 2135 | -7.3 ± 2.0 | 2133 ± 16 |
| AD 1175<br>BP 775 | -12.1 ± 1.5 | 851 ± 12 | BC 195<br>BP 2145 | -10.5 ± 2.2 | 2169 ± 18 |
| AD 1165<br>BP 785 | -14.9 ± 1.5 | 883 ± 12 | BC 205<br>BP 2155 | -12.9 ± 2.1 | 2198 ± 17 |
| AD 1155<br>BP 795 | -16.7 ± 1.5 | 908 ± 12 | BC 215<br>BP 2165 | -13.5 ± 2.1 | 2213 ± 17 |
| AD 1145<br>BP 805 | -20.1 ± 1.5 | 945 ± 12 | BC 295<br>BP 2245 | -2.1 ± 2.0 | 2198 ± 16 |
| AD 1135<br>BP 815 | -11.4 ± 2.0 | 884 ± 16 | BC 425<br>BP 2375 | -16.6 ± 2.0 | 2442 ± 16 |
| AD 1125<br>BP 825 | -13.6 ± 2.0 | 912 ± 16 | BC 435<br>BP 2385 | -11.7 ± 2.3 | 2412 ± 19 |
| AD 1115<br>BP 835 | -16.0 ± 2.0 | 941 ± 16 | BC 445<br>BP 2395 | -7.8 ± 2.2 | 2390 ± 18 |
| AD 1105<br>BP 845 | -10.6 ± 2.0 | 907 ± 16 | BC 455<br>BP 2405 | -4.6 ± 2.4 | 2374 ± 19 |
| AD 1095<br>BP 855 | -11.3 ± 2.0 | 922 ± 16 | BC 465<br>BP 2415 | -5.5 ± 2.2 | 2391 ± 18 |
| AD 1085<br>BP 865 | -8.7 ± 1.7 | 911 ± 14 | BC 475<br>BP 2425 | -5.4 ± 2.2 | 2400 ± 18 |
| AD 1075<br>BP 875 | -9.1 ± 1.7 | 924 ± 14 | BC 485<br>BP 2435 | -6.9 ± 2.4 | 2422 ± 19 |
| AD 1065<br>BP 885 | 0.1 ± 1.7 | 859 ± 14 | BC 495<br>BP 2445 | -5.4 ± 2.2 | 2419 ± 18 |
| AD 1055<br>BP 895 | -2.0 ± 2.0 | 886 ± 16 | BC 505<br>BP 2455 | -2.8 ± 2.2 | 2408 ± 18 |
| AD 1045<br>BP 905 | -6.4 ± 2.0 | 931 ± 16 | BC 515<br>BP 2465 | -5.6 ± 1.9 | 2440 ± 15 |
| AD 1035<br>BP 915 | -8.5 ± 2.0 | 958 ± 16 | BC 525<br>BP 2475 | -3.2 ± 2.0 | 2431 ± 16 |
| AD 1025<br>BP 925 | -10.1 ± 2.1 | 980 ± 17 | BC 535<br>BP 2485 | -3.3 ± 2.0 | 2441 ± 16 |

TABLE 3B

| cal AD/BC cal BP | $\Delta^{14}C$ | Radiocarbon age BP | cal AD/BC cal BP | $\Delta^{14}C$ | Radiocarbon age BP |
|---|---|---|---|---|---|
| BC 545 | -4.7 ± 2.0 | 2462 ± 16 | BC 1145 | 10.3 ± 2.5 | 2925 ± 20 |
| BP 2495 | | | BP 3095 | | |
| BC 555 | -7.3 ± 2.0 | 2493 ± 16 | BC 2375 | 32.1 ± 2.7 | 3949 ± 21 |
| BP 2505 | | | BP 4325 | | |
| BC 565 | -6.6 ± 2.0 | 2497 ± 16 | BC 2395 | 39.7 ± 2.7 | 3909 ± 21 |
| BP 2515 | | | BP 4345 | | |
| BC 575 | -8.0 ± 2.0 | 2518 ± 16 | BC 2415 | 39.9 ± 2.7 | 3927 ± 21 |
| BP 2525 | | | BP 4365 | | |
| BC 585 | -3.5 ± 2.2 | 2491 ± 18 | BC 2425 | 49.8 ± 1.8 | 3861 ± 14 |
| BP 2535 | | | BP 4375 | | |
| BC 595 | -1.3 ± 2.2 | 2483 ± 18 | BC 2435 | 42.8 ± 2.7 | 3924 ± 21 |
| BP 2545 | | | BP 4385 | | |
| BC 605 | -4.8 ± 2.2 | 2521 ± 18 | BC 2825 | 70.2 ± 2.4 | 4095 ± 18 |
| BP 2555 | | | BP 4775 | | |
| BC 615 | 0.2 ± 2.0 | 2491 ± 16 | BC 2835 | 76.4 ± 2.4 | 4058 ± 18 |
| BP 2565 | | | BP 4785 | | |
| BC 625 | 1.4 ± 2.0 | 2491 ± 16 | BC 2845 | 76.7 ± 2.4 | 4066 ± 18 |
| BP 2575 | | | BP 4795 | | |
| BC 635 | 0.6 ± 2.0 | 2507 ± 16 | BC 2855 | 67.5 ± 2.4 | 4144 ± 18 |
| BP 2585 | | | BP 4805 | | |
| BC 645 | 6.1 ± 1.8 | 2473 ± 14 | BC 2865 | 66.3 ± 2.4 | 4163 ± 18 |
| BP 2595 | | | BP 4815 | | |
| BC 1115 | 10.9 ± 2.5 | 2891 ± 20 | BC 2875 | 68.0 ± 2.4 | 4160 ± 18 |
| BP 3065 | | | BP 4825 | | |
| BC 1125 | 9.5 ± 2.5 | 2912 ± 20 | BC 2885 | 64.1 ± 2.4 | 4199 ± 18 |
| BP 3075 | | | BP 4835 | | |
| BC 1135 | 6.6 ± 2.6 | 2945 ± 21 | | | |
| BP 3085 | | | | | |

Legend

$\frac{\text{cal AD/BC}}{\text{cal BP}}$ : Mid-point of single decade sample

$$\Delta^{14}C : \Delta = \left[\frac{A_{SN}e^{\lambda(y-x)}}{A_{ABS}} - 1\right] 1000‰$$

calculated using the $^{14}C$ age ± 1$\sigma$ (Stuiver & Polach, 1977)

$\frac{\text{Radiocarbon}}{\text{age BP}}$ : Age of single decade sample ±1$\sigma$