Notes and News

The radiocarbon calendar recalibrated

In Richard Burleigh's account of the 8th International Conference on Radiocarbon Dating in our March issue (1973, 54–6) we learned that 'it was agreed that no particular calibration curve or table should be preferentially adopted at present'. Dr V. R. Switsur, of the Radiocarbon Dating Research Laboratory in the University of Cambridge, thought it would be interesting to examine how the two corrections were obtained and to see where and by how much they disagree. We think that our readers will be interested in, and find useful, his results.

During the 8th International Conference on Radiocarbon Dating at Lower Hutt City, New Zealand, two important papers were presented dealing with the calibration of the radiocarbon time scale by means of dendrochronologically dated specimens of Sequoia and Bristlecone Pine. The first was given by Dr Michael and Dr Ralph of the University of Pennsylvania and the second by Dr Damon, Dr Long and Dr Wallick of the University of Arizona.* Since each of these papers was intended to be used as a correction for raw radiocarbon dates, there was disappointment when it was stated that the two corrections did not agree and the Conference could not recommend their exclusive use. Let us then examine how the two corrections were obtained and see where and by how much they disagree.

Each calibration was based on about 600 radiocarbon analyses of dendrochronologically dated wood. A few measurements from the published data were rejected by the application of various critera. Chauvenet's criterion, the first to be applied, is known to reject a small number of good but outlying data and so both sets of authors required supplementary criteria for rejection purposes. 286 of the data points were taken from publications of Dr Suess of the La Jolla radiocarbon dating laboratory. These had to be obtained by the inspection of graphs, since Dr Suess has not yet presented his data in explicit tabular form, so they will all be subject to a small error in reading which is probably not more than about twenty years. The remaining information has been published in tables by Pennsylvania, Arizona and Yale radiocarbon dating laboratories.

The two groups of authors derived their corrections differently. Michael and Ralph first set out to reduce the statistical scatter of the raw data by obtaining the 9-sample floating averages for the whole curve of deviations from the true ages. This produced a second curve which preserved the larger of the kinks and wriggles of the Suess curve.† Next the 9-sample means were again averaged for given periods of 50 or 100 years. These figures were then used to derive the correction factors for the chosen periods and were given in the form of a table.

Damon, Long and Wallick calculated the difference between the radiocarbon age and dendrochronological age for each of the 600 odd points on the curve and then calculated 25-year averages of these. By computer, a curve was fitted to these averages with the method of curvilinear regression analysis using orthogonal polynomials. The standard deviation of the interval points about the curve for 250-year intervals was calculated. A change of variable

* H. N. Michael and Elizabeth K. Ralph, 1972. Discussion of radiocarbon dates obtained from precisely dated Sequoia and Bristlecone Pine samples, *Proc. 8th Int. Conf. on Radiocarbon dating, Lower Hutt City*. vol. 1., 28 to 43; P. E. Damon, A. Long and E. I. Wallick, 1972. Dendrochronology calibration of the Carbon-14 time scale, ibid., 45–59.

† H. E. Suess, 1970. Bristlecone Pine calibration of the radiocarbon time scale 5200 BC to the present, *XII Nobel Symposium* (Radiocarbon variations and absolute chronology), 303–309.

was introduced so that the deviations could be plotted against radiocarbon age (which is non-linear) and hence a correction factor was obtained as well as the standard deviation for 250-year intervals. This deviation is a function of the geomagnetic field intensity since sun-spot variations have a larger effect on radio-carbon production rate during periods of low magnetic field intensity compared with periods of high geomagnetic field intensity.

Throughout the discussion of the work on the Bristlecone Pine calibration of the radiocarbon time-scale Dr H. E. Suess has stated that his is the only true calibration and has refused to allow his results to be published on a single chart together with those from other laboratories.* He maintained the stand in New Zealand that nature is not necessarily as simple as we would wish and an attempt to draw a smooth curve amongst the measured points is probably the wrong approach. He believes that the 'kinks' and 'wriggles' are real and do represent rapid changes of atmospheric C14 activity. These idiosyncrasies of the original data are necessarily obscured by the extensive procedures of averaging used by both Michael and Ralph and Damon *et al.* in obtaining their new correction curves. The curves have the computational advantage, however, that each radiocarbon measurement yields but one calendar age.

In order to investigate the 'non-agreement' of the two correction factors the columns in Table 1 show the following: The first two columns give the radiocarbon age in terms of ad/bc and bp using the 5730 half-life for radiocarbon (in order to convert dates bp provided by the dating laboratory it is necessary to multiply by the factor 1·03). The third and fourth columns give the corrected age in calendar years as given directly by the Arizona correction and as derived from about the mid points of the Pennsylvania correction factor for the same BP age. The next column gives the difference, in years, between the two corrections; positive (+) if the Arizona correction yields the older age and negative (—) if the Pennsylvania correction gives the older age. The final column gives the mean of the two corrected ages.

The numbers in column 5 are plotted in FIG. 1 and one can immediately see from this the effects of either correction on any individual radiocarbon date. It will be observed that the difference in most cases is comfortingly small and probably within the limits of the standard deviation provided with the radiocarbon date. Only during the radiocarbon time period 3900 to 5500 bp does the difference exceed 100 years, the average difference for the whole of the time covered being only 34 years.

Since these two correction factors are so close, even though based on different methods of averaging it was thought convenient to accept their mean values as the best corrections available at the present state of the art. Accordingly, these are presented for the 50-year intervals in column 6 and are plotted in FIG. 2. It should be emphasized that the two papers given at the Conference contain full details of the derivation of the correction factors and tables containing a larger number of conversion points.

The conversion factors are based on about 600 individual measurements and it will be many years before a sufficiently greater number of measurements will be made to alter the shape of the deviation curve significantly. Hence there is little likelihood that correction factors that are very different from these given will be derived. There is every probability, however, that the curve will be extended and areas having a low density of measurements so far, will be made more definitive.

Finally, in Table 2, a systematic comparison is made between the ages obtained by the use of the new correction and those calculated by means of the equation found by Wendland and Donley in their exercise of fitting a curve to the tree ring measurements available at that time.† Their equation for the calendar age is:

* Olsson I. U. Explanation of plate IV (1970) Radiocarbon variations and absolute chronology, *XII Nobel Symposium*, 625–6.

† W. M. Wendland and D. L. Donley 1971. Radiocarbon-calendar age relationship, *Earth and planetary science letters*, vol. 11, 135–9.

$$112 + (0{\cdot}690 \times R) + (1{\cdot}520 \times 10^{-4} \times R^2) - (1{\cdot}38 \times 10^{-8} \times R^3)$$

where R is the radiocarbon age (5730 half life).

Over most of the time scale the equation predicts marginally older calendar ages than the new correction. The difference only reaches a magnitude of 70 to 100 years in the earlier two millennia, and is probably due to the larger number of data points now available yielding a more accurate result.

In practice, when converting radiocarbon ages to calendar ages, the statistical uncertainties must not be ignored. The uncertainty quoted with the radiocarbon date is squared and added to the square of the uncertainty given in Damon *et al* for the appropriate time range. The root of this sum is the uncertainty of the corrected date. As an example take a radiocarbon date of 5894 ± 110 bp

(*a*) correct to 5730 half life giving 6070

(*b*) correct by the calibration chart giving 6747

(*c*) the uncertainty is $\sqrt{110^2 + 77^2}$ (77 is from Damon *et al.*)

$$= \sqrt{12100 + 18029}$$
$$= 134$$

So the calendar age for this sample is 6747 ± 134 BP or 4797 ± 134 BC.

If this correction is carried out in a publication it is essential that the original date and laboratory number are quoted.

Table 1. Investigation of the non-agreement of the two correction factors

Columns 1 & 2: Radiocarbon age (5730 half-life), ad/bc (1) and bp (2)

Columns 3 & 4: Corrected age according to Arizona (3) and Pennsylvania (4)

Column 5: Difference between corrected ages

Column 6: Average of corrected ages BP

1	2	3	4	5	6
1837	113	179	167	+12	173
1787	163	221	227	+12	224
1737	213	263	324	−61	294
1687	263	305	347	−42	326
1637	313	347	397	−50	372
1587	363	390	433	−43	412
1537	413	432	438	−6	435
1487	463	475	467	+8	471
1437	513	517	542	−25	530
1387	563	560	580	−20	570
1337	613	603	627	−24	615
1287	663	647	659	−12	653
1237	713	691	682	+9	687
1187	763	735	721	+14	728
1137	813	779	762	+17	771
1087	863	824	813	+11	819
1037	913	869	868	+1	869
987	963	915	917	−2	916
938	1012	960	962	−2	961
887	1063	1007	1002	+5	1005
838	1112	1053	1062	−9	1058
788	1162	1101	1128	−27	1115
738	1212	1148	1151	−3	1150
688	1262	1197	1188	+9	1193
637	1313	1247	1254	−7	1251
588	1362	1295	1307	−12	1301
538	1412	1345	1345	0	1345
488	1462	1395	1375	+20	1385
438	1512	1446	1420	+26	1433
387	1563	1498	1475	+23	1487
338	1612	1548	1545	+3	1547
288	1662	1601	1597	+4	1599
238	1712	1653	1640	+13	1647
188	1762	1707	1702	+5	1705
137	1813	1761	1752	+9	1757
88	1862	1815	1792	+23	1804
38	1912	1869	1835	+34	1852
bc					
12	1962	1925	1886	+39	1906
62	2012	1980	1953	+27	1967
113	2063	2037	2015	+22	2026
162	2112	2093	2092	+1	2093
212	2162	2150	2109	+41	2130
262	2212	2207	2206	+1	2207
312	2262	2265	2248	+17	2257
363	2313	2324	2346	−22	2335
412	2362	2382	2454	−72	2418
462	2412	2441	2507	−66	2474
512	2462	2501	2504	−3	2503
562	2512	2560	2552	+8	2556
613	2563	2622	2622	0	2622
662	2612	2681	2707	−26	2694
712	2662	2742	2779	−37	2761
762	2712	2803	2843	−40	2823
812	2762	2864	2885	−21	2875
862	2812	2926	2896	+30	2911
912	2862	2988	2937	+51	2962
962	2912	3050	3029	+21	3040

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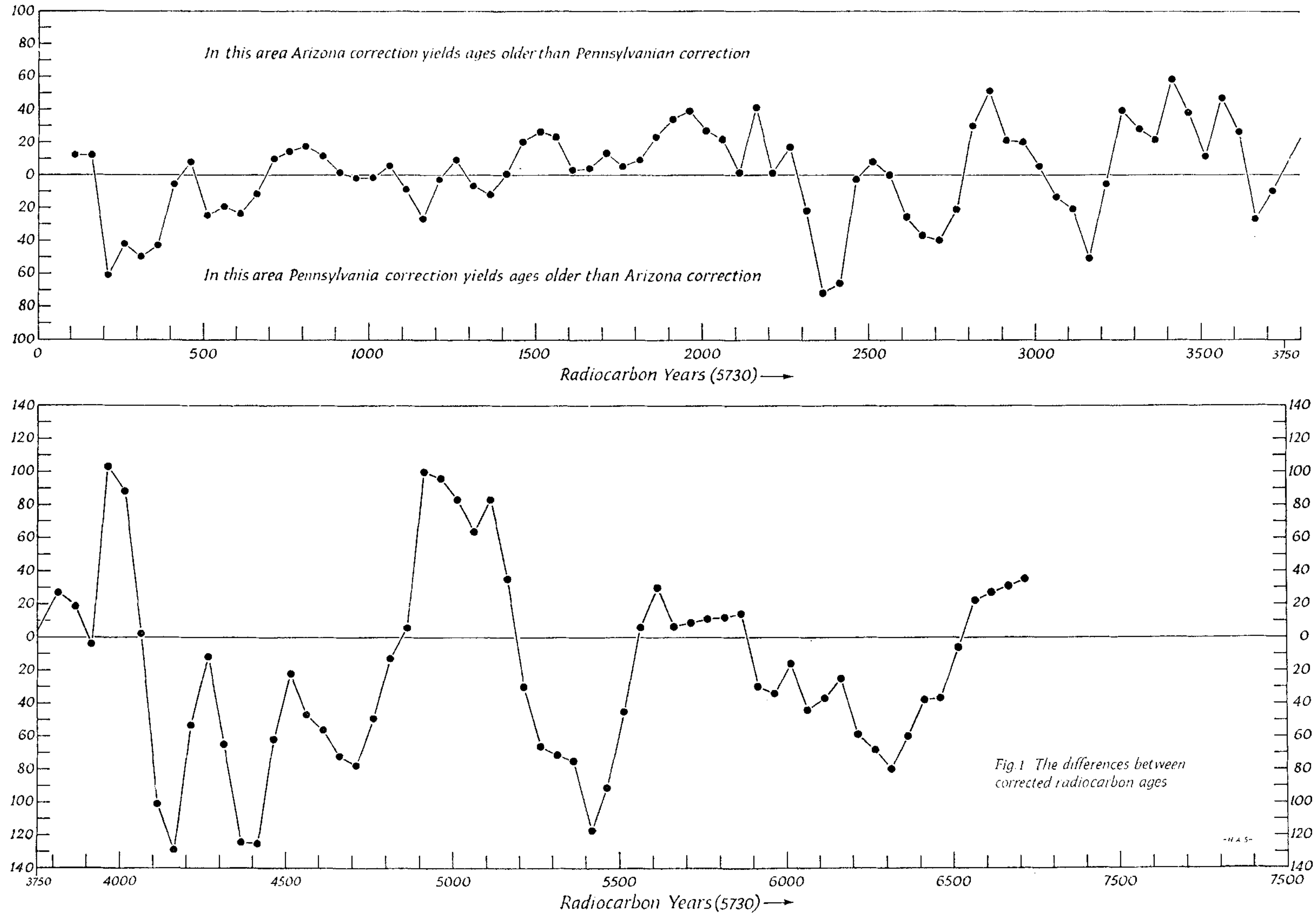

Fig. I. ***The difference in years between corrected radiocarbon ages***

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1	2	3	4	5	6
1012	2962	3112	3092	+20	3102
1062	3012	3175	3170	+5	3173
1113	3063	3238	3252	−14	3245
1162	3112	3300	3321	−21	3310
1212	3162	3358	3408	−51	3382
1262	3212	3420	3426	−6	3423
1312	3262	3483	3444	+39	3464
1363	3313	3547	3519	+28	3533
1412	3362	3610	3589	+21	3600
1462	3412	3673	3615	+58	3644
1512	3462	3736	3698	+38	3717
1562	3512	3793	3782	+11	3788
1612	3563	3858	3811	+47	3835
1662	3612	3920	3894	+26	3907
1712	3662	3984	4011	−27	3998
1762	3712	4047	4057	−10	4052
1863	3813	4168	4141	+27	4155
1912	3862	4230	4211	+19	4221
1962	3912	4293	4297	−4	4295
2012	3962	4356	4253	+103	4305
2062	4012	4419	4331	+88	4375
2113	4063	4482	4480	+2	4481
2162	4112	4544	4645	−101	4595
2212	4162	4606	4735	−129	4671
2262	4212	4668	4721	−53	4695
2312	4262	4730	4742	−12	4735
2363	4313	4792	4857	−65	4825
2412	4362	4853	4977	−124	4915
2462	4412	4914	5039	−125	4977
2512	4462	4974	5041	−67	5008
2562	4512	5035	5057	−22	5046
2613	4563	5096	5143	−47	5120
2662	4612	5155	5211	−56	5183
2712	4662	5214	5286	−72	5250
2762	4712	5273	5351	−78	5312
2812	4762	5332	5381	−49	5357
2863	4813	5391	5404	−13	5398
2912	4862	5448	5388	+6	5418
2962	4912	5506	5406	+100	5456
3012	4962	5563	5467	+96	5515
3062	5012	5620	5537	+83	5579
3113	5063	5677	5613	+64	5645
3162	5112	5732	5649	+83	5691
3212	5162	5787	5649	+35	5770
3262	5212	5842	5872	−30	5857
3312	5262	5897	5963	−66	5930
3363	5313	5952	6023	−71	5988
3412	5362	6005	6080	−75	6043
3462	5412	6059	6176	−117	6118
3512	5462	6111	6202	−91	6157
3562	5512	6164	6209	−45	6187
3612	5562	6217	6211	+6	6214
3662	5612	6268	6238	+30	6253
3712	5662	6319	6312	+7	6316
3762	5712	6370	6311	+9	6366
3812	5762	6421	6410	+11	6416
3863	5813	6472	6460	+12	6466
3912	5862	6521	6507	+14	6514
3962	5912	6570	6600	−30	6585
4012	5962	6619	6653	−34	6636
4062	6012	6668	6684	−16	6676
4113	6063	6718	6762	−44	6740
4162	6112	6765	6802	−37	6784
4212	6162	6813	6838	−25	6825
4262	6212	6861	6920	−59	6891
4312	6262	6908	6976	−68	6942
4363	6313	6957	7037	−80	6997
4412	6362	7003	7063	−60	7033
4462	6412	7050	7088	−38	7069
4512	6462	7097	7134	−37	7116
4562	6512	7144	7150	−6	7147
4613	6563	7191	7170	+22	7181
4662	6612	7238	7211	+27	7225
4712	6662	7285	7254	+31	7270
4762	6712	7332	7297	+35	7315

Table 2. Comparison of the new corrections with the Wendland and Donley regression equation

Years bp	This work	Wendland—Donley regression equation
113	173	192
263	326	304
513	530	054
763	728	721
1012	961	952
1262	1193	1197
1512	1433	1455
1762	1705	1724
2012	1967	2003
2262	2257	2291
2512	2556	2584
2762	2875	2887
3012	3173	3192
3262	3464	3501
3512	3788	3812
3712	4052	4062
4012	4375	4436
4262	4735	4745
4512	5046	5052
4762	5357	5354
5012	5579	5651
5262	5930	5941
5512	6187	6222
5762	6416	6494
6012	6676	6756
6262	6942	7005
6512	7147	7240
6712	7315	7418

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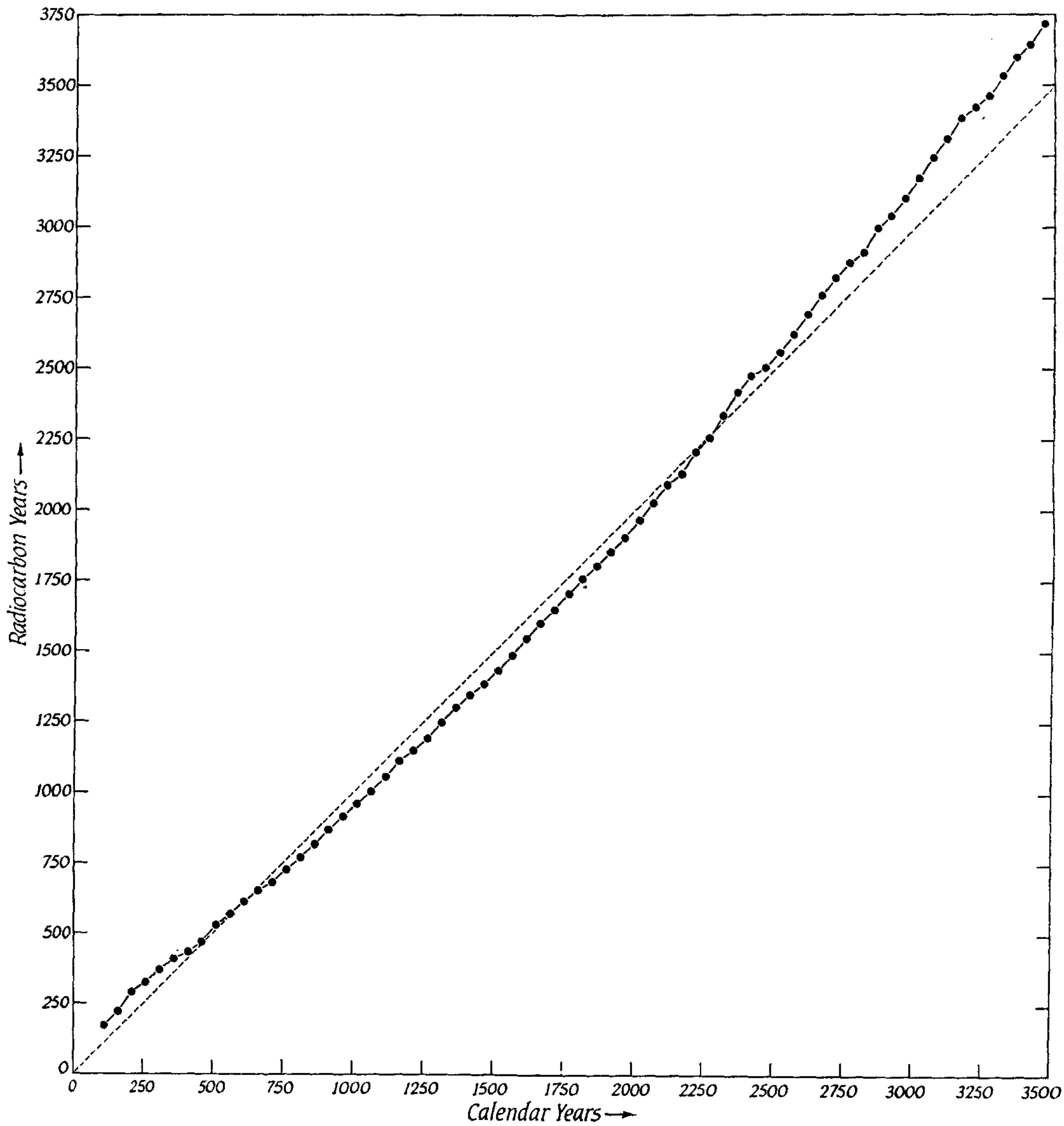
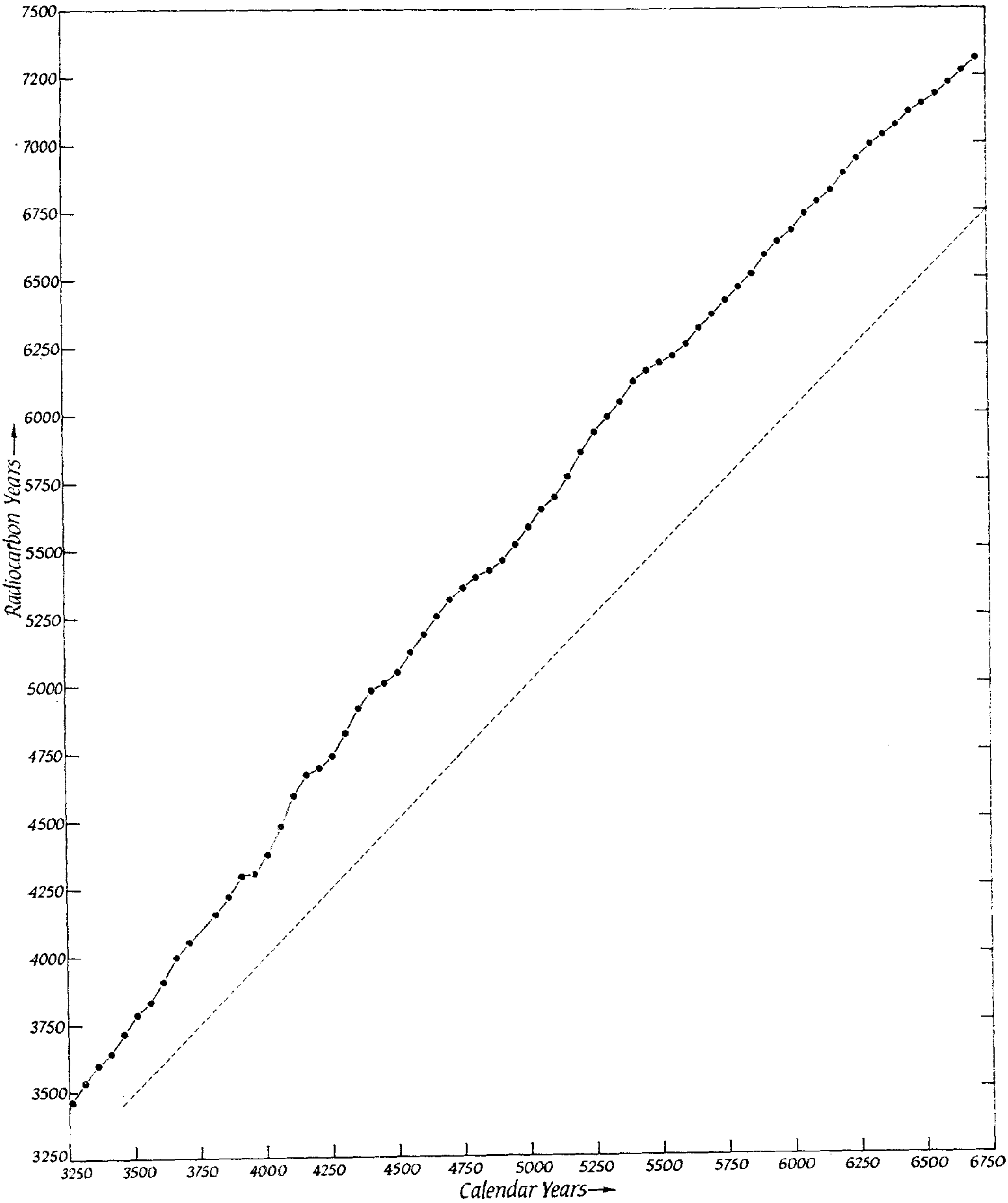


Fig. 2. Calibration chart: radiocarbon age versus *calendar age. For reasons of space this chart is printed in two parts, part 1 on this page, and part 2 opposite*



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