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RADIOCARBON CALIBRATION DATA FOR THE 6TH TO THE 8TH MILLENNIA BC

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ABSTRACT. ^{14}C calibration curves derived from South German oak tree-ring series are presented. They cover the interval between 4400 and 7200 BC complementing existing data sets and extending them to older periods. The atmospheric ^{14}C level before 6200 BC no longer follows the long-term sinusoidal trend fitted to the bristlecone data. This observation is supported by a tentative match of the Main 9 series.

INTRODUCTION

The Hohenheim oak series Donau 8, Main 6, Donau 6 and Main 4 have been measured by the ^{14}C laboratories of Heidelberg, La Jolla, and Seattle (see eg, Bruns *et al,* 1983; Linick, Suess & Becker, 1985; Stuiver *et al,* 1986). These series are floating but have been linked dendrochronologically in the past three years, resulting in a 3100-year floating series with ^{14}C ages in the interval 5200 to 8200 BP. Recently, this unified series has been matched to bristlecone pine (Linick, Suess & Becker, 1985; Stuiver *et al,* 1986) accurately enough to permit its use as a calibration data base and to permit an assessment of past atmospheric ^{14}C levels.

We report here the ^{14}C data obtained in Heidelberg on this series and compare them with results of other laboratories.

DATA

The tree-ring samples were prepared at the Hohenheim tree-ring laboratory. They were pretreated for ^{14}C dating as follows: samples measured before 1982 (lab numbers lower than 7000) were kept in hot HCl for two hours. Later, the samples were pretreated in the standard AAA sequence. All ^{14}C ages are normalized to oxalic acid, *ie,* all Heidelberg data obtained prior to June, 1982 were recalculated (Kromer, 1984).

The data of the unified series are given in Table 1. The absolute age was obtained using 7230 BC as zero point of the series. This is the best estimate using the matching to the bristlecone series mentioned above and comparing the Heidelberg data ca 6000 BP (Hd-9304 to Hd-9360 of Table 1) to the Irish oak series (Pearson *et al,* 1986).

For calibration purposes, the data are plotted in Figures 1–4 in the standard format. The uncertainty in the dendro-scale due to the matching to bristlecone pine has been estimated to 25 years (Stuiver *et al,* 1986).

The data points are connected by a cubic spline (Reinsch, 1967) using maximum smoothing ($S = N + (2N)^{1/2}$) in Eq (2) of Reinsch (1967). Confidence limits of ±30 yr are indicated. Spline plotting has been suppressed for those periods when data coverage is <1 per 60 yr.

The spacing of the samples is not uniform; at some intervals (eg, 7400 BP, 8150 BP) many samples were measured to identify new trees, filling gaps between the series. After successful dendrochronologic identification, these ^{14}C data were incorporated in the data set.

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ATMOSPHERIC ^{14}C LEVEL

Delta ^{14}C values of the series and an interpolating spline function are shown in Figure 5 (solid curve labeled "Hd"). The data are compared to the measurements in La Jolla (Linick, Suess & Becker, 1985) ("LJ") and Seattle ("S") (Stuiver *et al,* 1986). There is good agreement in the long-term trend in all data sets; on a short time scale (100 yr) differences of up to delta ^{14}C = 15 ‰ do exist.

The unified series discussed so far yields atmospheric ^{14}C levels back to 7200 BC. Thus, it can be checked whether the sinusoidal trend fitted to the bristlecone pine data up to 5400 BC (eg, Neftel, Oeschger & Suess, 1981; Carmi, Sirkes & Magaritz, 1984) is still maintained to older ages. It is obvious from Figure 5 that before 6200 BC the ^{14}C level is consistently higher than what is to be expected by the already declining sinusoidal trend. This observation is supported by a tentative match of the floating series Main 9, which extends from 8200 to 8700 ^{14}C yr BP and thus overlaps in ^{14}C years with the old end of the unified Donau/Main series. From the slope of the respective ends of both series, a minimum zero point of 7750 BC for the Main 9 series is obtained; the delta ^{14}C plots of both series show a smooth transition if 7825 BC is assumed as a zero point. Using this value, delta ^{14}C data of the Main 9 series are shown in Figure 5 (curve labeled "M9").

Evidently, the delta ^{14}C values of the Main 9 series are subject to the final absolute placement of this series but for the present argument it is essential only that the series cannot be shifted by more than 10 ‰ to lower values excluding the sinusoidal trend as a valid representation of the atmospheric ^{14}C level prior to 6200 BC.

It should be noted that the ^{14}C pattern derived from fixing the Main 9 series in the interval given above is fully consistent with the data obtained on the varve series of the Lake of the Clouds (Stuiver, 1970).

ACKNOWLEDGMENTS

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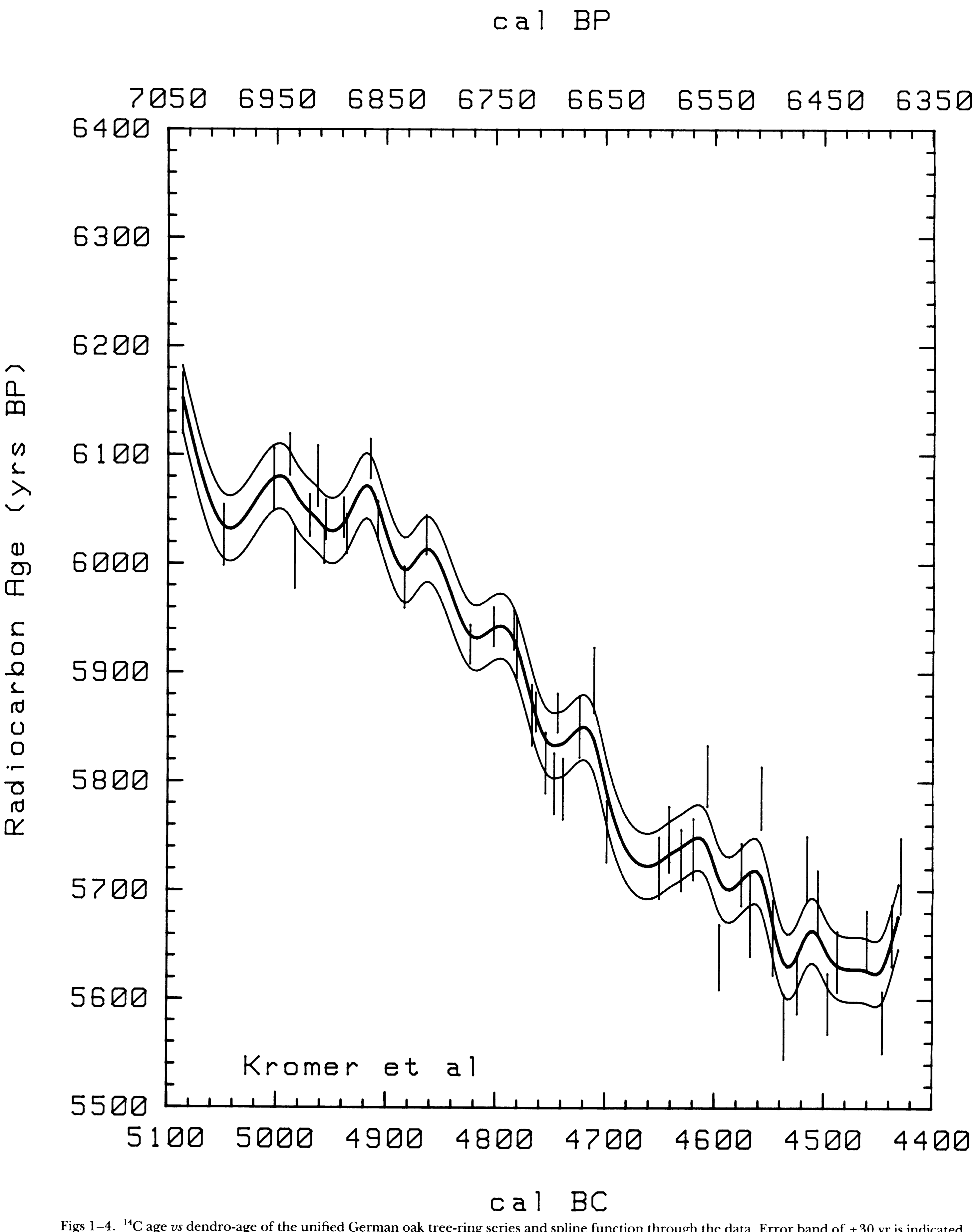
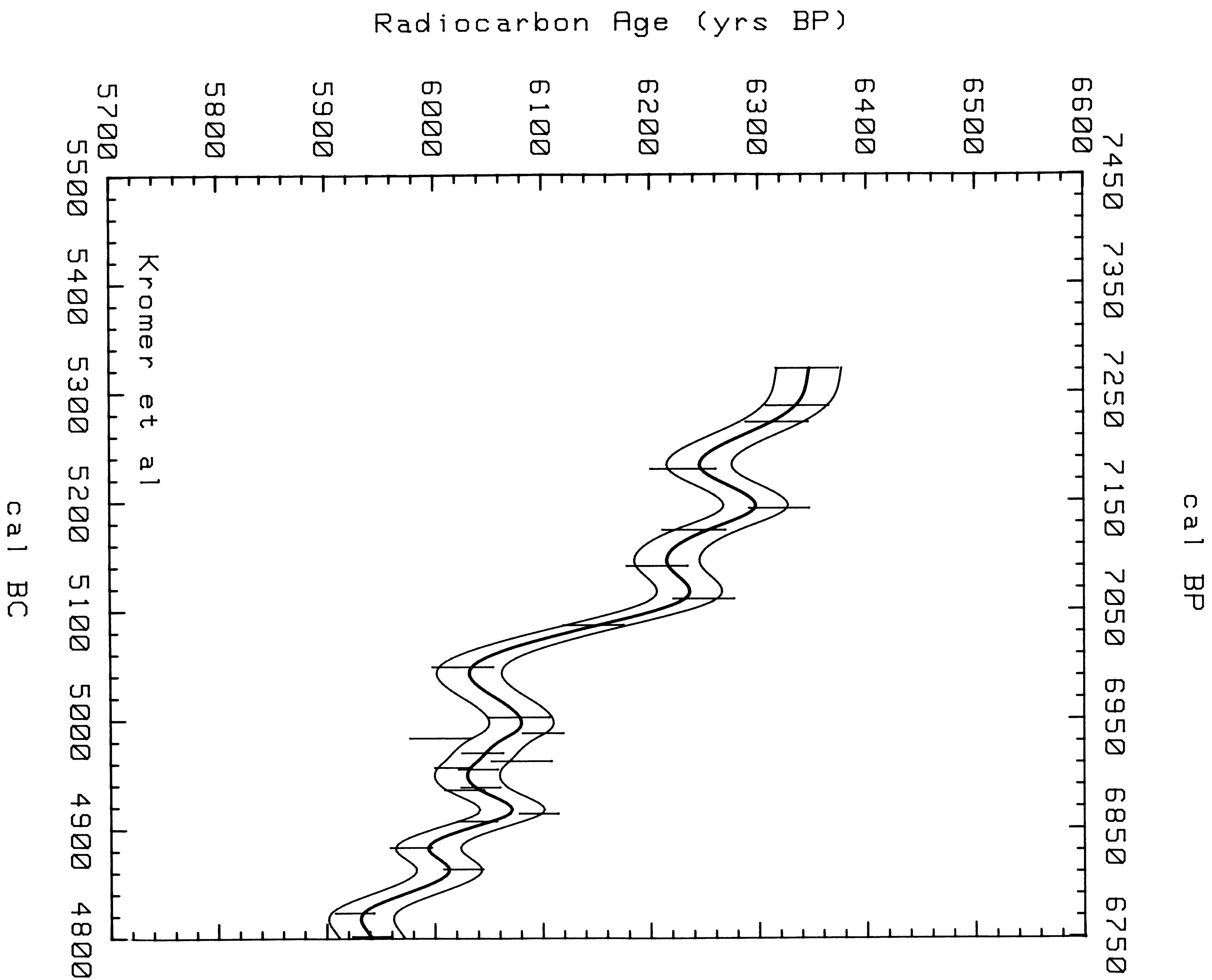
TABLE 1

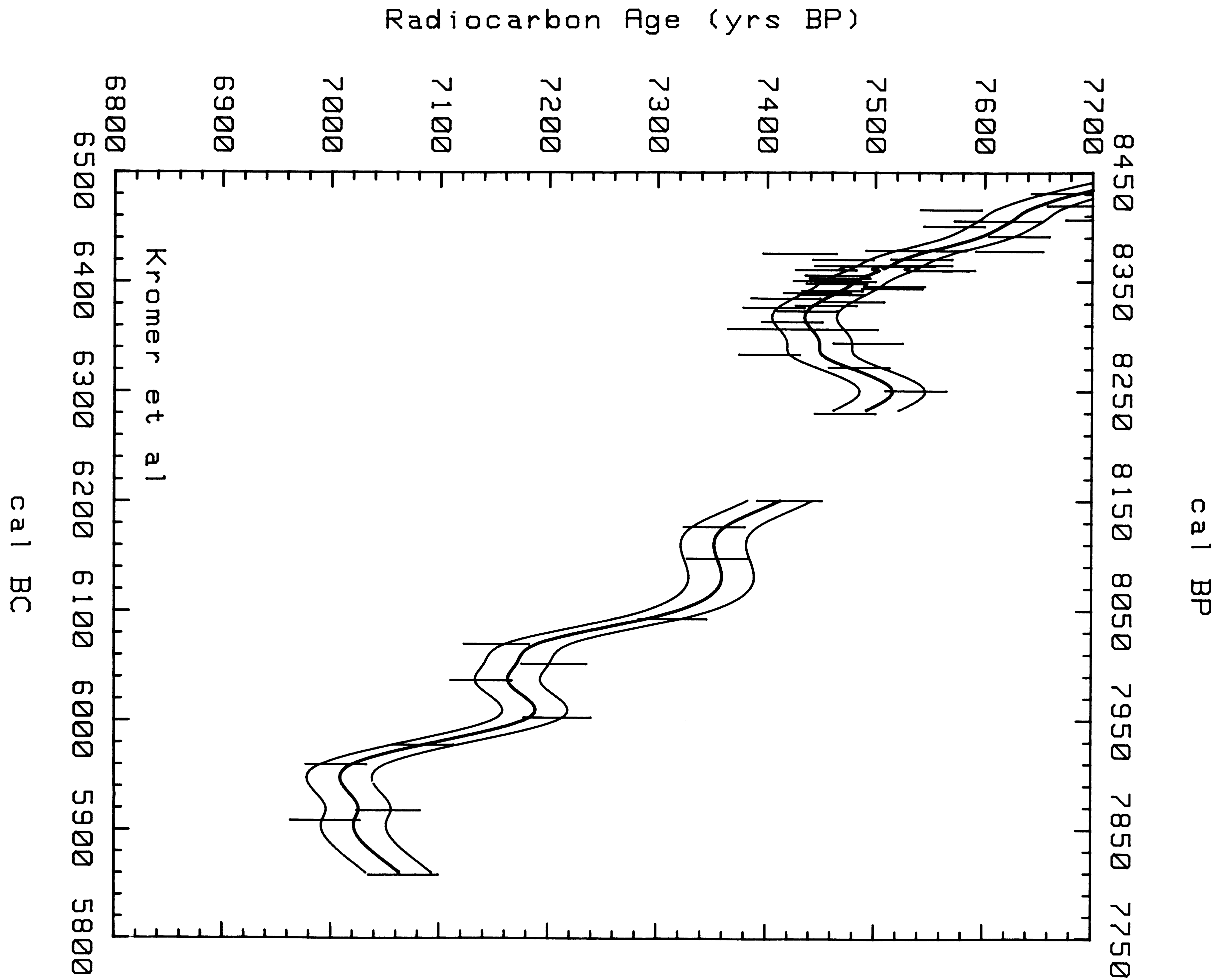
^{14}C data of the unified German oak tree-ring series; dendro-age has been obtained using 7230 BC as zero point of the series

Lab no.	Center ring	No. of rings	^{14}C Age (BP)	$\delta^{13}C$ (‰)	Age (BC) (approx)
Hd - 5028	23	3	8199 +- 41	-25.8	7207
Hd - 8092	37	7	8271 +- 28	-25.9	7194
Hd - 5162	52	4	8212 +- 33	-25.2	7178
Hd - 5263	57	5	8211 +- 35	-24.3	7173
Hd - 5204	64	2	8198 +- 35	-24.0	7166
Hd - 5577	97	5	8141 +- 34	-23.6	7133
Hd - 5529	101	3	8166 +- 35	-24.2	7129
Hd - 5401	123	4	8249 +- 39	-24.2	7107
Hd - 8101	133	5	8263 +- 28	-23.6	7098
Hd - 5733	142	2	8161 +- 29	-25 1	7088
Hd - 6494	143	5	8163 +- 28	-24.8	7087
Hd - 6478	145	3	8158 +- 62	-25.1	7085
Hd - 6408	153	5	8152 +- 28	-26 1	7077
Hd - 6521	156	3	8157 +- 28	-25.8	7074
Hd - 5047	158	2	8081 +- 40	-25.6	7072
Hd - 6484	161	3	8000 +- 28	-25.9	7069
Hd - 6483	166	2	8150 +- 28	-26 0	7064
Hd - 6407	168	2	8166 +- 32	-25.1	7062
Hd - 6449	170	2	8083 +- 28	-26.5	7060
Hd - 5576	172	5	8019 +- 32	-23.9	7058
Hd - 5476	195	3	7913 +- 34	-25.5	7035
Hd - 5523	213	3	7991 +- 28	-25.6	7017
Hd - 5732	227	5	8015 +- 41	-25 8	7003
Hd - 5731	252	5	8019 +- 32	-24.5	6978
Hd - 5522	267	5	8080 +- 36	-24.1	6963
Hd - 5533	292	5	7995 +- 28	-25.1	6938
Hd - 5811	302	2	8041 +- 34	-25.7	6928
Hd - 5439	326	2	7966 +- 28	-25.4	6904
Hd - 5068	334	2	7982 +- 39	-25.0	6896
Hd - 5503	352	2	7923 +- 35	-24.8	6878
Hd - 5502	384	2	7991 +- 32	-24.6	6846
Hd - 5755	398	2	7925 +- 42	-25 3	6832
Hd - 5888	411	3	7974 +- 33	-24.6	6819
Hd - 5885	420	2	7945 +- 28	-24.8	6810
Hd - 5048	437	4	8003 +- 35	-24.7	6793
Hd - 5810	452	5	7867 +- 32	-24.8	6778
Hd - 5027	467	5	7963 +- 31	-25.2	6763
Hd - 5850	482	5	7924 +- 33	-26.3	6748
Hd - 5402	503	1	8001 +- 33	-24 4	6727
Hd - 5744	522	5	7940 +- 32	-25.8	6708
Hd - 5116	547	5	7873 +- 36	-25.7	6683
Hd - 5742	568	2	7882 +- 58	-25.6	6662
Hd - 5743	577	5	7745 +- 34	-25.5	6653
Hd - 5532	613	2	7816 +- 32	-26 1	6617
Hd - 5092	621	2	7807 +- 32	-25.6	6609
Hd - 5754	623	2	7782 +- 28	-25 1	6607
Hd - 5753	645	2	7744 +- 31	-25.4	6585
Hd - 5521	682	5	7737 +- 33	-24.4	6548
Hd - 6321	713	2	7811 +- 32	-24.3	6517
Hd - 5026	737	5	7752 +- 30	-24.8	6493
Hd - 7495	750	1	7671 +- 28	-25.8	6481
Hd - 7496	761	1	7686 +- 28	-26.0	6469
Hd - 7740	765	2	7569 +- 28	-24.9	6465
Hd - 6087	774	2	7707 +- 32	-24.9	6456
Hd - 7647	775	2	7612 +- 40	-25.3	6455
Hd - 7741	780	1	7572 +- 28	-25.1	6450
Hd - 7513	789	1	7632 +- 28	-26.3	6441
Hd - 6213	803	1	7623 +- 31	-25.1	6428
Hd - 7717	802	1	7537 +- 46	-25.7	6428
Hd - 7840	805	1	7430 +- 34	-25 2	6425
Hd - 7704	810	10	7542 +- 28	-25.5	6420
Hd - 7692	811	2	7470 +- 28	-25.2	6420
Hd - 7751	816	2	7542 +- 28	-25.8	6415
Hd - 7703	820	10	7454 +- 28	-26.4	6410
Hd - 6439	816	1	7499 +- 55	-25.6	6414
Hd - 8308	820	2	7563 +- 28	-25.0	6410
Hd - 7686	821	2	7557 +- 28	-25.3	6410
Hd - 7846	825	1	7463 +- 28	-24.6	6405
Hd - 7708	828	5	7467 +- 28	-26.2	6403
Hd - 6212	830	1	7452 +- 28	-25.5	6400
Hd - 7756	831	1	7472 +- 28	-25.2	6400
Hd - 7836	833	3	7464 +- 28	-26 0	6398
Hd - 7687	835	1	7517 +- 28	-25.2	6395
Hd - 7713	837	4	7515 +- 28	-26.1	6393
Hd - 8324	839	2	7460 +- 28	-25.2	6391
Hd - 7688	841	2	7446 +- 31	-25.0	6389
Hd - 7735	843	3	7461 +- 28	-25.9	6388
Hd - 6291	846	5	7417 +- 32	-25 2	6384
Hd - 8325	849	2	7480 +- 28	-24.7	6381
Hd - 7837	853	3	7454 +- 28	-25.8	6378
Hd - 7644	855	4	7406 +- 28	-24.8	6376
Hd - 7707	858	3	7437 +- 28	-25 4	6373
Hd - 7849	868	3	7423 +- 28	-25.5	6363
Hd - 7646	874	2	7410 +- 46	-26.0	6356
Hd - 6292	874	3	7470 +- 32	-24.5	6356
Hd - 6229	887	6	7493 +- 32	-24.2	6343
Hd - 7645	898	5	7402 +- 28	-24.6	6333
Hd - 6227	909	3	7485 +- 28	-24.2	6321
Hd - 6216	930	2	7537 +- 28	-23.8	6300
Hd - 6214	951	3	7472 +- 28	-23.5	6279
Hd - 6228	1030	3	7421 +- 30	-25.7	6200
Hd - 6226	1054	4	7352 +- 28	-23.7	6176
Hd - 6215	1083	3	7355 +- 28	-23.3	6147
Hd - 6284	1138	6	7314 +- 31	-26.0	6092
Hd - 6371	1161	2	7152 +- 30	-26.1	6069
Hd - 6293	1179	3	7205 +- 30	-25.2	6051
Hd - 6372	1194	3	7138 +- 28	-24.5	6036
Hd - 6285	1228	3	7208 +- 31	-25.3	6002
Hd - 6368	1253	3	7085 +- 28	-25.1	5977
Hd - 6277	1271	5	7005 +- 28	-25.0	5959
Hd - 6370	1313	5	7053 +- 29	-27.2	5917
Hd - 6278	1322	6	6995 +- 32	-24.4	5908
Hd - 6279	1372	6	7067 +- 32	-25.2	5858
Hd - 6318	1909	3	6345 +- 29	-25.6	5321
Hd - 6359	1943	5	6336 +- 29	-24.9	5287
Hd - 6301	1958	4	6317 +- 29	-25.3	5272
Hd - 6322	2001	1	6230 +- 30	-23.9	5229
Hd - 6299	2037	6	6319 +- 28	-27.6	5193
Hd - 6367	2057	6	6240 +- 29	-25.4	5173
Hd - 6300	2090	1	6206 +- 28	-25.2	5140
Hd - 6369	2120	1	6249 +- 28	-23.5	5110
Hd - 6298	2144	1	6147 +- 28	-25.5	5086
Hd - 6328	2182	1	6026 +- 28	-23 8	5048
Hd - 6330	2228	2	6078 +- 28	-23.7	5002
Hd - 8498	2243	3	6100 +- 19	-26.4	4988
Hd - 6360	2247	1	6005 +- 28	-24.9	4983
Hd - 8726	2261	2	6044 +- 19	-26.0	4970
Hd - 6375	2268	2	6080 +- 28	-25.1	4962
Hd - 8727	2274	4	6016 +- 16	-25.8	4956
Hd - 9303	2276	3	6040 +- 18	-25.3	4955
Hd - 8737	2292	2	6042 +- 18	-26.4	4938
Hd - 9304	2295	2	6027 +- 18	-24.8	4936
Hd - 8739	2316	2	6096 +- 18	-26.5	4914
Hd - 9314	2323	2	6039 +- 18	-25.5	4907
Hd - 9315	2347	2	5978 +- 19	-25.2	4883
Hd - 9326	2367	2	6026 +- 18	-25.3	4863
Hd - 9327	2407	2	5926 +- 18	-25.2	4823
Hd - 9328	2429	5	5942 +- 18	-25.4	4802
Hd - 9329	2447	2	5939 +- 18	-25.3	4783
Hd - 7389	2450	3	5923 +- 28	-27.1	4781
Hd - 7390	2464	2	5861 +- 28	-25.8	4767
Hd - 9359	2467	2	5864 +- 18	-25.8	4763
Hd - 7391	2476	1	5817 +- 28	-26 4	4754
Hd - 7398	2484	1	5798 +- 28	-27.4	4746
Hd - 9360	2487	2	5863 +- 18	-26.1	4743
Hd - 7400	2492	1	5793 +- 28	-24.8	4738
Hd - 7402	2507	1	5850 +- 28	-24.9	4723
Hd - 7520	2520	1	5893 +- 30	-25.5	4710
Hd - 7653	2532	2	5754 +- 28	-25.4	4698
Hd - 7655	2580	1	5721 +- 28	-26.0	4650
Hd - 7654	2589	1	5747 +- 30	-26.2	4641
Hd - 7656	2600	1	5728 +- 28	-26.0	4630
Hd - 7666	2611	1	5738 +- 28	-23.6	4619
Hd - 7538	2624	1	5805 +- 28	-23 9	4606
Hd - 7667	2635	1	5639 +- 30	-23.7	4595
Hd - 7671	2655	1	5715 +- 29	-24.1	4575
Hd - 7681	2663	1	5677 +- 38	-26 2	4567
Hd - 7515	2673	1	5785 +- 29	-25.6	4557
Hd - 7682	2684	1	5657 +- 35	-24.7	4546
Hd - 7683	2694	1	5575 +- 30	-24.8	4536
Hd - 7706	2706	1	5615 +- 28	-24.1	4524
Hd - 7525	2715	1	5720 +- 30	-24.8	4515
Hd - 7528	2725	1	5690 +- 29	-24.6	4505
Hd - 7714	2734	1	5596 +- 28	-25.0	4496
Hd - 7715	2743	1	5635 +- 28	-25.2	4487
Hd - 7719	2770	1	5654 +- 28	-25.6	4460
Hd - 7729	2784	1	5579 +- 29	-25.0	4446
Hd - 7730	2793	1	5659 +- 28	-25.5	4437
Hd - 7539	2801	1	5714 +- 35	-26.2	4429
Hd - 8404	3043	3	5269 +- 18	-25.6	4188
Hd - 8428	3053	3	5334 +- 16	-25.5	4178
Hd - 8476	3063	3	5336 +- 18	-25.1	4168
Hd - 8477	3073	3	5318 +- 17	-25.3	4158
Hd - 8392	3083	3	5354 +- 17	-25.4	4148
Hd - 8497	3093	3	5368 +- 18	-25.5	4138
Hd - 8371	3103	3	5328 +- 20	-25.3	4128

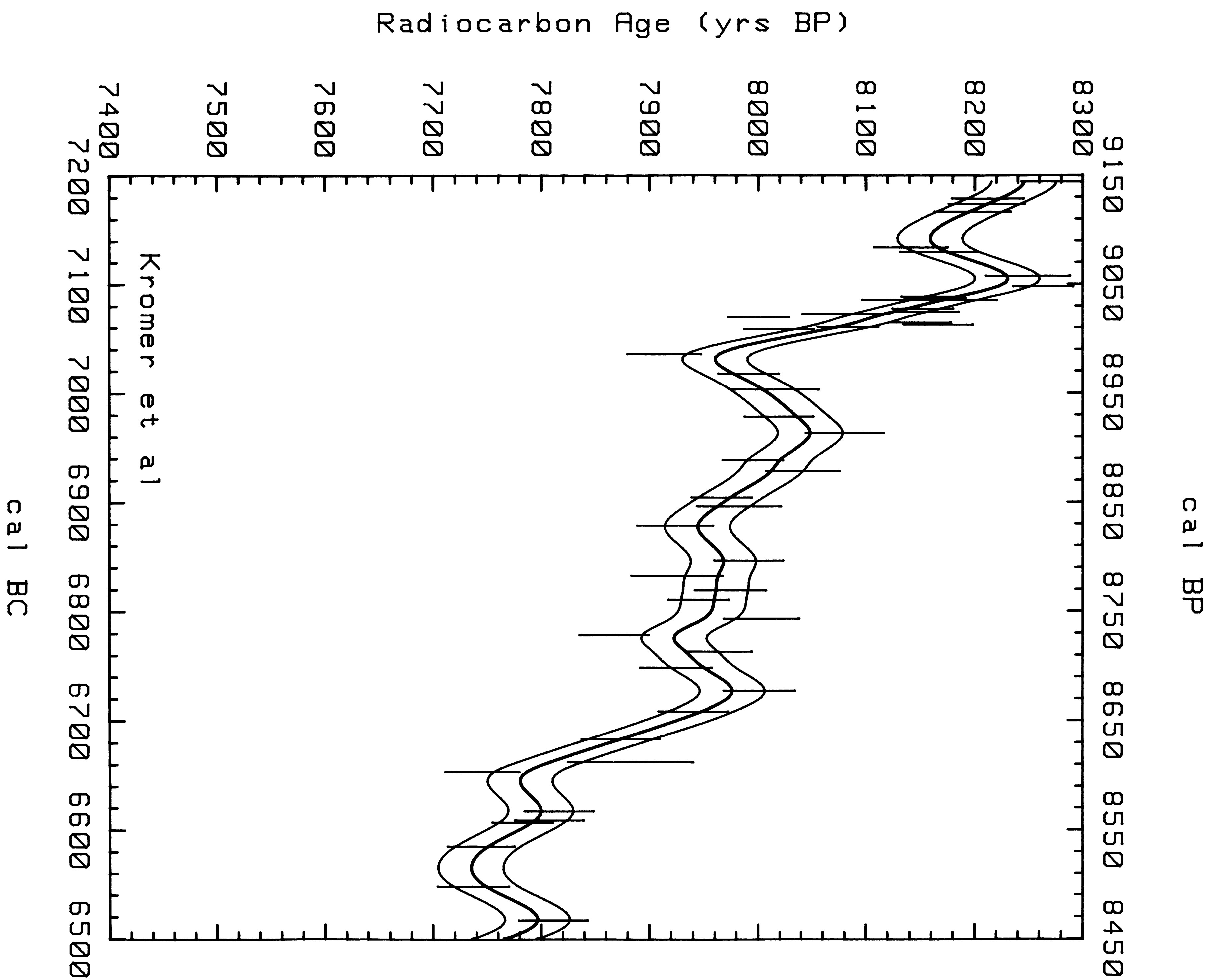


Figs 1–4. ^{14}C age *vs* dendro-age of the unified German oak tree-ring series and spline function through the data. Error band of ±30 yr is indicated. The dendro-scale is considered to be accurate to ±25 yr.


Radiocarbon Age (yrs BP)
5700 5800 5900 6000 6100 6200 6300 6400 6500 6600
cal BP
7450 7350 7250 7150 7050 6950 6850 6750
Kromer et al
5500 5400 5300 5200 5100 5000 4900 4800
cal BC



Radiocarbon Age (yrs BP)
6800
6900
7000
7100
7200
7300
7400
7500
7600
7700
cal BP
8450
8350
8250
8150
8050
7950
7850
7750
cal BC
6500
6400
6300
6200
6100
6000
5900
5800
Kromer et al


Radiocarbon Age (yrs BP)
cal BP
cal BC
Kromer et al
7400
7500
7600
7700
7800
7900
8000
8100
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8300
9150
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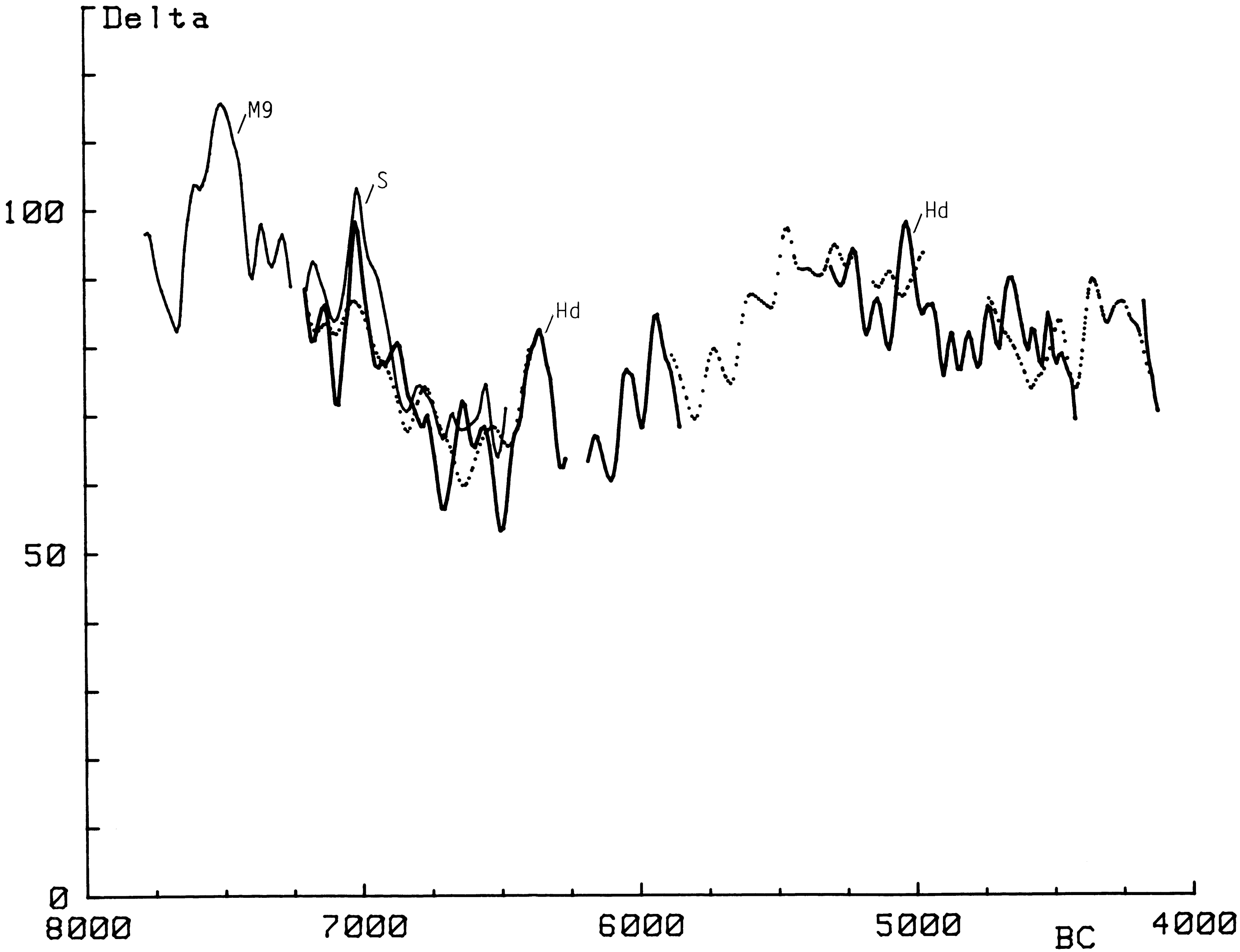

Fig 5. Delta ^{14}C values obtained from the unified German oak series
Solid curve (bold) labeled "Hd" = Heidelberg data (Table 1)
Solid curve labeled "S" = Seattle data (Stuiver *et al*, 1986)
Solid curve labeled "M9" = Heidelberg Main 9 data, delta values approximate (see text)
Dotted curve labeled "LJ" = La Jolla data (Linick, Suess & Becker, 1986)