[RADIOCARBON, VOL 27, NO. 1, 1985, P 1–19]

Radiocarbon

1985

25 YEARS OF TROPOSPHERIC ^{14}C OBSERVATIONS IN CENTRAL EUROPE

INGEBORG LEVIN, BERND KROMER,
HILDEGARD SCHOCH-FISCHER, MICHAEL BRUNS*,
MARIANNE MÜNNICH, DIETRICH BERDAU**,
JOHN C VOGEL†, and KARL OTTO MÜNNICH

Institut für Umweltphysik, Universität Heidelberg, Federal Republic of Germany

ABSTRACT. A long-term mountain station series of tropospheric ^{14}C data for the period 1959 to 1984 is presented. This series is considered representative of the *higher altitude* ^{14}C level over central Europe. Even tree-ring ^{14}C levels from a *rural ground level* site in southern Germany are consistently lower (by $\Delta^{14}C_{depression} = -15‰$ if compared with the mountain station summer average in atmospheric CO_2). The rural tree-ring series is considered to represent the additional continental Suess effect at ground level without local contamination. This Suess effect decreases gradually with the distance from the ground (*ie*, source) level. We therefore estimate the additional continental Suess effect in the vegetation period to be $\Delta^{14}C_{depression} = -5‰$ for the mountain station and $-20‰$ for a rural ground level site, respectively. Based on this assumption, yearly mean tropospheric ^{14}C levels corrected for fossil fuel contamination and representative of the Northern Hemisphere are provided for use in global carbon cycle models.

INTRODUCTION

With the beginning of extensive atmospheric nuclear bomb testing in 1954, the Heidelberg Radiocarbon Laboratory was one of the first institutions to continuously measure ^{14}C in atmospheric CO_2 samples. Until now the data have partly been published in graphs (Münnich & Vogel, 1963; Levin, Münnich & Weiss, 1980) but never in tabulated form. We intend to fill this gap and provide a complete ^{14}C data base—to replace "data read from graph"—and to complement the data from Nydal and Lövseth (1983), also compiled by Tans (1981). The new data base might be useful for the testing of recent carbon cycle models (see, eg, Enting & Pearman, 1982; Pearman, Hyson, & Fraser, 1983; Fung *et al*, 1983).

SAMPLING LOCATIONS

In the first years of tropospheric $^{14}CO_2$ observations (1955 to 1967) several stations were maintained in central and southern Europe (Heidelberg, 49° N, Schleswig, 55° N, Hohenpeißenberg, 48° N, Bergen, 60° N, Trapani, 38° N, Vermunt, 47° N). Since 1977 Schauinsland, 48° N, was added. We consider the ^{14}C levels at the Schauinsland and Vermunt sam-

*Present address: Technischer Überwachungsverein Baden eV, Dudenstr 28, 6800 Mannheim, FRG

**Present address: Blütenweg 10a, 6900 Heidelberg, FRG

†Present address: National Physics Research Laboratory, PO Box 395, Pretoria, South Africa

pling sites representative of the "true ^{14}C level" of the Northern Hemisphere or, at least, central European *continental* background air. Some early (1959–1961) data from Hohenpeißenberg and Bergen also are included. Recent studies (Levin, Münnich, & Weiss, 1980; Segl *et al*, 1983) have shown, that, especially in winter months, there is considerable "contamination" from fossil fuel sources of the Heidelberg ^{14}C level and conceivably also that of other urban stations, such as Schleswig, northern Germany, and Trapani, Sicily.

In addition to Northern Hemisphere ^{14}C data, we present some of the early Pretoria data, 26° S, collected by J C Vogel and measured in the Heidelberg Radiocarbon Laboratory. These data are corrected like all the other Heidelberg data (see below) and presented in tabular form.

Vermunt Station, Austria (47° N, 10° E) 1959–1983

The Vermunt sampling location was established in a remote electric power station situated at the upper water reservoir of the Ill-Werke (Partenen, Austria) at 1800m asl. Local fossil fuel contamination can only result from local traffic on a nearby private road open only during the summer. The samples were collected at the top of the building ca 10m above ground level (see table 1).

Schauinsland Station, W Germany (48° N, 8° E) 1977–1984

The Schauinsland samples were collected at the Background Air Pollution Monitoring station of the German Federal Environmental Agency on the Schauinsland mountain top 1205m asl. The station is an isolated house with electrical heating only. There can only be occasional contamination from local traffic (station personel). The sample air was collected from a heated stack with the air inlet ca 5m above the ground (see table 2).

Hohenpeißenberg Station, W Germany (48° N, 11° E) 1959–1961

CO_2 samples were collected at the Meteorological Observatory of the Deutscher Wetterdienst, Hohenpeißenberg, 975m asl (see table 3).

Bergen Station, Norway (60° N, 5° E) 1959–1961

CO_2 samples were collected at the Geophysical Institution of the University of Bergen (see table 4).

Pretoria Station, South Africa (26° S, 28° E) 1959–1961

CO_2 samples were collected at the Radioactivity Division, National Physics Research Laboratory, ca 15km east of Pretoria. The site should be free of contamination by fossil CO_2, except for occasional smog from the city of Pretoria (Vogel, 1970) (see table 5).

SAMPLING AND ANALYSIS TECHNIQUES

The sampling technique was modified twice during the period of observation:

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

1959–Nov 1965

Three dishes with 1.5L of a 0.5n sodium hydroxide solution were exposed to the atmosphere for ca 3 days. The method has been described by Münnich and Vogel (1959).

Nov 1965–May 1975

Samples were collected by pumping fresh air continuously for 10 days through a box containing 1.5L of a 0.5n sodium hydroxide solution. With this method the atmospheric CO_2 is absorbed nearly quantitatively in the NaOH solution.

May 1975–the present

Air is pumped through a rotating glass tube filled with a packed bed of Raschig rings (hardglass) to enlarge the surface of the absorbing NaOH solution (200ml of 4n NaOH). The CO_2 absorption is quantitative. The sampling technique is described by Levin, Münnich, and Weiss (1980). The samples represent mean values of 10 days to 2 weeks.

The samples were extracted from the NaOH solution[1] in the laboratory in a vacuum system by adding hydrochloric or sulphuric acid. The CO_2 gas samples were purified over charcoal and counted in a proportional counter. All the laboratory procedures have been described by Münnich (1957); Schoch *et al* (1980); and Levin, Münnich, and Weiss (1980).

CALIBRATIONS

All $\Delta^{14}C$ data are referred to NBS oxalic acid corrected for decay (Stuiver & Polach, 1977). They were also adjusted to the new Heidelberg calibration scale (Kromer, 1984). The data were corrected for isotopic fractionation on the basis of ^{13}C analysis of the sample CO_2. The $\delta^{13}C$ values are given relative to the PDB standard (Craig, 1957). These values do not represent the true atmospheric ^{13}C level because of isotopic fractionation during sample collection in the early period (till 1975) and small fractionation (up to $\delta^{13}C = \pm 0.2‰$) in the laboratory procedures. ^{13}C was not measured for some of the early samples (1959 to 1961). We took the mean value $\delta^{13}C$ (mean) $= -22.7‰$ of all samples collected by the same sampling technique from 1959 to 1965. Because the standard deviation of the $\delta^{13}C$ values, observed in the tray samples of this period, is 2‰, the assumed correction may lead to an additional error (not included in table 1) of $\Delta^{14}C = \pm 4‰$ in the data marked by an asterisk (*).

RESULTS AND DISCUSSION

Evaluation and Interpretation of the Data

The results from the Vermunt station are plotted in figure 1. In the early 1960's marked seasonal variations, up to ca $\Delta^{14}C = 200‰$, were observed in the tropospheric ^{14}C level resulting mainly from spring-time injections of bomb ^{14}C from the stratosphere. The observed ^{14}C variations

[1] The Pretoria samples were precipitated as $BaCO_3$ for shipment to the laboratory.

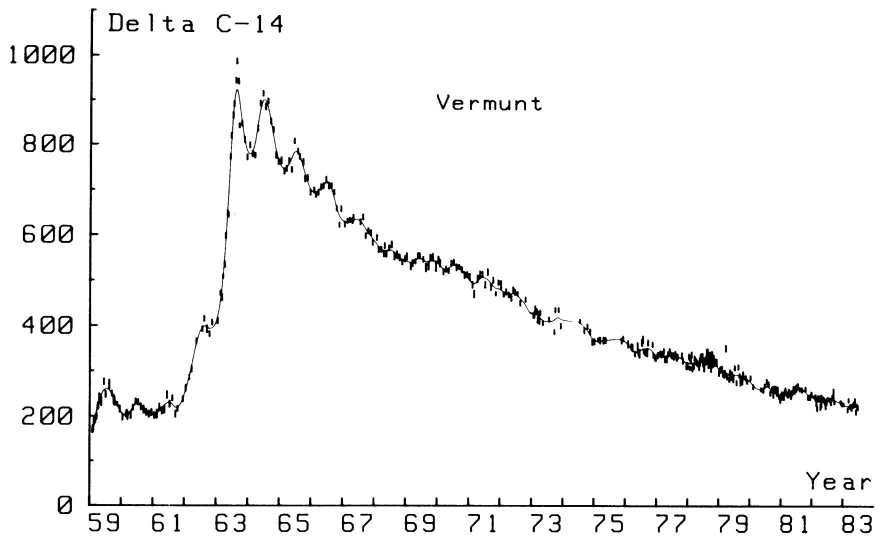

Fig 1. Tropospheric $\Delta^{14}C$ variations (with 1σ error bars) at the Vermunt station, Austria (47° N, 10° E) with the calculated spline function.

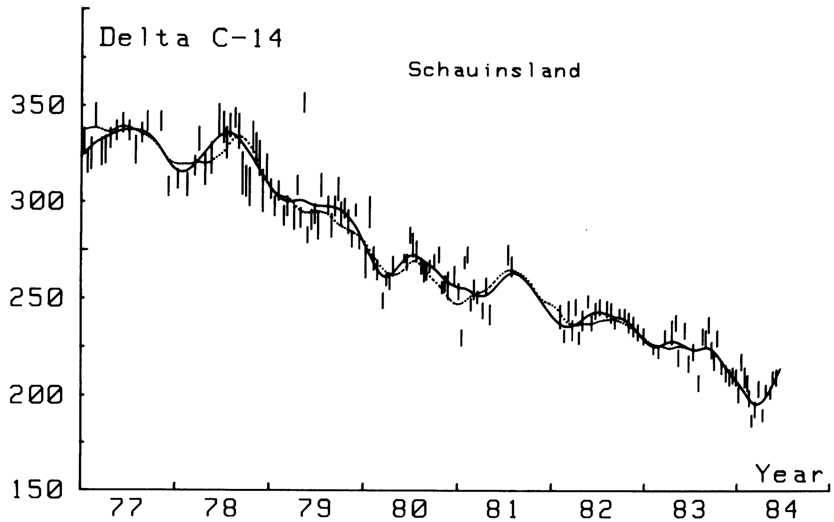

Fig 2. Tropospheric $\Delta^{14}C$ variations (with 1σ error bars) at the Schauinsland station, W Germany (48° N, 8° E). The solid line is a calculated spline function through these data; the dotted line represents the corresponding spline function through the Vermunt data (see fig 1). The periodic variations observed at both stations are mainly due to a general (seasonally varying) "European Suess effect".

in later years (peak to peak variations in $\Delta^{14}C = 20‰$) from 1976 onwards are, to a great extent, due to seasonal variations of the contribution of fossil fuel CO_2 at the sampling location. In 1978 (and 1981) there may have been some artificial ^{14}C variation resulting from the most recent Chinese bomb tests.

The ^{14}C data at the Schauinsland station from 1976 to 1984 are plotted in figure 2. The solid line is a calculated spline function (Reinsch, 1967) through this data set. We have also added the spline function through the corresponding Vermunt data from the same period (dotted line). The surprisingly close agreement between the two data sets from two different sampling locations $\cong$200km apart (in the Alps and Black Forest) indicates that the data indeed represent the ^{14}C level of tropospheric CO_2 above central Europe.

The question is now, "How representative are these data of the ^{14}C level of this latitude?"

Evidence of an additional ^{14}C depression on the European continent was given in several studies. Stuiver and Quay (1981) compared ^{14}C tree-ring data from supposedly uncontaminated trees grown on the U S west coast with those from Dutch trees (Tans, de Jong, & Mook, 1979). For the period, 1920 to 1950, they found a ^{14}C depletion of up to $\Delta^{14}C = -10‰$ in the Dutch trees. Referring to the west coast tree-ring series, de Jong and Mook (1982) found a ^{14}C depletion of ca $\Delta^{14}C = -5‰$ in tree-ring samples from southern Germany.

Using the energy consumption data from Rotty (1983), we can roughly assume that from the period, 1920–1950, to the present the yearly fossil fuel combustion rate has increased by a factor of 4–5. In addition to the *global* increase of the ^{14}C depletion, the "*European* Suess effect" should have increased by approximately this factor, *ie,* to ca $\Delta^{14}C \cong 5‰ * (4 \text{ to } 5) = -20$ to $-25‰$. Assuming the fossil fuel depression is lowest during the summer due to intensive vertical mixing of the atmosphere and better dilution of anthropogenic CO_2, Tans (1981) proposed that the upper envelope of his selected data set represented the Northern Hemisphere ^{14}C level.

On the basis of the arguments made above, a brief data analysis of the Schauinsland ^{14}C data of 1980, and 1982–1983, that are probably not influenced by additional bomb ^{14}C released during this interval, offers an independent estimate of representative tropospheric ^{14}C levels. Assuming that all negative deviations from the "upper envelope" of the Schauinsland ^{14}C data are due to fossil fuel contamination, we use a "straight line upper envelope" to the 1980–1983 Schauinsland data and compare the bulk of data with this line. By this procedure, we obtain a mean anthropogenic ^{14}C depletion for the Schauinsland station of ca $\Delta^{14}C = -9‰$ ($-5‰$ in summer and $-13‰$ in winter); presumably, these numbers are reliable within a $\pm 30\%$ range. Based on other atmospheric tracer data for the same site (eg, CO_2 concentration and ^{222}Radon activity), we seem to have good reasons to believe that our upper envelope in fact represents the ^{14}C level of the latitudinal belt beyond local or regional influence by fossil CO_2 sources.

In this context, it is also worth noting a single ring ^{14}C study (see table

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

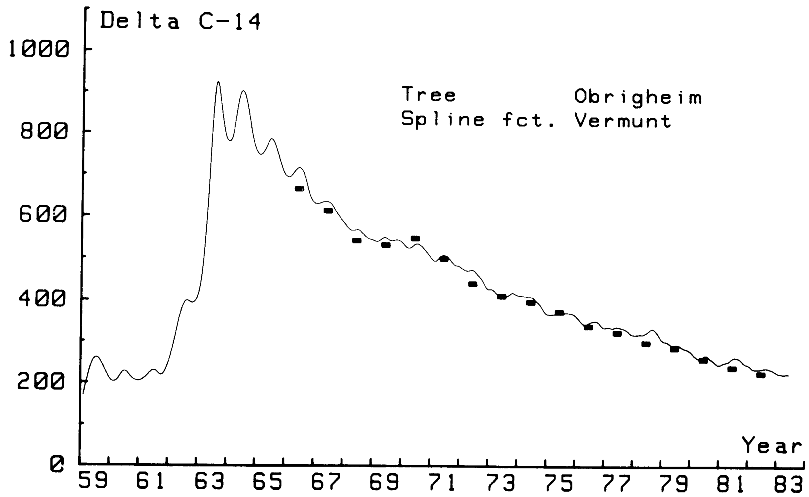

Fig 3. Spline function through the Vermunt data (fig 1) together with the tree-ring data from a pine (*Pinus nigra*) grown near Obrigheim, southern Germany (49° N, 9° E). Except for 1970 and 1975 (see text), a mean depression of $\Delta^{14}C = -15‰$ is found in the tree rings as compared to the ^{14}C level in tropospheric CO_2 at the mountain stations in summer.

6: 1966–1982) on a tree (*Pinus nigra*) grown near Obrigheim[2] in a rural area in southern Germany. There we found a mean $\Delta^{14}C$ depression of $-20‰$ compared to the "upper envelope" of the Schauinsland and Vermunt data (fig 3). This presumably means an average 20‰ fossil CO_2 contribution at ground level and daytime during the growing season, due to the average mesoscale source density of fossil fuel CO_2 ("continental effect").

The preceding estimates support the assumption of Tans (1981), that the "clean air" ^{14}C level of the Northern Hemisphere is represented by the "upper envelope" of the ^{14}C values, observed at European (continental) stations. The *mean* ^{14}C level at our mountain stations seems to be depleted from the true background by only ca $\Delta^{14}C = -9‰$ in the 1980's. The larger ^{14}C deviations in the ground level plant material may be due to the fact that it grows within the polluted layers influenced by anthropogenic CO_2 sources at ground level. At higher altitudes or rather at mountain tops reaching out of the ground layer at least in summer, the anthropogenic signal is reduced to only ca $\Delta^{14}C = -5‰$.

Proposed "Clean Air" ^{14}C Levels

In order to find representative ^{14}C levels suitable for carbon cycle modeling, we calculate a mean ^{14}C activity for each year of observation and

[2] This tree-ring analysis originally was performed to study the influence of reactor ^{14}C on plant material in the surroundings of the nuclear power plant Obrigheim (49° N, 9° E) pressurized water reactor, 300 MW electric power (see, eg, Levin, Münnich, & Weiss, 1980). Reactor ^{14}C in tree rings collected at a distance of 1km from the reactor stack is significant. This tree is grown at 4km distance, and we do not expect to find additional reactor ^{14}C here. This assumption is based on dispersion model estimates, which include release rates from the reactor stack, and experience gathered at similar reactor sites (Segl *et al*, 1983). We can not, however, exclude slight contamination for the years 1970 and 1975, when we also found high ^{14}C excess values at the sampling site closer to the reactor.

subtract for 1980 to 1983 a yearly mean fossil fuel contamination due to anthropogenic continental sources of $\Delta^{14}C_{depression} = -9‰$, *ie,* we reproduce and use the previous "upper envelope."

We derive the fossil fuel $\Delta^{14}C$ contribution for the period prior to 1980 by linear interpolation of the ^{14}C depression values of 1980 to 1983 and of 1959, respectively. We assume that the ^{14}C depression in 1959 is half that of 1980, based on a fossil fuel CO_2 release that is also half in 1959 of that in 1980 (Rotty, 1983). Thus, we arrive at the assumed "clean air" ^{14}C levels for the period between 1959 and 1983 listed in table 6.

Our "clean air levels" obtained by this procedure agree within $\Delta^{14}C \simeq \pm 20‰$ with the values proposed by Tans (1981) for the period from 1964 to 1977. Just prior to 1964, there is a discrepancy in the "clean air" levels proposed by Tans (1981), although he used essentially the same data set (Münnich & Vogel, 1963; Östlund & Engstrand, 1963) as we did in the present paper. His interpretations of "clean air" levels seem to be up to $\Delta^{14}C = 140‰$ too high compared to the fossil fuel corrected data presented here. This might be due to the fact that Tans, even in this period with maximum bomb ^{14}C production, took the upper envelope of the seasonally varying ^{14}C data. However, the extent to which the seasonal modulation in the late 1960's and early 1970's is due to fossil fuel contamination or to seasonal stratospheric injection is not known.

ACKNOWLEDGMENTS

This study was supported by the Heidelberg Academy of Sciences and by the Federal Minister of the Interior, Bonn. We wish to thank the following people for their help in obtaining the numerous samples: F Brugger, Vorarlberger Ill-Werke, Schruns, Austria, R Graul, Federal Environmental Agency, Kirchzarten, FRG, the staffs of the sampling stations at Hohenpeißenberg, Bergen, and Pretoria, C Junghans for running the ^{13}C measurements, and M Segl and M Barabas for the data documentation. Special thanks go to Minze Stuiver for helpful suggestions during the revision of this paper.

TABLE 1

Tropospheric $\Delta^{14}C$ activities at the Vermunt station, Austria (47°N, 10°E)
* = assumed $\delta^{13}C = -22.7‰$, see text.

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd- 611	Ver- 2	100259 - 130259	-26.35	173+- 7
Hd- 625	Ver- 3	200259 - 230259	-22.90	188+- 7
Hd- 633	Ver- 4	40359 - 70359	-24.10	192+- 7
Hd- 637	Ver- 5	200359 - 230359	-24.90	200+- 7
Hd- 643	Ver- 6	10459 - 40459	-25.30	220+- 6
Hd- 644	Ver- 7	100459 - 130459	-23.30	224+- 7
Hd- 667	Ver- 8	200459 - 230459	-23.40	243+- 7
Hd- 688	Ver- 11	150559 - 180559	-23.80	232+- 9
Hd- 697	Ver- 14	150659 - 180659	-20.40	276+- 7
Hd- 836	Ver- 16	50759 - 80759	*	248+- 7
Hd- 721	Ver- 20	150859 - 180859	-21.30	270+-10
Hd- 747	Ver- 23	150959 - 180959	-19.80	250+- 6

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd- 801	Ver- 25	51059 - 81059	*	237+- 9
Hd- 757	Ver- 26	151059 - 181059	-21.49	233+- 9
Hd- 779	Ver- 29	151159 - 181159	*	227+- 4
Hd- 824	Ver- 31	151259 - 181259	*	216+- 7
Hd- 832	Ver- 34	160160 - 190160	*	198+- 7
Hd- 953	Ver- 48	250260 - 280260	*	204+- 5
Hd- 954	Ver- 49	50360 - 80360	*	207+- 7
Hd- 847	Ver- 46	150360 - 180360	*	201+- 8
Hd- 853	Ver- 39	200460 - 230460	*	202+- 7
Hd- 872	Ver- 41	150560 - 180560	*	219+- 6
Hd- 900	Ver- 44	150660 - 180660	*	234+- 5
Hd- 913	Ver- 51	150760 - 180760	*	231+- 6
Hd- 927	Ver- 54	150860 - 180860	*	221+- 7
Hd- 931	Ver- 57	150960 - 180960	*	215+- 8
Hd- 957	Ver- 60	151060 - 181060	*	209+- 7
Hd- 959	Ver- 63	151160 - 181160	*	205+- 7
Hd-1061	Ver- 66	151260 - 181260	*	209+- 7
Hd- 998	Ver- 68	150161 - 180161	*	202+- 7
Hd-1004	Ver- 71	150261 - 180261	*	205+- 9
Hd-1014	Ver- 74	150361 - 180361	*	220+- 8
Hd-1060	Ver- 77	150461 - 180461	*	212+- 7
Hd-1036	Ver- 80	150561 - 180561	*	215+- 8
Hd-1069	Ver- 83	150661 - 180661	*	247+- 8
Hd-1079	Ver- 86	150761 - 180761	*	227+- 7
Hd-1087	Ver- 89	150861 - 180861	*	240+- 6
Hd-1108	Ver- 92	200961 - 230961	*	205+- 7
Hd-1178	Ver- 95	151061 - 181061	-21.70	217+- 6
Hd-1180	Ver-101	151261 - 181261	-24.70	238+- 6
Hd-1222	Ver-104	160162 - 190162	-23.60	262+- 7
Hd-1224	Ver-108	250262 - 280262	-24.80	286+- 5
Hd-1242	Ver-111	250362 - 280362	-24.00	304+- 6
Hd-1270	Ver-116	170562 - 200562	-24.90	366+- 6
Hd-1307	Ver-125	250762 - 280762	-21.40	393+- 6
Hd-1308	Ver-127	150862 - 180862	-21.60	416+- 6
Hd-1344	Ver-128	150962 - 180962	-24.80	393+- 8
Hd-1363	Ver-131	151062 - 181062	-24.25	382+- 6
Hd-1387	Ver-134	151162 - 181162	-25.10	408+- 6
Hd-1404	Ver-137	150163 - 180163	-23.09	411+- 6
Hd-1416	Ver-142	150263 - 180263	-24.00	473+- 5
Hd-1551	Ver-144	50363 - 80363	-24.00	463+- 7
Hd-1430	Ver-145	160363 - 190363	-23.80	509+- 4
Hd-1574	Ver-147	50463 - 80463	-23.10	535+- 6
Hd-1442	Ver-148	150463 - 180463	-23.40	599+- 6
Hd-1567	Ver-150	50563 - 80563	-23.80	649+- 5
Hd-1470	Ver-151	150563 - 180563	-21.90	645+- 5
Hd-1560	Ver-153	50663 - 80663	-23.30	774+- 5
Hd-1480	Ver-154	150663 - 180663	-23.30	821+- 6
Hd-1555	Ver-156	50763 - 80763	-22.70	867+- 7
Hd-1495	Ver-157	150763 - 180763	-20.60	893+- 6
Hd-1561	Ver-159	50863 - 80863	-20.90	946+- 6
Hd-1506	Ver-160	150863 - 180863	-21.95	989+- 6
Hd-1564	Ver-162	50963 - 80963	-20.00	944+- 6
Hd-1518	Ver-163	150963 - 180963	-20.60	844+- 5
Hd-1540	Ver-166	151063 - 181063	-22.10	849+- 5
Hd-1554	Ver-169	151163 - 181163	-22.80	812+- 6
Hd-1595	Ver-172	151263 - 181263	-23.00	773+- 6
Hd-1611	Ver-175	150164 - 180164	-23.50	800+- 6
Hd-1617	Ver-178	150264 - 180264	-22.70	780+- 6
Hd-1622	Ver-181	150364 - 180364	-24.27	777+- 6

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-1624	Ver-184	150464 - 180464	-23.88	838+- 6
Hd-1640	Ver-187	150564 - 180564	-20.30	895+- 6
Hd-1657	Ver-190	150664 - 180664	-19.50	917+- 6
Hd-1675	Ver-193	150764 - 180764	-20.70	887+- 7
Hd-1677	Ver-196	150864 - 180864	-19.10	900+- 6
Hd-1684	Ver-202	150964 - 180964	-19.50	854+- 6
Hd-1705	Ver-205	151064 - 181064	-17.80	835+- 6
Hd-1718	Ver-198	151164 - 181164	-18.50	778+- 7
Hd-1739	Ver-208	151264 - 181264	-23.40	763+- 6
Hd-1741	Ver-211	150165 - 180165	-20.20	766+- 7
Hd-1772	Ver-214	170265 - 200265	-20.70	742+- 6
Hd-1776	Ver-217	150365 - 180365	-20 70	748+- 6
Hd-1787	Ver-220	150465 - 180465	-24.50	766+- 6
Hd-1796	Ver-223	150565 - 180565	-24.00	746+- 6
Hd-1810	Ver-226	150665 - 180665	-26.90	810+- 6
Hd-1826	Ver-229	250765 - 280765	-22.50	787+- 6
Hd-1823	Ver-231	150865 - 180865	-22.40	775+- 6
Hd-1837	Ver-234	250965 - 280965	*	763+- 7
Hd-1838	Ver-236	151065 - 181065	-25.10	726+- 7
Hd-1850	Ver-239	161165 - 191165	-23.30	729+- 6
Hd-1867	Ver-243	151265 - 251265	-7.60	696+- 6
Hd-1895	Ver-246	250166 - 50266	-7.66	701+- 6
Hd-1887	Ver-248	150266 - 250266	-7.65	691+- 6
Hd-1908	Ver-255	150366 - 270366	-7.87	696+- 6
Hd-1916	Ver-258	150466 - 250466	-7.98	708+- 6
Hd-1929	Ver-261	150566 - 250566	-7.71	711+- 6
Hd-1951	Ver-264	150666 - 250666	-7.38	725+- 6
Hd-1962	Ver-267	150766 - 250766	-8.06	711+- 7
Hd-1973	Ver-270	150866 - 250866	-7.02	711+- 6
Hd-2003	Ver-273	150966 - 250966	-7.59	697+- 5
Hd-2019	Ver-276	151066 - 251066	-7.70	661+- 5
Hd-2009	Ver-279	151166 - 251166	-26 66	624+- 5
Hd-2012	Ver-281	51266 - 151266	-8.36	660+- 6
Hd-2055	Ver-285	150167 - 250167	-2.65	625+- 6
Hd-2058	Ver-288	150267 - 250267	-8.77	633+- 5
Hd-2061	Ver-291	150367 - 250367	-7.65	635+- 5
Hd-2113	Ver-293	150467 - 250467	-7.64	633+- 6
Hd-2118	Ver-294	250467 - 50567	-7.41	640+- 7
Hd-2121	Ver-297	150767 - 250767	-6.97	631+- 6
Hd-2147	Ver-303	150867 - 250867	-7.49	642+- 6
Hd-2196	Ver-306	150967 - 250967	-9.02	600+- 6
Hd-2197	Ver-309	151067 - 251067	-7.20	611+- 6
Hd-2198	Ver-312	151167 - 251167	-7.70	607+- 6
Hd-2244	Ver-314	51267 - 151267	-7.50	585+- 6
Hd-2259	Ver-315	250168 - 50268	-11.52	596+- 6
Hd-2260	Ver-317	150268 - 250268	-7.50	569+- 6
Hd-2271	Ver-320	150368 - 250368	-7.79	570+- 6
Hd-2286	Ver-323	150468 - 250468	-26.43	559+- 6
Hd-2261	Ver-321	250468 - 50568	-26 79	578+- 6
Hd-2295	Ver-326	150568 - 250568	-7.72	559+- 6
Hd-2296	Ver-329	150668 - 250668	-7.84	573+- 6
Hd-2376	Ver-333	150768 - 250768	-6.58	581+- 7
Hd-2377	Ver-332	150868 - 250868	-7.50	555+- 8
Hd-2378	Ver-335	150968 - 250968	-18.40	558+- 8
Hd-2379	Ver-338	151068 - 251068	-15.67	552+- 7
Hd-2380	Ver-341	151168 - 251168	-6.59	542+- 6
Hd-2433	Ver-344	151268 - 261268	-8.06	549+- 6
Hd-2507	Ver-346	60169 - 150169	-8.55	555+- 7
Hd-2512	Ver-350	250269 - 260269	-9 05	532+- 7

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-2513	Ver-353	150369 - 250369	-8.68	540+- 7
Hd-2514	Ver-356	150469 - 250469	-7.50	544+- 5
Hd-2515	Ver-359	150569 - 250569	-7.79	556+- 6
Hd-2827	Ver-361	50669 - 150669	-8.10	556+- 6
Hd-2586	Ver-365	150769 - 250769	-6.68	548+- 6
Hd-2585	Ver-368	150869 - 250869	-7.72	530+- 9
Hd-2576	Ver-371	150969 - 250969	-10.65	533+- 8
Hd-2814	Ver-373	51069 - 151069	-7.52	552+- 7
Hd-2817	Ver-376	51169 - 151169	-8.45	553+- 8
Hd-2818	Ver-379	111269 - 161269	-8.48	533+-11
Hd-2819	Ver-382	80170 - 150170	-8.22	548+- 7
Hd-2828	Ver-384	240170 - 50270	-8.73	540+- 8
Hd-2820	Ver-385	50370 - 170370	-8.00	521+- 6
Hd-2821	Ver-388	50470 - 150470	-8.43	527+- 6
Hd-2822	Ver-391	50570 - 150570	-7.21	523+- 5
Hd-2823	Ver-394	50670 - 150670	-7.29	540+- 6
Hd-2824	Ver-397	50770 - 150770	-5.35	542+- 6
Hd-2829	Ver-400	50870 - 150870	-7.03	531+- 7
Hd-2830	Ver-403	50970 - 150970	-7.69	532+- 5
Hd-2831	Ver-406	51070 - 151070	-7.75	526+- 6
Hd-2832	Ver-409	61170 - 151170	-7.39	514+- 7
Hd-2833	Ver-412	51270 - 161270	-7.98	515+- 6
Hd-2834	Ver-415	50171 - 150171	-7.85	510+- 7
Hd-2835	Ver-418	50271 - 150271	-5.02	493+- 7
Hd-2836	Ver-420	250271 - 50371	-6.96	473+- 8
Hd-2837	Ver-423	50471 - 150471	-7.52	506+- 8
Hd-2838	Ver-426	50571 - 150571	-7.34	515+- 8
Hd-3013	Ver-429	50671 - 150671	-7.67	516+- 6
Hd-3014	Ver-432	50771 - 150771	-7.66	493+- 7
Hd-3015	Ver-435	50871 - 150871	-7.50	521+- 7
Hd-3105	Ver-439	150971 - 150971	-7.50	488+- 7
Hd-3049	Ver-441	61071 - 161071	-8.17	503+- 6
Hd-3050	Ver-444	51171 - 151171	-8.40	474+- 4
Hd-3051	Ver-447	51271 - 151271	-9.19	498+- 5
Hd-3060	Ver-450	60172 - 150172	-8.45	493+- 9
Hd-3061	Ver-453	50272 - 150272	-8 42	472+- 5
Hd-3062	Ver-456	50372 - 150372	-8.20	478+- 6
Hd-3063	Ver-459	50472 - 150472	-7.85	471+- 6
Hd-3064	Ver-461	50572 - 150572	-7.95	464+- 6
Hd-3067	Ver-464	250572 - 50672	-7.90	483+- 5
Hd-3100	Ver-466	150672 - 250672	-7.50	477+- 6
Hd-3101	Ver-469	150772 - 250772	-7.83	474+- 4
Hd-3141	Ver-472	150872 - 260872	-7.71	453+- 6
Hd-3143	Ver-477	151072 - 261072	-7.99	461+- 5
Hd-3171	Ver-483	151272 - 261272	-8.23	431+- 0
Hd-3178	Ver-486	150173 - 250173	-8.53	426+- 6
Hd-3180	Ver-487	250173 - 50273	-8.29	427+- 6
Hd-3184	Ver-488	50273 - 150273	-8.17	442+- 5
Hd-3170	Ver-489	150273 - 260273	-8.47	435+- 5
Hd-3185	Ver-490	260273 - 60373	-7.41	435+- 5
Hd-3184	Ver-488	50273 - 150273	-8.17	442+- 5
Hd-3170	Ver-489	150273 - 260273	-8.47	435+- 5
Hd-3185	Ver-490	260273 - 60373	-7.41	435+- 5
Hd-3187	Ver-491	60373 - 160373	-8.37	415+- 6
Hd-3190	Ver-492	160373 - 260373	-7.68	428+- 5
Hd-3201	Ver-493	260373 - 50473	-8.76	412+- 5
Hd-3202	Ver-494	50473 - 150473	-8.26	432+- 5
Hd-3225	Ver-497	50573 - 150573	-8.24	409+- 5
Hd-3261	Ver-504	160773 - 250773	-7.64	417+- 5

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-3252	Ver-510	170973 - 250973	-7.97	389+- 5
Hd-3264	Ver-514	250973 - 71073	-8.05	438+- 5
Hd-3292	Ver-512	251073 - 251173	-7.80	438+- 5
Hd-3297	Ver-517	251173 - 171273	-8.32	402+- 6
Hd-3374	Ver-536	50774 - 250774	-7.92	413+- 4
Hd-3418	Ver-541	250874 - 160974	-8.13	392+- 6
Hd-3452	Ver-545	31074 - 261074	-8 38	401+- 5
Hd-3471	Ver-548	51174 - 251174	-8.13	389+- 6
Hd-3536	Ver-550	251174 - 251274	-11.05	366+- 6
Hd-3557	Ver-553	251274 - 150175	-8.40	367+- 6
Hd-3555	Ver-555	50275 - 250275	-8.10	371+- 4
Hd-3570	Ver-559	250275 - 250375	-8.74	370+- 7
Hd-3594	Ver-562	50475 - 50575	-8.06	370+- 7
Hd-3598	Ver-566	50575 - 250575	-8.30	370+- 6
Hd-3725	Ver-585	41175 - 251175	-8.33	369+- 6
Hd-3749	Ver-581	251175 - 151275	-9.57	374+- 5
Hd-3816	Ver-592	250176 - 50276	-8.33	362+- 8
Hd-3815	Ver-588	50376 - 150376	-9.30	356+- 6
Hd-3819	Ver-589	160376 - 250376	-9.88	354+- 8
Hd-6349	Ver-596	150476 - 250476	-9.72	340+- 5
Hd-3827	Ver-595	160576 - 250576	-9.53	356+- 9
Hd-6316	Ver-600	250576 - 60676	-10.17	341+- 4
Hd-3846	Ver-601	60676 - 170676	-9.26	341+- 9
Hd-3847	Ver-604	50776 - 160776	-9.44	365+- 7
Hd-3963	Ver-605	160776 - 270776	-8.84	372+- 8
Hd-6317	Ver-606	270776 - 50876	-8.42	346+- 5
Hd-6354	Ver-608	150876 - 250876	-7.68	343+- 6
Hd-3964	Ver-610	50976 - 150976	-8.06	343+- 8
Hd-4055	Ver-616	150976 - 250976	-7.94	365+- 6
Hd-4056	Ver-613	51176 - 161176	-8.54	361+- 5
Hd-4124	Ver-617	161176 - 251176	-8.60	337+- 5
Hd-4127	Ver-619	51276 - 151276	-8.90	331+- 5
Hd-4128	Ver-620	151276 - 251276	-8.52	331+- 6
Hd-4129	Ver-622	60177 - 150177	-8.52	337+- 6
Hd-4182	Ver-623	150177 - 260177	-8.86	339+- 4
Hd-4184	Ver-625	50277 - 150277	-8.80	342+- 5
Hd-4187	Ver-626	150277 - 250277	-8.68	338+- 5
Hd-4192	Ver-628	50377 - 150377	-8.52	340+- 5
Hd-4267	Ver-629	180377 - 260377	-8.58	347+- 5
Hd-4268	Ver-630	260377 - 150477	-8.69	327+- 5
Hd-4269	Ver-632	150477 - 70577	-8.58	327+- 5
Hd-4313	Ver-635	70577 - 150577	-8.61	340+- 5
Hd-4406	Ver-638	250577 - 50677	-8.03	347+- 5
Hd-4316	Ver-636	50677 - 150677	-8.48	340+- 4
Hd-4411	Ver-640	150677 - 260677	-8.15	337+- 6
Hd-4441	Ver-641	60777 - 260777	-8.53	335+- 7
Hd-4447	Ver-643	260777 - 150877	-8.34	340+- 6
Hd-4458	Ver-645	150877 - 250877	-8.38	331+- 6
Hd-4449	Ver-646	250877 - 50977	-7.88	335+- 5
Hd-4513	Ver-647	151077 - 261077	-10.30	338+- 5
Hd-4517	Ver-649	261077 - 51177	-9.42	325+- 6
Hd-4608	Ver-651	91277 - 151277	-8.84	314+- 7
Hd-4610	Ver-652	151277 - 261277	-8.15	315+- 7
Hd-4614	Ver-654	70178 - 150178	-8.69	334+- 6
Hd-4622	Ver-655	150178 - 250178	-9.33	309+- 4
Hd-4664	Ver-656	250178 - 60278	-9.06	327+- 5
Hd-4803	Ver-657	60278 - 150278	-9.74	339+- 6
Hd-4831	Ver-658	150278 - 260278	-9.57	308+- 6
Hd-4832	Ver-659	260278 - 60378	-10.11	312+- 5

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-4834	Ver-660	60378 - 160378	-11.72	314+- 6
Hd-4837	Ver-661	160378 - 250378	-9.68	331+- 5
Hd-4838	Ver-662	250378 - 50478	-9.93	326+- 5
Hd-4842	Ver-663	50478 - 160478	-10.30	323+- 5
Hd-4843	Ver-664	160478 - 260478	-10.00	320+- 5
Hd-4880	Ver-671	260478 - 70578	-9.77	318+- 4
Hd-4881	Ver-672	70578 - 160578	-9.40	310+- 5
Hd-4887	Ver-673	160578 - 250578	-9.57	323+- 8
Hd-4886	Ver-674	250578 - 60678	-9.57	334+- 6
Hd-4892	Ver-676	150678 - 250678	-9.02	334+- 8
Hd-4949	Ver-671	250678 - 50778	-9.40	322+- 9
Hd-4951	Ver-672	50778 - 150778	-8.72	309+- 7
Hd-5208	Ver-684	60178 - 250179	-8.80	306+- 6
Hd-4952	Ver-673	150778 - 250778	-8.35	324+- 7
Hd-4953	Ver-674	250778 - 50878	-8.00	326+- 8
Hd-4993	Ver-675	50878 - 160878	-8.57	342+- 8
Hd-4994	Ver-676	160878 - 260878	-7.52	346+- 6
Hd-5080	Ver-665	260878 - 50978	-8.51	321+-11
Hd-5078	Ver-666	50978 - 260978	-9.31	336+- 8
Hd-5083	Ver-668	260978 - 51078	-9.96	315+-14
Hd-5090	Ver-669	51078 - 161078	-8.27	339+- 7
Hd-5091	Ver-670	161078 - 251078	-9.35	320+- 8
Hd-5108	Ver-677	251078 - 51178	-9.80	330+- 8
Hd-5112	Ver-678	51178 - 251178	-9.65	322+- 7
Hd-5112	Ver-680	251178 - 151278	-9.65	322+- 7
Hd-5206	Ver-683	261278 - 60179	-3.08	298+- 6
Hd-5209	Ver-686	250179 - 50279	-8.45	308+- 6
Hd-5226	Ver-687	50279 - 260279	-8.14	296+- 5
Hd-5239	Ver-689	260279 - 50379	-8.74	295+- 7
Hd-5240	Ver-690	50379 - 160379	-8.92	299+- 6
Hd-5242	Ver-691	160379 - 250379	-8.73	353+- 7
Hd-5243	Ver-692	250379 - 160479	-8.87	290+- 5
Hd-5406	Ver-695	250479 - 50579	-8.89	284+- 5
Hd-5417	Ver-696	50579 - 150579	-8.55	300+- 6
Hd-5418	Ver-697	150579 - 270579	-8.25	291+- 7
Hd-5422	Ver-698	270579 - 100679	-8.58	295+- 6
Hd-5423	Ver-699	100679 - 250679	-8.93	286+- 8
Hd-5441	Ver-701	250679 - 150779	-8.49	310+- 5
Hd-5450	Ver-703	150779 - 60879	-7.83	277+- 5
Hd-5451	Ver-705	60879 - 250879	-7.74	312+- 5
Hd-5520	Ver-707	250879 - 50979	-7.68	293+- 4
Hd-5531	Ver-708	50979 - 160979	-7.99	278+- 7
Hd-5548	Ver-709	160979 - 250979	-7.76	282+- 6
Hd-5550	Ver-710	250979 - 51079	-8.12	283+- 9
Hd-5714	Ver-711	51079 - 151079	-8.36	294+- 8
Hd-5724	Ver-715	51179 - 151179	-8.08	288+- 5
Hd-5772	Ver-716	151179 - 61279	-8.40	280+- 5
Hd-5797	Ver-720	261279 - 150180	-8.46	288+- 5
Hd-5812	Ver-723	250180 - 150280	-8.52	268+- 5
Hd-6002	Ver-733	50580 - 150580	-8.33	262+- 4
Hd-6043	Ver-735	250580 - 150680	-8 90	259+- 4
Hd-6048	Ver-737	150680 - 250680	-8.18	270+- 4
Hd-6049	Ver-739	50780 - 250780	-8 15	280+- 5
Hd-6060	Ver-741	250780 - 150880	-8.07	274+- 5
Hd-6061	Ver-743	150880 - 60980	-8.28	254+- 5
Hd-6062	Ver-745	60980 - 250980	-7.99	263+- 5
Hd-6064	Ver-747	250980 - 51080	-8.64	251+- 7
Hd-6055	Ver-748	51080 - 161080	-8.53	263+- 7
Hd-6303	Ver-749	161080 - 51180	-9.38	263+- 6
Hd-6304	Ver-751	51180 - 141180	-10.00	254+- 5

TABLE 1 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-6337	Ver-752	141180 - 261180	-8.47	260+- 8
Hd-6342	Ver-753	261180 - 151280	-9.17	246+- 4
Hd-6355	Ver-755	151280 - 251280	-8.95	240+- 7
Hd-6356	Ver-756	251280 - 50181	-9.43	247+- 6
Hd-6362	Ver-757	50181 - 150181	-8.99	251+- 6
Hd-6376	Ver-758	150181 - 250181	-8.84	245+- 4
Hd-6377	Ver-759	250181 - 50281	-9.04	245+- 5
Hd-6506	Ver-760	50281 - 150281	-8 73	256+- 5
Hd-6507	Ver-761	150281 - 250281	-9.25	260+- 6
Hd-6515	Ver-763	50381 - 150381	-9.43	252+- 4
Hd-6522	Ver-764	150381 - 250381	-8.82	250+- 5
Hd-6554	Ver-765	250381 - 50481	-8.61	258+- 5
Hd-6556	Ver-766	50481 - 150481	-8.93	255+- 5
Hd-6559	Ver-767	150481 - 50581	-8.28	247+- 5
Hd-6564	Ver-769	50581 - 160581	-8.12	256+- 5
Hd-6565	Ver-770	160581 - 50681	-8.39	264+- 6
Hd-6566	Ver-772	270581 - 160681	-7.99	259+- 5
Hd-6727	Ver-773	150681 - 50781	-7.91	265+- 7
Hd-6729	Ver-775	50781 - 250781	-8.29	271+- 5
Hd-6730	Ver-777	250781 - 150881	-7.41	263+- 4
Hd-6805	Ver-774	240881 - 150981	-8.08	261+- 5
Hd-6807	Ver-778	51081 - 261081	-8.66	264+- 4
Hd-6892	Ver-779	71181 - 251181	-8.66	244+- 4
Hd-6902	Ver-781	21281 - 151281	-8.67	245+- 5
Hd-6907	Ver-783	151281 - 50182	-8.83	252+- 5
Hd-6980	Ver-785	150182 - 60282	-8 74	246+- 2
Hd-7012	Ver-788	60282 - 150282	-8.57	245+- 6
Hd-7025	Ver-790	150282 - 250282	-8 81	234+- 7
Hd-7321	Ver-791	250282 - 60382	-8 93	221+- 5
Hd-7320	Ver-792	60382 - 250382	-9.37	244+- 5
Hd-7322	Ver-794	250382 - 50482	-8 87	243+- 5
Hd-7323	Ver-795	50482 - 150482	-8.70	224+- 6
Hd-7308	Ver-796	150482 - 250482	-8 00	237+-13
Hd-7410	Ver-797	250482 - 160582	-8 34	243+- 4
Hd-7415	Ver-799	160582 - 250582	-8 26	240+- 4
Hd-7416	Ver-800	250582 - 50682	-8.29	236+- 5
Hd-7417	Ver-801	50682 - 150682	-7.96	225+- 5
Hd-7418	Ver-802	150682 - 250682	-8 17	235+- 5
Hd-7546	Ver-803	250682 - 70782	-7.69	242+- 3
Hd-7559	Ver-805	170782 - 50882	-7.91	240+- 4
Hd-7521	Ver-807	50882 - 160882	-7.84	233+- 4
Hd-7560	Ver-808	160882 - 50982	-7.83	246+- 4
Hd-7677	Ver-810	50982 - 150982	-7.98	254+-10
Hd-7669	Ver-811	150982 - 250982	-8.22	235+- 4
Hd-7664	Ver-813	271182 - 61282	-9.10	235+- 3
Hd-7678	Ver-814	61282 - 151282	-8 39	232+- 4
Hd-7670	Ver-815	151282 - 271282	-8.58	229+- 3
Hd-7821	Ver-816	271282 - 150183	-8.52	230+- 3
Hd-7806	Ver-812	180283 - 250283	-8.36	217+- 4
Hd-7822	Ver-822	250283 - 150383	-8.25	239+- 4
Hd-7907	Ver-818	150383 - 260383	-8.50	225+- 4
Hd-7908	Ver-819	260383 - 50483	-8.48	225+- 4
Hd-7909	Ver-820	50483 - 150483	-8.49	219+- 3
Hd-7910	Ver-824	150483 - 250483	-8.85	227+- 4
Hd-7923	Ver-825	250483 - 50583	-8.11	228+- 4
Hd-8066	Ver-826	50583 - 140583	-8.29	230+- 5
Hd-8067	Ver-827	140583 - 250583	-8.36	237+- 6
Hd-8068	Ver-828	250583 - 60683	-8.15	213+- 5
Hd-8069	Ver-829	60683 - 150683	-8.28	227+- 3

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 2
Schauinsland station, W Germany (48°N, 8°E)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-4155	Sch- 1	91276 - 231276	-7.98	320+- 8
Hd-4158	Sch- 2	231276 - 60177	-7.91	320+- 5
Hd-4161	Sch- 3	60177 - 200177	-7.98	332+- 6
Hd-4173	Sch- 4	200177 - 30277	-7.91	321+- 6
Hd-4178	Sch- 5	30277 - 170277	-7.97	325+- 8
Hd-4176	Sch- 6	180277 - 70377	-7.92	345+- 6
Hd-4215	Sch- 7	150377 - 290377	-7.92	326+- 7
Hd-4218	Sch- 8	290377 - 130477	-8.11	327+- 7
Hd-4306	Sch- 9	130477 - 60577	-7.88	333+- 5
Hd-4308	Sch- 10	60577 - 310577	-7.56	337+- 5
Hd-4307	Sch- 11	310577 - 260677	-7.50	341+- 5
Hd-4309	Sch- 12	260677 - 180777	-7.37	337+- 5
Hd-4475	Sch- 13	180777 - 150877	-7.40	327+- 7
Hd-4476	Sch- 14	150877 - 40977	-7.50	336+- 5
Hd-4468	Sch- 15	40977 - 270977	-7.47	342+- 5
Hd-4629	Sch- 16	261077 - 211177	-7.75	342+- 5
Hd-4630	Sch- 17	211177 - 251277	-7.83	308+- 5
Hd-4632	Sch- 18	251277 - 300178	-8.15	312+- 5
Hd-4633	Sch- 19	300178 - 90378	-8.69	309+- 6
Hd-4885	Sch- 20	90378 - 290378	-8.32	319+- 5
Hd-4867	Sch- 21	290378 - 90478	-8.54	333+- 6
Hd-4873	Sch- 22	180478 - 70578	-7.92	317+- 8
Hd-4874	Sch- 23	70578 - 50678	-8.10	323+- 8
Hd-4915	Sch- 24	70678 - 30778	-7.88	343+- 8
Hd-4916	Sch- 25	30778 - 130778	-7.77	339+- 8
Hd-4917	Sch- 26	130778 - 260778	-7.31	331+- 8
Hd-4920	Sch- 27	260778 - 80878	-7.39	340+- 6
Hd-4984	Sch- 28	150878 - 290878	-7.27	344+- 5
Hd-4985	Sch- 29	290878 - 110978	-7.20	337+- 9
Hd-4986	Sch- 30	120978 - 260978	-7.31	315+-11
Hd-4987	Sch- 31	260978 - 101078	-8.04	311+- 8
Hd-5003	Sch- 32	101078 - 231078	-7.72	308+-10
Hd-5074	Sch- 33	241078 - 51178	-8.39	334+- 8
Hd-5087	Sch- 34	51178 - 181178	-7.69	328+- 8
Hd-5075	Sch- 35	181178 - 11278	-11.53	323+- 9
Hd-5076	Sch- 36	11278 - 151278	-7.88	306+-11
Hd-5088	Sch- 37	151278 - 311278	-8.25	318+- 7
Hd-5181	Sch- 38	311278 - 140179	-8.12	307+- 5
Hd-5182	Sch- 39	140179 - 300179	-8.55	298+- 5
Hd-5183	Sch- 40	300179 - 120279	-8.60	306+- 5
Hd-5194	Sch- 41	200279 - 50379	-8.39	293+- 5
Hd-5195	Sch- 42	50379 - 180379	-7.89	298+- 5
Hd-5258	Sch- 44	310379 - 130479	-8.50	292+- 6
Hd-5259	Sch- 45	130479 - 260479	-8.36	309+- 5
Hd-5274	Sch- 46	260479 - 80579	-8.45	292+- 5
Hd-5275	Sch- 47	80579 - 210579	-8.22	352+- 5
Hd-5331	Sch- 48	210579 - 60679	-8.01	283+- 4
Hd-5339	Sch- 49	60679 - 190679	-7.50	291+- 5
Hd-5340	Sch- 50	190679 - 30779	-7.42	294+- 5
Hd-5343	Sch- 51	30779 - 150779	-7.47	288+- 7
Hd-5328	Sch- 52	150779 - 260779	-8.00	309+- 6
Hd-5485	Sch- 54	90879 - 240879	-7.51	299+- 4
Hd-5500	Sch- 55	240879 - 50979	-7.40	288+- 6
Hd-5480	Sch- 56	50979 - 180979	-7.44	298+- 5
Hd-5501	Sch- 57	180979 - 11079	-7.48	307+- 6
Hd-5493	Sch- 58	11079 - 101079	-7.57	294+- 6
Hd-5579	Sch- 59	121079 - 271079	-7.96	297+- 5

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 2 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-5574	Sch- 60	271079 - 101179	-7.90	290+- 6
Hd-5726	Sch- 61	101179 - 241179	-8.02	281+- 4
Hd-5581	Sch- 62	241179 - 101279	-8.37	296+- 3
Hd-5727	Sch- 63	101279 - 211279	-8.00	280+- 4
Hd-5825	Sch- 64	20180 - 180180	-8 29	269+- 8
Hd-5807	Sch- 65	180180 - 20280	-8.41	295+- 8
Hd-5806	Sch- 66	20280 - 170280	-8 01	271+- 6
Hd-5826	Sch- 67	170280 - 30380	-8.95	265+- 5
Hd-5935	Sch- 68	110380 - 240380	-8 88	249+- 4
Hd-5936	Sch- 69	240380 - 60480	-7.74	260+- 3
Hd-5941	Sch- 70	60480 - 190480	-8.90	259+- 4
Hd-5942	Sch- 71	200480 - 20580	-8.39	267+- 5
Hd-5970	Sch- 73	20680 - 140680	-8.06	271+- 2
Hd-5971	Sch- 74	140680 - 240680	-7.71	269+- 4
Hd-5956	Sch- 75	240680 - 70780	-8 52	283+- 4
Hd-5972	Sch- 76	70780 - 170780	-6 93	278+- 6
Hd-5954	Sch- 77	170780 - 40880	-7.35	275+- 5
Hd-6038	Sch- 78	70880 - 180880	-7.90	267+- 4
Hd-6039	Sch- 79	180880 - 290880	-7.24	264+- 5
Hd-6058	Sch- 80	290880 - 80980	-7.81	264+- 4
Hd-6059	Sch- 81	80980 - 220980	-7.69	267+- 3
Hd-6054	Sch- 82	220980 - 141080	-6.76	270+- 3
Hd-6222	Sch- 83	141080 - 271080	-7.95	273+- 4
Hd-6223	Sch- 84	271080 - 71180	-9.02	256+- 3
Hd-6224	Sch- 85	71180 - 181180	-8.94	258+- 4
Hd-6225	Sch- 86	181180 - 11280	-8.91	257+- 7
Hd-6270	Sch- 87	101280 - 291280	-8.04	262+- 5
Hd-6267	Sch- 88	291280 - 120181	-8.04	254+- 4
Hd-6271	Sch- 89	120181 - 220181	-7.85	230+- 4
Hd-6388	Sch- 90	220181 - 40281	-8.43	269+- 3
Hd-6389	Sch- 91	40281 - 160281	-8.28	273+- 4
Hd-6390	Sch- 92	160281 - 10381	-9.50	247+- 3
Hd-6391	Sch- 93	10381 - 130381	-9.15	255+- 5
Hd-6392	Sch- 94	130381 - 270381	-8.61	251+- 3
Hd-6527	Sch- 95	30481 - 160481	-8.23	244+- 4
Hd-6525	Sch- 96	160481 - 300481	-8.76	257+- 4
Hd-6526	Sch- 97	300481 - 150581	-8 55	242+- 5
Hd-6874	Sch- 98	100781 - 240781	-7.53	273+- 5
Hd-6875	Sch- 99	240781 - 70881	-7.52	267+- 5
Hd-6952	Sch-101	280182 - 120282	-7.00	241+- 6
Hd-6953	Sch-102	120282 - 20382	-7.18	231+- 3
Hd-7304	Sch-103	30382 - 170382	-7 68	244+- 5
Hd-7305	Sch-104	170382 - 10482	-8.44	234+- 5
Hd-7306	Sch-105	10482 - 140482	-8.29	246+- 4
Hd-7307	Sch-106	150482 - 270482	-8 29	230+- 3
Hd-7310	Sch-107	270482 - 110582	-7.97	239+- 5
Hd-7422	Sch-108	180582 - 20682	-7.74	249+- 3
Hd-7423	Sch-109	20682 - 160682	-7.95	238+- 4
Hd-7424	Sch-110	160682 - 20782	-7.67	244+- 4
Hd-7425	Sch-111	20782 - 190782	-7.17	246+- 4
Hd-7499	Sch-112	300782 - 170882	-7.73	245+- 4
Hd-7500	Sch-113	170882 - 310882	-7.28	243+- 5
Hd-7508	Sch-114	310882 - 150982	-7.50	237+- 2
Hd-7509	Sch-115	150982 - 71082	-7.96	243+- 2
Hd-7658	Sch-116	71082 - 251082	-8.47	242+- 3
Hd-7659	Sch-117	251082 - 81182	-7.82	238+- 5
Hd-7660	Sch-118	81182 - 291182	-8.35	236+- 5
Hd-7661	Sch-119	291182 - 151282	-8 23	233+- 4

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 2 (continued)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd-7662	Sch-120	151282 - 100183	-8.06	231+- 4
Hd-7807	Sch-121	260183 - 150283	-8.22	224+- 2
Hd-7808	Sch-122	150283 - 70383	-8.28	223+- 3
Hd-7809	Sch-123	70383 - 60483	-8.28	231+- 3
Hd-7810	Sch-124	60483 - 290483	-8.15	233+- 6
Hd-7843	Sch-125	290483 - 90583	-8.08	238+- 4
Hd-7857	Sch-126	90583 - 190583	-8.09	220+- 4
Hd-8024	Sch-127	10683 - 160683	-7.76	234+- 4
Hd-8025	Sch-128	160683 - 10783	-7.61	217+- 4
Hd-8026	Sch-129	10783 - 220783	-7.69	223+- 4
Hd-8034	Sch-130	220783 - 120883	-7.76	207+- 4
Hd-8114	Sch-131	120883 - 240883	-7.77	231+- 4
Hd-8115	Sch-132	240883 - 50983	-8.57	230+- 4
Hd-8120	Sch-133	50983 - 160983	-7.81	237+- 4
Hd-8121	Sch-134	160983 - 270983	-7.74	224+- 4
Hd-8188	Sch-135	270983 - 71083	-7.77	218+- 4
Hd-8187	Sch-136	71083 - 211083	-7.86	230+- 4
Hd-8202	Sch-137	211083 - 91183	-7.97	215+- 3
Hd-8266	Sch-138	91183 - 251183	-8.38	212+- 4
Hd-8267	Sch-139	251183 - 71283	-8.89	210+- 4
Hd-8276	Sch-140	71283 - 201283	-8.54	211+- 4
Hd-8365	Sch-141	201283 - 20184	-9.06	210+- 4
Hd-8388	Sch-142	20184 - 100184	-8.20	201+- 4
Hd-8389	Sch-143	100184 - 230184	-9.06	218+- 4
Hd-8366	Sch-144	260184 - 20284	-8.00	210+- 5
Hd-8474	Sch-145	70284 - 130284	-8.31	207+- 4
Hd-8461	Sch-146	130284 - 200284	-8.37	199+- 4
Hd-8447	Sch-147	200284 - 50384	-9.43	187+- 3
Hd-8448	Sch-148	50384 - 190384	-9.68	193+- 4
Hd-8494	Sch-149	190384 - 20484	-9.77	204+- 4
Hd-8577	Sch-151	60484 - 160484	-9.02	190+- 3
Hd-8578	Sch-152	160484 - 300484	-8.85	203+- 3
Hd-8579	Sch-153	70584 - 140584	-8.59	202+- 3
Hd-8580	Sch-154	140584 - 250584	-7.97	210+- 3
Hd-8634	Sch-155	250584 - 110684	-7.78	210+- 4

TABLE 3

Hohenpeißenberg station, W Germany (48°N, 11°E)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd- 673	Hoh- 2	150559 - 180559	*	249+- 7
Hd- 799	Hoh- 8	150759 - 180759	*	294+- 6
Hd- 800	Hoh- 11	150859 - 180859	*	263+- 7
Hd- 837	Hoh- 23	151259 - 181259	*	214+- 7
Hd- 920	Hoh- 45	50860 - 80860	*	222+- 7
Hd-1005	Hoh- 66	150361 - 180361	*	193+- 8

TABLE 4

Bergen station, Norway (60°N, 5°E)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd- 823	Ber- 12	151259 - 181259	*	203+- 8
Hd- 831	Ber- 15	250160 - 280160	*	78+- 9
Hd- 844	Ber- 18	150360 - 190360	*	174+- 8
Hd- 871	Ber- 23	160560 - 190560	*	204+- 8
Hd- 902	Ber- 26	150660 - 180660	*	183+- 6
Hd- 930	Ber- 34	150860 - 180860	*	219+-10
Hd- 933	Ber- 37	140960 - 170960	*	207+- 7
Hd-1022	Ber- 54	150361 - 180361	*	196+- 7
Hd-1099	Ber- 56	50461 - 80461	*	170+- 7
Hd-1092	Ber- 58	140661 - 170661	*	232+- 7
Hd-1084	Ber- 59	150761 - 180761	*	236+- 7

TABLE 5

Pretoria station, South Africa (26°S, 28°E)

ANALYSIS No.	SAMPLE No.	PERIOD OF EXPOSURE ddmmyy - ddmmyy	$\delta^{13}C$ ‰(PDB)	$\Delta^{14}C$ ‰
Hd- 798	Pre- 2	271159 - 301159	*	175+- 6
Hd- 802	Pre- 3	211259 - 241259	*	195+- 7
Hd- 813	Pre- 5	250160 - 250160	*	194+- 7
Hd- 843	Pre- 7	220260 - 250260	*	192+- 8
Hd- 860	Pre- 9	210360 - 240360	*	181+- 8
Hd- 908	Pre- 10	110460 - 140460	*	178+- 7
Hd- 873	Pre- 11	250460 - 280460	*	150+- 6
Hd- 928	Pre- 13	300560 - 30660	*	164+- 6
Hd- 922	Pre- 14	140660 - 170660	*	174+- 7
Hd- 929	Pre- 15	280660 - 10760	*	169+- 7
Hd- 925	Pre- 17	250760 - 280760	*	173+- 8
Hd- 961	Pre- 20	60960 - 90960	*	185+- 7
Hd-1078	Pre- 22	171060 - 201060	*	197+- 7
Hd- 996	Pre- 25	281160 - 11260	*	181+- 7
Hd-1077	Pre- 28	310161 - 30261	*	204+- 7
Hd-1096	Pre- 29	200261 - 230261	*	195+- 6
Hd-1097	Pre- 31	210361 - 240361	*	195+- 7
Hd-1089	Pre- 32	110461 - 140461	*	194+- 7
Hd-1083	Pre- 34	300561 - 20661	*	180+- 7
Hd-1115	Pre- 38	220861 - 250861	*	207+- 6

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

TABLE 6

Yearly mean ^{14}C levels observed at the Vermunt and Schauinsland stations, proposed Northern Hemispheric ^{14}C "clean air" level corrected for fossil fuel contamination and the corresponding values, proposed by Tans (1981). The ^{14}C activities observed in recent tree rings from a pine grown near Obrigheim, southern Germany (49°N, 9°E) are also presented. Values with an * presumably are slightly influenced by reactor ^{14}C; see text.

Year	Yearly mean Vermunt $\Delta^{14}C$ (‰)	Yearly mean Schauinsland $\Delta^{14}C$ (‰)	Proposed "clean air" $\Delta^{14}C$ (‰)	"Clean air" Tans (1981) $\Delta^{14}C$ (‰)	Tree rings Obrigheim $\Delta^{14}C$ (‰)
1959	227		232	240	
60	214		219	230	
61	221		226	280	
62	362		367	420	
63	711		716	860	
64	835		841	820	
65	755		761	750	
66	691		697	680	667 ± 5
67	624		630	630	614 ± 4
68	564		570	590	543 ± 9
69	544		551	570	533 ± 4
70	530		537	550	549 ± 5*
71	499		506	520	501 ± 5
72	465		472	480	442 ± 4
73	429		426	450	413 ± 3
74	401		409	420	399 ± 5
75	368		376	390	375 ± 5*
76	352		360	350	340 ± 3
77	334	333	342	330	325 ± 4
78	325	324	333		300 ± 4
79	291	295	302		287 ± 5
80	261	267	273		260 ± 5
81	257		266		240 ± 4
82	238	239	248		226 ± 4
83		225	234		

https://doi.org/10.1017/S0033822200006895 Published online by Cambridge University Press

References

Craig, Harmon, 1957, Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide: Geochim et Cosmochim Acta, v 12, p 133–149.

Enting, I G and Pearman, G I, 1982, Description of a one-dimensional global carbon cycle model: Division Atmos Physics tech paper no. 42, Commonwealth Sci Industrial Research Org, Melbourne, Australia.

Fung, I, Prentice, K, Matthews, E, Lerner, J, and Russel, G, 1983, Three dimensional tracer model study of atmospheric CO_2: Response to seasonal exchanges with the terrestrial biosphere: Jour Geophys Research, v 88, no. C2, p 1281–1294.

Jong, A F M, de and Mook, W G, 1982, An anomalous Suess effect above Europe: Nature, v 298, no. 5875, p 641–644.

Kromer, Bernd, 1984, Recalibration of Heidelberg ^{14}C laboratory data: Radiocarbon, v 26, p 148.

Levin, I, Münnich, K O, and Weiss, W, 1980, The effect of anthropogenic CO_2 and ^{14}C sources on the distribution of ^{14}C in the atmosphere, *in* Stuiver, Minze and Kra, Renee, eds, Internatl radiocarbon conf, 10th, Proc: Radiocarbon, v 22, no. 2, p 379–391.

Münnich, K O, (ms), 1957, Messung natürlichen Radiokohlenstoffs mit einem CO_2-Proportionalzählrohr: PhD thesis, Univ Heidelberg.

Münnich, K O and Vogel, J C, 1959, Variations in ^{14}C content during the last years: Paper presented at Internatl carbon-dating conf, 4th, Groningen, Sept 1959.

——————— 1963, Investigations of meridional transport in the troposphere by means of Carbon-14 measurements, *in* Symposium on radioactive dating, Proc: IAEA, Vienna.

Nydal, R and Lövseth, K, 1983, Tracing bomb ^{14}C in the atmosphere 1962–1980: Jour Geophys Research, v 88, no. C6, p 3621–3642.

Östlund, H G and Engstrand, L G, 1963, Stockholm natural radiocarbon measurements V: Radiocarbon, v 5, p 203–227.

Pearman, G I, Hyson, P, and Fraser, P J, 1983, The global distribution of atmospheric carbon dioxide, 1, Aspects of observations and modeling: Jour Geophys Research, v 88, no. C6, p 3581–3590.

Reinsch, C, 1967, Smoothing by spline functions: Numerische Mathematik, v 10, p 177–183.

Rotty, R, 1983, Distribution of and changes in industrial carbon dioxide production: Jour Geophys Research, v 88, no. C2, p 1301–1308.

Schoch, H, Bruns, M, Münnich, K O, and Münnich, M, 1980, A multicounter system for high precision carbon-14 measurements, *in* Stuiver, Minze and Kra, Renee, eds, Internatl radiocarbon conf, 10th, Proc: Radiocarbon, v 22, no. 2, p 442–447.

Segl, M, Levin, I, Schoch-Fischer, H, Münnich, M, Kromer, B, Tschiersch, J, and Münnich, K O, 1983, Anthropogenic ^{14}C variations, *in* Stuiver, Minze and Kra, Renee, eds, Internatl radiocarbon conf, 11th, Proc: Radiocarbon, v 25, no. 2, p 583–592.

Stuiver, M and Polach, H A, 1977, Discussion: Reporting of ^{14}C data: Radiocarbon, v 19, p 355–363.

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

Tans, P P, de Jong, A F M, and Mook, W G, 1979, Natural atmospheric ^{14}C variation and the Suess effect: Nature, v 280, p 826–828.

Tans, P P, 1981, A compilation of bomb ^{14}C data for use in global carbon model calculations, *in* Bolin, B, ed, Scope 16: Carbon cycle modeling: Chichester, New York, Brisbane, Toronto, J Wiley & Sons.

Vogel, J C, 1970, Groningen radiocarbon dates IX: Radiocarbon, v 12, no. 2, p 444–471.