UNIVERSITY OF PENNSYLVANIA DATES VII

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INTRODUCTION

Measurements of samples of known age have been undertaken in this laboratory since its beginning in 1951 when it was found that modern wood samples taken from the outer rings of young trees did not afford a basis of counter calibration consistent with archaeologically dated samples (Ralph, 1955). This depletion was explained by Suess (1955). Subsequent measurements of samples representative of the early Egyptian dynasties, however, revealed that even with the counter calibration corrected for the modern depletion, there was a discrepancy between C^{14} dates and the early Egyptian chronology (Arnold and Libby, 1951; deVries, Barendsen, and Waterbolk, 1958; deVries and Waterbolk, 1958; Barker and Mackay, 1959, 1961; Ralph, 1959; Damon and Long, 1962). Obviously, there was, and still is, a need to find samples of known age for this time range. Dendrochronology may ultimately provide the answer, and in the meantime tree-ring dated samples have afforded a means of assessing the atmospheric C^{14} inventory during the last 3000 yr.

With financial support from the National Science Foundation, which we gratefully acknowledge, we undertook a program of dating sections of Sequoia and bristlecone pine trees both by dendrochronology and by C^{14}. We are indebted to the Laboratory of Tree-Ring Research, University of Arizona, for assistance and collaboration with the tree-ring dating.

The tree-ring dating of the Sequoia sections was readily completed, but that of the bristlecone pines is still in process. C^{14} dates have helped to accelerate the latter, however, by defining the range of possible tree-ring correlations and have demonstrated also that living bristlecone pine trees extend back 4000 yr. It is hoped that this range may be extended back another 1000 to 2000 yr with "floaters," trees that died years ago but which remain in good condition on the forest floor. It is for these reasons that the C^{14} results in this list are presented as dates for samples of known age for the Sequoias, that is, as per mil deviations in counting rates. The majority of the bristlecone pines, however, have been treated as samples of unknown age.

All Sequoia samples and bristlecone pines from section P-SW-INY-11A have been corrected for deviations in C^{13}/C^{12} ratios. For the few Sequoia samples which were dated before a mass spectrograph was available, the average value for the section has been used for this correction. The standard statistical uncertainty of the average values of the C^{13}/C^{12} measurements for each section has been added to that of the C^{14} to obtain the uncertainty in the Δ value. The δC^{13} values listed represent the deviations (multiplied by 2) of the samples measured from the δC^{13} value of our 100-yr old standard oak sample which is also the reference value for the calculation of δC^{14}. The δC^{13} relationship between our standard oak sample and NBS limestone standard
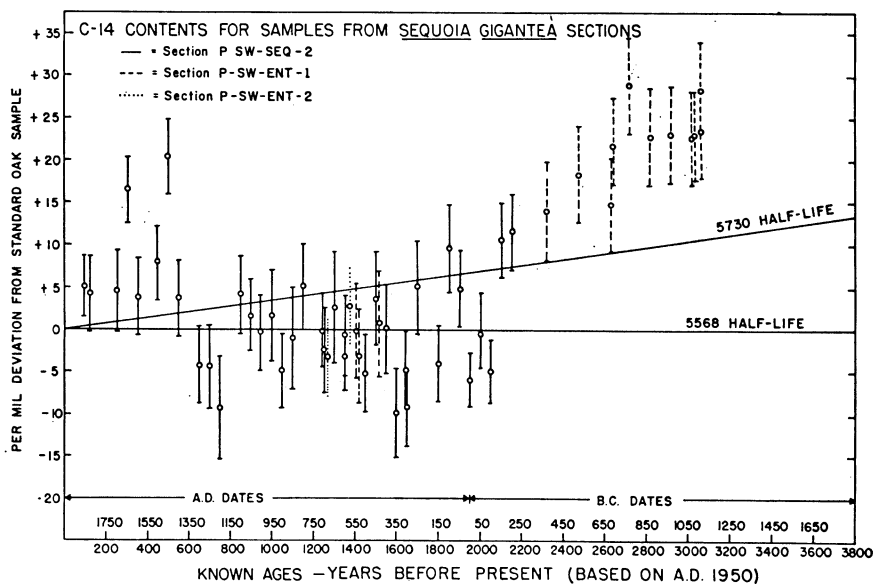
Fig. 1. Per mil deviations from 100-yr-old oak standard of dendrochronologically dated sequoia samples. All have been corrcted for C^{13}/C^{12} variations.

#20 is -25.7 ± 1.3 mils as measured on the University of Pennsylvania mass spectrograph.

It is seen in Tables 1 and 2 that most of the values of $2 \times \delta C^{13}$ do differ slightly from the δC^{13} value of our 100-yr old standard oak sample. It must be remembered, however, that these figures are $2 \times \delta C^{13}$. For comparison with Craig's (1954) data, let us take the average of the three averages $(-7.8 \pm 1.9, -8.2 \pm 3.8, \text{ and } -6.3 \pm 1.3)$ and divide by 2. We obtain $\delta C^{13} = -3.7 \pm 1.6$ mils as our average deviation for Sequoias from our oak standard. In relation to the NBS #20 limestone standard this deviation would then be -22 mils which is in excellent agreement with the average value of Craig's determinations. Also, the data exhibit a small irregular scatter as do Craig's. Ours is somewhat larger but our instrument is much less precise. The reason is not clear, however, for the small significant difference in δC^{13} between the Sequoias and our oak standard which is close to the accepted average deviation of woods from limestone (-25 mils).

The Sequoia results are plotted in Fig. 1. One sees evidence of the oscillations noted by de Vries (1958), Broecker, Olson, and Bird (1959), Willis, Tauber, and Munnich (1960), Suess (1961), and Damon (1963) in the range of A.D. 1700 to 1400 while C^{14} contents from A.D. 1100 to 100 B.C. cluster consistently just below the 5730 half-life line. A divergence (recorded also by Suess, Damon, and others), which seems to increase with age, is then apparent in the earlier period. The average deviation of the samples representative of the period 650 B.C. to 1150 B.C. represents a difference of approx. 2.3%, or 200 yr in B.P. ages calculated with the 5568 half-life.

Descriptions of the sections and lists of dates follow. In these lists C¹⁴ dates and deviations have been calculated with the 5568 half-life, and B.P. dates are based on A.D. 1950. The uncertainties quoted for the dendrochronologically determined ages represent the age spans of the samples cut out for processing. Since the true dates are close to the median values listed, no allowance for these small spans has been made in the calculations.

Sequoia series (P-SW-SEQ-2)

Radial sec. of *Sequoia gigantea*, felled in 1950, from Giant Forest (36° 35′ N Lat, 118° 48′ W Long), Sequoia Natl. Park, California. Sec. from part of

TABLE 1

P-SW-SEQ-2 *Sequoia gigantea*

Lab. No.	Dendrochronologically Determined Age A.D.-B.C.	B.P. (1950)	δ14 (deviation from Oak St'd mils)	$2 \times \delta C^{13}$ (deviation from Oak St'd mils)	Δ (δ14 corrected for δ13 mils) ones without δC^{13} are corrected with average value of δC^{13}
P-494	200 ± 5 B.C.	2150	+ 17.92 ± 4.12	−6.2	+ 11.6 ± 4.5
P-495	150 ± 5 B.C.	2100	+ 17.95 ± 4.02	−7.2	+ 10.6 ± 4.4
P-496	100 ± 5 B.C.	2050	+ 2.97 ± 3.21		− 4.9 ± 3.7
P-497	50 ± 5 B.C.	2000	+ 9.05 ± 4.03	−9.0	− 0.1 ± 4.4
P-375	A.D. 1 ± 8	1950	+ 2.00 ± 2.60		− 5.9 ± 3.2
P-498	A.D. 50 ± 5	1900	+ 12.73 ± 4.06		+ 4.8 ± 4.5
P-499	A.D. 100 ± 5	1850	+ 15.10 ± 4.83	−5.4	+ 9.6 ± 5.2
P-606	A.D. 150 ± 5	1800	+ 1.43 ± 4.13	−5.4	− 4.0 ± 4.5
P-396A	A.D. 250 ± 8	1700	+ 13.90 ± 5.14	−8.8	+ 5.0 ± 5.5
P-607	A.D. 300 ± 5	1650	− 2.15 ± 4.00	−7.2	− 9.4 ± 4.4
P-397A	A.D. 302 ± 10	1648	+ 3.00 ± 4.06		− 4.8 ± 4.5
P-608	A.D. 350 ± 5	1600	− 2.06 ± 4.93		− 9.9 ± 5.3
P-609	A.D. 400 ± 5	1550	+ 5.48 ± 4.97	−5.4	+ 0.1 ± 5.3
P-610	A.D. 450 ± 5	1500	+ 7.74 ± 5.21	−4.0	+ 3.7 ± 5.5
P-589B	A.D. 500 ± 8	1450	+ 3.59 ± 4.18	−8.8	− 5.2 ± 4.6
P-638A	A.D. 600 ± 8	1350	+ 7.20 ± 4.40		− 0.7 ± 4.8
P-812	A.D. 600 ± 7	1350	+ 4.92 ± 3.73	−8.1	− 3.2 ± 4.1
P-643	A.D. 650 ± 5	1300	+ 9.84 ± 6.29	−7.2	+ 2.6 ± 6.6
P-813	A.D. 700 ± 10	1250	+ 5.46 ± 4.73		− 2.4 ± 5.1
P-387	A.D. 702 ± 10	1248	+ 7.67 ± 4.00		− 0.1 ± 4.4
P-644	A.D. 800 ± 5	1150	+ 12.96 ± 4.72		+ 5.1 ± 5.0
P-645	A.D. 850 ± 5	1100	+ 6.71 ± 5.83		− 1.1 ± 6.1
P-703	A.D. 900 ± 8	1050	+ 2.15 ± 3.88	−7.0	− 4.9 ± 4.3
P-646	A.D. 950 ± 5	1000	+ 12.33 ± 5.09	−10.6	+ 1.6 ± 5.4
P-634	A.D. 1003 ± 11	947	+ 8.55 ± 4.19	−8.8	− 0.3 ± 4.6
P-551	A.D. 1052 ± 10	898	+ 9.59 ± 3.81		+ 1.7 ± 4.3
P-633	A.D. 1100 ± 8	850	+ 9.55 ± 4.22	−5.4	+ 4.1 ± 4.6
P-632	A.D. 1200 ± 8	750	− 1.53 ± 5.74		− 9.3 ± 6.1
P-549	A.D. 1250 ± 7	700	+ 3.48 ± 4.51		− 4.4 ± 4.9
P-701	A.D. 1299 ± 7	651	+ 4.68 ± 4.11	−8.8	− 4.2 ± 4.5
P-700	A.D. 1400 ± 8	550	+ 12.80 ± 4.09	−9.0	+ 3.7 ± 4.5
P-647	A.D. 1450 ± 10	500	+ 28.38 ± 4.45	−7.8	+ 20.4 ± 4.5
P-631	A.D. 1505 ± 13	445	+ 16.89 ± 4.21	−8.8	+ 7.9 ± 4.6
P-630	A.D. 1597 ± 5	353	+ 12.67 ± 4.22	−8.8	+ 3.8 ± 4.6
P-545	A.D. 1646 ± 4	304	+ 24.52 ± 3.42		+ 16.5 ± 3.9
P-702	A.D. 1697 ± 5	253	+ 15.39 ± 4.37	−10.6	+ 4.6 ± 4.8
P-346	A.D. 1829 ± 13	121	+ 12.13 ± 4.10		+ 4.2 ± 4.5
P-543A	A.D. 1855 ± 13	95	+ 16.20 ± 3.09	−10.9	+ 5.1 ± 3.6

Average = −7.8 ± 1.9

trunk ca. 20 to 25 ft above forest floor while tree was standing. Coll. 1959 and subm. by H. N. Michael, Univ. Mus., Univ. of Pennsylvania. *Comment*: sec. (P-SW-SEQ-2) was tree ring-dated at Lab. of Tree-Ring Research, Univ. of Arizona, Tucson. Its age range is 212 B.C. to A.D. 1946. Sec. adjacent to this radial sec. was dated by Arizona Radiocarbon Lab. (see Arizona IV, A-255: 1 to 7). Measurements of samples from this sec. are listed in Table 1.

Sequoia series (P-SW-ENT-1)

Radial sec. of *Sequoia gigantea* from Enterprise Mill area of Balch Park (36° 13′ N Lat, 118° 41′ W Long), Mountain Home State Forest, California. Tree probably felled in 1874. Radial sec. came from "butt log" of the tree, a part of the trunk ca. 20 ft above the forest floor while the tree was standing. Butt log labeled D-22A by Douglass (1919, 1945). Coll. 1960 and subm. by H. N. Michael. *Comment*: this Sequoia sec. was cross-dated with other Sequoia samples in possession of the Radiocarbon Lab. (samples dated previously by Lab. of Tree-Ring Research, Tucson). The cross-dating was further checked with published data of various sensitive records (Douglass, 1936, 1949). Rings of the sec. cover age span of 1121 B.C. to A.D. 1691. Measurements of these samples listed in Table 2.

Sequoia series (P-SW-ENT-2)

Radial sec. of *Sequoia gigantea* from Enterprise Mill area of Balch Park (36° 13′ N Lat, 118° 41′ W Long), Mountain Home State Forest, California.

TABLE 2

P-SW-ENT-1 *Sequoia gigantea*

Lab. No.	Dendrochronologically Determined Age A.D.-B.C.	B.P. (1950)	δ14 (deviation from Oak St'd mils)	$2 \times \delta C^{13}$ (deviation from Oak St'd mils)	Δ (δ14 corrected for δ13 mils) ones without δC^{13} are corrected with average value of δC^{13}
P-668	1117 ± 4 B.C.	3067	+32.36 ± 3.73	–8.7	+23.4 ± 5.3
P-780	1109 ± 3 B.C.	3059	+35.66 ± 4.11	–7.1	+28.4 ± 5.7
P-450	1082 ± 8 B.C.	3032	+31.47 ± 3.56		+23.0 ± 5.2
P-667	1068 ± 5 B.C.	3018	+28.18 ± 4.09	–5.3	+22.7 ± 5.6
P-665	968 ± 5 B.C.	2918	+42.81 ± 4.25	–18.9	+23.1 ± 5.7
P-663	868 ± 5 B.C.	2818	+28.78 ± 4.19	–5.8	+22.8 ± 5.7
P-661	768 ± 5 B.C.	2718	+36.23 ± 4.18	–7.1	+28.9 ± 5.7
P-449	688 ± 4 B.C.	2638	+30.25 ± 4.09		+21.8 ± 5.6
P-448	679 ± 5 B.C.	2629	+23.19 ± 4.09		+14.8 ± 5.6
P-491	520 ± 10 B.C.	2470	+25.60 ± 4.09	–7.0	+18.4 ± 5.6
P-656	368 ± 5 B.C.	2318	+24.16 ± 4.46	–9.9	+14.0 ± 5.9
P-738	A.D. 436 ± 11	1514	+ 4.26 ± 5.20	–3.5	+ 0.8 ± 6.3
P-636	A.D. 544 ± 22	1406	+ 8.78 ± 4.06	–8.8	– 0.1 ± 5.6
P-815	A.D. 532 ± 20	1418	+ 4.11 ± 4.08	–7.2	– 3.1 ± 5.6

Average = –8.2 ± 3.8

P-SW-ENT-2 *Sequoia gigantea*

Lab. No.	Dendrochronologically Determined Age A.D.-B.C.	B.P. (1950)	δ14 (deviation from Oak St'd mils)	$2 \times \delta C^{13}$ (deviation from Oak St'd mils)	Δ
P-818	A.D. 577	1373	+ 8.25 ± 4.27	–5.4	+ 2.8 ± 4.5
P-821	A.D. 677	1273	+10.50 ± 4.33	–7.2	– 3.2 ± 4.6

Average = –6.3 ± 1.3

Tree probably felled in 1874. Sec. from high stump (ca. 6 ft above forest floor) of a tree labeled D-43 by Douglass (1936). Coll. 1960 and subm. by H. N. Michael. *Comment*: this Sequoia sec. cross-dated with other Sequoia samples in possession of the Radiocarbon Lab. (samples dated previously by Lab. of Tree-Ring Research). Cross-dating further checked with published data of various sensitive records (Douglass, 1928, 1949). Sec. has age span from 1119 B.C. to A.D. 1699. Measurements of these samples listed in Table 2.

Bristlecone Pine series (P-SW-INY-1)

Horizontally cut cross-sec. from stump of *Pinus aristata* from White Mountains, California-Nevada. Tree felled in 1956 and labeled WHTw4779 by Schulman (1956, 1958). It grew at elevation of 10,500 ft (37° 25′ 30″ N Lat, 118° 10′ 20″ W Long(, approx. 4000 ft W of Goat Springs. Coll. 1960 and subm. by H. N. Michael. *Comment*: specimen not fully analyzed or cross-dated. However, ring count and C^{14} determinations indicate age span slightly in excess of 4000 yr.

The following samples from this section were processed:

Lab. No.	C^{14} Date (A.D.-B.C.)	C^{14} Date (B.P.)
P-407	2092 ± 69 B.C.	4042 ± 69
P-600	2056 ± 52 B.C.	4006 ± 52
P-434	1988 ± 51 B.C.	3938 ± 51
P-435	1817 ± 56 B.C.	3767 ± 56
P-413	1797 ± 67 B.C.	3747 ± 67
P-411	1722 ± 66 B.C.	3672 ± 66
P-602	1156 ± 42 B.C.	3106 ± 42
P-493	1052 ± 57 B.C.	3002 ± 57
P-451	500 ± 47 B.C.	2450 ± 47
P-430	379 ± 46 B.C.	2329 ± 46
P-436	327 ± 42 B.C.	2277 ± 42
P-492	498 ± 47 B.C.	2448 ± 47
P-433	A.D. 1323 ± 56	627 ± 56
P-453	A.D. 1349 ± 48	601 ± 48
P-431	A.D. 1294 ± 40	656 ± 40
P-416	A.D. 1781 ± 47	169 ± 47

Bristlecone Pines series (P-SW-INY-2)

Horizontally cut cross-sec. from stump of *Pinus aristata* from White Mountains, California-Nevada. Tree felled in 1956 and given the Lab. of Tree-Ring Research acquisition number WHT_{B_2} 5547, according to C. W. Ferguson of that lab. Tree grew in "Methuselah Walk" area (37° 23′ 40″ N Lat, 118° 09′ 30″ W Long), ca. 2.2 mi by trail from Schulman Grove. Coll. 1960 and subm.

Bristlecone Pine series (P-SW-INY-11A)

Cross-sec. from snag top of down and dead *Pinus aristata* from White Mountains, California-Nevada. Tree located near trail (37° 22' 30" N Lat, 118° 09' 20" W Long), leading from Shulman Grove to "Methuselah Walk" ca. 1.5 m from Shulman Grove. Coll. 1962 and subm. by H. N. Michael. *Comment:* sec. tree-ring dated on the basis of the dating of an adjoining sec. from same snag top obtained by C. W. Ferguson. P-SW-INY-11A has age span of 1590 yr, from 935 B.C. to A.D. 655. Sample P-811, the oldest, has a large positive C^{14} discrepancy, agreeing with Sequoia measurements in this age range (Fig. 1).

The following samples from this sec. were processed:

Lab. No.	Dendrochronologically Determined Age (A.D.-B.C.)	C^{14} Date (A.D.-B.C.)	C^{14} Date (B.P.)	δC^{14} (deviation from oak st'd, mils)	$2 \times \delta C^{13}$ (deviation from oak st'd, mils)	Δ corrected δC^{14} for δC^{13}, mils)
P-811	690 ± 19 B.C.	417 ± 46 B.C.	2367 ± 46	+23.08 ± 4.25	− 9.0	+13.9 ± 4.4
P-785	285 ± 15 B.C.	197 ± 46 B.C.	2147 ± 46	+11.01 ± 4.34	−10.1	+ 0.8 ± 4.5
P-786	A.D. 266 ± 15	A.D. 374 ± 43	1576 ± 43	+13.77 ± 4.22	− 7.1	+ 6.6 ± 4.4
P-787	A.D. 601 ± 27	A.D. 607 ± 66	1357 ± 66	+ 0.78 ± 6.96	− 9.0	− 8.2 ± 7.1
					Average = −8.8 ± 1.2	

by H. N. Michael. *Comment*: specimen cross-dated only in its A.D. range. The following samples from this sec. were processed:

Lab. No.	C[14] Date (A.D.-B.C.)	C[14] Date (B.P.)
P-415	1287 ± 55 B.C.	3237 ± 55
P-429	882 ± 44 B.C.	2832 ± 44
P-427	397 ± 48 B.C.	2347 ± 48
P-428*	A.D. 356 ± 40	1594 ± 40

* The dendrochronologically determined date for this sample is A.D. 345 ± 20.

White Mountains, California "floater" series, Bristlecone Pines

Wood, *Pinus aristata*, from immediate vicinity of Schulman Grove (37° 23' 15" N Lat, 118° 10' 30" W Long), White Mountains, California. *Comment*: the three samples described below are "floaters," i.e., weathered pieces of wood picked up from the forest floor which were thought to be chronological predecessors of some of the present trees and which might prove useful in cross-dating with other samples.

P-603.   Sec. No. P-SW-INY-13b
1952 ± 36
2 B.C.

Wood, *Pinus aristata*, from White Mountains (37° 23' 20" N Lat, 118° 10' 40" W Long), California. Coll. 1962 and subm. by H. N. Michael.

P-604.   Sec. No. P-SW-INY-10 (TRL 62-81b)
2602 ± 35
652 B.C.

Wood, *Pinus aristata*, from White Mountains (37° 23' 05" N Lat, 118° 10' 40" W Long), California. Coll. 1962 by C. W. Ferguson, Univ. of Arizona; subm. by H. N. Michael.

P-605.   Sec. No. P-SW-INY-9 (TRL 62-80b)
3225 ± 47
1275 B.C.

Wood, *Pinus aristata*, from White Mountains (37° 23' 05" N Lat, 118° 10' 40" W Long), California. Coll. 1962 by C. W. Ferguson; subm. by H. N. Michael.

REFERENCES

Date list:
    Arizona IV   Damon, Long, and Sigalove, 1963
Arnold, J. R., and Libby, W. F., 1951, Radiocarbon dates: Science, v. 113, p. 111.
Barker, H., and Mackey, C. J., 1959, British Museum natural radiocarbon measurements I: Am. Jour. Sci. Radioc. Supp., v. 1, p. 83-85.
———— 1961, British Museum natural radiocarbon measurements III; Radiocarbon, v. 3, p. 39-45.
Broecker, W. S., Olson, E.A., and Bird, J., 1959, Radiocarbon measurements on samples of known age: Nature, v. 183, p. 1582-1584.
Craig, H., 1954, Carbon-13 variations in Sequoia rings and the atmosphere: Science, v. 119, p. 141-143.
Damon, P. E., and Long, A., 1962, Arizona radiocarbon dates III: Radiocarbon, v. 4, p. 204-238.
Damon, P. E., 1963, Carbon-14, carbon dioxide and climate: Paper delivered at IUGG 13th Assembly, Berkeley, California.
Damon, P. E., Long, A., and Sigalove, J. J., 1963, Arizona radiocarbon dates IV: Radiocarbon, v. 5, p. 285-286.

Douglass, A. E., 1919, Climatic cycles and tree growth: A study of the annual rings of trees in relation to climatic and solar activity: Carnegie Inst. of Washington pub. 289, v. 1, p. 44-53.
———— 1928, Climatic cycles and tree growth, v. II: A study of the annual rings of trees in relation to climate and solar activity: Carnegie Inst. of Washington pub. 289, v. 2, p. 5-56 and p. 139-158.
Douglass, A. E., 1936, Climatic cycles and tree growth, v. III: A study of cycles: Carnegie Inst. of Washington pub. 289, v. 3, p. 3 and p. 99-105.
———— 1945, Survey of sequoia studies: Tree Ring Bull., v. 11, p. 26-32.
———— 1949, A superior sequoia ring record: Tree-Ring Bull., v. 16, p. 2-6.
Ralph, E. K., 1955, Univ. of Pennsylvania radiocarbon dates I: Science, v. 121, p. 149.
———— 1959, Univ. of Pennsylvania radiocarbon dates III: Am. Jour. Sci. Radioc. Supp., v. 1, p. 47-48.
Schulman, E., 1954, Dendroclimatic changes in semiarid regions: Tree-Ring Bull., v. 20, p. 26-30.
———— 1956, Dendroclimatic changes in semiarid America: Tucson, Univ. of Arizona Press, 142 p.
———— 1958, Bristlecone pine, oldest known living thing: Natl. Geog. Mag., v. 113, p. 355-372.
Suess, H. E., 1955, Radiocarbon concentration in modern wood: Science, v. 122, p. 415-417.
———— 1961, Secular changes in the concentration of atmospheric radiocarbon: *in* Problems related to interplanetary matter, proc. of an informal conference, Highland Park, Illinois: Natl. Acad. of Sci., pub. 845, p. 90-95.
Vries, H. de, 1958, Variation in concentration of radiocarbon with time and location on earth: Proc. Kon. Ned. Akad. van Wetenschappen, ser. B, v. 61, p. 1-9.
Vries, H. de, and Waterbolk, H. T., 1958, Groningen radiocarbon dates III: Science, v. 128, p. 1550-1556.
Vries, H. de Barendsen, G. W., and Waterbolk, H. T., 1958, Groningen radiocarbon dates II: Science, v. 127, p. 129-137.
Willis, E. H., Tauber, H., and Munnich, K. O., 1960, Variations in the atmospheric radiocarbon concentration over the past 1300 years: Am. Jour. Sci. Radioc. Supp., v. 2, p. 1-4.