EDITORIAL STATEMENT TO CONTRIBUTORS

Since its inception, the basic purpose of Radiocarbon has been the publication of compilations of \(^{14}\text{C}\) dates produced by various laboratories. These lists are extremely useful for the dissemination of basic \(^{14}\text{C}\) information.

In recent years, Radiocarbon has also been publishing technical and interpretative articles on all aspects of \(^{14}\text{C}\). The editors and readers agree that this expansion is broadening the scope of the Journal. Next year we will publish the Proceedings of the Eleventh International Radiocarbon Conference which will be held in Seattle, Washington, June 20-26, 1982. We also published the Proceedings of the Tenth International Radiocarbon Conference in 1980.

Another section is added to our regular issues, “Notes and Comments”. Authors are invited to extend discussions or raise pertinent questions to the results of scientific investigations that have appeared on our pages. The section will include short, technical notes to relay information concerning innovative sample preparation procedures. Laboratories may also seek assistance in technical aspects of radiocarbon dating. Book reviews will also be included for special editions.

All correspondence, manuscripts and orders should be sent to the Managing Editor, Radiocarbon, Kline Geology Laboratory, Yale University, 210 Whitney Ave, PO Box 6666, New Haven, Connecticut 06511.

The Editors
NOTICE TO CONTRIBUTORS TO THE PROCEEDINGS OF
THE 11th INTERNATIONAL RADIOCARBON CONFERENCE

The editors of RADIOCARBON announce the publication of the Proceedings of the 11th International Radiocarbon Conference to be held in Seattle, Washington, June 20-26, 1982. The Proceedings will appear in one of the three regular numbers of Volume 25, 1983, and will be offered as part of the subscription for that year.

Rising inflationary costs and cutbacks in government funding for scientific research have seriously affected our plans for publication. We are forced to impose stringent rules on our contributors, and hope they will understand our limitations.

Presentation of a paper at the Conference will not guarantee publication in the Proceedings issue. If a paper is accepted but will not fit into the Proceedings, it will be considered for publication in one of RADIOCARBON’s regular issues. Only those manuscripts submitted in proper form (in three typewritten copies) at the Conference will be considered for publication. Articles may not exceed 10 pages including references, illustrations, and tables. No more than four illustrations per paper are recommended, reducible to no more than two pages. Figures should be reduced as much as possible. Preference will be given to shorter articles. No discussions will be published.

The normal review system will be employed. Style guidelines follow the previous Proceeding issues (Volume 22, Nos. 2 & 3, 1980) or the Instructions to Contributors in each issue of RADIOCARBON.

Because we will be using the photo-offset method of printing for this issue, the author will receive detailed instructions, after review of the paper, as well as standardized sheets for the preparation of final copies. If the author prefers, RADIOCARBON will prepare the final text for a reasonable fee, payable in advance.

Each institution sponsoring research reported in an article will be asked to pay a charge of $80.00 per printed page. Institutions paying such charges will be entitled to 100 free reprints without covers.

We look forward to this project and our renewed associations.

THE EDITORS OF RADIOCARBON
NOTICE TO READERS

**Half life of ¹⁴C.** In accordance with the decision of the Fifth Radiocarbon Dating Conference, Cambridge, 1962, all dates published in this volume (as in previous volumes) are based on the Libby value, 5570 ± 30 yr, for the half life. This decision was reaffirmed at the 9th International Conference on Radiocarbon Dating, Los Angeles/La Jolla, 1976. Because of various uncertainties, when ¹⁴C measurements are expressed as dates in years BP the accuracy of the dates is limited, and refinements that take some but not all uncertainties into account may be misleading. The mean of three recent determinations of the half life, 5730 ± 40 yr, (Nature, v 195, no. 4845, p 984, 1962), is regarded as the best value presently available. Published dates in years BP, can be converted to this basis by multiplying them by 1.03.

**AD/BC Dates.** In accordance with the decision of the Ninth International Radiocarbon Conference, Los Angeles and San Diego, 1976, the designation of AD/BC, obtained by subtracting AD 1950 from conventional BP determinations is discontinued in Radiocarbon.

Authors or submitters may include calendar estimates as a comment, and report these estimates as AD/BC, citing the specific calibration curve used to obtain the estimate.

**Meaning of δ¹⁴C.** In Volume 3, 1961, we endorsed the notation Δ (Lamont VIII, 1961) for geochemical measurements of ¹⁴C activity, corrected for isotopic fractionation in samples and in the NBS oxalic-acid standard. The value of δ¹⁴C that entered the calculation of Δ was defined by reference to Lamont VI, 1959, and was corrected for age. This fact has been lost sight of, by editors as well as by authors, and recent papers have used δ¹⁴C as the observed deviation from the standard. At the New Zealand Radiocarbon Dating Conference it was recommended to use δ¹⁴C only for age-corrected samples. Without an age correction, the value should then be reported as percent of modern relative to 0.95 NBS oxalic acid. (Proceedings 8th Conference on Radiocarbon Dating, Wellington, New Zealand, 1972). The Ninth International Radiocarbon Conference, Los Angeles and San Diego, 1976, recommended that the reference standard, 0.95 times NBS oxalic acid activity, be normalized to δ¹⁴C = −19‰.

In several fields, however, age corrections are not possible. δ¹⁴C and Δ, uncorrected for age, have been used extensively in oceanography, and are an integral part of models and theories. For the present, therefore, we continue the editorial policy of using Δ notations for samples not corrected for age.

**Citations.** A number of radiocarbon dates appear in publications without laboratory citation or reference to published date lists. We ask that laboratories remind submitters and users of radiocarbon dates to include proper citation (laboratory number and date-list citation) in all publications in which radiocarbon dates appear.

**Radiocarbon Measurements: Comprehensive Index, 1950-1965.** This index, covering all published ¹⁴C measurements through Volume 7 of Radiocarbon, and incorporating revisions made by all laboratories has been published. It is available to all subscribers to Radiocarbon at $20.00 US per copy.

**Publication schedule.** Beginning with Volume 15, Radiocarbon has been published in three issues: Winter, Spring, and Summer. Contributors who meet our deadlines will be given priority but publication is not guaranteed in the following issue.

**List of laboratories.** The comprehensive list of laboratories at the end of each volume appears in the third number of each volume. Changes in names or addresses should be reported to the Managing Editor by May 1.

**Index.** All dates appear in index form at the end of the third number of each volume.
INSTRUCTIONS TO CONTRIBUTORS

Manuscripts of radiocarbon papers should follow the recommendations in Suggestions to Authors, 5th ed. All copy (including the bibliography) must be typewritten in double space. Our deadline schedule is:

<table>
<thead>
<tr>
<th>For</th>
<th>Date</th>
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<tbody>
<tr>
<td>Vol 24, No. 3, 1982</td>
<td>May 1, 1982</td>
</tr>
<tr>
<td>Vol 25, No. 1, 1983</td>
<td>Sept 1, 1982</td>
</tr>
<tr>
<td>Vol 25, No. 2, 1983</td>
<td>Jan 1, 1983</td>
</tr>
</tbody>
</table>

General or technical articles should follow the recommendations above and the editorial style of the American Journal of Science or the Proceedings of the Tenth International Radiocarbon Conference. Date lists should follow the format shown in the most recent issue of RADIOCARBON. More detailed instructions are available upon request. Separate mailings have been discontinued.

Illustrations should include explanation of symbols used. Copy that cannot be reproduced cannot be accepted; it should be capable of reduction to not more than 10 by 17.5, all lettering being at least 1/6 inch high after reduction. When necessary, one large map or table can be accepted, if it will not exceed 17.5 inches in width after reduction. Line drawings should be in black India ink on white drawing board, tracing cloth, or coordinate paper printed in blue and should be accompanied by clear ozalids or reduced photographs for use by the reviewers. Photographs should be positive prints. Photostatic and typewritten material cannot be accepted as copy for illustrations. Plates (photographs) and figures (line drawings) should each be numbered consecutively through each article, using arabic numerals. If two photographs form one plate, they are figures A and B of that plate. All measurements should be given in SI (metric units).

Reprints. The minimum reprint order for each article will be 100 copies without cover. No reprints will be furnished free of charge unless page charges are paid. The cost of additional copies will, of course, be greater if the article is accompanied by plates involving unusual expense. Copies will be furnished with a printed cover giving the title, author, volume, page, and year, when specially ordered.

Page charges. Each institution sponsoring research reported in a technical paper or a date list, will be asked to pay a charge of $80.00 per printed page, due when galley proof is returned. Institutions or authors paying such charges will be entitled to 100 free reprints without covers. No charge will be made if the author indicates that his institution is unable to pay them, and payment of page charges on an article will not in any case be a condition for its acceptance.

Back issues and price lists may be obtained from the office of RADIOCARBON.

Missing issues will be replaced without charge only if claim is made within three months (six months for India and Australia) after the publication date. Claim for missing issues will not be honored if absence results from failure by the subscriber to notify the Journal of an address change.

US NATIONAL COMMITTEE FOR INQUA ANNOUNCES
TRAVEL SUPPORT PROGRAM
FOR XI INQUA CONGRESS IN USSR

The US National Committee of the International Union for Quaternary Research (INQUA) is seeking funding for a travel support program to ensure that the United States will be represented by an adequate number of qualified scientists at the XI International Congress of INQUA, to meet in Moscow, USSR, August 1-9, 1982. Funds for this purpose, now being solicited from a number of government agencies and private institutions, will be coordinated by the US National Committee for INQUA. Applications from younger scientists are encouraged.

Applicants for travel grant support should request application forms from Mr W L Petrie, USNC/INQUA, National Academy of Sciences, 2101 Constitution Ave, NW, Washington, DC 20418. Four completed application forms, together with four copies of the abstract of the paper submitted to INQUA should be received by the Academy Office by the end of January, 1982. Grant awards may be made as late as July 15, 1982, depending on funds received. If possible, some advance indication of tentative selections will be communicated earlier.

The purpose of the International Union for Quaternary Research (INQUA) is to bring together, on a world-wide basis, scientists in all disciplines concerned with the history of man's environment, and with the processes by which environment and man's relation to it have evolved. Included among these disciplines are: archaeology, botany, climatology, ecology, geochemistry, geography, geomorphology, geophysics, hydrology, paleontology, limnology, oceanography, palynology, physical anthropology, soil science, tectonophysics, and zoology.

The National Academy of Sciences is the adhering body to INQUA on behalf of the American scientists. The US National Committee, under the chairmanship of Dr R S Hoffmann, University of Kansas, plans US participation in INQUA activities. One of the functions of the Committee is to arrange for travel support of US scientists attending the international congresses of INQUA held at four-year intervals. Further information about the XIth Congress may be obtained by writing to Dr Ismail P Kartashov, Secretary-General, XI INQUA Congress, Geological Institute, USSR Academy of Sciences, Pyzhevsky 7, Moscow 109017, USSR.
CONTENTS

A high-precision calibration of the AD radiocarbon time scale
   Minze Stuiver ................................................................. 1

Charcoal production from wood and cellulose: implications to radiocarbon dates and accelerator target production
   S W Leavitt, D J Donahue, and Austin Long ......................... 27

DATE LISTS

ANU  H A Polach, E G Rhodes, John Head, and John Gower
      ANU Date List IX .......................................................... 36

BS   G Rajagopalan, Vishnu-Mitre, B Sekar, and T K Mandal
     Birbal Sahni Institute Radiocarbon Measurements III ............ 45

UCR  R E Taylor
      UCR Radiocarbon Dates III ........................................... 54

WAT  J C Berry and R J Drinnie
     University of Waterloo Radiocarbon Dates I ...................... 68

WIS  Margaret M Bender, David A Baerreis, Reid A Bryson, and Raymond L Steventon
     University of Wisconsin Radiocarbon Dates XIX .................. 83

BOOK REVIEW

Pieter M Grootes
   Proceedings of the Regional Conference on the Application of Isotope Analyses in Archaeology, Hydrology and Geology; edited by Dušan Srdoč, Bogomil Obelić, and Adela Sliepčević ............ 101
A HIGH-PRECISION CALIBRATION OF THE AD
RADIOCARBON TIME SCALE

MINZE STUIVER

Department of Geological Sciences and Quaternary Research Center
University of Washington, Seattle, Washington 98195

ABSTRACT. A high-precision calibration curve, derived from the radiocarbon age
determinations of 195 decade samples spanning the AD 1 to 1950 interval, is presented.
Though derived for the Pacific Northwest and California, the curve can be used
for a large part of the northern hemisphere. This is proven by the radiocarbon ages
of contemporaneous sample pairs which are, in most instances, identical within the
quoted precision. Two sets of single-year data reveal no evidence for an 11-year cycle
with an amplitude beyond the 12-year measuring precision. This indicates that the
calibration curve is also applicable for single-year 14C samples.

Analysis of the Seattle data sets and comparison with those published by the
Belfast, La Jolla, and Heidelberg laboratories show that the total variability in a
radiocarbon age determination is often larger than that predicted from the quoted
errors. Upper limits for the error multiplier (i.e., the factor with which the quoted
error has to be multiplied to obtain the overall laboratory variability) are estimated
at 1.5 for Seattle and Belfast, 1.1 to 1.4 for La Jolla, and 2.0 for Heidelberg.

The comparisons with Belfast, La Jolla, and Heidelberg also reveal offsets with
the Seattle calibration curve of, respectively, 4, 27 to 55, and 58 years. These offsets
are most likely due to laboratory bias. An improvement of the present calibration
curve by combining data sets from other laboratories will only be possible when offsets
and error multipliers are precisely known through interlaboratory calibration.

INTRODUCTION

The basic information contained in a sample submitted for radiocarbon dating is the remaining present-day 14C activity. A conventional radiocarbon date (Stuiver and Polach, 1977) is derived from this information by comparing the present-day sample activity with an atmospheric 14C level which is assumed to have been constant in the past. Past atmospheric 14C levels have fluctuated, however, and as a result, a radiocarbon age is only an approximation of the historical age expressed in calendar years.

Past atmospheric 14C levels are recorded in trees because carbon, derived from atmospheric carbon dioxide through photosynthesis, is incorporated into their cells. The cell-wall cellulose formed each year during the growing season has a 14C content that reflects the atmospheric 14C content of that year. After fractionation of the isotopes has been taken into account through normalization procedures (Stuiver and Polach, 1977), the original atmospheric 14C level can be calculated from the measured 14C tree-ring activity. This procedure is the reverse of 14C dating because the age of the material is known through dendrochronological means and tree-ring counting, thus enabling the researcher to correct for the 14C decay that took place after the tree ring was formed.

Radiocarbon ages were determined for dendrochronologically dated
wood of each decade of the AD 1 to 1950 interval (where the first “decade”
covers 9 years (AD 1 to 9). For perfectly dendrochronologically dated wood, the number of “dendroyears” is equal to the number of calendar years. When constructing a calibration curve, the years are given as dendroyears in order to indicate the possibility of errors in the tree-ring count. Such errors in the dendro-age are probably no more than a couple of years.

DENDROCHRONOLOGY

The trees used for the radiocarbon age determinations were either Douglas Fir (*Pseudotsuga menziesii*) from the Pacific Northwest, or Sequoia (*Sequoia giganteum*) from California. These trees, with the corresponding dendro-age intervals used for construction of the time-scale calibration curves, are listed in table 1.

The Sequoia trees were cross-dated by H Garfinkel of the University of Washington with the *Sequoia giganteum* master chronology (Douglas, 1919). The Douglas Fir from Vancouver Island (used for the AD 730 to 1320 interval) was collected and cross-dated by M L Parker, L Joza, and P Bramhall of the Western Products Forestry Laboratory in Vancouver, British Columbia. The ages of the rings of the post AD 1320 Douglas Firs were all determined by tree-ring counting. The well-developed rings of these trees were easily counted, and errors in this part of the chronology are unlikely (pers commun, H C Fritts, after inspection of the trees).

The determination of radiocarbon ages of tree sections that overlap in dendro-age provides a check on the chronology. For instance, the four-decade sample pairs of common dendro-ages of the two Sequoia trees (AD 230 to 270 interval) differ in radiocarbon age by 12 ± 22, 18 ± 18, 22 ± 17, and −47 ± 22 years. The mean weighted age difference for the four samples is a negligible 5 radiocarbon years. An even better test is provided by the 14 contemporaneous samples of the youngest portion of the Sequoia chronology, and the oldest part of the Douglas Fir chronology (AD 730 to 940 interval). The decadal samples of the Sequoia chronology yield radiocarbon age $R_s(x)$, where x is the dendro-age. The 14 Douglas Fir radiocarbon ages $R_f$ are compared to the $R_s(x)$ curve by taking the square root of the average quadratic deviation

$$\sqrt{\frac{\sum (R_f(x + \Delta x) - R_s(x))^2}{N}}$$

where N is the number of samples being compared. We calculated this radiocarbon age “difference” by assuming the dendro-ages of the Douglas Fir to be accurate ($\Delta x = 0$), or to be offset by systematic age differences.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Lab code</th>
<th>Location</th>
<th>Dendro-age used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas Fir</td>
<td>C</td>
<td>47°46'N, 124°06'W</td>
<td>AD 1910 - 1950</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>A</td>
<td>47°46'N, 124°06'W</td>
<td>AD 1820 - 1910</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>F</td>
<td>43°07'N, 123°40'W</td>
<td>AD 1510 - 1820</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>R</td>
<td>~47°N, ~122°W</td>
<td>AD 1320 - 1510</td>
</tr>
<tr>
<td>Douglas Fir</td>
<td>S</td>
<td>48°40'N, 128°40'W</td>
<td>AD 730 - 1320</td>
</tr>
<tr>
<td>Sequoia</td>
<td>RC</td>
<td>~36.5°N, 118.5°W</td>
<td>AD 230 - 940</td>
</tr>
<tr>
<td>Sequoia</td>
<td>SR</td>
<td>~36.5°N, 118.5°W</td>
<td>AD 1 - 270</td>
</tr>
</tbody>
</table>
of 1, 2, etc years ($\Delta x = \pm 1, \pm 2 \ldots$). The best fit for the Douglas Fir chronology is obtained for an offset of 4 years only (see fig 1).

The quadratic term (standard deviation of the $R_f$ radiocarbon ages around curve $R_f(x)$) is 22 years minimally (fig 1). This age is, as expected, of the same magnitude as the average quoted precision of 15 years for the radiocarbon ages. For a 2$\sigma$ (30 years) cut-off, the matching of the Sequoia and Douglas Fir dendro-ages is fixed within $-8$ and $+6$ years (see fig 1).

**TECHNIQUE**

A new underground $^{14}$C facility was constructed in 1972, as part of the Quaternary Research Center at the University of Washington. The laboratory uses the code QL (Quaternary Isotope Laboratory) for the reporting of radiocarbon dates. High-precision $^{14}$C tree-ring measurements started in December 1973 with a 4.5-liter copper CO$_2$ gas counter. The background counting rate of this counter is 1.6 cpm, and oxalic acid count rate is 90 cpm (Stuiver, Robinson, and Yang, 1979). Three slightly larger counters (oxalic acid counting rates up to 100 cpm) were added in 1976 and 1977. The data reported here were obtained during several years of measurements with these four counters. A typical precision for a four-day measurement is 15 radiocarbon years.

Additional details of the analytical procedures were described previously (Stuiver, 1978; Stuiver and Quay, 1980; 1981). Cellulose was prepared for 20th century samples, whereas for the older samples, the De Vries wood preparation method was utilized. The error introduced
in the radiocarbon age by using the De Vries method amounts to approximately three radiocarbon years maximally (Stuiver, 1978; Stuiver and Quay, 1980; 1981).

GLOBAL VALIDITY OF CALIBRATION CURVES

A time-scale calibration curve is universally acceptable only if regional (latitudinal and longitudinal) differences in atmospheric $^{14}$C levels can be neglected. Any regional difference in $^{14}$C level, if constant, would introduce systematic age differences between contemporaneous sample pairs. Such postulated age differences can be evaluated by comparing the radiocarbon ages of wood samples of the same dendro-age. A complicating factor in such an investigation is possible biases in the laboratory measurements which also introduce offsets between data sets (Scott, Baxter, and Aitchison, in press).

The age differences of sample pairs measured in the same laboratory will not be influenced by laboratory bias if such bias is constant with time. Most of the comparisons made in this section are for measurements made in a single laboratory (Quaternary Isotope Laboratory) during a seven-year interval. The radiocarbon ages obtained by Pearson of the University of Belfast are also suitable for comparison with the Seattle data because international calibration efforts show the absence of systematic radiocarbon age differences between the Seattle and Belfast laboratories (Scott, Baxter, and Aitchison, in press; Mann, pers commun, 1980).

A comparison of Irish Oak (Pearson, 1980; pers commun, 1981) and Pacific Northwest Douglas Fir radiocarbon ages of 53 sample pairs with dendro-ages between AD 955 and 1840 yields a mean age difference of 2 ± 3 radiocarbon years. The standard deviation in the age difference is based on the quoted errors in the radiocarbon age measurements. Similarly, the mean radiocarbon age difference of the previously discussed 14 sample pairs of identical dendro-age of one of our Sequoias (36.5°N, 118.5°W), and the oldest Douglas Fir (48°40′N, 123°40′W), is 9 ± 5 years.

Additional sample pairs measured in the Quaternary Isotope Laboratory, listed in Stuiver and Quay (1981) yield a mean age difference of 16 ± 9 years for 8 sample pairs between 1829 and 1844 of English Oak (51°48′N, 2°37′W) and Douglas Fir (47°46′N, 124°06′W), of 0 ± 12 years for two samples of Bristlecone Pine (36°N, 118°W) and Douglas Fir (47°N, 122°W), and of 7 ± 15 years for a single pair of Douglas Fir samples from 47°46′N, 124°06′W, and 32°23′N, 110°41′W. For none of these samples do we find differences beyond twice our quoted measuring precision.

We do find a systematic difference of 23 ± 6 radiocarbon years between 12 sample pairs of German Oak and Douglas Fir wood. However, as discussed in the section on interlaboratory time-scale comparisons, we may have been biased in our sample selection towards the largest possible age discrepancies. Further work is needed for a confirmation of the suspected systematic difference (which, if real, also could be caused by errors in the dendrochronology).
The above-cited radiocarbon age differences of contemporaneous sample pairs from different regions are not statistically significant (except for the latter case), proving that regional differences in atmospheric $^{14}$C concentration, if they exist at all, are small. Thus, the time-scale calibration curves can be used at least for a large part of the northern hemisphere. Systematic radiocarbon age differences for southern hemispheric samples still have to be tested in more detail. An upper limit appears to be the 52-year radiocarbon age difference given by Lerman for South American wood (Lerman, Mook, and Vogel, 1970).

**TIME-SCALE CALIBRATION**

The $^{14}$C determinations of 195 decades were used for the construction of the calibration curve (fig 2). Calibration data can be plotted in various ways. A normal orthogonal orientation is given in figures 2 and 3 where dendroyears are directly compared to radiocarbon years. Figure 4 plots the age anomalies versus radiocarbon age. This gives the appearance of a "tilting" of the calibration curve.

For conventional radiocarbon dating, the zero year BP is AD 1950. The dendro-age, $T$, corresponding with the radiocarbon age, $R$, is also given in years BP, and is equal to the number of calendar years before AD 1950 if the tree-ring determination is without error. The correction to be applied to the radiocarbon age is $\Delta t$ years, as listed in the vertical axis of figure 4. Thus, dendro-age BP (calendar years before AD 1950 for perfect tree-ring counts) $= \text{radiocarbon age} + \Delta t$, or $T = R + \Delta t$.

Compared to dendro-ages, the radiocarbon ages are too young for positive $\Delta t$, and too old for negative $\Delta t$. Thus, the radiocarbon ages between 700 and 2000 yr BP are mostly too old, whereas many of the 0 to 700-year BP dates are too young. Multiple intersections of the horizontal (fig 2) or vertical (fig 4) line drawn through a given radiocarbon age result in multiple dendroyear ages.

The standard deviation of each $^{14}$C activity determination is 16 years or less. For parts of the curve, single years were dated and averaged for the decade. Here, the standard deviation in the radiocarbon age approximates four radiocarbon years.

The errors (one standard deviation) given in the figures were derived from the Poisson counting statistics of the sample and standard activities. The effect of additional errors is to enlarge the long-term overall laboratory error. In the following sections, the possibility of a larger error is discussed. It will be shown that the errors in the figures, although probably somewhat underestimated, are a fairly realistic estimate of the overall variability in the measurement.

**AGE CONVERSION**

Because the past atmospheric $^{14}$C levels are variable, it is possible for samples with differing dendro-ages to have identical present-day $^{14}$C activities, and thus, identical conventional radiocarbon ages. This case is illustrated in figure 5 where the $^{14}$C decay of a sample formed in 1690 is followed. The exponential decay of $^{14}$C is, as a first approximation,
Minze Stuiver
A high-precision calibration of the AD radiocarbon time scale

Fig 2A, B. Radiocarbon age versus dendro-age of decadal samples of Pacific Northwest Douglas Fir and California Sequoia. The number of dendroyears was dendrochronologically derived. Dendro-ages are equal to calendar years AD for perfect ring counts. The ordinate gives the conventional radiocarbon age in years BP (before 1950). The vertical error bars are one standard deviation in the measurement, based on counting statistics only. The standard deviation is about equal to the radius of the open circles when error bars are missing. The overall laboratory variability may be up to 1.5 times the given standard deviation (see text).
Fig 3A, B. Radiocarbon age versus dendro-age for the decadal samples plotted in figure 2. The shaded area represents one standard deviation (derived from counting statistics only) on each side of the measured radiocarbon ages.
Fig 4. The correction $\Delta t$ (years) to be applied to a conventional radiocarbon date in order to obtain a dendro-age in years before AD 1950. The center line was constructed from the data in figure 2. The width of the "open" area is twice the standard deviation in the radiocarbon age (one sigma on each side). The standard deviation was derived from counting statistics only.
linear over short time intervals (solid “straight” line in figure 5). The Δ14C values given in the figure are the relative deviations of the measured 14C activities, after correction for age and isotopic fractionation, from the National Bureau of Standards (NBS) oxalic acid 14C activity. The Δ14C contents of samples formed in the years 1729, 1809, and 1927 fall on the 14C decay line as well. Thus, all four samples, each formed in equilibrium with atmospheric Δ14C levels prevalent during their time of formation, will end up with the same 14C deficiency of 16 per mil in the year 1950. This Δ14C level (measured in later years but age-corrected back to the year 1950) is the only available information we have from the 14C counts, and results in a radiocarbon age of 130 years (“AD 1820”) for all four samples. The calculation of a conventional radiocarbon age is based on the 5568-year half-life, which is different from the 5730-year half-life used for the actual decay; hence, the different decay line (dashed) that yields the radiocarbon age when intersecting the assumed constant Δ14C level (the horizontal zero axis in figure 5).

When converting from a radiocarbon age to a dendro-age, the error in the radiocarbon measurement, as illustrated in figure 5, has to be considered also. Whereas the error in the radiocarbon age is normally symmetrical around the age, such is not true for the derived dendro-age. Thus, the 130 ± 32 years BP radiocarbon age is equivalent with dendro-ages of 260 ± 20, 221 + 10 - 14, 141 + 9 - 72, and 23 + 15 - 23 years before 1950.

![Figure 5](image_url)

Fig 5. Atmospheric Δ14C levels, expressed as per mil deviation from NBS oxalic acid standard 14C activity, of the AD 1600 to 1900 period. The heavy line follows the radioactive decay of a sample formed in the year AD 1690. All four samples listed in the figure have, after decay, a 16 per mil 14C deficiency by AD 1950, and thus, the same radiocarbon age. The error (4 per mil, or 32 years for the radiocarbon age) is also illustrated for each sample. The radiocarbon age is the intercept of the Δ14C = 0 axis with the dashed line (see text).
When the $^{14}$C levels decrease parallel to the decay line, the errors are increased, whereas a smaller dendro-age error occurs when the $^{14}$C increases or the change is fast. It is, therefore, possible that a radiocarbon age error decreases when converted into a dendro-age error.

When calculating the dendro-age errors, the uncertainty in the calibration curve should be considered. The following steps are recommended:

1) Estimate the width, in radiocarbon years, of the calibration curve in figure 3 for the age range to be considered. Divide this number by two to obtain the average standard deviation of the calibration curve ($\sigma_{\text{cal}}$).
2) Use figure 2 to convert to a dendro-age, with the sample-age error equal to $\sqrt{\sigma_{\text{sample}}^2 + \sigma_{\text{cal}}^2}$.

For a typical routine radiocarbon age determination with an age error of about 50 years or more, the increase in error due to the uncertainty of the calibration curve is negligible. For instance, for $\sigma_{\text{sample}} = 60$ years and $\sigma_{\text{cal}} = 15$ years, the square root term is 62 years. Of course, the influence of the uncertainty in calibration becomes more important when the quoted radiocarbon age error approaches the average error of the calibration curve.

**SINGLE-YEAR AGES VERSUS DECADE AGES**

The calibration curves are based on radiocarbon ages of decadal samples. Radiocarbon ages of samples grown in single years (such as seeds,
A high-precision calibration of the AD radiocarbon time scale

leaves, etc) could deviate from the calibration curves. Such anomalies could possibly be introduced by the 11-year modulation of the cosmic ray flux, and upper atmospheric $^{14}$C production. Some recent studies of the modulation of 19th and 20th century atmospheric $^{14}$C levels indicate 11-year variability with either about 8 radiocarbon years or 33 radiocarbon years amplitude (Stuiver and Quay, 1981; Burchuladze, Pagava, and Povinec, 1980).

Two sets of single-year data were measured. They span the AD 1510 to 1625 and AD 1820 to 1952 intervals. A few points of the latter interval comprise 2- or 3-year samples (see table in Stuiver and Quay, 1981). The radiocarbon ages of the single-year measurements are given in figures 6 and 7.

As will be shown in the following section, the scatter of the single-year data around the decade average trend is entirely compatible with the scatter expected solely from the quoted errors in the single-year measurements. The curves in figures 2 to 4 can, therefore, also be used for radiocarbon ages of single-year samples. The resulting dendro-ages are equally accurate as those obtained for samples covering an entire decade.

Spectral analysis of the data given in figures 6 and 7 does not yield any evidence for an 11-year cycle with an amplitude beyond the 12-year measuring precision.

Fig 7. Radiocarbon ages of single-year Douglas Fir samples of the AD 1820 to 1954 interval. Vertical bars denote one standard deviation (derived from counting statistics only). The variability of the single-year radiocarbon ages around the decadal means does not exceed the quoted precision (see text).
INTERLABORATORY TIME-SCALE COMPARISONS

To establish the curves in figures 2 to 4 as an absolute radiocarbon age-correction curve, the possibility of a systematic difference in the measured radiocarbon ages has to be explored. Likewise, the contributions of factors other than counting statistics to the overall age variability has to be assessed to estimate the uncertainty in the calibration curves. These two goals can be achieved by interlaboratory comparisons combined with careful analysis of the Seattle data base.

G W Pearson (1980) recently compared the radiocarbon ages of 23 samples of Irish Oak with the previously published AD 1450 to 1950 portion (Stuiver, 1978) of the calibration curve of figure 2. The differences between the Irish and North American results were small, and Pearson concludes that the results show remarkable agreement, especially when considering that the two techniques — liquid scintillation versus gas counting, and two tree species — oak versus pine were used, and the samples were from Ireland and America, respectively (Pearson, 1980).

The complete set of published Belfast determinations (AD 1400 to 1950) and the Seattle results are given in figure 8.

Plots of radiocarbon ages of Seattle Douglas Fir and Sequoia versus La Jolla Bristlecone Pine (Suess, 1978) are given in figures 9A and B. Suess' measured AD samples span the AD 1 to 500 and AD 700 to 1300 intervals. For both intervals there is good agreement between the basic trends, but the Bristlecone Pine radiocarbon ages have a tendency towards

![Fig 8. A comparison of Seattle Douglas Fir (○) and Belfast Oak (×) radiocarbon ages. Vertical bars represent the quoted standard deviation.](image-url)
younger ages. This is also true for the La Jolla German Oak results (Suess, 1978) of the AD 1100 to 1300 interval (fig 9C).

For the AD 250 to 750 interval, Heidelberg German Oak determinations are available (Bruns, Münich, and Becker, 1980). Again we note agreement in trends between the Seattle and Heidelberg data (fig 9D). There is, however, a clear offset in the Heidelberg data towards younger radiocarbon ages. This has been corrected for in figure 9D by adding 58 years to all Heidelberg ages.

The wood used for the radiocarbon age determinations of the Seattle laboratory always covers one decade (for instance, AD 1720 to 1729). Samples from the comparison laboratories, however, may cover a time span of a few years to two decades. For the following statistical analysis, we neglected the difference in time span of each individual sample, and only considered the midpoint in dendro-age.

The Seattle data are evenly spaced with dendro-age midpoints in the middle of each decade. The samples to be compared with the Seattle data set (comparison samples) are treated as follows: If the midpoint dendro-age of the comparison sample differs less than 2.5 years from a Seattle midpoint, the difference, \( x_i \), in radiocarbon age is calculated. If the age difference is more than 2.5 years, the radiocarbon age of the comparison sample is evaluated against a Seattle radiocarbon age obtained by averaging the radiocarbon ages of the two relevant consecutive decade samples. Therefore, the midpoints of the dendro-ages of the Seattle and comparison samples never differ by more than 2.5 years.

With \( N \) being the number of comparisons made, each yielding a radiocarbon age difference of \( x_i \pm \sigma_i \) years, the mean difference, \( \bar{x} \), in radiocarbon ages is given by \( \bar{x} = \frac{\sum x_i W_i}{\sum W_i} \) with \( W_i = \frac{1}{\sigma_i^2} \). The calculated mean radiocarbon age differences are given in table 2.

A very small radiocarbon age difference (4.4 years) is found for the Seattle and published Belfast data set. These laboratories also participated in the calibration of the new NBS oxalic acid standard (Mann, pers commun), and in the Glasgow Calibration Project (Scott, Baxter, and Aitchison, in press). These efforts showed the absence of systematic differences in the Belfast and Seattle radiocarbon ages. Evidently, the Irish Oak and Pacific Northwest Douglas Fir have nearly identical \(^{14}C\) levels (and radiocarbon ages).

Additional Belfast results, back to AD 955, were recently made available for comparison by G W Pearson of the University of Belfast. Again, excellent agreement is obtained, with a mean age difference of 2 ± 3 radiocarbon years between the complete data sets of 53 sample pairs (AD 955 to 1840).

The radiocarbon ages of the Seattle Douglas Fir are, on average, 55 years older than the La Jolla Bristlecone Pine ages. The radiocarbon ages of two Bristlecone Pine samples (AD 1080 to 1090 and AD 1480 to 1490), determined in the Seattle laboratory (Stuiver and Quay, 1981), differ in age from the corresponding Douglas Fir samples by +10 ± 14 and −10 ±
A high-precision calibration of the AD radiocarbon time scale

Fig 9. A) Seattle Sequoia (○) and La Jolla Bristlecone Pine (×) radiocarbon ages for the AD 1 to 650 interval. Vertical bars represent the quoted standard deviations in the age determinations. B) Seattle Sequoia (○), Seattle Douglas Fir (○) and La Jolla Bristlecone Pine (×) radiocarbon ages for the AD 650 to 1250 interval. C) Seattle Douglas Fir (○), and La Jolla German Oak (□ and △) radiocarbon ages between AD 1100 and 1300. D) Seattle Sequoia (○) and Heidelberg Oak (★) radiocarbon ages between AD 200 and 800. All Heidelberg radiocarbon ages were increased by 58 years.
18 years. These intralaboratory results support the idea that systematic age differences between Bristlecone Pine and Douglas Fir are less than the 55 years calculated from the La Jolla-Seattle data sets. The difference is, therefore, more likely to result from a difference in laboratory calibration. A complicating factor in evaluating this difference is the absolute calibration of the La Jolla data. Suess (1978) mentions the possibility of uncertainties in the $^{14}$C contents of the wood standards used prior to 1973. Different portions of this standard, wood from the second half of the 19th century, may have varied in $^{14}$C content by some 7 per mil (Stuiver and Quay, 1981). Such variability could possibly introduce calibration inaccuracies in the La Jolla data set of up to 58 radiocarbon years.

The Seattle Douglas Fir radiocarbon ages average 27 years older than the La Jolla German Oak dates. Similarly, Seattle Sequoia dates average 37 more radiocarbon years than the La Jolla Bristlecone Pine dates. These small differences likewise indicate the probability of laboratory bias.

**Table 2**

$x$ (in years) is the weighted mean of the radiocarbon age differences of contemporaneous sample pairs from two data sets. $\sigma_n$ is the standard deviation in this mean, calculated from the quoted errors in the radiocarbon ages. The second column gives the average error (in years) in the age differences of sample pairs, calculated from the quoted errors. The actual standard deviation $\sigma_{12}$ in the age differences is given in years in the third column. The error multiplier, $k_{12}$, is $\sigma_{12}$ divided by average, $\sigma$. The number of sample pairs used for the calculations is given in the last column.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>$x \pm \sigma_n$</th>
<th>Quoted average $\sigma$ in difference</th>
<th>Actual $\sigma_{12}$</th>
<th>$K_{12}$</th>
<th>AD interval</th>
<th>Number of comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle Douglas Fir</td>
<td>4.4 ± 3.9</td>
<td>18.6</td>
<td>27.4</td>
<td>1.47</td>
<td>1410-1840</td>
<td>23</td>
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<tr>
<td>Belfast Irish Oak</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Seattle Douglas Fir</td>
<td>-27.2 ± 8.7</td>
<td>39.0</td>
<td>43.1</td>
<td>1.11</td>
<td>1120-1296</td>
<td>20</td>
</tr>
<tr>
<td>La Jolla German Oak</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seattle Douglas Fir</td>
<td>-55.3 ± 9.7</td>
<td>38.8</td>
<td>43.3</td>
<td>1.12</td>
<td>1085-1285</td>
<td>16</td>
</tr>
<tr>
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<td></td>
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<td>Pine</td>
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<tr>
<td>Seattle Sequoia</td>
<td>-37.4 ± 7.6</td>
<td>47.6</td>
<td>65.0</td>
<td>1.37</td>
<td>245-895</td>
<td>39</td>
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</tr>
<tr>
<td>Seattle Sequoia</td>
<td>-57.9 ± 2.8</td>
<td>23.0</td>
<td>44.4</td>
<td>1.93</td>
<td>240-760</td>
<td>66</td>
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<tr>
<td>Heidelberg German Oak</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seattle Sequoia</td>
<td>-22.9 ± 5.6</td>
<td>19.4</td>
<td>25.1</td>
<td>1.30</td>
<td>585-765</td>
<td>12</td>
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<tr>
<td>Seattle German Oak</td>
<td></td>
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<tr>
<td>Seattle A</td>
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<td>Seattle B</td>
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A substantial systematic difference exists between the Seattle Sequoia and Heidelberg German Oak radiocarbon ages. In order to investigate the reality of a 58-year offset, we determined the radiocarbon ages of 12 oak samples provided by Bernd Becker of the University of Hohenheim. These samples were selected from parts of the radiocarbon record where the age discrepancies were largest. An age difference of nearly 23 ± 6 radiocarbon years was found between Sequoia and German Oak, both measured in the Seattle laboratory. However, because we were biased in our sample selection towards the largest discrepancies, it is possible that the actual differences between complete series is less than 23 years.

Currently, the Heidelberg laboratory is remeasuring their secondary Heidelberg standard to investigate the possibility of a laboratory offset (Bruns, pers commun, 1981).

The excellent agreement between the Seattle and Belfast results, obtained on different tree species from different longitudes using different counting techniques, confirms the accuracy of the calibration curves. The offsets between the Seattle and La Jolla, and the Seattle and Heidelberg data sets, may be partly, and perhaps completely, due to laboratory bias. When measured in a single laboratory, the only systematic radiocarbon age difference is found between California Sequoia and German Oak, where the age difference amounts to 23 years maximally.

The laboratory error, quoted for a radiocarbon age, should ideally include the individual error resulting from any factor affecting the accuracy of the measurement. The error (one standard deviation) quoted for the Seattle radiocarbon determinations is based on the Poisson counting statistics of the sample and standard activities. The effect of additional errors that are unaccounted for in the quoted precision is to enlarge the overall laboratory error.

Systematic differences ("bias"), as well as increased variability, contribute to the larger error. The increased variability can be expressed relative to the quoted error \( \sigma \). The actual laboratory error \( \sigma_L \) associated with the variability (effective laboratory variability) can be expressed as \( \sigma_L = k \sigma \), where \( k \), the "error multiplier", is a constant.

The Seattle Quaternary Isotope Laboratory recently participated in two calibration projects that provide information on the magnitude of the Seattle error multiplier \( k \), and bias, during the time these intercalibration samples were measured. Six samples were measured as part of the Glasgow intercalibration project of 20 radiocarbon laboratories (Scott, Baxter, and Aitchison, in press). Three different estimates of base lines were made for this study. For the Quaternary Isotope Laboratory, the average bias was 16.7 years (range of 7.4 to 25.1 years) towards older radiocarbon dates. As part of the calibration of new oxalic acid (Mann, pers commun, 1980) we determined the activity ratio of the new oxalic acid versus old oxalic acid. When expressing this ratio as an age, the bias of the Quaternary Isotope Laboratory, relative to the mean for nine laboratories, was less than two years.
For the Glasgow study, the Seattle error multiplier $k_a$ was estimated at 1.7 in two different baseline interpretations (Scott, Baxter, and Aitchison, in press). When combining these results with the two Seattle ratio measurements of the oxalic acid project, we arrive for eight measurements at a $k_a$ value of 1.6. These measurements would indicate an overall laboratory variability 1.6 times larger than the mean quoted error. However, these results were obtained for a small number of samples, and $k_a = 1$ cannot be excluded.

The above intercalibration projects provide valuable information on the order of magnitude of the effective laboratory error. The inherent weakness of these efforts is that they cover only the laboratory conditions encountered during a small fraction of its operating time. The following comparison of time-scale calibration data sets provides information on long-term variability.

When comparing two data sets, the standard deviation in the age difference of contemporaneous samples of identical $^{14}$C content would be $\sqrt{\sigma_1^2 + \sigma_2^2}$ when the mean quoted laboratory errors $\sigma_1$ and $\sigma_2$ are valid. This error can be compared to the standard deviation $\sigma_{12}$ of the differences of the two data sets [variance $\sigma_{12}^2 = \frac{1}{N-1} \Sigma(x_i - \bar{x})^2$] where $N$ is the number of comparisons, $x_i$ the difference in radiocarbon ages of wood samples of the same dendro-age, and $\bar{x}$ the mean age difference between the radiocarbon ages of contemporaneous samples. Ideally, the standard deviation around the mean age difference should be of the same order of magnitude as the mean quoted laboratory error in the difference. The distributions of age differences, around the mean radiocarbon age difference, are given in figure 10. A gaussian distribution (solid line) was fitted to the data using the calculated $\sigma_{12}$. The dashed line gives the calculated distribution based on the quoted laboratory errors. In all instances we find a broadening of the sample distribution. Table 2 gives the measure of broadening through the parameter, $k_{12}$, which is defined through $\sigma_{12} = k_{12} \sqrt{\sigma_1^2 + \sigma_2^2}$.

The larger-than-expected variances in the age differences may be due partly to actual differences in $^{14}$C content of the wood. In the following discussion, we first neglect the contribution to the variance caused by these differences, and ascribe the complete variability to an underestimation of the laboratory error. Through this approach, it is possible to obtain an upper limit for the effective laboratory variability, $k\sigma$.

If the entire increase in variance is ascribed to laboratory variability, the standard deviation of the age differences $\sigma_{12}$ equals $\sqrt{k_1^2 \sigma_1^2 + k_2^2 \sigma_2^2}$. Substitution of the mean quoted errors, $\sigma_1$ and $\sigma_2$, yields a relationship between the error multipliers, $k_1$ and $k_2$. This relationship is plotted in figure 11 for the various data sets.

The horizontal $k_1$ axis in figure 11 refers to the Seattle data whereas the vertical axis represents the possible $k$ values of the comparison laboratories. For a set of 30 comparisons of pairs on contemporaneous samples of different trees, all measured in the Seattle laboratory, we
obtain a $k_3$ value of 1.53 ($\sigma_{11} = k_3\sigma_3\sqrt{2}$, table 2, last row and figure 10). Acceptance of the 1.53 error multiplier for the Seattle laboratory (which is close to the 1.6 derived from the international calibration projects) leads to error multipliers of about 2.0 for Heidelberg, 1.5 for Belfast, and 1.1 to 1.4 for La Jolla. A slightly larger upper limit for the $k$ values of these laboratories is given by the intercepts with the $k_2$ axis (figure 11). Calculated in radiocarbon years, the mean quoted error associated with variability (not bias) should be increased from 12 to 18 years for Seattle, from 17 to 25 years for Belfast, from 21 to about 42 years for Heidelberg, and from 41 to 48 years for La Jolla. Expressed as additive sources of variances, these increases are, for the respective laboratories, equivalent with an additional variance of $13^2$, $18^2$, $36^2$, and $25^2$ radiocarbon years$^2$.

Fig 10. The distribution of radiocarbon age differences of sample pairs of the same dendro-age. The dashed curve gives the Gaussian distribution derived from the quoted standard deviations in the radiocarbon ages; the solid line gives the actual distribution. Narrowest distributions are derived for data sets with the highest precision. The frequency distributions were derived from data given in figures 8 and 9, except for Seattle A versus B which is an intra-lab comparison.
There are also factors outside the realm of the radiocarbon laboratory that may account for differences in reported radiocarbon ages of wood of the “same” dendro-age. Errors in the dendrochronologic evaluation of the tree rings, yielding an incorrect AD age, invalidate the premise of wood of equal age. Such errors probably contribute mostly to offsets between data sets. Once the correct AD age has been obtained, the wood cellulose $^{14}$C content of different trees could possibly differ, and thus, provide different radiocarbon ages. Such differences could be due to variable regional differences in atmospheric $^{14}$CO$_2$ levels, or perhaps to a very limited extent of variable root $^{14}$CO$_2$ uptake in regions with a limestone soil CO$_2$ component. Variable levels of recycled CO$_2$ of biospheric origin, different in $^{14}$C content from the atmospheric level, may also introduce anomalies.

In the previous discussion, we arrived at a maximum estimate of the error multiplier by neglecting the $^{14}$C content variability of wood series of the same dendro-age (but not necessarily the same AD age). By taking the $^{14}$C differences (standard deviation $\sigma_{tr}$) of the wood analyzed by different laboratories into account, as well as the effective laboratory errors, the following expression is obtained:

$$\sigma_{12}^2 = k_1^2 \sigma_1^2 + k_2^2 \sigma_2^2 + \sigma_{tr}^2$$

For the comparison of age series of samples of different trees of the same dendro-age within a single laboratory we obtain:

$$\sigma_{11}^2 = 2k_1^2 \sigma_1^2 + \sigma_{tr}^2.$$
As discussed, $\sigma_{11} = 27.7$ years for a series of 30 Seattle samples (table 2). A lower limit for the Seattle error multiplier, $k_s$, would be 1.0. Actually, the choice of 1.0 appears a not-too-optimistic estimate when considering the single-year data sets discussed previously (figs 6 and 7). The variance of the single-year data around the decade averaged trend (fig 12) appears to be entirely compatible with the quoted laboratory error, $\sigma_l$. This conclusion is valid when considering the scatter of the single-year data around ten-year averages, thus creating a “stepped” curve, as well as when considering the scatter around a “continuous” curve through the decade averages. Because the variance of the single-year data around these trends is not any larger than the $\sigma_l^2$ variance, the quoted precision, $\sigma_l$, has, at least for the single-year data, to be close to the effective laboratory error. Therefore, an error multiplier, $k_s = 1.0$, appears possible.

The use of $\sigma_{11} = 27.7$ years, $k_s = 1$, and $\sigma_l = 12.9$ years yields a $\sigma_{tr}$ of 20.8 years.

Perhaps a $\sigma_{tr}$ value of 20 years is valid for other tree age comparisons as well. In that instance, we arrive at error multipliers for Belfast, Heidelberg, and La Jolla of, respectively, 1.0, 1.7, and 1.0 to 1.3. These error multipliers are smaller than those derived earlier because we now have assigned a portion of the variance between data sets to the tree $^{14}C$ levels, and not solely to the laboratory measurements.

Although a $k_s = 1.0$ value is likely for the Seattle single-year measurements, such a low error multiplier is not necessarily valid for all our decade samples. The 20-year value for $\sigma_{tr}$ should, therefore, be considered an upper limit only.

**CONCLUSIONS**

The calibration curves of figures 2 to 4 are an improvement upon existing calibration curves because high-precision radiocarbon ages are given for each decade. The conversion for the current millennium should be considered as the most reliable because this part of the curve has been confirmed by the data of the Belfast laboratory (Pearson, 1980; pers commun, 1981).

The interlaboratory comparison with La Jolla and Heidelberg yields offsets between data sets. These offsets (up to 58 radiocarbon years) are most likely due to laboratory bias. A “real” offset, of perhaps 23 years, appears possible for the California Sequoia and German Oak radiocarbon ages. This offset may be due to differences in wood $^{14}C$ content, but may also be due to errors in the dendro-age determinations.

The variability in the radiocarbon ages of different laboratories leads to certain estimates of the error multiplier, i.e, the constant with which the quoted laboratory precision has to be multiplied to obtain the overall laboratory variability. For the Seattle, Belfast, La Jolla, and Heidelberg laboratories, the error multipliers are, respectively, in the range of 1.0 to 1.53, 1.0 to 1.5, 1.1 to 1.4, and 1.7 to 2.0.

A complication in comparing radiocarbon age errors is the possible difference in $^{14}C$ content of wood samples of the same dendro-age. The influence of these $^{14}C$ differences on calibration curves appears limited
Fig 12. The distribution of the differences in radiocarbon age of single-year wood samples and decadal means. All age differences were obtained by comparing with the curve drawn through the decade averages. The dashed line is the expected Gaussian distribution calculated from the quoted radiocarbon age standard deviations (which are given in figures 6 and 7). The solid Gaussian curve is the actual distribution. The deviations from the decadal averages, as shown in the bottom figure, demonstrate the lack of a measurable 11-year cycle in the single-year radiocarbon ages.
because offsets are unlikely, and because the variability in 14C level of contemporaneous wood ($\sigma_{tr}$) is, at the most, 20 years and probably less.

Data averaging would not improve the calibration curves of figures 2 to 4. For such averaging, the magnitude of the laboratory bias has to be established first through improved interlaboratory calibration. Assignment to each laboratory of a realistic error multiplier, and perhaps an estimate of $\sigma_{tr}$, is also needed. A first attempt in averaging will be made by combining the Seattle data with those of the Belfast laboratory when the latter laboratory has finished the calibration of the last 2000 years of the Irish chronology.

Evidently, errors other than Poisson counting statistics increase the variability of the 14C measurements. However, their influence is moderate. When the entire laboratory variability is taken into account, the uncertainty region of the calibration curves (one standard deviation) increases from about 12 years to a maximum of 18 years.

ACKNOWLEDGMENTS

Many members of the Quaternary Isotope Laboratory contributed to this research. P M Grootes critically read the manuscript, R L Burk collected several of the tree sections, and P J Reimer handled most of the statistical calculations. For many years, P J Wilkinson dedicated much time to the high-precision measurements.

The Vancouver Island Douglas Fir was collected and cross-dated by M I. Parker, L. Goza, and P Bramhall of the Western Products Forestry Laboratory in Vancouver, British Columbia. The cross-check samples of German Oak were provided by Bernd Becker of the University of Hohenheim (Stuttgart), West Germany. The Bristlecone Pine samples were provided by C W Ferguson of the University of Arizona, Tucson.

The study of the relationship between atmospheric 14C variations and climatic change, supported by National Science Foundation grant ATM-8022240 of the Climate Dynamics Program, resulted in many of the radiocarbon measurements reported in this paper. The interpretive portion and some of the earlier measurements were supported by the NSF geochemistry program, Grant EAR-8018141.

REFERENCES


CHARCOAL PRODUCTION FROM WOOD AND CELLULOSE:
IMPLICATIONS TO RADIOCARBON DATES AND
ACCELERATOR TARGET PRODUCTION

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ABSTRACT. Radiocarbon dating with accelerators requires the manufacture of suitable carbon targets. Carbon yield and 13C fractionation were investigated for the simple and direct pyrolysis of wood and cellulose to charcoal. Under continuous vacuum removal of evolved volatiles, carbon yields of 35 to 40% and 8°C fractionation of −2.5% were observed in the pyrolysis of wood to charcoal, whereas yields of 30% and fractionation of −0.8% were obtained in the pyrolysis of cellulose to charcoal. Yield and fractionation leveled off at temperatures above 500°C. Yields and fractionations were also measured for pyrolysis of wood and cellulose in a continuously-flowing argon atmosphere. Yields were higher and fractionations smaller than for the corresponding vacuum cases. For cellulose sealed in evacuated glass tubes and pyrolyzed at 550 to 600°C, carbon yields greater than 60% and fractionation of about −0.5% were observed. Yields increased and fractionation tended to decrease as the ratio of tube volume/mass of cellulose decreased, i.e., as the pressure increased. Reheating of this charcoal under continuous vacuum pumping revealed no loss of mass and no alteration of carbon isotopic composition. Fractionation measurements were additionally performed on wood and the charcoal produced from burning in a fireplace, conditions approximating the “natural” production of charcoal. Despite the large potential fractionation suggested in the wood pyrolysis experiments, charcoal produced in the fireplace showed very small or no fractionation.

INTRODUCTION

The advent of radiocarbon dating by tandem accelerator mass spectrometry (TAMS) (Bennet et al, 1977) has greatly enhanced prospects for determining ages of samples too small to date with conventional gas-proportional or liquid-scintillation counting techniques. The anticipated procedure for accelerator dating will require extraction of carbon from the sample and production of a solid target which is most easily accommodated in a sputter-type ion source. Two important requirements of this method are: 1) maximizing the recovery and minimizing the isotopic fractionation during the conversion of the sample to the carbon target, and 2) obtaining satisfactory C− beam strength from the target. Methods of producing such targets can involve fairly elaborate chemical procedures, as in the cracking of acetylene to graphite on a hot filament (Hedges, Wand, and White, 1980). In this method, the cracking is only the final step and must be preceded by sample conversion to CO2, reaction of the CO2 with molten lithium to produce Li2C2, and finally, reaction of the cold Li2C2 with water to generate acetylene.

We have conducted a series of experiments to study the carbon yield and 13C fractionation during the direct pyrolysis of wood and cellulose samples to charcoal in order to ascertain if such minimal treatment could yield carbon satisfactory for sputter ion source targets. Although recent tests of charcoal accelerator targets (Hedges, Wand, and White, 1980) revealed low C− beam strengths relative to graphite, the target quality of charcoal carbon may possibly be upgraded by incorporation as a metal carbide or perhaps through the recently reported graphitiza-

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tion of charcoal with chromium oxide catalysts (Mochida, Ohtsubo, and Takeshita, 1980). Results from the present experiments also revealed that additional errors may be introduced to radiocarbon dates of anthropologic charcoal samples, eg, from a campfire or hearth, if a δ13C correction for fractionation (Stuiver and Polach, 1977) is not applied.

MATERIALS AND METHODS

Wood was obtained from branches of a juniper tree (Juniperus monosperma) on the grounds of the University of Arizona. After bark removal, the sample was ground in a mill fine enough to pass through a 20 mesh screen. From one half of the ground wood, oils and resins were removed in a soxhlet extraction apparatus with toluene and ethanol solvents. One half of this resin-extracted wood was then treated with an acidified, heated sodium chloride solution to isolate cellulose (holocellulose) in a procedure modified from that of Green (1963). Another similarly prepared cellulose sample was obtained from 700-year-old wood of white fir (Abies concolor) from Casa Grande, Arizona.

In the first set of experiments, ca 28 mg of sample, inserted in pyrex bulbs plugged with glass wool, was heated in a continuously-pumped vacuum furnace. (These will be referred to as our “regular” runs.) A thermocouple vacuum gauge allowed monitoring of degassing during heating. Additionally, two samples were pyrolyzed in a flowing argon atmosphere. Most samples were heated for 35 minutes to various temperatures from 290° to 700° (see table 1). Heating began from room temperature and normally attained the pre-set temperature within 5 minutes.

Charcoal was weighed after pyrolysis in order to determine the yield. To test for fractionation, the wood and charcoal samples were first burned to CO2 (measurements indicate complete conversion to CO2) in a micro-combustion system. The carbon isotopic composition was then measured as δ13C* in ‰ units relative to the PDB standard, on a Micro-mass 602C mass spectrometer. Analytical precision (combustion and measurement) is estimated to be ±0.1‰.

The second set of experiments, also summarized in table 1, was an effort to determine if pyrolysis of sealed samples would yield more carbon than that recovered in the regular vacuum runs. White fir cellulose samples were sealed in pyrex tubes under a vacuum and heated for 35 minutes at 550 to 600°C.

Lastly, to explore the “natural” production of charcoal in fires, the charcoal and adjacent wood from logs (one orange tree, the other unidentified) burned in a household fireplace were collected and analyzed for 13C fractionation. Also, a portion of wood from the 1979 growth ring of a juniper tree (Juniperus deppeana) from Prescott, Arizona, was placed into the fireplace fire until it was wholly charcoal (less than 5 minutes). A sample of original raw wood was retained for δ13C measurement to determine fractionation.

\[ *\delta^{13}C = \left\{ \frac{({}^{13}C/{}^{12}C)_{\text{sample}}}{({}^{13}C/{}^{12}C)_{\text{standard}}} - 1 \right\} \times 1000 \]
Charcoal production from wood and cellulose

Table 1

Summary of pyrolysis results (masses and $\delta^{13}C$ rounded to nearest tenth)

Vacuum pyrolysis of juniper wood

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temp/time</th>
<th>Initial wood mass</th>
<th>Final charcoal mass</th>
<th>Carbon yield</th>
<th>$\delta^{13}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-1</td>
<td>300°C/35 min</td>
<td>26.9 mg</td>
<td>4.0 mg</td>
<td>37%</td>
<td>-25.0%</td>
</tr>
<tr>
<td>CH-2</td>
<td>400/35</td>
<td>27.7</td>
<td>4.3</td>
<td>39</td>
<td>-25.2</td>
</tr>
<tr>
<td>CH-3</td>
<td>200/35</td>
<td>26.6</td>
<td>7.2</td>
<td>67</td>
<td>-24.2</td>
</tr>
<tr>
<td>CH-4</td>
<td>500/35</td>
<td>27.5</td>
<td>3.7</td>
<td>33</td>
<td>-25.2</td>
</tr>
<tr>
<td>CH-5</td>
<td>300/60</td>
<td>26.9</td>
<td>4.7</td>
<td>44</td>
<td>-24.9</td>
</tr>
<tr>
<td>CH-6</td>
<td>200/30;500/35</td>
<td>26.5</td>
<td>3.8</td>
<td>35</td>
<td>-25.0</td>
</tr>
<tr>
<td>CH-7</td>
<td>100/15;200/15;500/30</td>
<td>26.5</td>
<td>4.2</td>
<td>40</td>
<td>-25.0</td>
</tr>
<tr>
<td>CH-8</td>
<td>75/1 week; 400/35</td>
<td>26.3</td>
<td>4.0</td>
<td>38</td>
<td>-25.1</td>
</tr>
<tr>
<td>CH-20*</td>
<td>500/35</td>
<td>26.8</td>
<td>4.5</td>
<td>42</td>
<td>-25.1</td>
</tr>
<tr>
<td>CH-29**</td>
<td>500/35;650/45</td>
<td>27.3</td>
<td>6.5</td>
<td>60</td>
<td>-24.1</td>
</tr>
</tbody>
</table>

* Resin-extracted wood  
** Argon flow, no pumping

Vacuum pyrolysis of white fir cellulose

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temp/time</th>
<th>Initial cellulose mass</th>
<th>Final charcoal mass</th>
<th>Carbon yield</th>
<th>$\delta^{13}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-9</td>
<td>300°C/35 min</td>
<td>29.2 mg</td>
<td>5.3 mg</td>
<td>41%</td>
<td>-23.9%</td>
</tr>
<tr>
<td>CH-10</td>
<td>400/35</td>
<td>28.0</td>
<td>3.8</td>
<td>30</td>
<td>-24.0</td>
</tr>
<tr>
<td>CH-11</td>
<td>500/35</td>
<td>27.8</td>
<td>3.6</td>
<td>30</td>
<td>-23.9</td>
</tr>
<tr>
<td>CH-12</td>
<td>600/35</td>
<td>28.2</td>
<td>2.9</td>
<td>23</td>
<td>-24.0</td>
</tr>
<tr>
<td>CH-13</td>
<td>200/35</td>
<td>28.4</td>
<td>12.1</td>
<td>97</td>
<td>-23.4</td>
</tr>
<tr>
<td>CH-14</td>
<td>250/35</td>
<td>28.3</td>
<td>4.2</td>
<td>34</td>
<td>-23.6</td>
</tr>
<tr>
<td>CH-19*</td>
<td>600/35</td>
<td>28.6</td>
<td>4.5</td>
<td>36</td>
<td>-23.8</td>
</tr>
<tr>
<td>CH-18**</td>
<td>600/35</td>
<td>28.8</td>
<td>4.4</td>
<td>35</td>
<td>-21.2</td>
</tr>
<tr>
<td>CH-21**</td>
<td>600/35</td>
<td>28.5</td>
<td>3.9</td>
<td>31</td>
<td>-21.6</td>
</tr>
</tbody>
</table>

* Argon flow, no pumping  
** Cellulose from juniper wood

Pyrolysis of white fir cellulose in evacuated sealed tubes (t=35m)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temp</th>
<th>Inside volume</th>
<th>Initial cellulose mass</th>
<th>Final charcoal mass</th>
<th>Carbon yield</th>
<th>$\delta^{13}C$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-24</td>
<td>600°C</td>
<td>3.7 cm³</td>
<td>10.6 mg</td>
<td>2.1 mg</td>
<td>46%</td>
<td>-23.9%</td>
</tr>
<tr>
<td>CH-25</td>
<td>600</td>
<td>3.7</td>
<td>10.0</td>
<td>1.9</td>
<td>43</td>
<td>-23.8</td>
</tr>
<tr>
<td>CH-26</td>
<td>600</td>
<td>4.5</td>
<td>20.9</td>
<td>3.8</td>
<td>41</td>
<td>-23.8</td>
</tr>
<tr>
<td>CH-27</td>
<td>600</td>
<td>2.3</td>
<td>10.8</td>
<td>2.7</td>
<td>57</td>
<td>-23.6</td>
</tr>
<tr>
<td>CH-28</td>
<td>600</td>
<td>1.8</td>
<td>10.9</td>
<td>3.2</td>
<td>71</td>
<td>-23.6</td>
</tr>
<tr>
<td>CH-31</td>
<td>600</td>
<td>1.8</td>
<td>10.4</td>
<td>4.2</td>
<td>97</td>
<td>-23.5</td>
</tr>
<tr>
<td>CH-33</td>
<td>550</td>
<td>0.9</td>
<td>9.7</td>
<td>4.2</td>
<td>62</td>
<td>-23.6</td>
</tr>
<tr>
<td>CH-42</td>
<td>550</td>
<td>1.1</td>
<td>10.4</td>
<td>2.8</td>
<td>59</td>
<td>Not measured</td>
</tr>
<tr>
<td>CH-43</td>
<td>550</td>
<td>1.1</td>
<td>9.9</td>
<td>2.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
RESULTS

Pyrolysis of whole wood in a vacuum

Figure 1 (see also table 1) depicts isotopic composition of charcoal produced from the juniper branches (δ13Cwood = −22.6‰). The carbon yield (%e) calculations are based on the assumptions that charcoal formed during a pyrolysis run is all carbon, and that dry wood has the general composition CH₂O so that ca 40% of the weight of the original wood is carbon. The product from the run at 200°C (CH-3) was visibly brownish, suggesting that the first assumption does not hold at this temperature and, thus, the calculated yield at 200°C is certainly overestimated. Carbon yield appears to have greatest validity at temperatures above 300°C at which yields level off at 35 to 40% and carbonization has apparently gone to completion.

Pre-drying of the wood at 75°C (Sample CH-8) for one week and then pyrolyzing at 400°C yielded a point (figure 1) essentially identical to the regular run at 400°C (sample CH-2). A run was conducted at 300°C (sample CH-5) for 60 minutes to determine if pyrolysis had been carried out to its fullest extent in the 35-minute runs. The δ13C result (figure 1) was nearly identical to the regular run at 300°C (CH-1) and the yield was within 6%. Two other tests (CH-6 and CH-7, not illustrated) brought the temperature up in steps to 500°C during the runs. Neither of these runs (table 1) appears significantly different from the regular run at 500°C depicted in figure 1 (CH-4).

Fig. 1. Carbon yield (▲) and isotopic composition (‰) of charcoal produced by pyrolyzing juniper wood under a continuously-pumping vacuum, as a function of temperature. δ13C of the whole wood is −22.6‰; δ13C of cellulose from this wood is ca −20.7‰.
Resin-extracted wood was pyrolyzed at 500°C (CH-20). Toluene/ethanol extraction removed only ca 5% of the weight of the whole wood with the result that neither the δ¹³C of this wood nor its charcoal differed significantly from the normal runs with whole wood at 500°C (CH-4). Some woods may have a higher proportion of extractives (e.g., conifer heartwoods lose ca 10% upon extraction), components which tend to have more negative δ¹³C values (Park and Epstein, 1961). Consequently, the δ¹³C of such woods may be more affected by extraction.

A test was made to see if yields could be increased if argon was circulated over the sample during heating instead of the continuous vacuum pumping employed in the regular runs. Results from one run of whole wood in argon (CH-29, table 1) indicate increased yield and decreased fractionation relative to the regular run at 500°C.

Pyrolysis of cellulose in a vacuum

For radiocarbon work with wood materials, it has been shown (Long et al., 1979) that the cellulose component (typically 40 to 50% of the weight of whole wood) has the greatest likelihood of retaining an isotopic composition representative of the year of growth. Therefore, we generated the pyrolytic charcoal curve in figure 2 from white fir cellulose (δ¹³C = -23.1‰). Again, the δ¹³C curve for charcoal levels off above 300°C, but the fractionation between the original cellulose and charcoal is only ca -0.8‰. Carbon yields were determined with the assumption that 44% of the original cellulose (formula (C₆H₁₀O₅)n) was carbon. The

![Fig 2. Carbon yield (▲) and isotopic composition (×) of charcoal produced by pyrolyzing white-fir cellulose under a continuously-pumping vacuum, as a function of temperature. δ¹³C of this white-fir cellulose is ca -23.1‰.](image)
yield is similar to that observed for the whole wood runs, although the yield curve may not have fully leveled off by 600°C. The “high” yield at 200°C (CH-13) is due to incomplete carbonization as indicated by the brownish color of the end product. A test in which argon was continuously run through the system during pyrolysis at 600°C (CH-19) again yielded charcoal with a higher yield (36%) and somewhat less fractionation ($\delta^{13}C = -23.8\%$), although this decrease in fractionation relative to the regular run at 600°C may be within the errors of the measurements.

After this curve was generated and it became apparent that the full fractionation between cellulose and charcoal for this process could be determined at temperatures above 300°C, cellulose from the juniper wood used to develop figure 1 was pyrolyzed to determined if fractionation was reproducible among species. Charcoal from two pyrolysis runs (CH-18,21) on this juniper wood cellulose at 600°C was isotopically lighter than the cellulose by an average of 0.6% as compared to a 0.8% difference between white fir cellulose and its charcoal (figure 2). Thus, the fractionation seen between this juniper wood cellulose and its charcoal is the same order of magnitude as for white fir cellulose and its pyrolysis charcoal.

**Pyrolysis of cellulose in sealed tubes**

In an effort to increase yield, cellulose was heated to 550 to 600°C for 35 minutes in evacuated, sealed pyrex tubes of various sizes. Details of these runs including $\delta^{13}C$ of the product charcoals are summarized in table 1. Because smaller tube volumes were observed to puff out at 600°C (above annealing temperature of glass), tubes smaller than 1.8 cm$^3$ were pyrolyzed at 550°C. Further, both annealing after sealing the tubes and raising the temperature slowly to 550°C were helpful in preventing the glass from exploding during the initial stages of heating. For samples of approximately equal masses, a general trend of increasing carbon yield and decreasing fractionation was seen with decreasing volume. In order to include all the results into a single curve, regardless of initial cellulose mass, yield and $\delta^{13}C$ were plotted versus the ratio of volume of the sealed tube to mass of the cellulose (figure 3). This volume/mass ratio for an ideal gas is inversely proportional to pressure so that on the abscissa in figure 3, pressure would increase toward the left.

Carbon yields by this method (figure 3, table 1) are significantly increased relative to pyrolysis of cellulose under continuous vacuum pumping. The anomalously high yield of CH-33 is somewhat suspect because we were unable to reproduce it. For these higher yields the fractionation between cellulose and charcoal was ca $-0.4$ to $-0.5\%$. This is less than the $-0.8\%$ cellulose-to-charcoal fractionation seen in the regular pyrolysis runs at 600°C (figure 2).

A sample of charcoal produced by this method was placed in a glass bulb, reheated to 550°C for one hour under continuous vacuum pumping, and showed no weight loss. Further, it had $\delta^{13}C = -25.5\%$, essentially identical to charcoal from other sealed-tube runs.
Fire experiments

To examine fractionation during charcoal production under fire conditions, wood from a fireplace was examined. In the first test, partially burned wood of an unidentified species was removed from the fireplace. Isotopic analysis of charcoal and wood directly adjacent to it yielded identical \( \delta^{13}C \) values of \(-23.2\%\). Wood from an orange tree was then burned in the fireplace and the charcoal produced was found to have the same \( \delta^{13}C \) as the adjacent wood, \(-23.4\%\).

In a controlled experiment, one subsample of wood from the 1979 growth ring of a juniper tree was placed into a fireplace fire, while another subsample was not exposed to the fire. Several isotopic analyses were conducted and revealed the charcoal to be lighter than the wood by 0.3\% \((-22.8 \text{ vs } -23.1\%\)). This fractionation is much less than that seen in the regular pyrolysis experiments with whole wood and similar to that observed in pyrolysis of cellulose.

DISCUSSION AND CONCLUSIONS

Based on the results of our experiments, several conclusions can be drawn which are discussed below.

![Graph showing carbon yield and isotopic composition of charcoal produced by pyrolyzing white-fir cellulose in sealed, evacuated tubes, as a function of tube volume/cellulose mass. Pressure would increase to the left on the abscissa.](image)
1) In the direct pyrolysis of wood to charcoal in a vacuum, yields 
\[ \left( \frac{\text{Mass of Product Charcoal}}{\text{Mass of Carbon in Original Wood}} \right) \] of between 25 and 40% were obtained at temperatures above 300°C in runs of 35 minutes. In this process, \(^{13}\text{C}\) fractionation as determined from the difference between the \(\delta^{13}\text{C}\) of the wood and the charcoal amounted to ca. \(-2.5\%\).

2) \(^{13}\text{C}\) fractionation during the "natural" production of charcoal was determined from several woods burned in a fireplace. Fractionation was quite small and near or within the uncertainties of the measurements (ca. 0.1%).

The primary difference between our pyrolysis of wood and the "natural" production is the pumping away of vapors as they are evolved during pyrolysis. In the fireplace fire, the wood is bathed in flame and a gaseous atmosphere (\(\text{CO}_2\), \(\text{CO}\), \(\text{H}_2\text{O}\), \(\text{O}_2\) and hydrocarbons). Other differences may include temperature, surface area (ground samples in pyrolysis, large pieces in fireplace), and the possibility of heat and/or smoke alteration of wood adjacent to the charcoal which was taken as the "raw" wood.

3) Pyrolysis of cellulose to charcoal in a vacuum or in a circulating argon atmosphere resulted in yields 
\[ \left( \frac{\text{Mass of Product Charcoal}}{\text{Mass of Carbon in Original Cellulose}} \right) \] of 25 to 40% in the 35-minute runs at temperatures above 300°C. \(^{13}\text{C}\) fractionation of \(-0.6\) to \(-0.8\%\) was observed.

4) Experiments on the pyrolysis of cellulose to charcoal in sealed, evacuated tubes indicate that the carbon yields can be increased as the ratio of \(\frac{\text{Inside Tube Volume}}{\text{Initial Mass of Cellulose}}\) is decreased, \(ie\), as the pressure is increased. Yields of 60% and higher were obtained at temperatures of 550 to 600°C. Fractionation in these tubes, typically ca. \(-0.5\%\), shows evidence of decreasing with increasing pressure. Later heating of this charcoal under vacuum pumping produced no weight loss and no alteration of its isotopic composition.

5) In all of the experiments, the observed fractionation was negative, \(ie\), the charcoal was lighter than the original material. For the wood pyrolysis, this fractionation was especially pronounced. This negative fractionation for \(^{13}\text{C}\) occurs despite several processes which should make the charcoal product "heavier" (enriched in \(^{13}\text{C}\)). These include, a) the expected early weight losses during heating which should include large contributions from components of relatively high volatility such as oils and resins, compounds which tend to be depleted in \(^{12}\text{C}\) relative to compounds such as cellulose (Park and Epstein, 1961); b) for specific organic compounds, molecules enriched in \(^{12}\text{C}\) would have higher vapor pressures and, hence, enrichment of the residual material in \(^{13}\text{C}\); c) the higher zero-point energies of \(^{12}\text{C}\) bonds would result in greater ease of breaking during pyrolysis and enhance \(^{12}\text{C}\) loss.

The fractionation observed is, however, in the direction expected for isotopic equilibrium between graphite and carbon dioxide (Bottinga,
1969), if CO₂ was one of the predominant gases in the sealed pyrolysis tubes. A quantitative prediction of equilibrium isotopic compositions in the experimental tubes is not possible due to, a) the lack of fractionation factor data for all gases probably involved, and b) the probability of significant amounts of thermodynamically unstable gases.

6) The ¹³C fractionation of $-2.5\%$ in wood pyrolysis in a vacuum would imply a ¹⁴C fractionation (Craig, 1954) of ca $-0.5\%$, equivalent to an additional error of ca 40 years on a charcoal date not corrected by stable carbon isotope analysis. The smaller ¹³C fractionation observed for cellulose pyrolysis implies an age error of ca 10 years for uncorrected dates. Despite the minimal fractionation seen in the production of “natural” charcoal (fireplace), perhaps representative of the processes which produce most charcoal of use to anthropologists, our vacuum pyrolysis of wood reveals a potential for substantial fractionation in “natural” samples and underscores the importance of normalization of ¹⁴C activities and ages to $\delta^{13}C = -25\%$ as recommended by Stuiver and Polach (1977).

7) Overall, charcoal is attractive for carbon accelerator targets because of its relative ease of preparation from wood or cellulose compared to some of the other methods of carbon production. Additionally, fractionation is small relative to the expected precision of accelerator measurements and is reproducible. The yields are high relative to some of the other methods.

ACKNOWLEDGMENT

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REFERENCES


ANU RADIOCARBON DATE LIST IX

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Compiled by Stella Wilkie

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AGE STRUCTURE OF HOLOCENE COASTAL SEDIMENTS: GULF OF CARPENTARIA

During the last seven years, there has been a concerted effort in eastern Australia to obtain \(^{14}C\) ages from detrital shell samples of prograded sand barriers composed of beach ridges and chenier deposits (Cook and Polach, 1973; Cook and Mayo, 1977; Thom, Polach, and Bowman, 1978; Thom et al, 1981). These ages were used to establish the age sequence of deposition and rates of progradation. This date list is the result of work in two areas of the Gulf of Carpentaria, Queensland, Australia, where 57 shell samples were collected for \(^{14}C\) dating. For details of this research, see Rhodes et al (1980).

Ages are reported as \(^{14}C\) yr BP, ie, corrected for isotopic fractionation and based on the Libby half-life of 5568 yr. The modern reference standard was ANU sucrose, secondary international calibration standard, correlated with 95\% of \(^{14}C\) activity of NBS oxalic acid, normalized to \(\delta^{13}C = -19\%_o\) wrt PDB (Polach, 1979; Currie and Polach, 1980). For purposes of interpretation, \(^{14}C\) results based on marine shell samples are adjusted for oceanic reservoir environmental effect established by Gillespie and Polach (1979) to be 450 ± 35 yr for the south and east coasts of Australia. Adjusted results are annotated BP*.

The outer surface of the shells was removed, either by dentist’s drill or dilute HCl and the ‘unaltered’ core dated. Except where noted: \(\delta^{13}C\) PDB of shell is estimated to be 0.0 ± 2.0\%\_o and peat −24.0 ± 2.0\%\_o; all samples coll by E G Rhodes, Dept Biogeog and Geomorph, Australian National University.

SAMPLE DESCRIPTIONS

MODERN CONTROL SAMPLES

ANU-1828. \[D^{14}C = -71.0 \pm 6.6\%_o\] \[640 \pm 60\]

Shell \((Anadara)\) coll live from 15m water in 1903, offshore Mapoon, Queensland, ca 80km N Weipa, by C Hedley, Australian Mus, Sydney. Australian Mus No. C14195.

ANU-2092. \[D^{14}C = -46.3 \pm 6.5\%_o\] \[380 \pm 60\]


ANU-2099. \[D^{14}C = +196.7 \pm 8.6\%_o\] \[119.7 \pm 0.9\%\_o\]现代

Shell \((Volachlamys\ sp)\) coll 1978 live from 25m depth offshore Edward R. Meat removed from shells, shells boiled in distilled water,

* Comalco Ltd, P O Box 246, Glenside, South Australia
scrubbed with stiff brush, dried, and crushed. Comment: to test applicability of correction factor for the Gulf (Gillespie and Polach, 1979), samples were corrected for isotopic fraction and AD 1903 samples age-corrected for difference in time of colln and 14C ref yr, AD 1950, ANU-1828 corrected value of 530 ± 60 and ANU-2092 corrected value of 390 ± 60 give mean corrected value of 460 ± 45 yr BP*. ANU-2099 is deemed to have same correction factor, 450 ± 35 yr BP, as used for E and S Australia.

Chenier ridge formation series

ANU-1999. \[ D^{14}C = -59.8 \pm 7.6\%o \] 500 ± 70
Marine bioclastic from coastal plain 50km W Karumba (17° 39' S, 140° 25' E). Develop into summer berm seaward of vegetated chenier ridge by wave action. Corrected age: 50 ± 80 yr BP*.

ANU-1924. \[ D^{14}C = -64.2 \pm 7.4\%o \] 530 ± 70
Shell (Mactra) from Inverleigh transect (17° 39' S, 140° 26' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 80 ± 75 yr BP*.

ANU-1998. \[ D^{14}C = -65.5 \pm 8.7\%o \] 550 ± 80
Shell (Mactra and Saccostrea) from ca Disaster Inlet (17° 45' S, 139° 50' E). Bioclasts deposited in strandline material shortly after death. Coll in bulk from active summer berm. Corrected age: 100 ± 90 yr BP*.

ANU-1997. \[ D^{14}C = -80.7 \pm 7.4\%o \] 680 ± 70
Shell (Mactra) from ca Disaster Inlet. Coll from pit, 0.5m deep, in ridge. Corrected age: 230 ± 80 yr BP*.

ANU-1990. \[ D^{14}C = -65.5 \pm 8.7\%o \] 550 ± 80
\[ \delta^{13}C = 0.0 \pm 0.2\%o \] 1080 ± 60
Shell (Anadara and Mactra) from Burketown transect I (17° 28' S, 140° 47' E). From drill hole 5221 on active storm berm of present beach, ca 1m depth. Corrected age: 630 ± 70 yr BP*.

ANU-1923. \[ D^{14}C = -133.3 \pm 7.3\%o \] 1150 ± 70
Shell (Anadara and Mactra) from Inverleigh transect (17° 39' S, 140° 25' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 700 ± 80 yr BP*.

ANU-1927. \[ D^{14}C = -197.5 \pm 6.7\%o \] 1770 ± 70
Shell (Anadara) from breach in modern ridge 5km W Karumba (17° 29' S, 140° 47' E). Whole bivalves develop into strandline by wave action. Bagged from cut bank. Corrected age: 1320 ± 80 yr BP*. This sample completes group forming Episode IV.

ANU-1929. \[ D^{14}C = -241.3 \pm 8.0\%o \] 2200 ± 90
Shell (Mactra) from N ridge, Port Norman complex (17° 35' S, 140° 46' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 1750 ± 90 yr BP*.
38 H A Polach, E G Rhodes, John Head, and John Gower

ANU-2070. \[ ^{14} \text{C} = -240.6 \pm 6.8\% \]
2210 ± 70
Shell \( (Mactra) \) 50km W Karumba \( (17^\circ 45' S, 140^\circ 24' E) \). Bivalves develop into strandline by wave action. Bagged from shallow pit. Corrected age: 1760 ± 80 yr BP*.

ANU-1921. \[ ^{14} \text{C} = -244.5 \pm 7.4\% \]
2250 ± 80
Shell \( \text{(Anadara)} \), loc as for ANU-2070. Corrected age: 1800 ± 85 yr BP*.

ANU-1900. \[ ^{14} \text{C} = -247.8 \pm 6.6\% \]
2290 ± 70
Shell \( \text{(Anadara and Mactra)} \) from Bynoe R, Karumba \( (17^\circ 35' S, 140^\circ 43' E) \). Molluscan bivalves deposited in beach ridge ca MHW. Bagged directly from pit in bank. Corrected age: 1840 ± 80 yr BP*.

ANU-1928. \[ ^{14} \text{C} = -258.6 \pm 6.2\% \]
2400 ± 70
Shell \( \text{(Mactra)} \) from S ridge, Port Norman complex \( (17^\circ 35' S, 140^\circ 46' E) \). Whole bivalves develop into strandline by wave action. Bagged directly from pit. Corrected age: 1950 ± 80 yr BP*.

ANU-1743. \[ ^{14} \text{C} = -380.7 \pm 11.1\% \]
3840 ± 140
\[ \delta^{13} \text{C} = -0.5 \pm 0.2\% \]
Shell \( \text{(Anadara and Mactra)} \) from ca base of beach face near active swash zone, Burketown transect I \( (17^\circ 33' S, 140^\circ 37' E) \). Coll from drill hole 5220. Dilution, 32% sample. Corrected age: 3390 ± 150 yr BP*.

ANU-1744. \[ ^{14} \text{C} = -431.7 \pm 5.3\% \]
4540 ± 80
Shell \( \text{(Mactra)} \) coll from drill hole 5220 just below facies change separating it from ANU-1743. Corrected age: 4090 ± 90 yr BP*. Comment: downhole dating of secs shows vertical accretion is slow in contrast to rapid horizontal progradation; illustrated by ANU-1928, -1743, and-1744, showing vertical accretion rate in 1 to 2mm/yr range.

ANU-1827. \[ ^{14} \text{C} = -270.4 \pm 6.6\% \]
2520 ± 60
\[ \delta^{13} \text{C} = -0.7 \pm 0.2\% \]
Shell \( \text{(Mactra)} \) from ca Pandanus Yard \( (17^\circ 45' S, 139^\circ 50' E) \). Bio-clasts deposited in strandline material shortly after death. Coll from pit, 0.5m deep. Corrected age: 2070 ± 70 yr BP*. Sample completes Episode III group.

ANU-1742. \[ ^{14} \text{C} = -348.0 \pm 5.6\% \]
3430 ± 60
\[ \delta^{13} \text{C} = -0.6 \pm 0.2\% \]
Shell \( \text{(Mactra)} \) from Burketown transect I \( (17^\circ 35' S, 140^\circ 46' E) \). Coll from pit, 0.5m pit, deep in ridge remnant on deltaic marine plain. Corrected age: 2980 ± 70 yr BP*.

ANU-1746. \[ ^{14} \text{C} = -358.3 \pm 5.6\% \]
3560 ± 70
Shell \( \text{(Mactra)} \) from ca Karumba \( (17^\circ 28' S, 140^\circ 47' E) \). Shell and fragments deposited in nearshore environs in matrix of fine blue-green clay; coll from drill hole 5221. Corrected age: 3110 ± 80 yr BP*.
ANU-1926. \[ \text{D}^{14}\text{C} = -375.7 \pm 6.9\% \] \[ 3780 \pm 90 \]
Shell (Mactra and Anadara) from coastal plain 8km S Karumba (17° 35' S, 140° 51' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 3330 ± 100 yr BP*.

ANU-1741. \[ \text{D}^{14}\text{C} = -412.4 \pm 7.9\% \] \[ 4260 \pm 100 \]
\[ \delta^{13}\text{C} = -0.8 \pm 0.2\% \]

ANU-2071. \[ \text{D}^{14}\text{C} = -415.0 \pm 5.8\% \] \[ 4310 \pm 80 \]
Shell (Mactra) from coastal plain 50km W Karumba (17° 40' S, 140° 24' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 3860 ± 90 yr BP*.

ANU-1922. \[ \text{D}^{14}\text{C} = -423.7 \pm 6.4\% \] \[ 4430 \pm 90 \]
Shell (Anadara), loc as for ANU-2071. Corrected age: 3980 ± 100 yr BP*.

ANU-1925. \[ \text{D}^{14}\text{C} = -440.3 \pm 6.3\% \] \[ 4660 \pm 90 \]
Shell (Anadara and Mactra) from 8km S Karumba. Whole bivalves develop into strandline by wave action. Bagged directly from pit. Corrected age: 4210 ± 100 yr BP*. Sample completes Episode II group.

ANU-2000. \[ \text{D}^{14}\text{C} = -498.1 \pm 8.1\% \] \[ 5540 \pm 140 \]
Shell (Mactra and Anadara) from 2km E Flinders R, ca upland surface (17° 42' S, 140° 40' E). Slightly recrystallized bioclastic material deposited in strandline, a chenier remnant perched above unvegetated flat. Dilution, 47% sample. Corrected age: 5090 ± 150 yr BP*.

ANU-1740C. \[ \text{D}^{14}\text{C} = -514.1 \pm 5.6\% \] \[ 5780 \pm 90 \]
\[ \delta^{13}\text{C} = -1.1 \pm 0.2\% \]
Shell (Anadara sp) from ca Karumba (17° 37' S, 140° 48' E). Outer fraction 24% calcite, 76% aragonite. Corrected age: 5330 ± 100 yr BP*.

ANU-1691. \[ \text{D}^{14}\text{C} = -516.0 \pm 5.9\% \] \[ 5380 \pm 100 \]
Shell hash in sand, separated by sieving, from Pandanus Yard (17° 45' S, 139° 50' E). Corrected age: 5380 ± 110 yr BP*.

ANU-1896. \[ \text{D}^{14}\text{C} = -520.6 \pm 5.6\% \] \[ 5900 \pm 90 \]
Shell (Anadara) from ca Karumba (17° 37' S, 140° 47' E). Bivalves deposited in beach ca mean high water. Bagged from pit, 0.5m deep. Corrected age: 5450 ± 100 yr BP*.

ANU-1740A. \[ \text{D}^{14}\text{C} = -526.7 \pm 5.8\% \] \[ 5990 \pm 90 \]
\[ \delta^{13}\text{C} = -1.1 \pm 0.2\% \]
Shell (Anadara) from ca Karumba (17° 37' S, 140° 48' E). Shells deposited in crest of beach berm in well-drained beach ridge perched
on marine mudflat, crest within storm tide range. Coll from pit near drill hole 5217. Corrected age: 5540 ± 100 yr BP*

**ANU-1920.**  
$D^{14}C = -528.0 \pm 5.3\%$  
6030 ± 90

Shell (*Anadara*) from coastal plain 50km W Karumba (17° 48' S, 140° 24' E). Whole bivalves develop into strandline by wave action. Bagged directly from shallow pit. Corrected age: 5580 ± 100 yr BP*. This sample completes Episode I group.

**ANU-1869.**  
$D^{14}C = -986.9 \pm 2.9\%$  
34,900 ± 90

+ 2000  
- 1600

Shell (*Saccostrea cucullata*) from ca Norman R (17° 34' S, 140° 52' E), Karumba area. Sample in situ from oyster reef in growth position on bedrock bench in excellent state of preservation. Comment: 100% calcite level and absence of stable isotope measurement ($\delta^{13}C = 0.0 \pm 2.0\%$) suggests questionable age.

**ANU-1895.**  
$D^{14}C = -994.3 \pm 7.7\%$  
>28,000

Est $\delta^{14}C = -5.0 \pm 2.0\%$

Carbonate nodules from ca Karumba (17° 30' S, 140° 45' E), preserved in buried soil horizon. Dilution, 40% sample.  
General Comment: groupings of $^{14}C$ determinations based on modified Wilson-Ward (1981) approach suggest four distinct episodes of strandline formation in chenier plain. Episode I began postglacial sea-level max ca 5800 $^{14}C$ yr ago in Gulf. This brief period continued for ca 350 yr until hiatus of ca 750 yr separated it from Episode II, a longer period of ca 1600 yr, centered ca 3700 $^{14}C$ yr ago. Another hiatus of strandline formation separates Episode II from III, ca 350 yr centered ca 1900 $^{14}C$ yr ago. Finally, there is evidence of recent Episode IV, possibly begun 1200 $^{14}C$ yr ago and still active.

**Beach ridge series**

**ANU-1898.**  
$D^{14}C = -72.8 \pm 7.8\%$  
610 ± 70


**ANU-1899.**  
$D^{14}C = -82.6 \pm 8.7\%$  
690 ± 80

Shell (*Anadara sp*) from same loc. Coll from ridge crest. Sample 100% aragonite. Corrected age: 240 ± 90 yr BP*. These 2 samples belong to still active Episode IV.

**ANU-2057.**  
$D^{14}C = -143.2 \pm 7.3\%$  
1240 ± 70

Shell (*Anadara*) from ca Edward R settlement (14° 46' S, 141° 36' E) deposited after death in beach deposit ca MSL. Coll from Well #1. Corrected age: 790 ± 80 yr BP*. 
ANU Radiocarbon Date List IX

41

ANU-2103.  D¹⁴C = -208.8 ± 9.1‰  1880 ± 90

Shell (Anadara) from ca Edward R settlement (14° 46' S, 141° 35' E),
deposited shortly after death in beach deposit ca MSL. Shells in sandy
matrix with alternating clay layers, coll from 1.8m in Well #2 in small
swale between two major ridges Corrected age: 1430 ± 100 yr BP*.

ANU-1728.  D¹⁴C = -212.1 ± 12.5‰  1920 ± 120

δ¹³C = +0.2 ± 0.2‰

Shell hash from ca Edward R Mission (15° 35' S, 141° 33' E). Coll
from relict beach berm subjected to variable freshwater table. Dilution,
27% of sample. Corrected age: 1470 ± 130 yr BP*.

ANU-2058.  D¹⁴C = -267.1 ± 6.8‰  2500 ± 80

Shell (Anadara) from ca Edward R (14° 46' S, 141° 35' E), deposited
shortly after death in beach ca MSL. Coll from Well #4. Corrected age:
2050 ± 90 yr BP*. This group completes Episode III.

ANU-1735.  D¹⁴C = -325.1 ± 6.1‰  3110 ± 70

δ¹³C = -2.9 ± 0.2‰

Granulated carbonate and shell fragments (predom Turritella) from
ca Edward R Mission (15° 35' S, 141° 34' E). Comment: abnormal nega-
tive ¹⁸O/¹⁶O values, (δ¹⁸O = -8.4 ± 0.2‰), depleted ¹³C/¹²C ratios and
100% calcite replacement of original aragonite suggest questionable
age. Corrected age: 2660 ± 80 yr BP*.

ANU-1736.  D¹⁴C = -322.6 ± 6.2‰  3130 ± 70

δ¹³C = 0.0 ± 0.2‰

Shell hash from ca Edward R Mission (15° 35' S, 141° 33' E). Comment:
highly recrystallized granular carbonate from beach-ridge facies has stable isotope
dratios suggesting calcite recrystallization proceeded without contamination. Corrected age: 2680 ± 80 yr BP*.

ANU-2060.  D¹⁴C = -326.4 ± 8.5‰  (? )3170 ± 110

Shell hash from ca Edward R (14° 46' S, 141° 35' E). Sample 100% cal-
tite coll from beneath swale near ANU-2059, subject to freshwater
ponding during wet season. Corrected age: (?)2720 ± 120 yr BP*.

ANU-1737.  D¹⁴C = -330.1 ± 6.3‰  3220 ± 70

δ¹³C = 0.0 ± 0.2‰

Shell hash from ca Edward R Mission (15° 35' S, 141° 33' E). Sample
in sandy matrix from low-tide mud below sand facies. Corrected age:
2770 ± 80 yr BP*.

ANU-2102.  D¹⁴C = -347.3 ± 7.6‰  3430 ± 100

Shell hash from ca Edward R (14° 46' S, 141° 35' E) deposited
shortly after death in beach deposit ca MSL. Shells in sandy matrix with
alternating clay layer beneath. Coll from Well #3. Corrected age:
2980 ± 110 yr BP*. 
ANU-1734. \[ \text{D}^{14}\text{C} = -366.6 \pm 5.9\% \] \[ 3610 \pm 70 \]
\[ \delta^{13}\text{C} = -3.2 \pm 0.2\% \]
Shell hash from ca Edward R Mission (15° 35' S, 141° 34' E).
\textit{Comment}: abnormal negative \(^{18}\text{O}/^{16}\text{O} \) values (\( \delta^{18}\text{O} = -11.4 \pm 0.2\% \)), depleted \(^{13}\text{C}/^{12}\text{C} \) ratios and 100\% calcite replacement of original aragonite suggest questionable age. Corrected age: 3160 ± 80 yr BP*.

ANU-2059. \[ \text{D}^{14}\text{C} = -373.2 \pm 6.0\% \] \[ 3750 \pm 80 \]
Shell hash from ca Edward R (14° 46' S, 141° 35' E), deposited shortly after death in beach deposit ca MSL. Coll from 2.5m in Well #10. Corrected age: 3300 ± 90 yr BP*. This sample completes Episode II.

ANU-1732. \[ \text{D}^{14}\text{C} = -487.3 \pm 9.6\% \] \[ 5370 \pm 60 \]
Shell hash of recrystallized shell material, granular carbonate sand and clay from ca Edward R Mission (15° 35' S, 141° 34' E). Dilution, 30\% of sample. Corrected age: 4920 ± 70 yr BP*.

ANU-1733. \[ \text{D}^{14}\text{C} = -500.6 \pm 8.1\% \] \[ 5570 \pm 120 \]
\[ \delta^{13}\text{C} = -0.1 \pm 0.2\% \]
Shells and shell fragments mixed with sand from ca Edward R Mission (15° 35' S, 141° 34' E). Dilution, 42\% of sample. Corrected age: 5120 ± 130 yr BP*.

ANU-1730. \[ \text{D}^{14}\text{C} = -501.3 \pm 15.2\% \] \[ 5590 \pm 250 \]

ANU-2101. \[ \text{D}^{14}\text{C} = -510.6 \pm 6.1\% \] \[ 5760 \pm 110 \]
Shell \textit{(Anadara and Mactra)} from ca Edward R (14° 46' S, 141° 35' E) deposited shortly after death in beach deposit ca MSL. Sample in sandy matrix (lens) with sandy layers under. Coll at 0.9m depth, Well #5. Corrected age: 5310 ± 120 yr BP*.

ANU-2100. \[ \text{D}^{14}\text{C} = -525.9 \pm 5.6\% \] \[ 6000 \pm 100 \]
Shell hash from ca Edward R (14° 46' S, 141° 35' E) deposited shortly after death in beach deposit ca MSL. Coll at 2m depth from Well #7, 75m E of largest ridge in Edward R complex. Corrected age: 5550 ± 110 yr BP*.

ANU-1739A. \[ \text{D}^{14}\text{C} = -533.9 \pm 5.5\% \] \[ 6060 \pm 90 \]
\[ \delta^{13}\text{C} = -4.1 \pm 0.2\% \]
Shells \textit{(Anadara and Turritella)} from ca Edward R Mission (15° 44' S, 141° 34' E). Corrected age: 5610 ± 100 yr BP*. \textit{Comment}: sample has abnormal negative \(^{18}\text{O}/^{16}\text{O} \) values (\( \delta^{18}\text{O} = -9.8 \pm 0.2\% \)), depleted \(^{13}\text{C}/^{12}\text{C} \) ratios and 95\% calcite replacement of original aragonite suggesting questionable age. Aerial photo indicates that paleo-strandline is approx correlated to Episode I on Holroyd transect II, ca 15km to N. Date should be and is close to ANU-1730.
ANU Radiocarbon Date List IX

ANU-1729. \( \Delta^{14}C = -536.7 \pm 10.3\% \) \( \delta^{13}C = -1.1 \pm 0.2\% \) 6160 ± 180


ANU-1690. \( \Delta^{14}C = -551.4 \pm 5.2\% \) \( \delta^{13}C = -2.2 \pm 0.2\% \) 6400 ± 90

Shell hash of partially degraded fragments, mud and rock pebbles from ca Edward R. Corrected age: 5950 ± 100 yr BP*.

ANU-1738. \( \Delta^{14}C = -552.2 \pm 5.3\% \) 6450 ± 100

Peat from Edward R Mission (15° 44’ S, 141° 34’ E). Woody material mixed with clay; coarse 10# fraction boiled in 2N HCl to eliminate carbonate contamination.

ANU-1739B. \( \Delta^{14}C = -502.6 \pm 5.5\% \) \( \delta^{13}C = -5.0 \pm 2.0\% \) 5530 ± 90

Carbonate cement from shells of ANU-1739A. Comment: slightly younger age than 1739A (6130 ± 100) should not be affected by possible contamination from cement.

ANU-1897. \( \Delta^{14}C = -403.3 \pm 5.9\% \) \( \delta^{13}C = -5.0 \pm 2.0\% \) 4150 ± 80

Carbonate nodules from Edward R (14° 46’ S, 141° 36’ E). Sample in buried soil zone in heavy compact clay.

ANU-2093. \( \Delta^{14}C = -187.8 \pm 9.4\% \) 1670 ± 90

Peat from ca Edward R (14° 46’ S, 141° 55’ E). Bagged directly from pit; compare with ANU-1898 and -1899 from overlying facies.

General Comment: numerical procedure also shows that strandline development on beach-ridge plain followed episodic history. Episode I continued for ca 1200 yr after max postglacial marine transgression in Gulf of Carpentaria. No beach ridges appear in period 4700 to 3500 ^14C yr ago. Episode II of moderate duration (ca 1000 yr) produced beach ridges 3500 to 2500 yr ago. Episode III is centered ca 1400 ^14C yr ago and present deposition appears to have been active since 400 yr ago (Episode IV).

References
ERRATUM

MARINE RESOURCES RESEARCH INSTITUTE
RADIOCARBON DATES IV

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(R, 1981, v 23, p 222-226). Due to an error in the value for NBS oxalic acid (as entered into the MRRRI computer program for age and standard deviation calculations) the dates reported in this date list and repeated in the index are all incorrect. Each date should be younger by 2960 years, resulting in finite ages for most of the samples. The exceptions are MRRRI -223, -239, -249, -263, -264, -267, -269, and -274-277, which are all modern in age or in the future. We interpret these future dates as indications of contamination with bomb 14C. No other dates were affected in any way since the dates in this list were calculated as a group.
The radiocarbon dates reported in this date list cover the measurements carried out in 1979 to 1980. Chemical and counting procedures are the same as reported earlier (R, 1978, v 20, p 398-404). Age calculations are based on the conventional $^{14}$C half-life (5570 yr) and on the contemporary value of 95% of the activity of NBS oxalic acid. Errors quoted correspond to $1\sigma$ value which takes into account the counting statistics, the uncertainty in the half-life, and the instability of the counting system. The ages are not corrected for isotopic fractionation in nature.

Some modifications and improvements have been carried out in the electronics unit. A four-channel preset timer-printer unit has been incorporated with the scalers to record the counting data at preset time intervals. Statistical analyses of the printer output are regularly carried out for the detection of any abnormal behavior in the counting system and rejection of data using the methods described by Erlenkeuser and Willkomm (1972).

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QUATERNARY SAMPLES

Naini Tal series

Peat and laminated clay samples from Naukuchiya Tal (29° 19' N, 79° 35' E) dist Naini Tal. Samples coll by boring, subm by H P Gupta, Birbal Sahni Inst Palaeobotany (BSIP) to date pollen diagrams.

Profile I (lake margin)

**BS-116. Organic mud**

Depth, 190 to 220 cm from swamp surface.

**BS-114. Brownish gray peat**

Depth, 290 to 320 cm.

**BS-115. Black humified peat**

Depth, 390 to 420 cm.

**BS-105. Peat with wood fragments**

Depth, 490 to 520 cm.

**BS-104. Humified clayey peat**

Depth, 590 to 620 cm.
Comment: pollen diagram of this profile is under preparation. Age of profile of pub pollen diagram from this lake (Vishnu Mittre, Gupta, and Robert, 1967; Gupta, 1977) was earlier interpreted much younger than these dates indicate.

Profile II (lake margin)

BS-140. Peat
Depth, 120 to 150 cm.

3790 ± 110

BS-141.
Clay with organic debris and wood fragments at depth 220 to 250 cm.

4340 ± 120

BS-142.
Clay with wood fragments at depth 320 to 350 cm.

Comment: in absence of hiatus in stratigraphy, Profile II indicates low sedimentation rate for compact portion of deposit. Pollen analytic results are awaited for comparison of pollen diagrams of Profiles I and II.

Terrace sediment from natural exposure, Bhim Tal lake (29° 24' N, 79° 26' E) dist Naini Tal. Coll and subm by H P Gupta to date terrace.

BS-144. Sandy clay
Depth, 140 to 160 cm.

620 ± 100

BS-157. Clay
Depth, 45 to 60 cm.

120 ± 130

BS-158. Organic mud
Depth, 60 to 90 cm.

820 ± 80

BS-159. Brown peat
Depth, 110 to 140 cm.

940 ± 70

BS-160. Peat
Depth, 190 to 215 cm.

1400 ± 100

BS-161. Peat
Depth, 235 to 265 cm.

2410 ± 100

BS-162. Clay
Depth, 385 to 415 cm.

1550 ± 70

Nilgiris series
Peat and peaty clay samples from different swampy regions of dist Nilgiris. Samples coll by boring and subm by K Prasad, BSIP, to date pollen diagrams.
Race course (11° 24' 8" N, 76° 42' E).

**BS-148. Peat**
Depth, 20 to 50cm.

**BS-149. Peat**
Depth, 120 to 150cm.

**BS-150. Peat**
Depth, 170 to 200cm.

Kappeathorai (11° 21' 50" N, 76° 38' 40" E).

**BS-151. Peaty clay**
Depth, 20 to 50cm.

*Comment:* other two samples of Kappeathorai profile at depths 70 to 100cm and 120 to 150cm were very low in carbon content, *ie,* undatable.

Kakatho (11° 35' N, 76° 52' E).

**BS-156. Peaty clay**
Depth, 20 to 50cm.

**BS-186. Peaty clay**
Depth, 20 to 50cm.

**BS-196. Peaty clay**
Depth, 70 to 100cm.

**BS-187. Peaty clay**
Depth, 120 to 150cm.

**BS-197. Peaty clay**
Depth, 170 to 200cm.

**BS-188. Peaty clay**
Depth, 220 to 250cm.

**BS-198. Fibrous peaty clay**
Depth, 270 to 300cm.

**BS-199. Clay**
Depth, 370 to 395cm.

*Comment:* dates support earlier estimate of sedimentation rate based on two $^{14}$C dates (Agrawal, Gupta, and Kusumgar, 1969) for pollen diagram from this site. Pollen analytic studies of this profile are being made at present. Earlier pollen diagram revealed expansion of shrubs at 32,000 yr BP into grassland savannah, formation of Shola forest ca 14,400 yr BP, its decline at 11,000 yr BP, and savannization later (Vishnu-Mittre, ms).

Colgrain (11° 35' N, 76° 52' E).

**BS-167. Peaty clay**
Depth, 20 to 50cm.
BS-168. Peaty clay 16,640 ± 270
Depth, 70 to 100cm.

BS-169. Clay 11,820 ± 160
Depth, 120 to 150cm.
Comment: date of BS-167 agrees well with earlier measurement, BS-10, for another profile from this site (R, 1978, v 20, p 398-404).

Rajasthan series
Clay samples from trial trenches in Didwana lake (27° 30' N, 74° 30' E) dist Nagaur to date climatic and vegetational history of Rajasthan. Coll and subm by A K Saxena, BSIP.

BS-123. Depth, 100 to 105cm
BS-121. Depth, 210 to 215cm 5900 ± 100

Himachal Pradesh series
Peat samples from lake margin of Parasram Tal, Nahan (30° 30' N, 70° 28' E) dist Sirmur. Samples coll by boring and subm by Chayya Sharma, BSIP, to date pollen diagram. Pollen analysis of profile is in progress.

BS-170. Depth, 100 to 130cm 960 ± 100
BS-171. Depth, 170 to 200cm 2750 ± 100
BS-172. Depth, 320 to 350cm 4000 ± 120
BS-173. Depth, 460 to 490cm 3140 ± 100

Renuka lake, Nahan (30° 30' N, 70° 27' E).

BS-166. Clay Modern
Depth, 30 to 50cm.

Tripura and Manipur series
Samples from trial trenches in peat deposits coll and subm by A Bhattachatrya, BSIP, to date pollen diagram.

Bisalgarh (22° 56' N, 91° 10' E) dist West Tripura.

BS-208. Peat, 2.25m 1750 ± 100
BS-209. Peat, 2.9m 2600 ± 90
BS-210. Wood, 2.9m 6930 ± 120

Chandrapur (22° 56' N, 91° 15' E) dist West Tripura.

BS-205. Peat, 1.9m 1870 ± 100
BS-206. Peat, 2.75m 2980 ± 110
BS-207. Wood, 2.75m 2040 ± 90

Comment: dates of wood samples are inconsistent.

Samples from peat deposits. Coll and subm by S Chanda, Bose Research Inst, Calcutta, to date pollen diagrams.

Kalpana (25° N, 91° E) dist Tripura. Samples coll by boring.

BS-152. 90 to 105cm 2940 ± 200
BS-189. 195 to 215cm Modern
BS-153. 260 to 275cm Modern

Comment: BS-189 and -153 are probably contaminated.

Sekerkot (24° N, 91° E) dist Tripura. Samples coll from trial trench.

BS-174. Peat, 30 to 40cm 1930 ± 120
BS-156. Wood, 380cm 3340 ± 140

Lamphelpet (25° N, 93° E) dist Manipur. Sample coll from trial trench.

BS-194. Peat, 35 to 40cm 7930 ± 470

Turcul (25° N, 93° E) dist Tripura. Sample coll from natural exposure.

BS-175. Lignite >40,000

Tinsukia Forest Bungalow (27° 30’ N, 95° 30’ E) dist Upper Assam.

BS-154. Peat, 2.10m 12,210 ± 340

Matikhad (27° 12’ N, 95° 48’ E) dist Upper Assam.

BS-155. Peat, 2.5m 17,920 ± 570

Wood and peat samples from Kantalia (22° 30’ N, 88° 27’ E) dist Howrah, coll during systematic excavation. Coll and subm by B B Mukherjee, Bose Research Inst, Calcutta, to date sedimentologic processes.

BS-190. Peat, 3.29m 1400 ± 100
BS-191. Wood, 4.03m 5610 ± 110
BS-192. Wood, 4.61m 5580 ± 130
BS-164. Wood, 7.34m 6540 ± 120
BS-165. Wood, 7.93m 5000 ± 120

Comment (BBM): BS-192 and -165 are inconsistent.

GEOLOGIC SAMPLES

BS-124. Manjrod, Maharashtra 200 ± 90

Charcoal from natural exposure 100m downstream on right bank of Tapti in Manjrod (21° 13’ N, 74° 59’ E) dist Dhule.
BS-125. Tamasvadi, Maharashtra
Charcoal from natural exposure right of Panjhra R, 300m N of Tamasvadi (21° 03’ N, 74° 51’ 30” E) dist Dhule. Comment: samples coll and subm by G V Rao, Geol Survey India to date sedimentologic history of Tapti and its sub-basins.

BS-139. Katra, Jammu & Kashmir
Carbonaceous clay from natural exposure depth, 3m from Katra (33° 15’ N, 75° 40’ E), dist Udhampur. Coll to date Riasi thrust. Coll and subm by K S Krishnamurthy, Geol Survey India.

Peaty clay from trial trenches in area that formed Lohtak lake bed before canal excavation (24° 35’ 15” N, 93° 43’ E), dist South Manipur. Coll and subm by Eng Geol Div, Geol Survey of India, to date geomorphic and tectonic history of Lohtak basin under Loktak Hydel project.

BS-145. Peaty clay, depth 5.3m
11,470 ± 190

BS-147. Peaty clay, depth 12m
25,500 ± 660

Peaty clay samples from dist Sirmur, Himachal Pradesh in black zone along Krol thrust. Coll and subm by Eng Geol Div, Geol Survey India, to date neotectonic activity along Krol thrust zone in Himalaya.

BS-183. (30°33’N, 77°48’E) 31,000 ± 1640

BS-184. (30°33’N, 77°42’E) >40,000

Wood and peat samples coll and subm by S Subramaniam, Geol Survey India, to study development of coastal plain and neotectonic activity.

Vyasarpadi (13° 7’ N, 15’ 45” E), dist Madras.

BS-185. Wood, depth 6.3 to 6.6m
7000 ± 120

Sengammal (12° 45’ 50” N, 80° 12’ 50” E), dist Chengalpat.

BS-193. Peat, depth 120 to 150cm
6230 ± 120

BS-195. Carbonaceous sediment
6400 ± 160

Depth, 120 to 150cm.

BS-200. Gaik, Jammu & Kashmir
Charcoal, depth 30cm from natural exposure from Gaik (35° 20’ N, 79° E) dist Leh. Coll and subm by K K Sharma, Wadia Inst Himalayan Geol, Dehra Dun, to date terrace formation.

Shell samples from E coast of S India to date fossil sand dunes and eustatic changes. Samples coll and subm by R V Joshi, Deccan Coll, Pune.

Idindakarai (8° 10’ N, 77° 45’ E), dist Tirunelveli.

BS-134. Land snails, surface
20,000 ± 400
### Birchal Sahni Institute Radiocarbon Measurements III

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Description</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-133</td>
<td>Land snails, depth 30cm</td>
<td>33,700 ± 1640</td>
</tr>
<tr>
<td></td>
<td>Kanyakumari (8° 2' N, 77° 35' E), dist Kanyakumari.</td>
<td></td>
</tr>
<tr>
<td>BS-132</td>
<td>Marine shells, depth 2m</td>
<td>29,900 ± 960</td>
</tr>
<tr>
<td>BS-43</td>
<td>Nirgudsar, Maharashtra</td>
<td>39,000 ± 3200</td>
</tr>
<tr>
<td></td>
<td>Wood from trench 6m below modern bed level in cemented pebbly gravel, Nirgudsar (18° 31' 30'' N, 74° 22' 30'' E) dist Pune. Sample to date Late Stone age culture of Ghod Valley. Subm by S N Rajguru, Deccan Coll, Pune.</td>
<td></td>
</tr>
<tr>
<td>BS-146</td>
<td>Inamgaon, Maharashtra</td>
<td>11,700 ± 150</td>
</tr>
<tr>
<td></td>
<td>Shells at depth 90cm, from systematic excavation in Ghod valley of Late Stone age culture at Inamgaon (19° 36' 12'' N, 74° 37' 54'' E), dist Ahmednagar. Subm by S N Rajguru. Comment (SNR): dates agree with estimates based on geomorphic and lithostratigraphic history of Ghod valley.</td>
<td></td>
</tr>
<tr>
<td>BS-163</td>
<td>Nandur Madmeshwar, Maharashtra</td>
<td>26,600 ± 430</td>
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<tr>
<td></td>
<td>Well-preserved shells at depth 7.62 to 9.14m from natural exposure at Nandur Madmeshwar (20° N, 74° 5' E). Coll to date Middle Palaeolithic culture of upper Godawari valley. Comment (SNR): date agrees with estimates based on geomorphologic and palaeontologic correlations. Subm by S N Rajguru.</td>
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</tr>
<tr>
<td>BS-135</td>
<td>Peddarajupalli</td>
<td>1010 ± 100</td>
</tr>
<tr>
<td></td>
<td>Freshwater molluscan shells from natural exposure below red sandy loam layer, depth 10 to 20cm found in assoc with artifacts of Upper Palaeolithic culture at Peddarajupalli (14° 4' 30'' N, 79° 22' E), dist Cuddapah. Subm by M L K Murthy, Deccan Coll, Pune. Comment: sample probably contaminated due to percolation of water from surface.</td>
<td></td>
</tr>
<tr>
<td>BS-127</td>
<td>Dhupdhara, Assam</td>
<td>3370 ± 130</td>
</tr>
<tr>
<td></td>
<td>Wood from trial trench at depth 8m, from Dhupdhara (25° 26' N, 90° 30' E), dist Goalpara. Subm by M C Goswami, Dept Anthropol, Gauhati Univ, Gauhati.</td>
<td></td>
</tr>
<tr>
<td><strong>Daimabad series</strong></td>
<td></td>
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<tr>
<td></td>
<td>Charcoal samples in sequence from Jorwe to Late Harappa cultures from systematic excavation at Daimabad (19° 30' N, 74° 31' E), dist Ahmednagar. Coll and subm by S A Sali, Archaeol Survey India, Auranagabad.</td>
<td></td>
</tr>
<tr>
<td>BS-176</td>
<td>Trench GZ 63</td>
<td>3590 ± 90</td>
</tr>
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<td></td>
<td>Sample from depth 4.1m, Sec I, Layer (15), House No. 12.</td>
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</tr>
<tr>
<td>BS-177</td>
<td>Trench Z'3</td>
<td>3460 ± 100</td>
</tr>
<tr>
<td></td>
<td>Sample from depth 2.25m, Sec II, Pit 145, sealed by (10A).</td>
<td></td>
</tr>
</tbody>
</table>
BS-178. Trench Y'2 2950 ± 100
Sample from depth 10cm, Kiln No. 1, sealed by (1), Sec II.

BS-179. Trench DZ'3 2970 ± 100
Sample from depth 30cm, upper levels of House No. 38, Sec II.

BS-180. Trench ZD60 3390 ± 100
Sample from depth 2.3m, Sec IV, from hearth sealed by (11).

BS-181. Trench Y'3 2990 ± 100
Sample from depth 1.36m, Sec II, Layer (7).

BS-182. Trench Z'3 3130 ± 90
Sample from depth 2.1m, Sec II, Layer (10).

Comment (SAS): dates for BS-176, -180, -181, and -182 are stratigraphically inconsistent. Dates also do not agree with estimates for various phases of Daimabad series based primarily on 14C dates for Malwa and Jorwe cultures from Inamgaon, Chandoli, Songoan, and Navasa in Maharashtra and chronology of Harappa culture.

Allahabad series
Samples from various phases of Mesolithic and Upper Palaeolithic cultures in Ganga valley coll during systematic excavation. Subm by G R Sharma, Dept Ancient Hist & Archaeol, Allahabad Univ.

Mahagara (24° 54' 50" N, 82° 3' 20" E) dist Allahabad.

BS-130. Trench L/6 11,550 ± 180
Shell from depth 17 to 33cm, upper level cemented gravel III, Loc XXX-XXXVI.

BS-131. Trench L/6 9830 ± 160
Shell from depth 33 to 73cm, middle level cemented gravel III, Loc XXX-XXXVI.

BS-128. Trench G/7 3330 ± 100
Charcoal from depth 2.8 to 3.5m, Pit 8B(18), Loc XXXVI-XXXVII.

Chopani Mando (25° 34’ N, 81° 53’ E) dist Allahabad.

BS-129. Trench F/5 4540 ± 110
Charcoal from depth 20 to 30cm, Layer (2A) and (3), Loc I-VI.

Mahadaha (25° 59' 2" N, 82° 11' 30" E) dist Pratapgarh.

BS-136. Trench F/3 (cemetery area) 4010 ± 120
Charred bones (carbonate) from depth 20m, Pit 8B(2), Loc XII-XIV.

BS-137. Trench F/3 2380 ± 250
Charred bones (carbonate) from depth 16 to 26cm, Layer (3), Loc XII-XVIII.
BS-138. Trench F/2 3840 ± 130
Charred bones (carbonate) from depth 27 to 42cm, Loc VI-XII.
Comment (GRS): dates are much younger than estimates based on PRL-100 and -101 (Agrawal et al, 1976). Samples are probably contaminated by percolation of water through secs.

Satanikota series
Charcoal samples from Satanikota (15° 56' N, 78° 14' E), dist Kurnool, coll during systematic excavation of megalithic site. Subm by N C Ghosh, Archaeol Survey India, Nagpur, to date megaliths of S India.

BS-201. Depth, 0.75m 1620 ± 100
BS-202. Depth, 1.7 to 1.85m 1440 ± 100
BS-203. Depth, 1.95m 7520 ± 140
BS-204. Depth, 2.55m 8960 ± 120
Comment: BS-201 and -202 are inconsistent with estimate. BS-203 and -204 agree with estimates based on assoc Black and Red ware and red slipped sherds belonging to Megalithic period.

References
Vishnu-Mitrre, ms, Biostratigraphy of Kakathope pollen profile from Ootacamund, Nilgiris, India, in press.
UCR RADIOCARBON DATES III

R E TAYLOR

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This list reports a portion of the analysis completed on archaeologic and paleo-environmental samples measured in the UCR laboratory between August 1974 and August 1976. Results of measurements made during that period on sample suites which are not as yet completed or lack review by submitters will be reported in a subsequent date list.

A second CO₂ proportional counting system, designed to accommodate samples containing as little as 250mg of carbon has been installed. The volume of the detector is 500ml attached to a filling system which maximizes the percentage of sample gas introduced into the effective volume of the detector. Techniques of sample preparation are as reported previously (R, 1975, v 17, p 396-408). Ages continue to be expressed with respect to 0.95 NBS oxalic acid based on the 5568 half-life. Results are reported in years before AD 1950. One-sigma counting errors include standard deviation of count rate of sample, contemporary standard, and background. Routine measurement of δ¹³C values on samples is now being undertaken. Reporting of these measurements will begin with UCR IV. The measured δ¹³C value of the NBS oxalic acid standard is −19.7 per mil relative to PDB.

ACKNOWLEDGMENTS

The dedicated laboratory work of Peter Slota and Louis Payen is gratefully acknowledged. The laboratory is partially supported by the National Museum Act, Smithsonian Institution, and UCR Intermural Research Fund.

I. ARCHAEOLOGIC SAMPLES

A. United States

California

Central California Archaeologic Chronology series

The Cultural Resources Sec, California State Dept Parks and Recreation has supported radiocarbon studies of archaeol materials from a number of N and central California sites. Determinations listed here are a continuation of those reported in UCR II (R, 1975, v 17, p 400-402). Samples subm by F A Riddell, Dept Parks and Recreation, California. Comments by J A Bennyhoff, California State Coll, Sonoma.

UCR-169. CA-Sac-65  530 ± 160

Human bone collagen from Burial 3, 60 to 70cm depth, from intrusive pit into sterile subsoil from Site CA-Sac-65 (120° 30' N, 38° 19' W) Sacramento Co. Assoc with 2 non-diagnostic charmstones. Coll 1974 by P Schulz. Comment (JAB): phasing uncertain but date should represent Late Phase 1 of Late Horizon.
UCR-183. Oroville, Structure 18 240 ± 150
Charred bark (Pinus sp?) from floor of Structure 18, 90 cm from surface from Site CA-But-S84 (39° 34' N, 122° 27' W) near Oroville, N. Sierra Foothills. Clam disk beads and desert side-notched points found in fill above floor. Coll 1974 by E Ritter. Comment (JAB): date acceptable for terminal component, Oroville Complex (Olsen and Riddell, 1963) representing Late Phase 2 of Late Horizon.

UCR-184. Oroville, Burial 117 950 ± 150
Human bone collagen, 120 cm depth on bedrock, from Site CA-But-S84. Assoc with variant of Gunther barbed arrow point, assigned to Late Bidwell Complex which is probably contemporaneous with Early Phase 1 of Late Horizon (AD 900 to 1100, Scheme B). Coll 1967 by E Ritter. Comment (JAB): date acceptable at present.

UCR-192. Franklin, Burial 8 1090 ± 150
Human bone collagen, 90 to 108 cm depth, from Site CA-Sac-145 (38° 20' N, 121° 27' W) near Franklin in lower Sacramento Valley. No artifact assoc. Coll 1971 by W E Pritchard. Comment (JAB): date acceptable for Middle/Late Horizon (AD 700 to 1100, Scheme A). Date series from site is discordant by depth.

UCR-193. Franklin, Burial 4 2020 ± 150
Human bone collagen, 80 to 90 cm depth from Site CA-Sac-145. No artifact assoc. Coll 1971 by W E Pritchard. Comment (JAB): burial should represent Middle/Late Horizon Transition phase, so date supports Scheme A (100 BC to AD 100). Date must be rejected as too old if Scheme B (AD 700 to 900) is correct. Dates from site discordant by depth.

UCR-194. CA-Sac-34, Burial 23 2000 ± 150
Human bone collagen, 117 cm depth in intrusive pit into sterile soil from Site CA-Sac-34 (38° 34' N, 121° 28' W) in lower Sacramento Valley. Coll 1959 by W H Olsen and L A Payen. Comment (JAB): date acceptable for oldest component (Olsen, 1961, p 38) representing Early phase of Middle Horizon (200 BC to AD 100, Scheme B).

UCR-195. Verona, Burial 42 940 ± 150
Canid bone collagen assoc with Burial 42 from Site CA-Yol-13 (38° 47' N, 120° 37' W) near Verona in Sacramento Valley. Coll 1957 by W H Olsen and L A Payen. Comment (JAB): older range of date acceptable for Middle/Late Horizon Transition phase (AD 700 to 900, Scheme B).

UCR-196. Verona, Burial 28 1010 ± 150
Human bone collagen, 61 cm depth in midden at Site CA-Yol-13. Dorsally extended child with Olivella split, punched beads. Coll 1957 by F A Riddell and D F McGeein. Comment (JAB): assoc diagnostic of Middle/Late Horizon Transition phase (AD 700 to 900, Scheme B). Older range of date acceptable.
UCR-197. Verona, Burial 63  1280 ± 150

Human bone collagen, 104 cm depth in midden at Site CA-Yol-13. Flexed burial with Olivella center-perforated thin rectangles. Coll 1958 by W H Olsen and L A Payen. Comment (JAB): younger range of date acceptable for Middle/Late Horizon Transition phase (AD 700 to 900, Scheme B).

UCR-198. Hood, Burial 18  900 ± 150

Human bone collagen, 46 cm depth in midden at Site CA-Sac-21 (38° 30' N, 121° 31' W) near Hood, lower Sacramento Valley. Assoc include Olivella center-perforated thin rectangles, scored abalone ornaments diagnostic of Early Phase 1, and stemmed arrow points diagnostic of Middle Phase 1 of Late Horizon. Coll 1939 by F Fenenga (Lillard, Heizer, and Fenenga, 1939, p 57-59). Comment (JAB): mean date acceptable for transition between Early and Middle Phase 1 of Late Horizon.

UCR-199. Hood, Burial 17  980 ± 150

Human bone collagen, 64 cm depth in midden at Site CA-Sac-21. Assoc with center-perforated thin rectangles; deeper than Burial 18 (UCR-198). Coll 1939 by F Fenenga. Comment (JAB): mean date acceptable for Early Phase 1 of Late Horizon.

UCR-214. Carquinez Strait, Burial 12  570 ± 130

Charcoal, 198 cm depth at Site CA-Sol-236 (38° 04' N, 122° 12' W) Shore of Carquinez Strait, E San Francisco Bay. Assoc with Olivella thin rectangles (both center- and end-perforated), abalone triangular girdle ornaments, and incised metapodials, all diagnostic of Middle Phase 1 of Late Horizon. Coll 1912 by L Loud. Comment (JAB): older range of date acceptable for Middle Phase 1 (AD 1100 to 1300, Scheme B). Charcoal from same bottle gave previous values of 950 ± 50 BP (UCLA-1909) and 1080 ± 200 BP (M-886: R, 1960, v 2, p 43) which support Scheme A dating of Middle Phase 1 between AD 700 to 1100. Presumably wood of different ages was used in this single fire which yielded mean dates 500 yr apart.

UCR-224. CA-Sac-99L  1050 ± 150

Bone collagen from miscellaneous faunal remains, 60 to 70 cm depth from Site CA-Sac-99L (38° 36' N, 121° 19' W) E Sacramento Valley. Basal component, 15 to 30 cm above subsoil. Higher levels in unit yielded Olivella square saddle and saucer beads. Coll 1978 by J A Bennyhoff. Comment (JAB): expected age for Intermediate phase of Middle Horizon by Scheme B is AD 100 to 300; date rejected as too young.

UCR-226. CA-Sac-151  510 ± 150

Human bone collagen from Burial 19, 89 cm depth in midden at Site CA-Sac-151 (38° 18' N, 121° 22' W) near Galt in lower Sacramento Valley. Assoc with abalone ornaments and obsidian point (Napa 3.2 μ) indicative of Late phase of Middle Horizon (AD 500 to 500, Scheme B). Coll 1939 by F Fenenga. Comment (JAB): date rejected as too young on basis of assoc and obsidian hydration values.
UCR-215. CA-SJo-142, Cremation 3  
1740 ± 150
Human bone collagen, 76cm depth at Site CA-SJo-142 (38° 15' N, 121° 27' W) San Joaquin Delta. Assoc with Olivella beveled and oval saddle beads diagnostic of Early/Middle Horizon Transition phase, dated by eight other samples between 500 to 200 BC, Scheme B. Coll 1938 by R F Heizer (Lillard, Heizer, and Fenenga, 1939, p 37-38). Comment (JAB): date rejected as too young; should approx same age as UCR-216, below.

UCR-216. CA-SJo-142, Burial 30  
2180 ± 150
Human bone collagen, 51cm depth from Site CA-SJo-142. Assoc with Olivella oval saddle beads diagnostic of Early/Middle Horizon Transition phase (500 to 200 BC, Scheme B). Coll 1938 by R F Heizer. Comment (JAB): mean date accepted for end of phase.

UCR-218. CA-Sac-60, Burial 38-11  
1550 ± 150
Human bone collagen, 122cm depth in midden at Site CA-Sac-60 (38° 22' N, 122° 31' W) lower Sacramento Valley. Assoc with obsidian drill (Bodie Hills 3.8µ) and point fragment (Bodie Hills 4.1µ) at depth representing Intermediate phase of Middle Horizon (AD 100 to 300, Scheme B). Coll 1938 by F Fenenga. Comment (JAB): older range of date is acceptable.

UCR-219. CA-Sac-60, Burial 38-21  
1200 ± 150
Human bone collagen, 163cm depth in midden from Site CA-Sac-60. Assoc with slate pendants, rib sudatores, and spatulae diagnostic of Intermediate phase of Middle Horizon (AD 100 to 300, Scheme B). Coll 1938 by F Fenenga. Comment (JAB): date rejected as too young; discordant by depth with UCR-218.

UCR-217. CA-Sac-43, Burial 12  
1320 ± 150
Human bone collagen, 76cm depth in midden deposit at Site CA-Sac-43 (38° 28' N, 121° 31' W) lower Sacramento Valley. Assoc with obsidian point (Mt Hicks 3.5µ) at depth representing Terminal phase of Middle Horizon (AD 500 to 700, Scheme B). Coll 1939 by F Fenenga. Comment (JAB): mean date acceptable.

UCR-227. CA-Sac-43, Burial 14  
1080 ± 150
Human bone collagen, 107cm depth in midden at Site CA-Sac-43. Assoc with Olivella full and square saddle beads and square abalone ornament diagnostic of Late phase of Middle Horizon (AD 300 to 500, Scheme B). Coll 1939 by F Fenenga. Comment (JAB): date rejected as too young; discordant by depth with UCR-217, -220, -221, -222, -229, -230.

UCR-221. CA-Sac-43, Burial 34  
1900 ± 150
Human bone collagen, 48cm depth in midden at Site CA-Sac-43. Assoc with Olivella square saddle and small saucer beads diagnostic of Terminal phase of Middle Horizon (AD 500 to 700, Scheme B). Coll 1939 by F Fenenga. Comment (JAB): date rejected as too old; discordant by depth with 7 other Sac-43 dates. Date would support Scheme A (400 BC to AD 1).
UCR-228. CA-Sac-43, Burial 36 980 ± 150
Human bone collagen, 91cm depth in midden at Site CA-Sac-43. Assoc with abalone ornaments and *Olivella* full saddle and small saucer beads indicative of transition from Late to Terminal phase of Middle Horizon (ca AD 500, Scheme B). Coll 1939 by F Fenenga. *Comment* (JAB): date rejected as too young; discordant by depth with UCR-217, -221, -222.

UCR-229. CA-Sac-43, Burial 48 1360 ± 150
Human bone collagen, 97cm depth in midden from Site CA-Sac-43. Assoc with obsidian point (Napa 3.4μ) and *Olivella* full saddle and square saddle beads diagnostic of Late phase of Middle Horizon (AD 300 to 500, Scheme B). Coll 1939 by F Fenenga. *Comment* (JAB): older range of date acceptable.

UCR-230. CA-Sac-43, Burial 50 1140 ± 150
Human bone collagen, 91cm depth in midden from Site CA-Sac-43. Assoc with obsidian point (Napa 2.5μ), many bone tools, and *Olivella* full saddle, square saddle, and small saucer beads indicative of transition from Late to Terminal phase of Middle Horizon (ca AD 500, Scheme B). Coll 1939 by F Fenenga. *Comment* (JAB): date rejected as too young; discordant by depth with UCR-217, -221, -222.

UCR-220. CA-Sac-43, Burial 69 780 ± 130
Human bone collagen, 64cm depth in midden at Site CA-Sac-43. Individual killed by obsidian point (Napa 3.4μ) through manubrium; depth represents Terminal phase of Middle Horizon (AD 500 to 700, Scheme B). Coll 1939 by F Fenenga. *Comment* (JAB): date rejected as too young on basis of depth, assoc, and obsidian hydration value.

UCR-222. CA-Sac-43, Burial 25 1170 ± 150
Human bone collagen, 84cm depth in midden from Site CA-Sac-43. Assoc with obsidian point (Napa 3.2μ), basalt point, and abalone ornament diagnostic of Terminal phase of Middle Horizon (AD 500 to 700, Scheme B). Coll 1939 by F Fenenga. *Comment* (JAB): older range of date acceptable.

*General Comment* (JAB): review of some 150 radiocarbon dates from central California suggests that the current chronology (Scheme A: Middle Horizon falls between 1000 BC to AD 300) should be shortened (Scheme B: Middle Horizon falls between 500 BC to AD 900). Many dates, particularly from bone collagen, do not agree with either dating scheme. The 8 collagen dates reported from CA-Sac-43 are chaotic in terms of depth, assoc, and obsidian hydration values; a series of 6 collagen dates from CA-Sac-145 (2 herein) is similarly discordant, while UCR-226 and -219 are impossibly late.

**Vandenberg Air Force Base Project series**

Testing and evaluation of archaeological sites within 33.7km sq area of Vandenberg Air Force Base, Santa Barbara Co, was conducted by Univ California, Santa Barbara and supported by US Dept Interior, Natl Park...
Service. Charcoal and marine samples were submitted from 12 sites that demonstrate considerable depth, complexity, seasonal and/or specialized activities, and temporal uniqueness (Spanne and Glassow, 1975). Samples collected in 1974 and submitted by M Glassow and P Martz.

**UCR-254. SBa 210, 180 to 200 cm**

*Haliotis cracherodii* and *Haliotis rufescens* from base of observed stratigraphic level in Unit 8 (34° 35' N, 120° 35' W). Comment (PM): indicates occupation during Hunting Transitional sequence (Greenwood, 1972; Rogers 1929).

**UCR-255. SBa 210, 340 to 360 cm**

*Mytilus californianus* associated with Feature 13, rocks and sea mammal bone from Unit 8. Comment (PM): date is anomalous as it appeared stratigraphically above a more recent date. Rodent disturbance may have caused mixing resulting in misassociation of sample. Additional *Mytilus californianus* sample was collected from column sample for this depth (UCR-299, this list) which produced a date correlating with stratigraphy and artifact assemblage, placing occupation somewhat earlier within Hunting-Transitional sequence.

**UCR-257. SBa 530**

*Mytilus californianus* coll from base of site deposit at 100 to 120 cm (34° 36' N, 120° 38' W). Comment (PM): site is buried beneath stabilized sand dune on sea cliff. Date indicates occupation during Millingstone sequence (Wallace, 1955).

**UCR-258. SBa 551, 80 to 100 cm**

*Haliotis cracherodii* coll from concentration in Unit 1 (34° 36' N, 120° 38' W). Comment (PM): indicates occupation during Hunting-Transitional sequence. Charcoal sample (UCR-259, 690 ± 150 BP) was also submitted from this depth and gave more recent date. As shell was carefully treated to remove calcium carbonate contamination and upwelling is not considered a problem along this coastline, charcoal date is suspect. Site was subject to extensive rodent activity and charcoal may have filtered down from above.

**UCR-259. SBa 551, 80 to 100 cm**

Charcoal taken from sea-mammal bone concentration in Unit 5. Comment (PM): date appears too recent for depth and associated artifact assemblage as observed in sites throughout area (Martz, ms).

**UCR-260. SBa 552, 140 to 160 cm**

Charcoal coll from concentration in Unit 1 (34° 38' N, 120° 35' W). Comment (PM): indicates occupation during Hunting-transitional sequence.

**UCR-261. SBa 552, 160 to 180 cm**

*Mytilus californianus* coll from Unit 1 above compacted surface (floor). Comment (PM): indicates occupation near beginning of Hunting-Transitional sequence.
UCR-262. SBa 552, 260cm
Charcoal assoc with Feature 4, metate and mano concentration. Comment (PM): illustrates stratigraphy of site with occupation near end of Millingstone sequence.

UCR-263. SBa 552, 520cm
Mytilus californianus coll from base of deposit. Comment (PM): date indicates occupation well within Millingstone cultural sequence.

UCR-264. SBa 662
Haliotis cracherodii from compacted surface in Unit 5, 80 to 100cm (34° 35' N, 120° 38' W). Comment (PM): indicates occupation during Hunting-Transitional sequence.

UCR-265. SBa 670
Charcoal coll immediately above base of deposit (34° 36' N, 120° 37' W). Comment (PM): date places occupation within Phase I of Chumash sequence (Gibson, ms).

UCR-266. SBa 690
Charcoal assoc with Feature 1, concentration of fire-cracked rock at base of deposit (60cm) (34° 41' N, 120° 35' W). Comment (PM): date places occupation within Phase I of Chumash sequence.

UCR-267. SBa 712
Mytilus californianus coll from base of deposit at 100cm (34° 33' W, 120° 37' W). Comment (PM): date indicates occupation during Millingstone sequence.

UCR-268. SBa 931
Mytilus californianus coll from base of deposit at 160cm (34° 41' N, 120° 35' W). Comment (PM): indicates occupation during Millingstone sequence.

UCR-269. SBa 1010
Mytilus californianus coll from base of deposit at 182 to 243cm (34° 46' N, 120° 29' W). Comment (PM): indicates occupation at this depth during Hunting-Transitional sequence.

UCR-270. SBa 1118
Mytilus californianus coll from base of deposit at 60cm (34° 33' N, 120° 37' W). Comment (PM): places occupation within Phase I of Chumash sequence.

UCR-271. SBa 663
Mytilus californianus coll from base of deposit at 120cm (34° 35' N, 120° 37' W). Comment (PM): places occupation within Phase I of Chumash sequence.
UCR-298. SBa 210 4320 ± 200
Mytilus californianus coll from Unit 8 column sample at base of deposit at 520 to 540 cm (34° 33' N, 120° 35' W). Comment (PM): dated to verify UCR-299.

UCR-299. SBa 210 3530 ± 200
Mytilus californianus coll from Unit 8 column sample at 340 to 360 cm. Comment (PM): date fits stratigraphic sequence and shows UCR-255 is anomalous date, probably due to misassoc of sample caused by rodent disturbance. General Comment (PM): this series of dates from several diversified sites, and especially those from two large coastal villages (SBa 210 and SBa 552) which have considerable depth (>5m) and heavy cultural density, provide exceptional opportunity for further understanding of cultural processes.

Because many of the artifacts found in these sites such as manos do not change through time and could represent seasonal activities rather than chronology, California coastal middens probably were quite homogeneous through time with no significant change in cultural residues until Late Horizon (post 1500 BP) when there is greater diversity and variation in beads and other artifact types (Meighan, 1959).

At least three cultural sequences can be distinguished from radiocarbon dates and assoc artifact assemblages from Vandenberg series. Millingstone cultural sequence demonstrates emphasis upon seed processing. A large proportion of manos and metates and rare hunting implements are assoc with radiocarbon dates at ca 7000 to 9000 BP. Hunting or Intermediate period is distinguished by absence of hook and line fishing, and artistic elaboration, less emphasis upon seed collecting, and improved hunting methods involving better implements and greater variety of fauna. Time span at Vandenberg appears to be ca 2500 to 7000 BP. Chumash cultural sequence is primarily distinguished by artifacts relating to hook and line fishing and many bead varieties, which are found in assoc with post AD 500 dates (Martz, 1975).

Newport Bay series
Samples coll during excavations by Chapman Coll and Cypress Coll at Ca-Ora-119, Orange Co (33° 39' N, 117° 51' W). Material inventory indicates two components (Late Prehistoric Horizon and Intermediate Horizon) and some evidence for third component (Milling Stone Horizon). Samples coll 1975 and subm by H C Koerper, Dept Anthropol, Univ California, Riverside.

UCR-316. Burial 1, 53 to 80 cm 390 ± 140
Human bone collagen (left femur) from Burial 1, intrusive burial, at Site Ca-Ora-119, adjacent to Univ California, Irvine. Comment (HCK): sample should date late component at site attributed to Late Prehistoric Horizon.

UCR-310. 0 to 20 cm 1670 ± 160
Marine shell (Chione californiensis) from W sidewall, Pit 0-15.
UCR-311. 20 to 40cm 1560 ± 150
Marine shell (Chione californiensis) from W sidewall, Pit 0-15.

UCR-308. 40 to 60cm 2070 ± 150
Marine shell (Chione californiensis) from W sidewall, Pit 0-15.

UCR-309. 60 to 80cm 1870 ± 160
Marine shell (Chione californiensis) from W sidewall, Pit 0-15.

UCR-307. 80cm 5750 ± 170
Marine shell (Chione californiensis) from Pit I, 80cm. Comment (HCK): sample should date either terminal Milling Stone Assemblages Horizon component or early Intermediate Cultures Horizon component.

UCR-277. Huntington Beach 4340 ± 200
Marine shell carbonate at 30 to 50cm level at CA-Ora-82 (34° 40’ W, 118° 0’ W) Huntington Beach, Orange Co. Coll 1974 and subm by L Savio, Pacific Coast Archaeol Soc.

Casa Diablo series
The Archaeological Research Unit, Dept Anthropol, Univ California, Riverside, conducted archaeol investigations during 1974 to mitigate impact of construction of power transmission line by Southern California Edison Co along 44km corridor in Inyo and Mono Cos in SE California. Radiocarbon and obsidian hydration samples were obtained to clarify chronologic questions. Samples subm 1974 by R Cowan, Archaeol Res Unit, Univ California, Riverside.

UCR-245. Rutabaga Hill 280 ± 150
Charcoal from 25 to 35cm level at Site 14, Rutabaga Hill (37° 40’ N, 118° 35’ E). Coll 1974 by R Cowan.

UCR-246. Rutabaga Hill <150
Charcoal from 40 to 50cm level at Site 14. Coll 1974 by R Cowan.

UCR-247. Site 13.5 1300 ± 150

UCR-248. Watterson Trough 250 ± 130
Charcoal from 20 to 30cm level from Site 23 (37° 40’ N, 118° 35’ E). Coll 1974 by K Collins.

Nevada
UCR-160. Fremont Point 1120 ± 180
Arizona

Chevelon series

Four dry cave or rockshelter sites were excavated in Chevelon Canyon, N central Arizona, in order to compare samples of stratified cultural and biological remains from both cultural and noncultural contexts. Samples subm by F Briuer, Dept Anthropol, Univ California, Los Angeles.

UCR-210. Site 561A, 40 to 50 cm 2900 ± 300

Assorted vegetation (Juniperus sp, Opuntia sp, Artemisia sp, Juglans major, Nolina sp, Yucca sp, Pinus edulis) from Site 561A, Chevelon Canyon (34° 38' N, 110° 42' W) 64 km S of Winslow. Coll 1972 by F Briuer and S de Atley. Comment (FB): plant microfossils, pollen, and faunal remains from this noncultural site were compared with plant and animal remains at a nearby cultural site.

UCR-211. O'Haco Rock Shelter <200

Woodrat (Neotoma sp) and mouse (Peromyscus sp) feces from St 2 containing a high concentration of artifacts and ecofacts in rock shelter (34° 39' N, 110° 43' W) Chevelon Canyon. Coll 1972 by F Briuer.

UCR-231. O'Haco Rock Shelter 4170 ± 200

Charcoal in ash from Unit 9, St 4, one of the lowest strata containing clear evidence of human activities. Coll 1972 by F Briuer.

New York

Smith Farm series

Samples coll during test excavations at Smith Farm, Otego, New York (42° 23' N, 75° 11' W) as part of preliminary study of sites threatened by construction of Interstate 88. Samples coll 1973 by J C Weber and subm by M C Stewart and M L Weide, State Univ New York, Binghamton.

UCR-284. Locus 1, Feature 4 550 ± 160

Charcoal from Sq E8/S8, Level II.

UCR-285. Locus 1, Feature 3 1290 ± 150

Charcoal from Sq E8/S6, Level III.

UCR-286. Locus 1, Feature 12 760 ± 150

Charcoal from Sq E12/S12, Level II. Comment (MW): Smith Locus 1 (SUB i-25) was occupied during Middle to Late Woodland times. UCR-284 dates material assoc with Chance Phase ceramics and is consistent with other dates for this phase. UCR-285 and -286 suggest that occupation begun in Middle Woodland period, recurred in Owasco phase of Late Woodland.

UCR-287. Locus 2 2060 ± 160

Charcoal from Sq E68/S65, at 40 cm, assoc with flint chips from Level III. Comment (MW): single determination from Smith Locus 2 (SUB i-26)
falls into Early Woodland period and is later than expected for Late Archaic-Transitional assignment expected from cultural remains.

UCR-288. **Locus 6, Stratum 3**  
Charcoal from Sq E234/S41, at 73cm depth, assoc with fire-cracked rock, lithics, and possible Point Peninsula ceramic vessel.

UCR-289. **Locus 6, Stratum 4**  
Charcoal from Sq E234/S41 at 85 to 88cm depth at base of Point Peninsula level.

UCR-290. **Locus 6, Feature 1**  
Charcoal from Sq E230-232/S39, at 65 to 70cm depth, assoc with fire-cracked rock. Comments (MW): three dates from Smith Locus 6 (SUB i-37) are consistent with Early to Middle Woodland assignment based on assoc with early Point Peninsula pottery. UCR-288 and -289 suggest that dentate-stamped pottery was being made 200 yr earlier in Upper Susquehanna drainage than previously dated at Cottage site, 1810 ± 100 BP (Y-2348).

**B. Israel**

UCR-276. **Quesarya**  
Human bone collagen from burial, 125cm below surface at Quesarya (Caesarea Maritima). Coll 1972 and subm by J H Stirling, Loma Linda Univ, Loma Linda, California.

**C. Africa**

**Mumbwa Caves series**

Samples from Mumbwa Caves (14° 59′ S, 27° 05′ E) Zambia, S central Africa were measured to date lithic assemblages of a major archaeol site known to contain Middle Stone Age—Later Stone Age—Iron Age sequence.

Previous excavations were made in 1930 and 1939 within a deep cave in N portion of dolomitic limestone outcroppings (Dart and del Grande, 1931; Clark, 1942). Recent radiocarbon dates (UCLA-1750B, -1750C, -1750D) on hominid and faunal remains from lowest levels of 1930 excavations indicate that a portion of Middle Stone Age horizon may date to 20,000 to 18,000 BP (Protsch, ms).

Excavations were made in 1973 within bedrock solution cavities in front of a shallow cave in outcrop to S of main cave (Savage, ms in preparation). The following radiocarbon dates were obtained from this excavation. Coll 1973 by D K Savage and subm by G Isaac, Dept Anthropol, Univ California, Berkeley.

UCR-272. **Square D**  
Charcoal from red-brown earth layer of Sq D, 10 to 40cm below surface, containing potsherds, but few quartz artifacts. Paucity of charcoal necessitated combining samples from entire level. Two runs on sample from level below in same square (LJ-2987 and -3031) also
produced younger than expected dates and suggests some disturbance in this square.

UCR-273. Square G 2250 ± 160
Charcoal from red-brown earth layer of Sq G, 20 to 50cm below surface, containing pottery, iron, and quartz artifacts. Comments (DS): sample was obtained primarily from badly disintegrated and scattered hearth at ca 40cm below surface and dates presence of iron at site.

UCR-274. Square I 500 ± 130
Charcoal from top portion of red-gritty layer of Sq I, 156 to 195cm below surface. Paucity of charcoal again necessitated combining wide dispersion of charcoal to date main Later Stone Age occurrence. Comments (DS): reason for anomalous date is unknown.

UCR-275. Square M 9000 ± 370
Charcoal from pocket within middle portion of red-gritty layer in Sq M at 149cm below surface. Comment (DS): date is further supported by LJ-2988 and -2989 from same level in different square, and dates late Middle Stone Age horizon with some microliths, heavy-duty grinding and baking equipment, and a small hand-axe.

II. PALEOENVIRONMENTAL SAMPLES

A. United States

Lucerne Valley series
Stratified midden (GM-5) of wood rat (Neotoma) under overhang on S facing granitic outcropping on Negro Butte (34° 29' N, 116° 46' E) Lucerne Valley, alt 1006m, was excavated by trenching to provide series of stratigraphically controlled samples (King, 1976). Series obtained as part of paleoclimatic study of late Pleistocene and Holocene periods in W Mohave Desert of interior S California. Determinations listed here are continuation of those reported in UCR II (R, 1975, v 17, p 405-406). Samples coll 1974 and subm by T Jackson King, Jr and R E Taylor, Dept Anthropol, Univ California, Riverside.

UCR-235. Level F 3650 ± 210
Twigs and stems from upper portion of Level F, 10cm from midden face, 1m E of W face of trench.

UCR-236. Level F 3750 ± 210
Twigs and stems from lower portion of Level F, external central face of midden, ca 10cm below UCR-235, 1m E of W face of trench.

UCR-237. Level D 3690 ± 210
Twigs and stems from Level D, external central face of midden, ca 15cm below UCR-236, 1m E of W face of trench.
UCR-239. Level G  4300 ± 240
Twigs and stems from lower portion of Level G, 20cm W of E face of trench.

UCR-241. Level G  7100 ± 250
Twigs and stems from Level G, 10cm from midden face, ca 50cm W of E face of trench, 20cm above UCR-239.

UCR-187. Level B  11,100 ± 420
Juniper (Juniperus osteosperma) seeds from Level B, 10cm below UCR-185.

UCR-186. Level C  8300 ± 780
Juniper (Juniperus osteosperma) twigs and seeds from Level C, 50cm from face of midden.

UCR-185. Level C  7820 ± 570
Twigs of various sp directly above juniper-bearing portion of upper layer in Level C.

UCR-249. Level C  7800 ± 350
Juniper (Juniperus osteosperma) seeds and twigs from Level C.

UCR-176. Black Butte B-13  <150

UCR-190. Yuba, Sacramento Valley  10,600 ± 900
Dispersed carbon in drilled core from 51m depth, 3.2km NE of Live Oak (39° 12' N, 121° 36'). Coll 1974 by E Porter; subm by D Packer, Woodward Clide Consultants, Oakland, California.

UCR-191. Yuba, Sacramento Valley  3860 ± 900
Dispersed carbon in drilled core from 38m depth, 6.4km NE of Live Oak, California. Coll 1974 by T Bruce and P Corbett; subm by D Packer.

B. Nicaragua

UCR-189. Villa Fontana  <150
Wood above air fall tuff in alluvial fan from Villa Fontana, Managua (12° 12' N, 86° 24' E) assoc with recent (1000 to 25,000 yr) volcanic activity. Coll 1974 by L Hintze; subm by D Packer.

References
Clark, J D, 1942, Further excavations (1939) at the Mumbwa Caves, Northern Rhodesia: Royal Soc South Africa Trans, v 29, pt 3, p 133-201.


Meighan, C W, 1959, California cultures and the concept of an archaic stage; Am Antiquity, v 24, p 289-305.


Rogers, D B, 1929, Prehistoric man from the Santa Barbara coast: Santa Barbara Mus Nat Hist, Santa Barbara, California.


UNIVERSITY OF WATERLOO RADIOCARBON DATES I

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Department of Earth Sciences, University of Waterloo
Waterloo, Ontario, Canada

The radiocarbon dating laboratory is part of the Department of Earth Sciences, University of Waterloo. The natural level radio-isotope facility, built in the spring of 1974, was built primarily for dating ground-water and a combustion line for organic samples was added in 1975.

The method employed is liquid scintillation counting on synthesized benzene in a refrigerated Intertechnique SL-30 counter. Four grams of sample, diluted with reagent grade benzene, if necessary, are weighed into an Amersham nylon vial containing 40mg of solid Butyl PBD scintillator. Ten vials, selected for their low backgrounds, are used repetitively, alternating sample analysis with background determinations. Each vial has a discrete background (range 3.25 to 3.44cpm) and was therefore given an identifying letter. Samples are counted for 1500 to 2500 minutes depending on their size and activity. Backgrounds, standards, and samples are counted sequentially at 100-minute intervals.

Radiocarbon dates in this list are based on 95\% activity of NBS oxalic acid as modern standard, using the Libby half-life (5568±30) with a 2-sigma counting error including variations in the sample and background. Current oxalic acid standard value is normalized for $\delta^{13}C = -19.0\%$ PDB according to Craig (1961). Carbon-13 determination for each sample is done on a Varian Mat GD-150 mass spectrometer or more recently on a Micromass 602D-TWIN.

Sample types include 1) BaCO$_3$, obtained by precipitating the total inorganic carbonate in water samples with BaCl$_2$·2H$_2$O in an alkaline medium (pH~12), achieved with carbonate free NaOH, 2) rock carbon, 3) organic matter in sediment samples, and 4) “pure” organic matter such as peat and wood. CO$_2$ is produced from the barium carbonate and rock samples with 50\% H$_3$PO$_4$. No pretreatment is required.

Pretreatment of combustible samples consists of removing all visible contaminants as well as hot NaOH and HCl rinses to remove humic compounds and inorganic carbon. Samples are dried overnight at 110°C. Carbon dioxide is produced by direct combustion in a stream of purified oxygen. Gas contaminants are removed as the CO$_2$ is passed through a MnO$_2$ and CuO (500°C) furnace and KMnO$_4$ and H$_2$O bubblers. A dry-ice methanol cooled trap desiccates the carbon dioxide and two liquid nitrogen cooled traps collect the CO$_2$. Carbon dioxide is further desiccated by sublimation from the collection traps at methanol-dry-ice temperatures. The CO$_2$ of all samples is transformed to acetylene by Li$_2$C$_2$. Trimerization takes place on a catalyst of Mobil Durabead 1 which has been activated at 250°C under vacuum overnight.

Measurements presented below were determined during 1975-1979. Only the organic sample results are published. Results after WAT-318
have been normalized to a $\delta^{13}C = -25$% PDB. The descriptions of the samples are based on information provided by the submitters.

ACKNOWLEDGMENTS

We wish to thank the National Research Council of Canada for financial support to several faculty members in the Department of Earth Sciences at the University of Waterloo; including grants to Anne Morgan and A V Morgan (A8294), P F Karrow (A5245), and our supervisor, Peter Fritz (A7954).

We are also indebted to the collectors and submitters for their sample descriptions and comments and to Marjorie Roberts for her typing.

I. INTERLABORATORY CHECK SAMPLES

A. France

**WAT-40. Biscaye Gulf**

$18,400 \pm 2000$

$\delta^{13}C = +0.78$%

Rock sample subm 1974 by J C Fontes, Paris, France. Age given by Fontes was 10,350±350. Waterloo lab crushed sample to -140 mesh, whereas Paris lab did not. This difference in sample preparation is possible reason for incompatible dates.

B. Britain

**WAT-64. Broxbourne, Hertfordshire**

$3640 \pm 200$


C. United States

**WAT-57. Wisconsin**

$11,870 \pm 170$


**WAT-244. Wisconsin**

$11,440 \pm 200$

$\delta^{13}C = -26.3$%


**WAT-72. Ausable River, Michigan**

$4020 \pm 30$

$\delta^{13}C = -25.1$%

Wood from enclosing material of silty clay 12km W of Oscada, Michigan (44° 25' N, 83° 28' W). Subm by A V Morgan. Comment (AVM): date agrees well with log taken from same sec (I-8736: 4130±90; Elias, Morgan, and Morgan, 1981). Date is approx for river deposits grading into Lake Nipissing.
Jeanne C Berry and Robert J Drimie

70

WAT-117.  Mahomet, Illinois


WAT-311.

CO₂ combined from two combustions. See WAT-176.

WAT-463.

See WAT-176.

D. Canada

WAT-119.  British Columbia

WAT-130.

See WAT-119. Sample washed again.

WAT-199.

See WAT-119. Combusted without auxiliary oven.

WAT-76.


WAT-202.

See WAT-76.

II. GEOLOGIC SAMPLES

A. Canada

Lake Ontario series
Silty clay lake sediment core samples from Lake Ontario, Ontario (43° 30.2' N, 76° 55' W); dated to determine sedimentation rates. Coll

WAT-134. E-30
Sample from 0 to 10cm depth.

WAT-144. E-30
Sample from 10 to 15cm depth.

WAT-136. E-30
Sample from 15 to 20cm depth.

WAT-140. E-30
Sample from 20 to 25cm depth.

WAT-120. E-30
Sample from 40 to 45cm depth.

WAT-142. E-30
Sample from 55 to 60cm depth.

WAT-143. E-30
Sample from 65 to 70cm depth.

WAT-156. E-30
Sample from 70 to 80cm depth.

WAT-128. E-30
Sample from 80 to 85cm depth.

WAT-217. E-30
Sample from 85 to 90cm depth.

WAT-145. E-30
Sample from 90 to 95cm depth.

WAT-116. E-30
Sample from 105 to 110cm depth.

WAT-138. E-30
Sample from 120 to 125cm depth.
<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Series</th>
<th>Depth Range</th>
<th>Sample Description</th>
<th>δ¹³C Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAT-98.</td>
<td>E-30</td>
<td>125 to 135 cm</td>
<td>Sample from 125 to 135 cm depth. CO₂ combined from three combustions.</td>
<td>δ¹³C = -28.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-29.1‰</td>
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<tr>
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<td></td>
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<td>-28.9‰</td>
</tr>
<tr>
<td>WAT-93.</td>
<td>E-30</td>
<td>140 to 150 cm</td>
<td>Sample from 140 to 150 cm depth.</td>
<td>δ¹³C = -28.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-28.9‰</td>
</tr>
<tr>
<td>Lake Erie series</td>
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<tr>
<td>Silty clay lake sediment core samples from Lake Erie, Ontario (45° 39.5' N, 79° 39.5' W); dated to determine sedimentation rates. Coll 1973 by A W L Kemp; subm 1975 by R J Drimmie. Comment (RJD): dates were much older than expected.</td>
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<tr>
<td>WAT-190.</td>
<td>M-32</td>
<td>0 to 25 cm</td>
<td>Sample from 0 to 25 cm depth.</td>
<td>δ¹³C = -27.2%</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-29.7‰</td>
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<td></td>
<td>-26.8‰</td>
</tr>
<tr>
<td>WAT-250.</td>
<td>M-32</td>
<td>30 to 55 cm</td>
<td>Sample from 30 to 55 cm depth.</td>
<td>δ¹³C = -28.2%</td>
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<td>-28.1‰</td>
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<td></td>
<td></td>
<td></td>
<td>-29.2‰</td>
</tr>
<tr>
<td>WAT-251.</td>
<td>M-32</td>
<td>60 to 85 cm</td>
<td>Sample from 60 to 85 cm depth.</td>
<td>δ¹³C = -27.8%</td>
</tr>
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<td></td>
<td>-27.8‰</td>
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<td></td>
<td></td>
<td>-28.3‰</td>
</tr>
<tr>
<td>WAT-225.</td>
<td>M-32</td>
<td>90 to 115 cm</td>
<td>Sample from 90 to 115 cm depth.</td>
<td>δ¹³C = -27.9%</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>-23.5‰</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>-24.7‰</td>
</tr>
<tr>
<td>Gage Street, Kitchener series</td>
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</tr>
<tr>
<td>Samples from Gage Street, Kitchener, Ontario (43° 26' 48&quot; N, 80° 31' 35&quot; W); dated to establish chronology for beetle stratigraphy. Site was severely disturbed stand of swamp composed of Thuja occidentalis L. Coll from an excavated face. Coll and subm 1975 by D P Schwert, Depth Earth Sci, Univ Waterloo.</td>
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<tr>
<td>WAT-166.</td>
<td></td>
<td>4.5 to 4.64 m</td>
<td>Marl with included plant organics at depth 4.5 to 4.64 m. Acid added for five hr to obtain date based on calcite/dolomite. Comment (DPS): expected date: 12,300 yr.</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>δ¹³C = -0.5‰</td>
</tr>
<tr>
<td>WAT-169.</td>
<td></td>
<td></td>
<td>See WAT-166. Acid added for nine min to obtain date based on calcite fraction.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>δ¹³C = -0.5‰</td>
</tr>
</tbody>
</table>
WAT-249.  
$\Delta^{13}C = -28.7\%$
Plant detritus from depth 1.04 to 1.14m. Enclosing material was marl. Comment (DPS): expected date: 6900.

WAT-263.  
$\Delta^{13}C = -27.8\%$
Plant detritus from depth 2.26 to 2.36m. Enclosing material was marl. Comment (DPS): expected date: 8800.

WAT-265.  
$\Delta^{13}C = -28.5\%$
Peat with wood from depth 0.74 to 0.84m. Comment (DPS): expected date: 6900.

WAT-287.  
$\Delta^{13}C = -34.6\%$
Plant detritus from depth 3.68 to 3.79m. Enclosing material was saturated marl. Comment (DPS): expected date: 11,200.

WAT-298.  
$\Delta^{13}C = -27.5\%$
Plant detritus from depth 3.28 to 3.38m. Enclosing material was saturated marl. Comment (DPS): expected date: 10,700.

WAT-297. Blackwell  
$\Delta^{13}C = -25.9\%$

WAT-301.  
See WAT 297.

WAT-307.  
$\Delta^{13}C = -26.6\%$

WAT-310. Guelph  
$\Delta^{13}C = -26.5\%$
Organic silt from E outskirt of Guelph, Ontario (43° 33' N, 80° 14' W). Dated because paleosols are rare and buried (sub-till) organics are unusual. Coll 1975 and subm 1977 by P F Karrow. Comment (PFK): date places peat in middle Wisconsinan or older age range as expected and negates possibility of severe contamination.

WAT-367.  
See WAT-310.
**WAT-343. Cootes Paradise, Hamilton**

$4400 \pm 50$

$\delta^{13}C = -20.7\%o$

Wood from Cootes Paradise, Hamilton, Ontario ($43^\circ 17' 20''$ N, $79^\circ 53' 50''$ W). Sample found 18.6m below water surface and 18.1m below sediment surface. Measured to date aggradation during isostatic raising of lake Ontario outlet. Coll 1969 by R C La Forge; subm 1977 by P F Karrow. *Comment* (PFK): result is consistent with earlier dates from Burlington Bar at similar levels (Karrow, Clark, and Terasmae, 1961).

**WAT-493. Minesing**

$10.280 \pm 100$

$\delta^{13}C = -27.5\%o$

Wood from sand and gravel deposit, Minesing, Ontario ($44^\circ 11' N$, $79^\circ 57' W$). Sample 1 to 2m below buried woody peat deposit, which was in turn buried by 1m alluvial sand-silt. Coll and subm 1979 by W D Fitzgerald, Dept Earth Sci, Univ Waterloo. *Comment* (WDF): dated to provide max age of overlying peat deposit and enable correlation of pollen diagram with other pollen diagrams in S Ontario. Age was very close to expectation.

**WAT-507. Minesing Swamp**

$6170 \pm 70$

$\delta^{13}C = -25.3\%o$

Wood from Minesing Swamp, Ontario ($44^\circ 30' N$, $79^\circ 47' W$). Coll 1978 by W D Fitzgerald from borehole at depth 3.4m, composed of wet silty clays, shells and organics. Subm 1979 by W D Fitzgerald. *Comment* (WDF): dated to aid pollen correlation, sedimentation rate of material above sample, and age of shells for correlations with shell assemblages of other sites. Age corresponds with hemlock (Tsuga) peak in pollen diagram, considered ca 6000 to 7000 yr.

**WAT-559. Minesing site**

$4230 \pm 70$

$\delta^{13}C = -8.9\%o$

Clam shells from edge of road in ditch; 2.3km WSW of village of Minesing, Ontario ($44^\circ 26' N$, $79^\circ 52' W$). Cochina of shell from ground surface to ca 0.6m below in sandy soil matrix. Coll and subm 1979 by P F Karrow, W D Fitzgerald, and R F Miller to date shells for data on paleobiogeography. *Comment* (PFK): dates lake stage in Minesing basin equivalent to Nipissing stage of Lake Huron.

**WAT-567. Richmondville**

$5270 \pm 70$

$\delta^{13}C = -24.7\%o$

Wood from Richmondville Quad, Lake Huron Shorecliff, 1.6km S of Richmondville North Center, Ontario ($43^\circ 33' 30'' N$, $82^\circ 35' 10'' W$). Sample from wet green silt underlying 2.3m stratified sand and gravel. Silt is 1.5m thick with 3.6m slump covered sec below to beach level. Coll 1979 by P F Karrow and D F Eschman, Dept Geol, Univ Michigan; subm 1979 by P F Karrow. *Comment* (PFK): overlying sand contained shells (*Goniobasis livescens*); Nipissing age was expected and confirmed by date.
Manitoulin Island, Greenbush Swamp, 5th Concession series

Samples from Greenbush Swamp, dist Manitoulin, Ontario (54°56’ N, 82°00’ 30” W). Coll and subm 1979 by B G Warner, Dept Biol, Univ Waterloo. Comment (BGW): all dates seem reasonable and agree well with regional history and pollen stratigraphy (R, 1961, v 3, p 49). Dated to understand vegetational history, paleoecology, and wetland succession of Greenbush Swamp, Manitoulin I.

**WAT-571.**

7570 ± 170
\[ \delta^{13}C = -22.8\% \]

Gray gyttja from core; total length, 150cm. From extreme E side of swamp along road. Deposit was 142 to 148cm below surface at base of gyttja unit.

**WAT-574.**

6790 ± 100
\[ \delta^{13}C = -22.3\% \]

Coarse fibrous sedge peat from gyttja unit in stratigraphy, at 175cm below surface. Sample taken from bulk samples extracted from hand-dug pit. Total depth of core is 305cm. Sample located along extreme W side of swamp along road.

**WAT-579.**

9930 ± 90
\[ \delta^{13}C = -20.8\% \]

Gyttja from same core (pit) as WAT-574 at 235cm below surface immediately overlying sandy gravel deposit that is at least 70cm thick.

Loon Lake series


**WAT-550.**

3280 ± 150
\[ \delta^{13}C = -32.6\% \]

Iron-rich laminated gyttja. Comment (AMD): sediment is black, non-calcareous, and rich in iron. Vivianite \((\text{Fe}_3(\text{PO}_4)_2\cdot 8\text{H}_2\text{O})\) occurs sparingly throughout laminated parts of core. Varves consist of alternating pale and dark laminae and are distinctly preserved. Deposition should have taken place under strongly reducing and anaerobic conditions in monimolimnion. Age, ca 1650 BP, was expected from sample based on varve counting and estimate of sedimentation rate for upper 77cm of unlaminated sediments. \(^{14}C\) date is apparently too old.

**WAT-545.**

6320 ± 130
\[ \delta^{13}C = -30.7\% \]

Iron-rich, laminated gyttja (varves). Comment (AMD): sediment was so rich in iron that rusty crust of ferrous oxide formed on outside of core upon oxidation. Otherwise, same as WAT-550. Sample comes from base of varved sec which should date beginning of varve formation. \(^{14}C\) date is younger than varve date by ca 1000 yr, but is generally consistent with date obtained from top of same core (WAT-547).
WAT-546.
Black unlaminated gyttja. *Comment* (AMD): sediment is non-calcareous and should have been deposited under anaerobic conditions. 

$^{14}C$ date is stratigraphically consistent and acceptable.

WAT-547.
Iron-rich, laminated gyttja (varves). *Comment* (AMD): age of ca 5000 yr is expected based on varve counting and estimate of sedimentation rate for unlaminated upper part of core. Thus, $^{14}C$ date is younger than expected.

WAT-548.
Black unlaminated gyttja. *Comment* (AMD): sediment is non-calcareous and should have deposited under anaerobic conditions. Loon Lake is on Cartier I Moraine (Boissonneau, 1968) and lies within narrow belt that was deglaciated between ca 11,000 to 10,000 BP according to Saarnisto (1974). Sample comes from base of organic sediment and should yield min date for ice retreat from area. 

WAT-549.  Lake #6, Timmins  
Gyttja from Lake #6 (48° 23' 53" N, 81° 19' 28" W) ca 8km S of Timmins, Ontario. Coll and subm 1979 by K B Liu and A M Davis to obtain min date for draining of Glacial Lake Barlow-Ojibway in this area. *Comment* (AMD): date agrees with other dates reported from adjacent areas (Terasmae and Hughes, 1960).

WAT-563.  Pike Lake  
Gyttja from Pike Lake, Ontario (43° 57' N, 80° 49' W). Coll 1977 and subm 1979 by R A Penney, Dept Geog, Univ Toronto. Measured to date decline in pine pollen percentage, generally at ca 7300 to 7500 yr in S Ontario. *Comment* (RAP): date is acceptable particularly if hard water correction is used (surface standard at Edward Lake is 580 yr).

WAT-568.  Pike Lake  
Marl measured to date recovery of Tsuga pollen (Tsuga rise). See WAT-563. *Comment* (RAP): expected date, 3300 to 3500 yr. Date of 3780±70 is a bit old but hard-water effect may be responsible.

WAT-360.  Chilhil Lake  
Gray-brown clay gyttja from Chilhil Lake in Three Lakes Valley near Lillooet, British Columbia (50° 39' N, 121° 48' W). Lake bottom sediments were taken with 5cm diam piston corer. Coll 1977 by R W Mathewes and D McLennan; subm 1979 by R W Mathewes, Dept
Archeol, Simon Fraser Univ, British Columbia. Dated for basal date in lake core analyzed for pollen (White, Mathewes, and Mathews, 1979).

**WAT-361. Boone Lake**

<table>
<thead>
<tr>
<th>Date</th>
<th>Carbon Isotope</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;30,000</td>
<td>δ¹⁴C = -26.3‰</td>
<td></td>
</tr>
<tr>
<td></td>
<td>-26.9‰</td>
<td></td>
</tr>
</tbody>
</table>

Clay with organic content from basal clay of lake sediment core from Boone Lake, 19km N of Valhalla in Grande Prairie, Alberta (55° 34’ N, 119° 26’ W). Coll 1978 by J M White, Dept Archeol, Simon Fraser Univ, British Columbia and subm by R W Mathewes for basal date for lake core in area which may not have been covered by ice during late Wisconsin, nor inundated by glacial Lake Peace in early Holocene.

**WAT-362. Boone Lake**

See WAT-361. Sample taken from lake core 4.93 to 4.99m below modern sediment surface, just below clay lens 3cm thick. Sample is expected to date beginning of short period of inundation of lake by waters carrying heavy load of glacial sediment. This might represent meltwater from late ice advance from W.

**WAT-406. Boone Lake**

Gray clay with sand and minor organic fraction. *Comment* (JMW): date may have been made older by contamination with radiogenically dead carbon included in clay sediment as cretaceous-age organic detritus. Sample size was also very small.

**WAT-408.**

See WAT-406.

**Fiddlers Pond series**

Samples from Alberta Plateau 4.5km NE of Peace R-Halfway R confluence (56° 15’ 15” N, 121° 24’ 24” W). Pond sediment subm to obtain basal date of sediment core for pollen analysis. Coll and subm by J M White.

**WAT-380.**

Silty clay with organic fraction and some sand. *Comment* (JMW): date was expected to define final date of withdrawal of Glacial Lake Peace from Alberta Plateau and to fall in range >10,000 yr. It is now thought that formation of pond reflects some climatic event.

**WAT-551.**

See WAT-380. *Comment* (JMW): sample subm to control sedimentation rate in pond.
WAT-552.

Fibrous limnic peat with some sand. Comment (JMW): subm for controlling sedimentation rate in pond.

WAT-300. Kingston

Wood from Kingston Landfill site, Ontario (44° 12' N, 76° 30' W) from core of Cataraqui R bottom. Sample from 130cm depth below peat, overlying clay. Coll and subm 1976 by S K Frape, Dept Geol, Queen's Univ, Kingston, Ontario. Comment (SKF): dated to establish age of wood layer found throughout river bottom at this point. Wood layer is discontinuous but always found between clay and peat, and is believed to correspond to rise in Lake Ontario flooding of area, ca 4000 yr.

WAT-345. Medway Creek

Wood from W bank of Medway Creek, 100m S of W end of bridge on Hwy 22, NW London, Ontario (43° 01.2' N, 81° 18.3' W). Sample coll 2m below ground level from fresh, frozen face. Coll and subm 1978 by S R Hicock and Alexis Dreimanis, Dept Geol, Univ Western Ontario, London. Comment (SRH & AD): sample coll from wood layer within sandy pebble gravel, 1.5m thick, containing abundant mollusk. Gravel underlies 0.5m organic silt and peat (probably flood basin deposits) which is capped by 1m silty diamicton (probably mudflow deposit). Subm to learn if gravel is beach deposit assoc with Plum Point Interstadial, in which case it would have dated between 25,000 and 35,000 yr. However, in view of above date it appears to merely represent local creek bed deposit, at about same level as present. This indicates that Medway Creek shifted its bed laterally but accomplished negligible downcutting of its valley in past 1300 yr. It is presently a stable stream, near maturity, supported by sinuous meandering shape of its channel.

WAT-248. Parkhill

Spruce needles and some seeds from Borehole 234-75 at Parkhill, Ontario (81° 45' 25" W, 43° 10' 45" N, Grid Ref 392.826). From depth 7.6 to 7.8m below ground level in borehole. Comment (AVM): Chara oögonia in sample; subm to date advance of Lake Algonquin into Thedford embayment.

WAT-392. Parkhill

University of Waterloo Radiocarbon Dates I

B. United States

WAT-258. Muskoda, Minnesota

$\delta^{13}C = -26.3\%$

Wood from drainage ditch in gravel pit in Muskoda (46° 54' 29" N, 96° 24' 28" W). Coll and subm 1976 by Steve Moran, Univ North Dakota. Comment (SM): tills above and below sample are both probably of Late Wisconsinan age. Date should confirm this and give age of minor readvance during late Wisconsinan retreat.

33,800

$\delta^{13}C = -26.1\%$

WAT-243.

See WAT-258.

WAT-554. Harbour Beach

$\delta^{13}C = -0.47\%$

Shells (Goniobasis livescens) from small stream bank ca 1m deep and 10 to 20cm in from face in Harbour Beach, Michigan (43° 46' N, 82° 36' 10" W). Dated to determine if shells were of Nipissing age. Coll 1978; subm 1979 by P F Karrow. Comment (PFK): date confirms Nipissing age of deposit.

C. Britain

Stafford series


13,240 ± 290

$\delta^{13}C = -27.1\%$

Blue gray clay, pronounced detrital organic band at depth 18.9 to 18.95m in Core 'C'. Comment (AVM): age fits relatively well with sample run from same horizon (BIRM-150). Indicates approx time for start of deposition of organic debris at Stafford, following late Devensian ice retreat.

WAT-255.

12,070 ± 220

$\delta^{13}C = -31.0\%$

Blue gray clay with detrital organics at depth 18.85 to 18.9m in Core 'C'.

WAT-262.

9680 ± 140

$\delta^{13}C = -8.1\%$

Chara stalks at depth 13.95 to 14m. Comment (AVM): sample by gas evolution and acid digestion.
Jeanne C Berry and Robert J Drimmie

**WAT-267.**

Uniform green gyttja at depth 17.95 to 18.05m in Core 'C'.

**WAT-268.**

Yellow green silty gyttja from depth 5.95 to 6.1m in Core 'C'. Comment (AVM): repetition of pollen and diatom data suggests slumping. Sample is too young.

**WAT-269.**

Yellow-green silty gyttja at depth 3.95 to 4.1m in Core 'C'.

**WAT-274.**

Dark green-brown silty gyttja at depth 9.95 to 10.1m in Core 'C'.

**WAT-275.**

Fibrous Typha peat from depth 1.95 to 2.1m in Core 'C'.

**WAT-396.**

Green-yellow silty gyttja at depth 18.5 to 18.6m in Core 'C'. Comment (AVM): date is too young when compared with pollen stratigraphy.

**WAT-397.**

Alternating carbonate and organic rich bands at depth 13 to 13.15m in Core 'C'.

**WAT-398.**

Dark green-brown silty gyttja at depth 6.85 to 7m in Core 'C'.

**WAT-399.**

Uniform green gyttja at depth 17 to 17.1m in Core 'C'. Comment (AVM): date is too young when compared with pollen stratigraphy.
III. ARCHAEOLOGIC SAMPLES

A. Canada

WAT-189. Burlington, Ontario

Direct combustion of wood charcoal (N midden). It was predicted that careful excavation would show Woodland component over possibly sparse, Archaic component. Sample from Richardson Farm, Dundas, Ontario (43° 23' 55" N, 79° 49' 55" W); coll and subm 1976 by Arthur Roberts, Dept Geog, York Univ, Downsview, Ontario.

WAT-188.

Wood charcoal from S midden. See WAT-189.

L'anse aux Meadows site series, Newfoundland


WAT-496.

Base of peat, measured to date Pollen Zone A.

WAT-497.

Sample measured to date Pollen Zone A from S profile of Trench 4A715, 18m W of House D.

WAT-506.

Sample measured to date Norse level from E profile of Trench 4A71K, 3m W of House D.

WAT-409.

Peat, 0 to 20cm from base of Monolith 17; measured to date high pollen concentration in Pollen Zone B.

WAT-410.

Peat from base of Monolith 14; measured to date McAndrews A zone.

WAT-411.

Peat from base of Monolith 15; measured to date McAndrews A zone.

WAT-420.

Charred wood measured to date House D. Comment (BW): it is very possible that sample was contaminated with ancient carbon from oil derivatives.

WAT-306. Gwillim Lake, British Columbia

Charcoal from Gwillim Lake in NE British Columbia (55° 21' 06" N, 121° 23' 46" W). From fourth stratigraphic layer (48cm depth). Coll
1977 by R. Blacklaws; subm 1977 by B F Ball, Simon Fraser Univ, Vancouver, British Columbia. Measured to estimate age of archaeol site. Comment (RB): area appears to have been subjected to forest fire. Good portion of roots existed in soil along with sample.

**WAT-341.**

190% modern

Burned bone from Gwillim Lake (see WAT-306.) Sample found in first stratigraphic layer of excavation, 0 to 10cm deep, in archaeol site.

**WAT-561. Point Roberts Peninsula, Delta, British Columbia**

Bone from Point Roberts Peninsula, Delta, British Columbia (49° 02' 05" N, 123° 04' W). From Beach Grove site at 40cm depth showing no previous disturbance. Matrix was gray, black soil mixed with finely crushed sea shell. Coll and subm 1979 by B F Ball. Comment (BFB): expected age indicated by artifactual materials 2500 to 3000 yr BP. Sample measured to confirm estimates from artifact comparison and at request of local Indian band.

**References**


Lewis, C F M, 1969, Late Quaternary history of lake levels in the Huron and Erie basins: Conf on Great Lakes research, 12th, Proc, p 250-270.


Procedures and equipment have been described in previous date lists. Except as otherwise indicated, wood, charcoal and peat samples are pretreated with dilute NaOH–Na$_2$P$_2$O$_7$ and dilute H$_3$PO$_4$ before conversion to the counting gas methane; marls and lake cores are treated with acid only. Very calcareous materials are treated with HCl instead of H$_3$PO$_4$. Pretreatment of bone varies with the condition of the bone sample, solid bone with little deterioration is first cleaned manually and ultrasonically. The bone is treated with 8% HCl for 15 minutes, then dilute NaOH–Na$_2$P$_2$O$_7$ for 3 hours at room temperature, washed until neutral, and the collagen extracted by Longin’s method (Longin, 1971). Charred bone is treated with dilute HCl, NaOH–Na$_2$P$_2$O$_7$, and then dilute HCl again.

The dates reported have been calculated using 5568 as the half-life of $^14$C. The standard deviation quoted includes only 1σ of the counting statistics of background, sample, and standard counts. Background methane is prepared from anthracite, standard methane from NBS oxalic acid. The activities of the dated samples for which δ$^{13}$ values are listed have been corrected to correspond to a δ$^{13}$C value of −25‰; the activity of the standard methane has been corrected to −19‰.

Sample descriptions are based on information supplied by those who submitted samples.

ACKNOWLEDGMENTS

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1. ARCHAEOLOGIC SAMPLES

United States

Iowa

Wittrock site (130B4) series

Sample coll July 1980 from Wittrock site, component of Mill Creek culture of Iowa, O’Brien Co (43° 0′ N, 95° 30′ W). Floral analysis of site is underway as part of study of climatic changes in Iowa (Henning, 1968). Coll and subm by L A Zalucha, Univ Wisconsin-Madison. Acid treatment only.

* Margaret M Bender retired August 31, 1981.
WIS-1292.
Assorted sp of wood charcoal and charred corn from Level 2, Feature 80-2, trash pit, 94 to 137 cm below surface.

WIS-1293.
Assorted sp of wood charcoal and charred corn from Level 2, Feature 80-2, trash pit, 79 to 107 cm below surface.

Phipps site (13CK21) series
Test excavation at Phipps site conducted by L A Zalucha June 1981 to obtain soil samples from later levels of Mill Creek site (42° 45' N, 95° 30' W). Analysis of seeds and charcoal undertaken to test validity of current hypotheses concerning effects of climatic change on Mill Creek culture (Henning, 1968). Subm by L A Zalucha.

WIS-1274.
Wood charcoal and charred corn from Level 3, lowest natural level, trash pit, Feature 81-2, 89 to 109 cm below surface.

WIS-1273.
Wood charcoal and charred corn from base of trash pit, Feature 81-1, 78.7 to 86.4 cm below surface.

WIS-1220. Logansport site
Wood charcoal, ISU catalogue no. 7700 from Feature 7, cultural fill of large, rather shallow basin-shaped feature 1.7 m below present surface. Sample dated to provide temporal information on most deeply buried horizon at site, cultural stratum below successive Woodland and Great Oasis occupational zones but one from which no specifically diagnostic artifactual material had been recovered (Gradwohl and Osborn, 1976, p 165). Coll July 1979 from site in Boone Co (42° 4' 30" N, 93° 57' 30" W); subm by D M Gradwohl, Iowa State Univ, Ames, Iowa.

Kentucky

Carlston Annis site (15Bt5) series
Charcoal samples from 1x1 m pit (D14-2) excavated in shell midden in 10 cm levels July and Aug 1980 under supervision of W H Marquardt, Univ South Carolina, and P J Watson, Washington Univ, from site in Butler Co (37° 17' 29" N, 86° 48' 17" W). Subm by D A Baerreis.

WIS-1301.
Sample from Level 13, 120 to 130 cm deep. A radiocarbon date from Level 15 (UGa -3391) has been reported as 4670 ± 85 (Myers, 1981).
University of Wisconsin Radiocarbon Dates XIX

5350 ± 80
δ¹³C = -25.6‰

WIS-1302.
Sample from Level 19, 180 to 190cm deep. Radiocarbon date from Level 20 (UGa -3390) reported as 4350 ± 85 (Myers, 1981).

Tennessee

Snake Creek site (40HR35) series
Charcoal coll from site on W bank of Tennessee R, Hardin Co (35° 09' 45" N, 88° 31' 38") coll Jan 1978 and subm by D H Dye, Washington Univ, St Louis, Missouri.

1080 ± 100
δ¹³C = -25.8‰

WIS-1261.
Charred nut fragments (Juglans, Carya) and wood charcoal 60cm below surface in 1x2m test excavation of multi-component midden. In direct assoc were McKelvey series sherds (Futato, 1977; Webb and De-Jarnette, 1942).

2110 ± 80
δ¹³C = -26.2‰

WIS-1260.
Charred nut fragments (Carya, Juglans) 140cm below surface. In direct assoc were Longbranch series sherds (Futato, 1977; Oakley and Futato, 1975). Ceramic analysis indicates that sample is from Early Woodland Colbert component.

Wisconsin

Jones site (47RO203) series
Charcoal coll Nov 1977 from site in Rock Co (42° 45' N, 89° 07' W). Coll by William Green; subm by Constance Arzigian, Univ Wisconsin-Madison.

480 ± 60
δ¹³C = -26.6‰

WIS-1228.
Charcoal, including some oak, from Feature 11, Sq E3a-3, shallow pit containing burned bone and numerous cord-roughened Madison-ware sherds.

<200

WIS-1289.
Charcoal, including some oak, from Feature 15, possible hearth, 7cm below surface of unplowed field. Feature contained Madison-ware pottery.

Bluff Siding site (47 Bf 45) series
Charcoal from site in Buffalo Co (44° 04’ 15” N, 91° 36’ 30” W) coll July 1979 by J T Penman, State Hist Soc Wisconsin. Samples are first dated Late Woodland samples from Wisconsin site adjacent to Mississippi R (Penman, 1981). Subm by J T Penman.

780 ± 70
δ¹³C = -26.4‰

WIS-1206.
Sample from Feature 9, 30 to 40cm below surface.
WIS-1208.  
δ¹³C = -27.7‰  
Sample from Feature 1, Level 5, 40 to 50 cm below surface.

WIS-1251.  
δ¹³C = -26.5‰  
Charcoal (Quercus sp) from Feature 6, 30 cm below surface.

Plum Creek Bridge site (47 Pe 38) series
Charcoal coll from site in Pepin Co (92° 07’ 31” N, 44° 34’ 0” W) July 1981 by B W Ford, Jr. Site is Late Woodland, containing Madison triangular projectile points and Clam River Corded Stamped ceramics. Site is S-most Clam River site excavated at present time. Subm by J T Penman.

WIS-1299.  
δ¹³C = -26.2‰  
Charcoal from Sq 2-176-D, Level 2.

WIS-1296.  
δ¹³C = -27.0‰  
Charcoal from Sq 2-132, Level 4. Acid treatment only.

Pedretti III site (47Cr127) series
Charcoal coll July 1978 from site in Crawford Co (42° 05’ 26” N, 91° 08’ 36” W). Coll and subm by J B Stoltman, Univ Wisconsin-Madison.

WIS-1250.  
δ¹³C = -26.2‰  
Charcoal from Feature 2 in Levels 4 and 5, Sq 5 (N254/W235) 30 to 50 cm deep. Besides two Levens Stamped variety dentate sherds, Feature 2 contained linear stamped rim which presumably postdates Millville Phase. Date presumably applies to an immediately post-Millville (Lane Farm?) component.

WIS-1249.  
δ¹³C = -26.4‰  
Charcoal from Levels 11, 12, and 13, sandy, shell-rich levels below 90 cm silty alluvium. Of 46 identifiable sherds, 42 are Linn Ware types, 1 Havanna Ware and 3 are unid. Date applies to Millville Phase.

WIS-1290.  
δ¹³C = -26.2‰  
Charcoal from Level 3b (26 to 30 cm deep) in Square 6 assoc with two dentate Levens Stamped variety sherds of Millville Phase.

WIS-1291.  Clam Shell Point (47 Cr 187)  
δ¹³C = -27.1‰  
Charcoal (Morus rubra) id by L A Zalucha, from site in Crawford Co (43° 05’ 05” N, 91° 09’ 25” W). Sample from lowest levels yielding ceramics in Test Pit 2. Corded and pinch-decorated sherds suggest Early Woodland stage cultural affiliation. Coll and subm by J B Stoltman.
Outlet site (47 Da 3) series
Samples excavated 1949 by D A Baerreis from site in Dane Co (43° 02' 58" N, 89° 21' 53" W). Burial 3 of Mound 5 consisted of reburial of bones of several individuals. Bones were both charred and uncharred in close proximity in central portion of mound. Assoc of large quartzite blade of Hopewell style suggests Middle Woodland affiliation. Subm by D A Baerreis.

**WIS-1213.**
Collagen extracted from human bones by Longin’s method (Longin, 1971).

**1960 ± 80**
\[ \delta^{13}C = -19.7\% \]

Charred human bone.

**WIS-1217.**

**1540 ± 70**
\[ \delta^{13}C = -18.7\% \]

Charred human bone.

**WIS-1243.**

**1360 ± 70**
\[ \delta^{13}C = -19.2\% \]

Charred human bone.

II. GEOLOGIC SAMPLES

*United States*

*Alaska*

Squirrel River Lake site series
Core sampled April 1979 by L Parrish and P Anderson, Brown Univ, Providence, Rhode Island, from unnamed perched lake bordering Squirrel R in Kobuk R drainage of NW Alaska (67° 06' N, 100° 23' W). Subm by P Anderson.

**WIS-1166.**
Silty clay 325 to 245cm below mud-water interface.

**20,300 ± 380**
\[ \delta^{13}C = -27.7\% \]

**WIS-1163.**
Silty gyttja 275 to 295cm below mud-water interface. (One 3-day count.)

**22,700 ± 390**
\[ \delta^{13}C = -28.1\% \]

**WIS-1164.**
Silty clay 200 to 220cm below mud-water interface. Sample dates presence of Artemisia-rich tundra assoc with late glacial environments of Alaska and Canada. (One 3-day count.)

**17,360 ± 200**
\[ \delta^{13}C = -30.1\% \]

**WIS-1197.**
Silty gyttja 100 to 130cm below mud-water interface. Level marks rise of Betula pollen and indicates appearance of shrub tundra in Kobuk valley, important as indication of warmer climatic conditions.

**14,420 ± 230**
\[ \delta^{13}C = -31.4\% \]
M M Bender, D A Baerreis, R A Bryson, and R L Steventon

WIS-1193.

Gyttja 45 to 65 cm below mud-water interface. This level marks increase in *Picea* pollen and should date appearance of spruce gallery in Kobuk R region which is of potential significance in postulated climatic events and occupations of Kobuk Valley by N Archaic cultures.

Kiliovilik Creek Lake series

Core obtained April 1979 by P Anderson, P Colinvaux, and L Parrish from unnamed lake drained by Kiliovilik Creek (68° 13' N, 158° 20' W). Kiliovilik Creek Lake is first lake in Selawik R drainage to be cored for pollen analysis. Subm by P Anderson.

WIS-1154.

Gyttja 73 to 93 cm below mud-water interface.

WIS-1188.

Gyttja 145 to 155 cm and wood fragment 159 to 160 cm below mud-water interface. Dates decline of alder pollen.

Kaiyak Lake series

Core obtained April 1979 from lake in NW Alaska, Noatak R drainage (68° 7' N, 16° 25' W). Coll by L Parrish, J Walker, and P Anderson; subm by P Anderson. Depths are below mud-water interface.

WIS-1215.

Gyttja 15 to 25 cm depth. Dates decline in alder pollen percentages, perhaps marking end of time when conditions were warmer than at present at site. Counted in one counter only.

WIS-1218.

Gyttja 58 to 80 cm depth.

WIS-1216.

Gyttja 128 to 148 cm depth. Dates initiation of shrub tundra in middle Noatak R.

WIS-1219.

Silty gyttja 340 to 365 cm depth. Dates late glacial peak in grass pollen. Sample counted in one counter only.

WIS-1222.

Silty gyttja 500 to 523 cm depth. Dates decline in grass pollen frequencies.

WIS-1223.

Silty gyttja 675 to 700 cm depth, bottom of core. Sample activity not distinguishable from background.
Connecticut

Lantern Hill Pond series

**WIS-1277.**
Gyttja 927 to 932cm, bottom of core.

11,160 ± 110  
$\delta^{13}C = -33.8\%$

**WIS-1283.**
Gyttja 806 to 813cm deep. Dates change from spruce to oak and pine forest.

10,200 ± 100  
$\delta^{13}C = -31.9\%$

**WIS-1247.**
Gyttja 208 to 212cm deep.

Iowa

Holtz Bog series
Core 1979-A coll July 1979 from center of Holtz Bog, Muscatine Co (41° 26' N, 90° 55' W) by J K Huber and R G Baker. Core obtained to provide environmental evidence for nearby archaeol sites. This will be first pollen record in this area of Mississippi Valley. Subm by J K Huber, R G Baker, and J A Tiffany, Univ Iowa, City.

**WIS-1198.**
Silty, fine-grained peat 26 to 36cm below surface.

520 ± 70  
$\delta^{13}C = -29.4\%$

**WIS-1199.**
Sandy, fine-grained peat 179 to 199cm below surface.

1330 ± 80  
$\delta^{13}C = -27.4\%$

Massachusetts

Tom Swamp series
Core coll Nov 1979 from Tom Swamp, Harvard Forest, Worcester Co (42° 31' N, 72° 13' W). For pollen diagram of Tom Swamp, see Davis (1958). This core will be used to date earlier pollen diagram. Coll by C Lenk, N Miller, R Bradshaw, and G Thompson; subm by T Webb.

**WIS-1210.**
Clay with organic content, 955 to 965cm deep, base of spruce zone.

12,830 ± 120  
$\delta^{13}C = -28.0\%$

**WIS-1214.**
Organic gyttja 866 to 874cm deep, “mid-spruce” zone.

11,580 ± 110  
$\delta^{13}C = -29.5\%$
WIS-1212. Organic gyttja 767.5 to 772.5 cm deep, top of spruce zone. 

WIS-1211. Organic gyttja 667 to 673 cm deep.

WIS-1221. Hawley Bog Pond site

Algal gyttja 780 to 740 cm below water surface, water depth 1 m. Core coll from Hawley Bog Bond in Franklin Co (42° 34' N, 72° 53' W) Feb 1979 and subm by W A Patterson, III, Univ Massachusetts, Amherst. Other dates from site have been reported earlier (R, 1981, v 23, p 154-155). Sample dates max abundance of Picea pollen during A zone at Hawley Bog.

Duck Pond series

Core, 4.5 m, coll June 1980 from Duck Pond, Barnstable Co (41° 50' N, 70° 0' W) and subm by M Winkler, Univ Wisconsin-Madison. Depths recorded include initial 18.2 m water. Dates on earlier coring at site have been reported (R, 1981, v 23, p 153-154).

WIS-1298. Lake sediment 2208 to 2213 cm below lake surface. Nyssa-Picea assemblage in pollen samples may indicate time when ice sheet receded.

WIS-1297. Gyttja from 2176 to 2181 cm of core. Pollen shows transition from spruce and diploxylon pine to white pine, oak, and beech.

WIS-1271. Lake sediment 2144 to 2149 cm deep. Pollen diagram at this level shows change in diploxylon pine types indicating change in temperature regime.

WIS-1270. Gyttja 1955 to 1960 cm deep. Pollen diagram at this level shows decrease in hemlock, oak, and elm, and increase in beech, hickory, and grass herbs.

WIS-1300. Jelly-like gyttja 1870 to 1875 cm deep. At this level in pollen diagram white pine decreases and hemlock and birch increase.

Michigan

Cub Lake series

Core coll March 1980 from Cub Lake, Kalkaska Co (44° 42' N, 84° 57' W) by R E Bailey and J B Rasmussen, Central Michigan Univ,

WIS-1280.
Black algal gyttja 417.5 to 426.5cm deep. Post-dates spruce-pine transition in pollen record.

\[ 9220 \pm 100 \]
\[ \delta^{13}C = -31.6\% \]

WIS-1279.
Organic lake sediments 319.5 to 328.5cm deep. Sample corresponds to middle of “pine period” of postglacial times, may correspond to appearance of \textit{Pinus strobus} in N Michigan.

\[ 5030 \pm 80 \]
\[ \delta^{13}C = -31.3\% \]

WIS-1284.
Algal gyttja 198.5 to 207.5cm deep. Level corresponds to establishment of \textit{Tsuga} in pollen rain and decline of \textit{Pinus} below 50%.

\[ 3440 \pm 80 \]
\[ \delta^{13}C = -23.9\% \]

WIS-1295.
Algal gyttja 116.5 to 130.5cm deep.

\[ 1780 \pm 80 \]
\[ \delta^{13}C = -24.6\% \]

WIS-1285.
Organic sediments from 28 to 38cm deep, level immediately below land clearance. Acid treatment only.

\[ 2160 \pm 80 \]
\[ \delta^{13}C = -23.9\% \]

\[ 1780 \pm 80 \]
\[ \delta^{13}C = -24.6\% \]

\[ 280 \pm 80 \]

\[ 800 \pm 80 \]
\[ \delta^{13}C = -28.3\% \]

WIS-1269.
Lake sediment, 14 to 31cm deep. Acid treatment only.

\[ 2160 \pm 80 \]
\[ \delta^{13}C = -23.9\% \]

Minnesota

Little Trout Lake series

WIS-1229.
Lake sediment, 87.5 to 94.5cm deep, bottom of core.

\[ 800 \pm 80 \]
\[ \delta^{13}C = -28.3\% \]

Pogonia Bog Pond series
Cores, 5cm diam, coll from Pogonia Bog Pond—Core I, March 1974; Core II, March 1975—in Morris T Baker Park Reserve, Hennepin Co (45° 02' N, 93° 38' W). Pond is in Owatonna Moraine complex of E-central Minnesota, now occupied by deciduous forest (the Big Woods). Cores were analyzed for pollen by P Swain (ms); dates will be used to estimate pollen influx through Holocene. Depths measured from water surface, water depth 250cm, depth to glacial drift 1945cm.

WIS-1259.
Woody plant detritus including twigs, mycorrhizae, and needles of \textit{Picea} and \textit{Larix}, 1875 to 1880cm sec of Core II. Plant detritus immediately overlies glacial till. Marks melting of buried ice to form lake basin.
92  M M Bender, D A Baerreis, R A Bryson, and R L Steventon

WIS-1257.  
10,530 ± 110  
$\delta^{13}C = -35.8\%$

Silty algal copropel, non-calcareous, 1790 to 1800 cm sec of Core II. Decrease in spruce and increase of birch and pine pollen marks disappearance of spruce forest in early Holocene.

WIS-1258.  
6450 ± 70  

Algal copropel, silty, calcareous, irregularly banded with marly copropel from 1565 to 1575 cm sec of Core I. Peak of ragweed and other herb pollen is thought to indicate max development of prairie in region.

WIS-1253.  
3820 ± 80  
$\delta^{13}C = -33.4\%$

Moderately calcareous algal copropel with plant detritus, especially leaves of *Ceratophyllum* from 1300 to 1310 cm sec of Core I. Increase in oak pollen and decrease in herb pollen thought to mark development of oak forest on local slopes protected from fire.

WIS-1252.  
2750 ± 80  
$\delta^{13}C = -25.5\%$

Non-calcareous algal copropel with coarse plant detritus, especially leaves of *Ceratophyllum* from 930 to 940 cm sec of Core I. Increase in grass pollen thought to mark local spread of *Zizania* in basin.

WIS-1254.  
460 ± 70  
$\delta^{13}C = -33.4\%$

Non-calcareous algal copropel with *Drepanocladus* moss and plant detritus from 395 to 405 cm sec in Core I. Increase in pollen of ironwood, elm, basswood, and sugar maple and decrease in pollen of oak at this level thought to mark development of mesic forest in area.

WIS-1268.  
300 ± 70  

Non-calcareous algal copropel with coarse plant detritus from 310 to 319 cm in core II combined with 290 to 299 cm in Core I, correlated by pollen analysis which shows increase from 5 to 15% *Ambrosia* pollen in this interval.

Pogonia Bog series

Core, 10 cm diam, coll Nov 1973 from Pogonia Bog near SW limits of *Larix* and of *Sphagnum* bogs in Minnesota in Morris T Baker Park Reserve, Hennepin Co (45° 02' N, 93° 38' W). Coll and subm by Patricia Swain, Univ Minnesota, Minneapolis. Pollen analysis by P Swain (ms) to determine age and sequence of development of bog.

WIS-1255.  
180 ± 80  
$\delta^{13}C = -29.7\%$

Sedge peat with *Drepanocladus*-type moss, 47 to 50 cm sec of Core A, base of peat with lake sediment beneath. Dates inception of sedge mat in basin of Pogonia Bog Pond. Postdates increase in pollen of ironwood, elm, basswood, and sugar maple which marks development of mesic
forest on surrounding uplands, level dated by PBP I 395-405 (WIS-1254) above.

**WIS-1256.**  <100
\[ \delta^{13}C = -28.4\% \]^1

Sedge peat with Drepanocladius-type moss, 34 to 36 cm in Core A. Increase in pollen and other indicators of agriculture marks forest clearance and settlement that occurred here AD 1850 to 1860.

**Cruiser Lake**

**WIS-1226.**  2610 ± 80
\[ \delta^{13}C = -31.8\% \]^1

Gyttja 68.7 to 75.2 cm deep, bottom of core.

**WIS-1230.**  1650 ± 80
\[ \delta^{13}C = -29.2\% \]^1

Gyttja 32 to 39 cm deep. Dates beginning of rise in spruce pollen, increase in red/jack pine and fir, decrease in alder.

**WIS-1267.**  500 ± 70

Gyttja 8 to 18 cm deep, just below Ambrosia rise.

**Little Bass Lake series**
Core A taken with Livingstone piston sampler, 5 cm diam, from Little Bass Lake, Itasca Co (47° 17' N, 93° 36' W). Coll Dec 1977 by H E Wright et al; subm by E J Cushing, Univ Minnesota, Minneapolis. Lake is in mixed coniferous-deciduous forest of N central Minnesota on sandy outwash deposited by St Louis sub-lobe of Des Moines lobe. Pollen diagram from core has been completed by P C Swain and dates will be used to estimate pollen influx through Holocene. Depths measured from water surface, water depth 1282 cm. All samples were calcareous.

**WIS-1237.**  10,660 ± 110
\[ \delta^{13}C = -32.2\% \]^1

Silty algal copropel from 1790 to 1795 cm sec of Core A. This level marks decrease in pollen of Picea and increase in Pinus.

**WIS-1235.**  7780 ± 90
\[ \delta^{13}C = -27.5\% \]^1

Algal copropel from 1660 to 1670 cm sec of core. Level marks decrease in pine pollen and increase in oak and herbs.

**WIS-1234.**  5530 ± 90
\[ \delta^{13}C = -31.4\% \]^1

Algal copropel from 1590 to 1595 cm sec of core. Level marks decrease in pollen of Ostrya and Quercus and increase in Pinus.
94  M M Bender, D A Baerreis, R A Bryson, and R L Steventon

WIS-1231.  
Algal copropel from 1520 to 1525 cm sec of core. At 1520 cm in core, pollen assemblage shifts from higher values of herb and oak pollen to higher proportions of birch and pine, especially white pine.

WIS-1232.  
Algal copropel, calcareous, from 1375 to 1385 cm sec of core. Pollen assemblage between 1282 and 1520 cm in core dominated by pollen of Pinus strobus and Betula and is thought to have derived from regional vegetation similar to present.

Oklahoma

WIS-1189.  Cherokee Co, Oklahoma site  
**1340 ± 80**
Quercus sp coll. Oct 1979 by Michael Winter and W C Johnson, Univ Kansas, Lawrence, Kansas, 4.4 m below surface from site in Cherokee Co (36° 07' N, 94° 48' W). Alluvial dates from SW Wisconsin indicate river changes occurred at times of climatic variation (Johnson, 1978). Goal is to determine whether dates of river change is S Great Plains are synchronous with those in Wisconsin (Johnson, 1979) and, therefore, whether climatic variation had regional effect on course of river.

Rhode Island

WIS-1233.  Narragansett South site  
**1880 ± 80**

WIS-1248.  Narragansett North site  
**570 ± 70**

South Dakota

Medicine Lake series
Core 80A, 5 cm diam, 2240 cm deep, coll Feb 1980 from Medicine Lake, Codington Co (44° 59' N, 97° 21' W). Sample dates to be used to determine sedimentation rates (Watts and Bright, 1968; Van Zant, 1979).
Acid treatment only. Depths are from water surface, sediment was 946cm deep. Coll and subm by N J Radle, Univ Minnesota, Minneapolis.

**WIS-1225.**
Highly calcareous laminated silty gyttja at base of core, 2210 to 2217cm deep. Glacial silt immediately below.

**WIS-1227.**
Small bits of wood from litter layer at base of core, 2210 to 2217cm deep. Needles and seeds of *Picea* also present.

**WIS-1246.**
Lake sediment, 1952 to 1956cm deep, immediately below 10cm layer of gypsum crystals.

**WIS-1245.**
Lake sediment, 1644 to 1652cm below water surface.

**WIS-1242.**
Calcareous silty gyttja 1352 to 1356cm deep.

**WIS-1244.**
Calcareous silty gyttja 1040 to 1044cm deep.

**Wisconsin**

**WIS-1224. Miller site, Brush Creek**
Wood sample 280cm deep from one example of group of alluvial fan deposits with well-developed paleosols at mouths of several small tributaries in Brush Creek valley (McDowell, ms). Dates period of high sediment yields from tributaries and hillslopes assoc with shift to cooler and more moist climate after mid-Holocene warm/dry climate. Coll Nov 1978 by P McDowell from Miller farm, Monroe Co (43° 44' N, 90° 39' W). Subm by J C Knox, Univ Wisconsin-Madison.

**Hugo Arndt site series**

**WIS-1281.**
Wood 255cm below bank top. Date confirms early Holocene age of fluvial terrace widespread in upper Kickapoo R system and that fluvial sedimentology of early Holocene deposits have finer textures than Holocene fluvial deposits younger than ca 6000 radiocarbon years at same sites. Date also shows that channel incision assoc with WIS-1282 occurred between ca 7100 and 3900 BP.
WIS-1282.  

Wood 2.1m deep. Dates represent min age for abandonment of river channel active during late middle Holocene time. Sample date documents that middle to late middle Holocene river channels degraded beds 0.5 to 1.0m below elev of early Holocene channel beds. Degradation was accomplished in rather coarse resistant gravels and implies that large floods may have been assoc with degradation.

WIS-1294.  Long Lake  

Silty clay, 593 to 600cm sec of core at transition from organic matter to sand in lake sediments below 3.4m water. Coll March 1980 from Long Lake, Bayfield Co (46° 40' N, 91° 3' W) and subm by A M Swain. Sand below sample shows spruce pollen and sediment and may date warming of climate as indicated by vegetation change from spruce to pine and mixed hardwood pollen.

WIS-1265.  Waubesa Mound  

Sedge peat, 191 to 197cm depth, coll Oct 1980 with Hiller corer from peat mound in Waubesa Wetlands, Dane Co (43° 00' N, 89° 20' W) by M Winkler and T Kratz, Univ Wisconsin-Madison. Sample from sec overlying transition from silty clay to peat. Subm by M Winkler.

WIS-1286.  Powell site  

Wood, 256cm deep, at gravel-silt interface coll from site on Brush Creek tributary, Kickapoo R system, Monroe Co (43° 44' N, 90° 36' W). Coll Oct 1980 and subm by J C Knox. Sample dates paleochannel system, widespread in upper Kickapoo R drainage system of SW Wisconsin which is presumed to have been adjusted to magnitudes and frequencies of floods typical of late Holocene (Knox, McDowell, and Johnson, 1981).

WIS-1287.  McCoy site  

Wood, 2.6m deep, from Monroe Co on Kickapoo R, right stream bank in meander bend (43° 45' N, 90° 35' W). Coll Oct 1980 and subm by J C Knox. Sample dates segment of paleochannel system presumed to have been active during time of relatively rapid change from dryness to increased moisture.

Pine River site series  

Samples obtained from excavations at Janney site in Richland Co from drainage ditch tributary to Fancy Creek, Pine R system (43° 24' N, 90° 24' W). Coll Aug 1979 and subm by J C Knox. Spruce stump excavated from site, 180 to 190cm deep, was dated as 9520 ± 95 (WIS-1023, R, 1980, v 22, p 122-123).

WIS-1190.  

Wood fragments 120 to 125cm deep from transition zone between base of woody peat and top of woody zone which includes in situ spruce
stumps. Sample dates transition from dominance of tree growth on flood plain to shrub and sedge environment because of increasing warmth and dryness.

**WIS-1191.**

9120 ± 90

Woody peat 102 to 107cm deep. Sample from uppermost portion of woody peat zone which underlies black silt thought to represent valley alluviation assoc with warm/dry Atlantic episode.

**WIS-1192.**

3180 ± 80

Brown peat 45 to 55cm deep. Sample represents early stages of peat growth in late Holocene.

**Brander Bog site series**


7230 ± 90

δ¹³C = −30.2%

**WIS-1263.**

Peaty gyttja 223 to 232cm below surface of bog. Sample overlies transition to coarse sand and underlies transition to bog peat. Date should indicate beginning of wetland formation at site.

**WIS-1264.**

6770 ± 100

Alkali soluble fraction of 223 to 232cm sample.

1590 ± 80

δ¹³C = −30.3%

**WIS-1262.**

Fibrous peat with twigs 110 to 115cm below bog surface. Sample represents increase in hemlock and birch, decrease in white pine in pollen diagram.

1690 ± 90

δ¹³C = −28.7%

**WIS-1266.**

Alkali soluble fraction of 110 to 115cm sample.

**Stockton Bog site series**


5820 ± 80

δ¹³C = −29.2%

**WIS-1241.**

Sand and peat with leaves and seeds from 896 to 900cm depth, bottom of core. Dates formation of tombolo on which bog developed.

5450 ± 80

δ¹³C = −27.3%

**WIS-1240.**

Sandy peat and chunks of wood from 726 to 732cm depth, level at which pollen changes from all pine to all deciduous pollen other than pine.
**WIS-1239.**
Peat and gyttja from 395 to 400 cm deep. Sample represents transition from lake to bog, precedes large sphagnum increase in pollen diagram.

$\delta^{13}C = -27.8\%$

**WIS-1238.**
Fibrous peat 175 to 180 cm deep, level at which pollen diagram shows increase in white pine and hemlock.

$\delta^{13}C = -28.2\%$

**WIS-1236.**
Fibrous peat 100 to 106 cm deep. At this level, pollen diagram shows increase in white pine and sphagnum, decrease in birch, hemlock max.

Kelly’s Hollow site series

**WIS-1207.**
Herb peat 421 to 426 cm below surface. Dates occurrence of high percentage of *Acer saccharum*, *Ostrya/Carpinus* type, Cyperaceae and degraded pollen within *Pinus strobus* zone.

$\delta^{13}C = -29.8\%$

**WIS-1209.**
Wood-herb peat 119 to 124 cm below surface. Dates initiation of *Tsuga* pollen sedimentation at site.

Bermuda

**WIS-1288. Port Royal Bay**
Tropical peat including fern leaf fragments, sedge roots, *Myrica*-type leaf fragments and algal remains 26 m below mean low water in Port Royal Bay (32° 16’ N, 63° 51’ W). Sample 3.7 m below peat and pond mud, indicates former sea level (Neumann, 1972). Coll Sept 1980 by D Meischner; subm by Stanley Ashmore, Univ Maryland.

Peru

**WIS-1204. Lake Huataycoche**
Aquatic moss in marly silt, very calcareous, from base of lake sediment off sedge mat on E side of lake, beyond limits of local glaciation (10° 47’ S, 76° 35’ W), Junin prov, Oyon map sheet, Peru. Sample 373 to 383 cm below lake surface. Date is min for retreat of ice sheet that covered W cordillera during late Pleistocene. Coll and subm by H E Wright, Univ Minnesota.
Lake Huatacocha series
Samples coll July 1978 from Lake Huatacocha area, Junin prov, Oyon map sheet, Peru (10° 47' S, 76° 35' W). Coll and subm by H E Wright. Earlier dates from Huatacocha Delta Site 2 and Upper Fan B have been reported (R, 1980, v 22, p 128). Previously reported latitude was in error.

**WIS-1203.**
Moss layers 260 to 268cm below mud surface at base of lake sediments from S end of lake. Dates inception of Lake Huatacocha which postdates main cordilleran glaciation.

**WIS-1202. Huatacocha Upper Fan B**
Peat from base of 2 adjacent sediment cores, 201 to 204cm depth, from small drained lake behind moraine. Dates final withdrawal of ice from drainage basin which allowed peat to grow over lake bed. Sample from same core as WIS-1070 (R, 1980, v 22, p 128) which was also sampled from below fan surface.

**WIS-1205. Huatacocha Delta 1B**
Peat 78 to 84cm deep from core of Delta 1B, formed of outwash from recent glacial advance. Peat dates from time when glacier withdrew and outwash silts were no longer actively deposited on delta.

**WIS-1201. Huatacocha Delta 1B**
Peat 169 to 175cm deep from core of Delta 1B.

**WIS-1200. Pistag Delta site**
Peat 170 to 175cm deep from delta formed of outwash from small Pistag Glacier. Sample dates end of glacial outwash in delta. Coll July 1978 from E side of Lake Pistag, Junin prov, Oyon map sheet (10° 47' S, 76° 35' W) and subm by H E Wright.

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M M Bender, D A Baerreis, R A Bryson, and R L Steventon


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REVIEW


The tenth anniversary of the Rudjer Bošković Radiocarbon and Tritium Laboratory brought together a number of invited specialists and Yugoslav scientists interested in the application of natural stable and radioactive isotopes. The papers presented provide a general introduction to the field of natural isotope studies with a special emphasis on $^{14}$C.

The development of the radiocarbon dating method from the discovery of the production of radioactive nuclei by cosmic radiation in 1934 to the present is described together with some of the problems (contamination, isotope fractionation, varying atmospheric $^{14}$C levels, reservoir effects) encountered. The difficulties of using $^{14}$C in groundwater studies are evident from the discussion of the large number of models developed for this purpose. Naturally, the construction and the operation of the Rudjer Bošković $^{14}$C set-up are given in detail. The current techniques in use for tritium measurements are likewise described.

The general section is completed by a discussion of expected future developments in the use of natural isotopes like $^{39}$Ar, $^{83}$Kr, $^{36}$Cl, and $^{10}$Be made feasible by special background reduction of the counters used to detect their decay or by accelerator mass spectrometry.

The results that can be obtained by the use of natural isotopes like $^2$H, $^3$H, $^{13}$C, $^{14}$C, $^{18}$O, and $^{34}$S are nicely illustrated by one of the invited talks and several papers. It is unfortunate that a number of those are only included as an abstract.

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## CONTENTS

A high-precision calibration of the AD radiocarbon time scale  
*Minze Stuiver* ...................................................... 1

Charcoal production from wood and cellulose: implications to radiocarbon dates and accelerator target production  
*S W Leavitt, D J Donahue, and Austin Long* ........................ 27

### DATE LISTS

<table>
<thead>
<tr>
<th>Institution</th>
<th>Authors</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANU</td>
<td>H A Polach, E G Rhodes, John Head, and John Gower</td>
<td>ANU Date List IX .......... 36</td>
</tr>
<tr>
<td>BS</td>
<td>G Rajagopalan, Vishnu-Mittre, B Sekar, and T K Mandal</td>
<td>Birbal Sahni Institute Radiocarbon Measurements III .......... 45</td>
</tr>
<tr>
<td>UCR</td>
<td>R E Taylor</td>
<td>UCR Radiocarbon Dates III .......... 54</td>
</tr>
<tr>
<td>WAT</td>
<td>J C Berry and R J Drimmie</td>
<td>University of Waterloo Radiocarbon Dates I .... 68</td>
</tr>
<tr>
<td>WIS</td>
<td>Margaret M Bender, David A Baerreis, Reid A Bryson, and Raymond L Steventon</td>
<td>University of Wisconsin Radiocarbon Dates XIX ........ 83</td>
</tr>
</tbody>
</table>

### BOOK REVIEW

*Pieter M Grootes*  
Proceedings of the Regional Conference on the Application of Isotope Analyses in Archaeology, Hydrology and Geology; edited by Dušan Srdoč, Bogomil Obelić, and Adela Sliepčević .......... 101