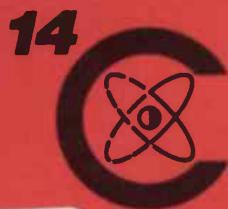


VOLUME 36 / NUMBER 2 / 1994

Radiocarbon

An International Journal of Cosmogenic Isotope Research



QC
798
.D3
A48
Sci
Current
Journal

Editor

AUSTIN LONG

Consulting Editor

A. J. T. JULL

Managing Editor

RENEE S. KRA

Assistant Editors

DAVID R. SEWELL

KIMBERLEY L. TANNER

Department of Geosciences
The University of Arizona
4717 East Ft. Lowell Road
Tucson, Arizona 85712 USA

ISSN: 0033-8222

RADIOCARBON

An International Journal of Cosmogenic Isotope Research

Editor: AUSTIN LONG

Consulting Editor: A. J. T. JULL

Managing Editor: RENEE S. KRA

Assistant Editors: DAVID R. SEWELL, KIMBERLEY L. TANNER

Published by

Department of Geosciences

The University of Arizona

Published three times a year at The University of Arizona, Tucson, AZ 85712 USA. © 1994 by the Department of Geosciences, The University of Arizona.

Subscription rate: \$105.00 (for institutions), \$73.50 (for individuals), \$36.75 (for students with proper identification). Foreign postage is extra. A complete price list, including Proceedings of International Conferences, appears in the back of this issue. Back issues may be obtained by contacting the *RADIOCARBON* office.

All correspondence and manuscripts should be addressed to the Managing Editor, *RADIOCARBON*, Department of Geosciences, The University of Arizona, 4717 East Ft. Lowell Road, Tucson, AZ 85712 USA. Tel: (602) 881-0857; Fax: (602) 881-0554. **Please note our e-mail addresses:**

BITNET: C14@ARIZVMS
INTERNET: c14@packrat.aml.arizona.edu
or rkra@packrat.aml.arizona.edu

Offprints. The minimum offprint order for each article will be 100 copies without covers. *No offprints will be furnished free of charge unless page charges are paid (see below).* Covers are also available.

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. Institutions or authors paying such charges will be entitled to 100 free offprints without covers. *No charges will be made if the author indicates that the author's institution is unable to pay, and payment of page charges for an article will, in no case, be a condition for its acceptance.*

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

Illustrations should include explanation of symbols used. Copy that cannot be reproduced cannot be accepted. Whenever possible, reduce figures for direct publication. 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. *Figures* (photographs and line drawings) should be numbered consecutively through each article, using Arabic numerals. Tables may be accepted as camera-ready copy.

Citations. A number of radiocarbon dates appear in publications without laboratory citation or reference to published date lists. We ask authors of research articles and date lists 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 covers all published ^{14}C measurements through Volume 7 of *RADIOCARBON*, and incorporates revisions made by all laboratories. It is available at \$25.00 per copy.

List of laboratories. Our comprehensive list of laboratories is available upon request. We are expanding the list to include additional laboratories and scientific agencies with whom we have established contacts. The editors welcome information on these or other scientific organizations. We ask all laboratory directors to provide their laboratory code designation, as well as current telephone and fax numbers, and e-mail addresses. Changes in names or addresses, additions or deletions should be reported to the Managing Editor. Conventional and AMS laboratories are now arranged in alphabetical order by country and we include laboratories listed by code designation.

CONTENTS

FROM THE EDITORS – To Our Friends

<i>Austin Long, Renee S. Kra and A. J. T. Jull</i>	iii
--	-----

ARTICLES

¹⁴ C Age Corrections in Antarctic Lake Sediments Inferred from Geochemistry <i>Rolf Zale</i>	173
Radiocarbon Chronology of Late Glacial and Holocene Sedimentation and Water-level Changes in the Area of the Gościąż Lake Basin <i>Anna Pazdur, M. F. Pazdur, Tomasz Goslar, Bogumił Wicik and Maurice Arnold</i>	187
Radiocarbon and Uranium-Series Dating of the Plitvice Lakes Travertines <i>Dušan Srdoč, J. K. Osmond, Nada Horvatinčić, Adel A. Dabous and Bogomil Obelić</i>	203
Radiocarbon Calibration Curve Variations and Their Implications for the Interpretation of New Zealand Prehistory <i>B. G. McFadgen, F. B. Knox and T. R. L. Cole</i>	221
The Rapid Preparation of Seawater ΣCO ₂ for Radiocarbon Analysis at the National Ocean Sciences AMS Facility <i>A. P. McNichol, G. A. Jones, D. L. Hutton and A. R. Gagnon</i>	237
AMS ¹⁴ C Age Determinations of Tissue, Bone and Grass Samples from the Ötztal Ice Man <i>Georges Bonani, Susan D. Ivy, Irena Hajdas, Thomas R. Niklaus and Martin Suter</i>	247

DATE LISTS

CH	Physical Research Laboratory (Chemistry) Radiocarbon Date List I <i>Ravi Bhushan, Supriya Chakraborty and Seth Krishnaswami</i>	251
Gd	Gliwice Radiocarbon Dates XI <i>Mieczysław F. Pazdur, Romuald Awasik, Tomasz Goslar, Anna Pazdur, Adam Walanus and Andrzej Zastawny</i>	257
Gd	Gliwice Radiocarbon Dates XII <i>Anna Pazdur, Mieczysław F. Pazdur and Andrzej Zastawny</i>	281
Z	Rudjer Bošković Institute Radiocarbon Measurements XIII <i>Bogomil Obelić, Nada Horvatinčić, Dušan Srdoč, Ines Krajcar Bronić, Adela Sliepčević and Sanja Grgić</i>	303

RADIOCARBON UPDATES	325
---------------------------	-----



ASSOCIATE EDITORS

For Accelerator Physics

DAVID ELMORE
ROBERT E. M. HEDGES
D. ERLE NELSON

West Lafayette, Indiana, USA
Oxford, England
Burnaby, British Columbia, Canada

For Archaeology

ANDREW M. T. MOORE
MICHAEL B. SCHIFFER

New Haven, Connecticut, USA
Tucson, Arizona, USA

For Atmospheric Sciences

GEORGE A. DAWSON

KUNIHIKO KIGOSHI
DAVID C. LOWE

Auckland, New Zealand
Tucson, Arizona, USA
Tokyo, Japan
Lower Hutt, New Zealand

For Geochemistry

PAVEL POVINEC

MINZE STUIVER

Bratislava, Slovakia
Monaco
Seattle, Washington, USA

For Geophysics

G. E. KOCHAROV
WILLEM G. MOOK

St. Petersburg, Russia
Texel, The Netherlands

For Ice Studies

HAROLD W. BURNS, JR.

Orono, Maine, USA

For Oceanography

EDOUARD BARD

ELLEN R. M. DRUFFEL

Gif-sur-Yvette, France
Marseille, France
Palisades, New York, USA
Irvine, California, USA

For Paleobotany

CALVIN J. HEUSSER

Tuxedo, New York, USA

FROM THE EDITORS

TO OUR FRIENDS

On the 35th anniversary of the founding of our journal, *RADIOCARBON* faces financial crisis. We informed attendees of the 15th International Radiocarbon Conference of the situation, and asked for their suggestions. Many valuable ideas were gathered during the week of the conference. Since our return to Arizona, we have been occupied with little else than financial analysis and problem-solving. We think we have devised a workable recovery plan, but the bottom line is that we cannot do it alone—*RADIOCARBON* needs your help.

We appreciate the general response of concern, support and encouragement to proceed with a plan for building a stable financial future for *RADIOCARBON*. The proposal for a Radiocarbon Society, discussed at the Business Meeting, has been withdrawn, in lieu of a strong business plan. Participants were eager to see a detailed account of our budget and our proposed remedies. Therefore, we have distributed copies of a newly designed conservative recovery plan for both the short and long term. With your help, we should be able to exceed these minimal goals.

The two areas of disproportional increases are personnel and printing. We are publishing more special issues and volumes outside the regular journal series, which, in turn, require more qualified personnel. Eliminating one staff member would severely hamper our productivity, endanger our commitments, and eventually destroy our image. We are determined to avoid this alternative. Although revenue has increased somewhat, our expenses far exceed our income. Part of the problem lies in library budget cuts; our subscriptions, mostly from libraries, have decreased by 13%. This is a great deal when the maximum number of subscribers is only 600. Collection of page charges has also shrunk to *ca.* 50% of what we received in previous years.

With a new, broad-based marketing scheme and a restructured journal, we plan to regain vitality by ensuring financial stability, growth and development, drawing from the strengths of the radiocarbon community. Our first dramatic change is that we have invited Tim Jull to join us in the capacity of Consulting Editor. He will monitor our budget and oversee present and future projects. We will institute theme issues, managed by Associate Editors in more participatory roles. The Governing Board will also take on new responsibilities; these innovations will ultimately improve the profile of the journal. We are engaging in a promotional campaign to enlarge our subscriber base. We have put together an all-new schedule of subscription categories, which includes, for the first time, electronically accessed datelists. This will cut printing costs substantially and increase possibilities for database construction.

Striking changes are being made to launch *RADIOCARBON* onto its new mission. It is our conviction that our journal is headed in the right direction, and that we are merely experiencing growing pains. Please support us by selecting a subscription package, ordering a full set of back issues (all laboratories **should** have current subscriptions **and** at least one full set), becoming a lifetime subscriber and/or making a tax-deductible contribution. Please encourage other members of your department or library to subscribe as well. Finally, give us your pledge to support *RADIOCARBON* in its time of need. Your immediate response (before the end of 1994) will determine the future of the journal.

Austin Long, Renee S. Kra and A. J. T. Jull

Radiocarbon

1994

¹⁴C AGE CORRECTIONS IN ANTARCTIC LAKE SEDIMENTS INFERRED FROM GEOCHEMISTRY

ROLF ZALE

Department of Geography, University of Umeå, S-901 87 Umeå, Sweden

ABSTRACT. Sediment from Lake Boeckella, Antarctic Peninsula, is richer in Ca, Cd, Cu, P, Sr and Zn than that of six other lakes in the area. The elements originate from Adélie penguin (*Pygoscelis adeliae*) guano on the lake shores. Changing Cu and P concentrations in the lake sediment are used as a proxy for penguin influence on the lake sediment from ca. 5850 BP to present. A ¹⁴C dating model suggests that the ¹⁴C correction factor in the lake sediments depends on the penguin proxy, the apparent age of the penguin guano and the amount of particulate carbon originating from the carbon-bearing shales in the watershed. Glacial meltwater and dissolved carbonates do not contain enough “old” carbon to contribute significantly to the correction factor. Ages corrected with the ¹⁴C dating model agree with the depth vs. age curve based on independently ¹⁴C-dated tephra horizons. The reservoir effect has been constant since at least 5800 BP, implying long-term stability of the currents and water masses in the area. The existing chronology for Lake Boeckella has been recalculated. The period of glacial advance, previously thought to have culminated at 5000 BP, is now thought to have culminated at 4700 BP; deglaciation of the area is thought to have occurred at 6300 BP instead of 8680 BP.

INTRODUCTION

Lake sediments from the Antarctic Peninsula and the surrounding islands were sampled in 1987 during the RV *Polarstern* expedition, ANT VI, and in 1989, during the 1988/89 SWEDARP expedition (Karlén *et al.* 1988; Björck *et al.* 1989) to reconstruct Holocene climate of the area (Zale and Karlén 1989). A problem with Antarctic ¹⁴C dates (*cf.* Zale and Karlén 1989; Björck *et al.* 1991) stems from the marine reservoir effect in the sea around Antarctica and the abundance of fossil carbon in the bedrock. (The term *reservoir effect* refers to the fact that marine plants and animals yield “old” ¹⁴C dates because deepwater wells up in the area, bringing “old” CO₂ to the surface (*cf.* Omoto 1983; Stuiver and Braziunas 1985; Stuiver, Pearson and Braziunas 1986).)

Lake Boeckella in Hope Bay (Fig. 1) displays the following three characteristics: 1) The uppermost deposits show ¹⁴C ages of ca. 2100 BP with no evidence for erosional loss of recent deposits or of non-deposition of sediment. A ¹⁴C correction factor of 2100 yr, based on the age of the modern sediment, was previously applied to the entire core (Zale and Karlén 1989). 2) Unlike most lakes in the area, Boeckella is eutrophic because of the input of nutrients from the nearby Adélie penguin (*Pygoscelis adeliae*) rookery (Hansson 1990, Izaguirre *et al.* 1993). 3) Lake Boeckella has a tephra chronology, independently ¹⁴C-dated at other sites (Björck, Sandgren and Zale 1991). Lake Boeckella dates lack reliability because the correction factor's variation with depth is unknown. Dating accuracy is important in Antarctica, in general, as evidence for environmental change is scarce.

The aim of this study is to test whether inputs of “old” carbon have influenced ¹⁴C dates and to estimate the correction factor at different depths of the Lake Boeckella sediment. The hypothesis is that the correction factor depends mainly on the variable influx of “old” marine carbon from the penguin rookery. The correction factor is used to convert ¹⁴C ages to “true” ¹⁴C ages when sediment containing a mixture of “recent” and “old” carbon is dated. “True” ¹⁴C ages refer to the standard NBS oxalic acid ¹⁴C time scale (*cf.* Olsson 1986) and include neither bomb-carbon nor fossil-fuel correction.

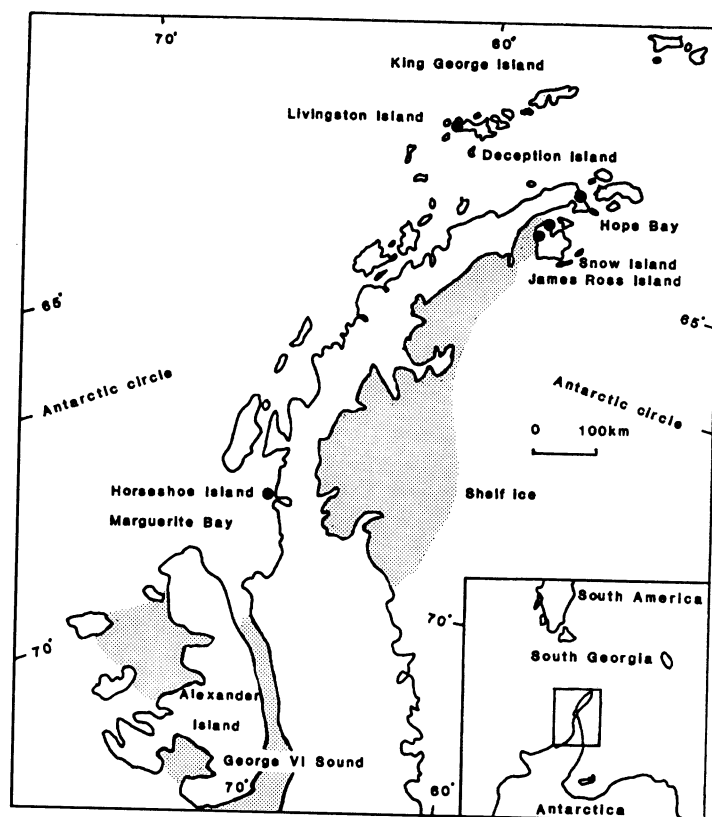


Fig. 1. The Antarctic Peninsula area. • = sampled lakes.

Results will be compared with the tephra chronology, and may shed light on dating difficulties in Antarctica.

Lake Boeckella is a small (0.06 km²), eutrophic, freshwater lake with a maximum depth of 9 m, *ca.* 800 m south of the Esperanza station in Hope Bay at 45 m asl (Fig. 1). Glacial meltwater flows into the lake. A large Adélie penguin rookery, which had *ca.* 200,000 adults in 1987, borders the lake to the northwest. (Adélie penguins prey mainly on euphausiids (krill) and marine crustacea (Culik 1987), including larval fish, cephalopods and other crustaceans (Watson 1975).) The bedrock in the area consists of Upper Paleozoic marine sediments and Middle Jurassic to Lower Cretaceous volcanic rocks (British Antarctic Survey 1979).

METHODS

Field Work

Lake Boeckella sediment samples were collected during the *Polarstern* expedition with a Livingstone-type corer (Zale and Karlén 1989). During the SWEDARP expedition, Björck *et al.* (1989) collected sediment cores from six lakes on the Antarctic Peninsula and surrounding islands. Sediment increments from these cores were analyzed to obtain reference or background concentrations of different elements without the influence of penguins or other marine animals. Water was sampled in both the inlet and outlet of Lake Boeckella to study relations among ionic concentration of inflow water, outflow water and sediment. Four samples of penguin guano were collected from each of two

Adélie penguin rookeries, one in Hope Bay and one at Penguin Point, Snow Island (Fig. 1) during the latter expedition to compare guano and sediment compositions.

Chemical Analyses

As it is not possible to measure directly the amount of carbon in sediment originating from penguin guano, I took an indirect approach. I assumed that a high concentration in the sediment of one or more elements from the penguin guano resulted from guano washing into the lake. Such element(s) could serve as proxy variable(s) for the penguin influence on the lake sediment (penguin proxy). Sixteen samples from the Lake Boeckella sediment core and 3 widely spaced stratigraphic horizons from each sediment core from the 6 reference lakes were analyzed for Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Sc, Si, Sn, Sr, Ti, Zn, Zr, V, W and Y. The samples were leached with a mixture of HNO₃ and HCl in a heated, ultrasonic bath and filtered prior to the ICP-AES analysis of the filtrate; they were kept in a freezer prior to analysis. Five of the 16 Lake Boeckella samples underwent separate analysis for Al₂O₃, CaO, Fe₂O₃, K₂O, MgO, Na₂O, P₂O₅, SiO₂, TiO₂, Ba, Be, Co, Cr, Cu, La, Mo, Nb, Ni, Pb, Sc, Snb, Sr, V, W, Y, Yb, Zn and Zr. These samples were melted with LiBO₂ and then dissolved in HNO₃ prior to ICP-AES analysis. Because of the low sample weights from Lake Boeckella, loss on ignition (LOI) (Zale and Karlén 1989) was used to estimate carbon content (Håkanson and Jansson 1983).

Water samples were analyzed for Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, La, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si, Sr, V and Zn. The water samples were filtered prior to ICP-AES analysis. Penguin guano samples were kept frozen until analyzed for Al, As, Ba, C, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, Ti, V and Zn. The samples were dried and then dissolved in HNO₃ and HCl in closed Teflon vessels in a microwave oven prior to ICP-AES analysis. Concentrations of all substances are expressed as percent or ppm of the dry weight, except for water analyses, which are expressed as mg liter⁻¹ or µg liter⁻¹.

The following criteria were established to identify elements to be used as proxies for the penguin contribution to the sediment carbon pool in Lake Boeckella: 1) They must originate from the penguin guano and be present in the sediment in concentrations above background concentrations; 2) they must be chemically stable in the sediment.

Background Element Concentrations

Background concentrations are mean element concentrations in the sediments from six lakes (18 samples) in the Antarctic Peninsula area that are not influenced by marine animals. Background levels in sediment of polluted lakes are often obtained from mud in the bottom of the core, deposited in pre-industrial times (Bruland *et al.* 1974; Kemp *et al.* 1976; Håkanson and Jansson 1983). This method alone is not suitable for Lake Boeckella, because the time of its penguin rookery establishment is unknown. However, it is used to "correct" the "reference lake method", as no substance should show a statistically significant lower level in any sample of the Lake Boeckella core than the background level. If it does, Lake Boeckella has an anomalously low concentration of that element.

Radiocarbon Dating

All ¹⁴C ages were measured at Laboratoriet för Isotopgeologi in Stockholm and were published previously (Zale and Karlén 1989). The penguin guano samples were not dated, mainly because of their very low dry weight and the lack of thick guano deposits in Hope Bay.

I developed a mathematical model that incorporates the amount and "age" of the carbon coming into the lake to calculate the "true" ¹⁴C age of the sediment. Lake Boeckella receives carbon from four

main sources: 1) particulate carbon from watershed rocks and soils; 2) penguin guano; 3) dissolved "old" atmospheric CO₂ in the inflowing glacier meltwater and dissolved carbonates in other inflowing water; 4) atmospheric CO₂.

I assumed that: 1) the particulate carbon originating from the watershed soil/bedrock is proportional to the amount of minerogenic material in the sample and has an infinite apparent age. This assumption is supported by the presence of fossil-bearing shales and mudstones containing carbon in the watershed (Bibby 1966); 2) the amount of carbon originating from penguin guano is proportional to the penguin proxy and of finite apparent age; 3) the apparent age of the water reaching the lake has been constant through time. Carbon originating from meltwater is mixed both with atmospheric CO₂ as the meltwater flows down to the lake, and with water containing dissolved carbonates from bedrock. This carbon makes up the rest of the carbon in the sediment, the apparent age of which is a function of the amount and age of the meltwater (finite apparent age), the amount of dissolved carbonates (infinite apparent age) and the amount of atmospheric carbon (apparent age zero) mixed in.

The "true" ¹⁴C age of a sample can be calculated with the formula

$$a_1 = j_1 - R_{a1} - R_{g1} \quad (1)$$

where

- a = "true" ¹⁴C age in years BP;
- j = ¹⁴C age of the dated sample in years BP;
- R_a = correction factor of the autochthonous carbon in years;
- R_g = correction factor of the penguin guano in years.

The subscripts denote the sample number starting with the sample closest to the sediment surface.

R_a and R_g can be written

$$R_{a1} = \ln(b_1 2^{(-m/h)} / k_1) / -i \quad (2)$$

$$R_{g1} = \ln(cd_1 2^{(-g/h)} / k_1) / -i \quad (3)$$

where

- b = amount of autochthonous carbon in percent;
- c = constant, proportional to the influence of the penguin proxy;
- d = penguin proxy;
- g = apparent age of the guano;
- h = half-life of ¹⁴C, 5568 yr;
- i = proportionality constant, $i = \ln 2/h$;
- k = amount of carbon in the sample in percent;
- m = apparent age of the autochthonous carbon in years.

The amount of autochthonous carbon (b) can be written

$$b_1 = k_1 - cd_1 - ef_1 \quad (4)$$

where

- e = constant, proportional to the influence of particulate bedrock/soil carbon.
- f = amount of minerogenic material in the sample in percent.

Equations (1), (2), (3) and (4) can be combined to produce the expression:

$$a_1 = j_1 - (\ln(((k_1 - cd_1 - ef_1)2^{(-m/h)} + cd_1 2^{(-g/h)})/k_1)/-i). \quad (5)$$

Equation (5) demonstrates how the “true” ^{14}C age of a sample can be calculated and will be applied to each of the six dated samples. This leaves 6 simultaneous equations, 1 for each sample, and 10 unknowns: the constants, c and e ; j_{1-6} , the “true” ^{14}C ages of samples 1 to 6; and g and m , the apparent ages of the penguin guano and autochthonous carbon, respectively. Of the unknowns, c , e , g and m are identical for all samples. These simultaneous equations are called the ^{14}C model. Some unknowns in this model must be estimated or assigned a reasonable value (discussed later), so that, at most, six unknowns remain and the simultaneous equations can be solved.

I ran the model several times (*i.e.*, the six simultaneous equations were solved) and the values of the unknowns changed from their previous values between the runs. The new value assigned to the unknown depended on the outcome of previous model runs and reasonable assumptions. I ran the model until the “true” ^{14}C ages j_{1-6} were compatible with both the lithostratigraphy of the sediment and a reasonable sedimentation rate. At the same time, I used reasonable values for the influence of carbon from different sources, c and e , and the apparent ages of this carbon, g and m .

RESULTS AND DISCUSSION

Lake Boeckella sediments are enriched in six elements—Ca, Cd, Cu, P, Sr and Zn—compared to the mean concentrations of the elements in the reference lake deposits (Figs. 2A–F). One of the 16 samples from the sediment core of Lake Boeckella was excluded from further analysis because of an exceptional chemical composition that makes the sample unrepresentative for the core as a whole. Two penguin guano samples were outliers, and were excluded from further analyses. Because the rookeries were completely abandoned at the time of sampling, it is possible that some samples represent old, partly decomposed guano.

The chemical analyses demonstrate that Ca is the only 1 of the 6 elements showing a significantly higher concentration when the sample is melted with LiBO_3 rather than leached with HNO_3 . This shows that none of the enriched elements, except Ca, is bound to primary minerals, and that the bed-rock is not the major source of these elements.

Lake Boeckella is eutrophic because it receives nutrients from the Adélie penguin rookery on the lake shores (Izaguirre *et al.* 1993), as is evident, for example, from the fact that all of the measured elements except Fe and Ba are present in higher concentration in the outlet than the inlet water. This indicates that the major source of these substances is not as solubles in the inflowing meltwater.

It seems reasonable to compare results from leached sediment samples with results from penguin guano. Both routines partly dissolve the sample, but leave most of the primary minerals undissolved. The comparison shows that the concentrations of the enriched elements in the upper four samples from the core approach or reach the mean concentrations of these elements in the guano (Figs. 2A–F). This is another indication that the guano is the major source of these elements and that the upper part of the core consists mainly of guano.

LOI correlates fairly well with the six enriched elements in the sediment of Lake Boeckella (Pearson correlation matrix, r 0.72–0.88). Carbon from the penguin guano washes into the lake, but in addition, P in the guano acts as a fertilizer and stimulates autochthonous production, thereby raising the concentration of carbon in the sediment.

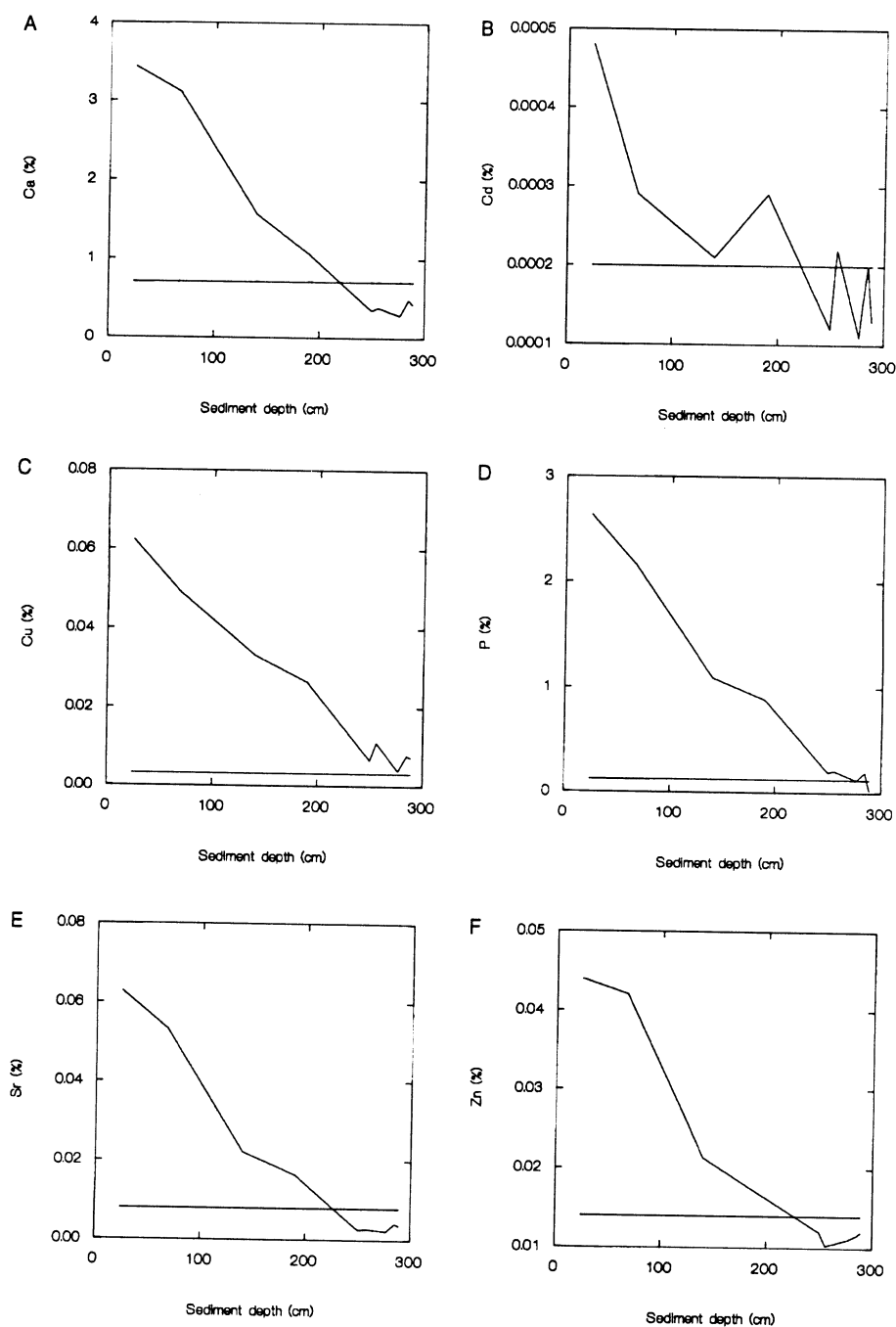


Fig. 2 A-F. Concentrations of Ca, Cd, Cu, P, Sr and Zn from leached samples vs. sediment depth in Lake Boeckella. Samples were analyzed from the following sediment depths (cm): 22-25, 41-45, 61-62, 66-67, 99-101, 139-140, 143-144, 187-188, 189-190, 249-251, 255-256, 265-270, 276-277, 284-286, 288-290. The mean concentrations of the same elements in the sediments from the reference lakes are shown as straight lines. Mean and 1σ concentrations of the elements in the penguin guano were: $6.6 \pm 1.9\%$ Ca; $0.00024 \pm 0.00014\%$ Cd; $0.042 \pm 0.023\%$ Cu; $4.8 \pm 1.3\%$ P; $0.012 \pm 0.006\%$ Sr; and $0.044 \pm 0.030\%$ Zn.

Elements Suitable as a Penguin Proxy

Phosphorus and most heavy metals are stable in sediment under most circumstances and are thus suitable as proxies (Dearing 1986). However, determining which elements in Lake Boeckella sediment are stable and which are not is difficult, because only a few chemical analyses were performed and similar lakes have seldom been investigated. The good correlations between Ca, Cd, Cu, P, Sr and Zn (Pearson correlation matrix) in the sediment indicate either that these elements are stable or that their mobility in the sediment is similar.

The concentrations of an element in the sediment samples used to calculate the background level must be normally distributed; otherwise, a significance level cannot be set. A variety of the Kolmogorov-Smirnov test, the Lilliefors test, shows that only the concentrations of Ca, Cu and P in the samples from the reference lakes are normally distributed (level of significance 95%). This means that the selection of reference lakes and/or sampling depths was biased w.r.t. the concentrations of Cd, Sr and Zn. Thus, the background concentrations of these elements cannot be used in further statistical analyses. In addition, concentrations of the selected elements should not be significantly lower in the study-lake sediments than the background levels measured in reference lakes. This criterion rules out Ca. Therefore, only Cu and P were used to evaluate the impact of guano on the sediment.

It seems reasonable to use the following as a proxy (unitless) for the penguin impact on the sediment

$$\text{Proxy} = (((A_P - U_P)/B_P) + ((A_{Cu} - U_{Cu})/B_{Cu}))/2 \quad (6)$$

where

- A = concentration in Lake Boeckella;
- U = upper confidence limit of the background level;
- B = mean background level.

Subscripts denote the element in question. Zero or a negative value means that no penguin effect can be detected in the lake sediments.

The ^{14}C Dating Model

The Apparent Age of the Penguin Guano

The apparent age of penguin guano is probably close to the apparent age of the penguins. Björck *et al.* (1991) reported a pre-bomb (1903) penguin collagen date from Hope Bay of 1280 ± 50 BP. The date gives a reservoir effect of 1230 yr for Adélie collagen from this area, a reasonable starting value for the apparent age of the penguin guano (g) in the model used here, since no published guano dates from the area were found. An “industrial effect” correction would be, at most, 20 yr and is thus negligible. Stuiver and Braziunas (1985) made an extensive compilation of Antarctic isotopic dates.

The “True” ^{14}C Ages of the Topmost Samples

If the “true” ^{14}C ages of the two topmost samples are set to reasonable values considering the sedimentation rate, and the apparent age of the autochthonous carbon (m) is set to 0, then two simultaneous equations (2 forms of Equation (5)) with 2 unknowns, the proportionality constants c and e, can be solved, and the values of c and e can be determined. The values of c and e can then be used to calculate the “true” ^{14}C ages of the other samples, and the result checked by comparing the sedimentation rates in different parts of the core.

The "true" ^{14}C age of sample 1 (1-cm depth) is somewhat difficult to determine. The upper sediment might be contaminated with bomb ^{14}C , producing a supermodern date (*cf.* Druffel 1981; Mabin 1986; Whitehouse *et al.* 1987). However, penguins, and thus fresh penguin guano, do not seem to be contaminated with bomb ^{14}C because ages of freshly killed Adélie penguins (Omoto 1983) are in reasonable agreement with ages of Adélie killed before 1950 (Whitehouse *et al.* 1987). Poisson and Chen (1987) reported a deficiency of anthropogenic CO_2 in the Weddell Sea, which might explain why penguins are not affected by bomb ^{14}C . Because sedimentary carbon largely originates from penguin guano (the penguin proxy = 5.1 in sample 1), a "true" ^{14}C age of sample 1 is probably close to -37 BP (AD 1987 subtracted from AD 1950).

The "true" ^{14}C age of sample 2 (12-cm depth) must be based on sedimentation rates. It is reasonable to assume that the apparent linear sedimentation rate diminishes because of sediment compaction. If the "true" ^{14}C age of sample 2 is set at 3 BP, then the apparent sedimentation rate between samples 1 and 2 is 3.0 mm yr^{-1} .

The proportionality constants, *c* and *e*, can be determined by solving two simultaneous equations (Eq. (5)) for the two topmost samples with sample 1 set at -37 BP and sample 2 at 3 BP. The result (Table 1, top) suggests a reasonable sedimentation rate between sample 2 and sample 3 (99-cm depth and 460 BP) of 1.9 mm yr^{-1} . These values are open to discussion, but the "true" ^{14}C ages of samples 1 and 2 are not at all critical, as can be seen from Table 1 (bottom). The shaded area encloses the ages

TABLE 1. The dated bulk sediment samples (top half of the table) and the dates calculated by the model for samples 3–6 (bottom half) depending on the ages chosen for samples 1 and 2 (bottom half). The values of *cd* (amount of carbon from penguin guano, bottom half, columns 1–3) depend on the ages chosen for samples 1 and 2 and the apparent age of the penguin guano. Shaded area represents the dates calculated by the model with sample 1 set to -37 and sample 2 to 3 BP, $\pm 1 \sigma$ of the original date.

Sample no.	1	2	3	4	5	6
Sediment depth (cm)	1	12	99	159	219	279
Carbon content (%)	8.1	13.0	20.3	16.5	13.4	5.5
Minerogenic content (%)	86	78	63	72	79	92
Penguin proxy	5.1	16.6	20.9	5.9	7.0	0.6
Lab no. (St-)	11990	11746	11747	11620	11748	11619
$\delta^{13}\text{C}$ (‰)	-28.0	-28.4	-27.0	-22.8	-25.7	-25.4
^{14}C age BP	2275	2585	2140	3720	4085	8615
Age $\pm 1 \sigma$	70	70	70	70	120	170

Values of cd_2 (%) if $g=1000 \text{ yr}$	Values of cd_2 (%) if $g=1230 \text{ yr}$	Values of cd_2 (%) if $g=1500 \text{ yr}$	Ages of samples 1 and 2 used as input		Ages for samples 3–6 as calculated by the model			
			1	2	3	4	5	6
16.8	13.9	11.6	-137	13	492	2588	2468	5101
18.3	15.1	12.6	- 37	- 27	436	2618	2507	5412
18.2	15.0	12.5	- 37	- 17	444	2619	2509	5402
18.0	14.9	12.4	- 37	- 7	452	2619	2511	5392
17.9	14.7	12.3	- 37	3	460	2620	2512	5381
17.7	14.6	12.2	- 37	13	468	2621	2514	5371
17.6	14.5	12.1	- 37	23	477	2622	2516	5360
17.4	14.3	11.9	- 37	38	489	2624	2518	5345
17.0	14.0	11.7	- 37	63	509	2626	2522	5318
16.3	13.5	11.2	- 37	113	551	2630	2531	5265
15.6	12.9	10.7	- 37	163	592	2635	2539	5112
15.8	13.3	10.9	63	213	610	2673	2593	5428

for samples 3–6, $\pm$ the counting error of the original date (*i.e.*, 1σ as reported for the sample age from the laboratory) calculated when sample 1 is set to -37 BP and sample 2 to 3 BP. Thus, a reasonable “true” ^{14}C age for sample 1 is -37 BP, and 3 BP for sample 2.

The Proportion of Allochthonous vs. Autochthonous Carbon and the Apparent Age of the Penguin Guano

The results of the modeling can be checked by the products, *cd* and *ef*, as these give the amount of carbon originating from the penguin guano and the watershed bedrock/soil, respectively (the apparent age of the autochthonous carbon, *m*, is still 0). The critical sample in the core is sample 2, where the penguin proxy is high and the amount of carbon, low. The amount of carbon from the bedrock/soil in the chosen example (“true” ^{14}C ages of -37 BP for sample 1, and 3 BP for sample 2) is calculated by the model (*ef*) to be 1.5% in sample 2. This leaves room for a maximum contribution from the penguin guano of 11.5% (as the amount of carbon in the sample is 13.0%), which is lower than calculated by the model, as shown in Table 1. The amount diminishes when the difference in age between sample 1 and 2 and/or the apparent age of the penguin guano increases.

If the amount of carbon originating from the bedrock/soil and the penguin guano is set at 13% , *i.e.*, the primary source in the lake was “old” carbon ($b=0$), then the apparent age of the penguin guano is calculated to 1610 yr, which is not unreasonable. Omoto (1983) concluded that the reservoir effect in Antarctica ranges between 0.8 and 3 ka. On the other hand, if the amount of carbon originating from the bedrock/soil and the penguin guano is set to 13% , and the apparent age of the penguin guano is set to 1230 yr, the model calculates the “true” ^{14}C age of sample 2 as 370 BP and sample 3 as 793 BP. This gives an apparent linear sedimentation rate between sample 1 and 2 of 0.29 mm yr^{-1} and between sample 2 and 3 of 2.1 mm yr^{-1} . I consider these figures highly unlikely, especially as no dramatic change in the sediment was found in this part of the core (Zale and Karlén 1989). Thus, a large portion of the sediment carbon stems from the penguin guano, the apparent age of which is at least 1610 yr.

The Influence and Apparent Age of the Autochthonous Carbon

If the apparent age of the autochthonous carbon (*m*) is set to positive values smaller than the apparent age of the penguin guano, then *c* (proportionality constant) increases. This requires that the apparent age of the penguin guano (*g*) is even older than 1610 yr. For example, if sample 1 is set to -37 BP, sample 2 to 3 BP, and the apparent age of the autochthonous carbon (*m*) is set to 0.5 ka, the apparent age of the penguin guano (*g*) is calculated by the model to 1829 yr. The age of sample 3 is calculated to 256 yr, and the ages of the rest of the samples differ in this example *ca.* 250 yr from the calculation where the apparent age of the autochthonous carbon (*m*) is set to 0 BP. This gives sedimentation rates between sample 1 and 2 of 0.37 mm yr^{-1} and between 2 and 3 of 3.4 mm yr^{-1} . The core provides no evidence of such a large change in sedimentation rate.

Apparent ages of the autochthonous carbon older than the apparent age of the penguin guano give unacceptable, supermodern results. A negative apparent age for the autochthonous carbon (*m*) is also highly unlikely. Thus, the apparent age of the autochthonous carbon is small, and its influence on the dates is negligible. This means that no effect of “old” glacial meltwater or dissolved bedrock carbonates can be detected. The chemical analyses support the view that the “hard water effect” resulting from carbonates in the bedrock is of minor importance, as evident from the anomalously low Ca content (Fig. 2A) in the lowermost sediment, which is not affected by penguins.

The Influence of the Allochthonous Carbon

Suppose the "true" ^{14}C age of sample 1 is set to -37 BP, sample 2 to 3 BP, the influence from the carbon originating from the penguin guano (c) to 0 and the apparent age of the autochthonous carbon (m) to 0. If the influence of the carbon from the bedrock/soil (e) is calculated, the result will also be unacceptable, *i.e.*, the error in the calculated date is >2 ka. Thus, "old" carbon originating from the penguin guano influences the ^{14}C -dating of the sediment.

Suppose the "true" ^{14}C age of sample 1 is set to -37 BP, sample 2 to 3 BP, and the influence of "old" carbon from the watershed bedrock/soil (e) is set to 0. The apparent age of the autochthonous carbon (m) and the influence of carbon from the penguin guano (c) can then be calculated. This results in errors of ~ 0.5 ka for sample 2, or unacceptable negative or very large values. Thus, "old" carbon from the bedrock/soil also influences the ^{14}C ages.

The ^{14}C Ages

One of the calculated ages for samples 4 (159-cm depth) and 5 (219-cm depth) must be erroneous as sample 4 cannot be older than sample 5. The validity of sample 4 was discussed previously (Zale and Karlén 1989). If the calculated date of sample 4 is accurate, but not that of sample 5, the resulting curve of sedimentation rates indicates changes for which no evidence exists in the core (Fig. 3). Based on this and the fact that sample 4 has the highest $\delta^{13}\text{C}$ value of all, indicating a possibly different origin of the carbon used for dating (Table 1), I believe that the dating of sample 5 is more likely to be correct than that of sample 4.

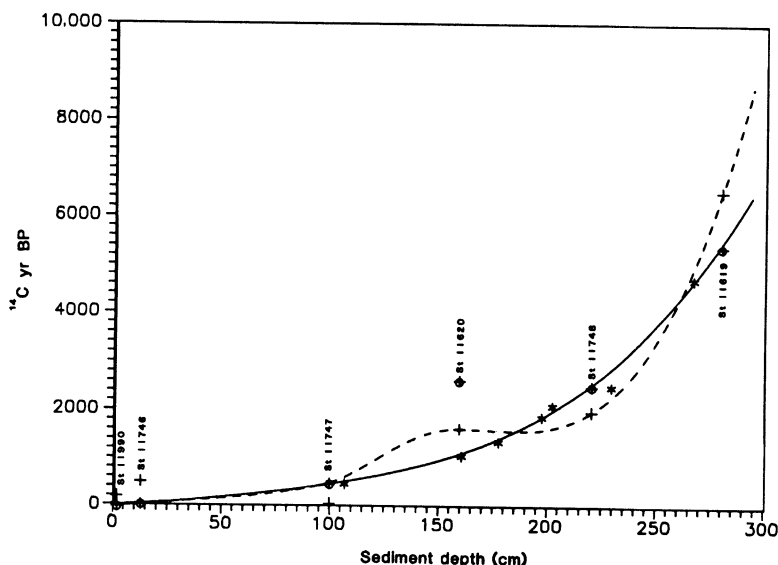


Fig. 3. Sediment depth vs. ^{14}C age in Lake Boeckella. --- from Zale and Karlén (1989), based on ^{14}C ages (+) minus a constant reservoir effect. — is based on the tephrochronology of Björck, Sandgren and Zale (1991). * = tephra horizon. ⊕ = ages calculated from the ^{14}C model.

The $\delta^{13}\text{C}$ Values

The $\delta^{13}\text{C}$ values of the samples (Table 1) agree with the *ca.* -22‰ $\delta^{13}\text{C}$ values for Adélie guano (Hebert 1980), and the -22 to -25‰ for penguin remains (Whitehouse *et al.* 1987, Björck *et al.* 1991). These values are not surprising because krill, the main diet of Adélies, has $\delta^{13}\text{C}$ values of *ca.* -28‰ (Wand 1987).

The Model

Björck, Sandgren and Zale (1991) studied the late Holocene tephrochronology of the northern Antarctic Peninsula. They found seven tephra horizons in Lake Boeckella by chemical and magnetic analyses, which they correlated to ^{14}C -dated tephra horizons in sediments from other locations around the Antarctic Peninsula. A comparison between the sediment depth vs. age curve (Fig. 3) and the independently dated tephra clearly demonstrates that the ages as calculated with the ^{14}C model are more accurate than the ages reported by Zale and Karlén (1989). The date, St-11620, 3720 ± 70 BP (Table 1), is clearly erroneous, as suggested earlier by Zale and Karlén (1989).

The model can also be used to draw the penguin proxy as a function of time (Fig. 4). Penguins have occupied the lake shores since *ca.* 5550 BP, except for a brief discontinuity *ca.* 5200 BP. This is in line with both Birkenmajer (1981), who dated penguin remains to 4950 BP, and Barsch and Mäusbacher (1986), who dated penguin bones from King George Island to *ca.* 5300–5800 BP. The penguin influence reached a maximum at *ca.* 40 BP and has since declined drastically. The size of the rookery is probably climate-dependent.

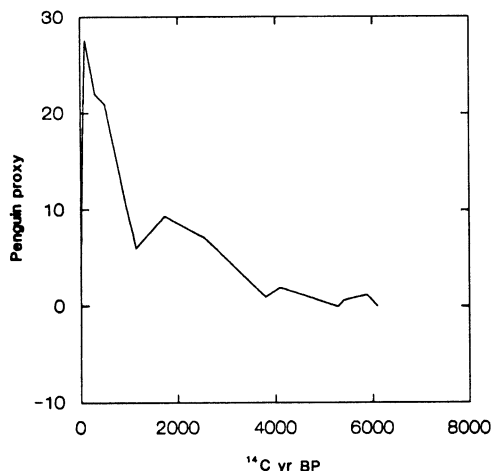


Fig. 4. The proxy for the penguin influence on the lake sediment vs. ^{14}C age. Ages calculated by the model were used. The plot uses the 9 samples chemically analyzed and the 6 samples both chemically analyzed and dated.

If the modeling results are used to recalculate the result of Zale and Karlén (1989), most of the changes are small. The major change is that the deglaciation occurred *ca.* 6300 BP instead of 8680 BP as previously thought, and the climatic deterioration culminates *ca.* 4700 BP instead of 5000 BP. The model also suggests that the reservoir effect has been constant for *ca.* 5800 ^{14}C yr in this area. This implies long-term stability of the currents and water masses around the tip of the Peninsula.

CONCLUSIONS

I have developed a ^{14}C dating model to show that the ^{14}C age correction factor in Lake Boeckella depends mainly on the amount of penguin guano in the lake sediment, the apparent age of the guano and the amount of carbon originating from the soil/bedrock. The model also shows the apparent age of the penguin guano to be at least 1610 yr. The supposedly "old" glacial meltwater does not affect the correction factor, nor do dissolved carbonates from the watershed bedrock/soil, *i.e.*, I can find no hard water effect. The model suggests that the reservoir effect has been constant for the last 5800 ^{14}C yr, implying a long-term stability of the water masses and currents in the area.

ACKNOWLEDGMENTS

I thank the following: Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, which organized the RV *Polarstern* expedition ANT VI; Prof. Sahrhage, who deftly directed the *Polarstern* expedition; SWEDARP for the 1988/1989 expedition and my support; Prof. Anders Karlqvist for the splendid SWEDARP expedition; the masters and crews, including the helicopter pilots and mechanics, on both RV *Polarstern* and MS *Stena Arctica*, who transported me safely and comfortably across stormy seas; Tommy Hammarström and Johan Delby, for sample collection; Svante Björck, Kerstin Nordström and Anders Wasell, for lake cores. Svante Björck, Lars Brydsten, Daniel Engstrom, Mats Jansson, Kerstin Nordström, Siv Olsson and Göran Skog and an anonymous referee, for valuable comments on the manuscript. The Swedish Natural Research Council, The Kempe Foundations, Gyllenstiernska Krapperupsstiftelse, Svenska Sällskapet för Antropologi och Geografi and Stiftelsen Lars Hiertas Minne supplied funds, and Antes Glas in Umeå supplied equipment.

REFERENCES

- Barsch, D. and Mäusbacher, R. 1986 New data on the relief development of the South Shetland Islands, Antarctica. *Interdisciplinary Science Review* 11(2): 211–218.
- Bibby, J. S. 1966 The stratigraphy of part of the northeast Graham land and the James Ross Island group. *British Antarctic Survey Scientific Reports* 53: 37 p.
- Birkenmajer, K. 1981 Raised marine features and glacial history in the vicinity of H. Arctowski station, King George Island (South Shetland Islands, West Antarctica). *Bulletin de l'Académie Polonaise des Sciences. Série des Sciences de la Terre* 29(2): 109–117.
- Björck, S., Hjort, Ch., Ingolfsson, O. and Skog, G. 1991 Radiocarbon dates from the Antarctic Peninsula region—problems and potentials. *Quaternary Proceedings* 1: 55–65.
- Björck, S., Nordström, K., Wasell, A. and Zale, R. 1989 Holocene environmental history around the Antarctic Peninsula based on lake sediment analyses. In Karlqvist, A., ed., *Swedish Antarctic Research Programme 1988/89, A Cruise Report*. Stockholm, Swedish Polar Research Secretariat: 81–97.
- Björck, S., Sandgren, P. and Zale, R. 1991 Late Holocene tephrochronology of the northern Antarctic Peninsula. *Quaternary Research* 36: 322–328.
- British Antarctic Survey 1979 British Antarctic Territory, Geological Map, Series BAS 500 G, Sheet 2, Edition 1.
- Bruland, K. W., Bertine, K., Koide, M. and Goldberg, E. 1974 History of metal pollution in Southern California Coastal zone. *Environmental Science and Technology* 8: 425–432.
- Culik, B. 1987 Fluoride excretion in Adélie penguins (*Pygoscelis adeliae*) and mallard ducks (*Anas platyrhynchos*). *Comparative Biochemistry and Physiology* 88A(2): 229–233.
- Dearing, J. A. 1986 Core correlation and total sediment influx. In Berglund, B. E., ed., *Handbook of Holocene Palaeoecology and Palaeohydrology*. Chichester, John Wiley & Sons: 247–270.
- Druffel, E. M. 1981 Radiocarbon in annual coral rings from the eastern tropical Pacific Ocean. *Geophysical Research Letters* 8(1): 59–62.
- Håkanson, L. and Jansson, M. 1983 *Principles of Lake Sedimentology*. Berlin, Springer-Verlag: 316 p.
- Hansson, L.-A., 1990 Interaction between periphytic and planktonic algae along a productivity gradient in Antarctic lakes. In Karlqvist, A., *Swedish Antarctic Research Programme 1988/89, A Cruise Report*. Stockholm, Swedish Polar Research Secretariat: 108–112.
- Hebert, D. 1980 Kohlenstoff-14-Datierung antarktischer Pinguinbrutstätten. *Beiträge zur Vogelkunde* 26(6): 335–341.
- Izaguirre, I., Mataloni, A., Vinocour, A. and Tell, G. 1993: Temporal and spatial variations of phytoplankton from Boeckella Lake (Hope Bay, Antarctic Peninsula). *Antarctic Science* 5(2): 137–141.
- Karlén, W., Hjort, Ch., Ingolfsson, O. and Zale, R. 1988 Holocene glacial history and climatic variation on the Antarctic Peninsula. In Fütterer, D. K., ed., *Die Expedition Antarktis-VI mit FS "Polarstern" 1987/1988, Berichte zur Polarforschung* 58. Bremerhaven, Alfred-Wegener-Institut für Polar- und Meeresforschung: 40–41.
- Kemp, A. L. W., Thomas, R. L., Dell, C. I. and Jaquet, J.-M. 1976 Cultural impact on the geochemistry of sediments in Lake Erie. *Journal of the Fishery Research Board of Canada* 33: 440–462.
- Mabin, M. C. G. 1986 ¹⁴C ages for "heroic era" penguin and seal remains from Cape Evans, McMurdo Sound. *New Zealand Antarctic Record* 7 (2): 19–20.
- Olsson, I. U. 1986 Radiometric dating. In Berglund, B. E., ed., *Handbook of Holocene Palaeoecology and Palaeohydrology*. Chichester, John Wiley & Sons: 273–312.
- Omoto, K. 1983 The problem and significance of radiocarbon geochronology in Antarctica. In Oliver, R. L., James, P. R. and Jago, J. B., eds., *Antarctic Earth Science*. Cambridge, Cambridge University Press: 450–453.

- Poisson, A. and Chen, C.-T. A. 1987 Why is there little anthropogenic CO₂ in the Antarctic bottom water? *Deep Sea Research* 34(7): 1255–1275.
- Stuiver, M. and Braziunas, T. F. 1985 Compilation of isotopic dates from Antarctica. *Radiocarbon* 27 (2A): 117–304.
- Stuiver, M., Pearson, G. W. and Braziunas, T. 1986 Radiocarbon age calibration of marine samples back to 9000 cal yr BP. In Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ¹⁴C Conference. *Radiocarbon* 28(2B): 980–1021.
- Wand, U. 1987 Kohlenstoff-14-Untersuchungen an Sturm-
vogelnistplätzen in der Antarktis. *Beiträge zur Vogelkunde* 33(3/4): 129–140.
- Watson, G. E. 1975 *Birds of the Antarctic and Sub-Antarctic*. Washington, American Geophysical Union: 350 p.
- Whitehouse, I. E., Chinn, T. J. H., von Hofle, H. C. and McSaveney, M. J. 1987 Radiocarbon contaminated penguin bones from Terra Nova Bay, Antarctica. *New Zealand Antarctic Record* 8(3): 11–23.
- Zale, R. and Karlén, W. 1989 Lake sediment cores from the Antarctic peninsula and surrounding islands. *Geografiska Annaler* 71A(3–4): 211–220.

RADIOCARBON CHRONOLOGY OF LATE GLACIAL AND HOLOCENE SEDIMENTATION AND WATER-LEVEL CHANGES IN THE AREA OF THE GOŚCIAŻ LAKE BASIN

ANNA PAZDUR,¹ M. F. PAZDUR,¹ TOMASZ GOSLAR,¹ BOGUMIŁ WICIK² and MAURICE ARNOLD³

ABSTRACT. We obtained ¹⁴C ages on samples of lake marl and other sediments from cores taken in Gościąż Lake and its environs. Comparison of ¹⁴C dates of bulk samples of laminated sediment with varve chronology and available AMS dates of terrestrial macrofossils indicates a reservoir correction of 2000 ± 120 yr for the basal series of lake sediments. ¹⁴C dates obtained on peat layers underlying the oldest lacustrine sediments in Gościąż and other lakes consistently locate the beginning of organogenic sedimentation in this area at *ca.* 13 ka BP. We distinguished three periods of lacustrine gyttja sedimentation in cores taken in Gościąż and adjacent lakes: 11.8–10.2 ka, 8–7 ka and 2.7–2.1 ka BP. From the ¹⁴C dates of lithological boundaries in these cores, we reconstruct a pattern of lake-level changes during the last 12 ka, remarkably similar to Swedish lakes and generally agreeing with available records from European and American lakes. The behavior of Gościąż Lake during the last 12 ka fairly well reflects global climate changes in the temperate zone during the Late Glacial and Holocene periods.

INTRODUCTION

Gościąż Lake, situated in the Płock Basin (Fig. 1), is the largest and the deepest in the system of the four “Na Jazach” lakes drained by the small Ruda Creek. The significance of this lake was recognized immediately after discovery of its laminated sediment in 1985. Over 18 m of Gościąż Lake’s basal sediments consist of carbonaceous-sulphuric gyttja with a large amount of iron and other elements, accumulated in a superaqueous environment dominated by reduction processes. The sediment reveals distinct lamination, consisting of *ca.* 12,500 laminae couplets, extending back from the present to the Allerød interstadial. Goslar *et al.* (1993) used varve chronology and AMS dates on macrofossils from Gościąż Lake to determine the duration of the Younger Dryas.

DESCRIPTION OF THE STUDY AREA

The Płock Basin is located in a glaciated area near the maximum southern advance of the Vistulian ice sheet, among the > 60 lakes of the Gostynin Lakeland. The region’s mean annual temperature is 7.9°C; January and July mean temperatures are –1.6°C and 18.7°C, respectively. Annual precipitation is *ca.* 520 mm and evaporation *ca.* 412 mm; dominating winds are westerly (Sierżęga and Narwojsz 1988).

Quaternary sediments of the Płock Basin were formed mostly during the last glaciation. Glacial tills, kame and ooze sands occur in the eastern part of the Płock Basin; sands and gravels dominate in the vicinity of Gościąż Lake. Most of the Płock Basin is covered with glaciofluvial sands and gravels deposited at the decline of the Poznań phase and before the beginning of the Pomeranian phase of the Vistulian glaciation. The surface of glaciofluvial sediments is marked by numerous subglacial troughs and melt-out basins, some forming present-day lakes. The initial glacial relief of the region is hidden by dunes of Late Glacial age.

Underlying the Quaternary sediments are Pliocene clays with layers of silts, silty/clayey sands and Miocene sands, clays and silts with layers of brown coal up to 5 m thick. Siderite concretions and

¹Radiocarbon Laboratory, Silesian Technical University, Krzywoustego 2, PL-44-100 Gliwice, Poland

²Faculty of Geography, Warsaw University, Krakowskie Przedmieście 30, PL-00-927 Warsaw, Poland

³Centre des Faibles Radioactivités, Laboratoire mixte CNRS-CEA, Domaine du CNRS, Avenue de la Terrasse, F-91198 Gif sur Yvette Cedex, France

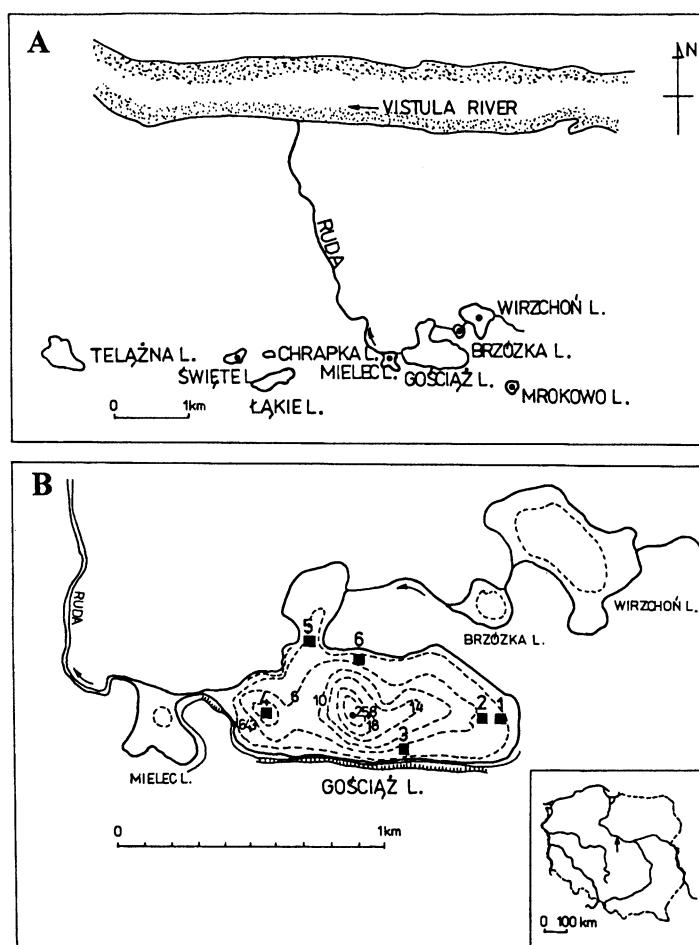


Fig. 1. Map of the study area. A. Environs of Gościąż Lake; • = cores from other lakes. B. Simplified bathymetric chart of the Na Jazach lake system. ■ = coring locations in Gościąż Lake; numbers = profiles shown in Fig. 2. Note: cores of laminated sediment from the central depression at water depth 25.8 m are not explicitly shown.

pyrite can be found in the Pliocene clays. The varied surface of Tertiary sediments exhibits denivelations of up to 130 m, caused by erosion, eversion and glaciotectionic processes (Skompski 1971; Madeyska 1993).

Gościąż Lake forms an intermediate stage of a system of four lakes drained by Ruda Creek (Fig. 1). The input to the system is on the eastern side of Wirzchoń Lake at the mouth of a small stream that drains several peaty and boggy depressions; output is from the western part of Mielec Lake. The four lakes form a cascade system dropping from Wirzchoń Lake, 64.4 m asl. This lake, which captures most of the allochthonous material, is presently *ca.* 2.6 m deep, and its basal sediments are 12.5 m thick.

The distinct chemical characteristics of groundwater in the drainage basin of the lake system indicate that Gościąż Lake is supplied by surface water from recent precipitation and by underground seepage from water-bearing Pleistocene sands and much deeper Pliocene/Miocene beds (Wicik and Więckowski 1991). The present surface area of Gościąż Lake is 0.45 km². It has two distinct basal depressions: a central one with a maximum depth of 25.8 m, in the form of an elliptical cone extending SE-NW for *ca.* 300 m (Więckowski 1993), and a western one of similar shape and dimension, slightly > 12 m deep. A third shallow depression in the eastern lake basin is not marked on the bathy-

metric chart of the lake. The lacustrine sediments vary in thickness from *ca.* 7 m to *ca.* 18 m in the depressions. In both eastern and western depressions, the lacustrine sediments overlie a thin peaty layer showing pollen spectra typical for the Allerød period (Ralska-Jasiewiczowa, Wicik and Więckowski 1987). Close examination of other cores shows that lacustrine sediments were deposited directly on sands with fragments of lignite. In the core taken *ca.* 350 m east of the central depression, below a series of sandy sediments of Pleistocene age, a level of gravels directly overlies Pliocene silts.

METHODS

We collected samples for ^{14}C dating from core segments 5 or 10 cm thick. Cores of laminated sediment were analyzed at the Institute of Botany, Polish Academy of Sciences, Krakow, by T. Goslar; other cores were analyzed at the Institute of Geography, Warsaw University, by A. Pazdur and B. Wicik. Samples of laminated sediment were pretreated with 0.5 N HCl; evolved CO_2 was trapped and, after purification, was used for ^{14}C activity measurements. Insoluble residue was washed until neutral reaction, dried and combusted in an oxygen stream. ^{14}C activity was measured using proportional counters filled with pure CO_2 . We collected small aliquots of CO_2 for $\delta^{13}\text{C}$ determinations just before filling the proportional counters. All $\delta^{13}\text{C}$ analyses were made on an MI1305 mass spectrometer at the Institute of Physics, Maria Curie Skłodowska University, Lublin.

Samples from other cores were treated with 0.5 N HCl to remove carbonates and, after washing and drying, were combusted to CO_2 and counted. We used only the organic fraction for ^{14}C determinations on most samples. Both old and new oxalic acid standards were used as modern reference samples. Ages were calculated according to the recommendations of Stuiver and Polach (1977). Plant fragments for accelerator mass spectrometry (AMS) dating were separated from 10-yr segments of core by Z. Tomczynska-Moskwa, and terrestrial macrofossils were identified and selected by M. Ralska-Jasiewiczowa at the Institute of Botany, Krakow. Because of the very low mass obtained, individual samples separated from adjacent 10-yr segments of core were combined at the Centre des Faibles Radioactivités, Gif sur Yvette, to obtain enough carbon for AMS dating (Arnold *et al.* 1987).

RADIOCARBON CHRONOLOGY OF GOŚCIAŻ LAKE SEDIMENTS

Beginning with the first coring in 1985, which yielded the first long laminated sequence (Pazdur *et al.* 1987a,b; Ralska-Jasiewiczowa, Wicik and Więckowski 1987), four other cores of laminated sediment were collected from the central depression at water depth 25.8 m (*cf.* Fig. 1B). These cores were used to establish a detailed varve chronology (Goslar 1993) as well as for isotopic and paleoecologic studies (Róžański *et al.* 1992; Goslar *et al.* 1992). Bulk samples of laminated sediment from cores G1/85, G1/87, G2/87 and G1/90 were used for ^{14}C age determinations on both carbonate and total organic matter fractions. Preliminary results were reported elsewhere (Pazdur *et al.* 1987a,b; Goslar *et al.* 1989) and were also used for tentative reconstruction of lake-level changes (Pazdur and Starkel 1989). Table 1 lists ^{14}C age determinations of all laminated sediment samples. Pazdur *et al.* (ms. in preparation) will discuss in detail the significance of isotopic data obtained from long cores of laminated sediment.

The size of the reservoir effect estimated by comparing varve chronology and ^{14}C dates obtained on bulk samples of laminated sediment varies with time and ranges from 900 to 3100 yr. ^{14}C content of dissolved inorganic carbon (DIC) of groundwater supplying the lake ranges from 63.4 to 70.0 pMC and in lake water equals 82.5 ± 1.7 pMC. Table 2 lists the results of AMS-dated terrestrial macrofossils separated from well-defined levels of laminated-sediment cores G1/97 and G2/97, obtained at the Gif

TABLE 1. ^{14}C Dates Obtained on Samples of Laminated Sediment From Cores Taken in the Central Depression of Gościąż Lake, Water Depth 25.8 m

Lab no. (Gd-)	Sample, depth	^{14}C age (BP)	$\delta^{13}\text{C}$ (‰)
2583	G1/85/1.5–1.6m/C*	2100 $\pm$ 90	–0.99
4066	G1/85/1.5–1.6m/O†	1730 $\pm$ 100	–30.24
3230	G1/85/2.65–2.75m/C	2200 $\pm$ 40	1.20
2649	G1/85/2.65–2.75m/O	2340 $\pm$ 80	–29.30
5008	G1/85/3.05–3.15m/C	3660 $\pm$ 50	0.00
2571	G1/85/3.05–3.15m/O	2730 $\pm$ 120	–30.36
5082	G1/85/3.9–4.0m/C	3880 $\pm$ 70	1.26
2620	G1/85/3.9–4.0m/O	3050 $\pm$ 80	–28.55
2618	G1/85/4.9–5.0m/C	4680 $\pm$ 120	1.61
2621	G1/85/4.9–5.0m/O	3800 $\pm$ 90	–30.17
3277	G1/85/6.1–6.2m/C	5350 $\pm$ 50	–1.20
2527	G1/85/6.1–6.2m/O	4230 $\pm$ 120	–31.52
5086	G1/85/6.9–7.0m/C	5690 $\pm$ 80	0.49
2623	G1/85/6.9–7.0m/O	5040 $\pm$ 110	–30.67
5094	G1/85/7.9–8.0m/C	6280 $\pm$ 80	0.35
2626	G1/85/7.9–8.0m/O	5530 $\pm$ 100	–30.63
5088	G1/85/8.9–9.0m/C	7390 $\pm$ 190	–0.04
4100	G1/85/8.9–9.0m/O	6320 $\pm$ 120	–31.37
1992	G1/85/9.60–9.65m/C	7930 $\pm$ 70	–1.05
2564	G1/85/9.60–9.65m/O	6840 $\pm$ 390	–32.00
5091	G1/85/10.0–10.1m/C	8190 $\pm$ 100	–0.49
5372	G1/85/10.0–10.1m/O	7630 $\pm$ 120	–31.23
5095	G1/85/10.45–10.55m/C	8420 $\pm$ 90	–2.16
4105	G1/85/10.45–10.55m/O	7880 $\pm$ 150	–31.59
5096	G1/85/11.0–11.1m/C	8800 $\pm$ 70	–1.80
3231	G1/85/11.45–11.50m/C	9160 $\pm$ 50	–4.54
2476	G1/85/11.45–11.50m/O	8960 $\pm$ 120	–32.00
5098	G1/85/12.0–12.1m/C	10,230 $\pm$ 90	–6.05
2627	G1/85/12.5–12.6m/C	10,710 $\pm$ 150	–6.38
4103	G1/85/12.5–12.6m/O	10,240 $\pm$ 250	–34.08
5099	G1/85/13.0–13.1m/C	10,830 $\pm$ 80	–6.58
4104	G1/85/13.0–13.1m/O	10,790 $\pm$ 220	–34.34
3225	G1/85/13.5–13.55m/C	10,640 $\pm$ 60	–8.29
2464	G1/85/13.5–13.55m/O	10,640 $\pm$ 100	–35.44
3223	G1/85/14.45–14.50m/C	12,100 $\pm$ 90	–6.96
4067	G1/85/14.45–14.50m/O	11,270 $\pm$ 350	–34.23
4007	G1/85/15.0–15.05m/C	12,570 $\pm$ 130	–7.82
4013	G1/85/15.0–15.05m/O	11,980 $\pm$ 430	–33.00
2584	G1/85/15.4–15.5m/O	12,650 $\pm$ 140	–33.19
5048	G1/85/15.40–15.50m/C	13,480 $\pm$ 120	–8.02
5444	G1/87/4.01–4.10m/C	3850 $\pm$ 70	0.75
5442	G1/87/4.31–4.40m/C	3720 $\pm$ 70	1.38
5441	G1/87/5.02–5.11m/C	3610 $\pm$ 60	1.85
5377	G1/87/6.15–6.25m/C	4520 $\pm$ 50	0.48
5376	G1/87/7.00–7.10m/C	4540 $\pm$ 70	0.56
5375	G1/87/7.90–8.00m/C	5430 $\pm$ 60	0.64
5374	G1/87/9.02–9.10m/C	6130 $\pm$ 60	0.02

TABLE 1. (Continued)

Lab no. (Gd-)	Sample, depth	¹⁴ C age (BP)	δ ¹³ C (‰)
2888	G1/87/9.42–9.52m/C	5270 ± 90	0.04
2889	G1/87/10.66–10.72m/C	7350 ± 120	–0.78
5373	G1/87/10.93–11.0m/C	7620 ± 60	–0.92
5372	G1/87/11.33–11.40m/C	7800 ± 70	–1.35
5242	G1/87/16.92–16.98m/C	13,240 ± 120	–10.20
2771	G1/87/16.92–16.98m/O	13,780 ± 200	–34.00
6371	G2/87/16.02–16.10m/C	11,980 ± 170	–8.37
5853	G2/87/16.10–16.20m/C	11,700 ± 120	–4.12
4676	G2/87/16.10–16.20m/O	10,470 ± 180	–30.00‡
6355	G1/90/14.89–14.92/O1	11,970 ± 130	–29.46
4669	G1/90/14.89–14.92/O2	12,350 ± 260	–25.00

*C = carbonate fraction

†O = organic fraction

‡Assumed value

sur Yvette AMS facility. Róžański *et al.* (1992) and Goslar *et al.* (1992) discussed the significance of these results for extending the calibration of the ¹⁴C time scale to the Late Glacial period.

For this study, we used the data listed in Tables 1 and 2 to evaluate the magnitude of the reservoir correction (“hard-water effect”). One may compare two independent time scales with the ¹⁴C dates of bulk samples of lake marl to derive the reservoir correction: the varve chronology elaborated by Goslar (1993), and the AMS dates listed in Table 2. The first approach yields a reservoir correction value of 2070 ± 120 yr, whereas the second approach yields a value of 1900 ± 120 yr. In both cases, we compared ten pairs of dates covering the Late Glacial segment of laminated sediment. From this comparison, we conclude that the reservoir correction for the basal sediments of Gościąg Lake is 2000 ± 120 yr. The observed scatter of individual differences in both cases is similar, with a standard deviation of $s_1 = 360$ yr.

TABLE 2. AMS Dates of Terrestrial Macrofossils from Core G2/87, Gościąg Lake

Sample	Varves	Sample material	¹⁴ C age (BP)
G201M	354–362	<i>Pinus</i> seedling, wood	10,030 ± 250
G202M	363–371	<i>Pinus</i> needle, <i>Betula</i> nutlet	10,450 ± 140
G223M			
+G224M			
+G225M	637–666	<i>Betula</i> nutlet, seed, scales	9600 ± 280
G233M	754–763	Bark	9950 ± 150
G236M			
+G237M	794–813	<i>Betula</i> nutlets, scales	9870 ± 150
G238M	824–833	<i>Betula</i> nutlets, scales	9870 ± 330
G244M			
+G245M			
+G245AM	886–910	Bud scales	10,040 ± 240
G252M			
+G255M	973–1020	<i>Pinus</i> seedlings, <i>Betula</i> nutlets	10,360 ± 160
G264M	1121–1130	Plant detritus	9750 ± 210
G268M	1171–1180	<i>Pinus</i> needles	10,050 ± 120

As a supplement to this study, we sampled a series of 12 cores along two lines in a W–E direction, to determine the thickness and stratigraphy of the lake sediments; we ^{14}C -dated six cores. Figure 1B shows core locations. Figure 2 shows the profiles of the cores and Table 3 lists the results.

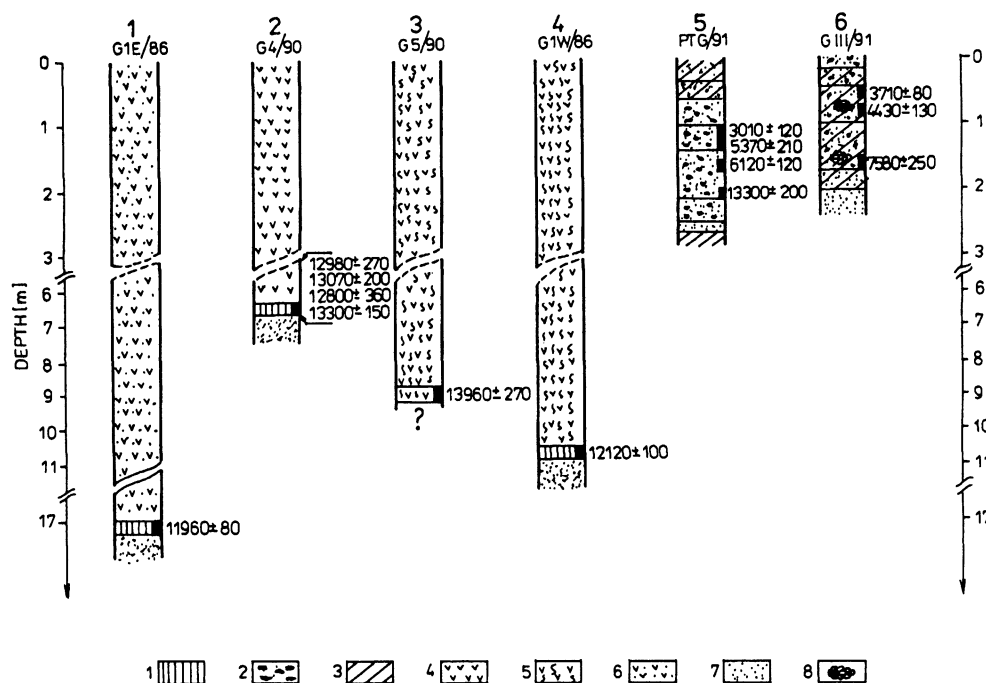


Fig. 2. Lithological profiles of sediment cores from Gościąż Lake. Key: 1. peat; 2. macroscopic plant remains (bark, twigs, charcoal); 3. fine detrital gyttja; 4. algal gyttja; 5. sulphuric-calcareous gyttja; 6. calcareous gyttja; 7. sand; 8. cone of *Picea* spp.

These results enable reliable and relatively precise dating of the beginning of organogenic sedimentation in the Gościąż Lake basin. The date of $13,300 \pm 150$ BP obtained on the deepest segment of the basal layer of peat underlying the lacustrine series in profile G4/90 (Fig. 2) determines the beginning of organic sedimentation in the eastern part of the lake. Taking into account the mean value of two dates obtained on the middle peat layer (6.6–6.7 m depth), $13,010 \pm 170$ BP, we obtain for the basal peat layer a series of three dates in good stratigraphic order. Because of relatively large dating errors, it seems reasonable to attribute to this peat layer the mean value of the whole set of four dates, $13,150 \pm 110$ BP. This result coincides well with the date, $13,300 \pm 200$ BP, which determines the beginning of organic sedimentation in the profile PTG/91 (Core 5 in Fig. 1, taken at the boundary between Gościąż Lake and Tobylka Bay), obtained on coarse-detrital gyttja.

Almost identical early dates were obtained on thin peat layers underlying lacustrine sediments in cores G3/92 and G20/92 ($13,020 \pm 160$ BP and $13,240 \pm 150$ BP, respectively), taken in peaty depressions of Ruda Creek valley at the eastern part of the study area (sampling points 11 and 13, Fig. 3). Similar dates were obtained on layers of peat and peaty detritus from basal sediment of Mielec and Wirzchoń Lakes (cf. Figs. 1 and 6 and Table 5).

TABLE 3. ¹⁴C dates of Cores Taken From Gościąg Lake

Lab no. (Gd-)	Sample, depth	Sample material	¹⁴ C age (BP)
3305	G1E/86/17m	Peaty gyttja	11,960 ± 80
4683	G4/90/6.55–6.60m	Peat	12,980 ± 270
6386	G4/90/6.6–6.65m	Peat	13,070 ± 200
4691	G4/90/6.6–6.7m	Peat	12,800 ± 360
5857	G4/90/6.71–6.78m	Peat	13,300 ± 150
4688	G5/90/9.04m	Calcareous gyttja	13,960 ± 270
4733	GIII/91/0.45–0.60m	Detrital gyttja	3710 ± 80
4732	GIII/91/0.70–0.90m	Detrital gyttja	4430 ± 130
4731	GIII/91/1.50–1.70m	Detrital gyttja	7580 ± 250
4788	PTG/91/1.00–1.34m	Charcoal	3010 ± 120
4790	PTG/91/1.46–1.64m	Charcoal	5370 ± 210
4789	PTG/91/1.94–2.12m	Wood and charcoal	6120 ± 120
4791	PTG/91/2.67–2.69m	Coarse detrital gyttja	13,300 ± 200
5049	G1W/86/11m	Peaty detrital gyttja	12,120 ± 110

CHRONOLOGY OF SEDIMENTATION IN THE AREA OF GOŚCIAŻ LAKE

Lithofacially differentiated sediments from the area of the lake contain important information about the development of the lake system and changes of its hydrological regime, including changing water levels during the last 13 ka BP. We conducted field work on these sediments for three seasons: in 1989, we sampled eight cores (Fig. 3); in 1992, we collected a second series of long cores reaching depths of *ca.* 8 m (Fig. 3); and we took 15 short cores along the southeast shore to determine the structure of subfossil lake terraces. From this series of corings, four samples were available for dating (LT-E1/92, LT-G3/92, LT-E5/92 and LT-J3/92 (Fig. 3); in 1993, we took two cores at the north shore of the lake (21 and 22 in Fig. 3). Figures 4 and 5 show detailed stratigraphy of some of these cores; Table 4 lists the ¹⁴C results.

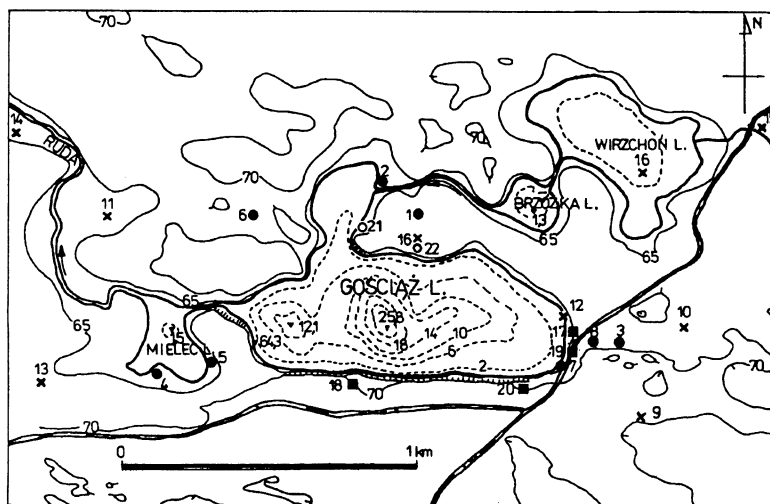


Fig. 3. Locations of cores and trenches around Gościąg Lake. • (1–8) = cores taken along the lakeshore in 1989; Fig. 4 shows lithological profiles. × (9–16) = cores taken in 1992; Fig. 5 shows lithological profiles (except core 16). ■ (17–20) = trenches made in 1992 to determine the structure of lake terraces; profiles are not shown. ○ (21–22) = cores taken in 1993.

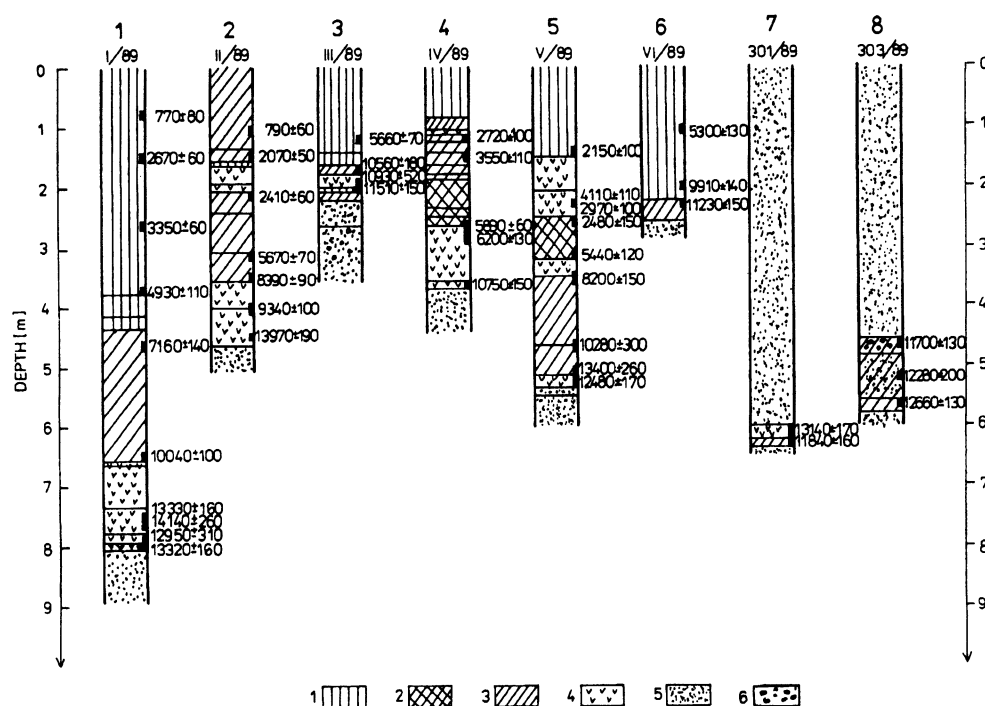


Fig. 4. Cores taken in 1989 around Gościąg and Mielec Lakes (• in Fig. 3): 1. peat; 2. decayed organic matter; 3. amorphous organic matter and humus sand; 4. lake marl (gyttja); 5. sand. Horizontal lines mark minor lithological boundaries.

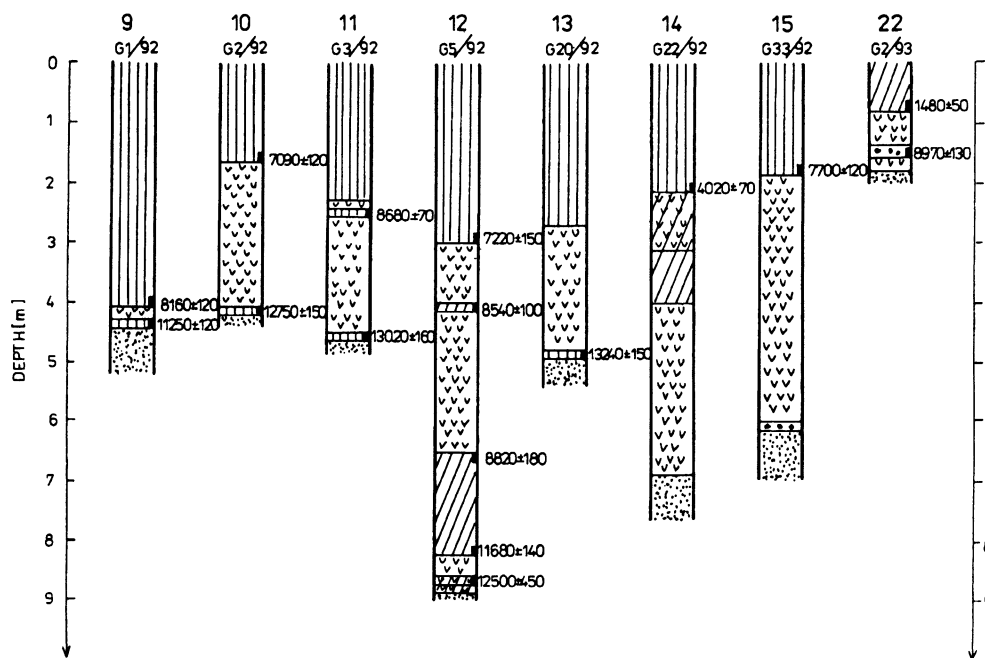


Fig. 5. Cores taken in 1992 and 1993; Fig. 3 shows locations. Key to lithological symbols is in Fig. 4.

TABLE 4. ¹⁴C Dates From Cores Taken in the Vicinity Of Gościąg Lake

Lab no. (Gd-)	Sample, depth	Sample material	¹⁴ C age (BP)
6171	GTOI/89/0.7–0.8m	Peat	770 ± 80
5656	GTOI/89/1.6–1.7m	Peat	2670 ± 60
5657	GTOI/89/2.6–2.7m	Peat	3350 ± 60
6174	GTOI/89/3.6–3.7m	Peat	4930 ± 110
6176	GTOI/89/4.6–4.7m	Peat	7160 ± 140
5659	GTOI/89/6.4–6.5m	Amorphous organic matter	10,040 ± 100
6219	GTOI/89/7.6–7.7m	Calcareous gyttja	13,330 ± 160
6192	GTOI/89/7.7–7.8m	Calcareous gyttja	14,140 ± 260
4549	GTOI/89/7.8–7.93m	Calcareous gyttja	12,950 ± 310
4559	GTOI/89/7.8–7.93m	Calcareous gyttja	13,320 ± 160
5678	GTOII/89/1.00–1.15m	Amorphous organic matter	790 ± 60
5669	GTOII/89/1.37–1.59m	Amorphous organic matter	2070 ± 50
5670	GTOII/89/2.13–2.30m	Amorphous organic matter	2410 ± 60
5679	GTOII/89/3.00–3.18m	Amorphous organic matter	5670 ± 70
5677	GTOII/89/3.51–3.61m	Amorphous organic matter	8390 ± 90
5676	GTOII/89/3.90–4.12m	Calcareous gyttja	9340 ± 100
6194	GTOII/89/4.50–4.69m	Calcareous gyttja	13,970 ± 190
5681	GTOIII/89/1.05–1.25m	Wooden peat	5660 ± 70
6200	GTOIII/89/1.55–1.71m	Amorphous organic matter	10,560 ± 180
4522	GTOIII/89/1.84m	Amorphous organic matter	10,930 ± 520
6201	GTOIII/89/1.94–2.05m	Peat	11,510 ± 150
4521	GTOIV/89/1.22–1.37m	Amorphous organic matter	2720 ± 100
4542	GTOIV/89/1.44–1.55m	Amorphous organic matter	3550 ± 110
5703	GTOIV/89/2.77–2.90m	Calcareous gyttja	5890 ± 60
6202	GTOIV/89/2.94–3.15m	Calcareous gyttja	6200 ± 130
6203	GTOIV/89/3.60–3.70m	Calcareous gyttja	10,750 ± 150
6205	GTOV/89/1.42–1.52m	Peat	2150 ± 100
6209	GTOV/89/2.18–2.35m	Calcareous gyttja	4110 ± 110
6221	GTOV/89/2.48–2.60m	Organic detritus	2970 ± 100
4564	GTOV/89/2.48–2.60m	Charcoal	2480 ± 150
4557	GTOV/89/3.00–3.12m	Detrital gyttja	5440 ± 120
6210	GTOV/89/3.32–3.42m	Calcareous gyttja	8200 ± 150
4565	GTOV/89/4.60–4.70m	Amorphous organic matter	10,280 ± 300
4558	GTOV/89/5.30–5.45m	Sand with organic matter	13,400 ± 260
6215	GTOV/89/5.57–5.77m	Calcareous gyttja	12,480 ± 170
6212	GTOVI/89/1.0–1.1m	Moss peat	5300 ± 130
6214	GTOVI/89/2.0–2.1m	Moss peat	9910 ± 140
6217	GTOVI/89/2.2–2.3m	Amorphous organic matter	11,230 ± 150
5696	GTO301/89/6.0–6.3m	Calcareous gyttja	13,140 ± 170
6220	GTO301/89/6.30–6.35m	Amorphous organic matter	11,840 ± 160
5789	GTO303/89/4.5–4.7m	Gyttja with organic detritus	11,700 ± 130
6297	GTO303/89/5.3–5.4m	Calcareous gyttja	12,280 ± 200
5778	GTO303/89/5.6–5.8m	Calcareous gyttja	12,660 ± 130
6753	G1/92/4.0–4.1m	Peat	8160 ± 120
6764	G1/92/4.27–4.33m	Peat	11,250 ± 120
6754	G2/92/1.50–1.59m	Peat	7090 ± 120
6759	G2/92/4.12–4.31m	Peat	12,750 ± 150
7227	G3/92/2.34–2.38m	Peat	8680 ± 70
6783	G3/92/4.53–4.60m	Peat	13,020 ± 160

TABLE 4. (Continued)

Lab no. (Gd-)	Sample, depth	Sample material	¹⁴ C age (BP)
4932	G5/92/2.83–3.0m	Peat	7220 ± 150
4933	G5/92/3.98–4.02	Calcareous gyttja	8540 ± 100
4934	G5/92/6.45–6.55m	Calcareous gyttja	8820 ± 180
6762	G5/92/8.1–8.13m	Calcareous gyttja	11,680 ± 140
4924	G5/92/8.7–8.8m	Calcareous gyttja	12,500 ± 450
4936	G20/92/4.80–4.85	Peat	13,240 ± 150
4935	G22/92/2.0–2.12m	Peat	4020 ± 70
4937	G33/92/1.8–1.9m	Peat	7700 ± 120
7187	GM43/92/0.65–0.67	Tufa	7730 ± 60
7258	G56/92	Lignite	>43,000
7364	G1/93WD/7.6m	Lignite	34,300 ± 700
7363	G2/93/0.60–0.80m	Soil	1480 ± 50
7353	G2/93/0.98–1.02m	Calcareous gyttja	12,120 ± 70
7352	G2/93/1.50–1.55m/C	Calcareous gyttja	12,720 ± 100
6900	G2/93/1.50–1.55m/O	Calcareous gyttja	8970 ± 130
8053	E5/92/0.65–0.75m	Fossil soil	3650 ± 170
8054	A1/92/2.95–3.0m	Organic silt	8100 ± 200
8054	G3/92/1.9–1.96m	Sand with organic layers	4400 ± 160
8055	J3/92/0.4–0.45m	Peat	2330 ± 180

Cores GTO/89

In all GTO cores, except GTO301/89 and GTO303/89, lacustrine marls of different thickness topped by peat overlie a basal sand layer. In cores GTOII/89, GTOIV/89 and GTOV/89, which show direct hydrological relations with the Gościąg Lake basin, layers of decayed organic sediments and sandy humus separate a series of lacustrine sediments that formed when the water table in the lake was *ca.* 2.5 m lower than at present. This may be regarded as an indicator of an exceptionally dry period.

The scatter of ¹⁴C dates obtained on lacustrine gyttja, observed in the bottom of profile GTOI/89 (Fig. 4), does not significantly exceed the limits predicted from comparative analysis of ¹⁴C dates obtained on bulk samples of laminated sediment and the corresponding varve dates or AMS dates of macrofossils. Four dates on the organic fractions of lake marl samples at depths ranging from 7.8 m to 7.93 m yield a mean value of 13,440 ± 250 BP. Given a reservoir correction of 2000 ± 120 yr, the beginning of lacustrine sedimentation in profile GTOI/89 may be dated to several centuries before 11,440 ± 300 BP.

Markedly similar sequences can be observed in profiles GTOIV/89 and GTOV/89, from the Mielec Lake shore (4 and 5 in Fig. 3). Decayed organic matter directly overlies lacustrine gyttja in profile GTOIV/89, indicating a break in sedimentation and the beginning of a dry episode and low water level. ¹⁴C dates on the organic fractions of the basal and top layers of the lacustrine series are 10,750 ± 150 BP (obtained on gyttja) and 5890 ± 60 BP, respectively. In profile GTOV/89, lacustrine gyttja accumulation is delimited by two ¹⁴C dates, 8200 ± 150 BP, obtained on amorphous organic matter, and 5440 ± 120 BP, obtained on mursh, from under- and overlying lacustrine series, respectively. Because the two profiles were taken from proximate sites in similar geomorphological settings, we assume that deposition of amorphous organic matter and mursh in both profiles was approximately synchronous. If so, the beginning of lacustrine accumulation in profile GTOIV may be dated to 8750 BP, after applying the reservoir correction of 2000 yr.

Cores G/92

We sampled cores from sites 17–20 (Fig. 3) from low peat bogs during several seasons of field work. According to geomorphological and geological data, these cores should reflect hydrological changes in the lake basin. We selected ¹⁴C-dated samples from these cores to supplement the determinations made earlier on cores GTO/89, which had few peaty organic horizons. Figure 5 shows the stratigraphy of the sediments; Table 4 lists the ¹⁴C results.

Lake Terraces

We collected four samples from lake terraces identified in the morphology of the southeastern lake shore (sites 17–20 in Fig. 3). Sample LT-J3/92 was taken from a peat layer in the spring terrace (site 18 in Fig. 3). Other samples were dispersed organic dust from lake sands of the beach facies.

RADIOCARBON CHRONOLOGY OF SEDIMENTS IN NEIGHBORING LAKES

We dated cores from three other lakes forming the Na Jazach lake complex and from Mrokowo and Święte Lakes (Fig. 1; Table 5). This system of lakes and peaty depressions has no common drainage; Ruda Creek drains the eastern area and the Zuzanka River drains the western area. Mrokowo and Święte Lakes are not drained.

TABLE 5. ¹⁴C Dates From Cores Taken in the Na Jazach Lake System

Lab no. (Gd-)	Sample, depth	Sample material	¹⁴ C age (BP)
6369	Wirzchoń/86/12.4–12.5m	Peat (?)	13,770 ± 150
4763	Brzózka/91/6.75–6.84m	Algal gyttja	4510 ± 80
6589	Brzózka/91/11.35–11.45m	Calcareous gyttja	11,340 ± 150
4679	Mielec 3/90/13.90–13.95m	Calcareous gyttja	14,380 ± 270
6370	Mielec 3/90/13.95–14.0m	Calcareous gyttja	12,590 ± 190
4692	Mielec 3/90/15m	Peat	13,280 ± 320
6491	Święte/91/4.0–4.1m	Algal gyttja	2840 ± 100
6485	Święte/91/8.05–8.14m	Algal gyttja	4510 ± 110
5948	Święte/91/9.65–9.75m	Calcareous gyttja	7010 ± 90
6487	Święte/91/11.86–11.88m	Bark fragments	10,060 ± 140
6467	Święte/91/12.22–12.27m	Peat	12,410 ± 170
6553	Święte/91/13.16–13.18m	Organic detritus	11,030 ± 170
6684	Mrokowo/91/7.9–8.0m	Gyttja	7760 ± 110
6685	Mrokowo/91/11.9–12.0m	Gyttja	8530 ± 110
6720	Mrokowo/91/12.9–13.0m	Rotten peat	9480 ± 120
6721	Mrokowo/91/14.0–14.1m	Peat	12,030 ± 130

Wirzchoń Lake was cored in 1986; other cores were taken in 1990 and 1991. Figure 6 shows the stratigraphy of all the cores used in this study. The sediments of the Wirzchoń and Mielec Lakes begin with a thin peat layer at the base, overlain by an almost uniform series of calcareous gyttjas. The profile obtained from Brzózka Lake is more differentiated, showing distinct irregular lamination at its base (between *ca.* 6.5 and 11.5 m); the core taken from this lake probably did not reach the bottom of the sediment. For dating, we used the basal segment of the core, consisting of algal gyttja with sand admixture.

Sediments from two lakes west of the Na Jazach lake complex begin with a layer of mursh (Mrokowo/91) or sandy peat (Święte/91) (Fig. 6). In the latter profile, sand with some macrofossils

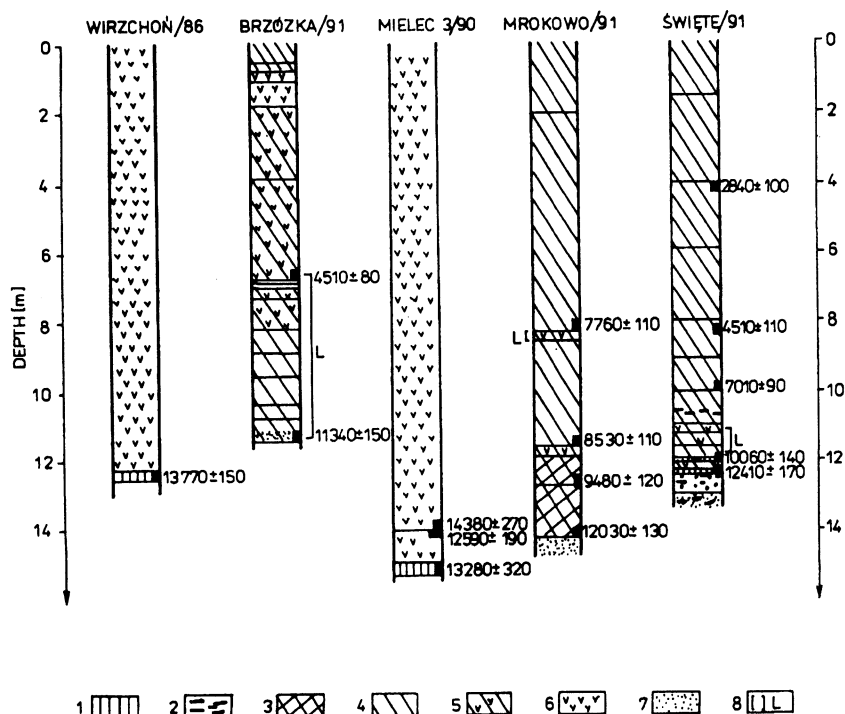


Fig. 6. Cores taken from other lakes in the study area. Coring location are • in Fig. 1A. Key: 1. peat; 2. macroscopic plant remains; 3. decayed organic matter; 4. algal gyttja; 5. algal-calcareous gyttja; 6. calcareous gyttja; 7. sand; 8. core segments with laminated sediment. Horizontal lines mark minor lithological boundaries.

overlies the organic level. Although both profiles consist mainly of non-calcareous algal gyttja, we found relatively thin layers of laminated algal-calcareous gyttja in each (Fig. 6). ^{14}C dates obtained on basal peat layers from Wirzchoń and Mielec Lakes, respectively $13,770 \pm 150$ and $13,280 \pm 320$ BP, indicate very early lacustrine sedimentation. These dates correlate well with the results obtained on basal peaty layers in Gościąż Lake ($13,300 \pm 200$ BP, core PTG/91, and $13,150 \pm 110$ BP, the mean of four dates on basal peat from core G4/90). Dates obtained on basal organic levels in profiles from Mrokowo and Święte Lakes (Fig. 6) indicate that the lacustrine sedimentation began almost synchronously in both lakes, but *ca.* 1 ka later than in the Na Jazach lake complex.

WATER-LEVEL CHANGES

Detailed and accurate reconstruction of water-level changes in Gościąż Lake from ^{14}C -dated facial and lithological changes observed in sediment cores taken from its shore and environs is complex. Differentiation of sediments is controlled by both local geomorphology in the beach zone and by short-term water-level changes resulting from seasonal variation in precipitation. Despite these limitations, one can distinguish periods of high water level related to accumulating lacustrine gyttja. One may assume that lacustrine gyttja accumulation records high water levels in more than one profile. On the other hand, low water levels are recorded by layers of organic sediments such as peat and amorphous organic matter. Layers of mursh or decayed organic matter indicate arid periods with very low lake levels.

Cores GTO/89 and G/92 provide records of three periods of lacustrine gyttja accumulation, indicating high water levels. The oldest period lasted from *ca.* 11.8 to 10.2 ka BP, and the youngest from 2.5 to 2.1 ka BP. The duration of the middle period, which is not well documented in Figure 7, may be estimated at 8.2 to 7.0 ka BP. Almost all GTO/89 profiles (GTO I, II, III, V and 301) record the older episode of high water. Determining the beginning of calcareous gyttja accumulation in profiles GTO II, IV and V is problematic because corresponding dates are based on organic fractions of lacustrine sediment and may be subject to inaccuracy in the applied reservoir correction. Assuming a correction of 2000 yr, calcareous gyttja accumulation in profiles GTOI/89 and GTOII/89 begins *ca.* 12 ka BP. If this is the case, gyttja accumulation begins synchronously in profiles GTO I, II, III and 301 in the interval between 11.8 and 10.2 ka BP. The short episode of lacustrine accumulation, marked by a thin gyttja layer in profile GTO V (dated to $12,480 \pm 170$ BP), coincides, after reservoir correction, with the end of that period. Relatively precise timing of younger episodes of lacustrine sedimentation is possible from ¹⁴C dates obtained on peat, mursh or amorphous organic matter. ¹⁴C dates determining the beginning and end of lacustrine sedimentation obtained from peat layers in profiles G/92 correlate quite well with dates obtained on lithological boundaries of profiles GTO/89.

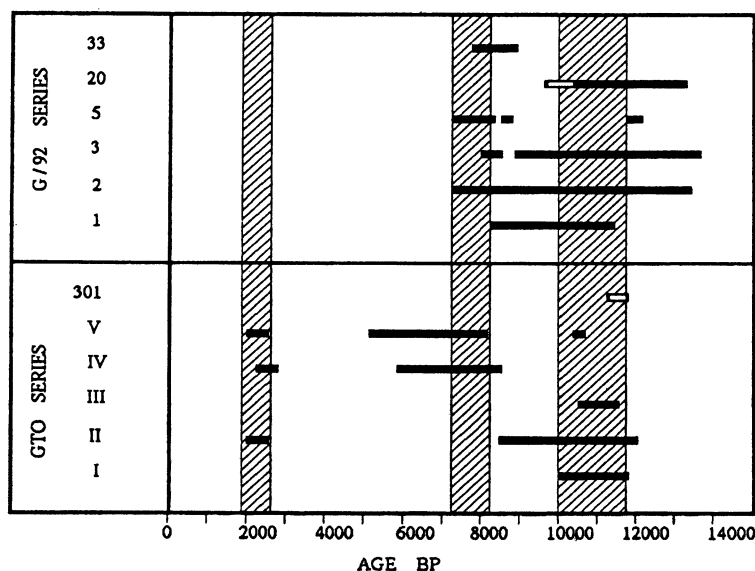


Fig. 7. Periods of lacustrine gyttja sedimentation near Gościąż Lake

We recorded no lacustrine sediments between 5.4 and 2.7 ka BP, which may indicate an extremely low lake level during this period. With the water level in Gościąż Lake at 62 m asl, Tobylka Bay was probably a shallow boggy basin. Figure 8 shows a reconstruction of water-level changes in Gościąż Lake from ¹⁴C-dated lithological boundaries of sediments around the lake, based on the above-mentioned assumptions.

We distinguished a rapid rise in the Gościąż Lake level *ca.* 11.8 ka BP by observing a disturbance at the eastern lake shore associated with a landslide on the sandy bank. A thick series of fine-grained sands overlying lacustrine sediment in profile GTO301/89 records this event. Perhaps the sandy layer at the bottom of profile G1/87 was deposited at the same time (Wicik and Więckowski 1991). Similar trends in water-level changes between 8100 and 2300 BP may be deduced from ¹⁴C dating

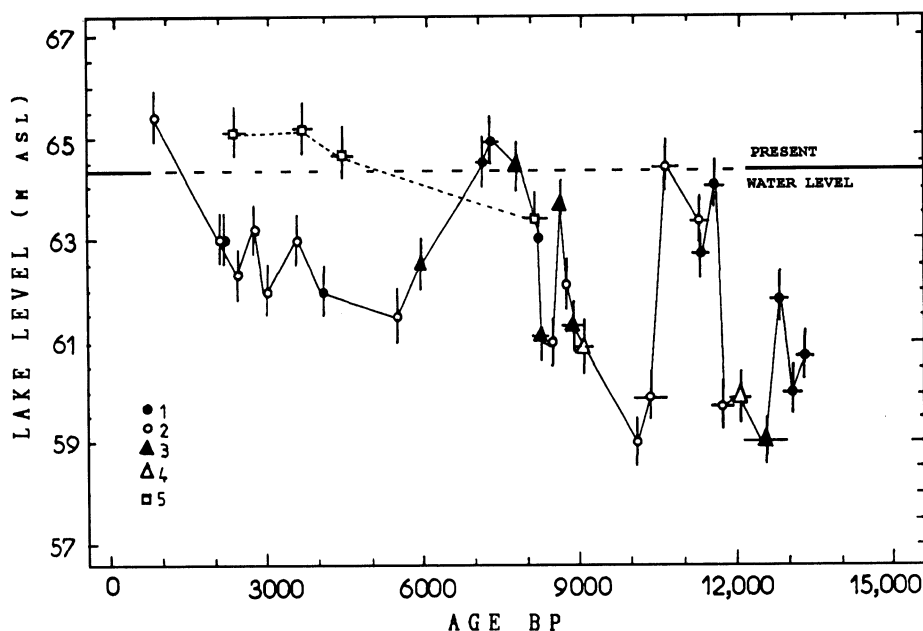


Fig. 8. Changes of water levels in Gościąg Lake from the Late Glacial to the present, expressed as changes in the elevation of the water table (m asl) estimated from lithological studies and ^{14}C -dating of cores around the lake. Key: 1. peat; 2. mursh; 3. detrital gyttja; 4. lake marl ($T_R = 2$ ka); 5. lake terraces.

of lake terraces. A water-level rise of *ca.* 1.5 m during this period corresponds to the formation of a terrace dated *ca.* 2300 BP at altitude *ca.* 1.5 m higher than that of the terrace at 8100 BP.

CONCLUSIONS

Lithological boundaries between lacustrine gyttja and non-lacustrine sediments reflect changes in the water level in Gościąg Lake. Correlating these locations with the ^{14}C dates enables us to reconstruct fluctuations in the lake's water table during the last 13 ka BP. Thus, the highest and lowest water levels of Gościąg Lake (Fig. 8) should correspond to other records of temperate-zone lake-level changes during the Late Glacial and Holocene. Holocene lake-level fluctuations recorded in southern Sweden by Digerfeldt (1988:173, Fig. 11) indicate the first distinct, rapid lake-level decline at 9.7–9.5 ka BP, and the second long period of a low lake level between 6.5 and 3.5 ka BP. Further, each of the nine lakes studied shows low levels between 2.7 and 2.0 ka BP. We have almost exactly replicated these findings with our data (Figs. 7 and 8).

The record of Holocene lake-level fluctuations in Jurassic and French subalpine lakes, obtained by Magny (1992, 1993) shows distinct similarities to the Gościąg Lake record. The two oldest transitions from transgression to regression, noted at 9.5–8.0 ka and 7.5–6.0 ka BP in French lakes, are also visible in the trend of Gościąg lake-level changes. No such distinct similarities occur in the late Holocene, but both records agree fairly well.

Gościąg lake-level changes also correlate to regional patterns of high and low lake levels obtained from statistical analyses of lakes in eastern North America (Harrison 1989) and Europe (Harrison, Prentice and Guiot 1993). Thus, we conclude that the behavior of Gościąg Lake during the last 12

ka fairly accurately reflects global climate changes in the temperate zone during the Late Glacial and Holocene.

ACKNOWLEDGMENTS

This study was initiated by the Committee of Quaternary Research of the Polish Academy of Sciences. The present report is part of research project PB 740/6/91, sponsored by the State Committee for Scientific Research.

REFERENCES

- Arnold, M., Bard, E., Maurice, P. and Duplessy, J.-C. 1987 C-14 dating with Gif-sur-Yvette tandemtron accelerator: Status report. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., *Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. Nuclear Instruments and Methods in Physics Research B29*: 120–123.
- Digerfeldt, G. 1988 Reconstruction and regional correlation of Holocene lake-level fluctuations in Lake Bysjön, South Sweden. *Boreas* 17:165–172.
- Goslar, T. 1993 Varve chronology of laminated sediments of Lake Gościąż. *Polish Botanical Studies, Guidebook Series* 8: 105–119 (in Polish).
- Goslar, T., Kuc, T., Pazdur, M. F., Ralska-Jasiewiczowa, M., Róžański, K., Szeroczyńska, K., Walanus, A., Wicik, B., Więckowski, K., Arnold, M. and Bard, E. 1992 Possibilities for reconstructing radiocarbon level changes during the late glacial by using a laminated sequence of Gościąż Lake. In Long, A. and Kra, R. S., eds., *Proceedings of the 14th International ¹⁴C Conference. Radiocarbon* 34(3): 826–832.
- Goslar, T., Kuc, T., Ralska-Jasiewiczowa, M., Róžański, K., Arnold, M., Bard, E., van Gel, B., Pazdur, M. F., Szeroczyńska, K., Wicik, B., Więckowski, K. and Walanus, A. 1993 High-resolution lacustrine record of the Late Glacial/Holocene transition in Central Europe. *Quaternary Science Reviews* 12: 287–294.
- Goslar, T., Pazdur, A., Pazdur, M. F. and Walanus, A. 1989 Radiocarbon and varve chronologies of annually laminated lake sediments of Gościąż Lake, Central Poland. In Srdoč, D., Long, A. and Kra, R. S., eds., *Proceedings of the 13th International ¹⁴C Conference. Radiocarbon* 31(3): 940–947.
- Harrison, S. P. 1989 Lake levels and climatic changes in eastern North America. *Climate Dynamics* 3: 157–167.
- Harrison, S. P., Prentice, C. and Guiot, J. 1993 Climatic controls on Holocene lake-level changes in Europe. *Climate Dynamics* 8: 189–200.
- Madeyska, T. 1993 Geomorphological map of the Płock Basin. *Polish Botanical Studies, Guidebook Series* 8: 9–13 (in Polish).
- Magny, M. 1992 Holocene lake-level fluctuations in the Jura and the northern subalpine ranges, France: Regional patterns and climatic implications. *Boreas* 21: 319–334.
- _____. 1993 Solar influences on Holocene climatic changes illustrated by correlations between past lake-level fluctuations and atmospheric ¹⁴C record. *Quaternary Research* 40: 1–9.
- Pazdur, A., Fontugne, M. R., Goslar, T. and Pazdur, M. F. (ms.) Late Glacial and Holocene water-level changes of Gościąż Lake, Central Poland, derived from carbon isotope studies of laminated sediment. Submitted to *Quaternary Science Reviews*.
- Pazdur, A., Pazdur, M. F., Wicik, B. and Więckowski, K. 1987a Radiocarbon chronology of annually laminated sediments from the Gościąż Lake. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 35: 139–145.
- Pazdur, A. and Starkel, L. 1989 New approach to explanation of changes in the volume and water level of the Gościąż Lake. *Zeszyty Naukowe Politechniki Śląskiej, Seria Matematyka-Fizyka* 57. *Geochronometria* 5: 29–44.
- Pazdur, M. F., Awiuk, R., Goslar, T., Pazdur, A., Walanus, A., Wicik, B. and Więckowski, K. 1987b. Calibrated radiocarbon chronology of annually laminated sediments from the Gościąż Lake. *Zeszyty Naukowe Politechniki Śląskiej, Seria Matematyka-Fizyka* 56. *Geochronometria* 4: 69–83.
- Ralska-Jasiewiczowa, M., Wicik, B. and Więckowski, K. 1987 Lake Gościąż—a site of annually laminated sediments covering 12,000 years. *Bulletin of the Polish Academy of Sciences, Earth Sciences* 35: 139–145.
- Róžański, K., Goslar, T., Dulinski, M., Kuc, T., Pazdur, M. F. and Walanus, A. 1992 The Late Glacial-Holocene transition in laminated sediments of the Lake Gościąż (Central Poland). In Bard, E. and Broecker, W. S., eds., *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. NATO ASI Series I, Global Environmental Change, Vol. 2. Berlin/Heidelberg, Springer-Verlag: 69–80.
- Sierzega, P. and Narwojsz, A. (ms.) 1988 The grip of groundwater from Quaternary sediment in the Jozefów region near Włocławek. Archive of Geological Enterprise, Gdansk Division, Gdansk (in Polish).
- Skompski, S. 1971 *Comments on the Detailed Geological Map of Poland, Scale 1:50000, Dobrzyń Chart*. Wydawnictwa Geologiczne, Warsaw (in Polish).
- Stuiver, M. and Polach, H. A. 1977 Discussion: Reporting of ¹⁴C data. *Radiocarbon* 19(3): 355–363.

Wicik, B. and Więckowski, K. 1991 The sediments of the “Na Jazach” lakes in the Płock Basin—conditions of their sedimentation and role in reconstruction and prognosis of the natural environment. *Przegląd Geograficzny* 63: 57–76 (in Polish).

Więckowski, K. 1993 The current state of recognition of bottom sediments in the “Na Jazach” lakes according to their macroscopic features. *Polish Botanical Studies, Guidebook Series* 8: 77–92 (in Polish).

RADIOCARBON AND URANIUM-SERIES DATING OF THE PLITVICE LAKES TRAVERTINES

DUŠAN SRDOČ,^{1,3} J. K. OSMOND,² NADA HORVATINČIĆ,³ ADEL A. DABOUS⁴ and BOGOMIL OBELIĆ³

ABSTRACT. Radiocarbon and uranium-series ages of the calcareous deposits of the Plitvice Lakes show that travertines were deposited during three warm, humid, interglacial oxygen isotope stages. According to our measurements, only calcite crystals or crystal aggregates represent reliable material for both $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ dating. Compact old travertine in the form of sandstone is less reliable; it can be dated by both methods provided that its detrital contamination is not significant, demonstrated by very low ^{14}C activity ($<1.5\text{--}2.0$ pMC) and a high $^{230}\text{Th}/^{232}\text{Th}$ ratio. Old porous travertine contaminated with recent carbonates and Th-bearing clay (pMC > 5 , $^{230}\text{Th}/^{232}\text{Th} < 5$) gives erroneous results by both methods. Stage 1 (Holocene) deposition is shown primarily by ^{14}C dating corroborated by sedimentological and palynologic studies as well as by both $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ disequilibrium methods. The intensive growth of travertine barriers coincided with significant climate warming in the Holocene. Stage 5 deposition is confirmed by the $^{230}\text{Th}/^{234}\text{U}$ dating of crystalline calcite aggregates embedded in the travertine matrix and by concordant $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ages, assuming that the $^{234}\text{U}/^{238}\text{U}$ activity ratio of 1.88 observed in modern streams and in Holocene deposits can be extended to past epochs. The travertine deposition period was very short, peaking ca. 120 ± 10 ka BP. Stage 11 deposition is indicated by $^{234}\text{U}/^{238}\text{U}$ dating only, the period being within the ^{234}U decay range, but not that of ^{230}Th . Stage 11 travertine was deposited ca. 420 ± 50 ka BP. We did not find travertine samples with U-series ages indicating a growth period during relatively warm Stages 7 and 9; due to the scarcity of old travertine outcrops, these and possibly other stages cannot be excluded on the basis of presented data. All of these isotopic dating results concur with the field relation of the travertine complex of the Plitvice Lakes.

INTRODUCTION

The Plitvice Lakes are a spectacular series of travertine dams, lakes and waterfalls located in the karst region of northwestern Dinarides in central Croatia (Fig. 1). According to Polšak (1979a,b), the area owes its abundant karst phenomena to the thick carbonate section of the Upper Triassic to the Cretaceous. The impermeable Upper Triassic and Lower Jurassic dolomites and marly limestones prevent vertical water circulation. The permeable regions are characterized by karst dolinas, swallow holes, caves and poljes, whereas springs are scarce. Travertines are deposited on either limestone or dolomite bedrock.

The tectonics of this area is dominated by faulting. A prominent, longitudinal, NW-SE striking fault separates the Senonian rudistic limestones from the Triassic rocks to the southwest. The transverse fault between Lakes Kozjak and Prošće controls the locations of a series of small lakes. During the Mesozoic, an environment prevailed, favorable for carbonate platform deposition within a tectonically quiescent regime. This situation terminated at the end of the Eocene when the Dinaric Mountains folded.

Travertine forms waterfalls, barriers and subaqueous fine-grained lake-fill accumulations throughout the Plitvice National Park. Barrier deposits form dams intercepting the free flow of water. Travertines are always associated with biota, predominantly microscopic algae and cyanobacteria, abundant moss growth and higher plant taxa (Golubić 1973; Chafetz and Folk 1984; Marčenko *et al.* 1989). Travertine begins to form with deposits of calcite microcrystals on the periphyton. Relatively rapid ramification follows, resulting in a fragile, spongy structure consisting of a large amount of

¹Brookhaven National Laboratory, S&EP, Bldg. 535A, P.O. Box 5000, Upton, New York, 11973-5000 USA

²Department of Geology, Florida State University, Tallahassee, Florida 32306 USA

³Rudjer Bošković Institute, P.O.B. 1016, Bijenička 41001 Zagreb, Croatia

⁴Geology Department, Ain Shams University, Cairo, Egypt

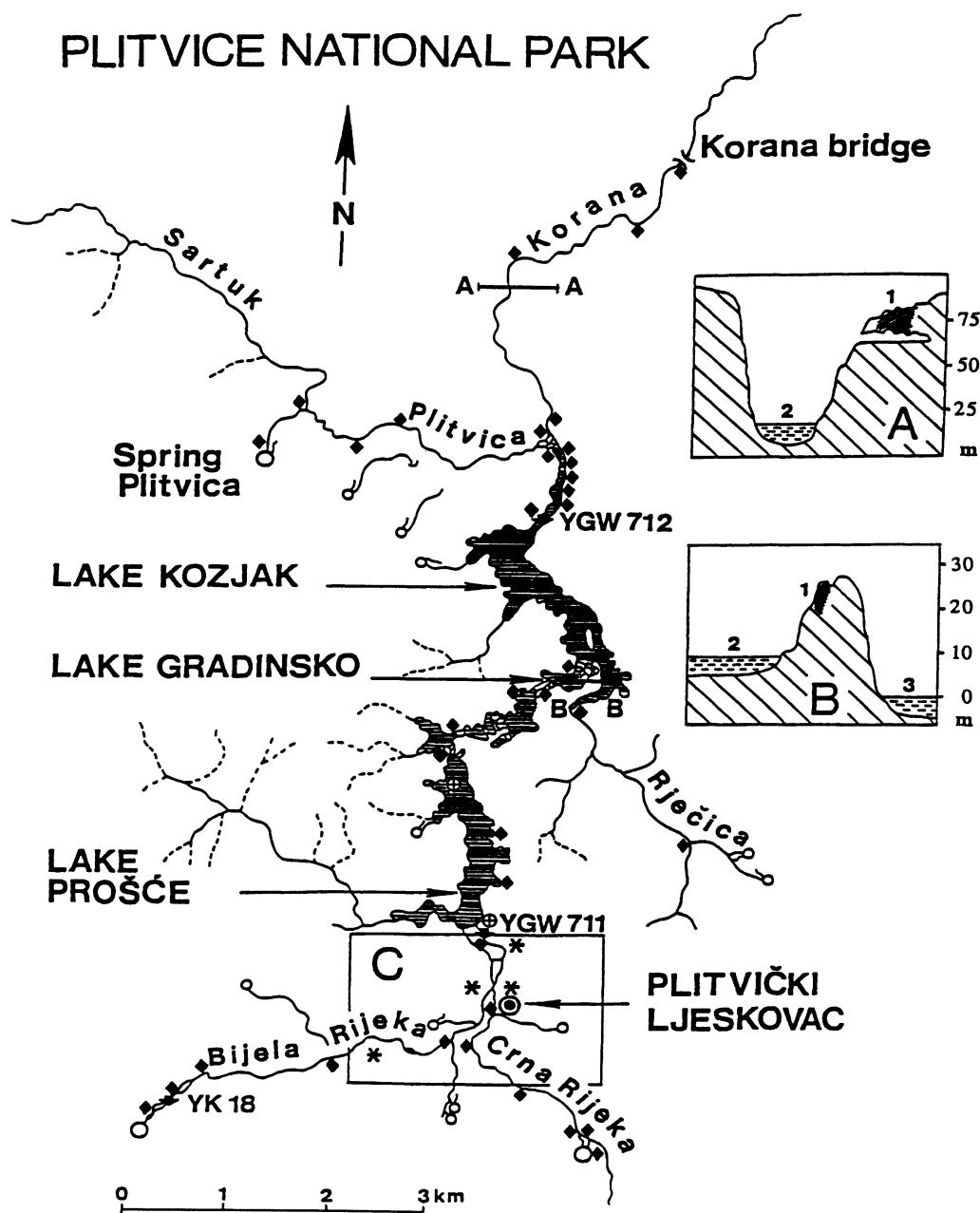


Fig. 1. Map of the Plitvice Lakes travertine deposition areas discussed in this study. A, B, C = sampling sites of old travertines; Holocene samples were collected throughout the entire area, mostly along the streams. ◆ = surface water sampling sites; ⊕ = lake sediment and peat coring sites; * = sampled old travertine outcrop; ◀ = surface water sampling sites for U-series dating; ○ = spring. Insets show geomorphic positions of (A) the Smolčića Pečina travertine and cave deposits and (B) Gradina old travertine. A. 1. Travertine and speleothems; 2. Korana River. B. 1. Old travertine outcrop; 2. Lake Gradinsko; 3. Lake Kozjak. C. Old travertine deposits near Plitvički Ljeskovac village.

organic matter in a calcite matrix, often called tufa. Further solidification into a typical travertine texture takes several thousand years and is characterized by loss of the organic components *via* microbial decomposition, and recrystallization of calcite to form a more compact and solid structure. According to Chafetz, Srdoč and Horvatinčić (1990), the Plitvice travertines are composed of very fine-to-medium crystalline, equant to bladed, low-magnesian spar. The internal truncation surfaces suggest alternating periods of erosion and precipitation of older spar crust. Petrographic analyses show that cyanobacteria, fungi and other microbial organisms bore into the spar and micrify it. This pervasive diagenetic process occurs throughout the waterfall and barrier deposits in this environment (Chafetz, Srdoč and Horvatinčić 1994).

In this paper, we discuss travertine samples ¹⁴C-dated at the Rudjer Boškovic Institute and U-series-dated at Florida State University. We credit other laboratories by indicating their code numbers in comparisons with our results. Tables 1–5 summarize the results of this study.

SAMPLING

Srdoč and co-workers collected samples of various forms of travertine in the Plitvice National Park, primarily for ¹⁴C dating. Samples Z-396, -398 and -940, from the same travertine outcrop near Plitvički Ljeskovac, were sent for cross-checking to various laboratories as indicated in Table 3.

A systematic search for relict travertine outcrops within the Park revealed old-appearing deposits resembling the present active barriers at three locations: Korana River Canyon; Gradina; and Plitvički Ljeskovac (Fig. 1). Outcrops of old travertine are very rare when compared with ubiquitous recent travertine deposited along the streams and lakes shown in Figure 1. A location abundant in old travertine occurs on the rim of the Korana River Canyon (Fig. 1A). The contour lines suggest an extinct travertine-depositing stream emptying into the Korana River. The location features a cave, Smolčića Pećina, and a travertine block protruding through the cave ceiling. On a hill overlooking Lake Kozjak, named Gradina (Fig. 1B), we found a single outcrop of old travertine. Its present position bears no relation to any travertine-depositing water body; the closest stream or lake is 35 m below the outcrop. This travertine block consists of porous calcite concretions resembling petrified aquatic moss and more compact sections without any distinct morphology. At the confluence of the Bijela Rijeka and Crna Rijeka creeks, in an area *ca.* 3 km long and 0.5 km wide, dry travertine barriers and huge scattered travertine blocks abound. We refer to this confluence area as Ljeskovac, after Plitvički Ljeskovac, a nearby village (Fig. 1C).

TABLE 1. Uranium Concentration and Activity Ratio of the Plitvice National Park Water Samples*

FSU [†] sample no.	Location	U concentration ($\mu\text{g liter}^{-1}$)	²³⁴ U/ ²³⁸ U activity ratio
YK-18	Bijela Rijeka, headwater spring	0.24 $\pm$ 0.04	1.91 $\pm$ 0.06
YGW-711	Matica, inflow	0.36 $\pm$ 0.03	1.85 $\pm$ 0.05
YGW-712	Kozjak Mostovi, outflow	0.33 $\pm$ 0.02	1.89 $\pm$ 0.04

*See Figure 1 for sampling locations

[†]FSU = Florida State University

The dense forest covering the park made a systematic search of old outcrops rather difficult. Also, erosion of old travertine during cold periods and recent alluvial deposits prevented a more thorough sampling, which could have revealed more travertine growth periods than described here. Drilling travertine barriers is not permitted in the national park; however, natural dislocations, crumbling and erosion of barriers exposed the entire profile of many travertine deposits, enabling us to collect a representative number of samples throughout the investigated area. When it became obvious that clean crystalline calcite aggregates were more reliable for $^{230}\text{Th}/^{234}\text{U}$ dating, we intensified our search for such samples, also preserving the adjacent porous travertine for analyses of paired samples. Whereas young travertines were fairly randomly sampled, we sampled old travertine rather systematically for clean calcite crystals. Consequently, the number of old travertine samples (Fig. 2A) far exceeds their actual abundance.

We also collected three 25-liter water samples (YGW-711, YGW-712, YK18) (Fig. 1), evaporated them to dryness and analyzed the residue for U concentration and for $^{234}\text{U}/^{238}\text{U}$ activity.

RADIOCARBON DATING HOLOCENE TRAVERTINES

Biogenic Carbon in Travertine

^{14}C dating of travertine (calcareous tufa) is based on the fact that a large proportion of its carbon is of biogenic origin (Srdoč *et al.* 1980). Theoretically, travertines should contain 50% biogenically originated carbon. However, in contrast to stoichiometric expectations, the measurements of initial ^{14}C activity of travertine-depositing stream water dissolved inorganic carbon (DIC) and freshly deposited tufa gave significantly higher ^{14}C activity, ranging from 60 to 90% of the modern standard. The excess ^{14}C is of biogenic or atmospheric origin, introduced into the groundwater *via* isotopic exchange between DIC and gaseous CO_2 during seeping and percolation (Mook 1976, 1980;

TABLE 2. Holocene Travertines of the Plitvice National Park* ^{14}C and U-Series Dating

Z-no. Lab no.	U (ppm)	$\frac{^{234}\text{U}}{^{238}\text{U}}$	$\frac{^{234}\text{U}}{^{238}\text{U}}$ age (ka)	$\frac{^{230}\text{Th}}{^{234}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$ age (ka)	^{14}C pMC age† (ka)
Z-1176 USGS: ZAG-4	0.38 ± 0.01	1.79 ± 0.03	38 ± 13	0.013 ± 0.005	--	1.4 ± 0.6	73.2
Z-941 NLfB: Uh-144	0.24 ± 0.01	1.85 ± 0.03	12 ± 13	0.004 ± 0.021	21	0.4 ± 1.9	Modern samples pre-nuclear bomb tests: growing period: $\sim$ AD 1800–1900
Z-2146 FSU: 62(I)	0.37 ± 0.04	1.78 ± 0.07	43 ± 33	--	--	--	
Z-1114 FSU: 1A(I)	0.38 ± 0.04	1.87 ± 0.06	4 ± 25	0.05 ± 0.04	33	3.1 ± 2.5	59.8 1670 ± 100
Z-1114 FSU: 1B(0)	0.31 ± 0.02	1.83 ± 0.06	21 ± 26	0.05 ± 0.03	46	3.1 ± 1.8	

*Samples were speleothems from travertine caves

†Initial ^{14}C activity = 74 pMC

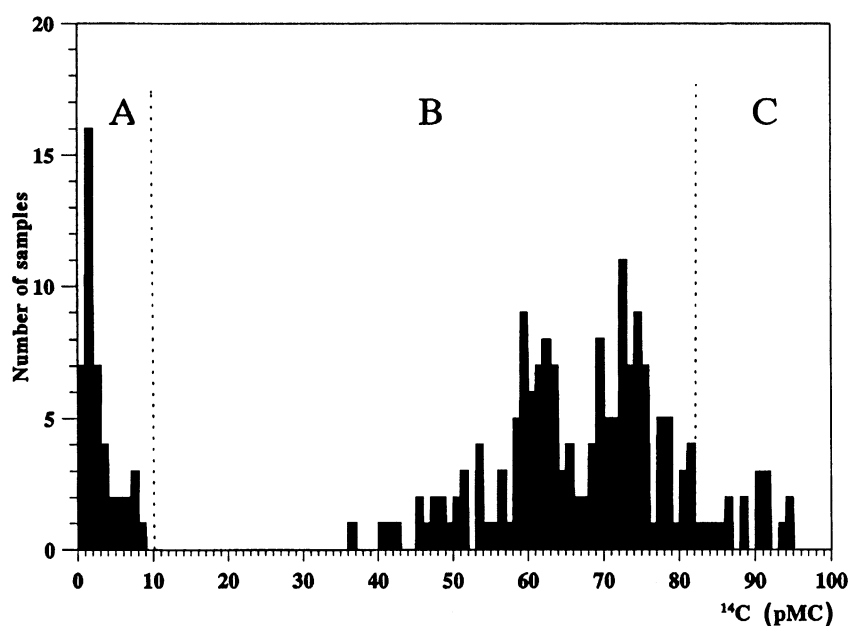


Fig. 2A. Number of samples collected in the Plitvice National Park vs. ^{14}C activity expressed as pMC. A. Old travertine outcrops sampled systematically; we regarded their ^{14}C content as contamination. B. Holocene samples collected randomly; C. Recent travertines deposited from surface water contaminated with bomb-test-produced ^{14}C .

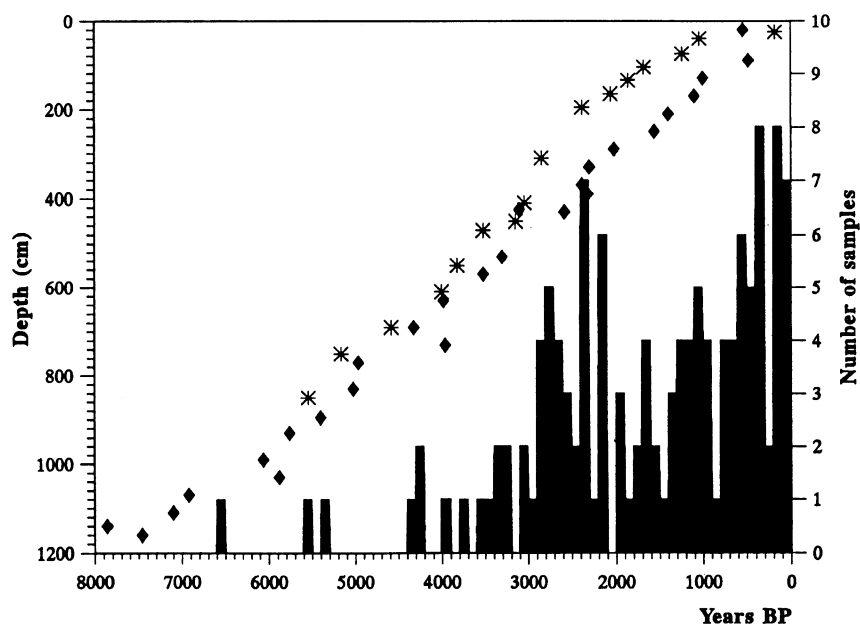


Fig. 2B. Number of randomly collected Holocene travertine samples (right) vs. ^{14}C age. ^{14}C age of travertine is calculated by applying the initial ^{14}C activity at sampling location, which ranged from ~ 70 to 83 pMC. Core depth (left): * = peat; ◆ = Lake Prošće sediment. Coring sites are shown in Fig. 1.

Krajcar Bronić *et al.* 1986). Redistribution of ^{14}C during travertine formation has been observed in young, growing travertine structures in the Plitvice National Park. Srdoč *et al.* (1980) showed that ^{14}C is evenly distributed in huge travertine aggregations due to the percolation of stream water throughout the porous structure during formation. The ^{14}C clock is set when the whole structure

TABLE 3. Inactive (Dry) Travertine Barriers of the Plitvice National Park, Plitvički Ljeskovac
U-Series Dating

Z-no. Lab no.	Sample structure	U (ppm)	$\frac{^{234}\text{U}^*}{^{238}\text{U}}$	$\frac{^{234}\text{U}^\dagger}{^{238}\text{U}}$	$\frac{^{234}\text{U}^\ddagger}{^{238}\text{U}}$ age (ka)	$\frac{^{230}\text{Th}}{^{234}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$ age (ka)	^{14}C pMC
Z-396 [§] USGS: ZAG-1	Speleothems, crystalline flowstone covering travertine matrix	0.317 ± 0.009	1.67 ± 0.03	1.94 ± 0.04	96 ± 16	0.71 ± 0.02	58 ± 27	120 ± 6.5	<0.5
Z-940 [§] NLfB: Uh-113		0.22 ± 0.01	1.66 ± 0.03	1.93 ± 0.04	101 ± 16	0.70 ± 0.03	8.2 ± 0.6	119 ± 9	
Z-398 [§] FSU: 4A(I)		0.27 ± 0.01	1.63 ± 0.05	1.87 ± 0.07	118 ± 29	0.68 ± 0.08	35	108 ± 24	
Z-2145 [§] FSU: 60(I)		0.41 ± 0.02	1.62 ± 0.06	1.83 ± 0.08	124 ± 36	0.65 ± 0.06	81	101 ± 18	
Z-1116 NLfB: Uh-115	Compact flowstone	0.20 ± 0.01	1.67 ± 0.03	1.96 ± 0.04	96 ± 16	0.707 ± 0.04	22 ± 5	127 ± 17	
Z-2142 FSU: 56 + 57		0.34 ± 0.02	1.69 ± 0.06	1.84 ± 0.07	86 ± 32	0.49 ± 0.04	87	69 ± 8	
Z-2144 [§] FSU: 58	Crystalline flowstone	0.33 ± 0.02	1.65 ± 0.06	--	107 ± 35	--	--	--	<1.0
Z-2144 [§] NLfB: Uh-664		0.221 ± 0.005	1.554 ± 0.025	1.79 ± 0.04	167 ± 16	0.751 ± 0.02	7.3 ± 0.4	127 ± 10	0.8 ± 0.1
Z-2164 NLfB: Uh-663	Very porous travertine	0.123 ± 0.003	1.38 ± 0.03	>2.07	296 ± 29	1.144 ± 0.03	2.9 ± 0.1	>364	8.0 ± 0.2
Z-685 FSU: 7A		0.24 ± 0.02	1.66 ± 0.05	--	101 ± 28	>1.0	--	--	7.4 ± 1

* $^{234}\text{U}/^{238}\text{U}$ ratio

†Initial $^{234}\text{U}/^{238}\text{U}$ ratio

‡ $^{234}\text{U}/^{238}\text{U}$ age assuming an average initial activity ratio of 1.88

§Replicate samples

TABLE 4. Travertines of the Plitvice National Park, Gradina U-Series Dating

Z-no. Lab. no.	Sample Structure	U (ppm)	$\frac{^{234}\text{U}^*}{^{238}\text{U}}$	$\frac{^{234}\text{U}^\dagger}{^{238}\text{U}}$	$\frac{^{234}\text{U}^\ddagger}{^{238}\text{U}}$ age (ka)	$\frac{^{230}\text{Th}}{^{234}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$ age (ka)	¹⁴ C pMC
Z-1210 NLfB: Uh-118	Compact travertine	0.14 ± 0.08	1.25 ± 0.05	>1.59	444 ± 78	1.30 ± 0.1	1.2 ± 0.1	>300 (>130) _{dc} [§]	1.5 ± 1
Z-1210 FSU: 5A, 5B 54, 55		0.26 ± 0.015	1.32 ± 0.05		357 ± 60	--	--	--	<1.5
Z-1208 FSU: 50 + 51	Porous travertine	0.3 ± 0.02	1.30 ± 0.07		379 ± 94	--	--	--	2.9 ± 1

 *²³⁴U/²³⁸U ratio

 †Initial ²³⁴U/²³⁸U ratio

 ‡²³⁴U/²³⁸U age assuming an average initial activity ratio of 1.88

§Detritus-corrected NLfB age

(e.g., a travertine barrier) stops growing, *i.e.*, exchanging its ¹⁴C with the environment because of perturbation of the surface flow leaving the barrier dry—a picture not too far from the basic principles of ¹⁴C dating, where the death of a living organism sets the ¹⁴C clock. By contrast, lake sediment in the same area, consisting of relatively pure, microscopic calcite rhombohedrons, showed a distinct ¹⁴C gradient that revealed its Holocene age (Srdoč *et al.* 1986b). Conventional and isotopic measurements were made on samples of spring and stream water collected year-round at 40 points along the Korana River, from the karst springs to the mouth (Fig. 1). Standard physicochemical analyses and stable (²H, ¹⁸O, ¹³C) and radioactive (³H, ¹⁴C) isotopic measurements revealed the chemistry and hydrology of the Korana River catchment area. The analysis of the data led us to the following conclusions on the formation and determination of the age of travertines (Srdoč *et al.* 1985b):

1. Chemical and stable isotope analyses confirmed the origin of calcareous deposits. The concentration of Ca²⁺ in water decreases sharply along the travertine depositing section of the Korana River, whereas Mg²⁺ concentration remains constant. This accords with calculated saturation indexes for CaCO₃ (supersaturated) and MgCO₃ (below or close to equilibrium). The pH of stream water in the region of intensive calcite precipitation ranges from 8.3 at the start (point YGW 711) to 8.5 (Korana Bridge) (Fig. 1).
2. The ¹³C content of DIC and freshly deposited tufa and lake sediment, expressed as δ¹³C, is close to −12.5 ± 0.3‰, again confirming that part of carbon in DIC and sediments is of biogenic origin. δ¹³C of limestone and dolomite surrounding the lakes is *ca.* 0.0 ± 1‰, typical for marine carbonates, whereas the δ¹³C of the predominant trees (*Fagus sylvatica*, *Abies* sp.) covering a large area around the lakes ranges from −28.1 to −30.0‰ (Krajcar Bronić *et al.* 1986). However, calculation of the initial ¹⁴C activity based on the stable ¹³C content of travertine and its sources of carbon, according to various models suggested in the literature (Tamers 1967; Mook 1976, 1980; Fontes 1983) gives erroneous results. During the isotopic exchange of carbon between ground and surface water DIC, and gaseous CO₂, the ¹⁴C activity of DIC always increases, whereas δ¹³C may increase in an exchange with atmospheric CO₂ (δ¹³C = −8‰) or decrease in the case of biogenic CO₂ (δ¹³C = −27‰). A combination of both is very plausible in

karst where groundwater is exposed to atmospheric CO₂ in underground caverns. Thus, although $\delta^{13}\text{C}$ values of DIC and calcareous deposits unmistakably prove that part of their carbon content is biogenically derived, they cannot be used to correct the ^{14}C age of travertine or groundwater in karst.

3. The ^{18}O content in travertines ranging in age from oxygen isotope Stage 11 to Recent is surprisingly constant ($\delta^{18}\text{O} = 20.0 \pm 0.8\text{‰}$ vs. Standard Mean Ocean Water (SMOW)) indicating that environmental conditions, mainly temperature, precipitation and vegetation were similar during each formation period. This is consistent with our present knowledge of the chemistry and hydrobiology of travertine formation.

TABLE 5. Speleothems and Travertines of the Plitvice National Park, Smolčića Cave U-Series Dating

Z-no. Lab. no.	Sample structure	U (ppm)	$\frac{^{234}\text{U}}{^{238}\text{U}}^*$	$\frac{^{234}\text{U}}{^{238}\text{U}}^\dagger$	$\frac{^{234}\text{U}}{^{238}\text{U}}^\ddagger$ age (ka)	$\frac{^{230}\text{Th}}{^{234}\text{U}}$	$\frac{^{230}\text{Th}}{^{232}\text{Th}}$	$\frac{^{230}\text{Th}}{^{234}\text{U}}$ age (ka)	^{14}C pMC
Z-1144 NLfB: Uh-116	Speleothems, short stalac- tites on cave ceiling	0.176 ± 0.009	1.27 ± 0.04	1.58 ± 0.30	417 ± 56	0.97 ± 0.05	3.2 ± 0.2	272 $\pm$ 90	3.5 $\pm$ 1
Z-1007 FSU: 48,49		0.51 ± 0.02	1.32 ± 0.03	--	357 ± 34	--	--	--	1.7 $\pm$ 1
Z-1145 FSU: 2A, 2B		0.55 ± 0.02	1.28 ± 0.04	--	404 ± 54	--	--	--	5.1 $\pm$ 1
Z-745 USGS: ZAG-2	Very porous travertine	0.47 ± 0.01	1.198 ± 0.02	--	525 ± 36	1.119 ± 0.07	1.0 ± 0.1	>350	5.0 $\pm$ 1
Z-741 USGS: ZAG-3		0.43 ± 0.01	1.096 ± 0.02	--	780 ± 80	1.02 ± 0.03	1.4 ± 0.1	>350	8.0 $\pm$ 1
Z-1213 NLfB: Uh-119	Compact travertine	0.33 ± 0.015	1.27 ± 0.02		417 ± 27	--	27 ± 31	--	1.6 $\pm$ 1
Z-1213 NLfB Uh-125 (Uh-119 redone)		0.350 ± 0.02	1.21 ± 0.02	1.42 ± 0.40	505 ± 35	0.97 ± 0.02	53 ± 21	243 ⁺¹¹⁰ ₋₅₅	
Z-1213 FSU: 3A & 3B 54, 55		0.44 ± 0.11	1.30 ± 0.04		379 ± 51	--	--	--	--

* $^{234}\text{U}/^{238}\text{U}$ ratio†Initial $^{234}\text{U}/^{238}\text{U}$ ratio‡ $^{234}\text{U}/^{238}\text{U}$ age assuming an average initial activity ratio of 1.88

Radiocarbon Dating of Plitvice Lakes Travertines

¹⁴C dating of travertines was introduced by Srdoč *et al.* (1980). Chemical processing of calcareous concretions for ¹⁴C dating poses no problem, since they consist of relatively pure CaCO₃, easily soluble in hydrochloric acid. Travertine samples were cleaned mechanically from intrusions and treated with diluted HCl. The developed CO₂ was trapped for subsequent purification and conversion to methane to be used as the filling gas in a proportional counter. The purification of gases, the catalytic hydrogenation of CO₂, and the counting procedure were previously described (Srdoč, Breyer and Sliepčević 1971).

Several hundred travertine dates have been published, mostly from the Plitvice Lakes area and northwest Dinarides, by the Rudjer Bošković ¹⁴C Laboratory group (Srdoč *et al.* 1977, 1980, 1982, 1987, 1992b; Obelić *et al.*, this issue), and from several locations in Europe: Poland (Pazdur, Pazdur and Szulc 1988); Czechoslovakia (Horvatinčić *et al.* 1989); England (Pentecost *et al.* 1990), and Spain (Mas-Pla, Trilla and Vals 1992), and also from the United States (Srdoč, Chafetz and Utech 1989).

Two conspicuous periods of growth of calcareous deposits were recognized in the Plitvice Lakes region: the Holocene and a much older period, corresponding to the Würm in Europe, which was close to or beyond the lower range of the ¹⁴C method (Fig. 2A). However, the older samples gave inconsistent results, sometimes yielding ages from 20–40 ka for the same travertine outcrop. Recognizing that the ¹⁴C method is sensitive to very small amounts of contamination, Srdoč *et al.* (1986c) suggested that this variability in the older samples was the result of exposure to atmospheric CO₂, rain, and surface and groundwater, thus rendering the ¹⁴C dating of travertines unreliable for samples other than those from the Holocene. The U-series dating of old travertines, containing up to ~10% of modern carbon (Fig. 2A), revealed their true age.

Contamination of old travertines with modern carbon, including the man-made ¹⁴C produced during thermonuclear bomb tests, renders such samples useless for ¹⁴C dating; however, the impact on Recent (Holocene) travertines is less critical. Typical contamination with recent carbonate, up to several percent of modern carbon, which is easily discerned in old travertine (Fig. 2A, Tables 3–5) makes the Holocene samples appear younger from 80 up to 200 yr (depending on the sample age) for each percent of modern carbon. This error is not very significant, taking into account other errors, such as the uncertainty in the initial activity of a travertine deposit. Previous research shows that the initial activity of calcareous deposits depends on geological setting, hydrogeology of the catchment area, vegetation and climate (Thorpe, Otlet and Sweeting 1980; Fontes 1983; Srdoč *et al.* 1986a; Pazdur 1988; Pazdur, Pazdur and Szulc 1988; Horvatinčić *et al.* 1989; Pentecost *et al.* 1990). Considering the importance of eliminating any ambiguity in ¹⁴C dating the Plitvice Lakes travertines, an extensive study of the initial ¹⁴C activity of DIC in travertine-depositing streams of the National Park area (Krajcar-Bronić *et al.* 1986) continued until recently (Krajcar-Bronić *et al.* 1992), through which a remarkably concordant and consistent set of data emerged (Srdoč *et al.* 1992a). Initial ¹⁴C activity of travertine based on measurement of ¹⁴C activity of organic material (wood, leaves) embedded in travertine and lake sediments and the adjacent calcareous deposit agreed with recent samples of travertine and the uppermost lake sediment layers, both from the pre-bomb test contamination era. An interesting feature, consistent with the concept of a constant isotopic exchange between the atmosphere and the hydrosphere, is a gradual downstream increase of the ¹⁴C activity of DIC along the water course. Groundwater already enriched in ¹⁴C above the stoichiometric value emerges at three karst springs and the surface water gains more ¹⁴C activity as it flows toward lower reaches. This phenomenon is more pronounced in turbulent waters along the

first 12 km of the Korana River, where numerous travertine barriers form waterfalls and cascades, than in its lower reaches. From the confluence of Crna Rijeka and Bijela Rijeka creeks near Plitvički Ljeskovac village to the Korana Bridge (12 km, Fig. 1), the present DIC ^{14}C activity increases from 71.5–91 pMC, whereas along the next 116 km in flat lower reaches, the increase amounts only to several percent (Srdoč *et al.* 1986a).

The ^{14}C ages of travertine samples in Fig. 2B in the form of a histogram were calculated by taking into account the initial ^{14}C activity at the sampling location. Most of the samples were collected in the area of present-day active travertine formation shown in Figure 1, where the initial ^{14}C activity of travertine ranges from 70–83 pMC. Freshly deposited contaminated travertines shown in Figure 2A, with pMC above the initial ^{14}C activity, are excluded from Figure 2B. The histogram of randomly collected samples of Holocene travertine shows a declining frequency of older samples coinciding with a substantial drop in temperature in the northern hemisphere. An evident notch in the histogram *ca.* 2000 BP may be also related to sudden shift to cold weather (Little Ice Age). We compared the ages of recent travertine from Plitvice with the ages of Lake Prošće sediment (Srdoč *et al.* 1986b) as well as dates from two peat cores adjacent to Lake Prošće (Srdoč *et al.* 1985a). The sediment cores reached bedrock, enabling ^{14}C dating of the entire profile. Although the sediment data clearly indicate the beginning of Lake Prošće formation at *ca.* 7500 $\pm$ 500 BP, the start of peat deposition and travertine formation is not well defined. The peat cores contained loose, partly decayed Hypnaceae; deposits of older travertine were either eroded or covered by recent debris or travertine deposits, which explains the lack of documentation for the early phase of peat and travertine formation shown in Figure 2B. Also, the peat and especially the travertine formation need not coincide with an early phase of lake formation. The growth rate of travertine progressed with the buildup of barriers, cascades and waterfalls, hence, the predominance of younger samples in the histogram (Fig. 2B). The lake formation, peat deposition and growth of recent travertine barriers coincided with global warming during the Holocene (Lamb, Lewis and Woodroffe 1966; Beget 1983; Bard *et al.* 1987).

URANIUM-SERIES DATING OF PLITVICE TRAVERTINES

Intensive travertine deposition during the Holocene moved downstream, leaving a few remnants of earlier and higher dams formed during the Pleistocene at several locations in the northwestern Dinarides (Plitvice Lakes, Krka and Janj Rivers). The characteristics of these travertines are: 1) their morphologic structure is similar to dry Holocene barriers or presently growing barriers; 2) most outcrops lie well above the present level of stream water; 3) their ^{14}C content is very low, between 0.0 and 1.5 pMC for crystallized calcite and up to several percent for porous travertine due to contamination with recent calcareous deposits. However, these travertine deposits are too old to be ^{14}C -dated, so that we undertook U-series dating. The $^{230}\text{Th}/^{234}\text{U}$ method has been particularly useful in determining ages of late Quaternary carbonate formations (Ku 1976; Schwarcz 1980; Hennig, Grün and Brunnacker 1983; Mahaney 1984; Latham and Schwarcz 1992; Fontes *et al.* 1992). In the case of relatively pure CaCO_3 deposits such as coral reefs and speleothems, results are often definitive (Atkinson and Harmon 1978; Harmon *et al.* 1975; Harmon, Ford and Schwarcz 1977; Harmon, Schwarcz and Ford 1977). Travertines are also suitable subjects for dating, but must be sampled and analyzed carefully, because of their porous structures and occasional impurities (Schwarcz *et al.* 1979; Harmon, Glazek and Nowak 1980; Hennig, Bangert and Herr 1980; Hennig, Grün and Brunnacker 1983; Blackwell and Schwarcz 1986; Kronfeld *et al.* 1988; Baskaran, Rajagopalan and Somayajulu 1989; Schwarcz and Latham 1989; Szabo 1990; Bischoff and Fitzpatrick 1991). In such cases, either closed-system conditions could be shown to apply, or the extent of contamination by older detritus could be demonstrated.

A few preliminary $^{230}\text{Th}/^{234}\text{U}$ runs on the Plitvice Lakes travertines by P. O'Malley of the U.S. Geological Survey, Denver, Colorado (personal communication 1983, samples ZAG-1 through ZAG-4, Tables 2, 3 and 5) produced only partially consistent data (samples ZAG-1 (Table 3) and ZAG-4 (Table 2)). Measurements made at the Niedersächsisches Landesamt für Bodenforschung (NLfB) Hannover, Germany by N. Horvatinčić (1985), are in general agreement with the USGS data; further measurements by Geyh and Hennig (personal communication 1990, samples Uh-663 and Uh-664, NLfB) confirmed earlier findings. Although the age of several samples of calcite crystal aggregates embedded in travertine clustered *ca.* 120 ka BP, data on the age of the porous travertine was inconsistent and widely scattered, prompting this research.

ANALYTICAL METHODS

We followed the standard procedures for alpha spectrometric analysis of U and Th as reviewed by Lally (1992), Ivanovich and Murray (1992) and Brook, Burney and Cowart (1990). We used ^{232}U and ^{236}U as tracers for determining of ^{238}U and ^{234}U ; and ^{228}Th and ^{229}Th served as tracers for determining of ^{232}Th and ^{230}Th . Chemical yields averaged 50% for both Th and U. We discarded samples that produced very low yields. In some cases, only the Th yields were unsatisfactory; for these we report the U data and calculate the $^{234}\text{U}/^{238}\text{U}$ ages.

RESULTS

Water and Recent Travertines

We analyzed three contemporary stream water samples for $^{234}\text{U}/^{238}\text{U}$ ratio, which averaged 1.88 (Table 1). The $^{234}\text{U}/^{238}\text{U}$ ratio for the four Holocene samples analyzed averaged 1.84 (Table 2). These values are identical, within uncertainty limits. This agrees with the ^{14}C data that recent travertines precipitated from contemporary surface waters.

The Holocene age of recent travertines is confirmed by our U-series disequilibrium studies. The most suitable samples for analysis were speleothem fragments from caves in the travertine. Three laboratories analyzed four samples (Table 2); all are low in daughter ^{230}Th , with ages less than a few thousand years. The uncertainty range of the $^{230}\text{Th}/^{234}\text{U}$ dating method is much larger than ^{14}C at this age.

Plitvički Ljeskovac Samples

A series of dry elevated barriers and outliers near Plitvički Ljeskovac yielded $^{230}\text{Th}/^{234}\text{U}$ ages in the range 100 to 130 ka (Table 3). However, not all samples were equally suitable for analysis. Two porous travertine samples gave results that were inconsistent with the compact flowstone speleothems. Six samples were concordant in U concentration, U isotopic ratio, and Th/U age; thus, we assigned the age of these deposits to Isotope Stage 5 (more specifically, 5e or 5c). The mean values, after rejecting the unreliable sample, Z-2164 (very porous travertine, ^{14}C content 7.4 pMC) and the $^{230}\text{Th}/^{234}\text{U}$ outlier, Z-2142, are: U concentration = 0.28 ± 0.07 ppm; $^{230}\text{Th}/^{234}\text{U}$ ratio = 0.70 ± 0.04 ; mean $^{230}\text{Th}/^{234}\text{U}$ age = 117 ± 10 ka; mean $^{234}\text{U}/^{238}\text{U}$ ratio is 1.645 ± 0.04 ; and corresponding $^{234}\text{U}/^{238}\text{U}$ age is 111 ± 24 ka.

Gradina and Smolčića Cave Samples

$^{230}\text{Th}/^{234}\text{U}$ determinations were inconsistent at Gradina and Smolčića Cave; samples from the same outcrop varied widely in ^{230}Th content; however, $^{234}\text{U}/^{238}\text{U}$ ratios were all between 1.20 and 1.32, except for 1 very porous sample (Z-741). Assuming an initial ratio of 1.88, the ages of nine samples

were in the range *ca.* 360–525 ka (Tables 3 and 4). Given the very large uncertainty range of the calculations, the consistency of these results is remarkable and prompts us to propose that the deposits from these two areas are in Stage 11. The mean values of Stage 11 travertines are: U concentration = 0.37 ± 0.13 ppm; $^{234}\text{U}/^{238}\text{U}$ ratio = 1.27 ± 0.03 ; and the corresponding $^{234}\text{U}/^{238}\text{U}$ age is 420 ± 50 ka.

Discussion of Uranium-Series Dating

Each of the techniques used in dating the Plitvice travertine deposits yielded generally consistent results, although there were a few anomalous results. Our confidence in the general conclusions of the study is based on the concordance of the three methods with respect to the three age groups (Fig. 3), and with field relations.

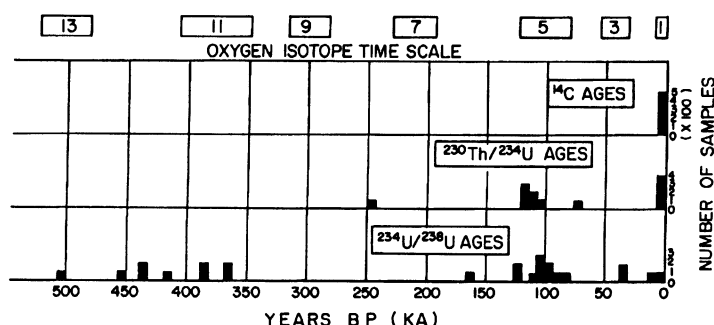


Fig. 3. Age determinations of the Plitvice Lakes carbonate samples using three dating methods. Stage 1 deposition is indicated by the ^{14}C and the two U-series methods, Stage 5 by the two U-series methods and Stage 11 by the $^{234}\text{U}/^{238}\text{U}$ method. Stages 3, 7 and 9 appear not to be represented in the Plitvice Lakes samples.

Figure 4 shows the covariation of $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ activity ratios for a dating system with no initial ^{230}Th . The curved lines show the trajectory for any given initial $^{234}\text{U}/^{238}\text{U}$ ratio. All of the Plitvice samples of Stages 1 and 5 age fall on or near the curve with initial $^{234}\text{U}/^{238}\text{U}$ activity ratio of 1.88. The older samples with lower $^{234}\text{U}/^{238}\text{U}$ values that do not fall on the same curve show $^{230}\text{Th}/^{234}\text{U}$ values beyond the range of the method. A useful application of Figure 4 is in backtracking individual sample point trajectories to obtain their original $^{234}\text{U}/^{238}\text{U}$ activity ratios (Tables 3–5). The results of these calculations confirm the choice of an assumed average initial ratio of 1.88.

The $^{230}\text{Th}/^{234}\text{U}$ ages of old travertine samples collected from the same outcrop near Plitvički Ljeskovac (Fig. 1, area C) were extremely discordant when the material differed petrographically. Old porous travertines are usually contaminated with recent carbonates, as shown by their ^{14}C content (Tables 3–5). Although a few percent of recent carbonates does not interfere significantly with U-series dating, the associated Th-bearing clay causes problems. A low $^{230}\text{Th}/^{232}\text{Th}$ ratio combined with a ^{14}C content >5 pMC indicate a high degree of contamination, rendering such samples useless for $^{230}\text{Th}/^{234}\text{U}$ dating. Typical examples, Z-2164, -741 and -745 of very porous travertine are shown in Tables 3 and 5. On the contrary, samples of clean crystal calcite aggregates embedded in a travertine matrix in the form of flowstones or speleothems as well as compact travertine had no significant ^{14}C activity (Tables 3–5). Paired samples Z-2144 (crystalline flowstone) and the adjacent, supposedly coeval porous travertine (Z-2146), Table 3, illustrate the effect of contamination with recent carbonates. Sample Z-2164, Table 3, contains 8% of recent carbonate, as suggested by

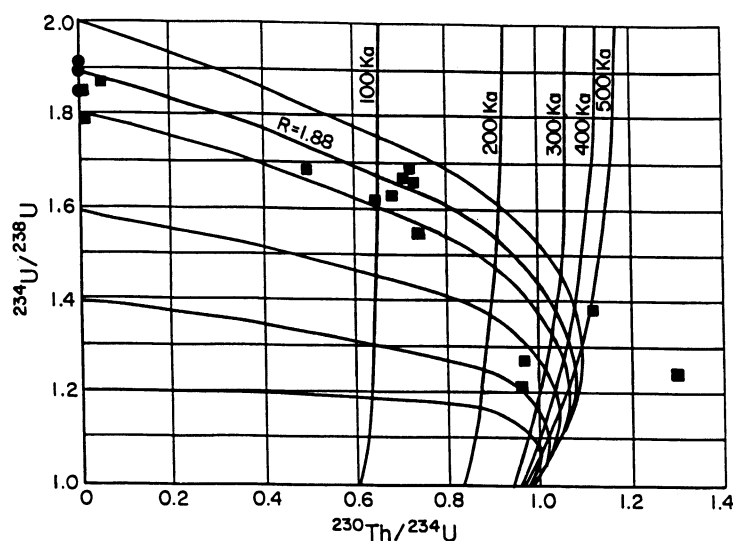


Fig. 4. Covariation decay trends of $^{234}\text{U}/^{238}\text{U}$ and $^{230}\text{Th}/^{234}\text{U}$ activity ratios in closed systems. Approximate ages of corresponding ratios are also shown. Most of the samples of this study are consistent with closed-system decay starting with $^{230}\text{Th}/^{234}\text{U}$ at 0 and $^{234}\text{U}/^{238}\text{U}$ at ca. 1.88. The anomalous samples in the lower half of the plot are thought to have experienced loss or gain of thorium. ● = modern water samples, ■ = travertines.

its ^{14}C content, and is contaminated with detrital Th ($^{230}\text{Th}/^{232}\text{Th} < 3$). This sample produced inconsistent $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ages, as opposed to the adjacent crystalline sample Z-2144 whose $^{230}\text{Th}/^{234}\text{U}$ and $^{234}\text{U}/^{238}\text{U}$ ages were both consistent with other crystalline or compact samples from the same area. $^{230}\text{Th}/^{234}\text{U}$ dating of these calcite crystal aggregates and compact travertine gave consistent and reproducible ages, clustering ca. 117 ± 10 ka (Table 3). The $^{234}\text{U}/^{238}\text{U}$ age obtained on the same suite of samples is 113 ± 24 ka (Table 3). Considering the inherently large error in the U ages, the agreement between the two U-series methods is remarkable.

Among the generally concordant Stage 5 samples, a tendency toward an inverse covariation between U concentration and $^{230}\text{Th}/^{234}\text{U}$ ratio is observed. A plausible inference is that the original U concentration of these samples was 0.3 to $0.4 \mu\text{g g}^{-1}$, and that the samples with less have suffered U loss. Geyh and Hennig (1986, personal communication 1990, $^{230}\text{Th}/^{234}\text{U}$ dates Uh-663 and Uh-664, NLfB) suggested that U leaching caused an excessive $^{230}\text{Th}/^{234}\text{U}$ age (e.g., Z-2164, $^{230}\text{Th}/^{234}\text{U} > 1$, age > 364 ka, Table 3). When the $^{230}\text{Th}/^{234}\text{U}$ ratio was corrected for U depletion (porous travertine contained 45% less U than the adjacent crystal calcite), a reasonable age of close to 130 ka was obtained. The adjacent flowstone (Z-2144, Table 3) gave 127 ± 9 ka, again consistent with a Stage 5 formation period.

$^{234}\text{U}/^{238}\text{U}$ dating depends on the degree of initial disequilibrium as well as stability. The relatively high ratio at Plitvice is fortunate in this respect, although such values have been reported in other carbonate groundwaters. Osmond and Cowart (1976, 1992), Osmond and Ivanovich (1992) and others have discussed the question of how such extreme isotopic fractionation occurs in natural waters. The reliability of $^{234}\text{U}/^{238}\text{U}$ dating depends primarily on the assumption of known initial ratio. The consistency of the ratio used, 1.88, with modern water samples, Holocene travertines and Stage 5 travertines, in this respect (Fig. 4), is the principal basis for our confidence in the dating of

the Stage 11 samples. This same approach has been used by others in the study of speleothems: confidence in the long-term stability of the $^{234}\text{U}/^{238}\text{U}$ ratio in some carbonate terrains seems justified (Thompson, Ford and Schwarcz 1975; Thompson *et al.* 1975; Harmon, Ford and Schwarz 1977; Gascoyne and Nelson 1983); in other cases, variability is suspected (Thompson *et al.* 1977; Harmon *et al.* 1978; Hennig, Grün and Brunnacker 1983). One would expect to find less secular variability in waters issuing from major springs, as at Plitvice, than from cave seeps. At Plitvice, carbonate deposition appears to have occurred only during warm climate stages, so that U isotopic responses to climate change would be minimized.

Because both parent and daughter have identical chemical behavior in $^{234}\text{U}/^{238}\text{U}$ dating, the possibilities for natural and laboratory fractionation, as with Th/U dating, are eliminated. Sample characteristics, such as density and porosity, should have less effect on the result. However, chemical exchange of young U with old mineral systems, or physical mixing of old and young travertines, could produce anomalous ages.

That Stage 11 travertines, but not 7 and 9, should be prominently represented at Plitvice may have special significance. Lloyd Burckle (ms.) of Lamont-Doherty Earth Observatory at Palisades, New York, has exhaustively reviewed the Quaternary climate record and believes that Stage 11 temperatures were probably warmer than any time before or since. Burckle points to supporting evidence in both the marine (Ruddiman *et al.* 1989; Oppo, Fairbanks and Gordon 1990) and continental (Rousseau, Puissegur and Lecolle 1992) spheres. Burckle also notes that much circumstantial evidence exists for a pre-Stage 5 warming episode which, for lack of a suitable dating technique, cannot definitely be assigned to Stage 11. Other investigators have assigned $^{230}\text{Th}/^{234}\text{U}$ travertine dates to Stage 7 (e.g., Harmon, Glazek and Nowak 1980; Blackwell and Schwarcz 1986). However, as Hennig *et al.* (1983) indicated, the pre-Stage 5 $^{230}\text{Th}/^{234}\text{U}$ carbonate dating is quite problematic and the accumulation of published results reveals no consistent pattern.

CONCLUSIONS

^{14}C and U-series techniques used in dating the Plitvice Lakes travertine deposits yielded results which were generally concordant, although there were, in each case, a few anomalies. Our confidence in the general conclusions of the study is based on the agreement of data obtained by the different methods for the three age groups (Stages 1, 5 and 11, Fig. 3), and with field relations.

^{14}C dating of Holocene travertine produced reliable ages concordant with sedimentological and climate studies, pollen analysis, and ^{14}C ages of detrital organic material (fragments of wood, leaves) embedded in travertine matrix, as well as of peat cores from peat bogs adjacent to the Lakes.

The reproducibility of $^{230}\text{Th}/^{234}\text{U}$ ages obtained on pure calcite crystal aggregates embedded in travertine assured us that the agreement between the mean age of clean calcite samples (120 ± 10 ka) and the warm, humid Stage 5 is not fortuitous. The concordant results of independent measurements at three laboratories further confirmed the reliability of the $^{230}\text{Th}/^{234}\text{U}$ technique for dating clean calcite samples within the range of the method. Porous travertine samples are not suitable for U-series dating. The reliability of U-series methods of dating travertine samples diminishes with increasing porosity indicated by high ^{14}C content of old samples (pMC >5) and Th contamination ($^{230}\text{Th}/^{232}\text{Th} < 3-5$). The dense crystalline speleothems yield the most consistent results, whereas the compact travertine is susceptible to contamination and requires testing for its purity.

The agreement between $^{230}\text{Th}/^{234}\text{U}$ ages and ^{14}C results on the Holocene samples gave assurance that the Stage 5 $^{230}\text{Th}/^{234}\text{U}$ ages are correct. By analogy, the agreement between $^{234}\text{U}/^{238}\text{U}$ ages and

$^{230}\text{Th}/^{234}\text{U}$ ages on Holocene and Stage 5 samples verified that the Stage 11 $^{234}\text{U}/^{238}\text{U}$ ages are correct. The ^{14}C and U-series ages indicate that there have been three short periods of travertine formation at the Plitvice Lakes, corresponding to climate oxygen isotopic Stages 1 (modern), 5 (last interglacial stage), and 11 (an earlier interglacial stage).

ACKNOWLEDGMENTS

The authors wish to express their gratitude to the following colleagues who supplied U-series analysis data obtained at their laboratories: B. J. Szabo and P. O'Malley of the U.S. Geological Survey, Denver, Colorado, and M. A. Geyh and G. Hennig of Niedersächsisches Landesamt für Bodenforschung, Hannover, Germany. Thanks are also due I. Krajcar Bronić for her help during preparation of the manuscript and the Rudjer Bošković ^{14}C Laboratory staff for the ^{14}C analyses of travertine samples. We gratefully acknowledge our reviewers for their valuable comments and suggestions, and persistence to upgrade the manuscript.

REFERENCES

- Atkinson, T. C. and Harmon, R. S. 1978 Paleolithic and geomorphic implications of $^{230}\text{Th}/^{234}\text{U}$ dates on speleothems from Britain. *Nature* 272: 24–26.
- Bard, E., Arnold, M., Maurice, P., Dupart, J. and Duplessy, J.-C. 1987 Retreat velocity of the North Atlantic polar front during the last deglaciation determined by ^{14}C accelerator mass spectrometry. *Nature* 328: 791–794.
- Baskaran, M., Rajagopalan, G. and Somayajulu, B. L. K. 1989 $^{230}\text{Th}/^{234}\text{U}$ and ^{14}C dating of the Quaternary carbonate deposits of Saurashtra, India. *Chemical Geology-Isotope Geoscience* 79: 65–82.
- Beget, E. J. 1983 Radiocarbon-dated evidence of worldwide early Holocene climate change. *Geology* 11: 389–393.
- Bischoff, J. L. and Fitzpatrick, J. A. 1991 U-series dating of impure carbonates: An isochron technique using total-sample dissolution. *Geochimica et Cosmochimica Acta* 55: 543–554.
- Blackwell, B. and Schwarcz, H. P. 1986 U-series analyses of the lower travertine at Ehringsdorf, DDR. *Quaternary Research* 25: 215–222.
- Brook, G. A., Burney, D. A. and Cowart, J. B. 1990 Desert paleoenvironmental data from cave speleothems with examples from the Chihuahuan, Somali-Chabi and Kalahari deserts. *Paleogeography, Paleoclimatology, Paleocology* 76: 311–329.
- Burckle, L. H. (ms.) Late Quaternary interglacial stages warmer than present (unpublished data).
- Burr, G. S., Edwards, R. L., Donahue, D. J., Druffel, E. R. M. and Taylor, F. W. 1992 Mass spectrometric ^{14}C and U/Th measurements in coral. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 611–618.
- Chafetz, H., and Folk, R. L. 1984 Travertines – depositional morphology and the bacterially constructed constituents. *Journal of Sedimentary Petrology* 54: 289–316.
- Chafetz, S. H., Srdoč, D. and Horvatinčić, N. 1990 Permeable sparification of waterfall and barrier travertines, Plitvice National Park, Croatia, Yugoslavia. 13th International Sedimentological Congress, Nottingham, England, 82–83. Abstract.
- Chafetz, S. H., Srdoč, D. and Horvatinčić, N. 1994 Early diagenesis of Plitvice Lakes waterfall and barrier travertine deposits. *Géographie Physique et Quaternaire*, in press.
- Fontes, J.-C. 1983 Dating of groundwater. In Guidebook on Nuclear Techniques in Hydrology. Vienna, IAEA, *Technical Report Series* 91: 285–317.
- Fontes, J.-C., Andrews, J. N., Causse, C. and Gibert, E. 1992 A comparison of radiocarbon and U/Th ages on continental carbonates. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 602–610.
- Gascoyne, M. and Nelson, D. E. 1983 Growth mechanisms of recent speleothems from Castleguard Cave, Columbia icefields, Alberta, Canada, inferred from a comparison of uranium-series and ^{14}C age data. *Arctic and Alpine Research* 15: 537–542.
- Geyh, M. A. and Hennig, G. J. 1986 Multiple dating of a long flowstone profile. In Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 503–509.
- Golubić, S. 1973 The relationship between blue-green algae and carbonate deposits. In Carr, N. G. and Whitton, B. A., eds., *The Biology of Blue-Green Algae*. Blackwell, Oxford: 434–472.
- Harmon, R. S., Ford, D. C. and Schwarcz, H. P. 1977 Inter-glacial chronology of the Rock and Mackenzie Mountains based upon $^{230}\text{Th}/^{234}\text{U}$ dating of calcite speleothems. *Canadian Journal of Earth Sciences* 14: 2543–2552.
- Harmon, R. S., Glazek, J. and Nowak, K. 1980 $^{230}\text{Th}/^{234}\text{U}$ dating of travertine from the Bilzingsleben archaeological site. *Nature* 284: 132–135.

- Harmon, R. S., Schwarcz, H. P. and Ford, D. C. 1977 Stable isotope geochemistry of speleothem and cave waters from the Flint Ridge-Mammoth Cave system, Kentucky: Implications for terrestrial climate change during the period 230,000 to 100,000 years B.P. *Journal of Geology* 86: 373-384.
- Harmon, R. S., Schwarcz, H. P., Thompson, P. and Ford, D. C. 1978 Critical comment on "Uranium series dating of stalagmites from Blanchard Springs Cavern, Arkansas, U.S.A.". *Geochimica et Cosmochimica Acta* 42: 433-439.
- Harmon, R. S., Thompson, P., Schwarcz, H. P. and Ford, D. C. 1975 Uranium-series dating of speleothems. *National Speleological Society Bulletin* 37: 21-33.
- Hennig, G. J., Bangert, U. and Herr, W. 1980 Dating of speleothem by disequilibria in the U-decay series. *British Museum Occasional Paper* 21: 73.
- Hennig, G. J., Grün, R. and Brunnacker, K. 1983 Speleothems, travertines, and paleoclimates. *Quaternary Research* 20: 1-29.
- Horvatinčić, N. (ms.) 1985 Radiocarbon Age Measurements of Tufa Deposits from the Plitvice Lakes Area (in Croatian with English summary). Ph.D. Dissertation, Zagreb University, Croatia.
- Horvatinčić, N., Srdoč, D., Šilar, J. and Tvrdikova, H. 1989 Comparison of the ^{14}C activity of groundwater and recent tufa from karst areas in Yugoslavia and Czechoslovakia. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 884-892.
- Ivanovich, M. and Murray, A. 1992 Spectrometric methods. In Ivanovich, M. and Harmon, R., eds., *Uranium Series Disequilibrium: Applications to Environmental Problems*, Second edition. Oxford, Oxford University Press: 127-173.
- Krajcar Bronić, I., Horvatinčić, N., Srdoč, D. and Obelić, B. 1992 Experimental determination of the ^{14}C initial activity of calcareous deposits. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 593-601.
- _____. 1986 On the initial ^{14}C activity of karst aquifers with short mean residence time. In Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 436-440.
- Kronfeld, J., Vogel, J. C., Rosenthal, E. and Weinstein-Evron, M. 1988 Age and climatic implications of the Bet Shean Travertines. *Quaternary Research* 30: 298-303.
- Ku, T. L. 1976 The uranium-series methods of age determination. *Annual Review of Earth and Planetary Sciences* 4: 347-379.
- Lally, A. E. 1992 Chemical procedures. In Ivanovich, M. and Harmon, R., eds., *Uranium Series Disequilibrium: Applications to Environmental Problems*, Second edition. Oxford, Oxford University Press: 79-106.
- Lamb, H. H., Lewis, R. and Woodroffe, A. 1966 Atmospheric circulation and the main climatic variables. *Proceedings of the International Symposium on World Climate from 8000 to 0 B.C.* London, Royal Meteorological Society: 174 p.
- Latham, A. G. and Schwarcz, H. P. 1992 Carbonate and sulphate precipitates. In Ivanovich, M. and Harmon, R., eds., *Uranium Series Disequilibrium: Applications to Environmental Problems*, Second edition. Oxford, Oxford University Press: 423-459.
- Mahaney, W. C., ed. 1984 *Quaternary Dating Methods*. Amsterdam, Elsevier Scientific Publishing Co.
- Marčenko, E., Srdoč, D., Golubić, S., Pezdić, J. and Head, M. J. 1989 Carbon uptake in aquatic plants deduced from their natural ^{13}C and ^{14}C content. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 785-794.
- Mas-Pla, J., Trilla, J. and Valls, M. L. 1992 Radiocarbon dating of travertines precipitated from freshwater. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 677-685.
- Mook, W. G. 1976 The dissolution-exchange model for dating groundwater with ^{14}C . Interpretation of environmental isotope and hydrochemical data. In *Groundwater Hydrology*. Vienna, IAEA: 213-225.
- _____. 1980 Carbon-14 in hydrology studies. In Fritz, P. and Fontes, J. C., eds., *Handbook of Environmental Isotope Geochemistry* 1: 49-74. Amsterdam, Elsevier Scientific Publishing Co.
- Obelić, B., Horvatinčić, N., Srdoč, D., Krajcar Bronić, I. and Sliepčević, A. 1994 Rudjer Bošković Institute Radiocarbon Measurements XIII. *Radiocarbon*, this issue.
- Oppo, D. W., Fairbanks, R. G. and Gordon, A. L. 1990 Late Pleistocene Southern Ocean ^{13}C variability. *Paleoceanography* 5: 43-54.
- Osmond, J. K. and Cowart, J. B. 1976 The theory and uses of natural uranium isotopic variations in hydrology. *Atomic Energy Review* 14: 621-679.
- _____. 1992 Ground water. In Ivanovich, M. and Harmon, R., eds., *Uranium Series Disequilibrium: Applications to Environmental Problems*, Second edition. Oxford, Oxford University Press: 290-323.
- Osmond, J. K. and Ivanovich, M. 1992 Uranium-series mobilization and surface hydrology. In Ivanovich, M. and Harmon, R., eds., *Uranium Series Disequilibrium: Applications to Environmental Problems*, Second edition. Oxford, Oxford University Press: 259-289.
- Pazdur, A. 1988 The relation between carbon isotope composition and apparent age of freshwater tufaceous sediments. *Radiocarbon* 30(1): 7-18.
- Pazdur, A., Pazdur, M. F. and Szulc, J. 1988 Radiocarbon dating of Holocene calcareous tufa in southern Poland. *Radiocarbon* 30(2): 133-151.
- Pentecost, A., Thorpe, P. M., Harkness, D. D. and Lord, T. C. 1990 Some radiocarbon dates for tufa of the Craven district of Yorkshire. *Radiocarbon* 32(1): 93-97.
- Polšak, A. 1979a Upper Cretaceous beds of the North-western part of outer Dinarides; Lika, Croatian littoral and Istria. In *Proceedings of the 16th European Mi-*

- cropaleontological Colloquium*. Slovenian Academy of Sciences, Ljubljana, Slovenia: 101–106.
- 1979b The Plitvice Lakes. In *Proceedings of the 16th European Micropaleontological Colloquium, Slovenian Academy of Sciences*. Slovenian Academy of Sciences, Ljubljana, Slovenia: 157–162.
- Rousseau, D.-D., Puissegur, J.-J. and Lecolle, F. 1992 West-European mollusc assemblages of isotopic stage 11 (middle Pleistocene): Climatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 92: 15–29.
- Ruddiman, W. F., Raymo, M. E., Martinson, D. G., Clement, B. M. and Backman, J. 1989 Pleistocene evolution of the northern hemisphere climate. *Paleoceanography* 4: 353–412.
- Schwarcz, H. P. 1980 Absolute age determination of archaeological sites by uranium series dating of travertine. *Archaeometry* 22(1): 3–24.
- Schwarcz, H. P., Blackwell, B., Goldberg, P. and Marks, A. E. 1979 Uranium series dating of travertine from archaeological sites, Nahal Zin, Israel. *Nature* 277: 558–560.
- Schwarcz, H. P. and Latham, A. G. 1989 Uranium series dating of contaminated calcite using leachates alone. *Chemical Geology (Isotope Geoscience Section)* 80: 35–43.
- Srdoč, D. 1986 The response of hydrological systems to the variations of the ¹⁴C activity of the atmosphere. In Povinec, P. ed., *Proceedings of the 3rd International Conference on Low Radioactivity Measurement and Application*, Bratislava. *Nuclear Instruments and Methods in Physic Research B* 17: 545–549.
- Srdoč, D., Breyer, B. and Sliepčević, A. 1971 Rudjer Bošković Institute radiocarbon measurements I. *Radiocarbon* 13(1): 135–140.
- Srdoč, D., Chafetz, H. and Utech, N. 1989 Radiocarbon dating of travertine deposits, Arbuckle Mts., Oklahoma. In Long, A., Kra, R. S. and Srdoč, D., eds., *Proceedings of the 13th International ¹⁴C Conference*. *Radiocarbon* 31(3): 619–626.
- Srdoč, D., Krajcar Bronić, I., Horvatinčić, N. and Obelić, B. 1986a The increase of ¹⁴C activity of dissolved inorganic carbon along the river course. In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 12th International ¹⁴C Conference*. *Radiocarbon* 28(2A): 515–521.
- Srdoč, D., Obelić, B., Horvatinčić, N., Culiberg M., Šercelj A. and Sliepčević, A. 1985a Radiocarbon dating and pollen analyses of two peat bogs in the Plitvice National Park. *Acta Botanica Croatica* 44: 41–46.
- Srdoč, D., Obelić, B., Horvatinčić, N. and Sliepčević, A., 1980 Radiocarbon dating of calcareous tufa; How reliable data can we expect? In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 10th International ¹⁴C Conference*. *Radiocarbon* 22(3): 858–862.
- Srdoč, D., Obelić, B., Horvatinčić, N., Krajcar Bronić, I., Marčenko, E., Merkt, S., Wong, H. K. and Sliepčević, A. 1986b Radiocarbon dating of lake sediments from two karstic lakes in Yugoslavia. In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 12th International ¹⁴C Conference*. *Radiocarbon* 28(2A): 495–502.
- Srdoč, D., Obelić, B., Sliepčević, A., Krajcar Bronić, I. and Horvatinčić, N. 1987 Rudjer Bošković Institute radiocarbon measurements X. *Radiocarbon* 29(1): 135–147.
- Srdoč, D., Sliepčević, A., Obelić, B., and Horvatinčić, N. 1977 Rudjer Bošković Institute radiocarbon measurements IV. *Radiocarbon* 19(3): 465–475.
- Srdoč, D., Horvatinčić, N., Ahel, M., Giger, W., Schaffner, C., Krajcar Bronić, I., Petricoli, D., Pezdič, J., Marčenko, E. and Plenković, A. 1992a Anthropogenic influence on the ¹⁴C activity of recent lake sediment. A case study. In Long, A. and Kra, R. S., eds., *Proceedings of the 14th International ¹⁴C Conference*. *Radiocarbon* 34(3): 585–592.
- Srdoč, D., Horvatinčić, N., Krajcar Bronić, I. Obelić, B. and Sliepčević, A. 1992b Rudjer Bošković Institute radiocarbon measurements XII. *Radiocarbon* 34(1): 155–175.
- Srdoč, D., Horvatinčić, N., Obelić, B. and Sliepčević, A. 1982 Rudjer Bošković Institute radiocarbon measurements VII. *Radiocarbon* 24(3): 352–371.
- Srdoč, D., Horvatinčić, N., Obelić, B., Krajcar, I. and Sliepčević, A. 1985b Calcite deposition processes in karstwaters with special emphasis on the Plitvice Lakes, Yugoslavia. *Carsus Iugoslaviae* 11/4-6: 101–204 (in Croatian, with extended English abstract).
- Srdoč, D., Horvatinčić, N., Obelić, B., Krajcar-Bronić, I. and O'Malley, P. 1986c The effects of contamination of calcareous sediments on their radiocarbon age. In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 12th International ¹⁴C Conference*. *Radiocarbon* 28 (2A): 510–514.
- Srdoč, D., Horvatinčić, N., Obelić, B., Krajcar Bronić, I. and Sliepčević, A. 1987 Rudjer Boškovic Institute radiocarbon measurements IX. *Radiocarbon* 29(1): 115–147.
- Szabo, B. J. 1990 Ages of travertine deposits in Eastern Grand Canyon National Park, Arizona. *Quaternary Research* 34: 24–32.
- Tamers, M. A. 1967 Surface-water infiltration and groundwater movement in arid zones of Venezuela. In *Isotope Hydrology*. Vienna, IAEA: 241–257.
- Thompson, G., Lumsden, N., Walker, R. and Carter, J. 1975 Uranium series dating of stalagmites from Blanchard Springs Cavern, U.S.A. *Geochimica et Cosmochimica Acta* 39: 1211–1218.
- Thompson, P., Ford, D. C. and Schwarcz, H. P. 1975 ²³⁴U/²³⁸U ratios in limestone cave seepage waters and speleothems from West Virginia. *Geochimica et Cosmochimica Acta* 39: 661–669.
- Thorpe, P. M., Otlet, R. L. and Sweeting, M. M. 1980 Hydrological implications from ¹⁴C profiling of UK tufa. In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 10th International ¹⁴C Conference*. *Radiocarbon* 22(3): 897–908.

RADIOCARBON CALIBRATION CURVE VARIATIONS AND THEIR IMPLICATIONS FOR THE INTERPRETATION OF NEW ZEALAND PREHISTORY

B. G. McFADGEN,¹ F. B. KNOX² and T. R. L. COLE³

ABSTRACT. The shape of a distribution of calibrated ¹⁴C dates displays spurious peaks and troughs, brought about by changes in the slope of the calibration curve interacting with the spreading effect of the stochastic distribution of counting errors. The distortion results in a positive correlation between the numbers of dates per calendar year and the slopes of the calibration curves, for assemblages of archaeological dates from such widely separated areas as British Columbia, South Australia and New Zealand. The distortion also increases the possibility of date reversals, and increases the overall spread of calibrated ¹⁴C dates. After taking into account this systematic distortion and inbuilt age of charcoal and wood samples, we estimate dates for the initial settlement and first appearance of fortifications, and infer a likely trend of population growth for prehistoric New Zealand.

INTRODUCTION

More than 800 ¹⁴C dates of terrestrial and marine samples exist for New Zealand prehistory, which is only *ca.* 500 yr long (Anderson 1991). This gives an average of > 1.5 dates per year. ¹⁴C dates are important for determining New Zealand settlement, and for dating events such as the extinction of the moa (a very large, extinct, flightless bird of New Zealand) and the first appearance of fortifications.

Calibration of ¹⁴C dates using accepted procedures (*e.g.*, Stuiver and Reimer 1993) produces strange results, which have led to fallacious inferences about the chronology of New Zealand prehistory. The distribution of calibrated shell dates is shorter than that of calibrated dates on charcoal and wood. The shell curve has a short “tail” with few dates older than 700 cal BP, and its peaks and troughs are located at different calendar dates than for charcoal and wood (Fig. 1B, C). For the shell dates, peaks correspond to steep slopes of the marine calibration curve, and troughs, to gentle slopes (Fig. 1A, C). For charcoal and wood, peaks correspond to steep slopes of the terrestrial calibration curve; troughs correspond to the “wiggles” (Fig. 1A, B). For charcoal and wood dates, the relation between peaks, troughs and calibration curve wiggles appears to be universal for the Pacific, and also occurs for South Australia and coastal British Columbia. Here we discuss these peculiarities of ¹⁴C date calibration in the context of New Zealand prehistory.

METHODS

We use the 1993 marine and terrestrial calibration curves (Stuiver and Braziunas 1993; Stuiver and Pearson 1993). In each case, we fit a cubic spline to pass through each data point and provide pairs of ¹⁴C/calendar dates for each calendar year back to 1400 cal BP. Characteristic wiggles identify sections of the curve where more than one calendar date exists for each ¹⁴C date. We call these sections *ambiguous regions* (Fig. 2). One can find the boundary of an ambiguous region by projecting from a wiggle maximum a horizontal line forward in calendar time to intercept the calibration curve (Fig. 2: f), and from a wiggle minimum backward in time to intercept the calibration curve (Fig. 2: e). Boundary values in calendar and ¹⁴C years are read off the appropriate calibration curve axis. The “slope” of an ambiguous region is represented by a line between the two points where the horizontal lines intercept the calibration curve.

¹Conservation Sciences Centre, Department of Conservation, P.O. Box 10420, Wellington, New Zealand

²900 Ohariu Valley Road, R.D., Johnsonville, New Zealand

³Department of Labour, P. O. Box 3705, Wellington, New Zealand

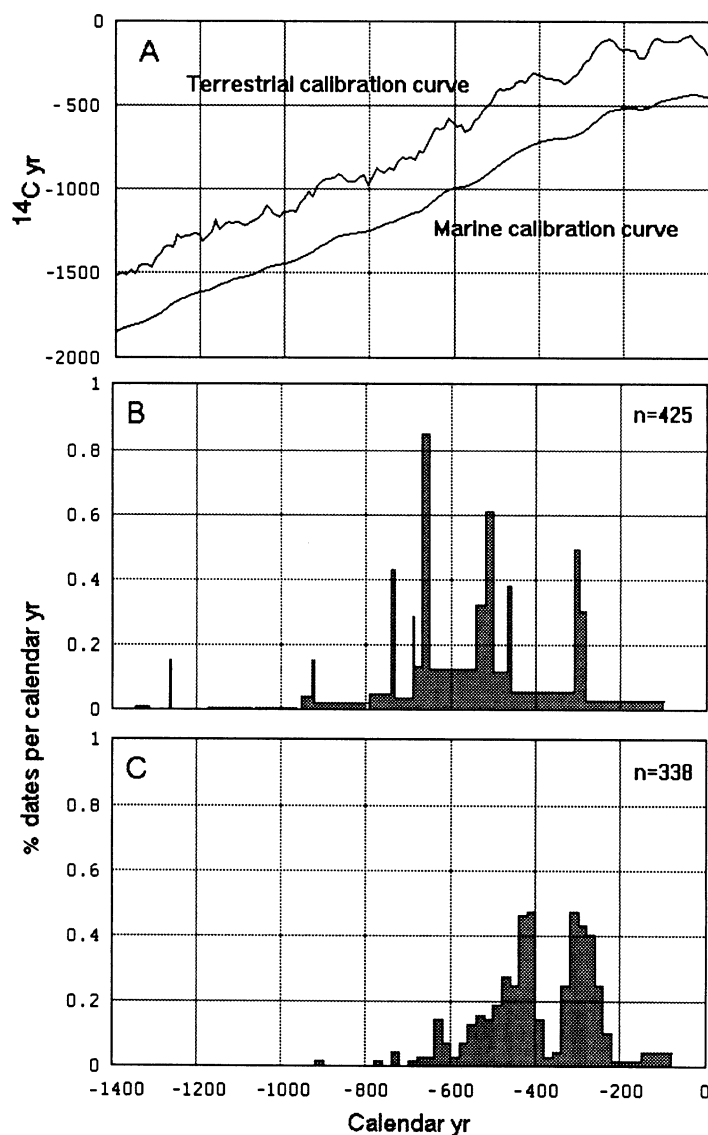


Fig. 1. Graphs of calibrated dates for New Zealand prehistory compared with the terrestrial and marine calibration curves. A. Calibration curve data from Stuiver and Pearson (1993) (terrestrial) and Stuiver and Braziunas (1993) (marine); B. wood and charcoal dates; C. marine shell dates. Note that calendar and ^{14}C years before present are shown as negative, with 0 representing AD 1950. n = the number of ^{14}C dates represented by each graph. For the wood and charcoal terrestrial dates, n = the number of dates between -121.92 and -1581.55 ^{14}C years (-100 and -1500 calendar years, respectively), and for the marine shell dates, between -452.01 and -1921.2 ^{14}C years (-78 and -1500 calendar years, respectively). For explanation of class widths, see text.

We do not apply a correction to the terrestrial calibration curve to compensate for the apparent offset of ^{14}C between the northern and southern hemispheres (Vogel *et al.* 1993). We find the data of Vogel *et al.* (1993) unconvincing because they indicate an inverse variation of ^{14}C between the two hemi-

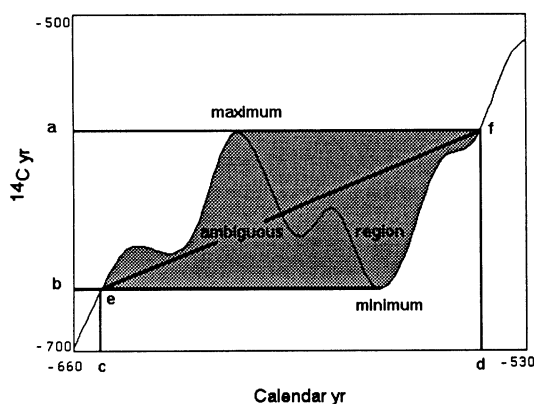


Fig. 2. Definition of an ambiguous region (▨). a, b = ambiguous region boundaries on the ^{14}C axis; c, d = ambiguous region boundaries on the calendar axis. The slope of an ambiguous region is the slope of the line joining e and f.

spheres. Recent measurement of the ^{14}C content of New Zealand tree rings suggests that the southern hemisphere offset is either very small or non-existent (Dr. R. G. Sparks, personal communication 1994). The peculiarities of ^{14}C calibration discussed here are present whether or not the 40-yr offset is applied.

Archaeological dates were determined at the Institute of Geological and Nuclear Sciences, Lower Hutt, prior to May 1992. All results since 1988, including accelerator mass spectrometry (AMS) dates, are in strict accordance with the recommendations of Stuiver and Polach (1977). Measurements made before 1988 have been recalculated to meet the same conventions. We have included published ^{14}C dates from other laboratories whenever available. All our dates are on charcoal, wood, moa bone or marine shell stratigraphically contemporary with evidence of human activity. We include estuarine samples except for mudsnail shells (*Amphibola crenata*), as these can have $\delta^{13}\text{C}$ values suggesting the ingestion of terrestrial carbon. Marine shell dates are calibrated using $\Delta R = -31$ (McFadgen and Manning 1990).

In our graphs of date distributions, bar heights represent the percentage of dates per calendar year for each class. The dates are calibrated conventional ^{14}C ages considered as "point" dates without regard for their standard errors. ^{14}C dates in ambiguous regions have multiple intercepts on the calibration curve and correspond to more than one calendar date. The number of ^{14}C dates in an ambiguous region must match the number of calendar dates. Thus, to avoid the dilemma of how to allocate one ^{14}C date among multiple calendar date possibilities (Stuiver and Reimer 1989), we treat each ambiguous region as a single class. (How to determine the distribution of dates within an ambiguous region is the subject of a future paper.) For parts of the calibration curve between ambiguous regions, a 20-yr class is adopted where the interval is sufficiently large. For shell date graphs, 20-yr classes are between 220 and 1400 cal BP. For charcoal and wood, and moa bone graphs, 20-yr classes are between 285 and 312 cal BP, and 501 and 544 cal BP, respectively.

EFFECTS OF INBUILT AGE AND CALIBRATION CURVE STOCHASTIC DISTORTION ON DISTRIBUTIONS OF CALIBRATED DATES

Two factors contribute to the differences between the two distributions of calibrated dates: inbuilt age (McFadgen 1982), and the "calibration stochastic distortion (CSD) effect". Inbuilt age is the difference in age between the death of the sample and the archaeological event dated. For wood, it is the combination of growth age (the age of old wood in a tree) and storage age (the time the tree was lying around before it was used). The CSD effect is the systematic increase or depletion of the num-

ber of calibrated dates on the calendar scale, related to the slope of the calibration curve. We show below that this occurs because the change in the slope of the calibration curve interacts with the spreading effect of the stochastic distribution of counting errors.

Charcoal and wood samples collected before the mid-to-late 1970s were rarely identified by species and little effort was made to collect twigs. Consequently, many charcoal and wood samples have an unknown and possibly large inbuilt age (McFadgen 1982). Samples collected since the mid-1970s have been routinely identified. Short-lived species are classed here as those with a potential life span of < 100 yr (*i.e.*, *ca.* 2 standard errors of an average ^{14}C date), and long-lived species as those with a potential life span of > 100 yr (Table 1).

TABLE 1. Life Expectancy of Plant Species Used for ^{14}C Dating in New Zealand*

Short (< 100 yr)	Medium (100–300 yr)	Long (> 300 yr)
<i>Aristotelia serrata</i>	<i>Ackama rosifolia</i> †	<i>Agathis australis</i>
<i>Brachyglottis</i> sp.	<i>Alectryon excelsus</i>	<i>Dacrydium cupressinum</i>
<i>Carmichaelia</i> sp.	<i>Beilschmiedia</i> sp.‡	<i>Halocarpus kirkii</i>
<i>Carpodetus serratus</i> ‡	<i>Cordyline australis</i>	<i>Lagarostrobos colensoi</i> †
<i>Cassinia</i> sp.	<i>Corynocarpus laevigatus</i>	<i>Laurelia novaezealandia</i> †
<i>Coprosma</i> sp.	<i>Discaria toumatou</i>	<i>Libocedrus bidwillii</i> †
<i>Coriaria</i> sp.	<i>Dysoxylum spectabile</i>	<i>Metrosideros</i> sp.
<i>Corokia macrocarpa</i>	<i>Hoheria</i> sp.†	<i>Nothofagus</i> sp.†
<i>Geniostoma rupestre</i>	<i>Knightia excelsa</i>	<i>Phyllocladus</i> sp.†
<i>Hebe</i> sp.	<i>Kunzea ericoides</i>	<i>Podocarpus totara</i>
<i>Hedycarya arborea</i> ‡	<i>Myrsine divaricata</i> †	<i>Prumnopitys spicatus</i>
<i>Leptospermum scoparium</i> ‡	<i>Myoporum laetum</i>	<i>Vitex lucens</i> †
<i>Leucopogon fusciculatus</i>	<i>Nestegis</i> sp.‡	
<i>Lophomyrtus obcordata</i> ‡	<i>Olearia</i> sp.	
<i>Macropiper excelsus</i>	<i>Pseudopanax</i> sp.†	
<i>Melicytus ramiflorus</i> ‡	<i>Paratropis microphylla</i>	
<i>Melicytus</i> sp.‡	<i>Pittosporum eugenoides</i>	
<i>Myrsine australis</i> ‡	<i>Pittosporum tenuifolium</i> †	
<i>Myrsine</i> sp.‡	<i>Plagianthus</i> sp.	
<i>Olearia rani</i> ‡	<i>Sophora microphylla</i>	
<i>Pseudopanax arboreus</i> ‡	<i>Sophora</i> sp.	
<i>Pseudopanax crassifolius</i> ‡	<i>Weinmannia</i> sp.	
<i>Pseudowintera</i> sp.		
<i>Pteridium esculentum</i>		
<i>Schefflera digitata</i>		
Tree fern		

*Data provided by Dr. Philip Simpson, Botanist, Science and Research Division, Department of Conservation.

†Life span can be much shorter than designated years.

‡Life span can be longer than designated years.

The distribution curve of dates on short-lived species has far fewer dates > 700 cal BP than the long-lived species (Fig. 3). The few short-lived species > 700 cal BP are from Central Otago, where dry conditions enhance the survival of dead trees and shrubs. Excluding the long-lived species, the spread of calibrated dates on identified charcoal and wood concurs with the shell dates, and gives an initial estimated date for human settlement of New Zealand of *ca.* 700–800 cal BP.

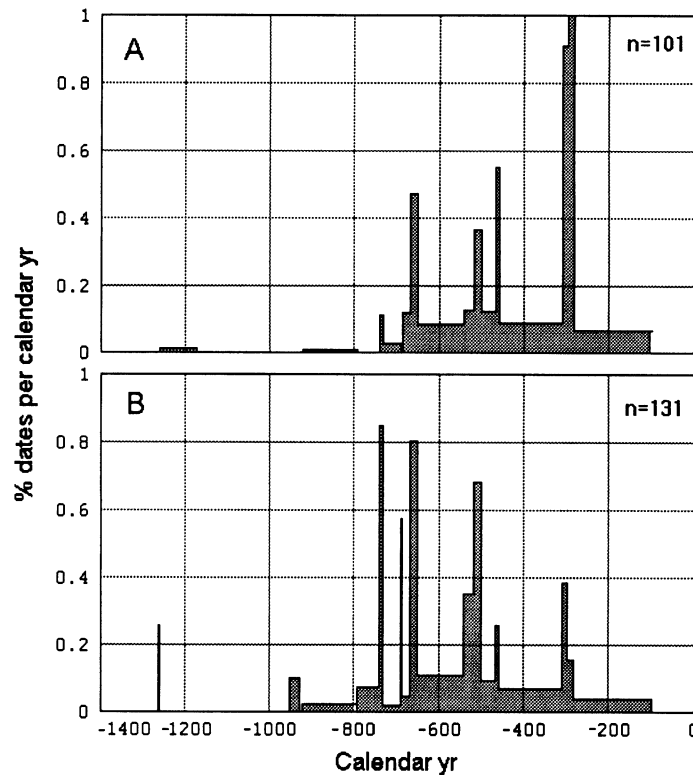


Fig. 3. Graphs of calibrated dates for New Zealand prehistory determined on short-lived (A) and long-lived (B) plant species. Note the far fewer dates on short-lived species older than 700 cal BP, and the contrast in the trend of peak heights with decreasing age.

The trend of peak heights of the calibrated shell date graph and the corresponding trend of peak heights for all the charcoal and wood dates do not agree. The trend of shell peak heights (Fig. 1) fits better with the trend of short-lived charcoal and wood peak heights (Fig. 3). Inbuilt age thus appears to account for the different trend in peak height between the shells and the total set of charcoal and wood dates. The earliest major peak of the calibrated shell dates (*ca.* 420 cal BP) is later than the earliest major peak of the total set of charcoal and wood dates (*ca.* 660 cal BP, Fig. 1). It will become apparent, below, that the displacement of the earliest major shell peak compared with the earliest major charcoal and wood peak is due to the CSD effect.

The effects of calibration stochastic distortion on ¹⁴C date calibration are well known (*e.g.*, Stuiver and Reimer 1989), and various methods of dealing with them have been proposed (*e.g.*, Geyh 1980; Stolk, Hogervorst and Berendsen 1989; Stuiver and Reimer 1989). However, these methods are *local* in that they correct isolated, individual dates or histogram classes. Our analysis of the CSD effect indicates that a *global* approach is necessary. All dates occurring over a ¹⁴C time range equal to at least 4–6 times the counting error (standard deviation) of a typical date need to be corrected as a group. The correction procedure, borrowed from signal processing, will be a deconvolution of the measured ¹⁴C distribution from the counting statistics to give the true ¹⁴C distribution, which may then be mapped through the calibration curve in the usual way to give a calendar distribution substantially free of CSD effects.

The CSD effect depletes the numbers of dates per calendar year in those parts of the calendar time scale which correspond to gentle slopes of the calibration curve or to wiggles, and increases the numbers of dates where the slopes are steep (Fig. 1). The effect is not due to the use of histograms to depict date distributions. It makes little difference whether point dates are used for the graphs, or whether standard errors are included and summed probabilities used for the graphs.

Depletion is most striking within the boundaries of the ambiguous regions of the terrestrial calibration curve, and less so within the boundaries of the flatter regions of the marine calibration curve. The effect is responsible for the narrow peaks and wide troughs of the charcoal and wood distribution, but because the flatter parts of the marine calibration curve cover fewer calendar years than the ambiguous regions of the terrestrial curve, the peaks of the shell distribution are wider and the troughs narrower. The peaks and troughs present in the New Zealand charcoal and wood distribution are matched (Fig. 4) in date assemblages of similar age on charcoals from South Australia (Bird and Frankel 1991) and British Columbia (Richards and Rosseau 1987). In all three locations, the slope of the calibration curve and the numbers of dates per calendar year within and between the ambiguous regions show a very significant positive correlation (Fig. 5). The New Zealand shell dates (Fig. 5) show a similar correlation.

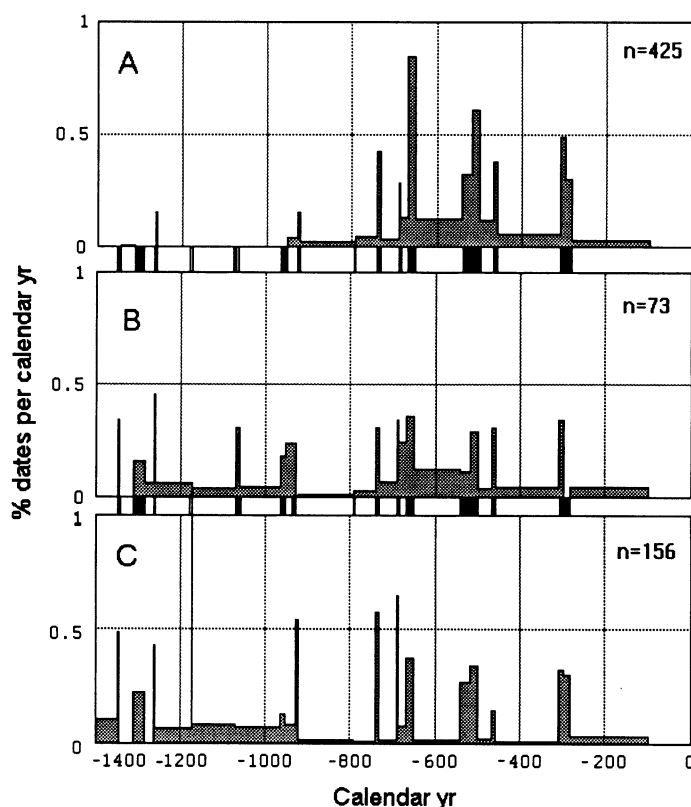


Fig. 4. Graphs of calibrated dates on charcoal and wood for New Zealand prehistory (A) compared with graphs of calibrated dates on charcoal for South Australian (B) and British Columbian (C) prehistory. Note the correspondence between non-ambiguous regions (■) and peaks of the graphs.

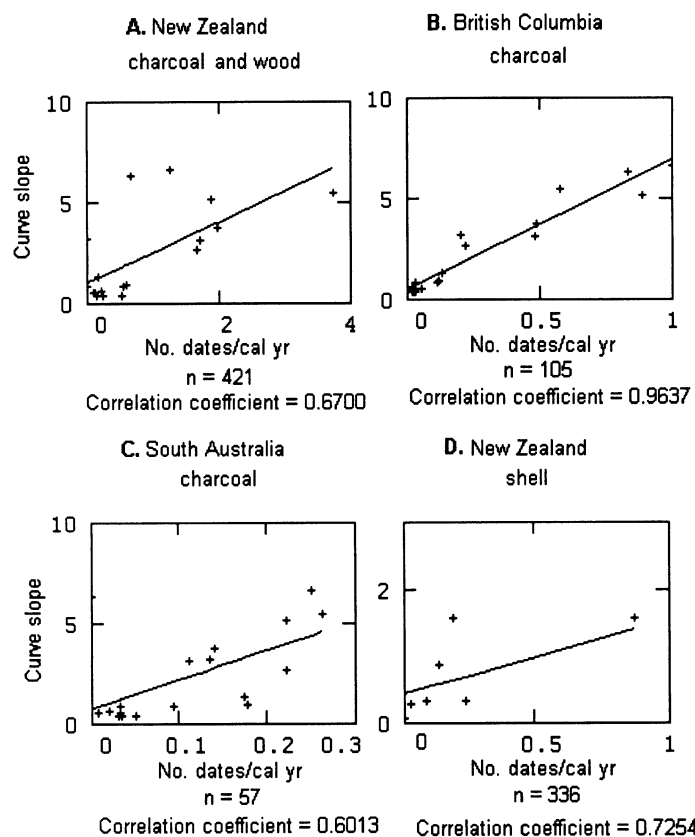


Fig. 5. Linear correlation of the numbers of dates per calendar year and the slope of the calibration curve within and between ambiguous regions for the period 100–1062 cal BP (charcoal and wood) and 0–640 cal BP (shells). Significance of correlation coefficient measured using test statistic

$$t = (r(n-2)^{0.5}) / ((1-r^2)^{0.5})$$

(Snedecor and Cochran 1967), where r = correlation coefficient and n = number of classes. d.f. = $n-2$. Correlation coefficient is highly significant in all cases: A. $t = 4.12$, $P < 0.001$; B. $t = 20.86$, $P < 0.001$; C. $t = 3.93$, $P < 0.005$; D. $t = 3.39$, $P < 0.025$.

The changes in the numbers of dates per calendar year between ambiguous and non-ambiguous regions could correspond to real changes in human activity in the past, correlation with the slope of the calibration curve being a common response to a factor such as climate. However, this apparent common response, of widely different cultures in different environments, to the geophysical phenomena responsible for variation in the calibration curve, makes us doubtful that this is a true cultural response. An alternative explanation of the CSD effect is that it is a construct of the interaction between changing calibration curve slope and spreading of ¹⁴C dates because of counting statistics. The CSD effect is significant when the counting errors of individual ¹⁴C dates are comparable with, or greater than, the time intervals over which appreciable changes in slope of the calibration curve occur. Figure 6 illustrates how the effect occurs.

Let line A represent a uniform true calendar date distribution. On mapping through the calibration curve, A becomes the line B, the true ¹⁴C date distribution. However, B is statistically spread by counting errors to become line B', the observed ¹⁴C date distribution. When B' is mapped back

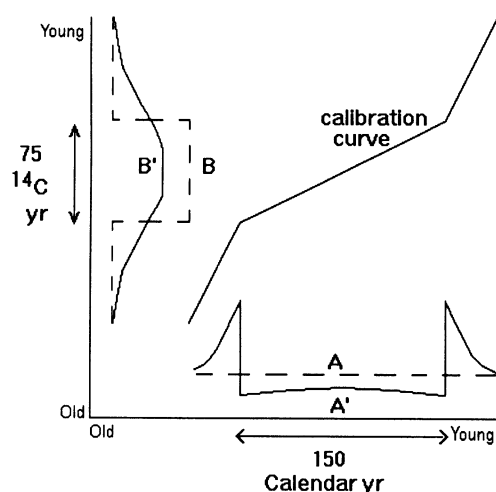


Fig. 6. Illustration of the CSD effect. A distribution of true calendar dates A (---) maps into a corresponding distribution of true ^{14}C dates B (---). The observed ^{14}C distribution B' (—) is the dates in B after their spread by counting errors (standard deviation = 50 yr), and maps back into A' (—), the resulting apparent calendar distribution.

through the calibration curve, it gives A', the apparent calendar date distribution, which differs systematically from A, the true distribution.

The effect is most marked around the ambiguous regions, because that is where changes in slope of the calibration curve are greatest. Distances between the beginnings and ends of ambiguous regions on the ^{14}C scale are between 6.5 and 91 yr (Table 2), less than twice the average standard error of archaeological ^{14}C dates. Thus, counting statistics spread the dates into those parts of the curve with the steepest slopes, with a high probability of a measured ^{14}C age falling outside an ambiguous region.

Figure 7 shows a true ^{14}C date centered on an ambiguous region. The bell-shaped curve is the statistical distribution of errors of a measured ^{14}C date estimating the true ^{14}C date. The width of the ambiguous region on the ^{14}C axis is shown as equal to twice the standard error of the measured date. The probability of the measured date falling outside the ambiguous region is indicated by the unshaded portion of the bell-shaped curve and is *ca.* 0.33. In reality, for the last 1500 yr, the width of all ambiguous regions is < 2 average standard errors, and for over half of the ambiguous regions, it is < 1 average standard error. Only between 544 and 652 cal BP is there a substantially better than even chance of a measured ^{14}C date falling within an ambiguous region of the terrestrial curve when the true ^{14}C date is centered in the region. This chance is reduced if the true date is off-center of an ambiguous region.

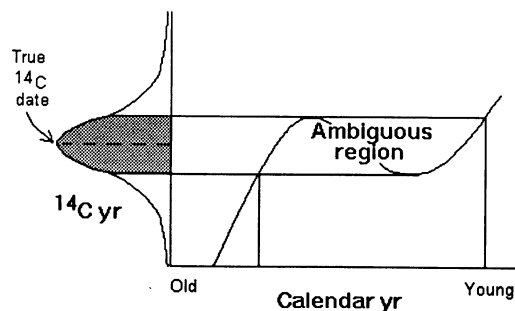


Fig. 7. Diagram to illustrate how the counting statistics of a ^{14}C date affects the probability that the date will fall outside an ambiguous region. The bell-shaped curve represents the statistical distribution of a true ^{14}C date centered on an ambiguous region that has a width in ^{14}C years equal to twice the standard error of a measured date. The unshaded portion of the curve represents the probability that the measured date falls outside the ambiguous region (0.33).

TABLE 2. Calendar and ¹⁴C age boundaries and durations of ambiguous (A) and non-ambiguous (N) regions of the terrestrial calibration curve. Note that, with one exception (929–952 cal BP), the slope of the calibration curve across ambiguous regions is < 45° (< 1.0000), and across non-ambiguous regions, > 45° (> 1.0000).

Calendar age (yr BP)	¹⁴ C age (yr BP)	Region duration (calendar yr)	Region duration (¹⁴ C yr)	Slope of region (tangent)	Region
0	0	--	--	--	--
285	227	285	227	0.7965	A
300	269.47	15	42.47	2.8313	N
312	312.26	12	42.79	3.5658	N
459	373.76	147	61.5	0.4184	A
468	397.47	9	23.71	2.6344	N
501	410.37	33	12.9	0.3909	A
520	501.34	19	90.97	4.7879	N
544	572.59	24	71.25	2.9688	N
652	662.97	108	90.38	0.8369	A
671	766.64	19	103.67	5.4563	N
688	781.97	19	15.33	0.8068	A
692	808.53	4	26.56	6.64	N
732	824.54	40	16.01	0.4003	A
741	871.23	9	46.69	5.1878	N
794	906.12	55	34.89	0.6344	A
794	906.12	0	0	0	N
923	976.23	129	70.11	0.5435	A
929	1014.01	6	37.78	6.2967	N
952	1044.79	23	30.78	1.3383	A
967	1092.3	15	47.51	3.1673	N
1062	1171.08	95	78.78	0.8293	A
1071	1182.32	9	11.24	1.2489	N
1174	1252.49	103	70.17	0.6813	A
1175	1261	1	8.51	8.51	N
1261	1313.96	86	52.96	0.6158	A
1264	1339.1	3	25.14	8.38	N
1286	1353.14	22	14.04	0.6382	A
1312	1456.11	26	102.97	3.9604	N
1346	1468.79	34	12.68	0.3729	A
1350	1488.63	4	19.84	4.96	N
1406	1515.31	56	26.68	0.4764	A
1415	1575	9	59.69	6.6322	N
1500	1581.55	85	6.55	0.0771	A

The CSD effect is robust, illustrated by the calibration of a simulated set of ¹⁴C dates derived from a uniform distribution of calendar dates. Figure 8 shows a typical result. The simulated dates are for every calendar year between 100 and 700 cal BP. The true ¹⁴C date corresponding to each calendar year is assigned a standard error of 50 yr, which is close to the average for New Zealand dates on charcoal and wood. The true ¹⁴C dates and their assigned standard errors randomly generate the simulated ¹⁴C dates. The resulting graph of calibrated dates closely resembles that of the archaeological dates; the outcome of repeated simulations differs little until standard errors reduce to < ca. 20 yr.

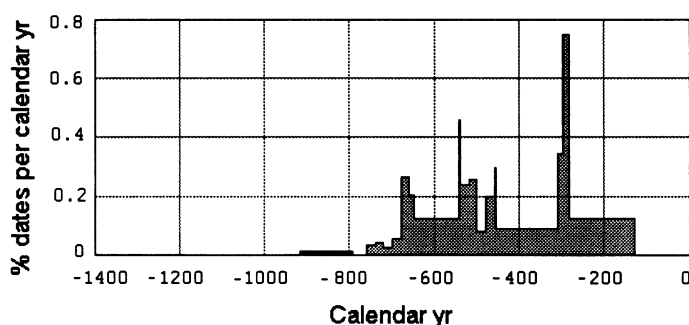


Fig. 8. Calibrated simulated ^{14}C dates, derived from a uniform distribution of calendar dates, show the production of peaks and troughs resembling the histogram of New Zealand dates on charcoal and wood

We do not observe significant change in the outcome when the distribution of dates in calendar time is non-uniform and weighted more than three times in favor of the ambiguous regions.

The simulation shows a tail to the distribution of calibrated dates, which extends back beyond 900 cal BP (Fig. 8), and is due entirely to the spreading effect of the standard errors. The tail is present in some simulations and absent in others. It indicates that the true beginning of a distribution of calibrated dates is likely to be younger than its histogram shows. The slight tail to the shell distribution, between 700 and 900 cal BP (Fig. 1), is almost certainly statistical in origin.

IMPLICATIONS OF INBUILT AGE AND THE CSD EFFECT FOR NEW ZEALAND PREHISTORY

The CSD effect makes it very difficult to determine the true calendar distribution of dates. Many of the peaks and troughs in both the charcoal and wood and the shell distributions are likely to be a function of the calibration curve. In the archaeological dates used here, the first high peak of the charcoal and wood distribution is unmatched in the shell distribution, which has a much smaller initial peak. Comparison with the distribution of short-lived charcoal and wood dates (Fig. 3) suggests a high inbuilt age component in the early charcoal dates. The true distribution of charcoal and wood dates in calendar time is probably closer to the distribution of shell dates.

The shell distribution begins *ca.* 900 cal BP. It increases to a maximum *ca.* 400 cal BP, drops into a marked trough *ca.* 350 cal BP, increases to a peak *ca.* 300 cal BP, and then declines after *ca.* 250 cal BP. After making allowance for the CSD effect, which we show above causes peaks, troughs and spreading, the distribution provides a plausible visual representation of the likely trend of population growth in prehistoric New Zealand, shown by the superposed hand-drawn curve in Figure 9.

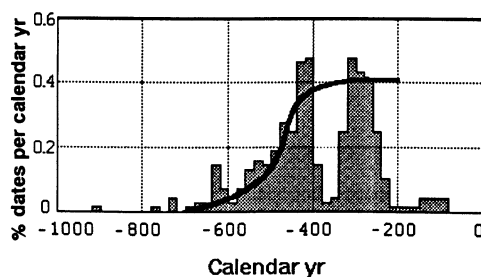


Fig. 9. Likely trend of population growth (—) for New Zealand prehistory, based on ^{14}C dates. The heavy line was drawn by hand to smooth out the variations in the histogram bar heights.

A settlement date of *ca.* 700 cal BP based on the shell distribution agrees with Anderson's (1991) settlement date of *ca.* 700 cal BP based on a selective analysis of dates on charcoal and wood; both are several hundred years later than the generally accepted date of 1000–1200 cal BP (Davidson 1984). The earlier settlement date requires only a small founding population and a reasonable growth rate to reach the population size estimated by the first European explorers (Davidson 1984), whereas the later date requires either an unreasonably high growth rate (Brewis, Molloy and Sutton 1990) or a much larger founding population.

Simmons' (1976) record of Maori oral history alludes to voyages to and from Polynesia and the arrival of many canoes, which is consistent with the archaeological evidence. The discovery of Mayor Island obsidian in early archaeological deposits on Raoul Island in the Kermadec Group, between New Zealand and the Cook Islands (Anderson and McFadgen 1990), strongly supports return voyages to Polynesia. Also, the discovery of a pearl shell fishing lure in an archaeological site at Tairua on the Coromandel Peninsula (Green 1967) in deposits dated several hundred years after first settlement (McFadgen 1994), strongly suggests more than one voyage to New Zealand from Polynesia. Eastern Polynesians 700 yr ago appear to have kept contact between island groups (Irwin 1992), so knowledge of the discovery of New Zealand was probably shared by more than one island group. Early archaeological evidence in New Zealand displays distinct cultural differences between different parts of the country (Davidson 1984), which is consistent with settlement from different parts of eastern Polynesia.

The CSD effect may distort interpretations of events following human settlement of New Zealand. True calendar dates for samples below the minimum turning point of an ambiguous region (Fig. 10A: a–b) are younger than those below the maximum turning point (Fig. 10A: b–c), but have true

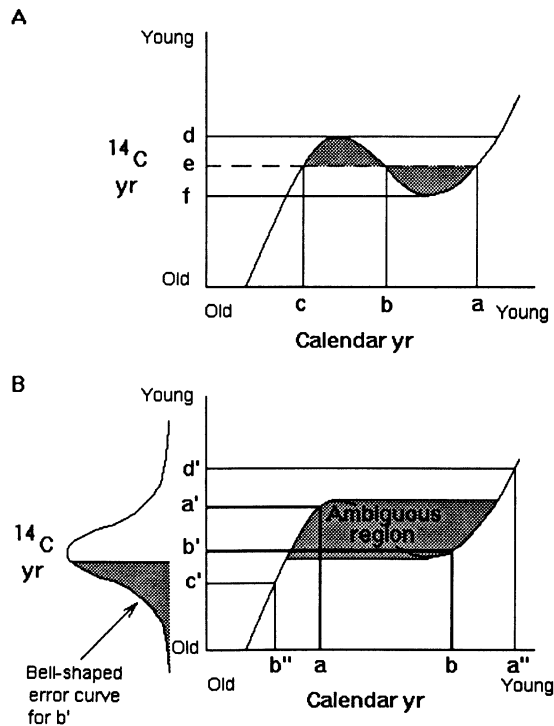


Fig. 10. Diagram showing ¹⁴C date reversals caused by ambiguous regions of the calibration curves. A. Two sets of calendar dates a–b and b–c map onto the ¹⁴C axis at e–f and d–e, respectively. The calendar dates between a and b are younger than those between b and c, but have true ¹⁴C dates (e–f) that are older than those for b and c (d–e). B. Two individual true calendar dates intercept the calibration curve near the turning points of an ambiguous region. The younger date b is near the minimum, the older date a is near the maximum. Their true ¹⁴C dates at b' and a' are reversed. If c' and d' are the measured ¹⁴C dates for b' and a', then their calibrated calendar dates are a'' and b'', which are reversed and more widely separated than the true calendar dates.

^{14}C dates that are older (Fig. 10A: e–f). Measured ^{14}C dates, which are estimates of the true dates, are spread by their counting statistics, in some cases, beyond the boundaries of the ambiguous regions (*cf.* Fig. 6).

In extreme cases, two events may have measured ^{14}C dates that are not only reversed with respect to their true calendar age, but that also fall outside the boundaries of the ambiguous regions and are significantly different. In Figure 10B, the probability that the measured ^{14}C date of b' will fall outside the older boundary of the ambiguous region (*e.g.*, at c') is indicated by the shaded part of the bell-shaped error curve and is greater than the probability of its falling outside the younger boundary. Similarly, the probability that the measured ^{14}C date of a' will fall outside the younger boundary (*e.g.*, at d') is greater than the probability of its falling outside the older boundary. The closer each true ^{14}C age is to the boundary of the ambiguous region, the more likely it is that the measured ^{14}C age will lie beyond the boundary. For true ^{14}C dates lying on their respective boundaries, the maximum probability that both measured dates will lie outside their respective boundaries is 0.25.

Distortion of this sort produced by the CSD effect may account for young dates on moa bones (Fig. 11) and for old dates on fortifications (Fig. 12). Calibrated dates for moa bones are as young as 300 cal BP, which would be expected if moa hunting stopped at 450 cal BP, shortly after the start of the ambiguous region that occurs between 459 and 312 cal BP on the terrestrial calibration curve. To illustrate this, we assumed that the end of moa hunting was 450 cal BP. We took a uniform sample of calendar dates at 5-yr intervals between 660 and 450 cal BP and their corresponding true ^{14}C dates, and assigned each ^{14}C date a standard error of 67 yr (the average for the moa bone dates). Using the true ^{14}C dates and their assigned standard errors, we generated a simulated set of measured dates. The spread of the calibrated simulated dates matches the spread of the calibrated measured ^{14}C dates (Fig. 11), from which we conclude that the observed moa bone dates could have been generated from samples no younger than 450 cal BP.

To illustrate the distortion of the fortifications' dates, we included dates with inbuilt age; 65 ^{14}C dates on charcoal and wood are stratigraphically contemporary with some aspect of fort construction or use, and all but 11 have an unknown and possibly large inbuilt age. We excluded dates older than

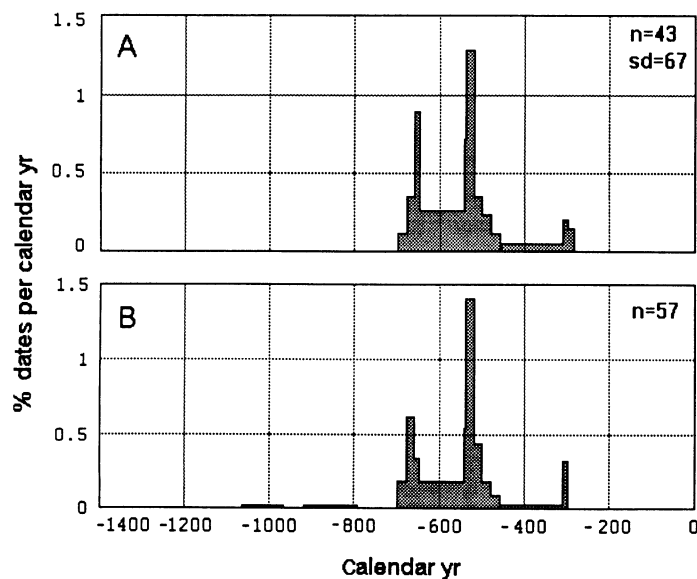


Fig. 11. Calibrated ^{14}C dates on moa bones compared with simulated dates. A. Calendar distribution of a simulated set of ^{14}C dates uniformly distributed at 5-yr intervals between 660 and 450 cal BP. B. Calendar distribution of calibrated ^{14}C dates on moa bone. We assume the end of simulated moa hunting to be 450 cal BP, just after the start of the ambiguous region of the terrestrial calibration curve, which occurred between 459 and 312 cal BP. The standard error for the simulated moa bone dates (67 yr) is the mean value for the measured ^{14}C dates on moa bones. The spread of the calibrated simulated dates closely matches the spread of calibrated measured dates and is explained by the spreading effect of counting errors illustrated by Figure 6.

600 cal BP that have an unknown and possibly large inbuilt age. We took a uniform sample of dates at 2-yr intervals between 380 and 250 cal BP, and generated a simulated set of measured dates, as described for the moa bone dates, using an assigned standard error of 56 yr. The spread of the calibrated simulated dates matches the spread of the calibrated measured ¹⁴C dates (Fig. 12), indicating that the observed dates for fortifications could have been generated from samples no older than 380 cal BP.

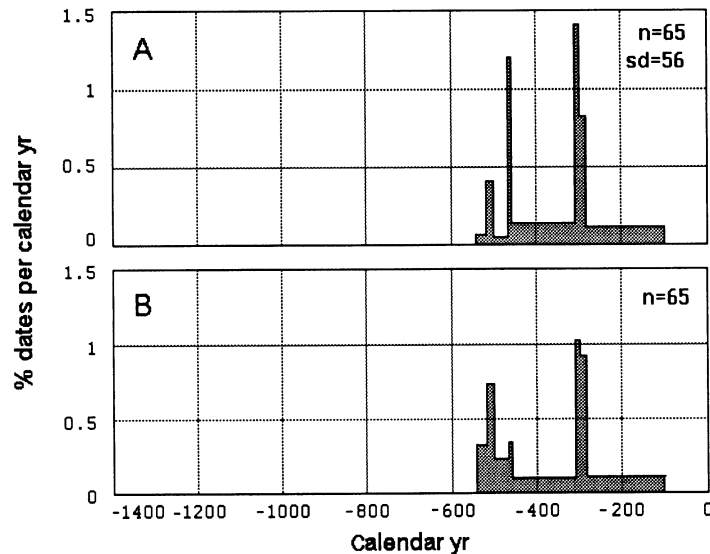


Fig. 12. Calibrated ¹⁴C dates on charcoal and wood for fortifications compared with simulated dates. A. Calendar distribution of a simulated set of ¹⁴C dates uniformly distributed at 2-yr intervals between 380 and 252 cal BP. B. Calendar distribution of calibrated ¹⁴C dates on charcoal and wood from fortifications. We assume the start of simulated fort construction to be 380 cal BP, within the latter part of the ambiguous region of the terrestrial calibration curve (459–312 cal BP). The standard error for the simulated dates (56 yr) is the mean value of the measured ¹⁴C dates. The spread of the calibrated simulated dates closely matches the spread of calibrated measured dates and is explained by the spreading effect of counting errors illustrated by Figure 6.

Although there is a gap of 70 yr between the oldest true calendar date for fortifications needed to account for the spread of measured dates and the youngest true calendar date on moa bone needed to account for the spread of measured moa bone dates, the calibrated measured dates overlap by > 200 yr. This overlap is caused by the spreading effect of the ambiguous region of the terrestrial calibration curve between 459 and 312 cal BP. The corresponding spread of dates in the marine calibration curve is somewhat less than for charcoal and wood, as illustrated by shell dates for fort construction or use (Fig. 13).

To illustrate the spread of dates on the marine calibration curve, we included measured dates on samples which, although taken from fortifications, may stratigraphically antedate fort construction. Altogether, there are 89 ¹⁴C dates on shells. To simulate these, we took a uniform sample of dates at 2-yr intervals between 450 and 202 cal BP and found their corresponding true ¹⁴C dates. Using the true ¹⁴C dates, we generated a simulated set of measured dates assuming a standard error of 45 yr. The spread of the calibrated simulated dates matches the spread of the calibrated measured dates

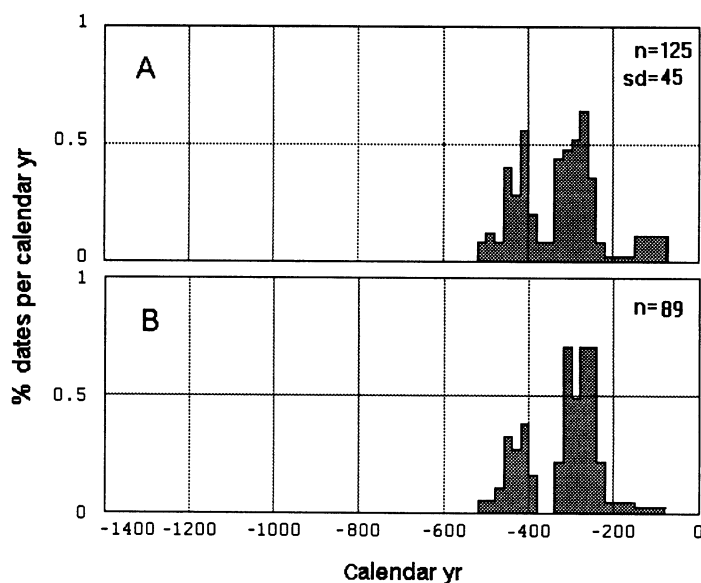


Fig. 13. Calibrated ^{14}C dates on marine shells for Maori fortifications compared with simulated ^{14}C dates. A. Calendar distribution of a simulated set of ^{14}C dates uniformly distributed at 2-yr intervals between 450 and 202 cal BP. B. Calendar distribution of calibrated ^{14}C dates on shells dating occupation of fortifications. We assume the start of simulated fort construction to be 450 cal BP, just before the slope of the marine calibration curve became gentle, and the end to be 202 cal BP. The standard error for the simulated dates (45 yr) is the mean value of the measured ^{14}C dates. The spread of the calibrated simulated dates closely matches the spread of calibrated measured dates and is explained by the spreading effect of counting errors illustrated by Figure 6.

(Fig. 13), indicating that the observed shell dates for fortifications could have been generated from samples no older than 450 cal BP. The difference between the oldest calibrated measured date for forts and the oldest true calendar date necessary to account for the spread of measured dates demonstrates the smaller spread on the marine calibration curve. For marine shell dates, the difference is *ca.* 70 yr; for charcoal and wood dates, *ca.* 180 yr.

Although some of the charcoal and wood samples for dating fortifications have inbuilt ages, and some of the shell samples may be stratigraphically older than defense construction, they indicate that the first appearance of forts is unlikely to be earlier than 450 cal BP, and may possibly be no older than 380 cal BP.

From the above, the first forts appear about the time the inferred trend of population growth (Fig. 9) begins to level off. This suggests an expected scenario: 1) settlement of a new land with abundant resources; 2) population explosion; 3) limitation by resources; and 4) eventual fortification to defend scarce resources.

The true ^{14}C distribution of archaeological dates is that which would be measured if their standard deviations were negligibly small. The observed ^{14}C distribution is the true ^{14}C distribution statistically mixed and spread by convolution with the normal error distribution (*i.e.*, the counting statistics). When the CSD effect is dealt with quantitatively by deconvolving the true ^{14}C distribution from the counting error distribution (a typical standard error for a New Zealand archaeological sam-

ple is 50 yr), the estimated date of settlement of New Zealand is likely to become somewhat later than 700 cal BP.

The CSD effect applies to all disciplines that use ¹⁴C dates and to all parts of the calibration curve that have wiggles or changes in slope. The effect is apparent in the peaks of the estimated pre-censal population graph for Hawaii that Dye and Komori (1993, Fig. 3) based on an annual frequency distribution for some 600 charcoal dates. These authors are correct to ignore the minor variations of their graph; now that we know the source of the variations, it may be appropriate to rework their data.

The CSD effect is accentuated for older dates because of generally larger standard errors. To obtain accurate distributions of calendar dates, the true ¹⁴C distribution is required. One should obtain the true ¹⁴C distribution from the observed ¹⁴C distribution by deconvolution from the counting error distribution, which reduces the spread of ¹⁴C dates and, when mapped through the calibration curve, evens out the troughs and peaks and shortens the tail of the calendar distributions. This applies whether the dates are archaeological, geological or the basis for the calibration curve itself. One can then obtain the true calendar distribution of dates from the true ¹⁴C distribution by using the calibration curve in the normal way. The CSD effect is present any time a non-linear transformation, combined with significant statistical spreading of observed data, is used to predict the value of a second variable. This is not necessarily restricted to ¹⁴C dating.

CONCLUSIONS

1. Inbuilt ages of old wood used for fires and sampled for ¹⁴C dating add to the distribution of archaeological dates a "tail", which may extend for several hundred years before the event being dated.
2. After excluding charcoal and wood likely to have inbuilt ages, the date of settlement of New Zealand indicated by dates on charcoal and wood is close to that indicated by dates on shells: *ca.* 700 cal BP.
3. The shape of the distribution of calibrated ¹⁴C dates is distorted by a CSD effect and displays spurious peaks and troughs, which are more extreme in the distribution of charcoal and wood dates than in the distribution of shell dates. After allowing for the CSD effect, we infer from the shell dates that the prehistoric population in New Zealand grew to a maximum *ca.* 400 cal BP and then leveled off.
4. The CSD effect increases the spread of calendar dates, enhances the possibility of date reversals, and causes some dates for events occurring within ambiguous regions to fall outside these regions. In general, the spread of dates on shells is less than the spread of dates on charcoal and wood. After taking the CSD effect into account, the first appearance of fortifications indicated by shell dates is unlikely to have been earlier than 450 cal BP, and as indicated by charcoal and wood dates, may have been no earlier than 380 cal BP.
5. The effects described in this paper show that many dates for an event are preferable to few dates, and where possible dates on both terrestrial and marine samples should be obtained. We are undertaking further research to reduce the spreading caused by the CSD effect and to refine the calibration of ¹⁴C dates.

ACKNOWLEDGMENTS

We thank Mr. Brian Sheppard, Science Manager, Science and Research Division, Department of Conservation, Wellington, for his outspoken support of the research covered in this paper. We are also grateful to Dr. Rodger Sparks, Rafter Radiocarbon Laboratory, Lower Hutt, for granting us access to the laboratory ¹⁴C database, and for useful discussion of the matters covered in this paper.

REFERENCES

- Anderson, A. J. 1991 The chronology of colonisation in New Zealand. *Antiquity* 65: 767–795.
- Anderson, A. J. and McFadgen, B. G. 1990 Prehistoric two-way voyaging between New Zealand and East Polynesia: Mayor Island obsidian on Raoul Island, and possible Raoul Island obsidian in New Zealand. *Archaeology in Oceania* 25: 24–37.
- Bird, C. F. M. and Frankel, D. 1991 Chronology and explanation in western Victoria and south-east South Australia. *Archaeology in Oceania* 26: 1–16.
- Brewis, A. A., Molloy, M. A. and Sutton, D. G. 1990 Modelling the prehistoric Maori population. *American Journal of Physical Anthropology* 81: 343–356.
- Davidson, J. M. 1984 *The Prehistory of New Zealand*. Auckland, Longman Paul: 270 p.
- Dye, T. and Komori, E. 1993 A pre-censal population history of Hawaii. *New Zealand Journal of Archaeology* 14: 113–128.
- Geyh, M. A. 1980 Holocene sea-level history: Case study of the statistical evaluation of ^{14}C dates. In Stuiver, M. and Kra, R. S., eds, Proceedings of the 10th International ^{14}C conference. *Radiocarbon* 22(3): 695–704.
- Green, R. C. 1967 Sources of New Zealand's East Polynesian culture: The evidence of a pearl shell lure shank. *Archaeology and Physical Anthropology in Oceania* 2: 81–90.
- Irwin, G. 1992 *The Prehistoric Exploration and Colonisation of the Pacific*. Cambridge, Cambridge University Press: 240 p.
- McFadgen, B. G. 1982 Dating New Zealand archaeology by radiocarbon. *New Zealand Journal of Science* 25: 379–392.
- 1994 Coastal stratigraphic evidence for human settlement. In Sutton, D. G., ed., *The Origins of the First New Zealanders*. Auckland, Auckland University Press: 195–207.
- McFadgen, B. G. and Manning, M. R. 1990 Calibrating New Zealand radiocarbon dates of marine shells. *Radiocarbon* 32(2): 229–232.
- Richards, T. H. and Rousseau, M. K. 1987 *Late Prehistoric Cultural Horizons on the Canadian Plateau*. Department of Archaeology Simon Fraser University Publication 16: 102 p.
- Simmons, D. R. 1976 *The Great New Zealand Myth: A Study of the Discovery and Origin Traditions of the Maori*. Wellington, Reed: 504 p.
- Snedecor, G. W. and Cochran, W. G. 1967 *Statistical Methods*. Ames, The Iowa State University Press: 593 p.
- Stolk, A., Hogervorst, K. and Berendsen, H. 1989 Correcting ^{14}C histograms for the non-linearity of the radiocarbon time scale. *Radiocarbon* 31(2): 169–178.
- Stuiver, M. and Braziunas, T. F. 1993 Modeling atmospheric ^{14}C influences and ^{14}C ages of marine samples to 10,000 BC. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 137–189.
- Stuiver, M. and Pearson, G. W. 1993 High-precision bidecadal calibration of the radiocarbon time scale, AD 1950–500 BC and 2500–6000 BC. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 1–23.
- Stuiver, M. and Polach, H. 1977 Discussion: Reporting of ^{14}C data. *Radiocarbon* 19(3): 355–363.
- Stuiver, M. and Reimer, P. J. 1989 Histograms obtained from computerized radiocarbon age calibration. In Long, A., Kra, R. S. and Srdoč, D., eds, Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 817–823.
- Stuiver, M. and Reimer, P. J. 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 215–229.
- Vogel, J. C., Fuls, A., Visser, E. and Becker, B. 1993 Pre-toria calibration curve for short-lived samples, 1930–3350 BC. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 73–85.

THE RAPID PREPARATION OF SEAWATER ΣCO_2 FOR RADIOCARBON ANALYSIS AT THE NATIONAL OCEAN SCIENCES AMS FACILITY

A. P. McNICHOL, G. A. JONES, D. L. HUTTON and A. R. GAGNON

Department of Geology and Geophysics, Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543 USA

and

R. M. KEY

Department of Geological and Geophysical Sciences, Princeton University
Princeton, New Jersey 08544 USA

ABSTRACT. We have established a laboratory for extracting ΣCO_2 from seawater samples for AMS analysis of the radio-carbon content. The seawater samples are collected at sea, poisoned and stored until analysis in the laboratory. Each sample is acidified; the inorganic carbon is stripped out as CO_2 with an inert carrier gas and then converted to graphite. We present results for Buzzards Bay surface H_2O and Na_2CO_3 standards that demonstrate we strip >98% of inorganic carbon from seawater. Stable isotope analyses are performed to better than 0.2‰, and the reproducibility of ^{14}C measurements on Buzzards Bay seawater is better than 13‰. Finally, we compare data from samples collected in 1991 to those collected in the 1970s and to large volume samples.

INTRODUCTION

Early studies demonstrating the viability of using accelerator mass spectrometry (AMS) to measure ^{14}C in seawater inorganic carbon (Bard *et al.* 1988; Kromer *et al.* 1987; Ostlund *et al.* 1987a; Schlosser *et al.* 1987) led to the inclusion of an AMS ^{14}C sampling program in the World Ocean Circulation Experiment (WOCE). One component of the WOCE Hydrographic Program (WHP), the collection of thousands of seawater samples for AMS ^{14}C analysis, was a driving force for the establishment of the National Ocean Sciences AMS (NOSAMS) facility at the Woods Hole Oceanographic Institution (WHOI). The WOCE program requires a precision of 5–10‰ for the AMS analysis of $\Delta^{14}\text{C}$ (Joyce, Corry and Stalcup 1991) in surface seawater samples and a precision of 3–4‰ for deepwater samples, *i.e.*, samples below *ca.* 1000 m.

Östlund *et al.* (1987a), Bard *et al.* (1987) and Kromer *et al.* (1987) made the first AMS measurements of seawater. In general, the methods used to strip CO_2 from an acidified seawater sample were either bubbling with a carrier gas (Bard *et al.* 1987; Ostlund *et al.* 1987a) or extraction with a vacuum source (Dörr and Münnich 1980). Bard *et al.* (1987) reported results with a standard deviation of 11‰, Kromer *et al.* (1987) reported a standard error of 5‰ and Ostlund *et al.* (1987a) reported a precision of 5–10‰.

Our laboratory was set up for the rapid preparation of inorganic carbon in seawater for analysis by AMS. In this paper, we describe in detail our method for extracting CO_2 from seawater, and we demonstrate our ability to accurately and reproducibly prepare seawater samples for AMS. We also present results from the analysis of local surface seawater and two WOCE ^{14}C AMS depth profiles.

METHODS

Seawater for all WOCE analyses is collected in pre-weighed 500-ml borosilicate glass bottles with high-quality ground-glass stoppers and poisoned according to a published protocol (McNichol and

Jones 1991). Dissolved inorganic carbon (ΣCO_2) is extracted as CO_2 gas from the samples on the vacuum line shown in Figure 1; the vacuum system consists of a molecular drag pump in tandem with a diaphragm pump. The samples are stripped in the bottles in which they are collected. Up to five samples can be attached to the line at one time. Samples to be analyzed are weighed and transferred to a glove bag where stripping probes are attached in an N_2 atmosphere (insert, Fig. 1). The bottles are then attached to Region I of the vacuum line, and the line is evacuated up to the valves on the stripping probe (Valves V1 and V2). Each sample is acidified by adding 4 ml of 85% H_3PO_4 by injection through a rubber septum. When the line has been evacuated, high-purity N_2 gas (99.99%) is added to Regions I, II and III to a pressure of *ca.* 0.8 atm. A cold bath at -80°C is placed on the trap in Region II and liquid nitrogen baths (-190°C) are placed on the loop traps in Region III. When the cold traps are in place and all the valves in the circulation loop are open, a recirculating pump (Parker Hannifan Metal Bellows MB-10) is turned on, forcing the carrier gas through the fritted end of the probe and producing a stream of fine bubbles throughout the seawater. Gaseous CO_2 partitions into the N_2 bubbles and is swept into the cold traps where it is frozen down. After 10 min, the pump is shut off, the N_2 carrier gas is slowly pumped away, the liquid nitrogen baths on the loop traps are replaced with -80°C cold baths and the CO_2 is collected in a calibrated volume (Region IV). The gas pressure is recorded and used to calculate the concentration of CO_2 (ΣCO_2) in each sample; the gas sample is then transferred to a storage manifold (Region V). Typical yields for seawater samples are *ca.* 1 mmol of CO_2 . While the sample is being quantified, the vacuum line is prepared for the next sample. The average analysis time is *ca.* 45 min.

After ten samples have been stripped, the storage manifolds are removed from the water line and attached to the graphite transfer line (Fig. 2) where the gas is split into aliquots for graphite target

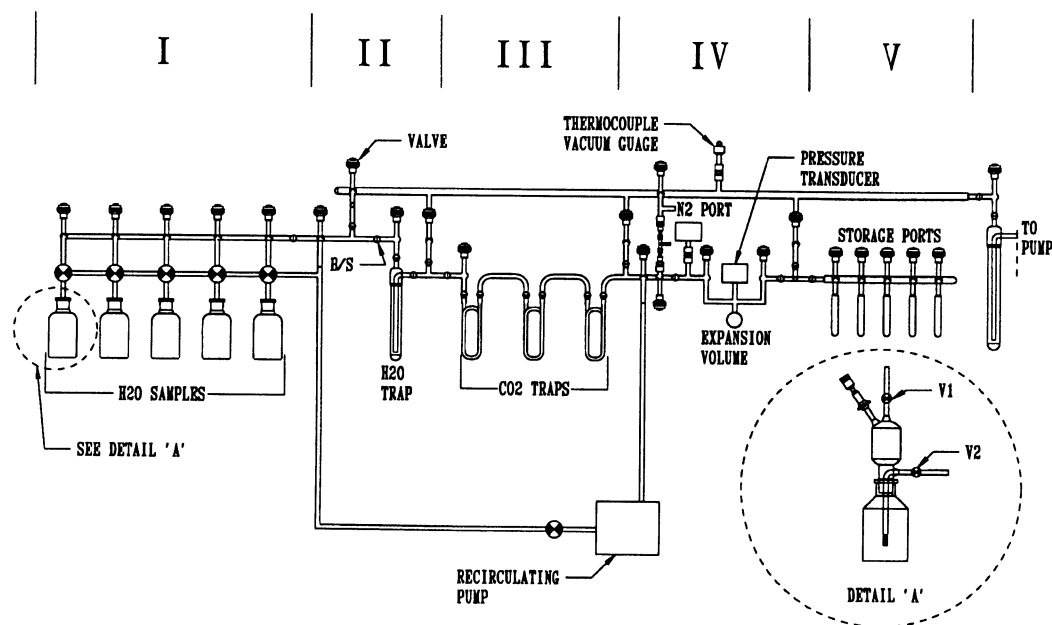


Fig. 1. Water stripping line and stripping probe (insert). Ball and socket O-ring joints (B/S) were added to facilitate dismantling and cleaning. The use of a glass system reduces the number of parts that must be replaced due to corrosion from salt water vapor. The stripping probe is designed to fit directly on bottles with a standard taper high-quality ground-glass joint. Valves V1 and V2 are integral parts of the stripping probe and are not part of the stripping line.

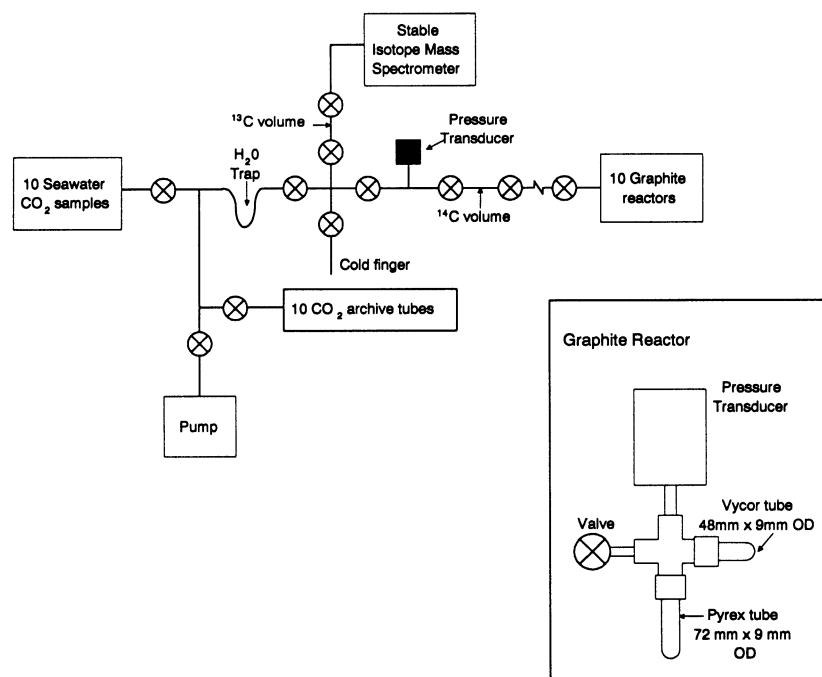


Fig. 2. Schematic diagram of graphite transfer line for seawater samples. A blowup of the reactor is shown in the insert. Sample manifolds are attached, and each sample is sequentially transferred to the cold finger. From the cold finger, splits of each sample are transferred to an isotope ratio mass spectrometer, to an archive tube and to a graphite reactor.

preparation (20%), stable isotope ratio analysis (10%) and archiving (70%). The graphite target preparation method used at NOSAMS has been described elsewhere (McNichol *et al.* 1992). Briefly, CO_2 is transferred to a reactor, where it is catalytically reduced to carbon filaments at high temperature (625°C) using H_2 gas as the reducing agent and Fe as the reduced metal catalyst; the reaction takes *ca.* 4 h. During 1992 and the first half of 1993, stable isotope analyses were performed on three different mass spectrometers—a VG Micromass 602E in the laboratory of Lloyd Keigwin (WHOI), a VG Prism in the Earth and Planetary Sciences Department at Harvard University and a VG Prism at our facility. Since June 1993, most stable isotope analyses for seawater samples are performed in the NOSAMS sample preparation lab on an in-line VG Optima mass spectrometer.

We use two types of samples as standards— Na_2CO_3 solutions and local surface seawater. We prepare our Na_2CO_3 standards in batches of 9–12 samples; Na_2CO_3 is dried overnight in a 250°C oven; *ca.* 424 mg are weighed accurately (± 0.01 mg) and quickly transferred to a 2-liter volumetric flask. Exposure to air is minimized because Na_2CO_3 absorbs water from air and forms a basic solution that absorbs CO_2 from the surrounding air. This is more likely to have an effect on the isotopic measurements than on the concentration measurements. Distilled water is degassed by bubbling with N_2 for at least 1 h, added to the volumetric flask and the solution is transferred to 500-ml sample bottles in an N_2 -filled glove bag. We have found that degassing reduces the inorganic carbon concentration of distilled H_2O by *ca.* 85% to a level where it contributes only 0.3% of the carbon in our standards. Local surface seawater (0–1 m depth) from Buzzards Bay, Massachusetts is collected in 20-liter carboys and transported to the sample preparation laboratory, where it is transferred to 500-ml sample flasks, poisoned with 100 μl saturated HgCl_2 solution, capped and stored until processing. After

preparation, both the Na_2CO_3 and Buzzards Bay seawater standards are handled in exactly in the same manner as the samples. Our standard procedure is to measure 1 Na_2CO_3 and 1 Buzzards Bay seawater standard after each suite of 16 WOCE samples.

RESULTS

From January 1992 to July 1993, we stripped over 850 samples and standards. Figure 3 shows concentration and stable isotope results for the Na_2CO_3 and Buzzards Bay samples. The Na_2CO_3 graph comprises data from many different batches and the Buzzards Bay graph displays results from four sample collections. To determine our analysis precision, we averaged the results from each data set shown in Figure 3, and rejected any point that deviated from the average by >3 standard deviations. Using the selected data, we calculate that for the Na_2CO_3 standards, we extracted $100.9 \pm 2.2\%$ of the inorganic carbon added to the standards and measured an average $\delta^{13}\text{C}$ of $-1.46 \pm 0.18\text{‰}$ (Table 1). To study the Buzzards Bay data, we separated the samples into batches to remove seasonal and interannual variability. From the two batches for which we have enough data (2/92 and 8/92), we measured the concentration to at least $\pm 0.04 \text{ mmol kg}^{-1}$ and $\delta^{13}\text{C}$ to better than $\pm 0.15\text{‰}$ (Table 1). The precision observed in the August 1992 samples is greatly improved from that observed in the February 1992 samples. We believe this is due to the steady improvement of our procedures.

TABLE 1. Concentration and isotope data for Buzzards Bay and Na_2CO_3 standards. Results presented in this table use the data remaining after applying the rejection criteria discussed in the text. Values in parentheses represent 1 σ error; the range is reported when there are only two analyses. Percent yield is the quantity $[(\text{mmol kg}^{-1} \text{ measured})/(\text{mmol kg}^{-1} \text{ prepared})] \times 100$.

Sample	ΣCO_2 (mmol kg^{-1})	n	$\delta^{13}\text{C}$ (‰)	n	$\Delta^{14}\text{C}$ ‰	n
<i>Buzzards Bay</i>						
2/91	1.953 (0.044)	3	1.125 (0.211)	2	61.5	1
2/92	1.981 (0.034)	36	1.183 (0.146)	31	65.4 (12.8)	13
8/92	1.898 (0.040)	16	1.244 (0.062)	14	69.4 (12.1)	4
6/93	1.782 (0.159)	3	1.318 (0.030)	3		
<i>Na_2CO_3</i>						
	%Yield	n	$\delta^{13}\text{C}$	n		
	100.91 (2.20)	61	-1.457 (0.180)	52		

Some of the Buzzards Bay samples were used in a sample storage experiment; bottles collected in February 1991 were stripped and analyzed over a 500-day period (Fig. 4). Within the error of the analyses, it is not possible to distinguish the sample analyzed almost 1.5 yr after the date of collection from those analyzed immediately after collection.

We have analyzed Buzzards Bay samples collected in February 1991, February 1992 and August 1992 for $\Delta^{14}\text{C}$ (Table 1, Fig. 4). Samples collected in February 1992 were analyzed 13 times using AMS between March 1992 and March 1993. For this period, we calculate a weighted average $\Delta^{14}\text{C}$ of 65.4‰ with a standard deviation of 12.8‰ . Reported $\Delta^{14}\text{C}$ values have been corrected for ^{13}C fractionation and adjusted to 1950 according to Stuiver and Polach (1977). At present, we observe no significant seasonal or annual differences. Although this particular set of samples does not reflect it, in recent months, our method has produced results demonstrating a precision of $\pm 3\text{‰}$ for individual AMS analyses (Jones *et al.* 1994).

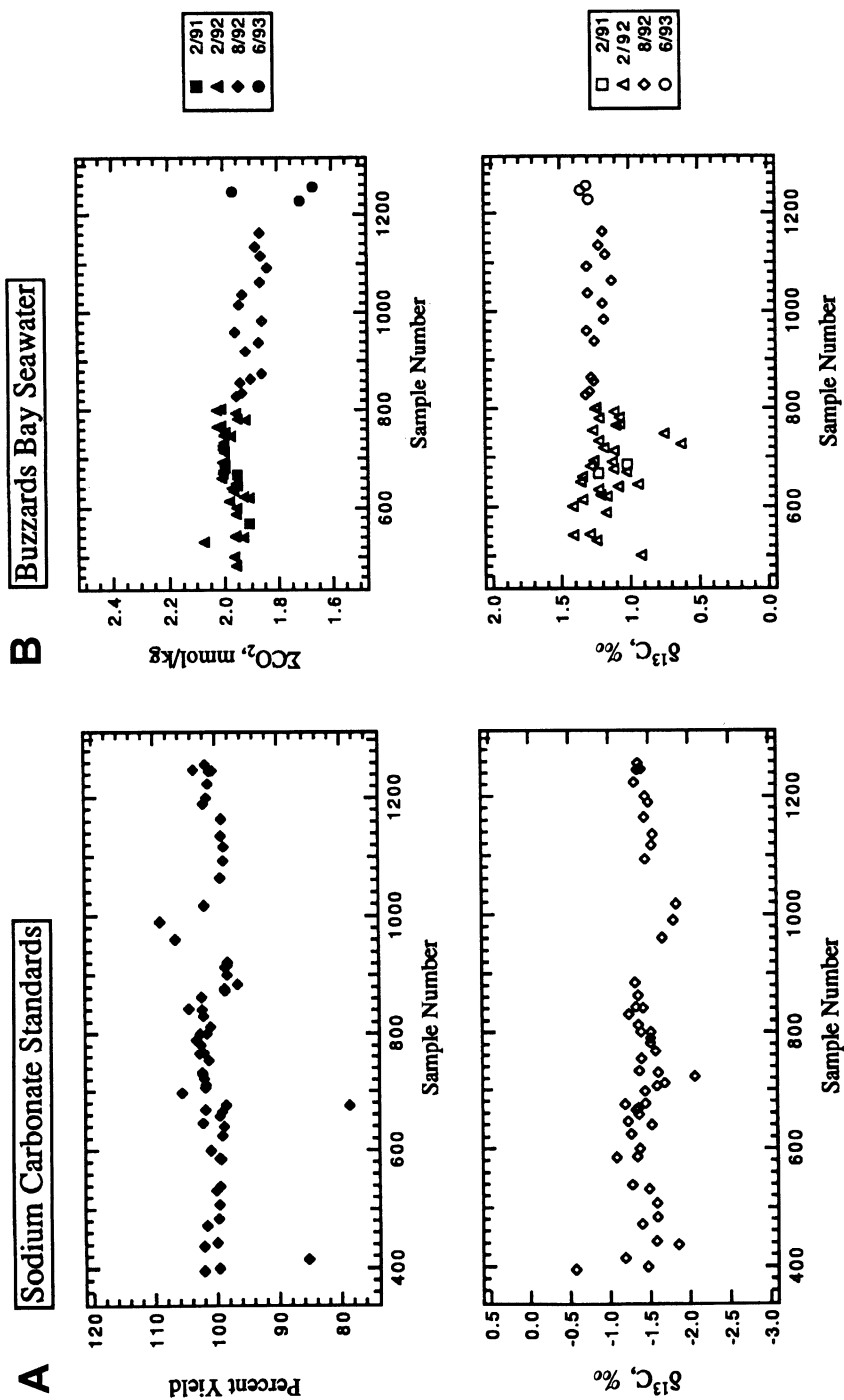


Fig. 3. Concentration and stable isotope results from (A) Na_2CO_3 and (B) Buzzards Bay standards. Sample number refers to the order in which the standards were stripped; all were stripped between January 1, 1992 and June 31, 1993. The dates in the key (B) refer to the month and year in which the batch of seawater was collected.

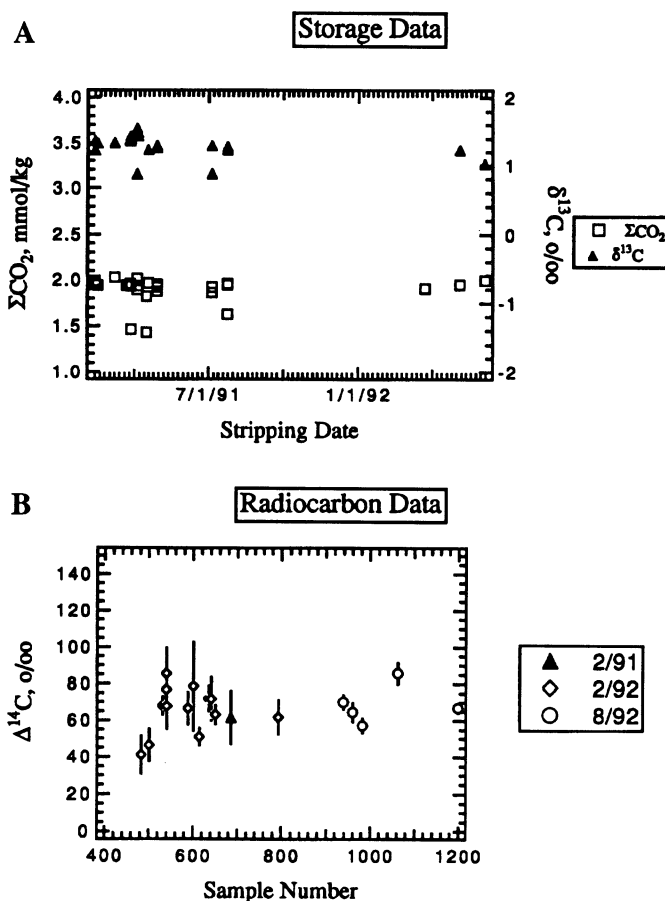


Fig. 4. (A) Storage and (B) radiocarbon data from Buzzards Bay seawater. Error bars shown in (B) represent the one-sigma error from the AMS analysis.

We have analyzed > 800 WOCE seawater samples and present ^{14}C data from two stations. The samples were collected during Cruise CGC-91 along WOCE line P16N. We present data from Stations 12 (35°N, 152°W) and 48 (42°N, 152°W) (site locations are shown in Fig. 5). In Figure 6, the WOCE data are compared to those from nearby GEOSECS stations and from samples measured using the β -decay counting technique. The WOCE samples were collected in March 1991, stripped and converted to graphite between January 1992 and July 1992, and analyzed on the AMS between September 1992 and December 1992.

DISCUSSION

To produce useful data for the WHP, we must provide results with an overall precision of ± 5 –10‰ in surface seawater and ± 3 –4‰ in deepwaters. These requirements are driven by the magnitude of the ^{14}C gradients observed in the different layers of the ocean. We have demonstrated through the analysis of standards that we can reproducibly and accurately strip CO_2 from seawater for stable and ^{14}C isotopic analysis. To achieve a precision of ± 3 ‰ in our ^{14}C measurements, we must know the $\delta^{13}\text{C}$ of the sample to better than 1‰, so that the stable isotope fractionation correction does not

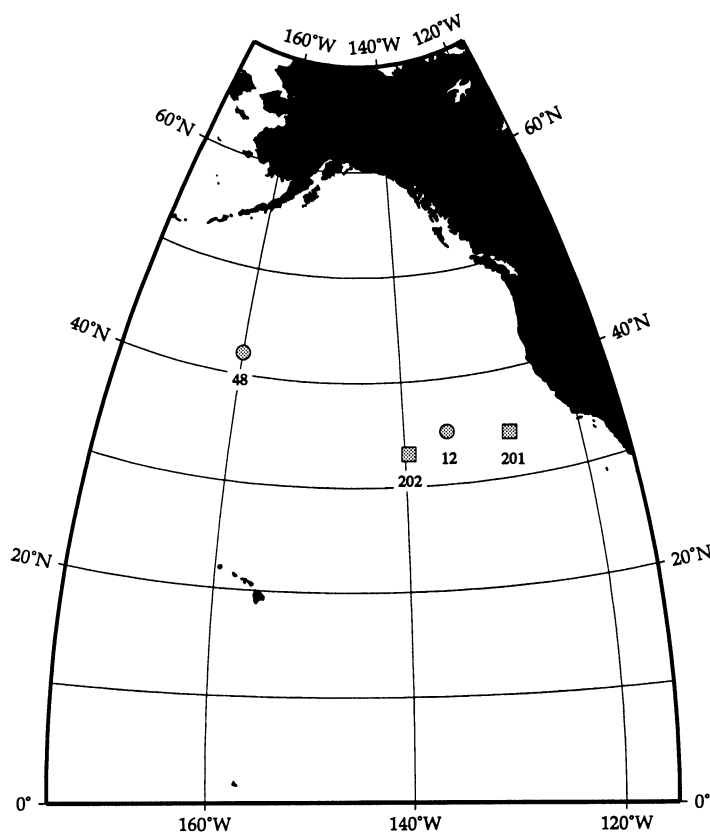


Fig. 5. Sample collection sites in North Pacific Ocean. Stations 12 and 48 were occupied in 1991 as part of the WHP, and Stations 201 and 202 were occupied in 1973 as part of the GEOSECS Program.

introduce a significant error to our final number. We have shown that we know the $\delta^{13}\text{C}$ of the CO_2 gas stripped from seawater to much better than this ($\pm 0.06\text{--}0.18\text{‰}$), and we make the assumption that reducing CO_2 to graphite does not greatly increase this error. Fractionation that is constant for all samples and standards will not compromise the overall precision as long as the standard deviation is $< 1\text{‰}$. We reported previously that our graphitization process introduced a stable isotopic fractionation of $ca. 1.2 \pm 0.3\text{‰}$ that was constant for a wide range of $\delta^{13}\text{C}$ values (McNichol *et al.* 1992). More recent results show that, because of improvements in our techniques, no fractionation is introduced during the graphitization process (Osborne *et al.* 1994).

We measure the inorganic carbon concentration as an internal laboratory quality check. Our average measured concentration for Buzzards Bay seawater in February 1991 ($1.95 \pm 0.04 \text{ mmol kg}^{-1}$) agrees with the measurement on three samples from the same batch using a coulometric method (Goyet and Hacker 1992) as an independent measure ($1.938 \pm 0.008 \text{ mmol kg}^{-1}$). We do not attempt to make a precise measurement of this parameter, and we report an error of $\pm 2\%$. One potential source of error in our concentration measurement is the lack of precise temperature control during our manometric measurements. For example, if the temperature of the glass expansion volume is just 3°C hotter or colder than the air surrounding the thermometer we use to read the ambient tem-

perature, we will introduce an error of ~1%. Other potential sources of error we have identified are listed in Table 2. Most of these sources affect only the concentration measurement and not the isotopic ratios.

TABLE 2. Potential Sources of Error in Seawater Measurements	
Error	Parameter affected
Exclusion of weight of stopcock grease in “empty” bottle weight	ΣCO_2
Chipping of glass bottles during sampling/processing	ΣCO_2
Small temperature fluctuation during manometric measurements	ΣCO_2
Multiple gas transfers	$\delta^{13}\text{C}$, $\Delta^{14}\text{C}$

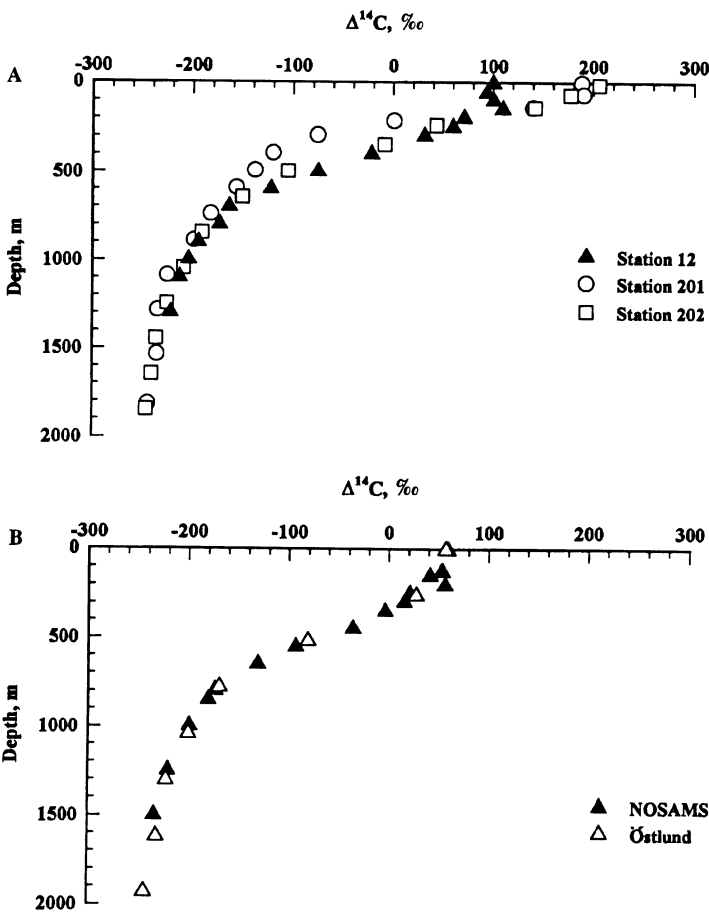


Fig. 6. A. NOSAMS data from Stations 12 (▲) collected in 1991, GEOSECS data from Stations 201 (○) and Station 202 (□) collected in 1973 (Östlund *et al.* 1987); B. comparison of NOSAMS small volume AMS results (▲) with RSMAS Tritium Laboratory large volume counting results (△) (Östlund 1992) from Station 48 collected in 1991.

The results of the storage experiment indicate that samples can be stored for prolonged periods without jeopardizing their integrity. This is important for the analysis of WOCE samples, because investigators in the WOCE program are collecting seawater samples at a much faster rate than they can be analyzed, and samples remain in their collection boxes for prolonged periods. Although we strip the samples as quickly as possible, often well before they are analyzed on the AMS, some samples can be stored for as long as 2–2.5 yr before analysis. Therefore, it was essential for us to demonstrate that samples can be stored for long periods of time without undergoing significant changes in concentration and/or isotopic composition.

The comparison of our data to those collected from similar locations during the GEOSECS program in 1973 (Östlund *et al.* 1987b) and to those collected in large-volume Gerard barrels provides further confirmation of the validity of our results (Fig. 6). At Station 12 (Fig. 6A), we observe that, below 1000 m within the error of the measurements, our analyses agree with the GEOSECS data, but that above this depth, the results differ. In the surface waters, results from the water samples between 0- and 200-m depth reflect the decrease in atmospheric ^{14}C concentration from 1973 to 1991 and, between 200 and 800 m, the results reflect the penetration of the “bomb signal” deeper into the water column. Below 1000 m, we do not expect the seawater $\Delta^{14}\text{C}$ to have changed significantly over the 20-yr period. At Station 48 (Fig. 6B), our data are compared to those reported by Östlund (1992) from 250-liter samples. We observe excellent agreement; the average reported error for the large-volume samples is $\pm 2\text{‰}$ and, for the AMS samples, $\pm 3\text{--}7\text{‰}$. This comparison shows that results from the two methods are indistinguishable and that AMS will provide a viable substitute for large-volume oceanographic sampling.

CONCLUSION

We have successfully established a laboratory capable of rapidly analyzing large numbers of seawater samples for AMS ^{14}C analysis. We have analyzed > 800 seawater samples since 1992 with a precision and accuracy that meet the demands of the WHP, and anticipate analyzing at least 2000 samples per year in the future. With the anticipated completion of our laboratory automation this year, increased throughput will not present a problem, and we should easily meet the demands of the U.S. WOCE ^{14}C program over the next five years.

ACKNOWLEDGMENTS

We are grateful to Bruno Marino for running many of our $\delta^{13}\text{C}$ analyses at the Earth and Planetary Sciences Department, Harvard University. We thank Liz Osborne and Greg Cohen for providing technical assistance; the AMS analyses are never possible without the contributions of Robert Schneider and Karl von Reden. This work was supported by the following grants from the National Science Foundation: OCE-8802509 and OE-9301015. This is WHOI contribution number 8580.

REFERENCES

- Bard, E., Arnold, M., Maurice, P. and Duplessy, J.-C. 1987 Measurements of bomb radiocarbon in the ocean by means of accelerator mass spectrometry: Technical aspects. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., *Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. Nuclear Instruments and Methods in Physics Research B29*: 297–301.
- Bard, E., Arnold, M., Östlund, H. G., Maurice, P., Monfray, P. and Duplessy, J.-C. 1988 Penetration of bomb radiocarbon in the tropical Indian Ocean measured by means of accelerator mass spectrometry. *Earth and Planetary Science Letters* 87: 379–389.
- Dörr, H. and Münnich, K. O. 1980 Carbon-14 and carbon-13 in soil CO_2 . In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 10th International ^{14}C Conference. Radiocarbon* 22(3): 909–918.
- Goyet, D. and Hacker, S. D. 1992 Procedure for calibration.

- tion of a coulometric system used for total inorganic carbon measurements of seawater. *Marine Chemistry* 38: 37–51.
- Jones, G. A., Gagnon, A. R., Schneider, R. J., von Reden, K. F. and McNichol, A. P. 1994 High-precision AMS radiocarbon measurements of central Arctic Ocean seawaters. *Nuclear Instruments and Methods in Physics Research* B92: 426–430.
- Joyce, T., Corry, C. and Stalcup, M., eds. 1991 *WOCE Operations Manual*. Part 3.1.2, *Requirements for WHP Data Reporting*. Woods Hole, Massachusetts, WHPO Publication 90-1: 71 p.
- Kromer, B., Pfeleiderer, C., Schlosser, P., Levin, I., Münich, K. O., Bonani, G., Suter, M. and Wölfi, W. 1987 AMS ^{14}C measurements of small volume oceanic water samples: Experimentation procedure and comparison with low-level counting technique. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., *Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. Nuclear Instruments and Methods in Physics Research* B29: 302–305.
- McNichol, A. P., Gagnon, A. R., Jones, G. A. and Osborne, E. A. 1992 Illumination of a black box: Analysis of gas composition during graphite target preparation. In Long, A. and Kra, R. S., eds., *Proceedings of the 14th International ^{14}C Conference. Radiocarbon* 34(3): 321–329.
- McNichol, A. P. and Jones, G. A. 1991 Measuring ^{14}C in seawater ΣCO_2 by accelerator mass spectrometry, WHP operations and methods. In Joyce, T., Corry, C. and Stalcup, M., eds. 1991 *WOCE Operations Manual*. Part 3.1.2, *Requirements for WHP Data Reporting*. Woods Hole, Massachusetts, WHPO Publication 90-1: 71 p.
- Osborne, E. A., McNichol, A. P., Gagnon, A. R., Hutton, D. L. and Jones, G. A. 1994 Internal and external checks in the NOSAMS Facility Sample Preparation Laboratory for target quality and homogeneity. *Nuclear Instruments and Methods in Physics Research* B92: 158–161.
- Östlund, H. G. 1992 Discoverer CGC91 Cruise: Radiocarbon result. Tritium Laboratory Data Release. Miami, Florida, RSMAS, #92-15.
- Östlund, H. G., Craig, H., Broecker, W. S and Spencer, D. 1987 *GEOSECS Atlantic, Pacific and Indian Ocean Expeditions*. Vol. 7. *Shorebased Data and Graphics*. Washington, D.C., National Science Foundation: 200 p.
- Östlund, H. G., Possnert, G. and Swift, J. H. 1987 Ventilation rate of the deep Arctic Ocean from carbon 14 data. *Journal of Geophysical Research* 93: 3769–3777.
- Schlosser, P., Pfeleiderer, C., Kromer, B., Levin, I., Münich, K. O., Bonani, G., Suter, M. and Wölfi, W. 1987 Measurement of small volume oceanic ^{14}C samples by accelerator mass spectrometry. *Radiocarbon* 29(3): 347–352.
- Stuiver, M. and Polach, H. A. 1977 Discussion: Reporting of ^{14}C data. *Radiocarbon* 19(3): 355–363.

AMS ^{14}C AGE DETERMINATIONS OF TISSUE, BONE AND GRASS SAMPLES FROM THE ÖTZTAL ICE MAN

GEORGES BONANI,¹ SUSAN D. IVY,^{1,2} IRENA HAJDAS,^{1,3} THOMAS R. NIKLAUS and MARTIN SUTER

ABSTRACT. ^{14}C ages of samples from the Ötztal Ice Man, found on the Hauslabjoch in the Tyrolean Alps in September 1991, were determined using accelerator mass spectrometry (AMS). Uncalibrated ^{14}C ages of 4555 ± 34 BP, 4560 ± 65 BP and 4535 ± 60 BP were measured on tissue (mean of four samples), bone and grass, respectively, from the Ice Man. The mean of all of our measurements is 4550 ± 27 BP.

INTRODUCTION

In September 1991, a mummified corpse was found in a small rock depression on the Hauslabjoch, in the Ötztaler Alps (part of the Similaun Massiv), South Tyrol, Italy. Although the associated artifacts, including a copper axe, suggested a Late Stone Age origin, it was imperative to determine an absolute age for the Ice Man himself. Because the preciousness of the find dictated using the smallest possible amount of material for dating, ^{14}C dating by accelerator mass spectrometry (AMS) was the only option.

AMS measurements were performed independently at both the Zurich and Oxford AMS facilities (Bonani *et al.* 1992a). We report here in greater detail the specific procedures we used to prepare the Ice Man tissue and bone samples, as well as the small pieces of grass that were found in the bottle with the ice man tissue, and we supply the previously unreported grass age.

METHODS

We received samples from the Ice Man, stored in a glass jar, in November 1991. The sample material was first checked for contaminants by examination under a binocular microscope. At this time, the entrained pieces of grass were noted and separated from the skin and muscle tissue. For the Ice Man tissue sample, two pieces of what appeared to be skin were chosen from the bulk sample material. Because this material is similar to animal-skin parchment, which can easily dissolve (especially at high pH), we had to attenuate the normal acid-base-acid (ABA) treatment used to clean samples (*cf.* Bonani *et al.* 1992b). We reduced both the time for each step and the strength of the solutions with respect to those we usually use.

The samples were weighed, put into glass beakers with distilled water, and placed in an ultrasonic bath for 15 min. As a control, sample 8345.1a was left overnight in a 60°C oven to dry, without further treatment. The other samples were first rinsed and submerged in 0.2 M HCl (*ca.* 50% the strength we usually use) for 15–60 min, depending on the appearance of the material during treatment. After rinsing 3 times with distilled water, they were left for 15 min in water, which was then checked for pH=7. We used 0.05 M NaOH for the next pretreatment step, followed again by rinsing. The first acid step should remove carbonate contamination, whereas the base step leaches soluble humic substances. A final acid rinse ensures that no atmospheric CO_2 remains. The final soaking in distilled water and check of the pH preceded oven-drying the sample at 60°C . Weight loss due to pretreatment was often >50%. The grass sample was treated both ultrasonically and by the ABA

¹Institut für Teilchenphysik, ETH-Hönggerberg, CH-8093 Zürich, Switzerland

²Ingenieurgeologie, ETH-Hönggerberg, CH-8093 Zürich, Switzerland

³EAWAG, Überlandstrasse 133, CH-8600 Dübendorf, Switzerland

procedure. Bone collagen was extracted from the bone samples by hydrolyzing the bone apatite with HCl (2 M). The remaining bone collagen was neutralized with water, oven-dried and then treated the same as the other samples.

After weighing, the samples were placed in pre-cooked (950°C) high-purity SiO₂ tubes with wire-form CuO and silver wire. The tubes were evacuated and sealed, then placed in a muffle furnace at 950°C where the sample material was oxidized to CO₂. The resulting CO₂ was reduced to graphite on cobalt in the presence of hydrogen (Vogel *et al.* 1984; Vogel, Southon and Nelson 1987) in a steel extraction line. For each sample, a volume equivalent to *ca.* 2 mg of carbon was reduced to graphite. The graphite-cobalt mixture from each sample was pressed onto disk-shaped copper targets for introduction to the ion source.

The graphite targets made from the tissue, bone collagen and grass samples were measured together with appropriate standards made from Oxalic Acid I and ANU Sucrose, and with blanks made from geological graphite and coal. ¹⁴C/¹²C and ¹³C/¹²C isotopic ratios for each target are measured quasi-simultaneously (Bonani *et al.* 1987). Details of the ¹⁴C measurement procedures at the ETH/PSI accelerator facility can be found in Suter *et al.* (1984) and Wölfli (1987).

RESULTS AND DISCUSSION

Table 1 lists the conventional ¹⁴C ages for the tissue, bone and grass samples. Each measurement was calculated using the procedures suggested by Stuiver and Polach (1977) with normalization to δ¹³C = -25‰, and are reported accordingly in years BP (years before 1950). The errors listed, which are at the 1 σ level, include the statistical (counting) error, the scatter of the standards and blanks, and the uncertainty in the δ¹³C determination.

TABLE 1. Sample Information, Conventional ¹⁴C Ages and δ¹³C Values

Lab no.	Sample material	¹⁴ C age (yr BP)	δ ¹³ C (‰)	Sample size (mg)
ETH-8345.1a	Tissue	4605 ± 65	-23.6 ± 1.0	16.5
ETH-8345.1b	Tissue	4500 ± 70	-25.6 ± 1.3	5.7
ETH-8345.1	Tissue	4585 ± 70	-22.9 ± 1.2	10.2
ETH-8345.2	Tissue	4515 ± 70	-23.9 ± 1.6	7.7
ETH-8342	Bone	4560 ± 65	-27.9 ± 1.0	13.5
ETH-8345.3	Grass	4535 ± 60	-25.4 ± 0.9	1.5

From the data in Table 1, we determined weighted averages (Table 2) for the measurements of the four tissue samples and for all of the measurements.

TABLE 2. Weighted Averages Calculated for the Conventional ¹⁴C Ages

Lab no.	Sample(s) treated	¹⁴ C age (yr BP)	χ ²
ETH-8345.1-2	Tissue	4555 ± 34	0.57
ETH-8342, -8345	Tissue, bone, grass	4550 ± 27	0.36

Within the 1 σ error, no age differences could be discerned among grass, tissue and bone samples. Similarly, we observed no differences in ages between subsamples that received different cleaning methods. Specifically, from a single piece of tissue, one subsample was cleaned only ultrasonically (ETH-8345.1a), whereas two others were given complete precleaning treatment (ETH-8345.1 and -8345.1b). The second piece of tissue was treated with both ultrasonic and chemical procedures

(ETH-8345.2). The χ^2 values (Table 2) show that the weighted average can be used to determine the age of the Ice Man.

Figure 1 shows the results of calibrating (Niklaus *et al.* 1992) the conventional ¹⁴C age for the Ice Man to the calendar age. The upper half of the figure shows the non-linear relation between the conventional ¹⁴C age and the calendar age, which is based on high-precision ¹⁴C measurements on tree rings (Pearson and Stuiver 1993; Stuiver and Pearson 1993). The three horizontal lines indicate the measured conventional ¹⁴C age with a $\pm 1 \sigma$ error band. The histogram in the lower part of the figure illustrates the probability density function for the calibrated age ranges for the Ice Man tissue samples (in 10-yr intervals). The black-filled regions indicate the 1σ area, which corresponds to the

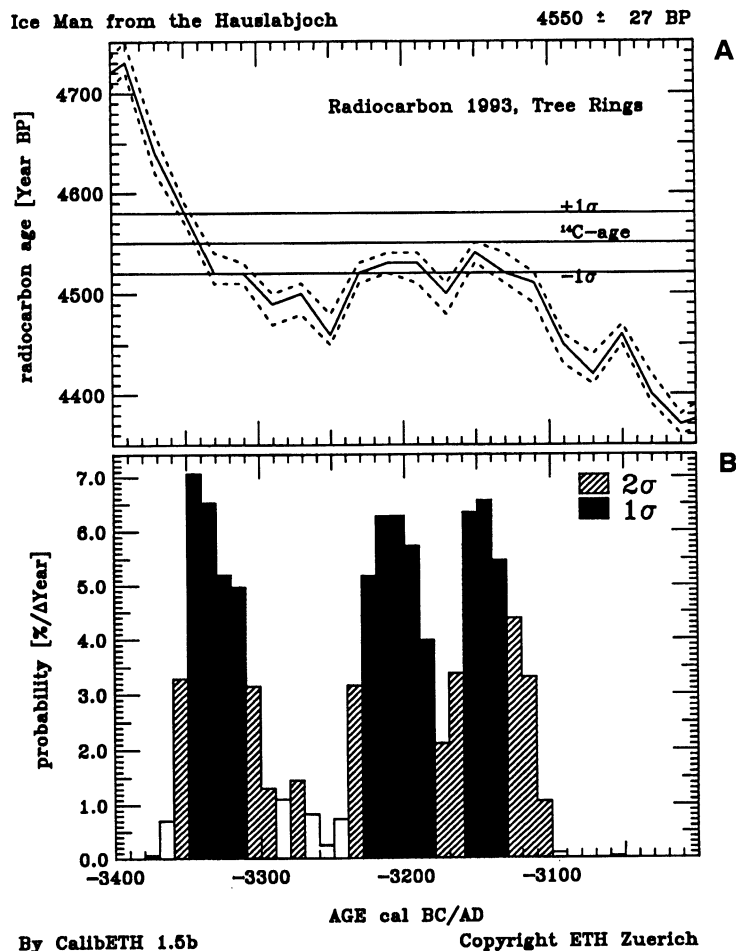


Fig. 1. A. The non-linear relation between the conventional ¹⁴C age and the calendar age for the Ice Man. The three horizontal lines mark the conventional ¹⁴C age with the corresponding 1σ standard deviation (4550 ± 27 BP). ---- = the $\pm 1 \sigma$ error band of the calibration curve. B. The probability density function resulting from the calibration of the conventional ¹⁴C age. Probability density is displayed as a histogram with a bar width of 10 yr. ■ = 1σ area (68% probability that the true age lies within this region); ▨ = 2σ region (95% probability). □ = area within which there is a 5% probability that the true age lies.

intervals within which the calendar age lies in a 68% probability. Doubling the error from 1–2 σ extends the intervals of probable calendar ages, so that with a 95% probability, the actual age of the Ice Man lies somewhere within the solid black and hatched areas.

Because of the trend of the calibration curve (Fig. 1), calibrating the conventional ^{14}C age 4550 ± 27 BP, yields the following ranges and percentages of total area within the 2 σ confidence level:

3359–3294 BC	33%
3277–3268 BC	1%
3239–3105 BC	66%.

Thus, with 66% probability, the Ice Man died between 3239 and 3105 BC. A 33% probability exists that he died between 3359 and 3294 BC, and a 1% chance that he died between 3277 and 3268 BC. Thus, the Ice Man lived during the Late Neolithic, between 3359 and 3105 BC.

ACKNOWLEDGMENTS

We thank Nora Steiner for help in sample preparation, and our tandem crew. This project was partially supported by the Swiss National Science Foundation.

REFERENCES

- Bonani, G., Beer, J., Hofmann, H.-J., Synal, H.-A., Wölfli, W., Pfeleiderer, C., Kromer, B., Junghaus, C. and Münnich, K. O. 1987 Fractionation, precision and accuracy in ^{14}C and ^{13}C measurements. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B29: 87–90.
- Bonani, G., Ivy, S. D., Niklaus, T. R., Suter, M., Housley, R. A., Bronk, C. R., van Klinken, G. J. and Hedges, R. E. M. 1992a Altersbestimmung von Milligrammproben der Ötztaler Gletscherleiche mit der Beschleuniger-massenspektrometrie-Methode (AMS). Report of the 1992 International Symposium in Innsbruck, Publications of the University of Innsbruck 187. *Der Man im Eis*. 1: 108–116.
- Bonani, G., Ivy, S. D., Wölfli, W., Broshi, M., Carmi, I. and Strugnell, J. 1992b Radiocarbon dating of fourteen Dead Sea Scrolls. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 843–849.
- Niklaus, Th. R., Bonani, G., Simonius, M., Suter, M. and Wölfli, W. 1992 CalibETH: An interactive computer program for the calibration of radiocarbon dates. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 483–492.
- Pearson, G. W. and Stuiver, M. 1993 High-precision bidecadal calibration of the radiocarbon time scale, 500–2500 BC. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 25–33.
- Stuiver, M. and Pearson, G. W. 1993 High-precision bidecadal calibration of the radiocarbon time scale, AD 1950–500 BC and 2500–6000 BC. In Stuiver, M., Long, A. and Kra, R. S., eds., Calibration 1993. *Radiocarbon* 35(1): 1–23.
- Stuiver, M. and Polach, H. A. 1977 Discussion: Reporting of ^{14}C data. *Radiocarbon* 19(3): 355–363.
- Suter, M., Balzer, R., Bonani, G., Hofmann, H. J., Morenzoni, E., Nessi, M., Wölfli, W., Andree, M., Beer, J. and Oeschger, H. 1984 Precision measurements of ^{14}C in AMS—some results and prospects. In Wölfli, W., Polach, H. A. and Anderson, H. H., eds., Proceedings of the 3rd International Symposium on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B5: 117–122.
- Vogel, J. S., Southon, J. R. and Nelson, D. E. 1987 Catalyst and binder effects in the use of filamentous graphite for AMS. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B29: 50–56.
- Vogel, J. S., Southon, J. R., Nelson, D. E. and Brown, T. A. 1984 Performance of catalytically condensed carbon for use in accelerator mass spectrometry. In Wölfli, W., Polach, H. A. and Anderson, H. H., eds., Proceedings of the 3rd International Symposium on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B5: 289–293.
- Wölfli, W. 1987 Advances in accelerator mass spectrometry. In Gove, H. E., Litherland, A. E. and Elmore, D., eds., Proceedings of the 4th International Conference on Accelerator Mass Spectrometry. *Nuclear Instruments and Methods in Physics Research* B29: 1–13.

PHYSICAL RESEARCH LABORATORY (CHEMISTRY) RADIOCARBON DATE LIST I

RAVI BHUSHAN, SUPRIYA CHAKRABORTY and SETH KRISHNASWAMI

Chemistry Laboratory, Physical Research Laboratory, Ahmedabad 380 009 India

INTRODUCTION

We present here radiocarbon dates obtained using a liquid scintillation system installed at the Physical Research Laboratory (PRL), which has been in operation for the past three years for ^{14}C measurements of oceanographic and geochemical samples from India.

We follow the procedure of Noakes *et al.* (1965) to synthesize benzene from the samples. This involves four major steps: 1) liberation of CO_2 from the samples by either dry combustion or hydrolysis; 2) conversion of CO_2 to Li_2C_2 at $\sim 700^\circ\text{C}$; 3) hydrolysis of Li_2C_2 to acetylene; and 4) trimerization of acetylene to C_6H_6 on activated alumina-coated vanadium catalyst. The sample benzene (~ 1.5 – 2.5 g) is transferred to a 7-ml low-potassium glass vial, made to 3 ml by weight (2.637 g) by adding scintillation-grade dead benzene. To this we add 0.5 ml of scintillation cocktail [42 g liter $^{-1}$ PPO + 0.7 g liter $^{-1}$ POPOP in benzene]. The benzene samples are counted using a Packard Tri-Carb® 2250CA liquid scintillation spectrometer in low-level mode. To reduce the background further, we use a Pico-XL™ plastic vial holder to surround the glass vial containing the sample benzene (Noakes and Valenta 1989). The samples are generally counted for 30 cycles of 100 min each.

Figure 1 shows the background count rate in the 11–98 keV region as determined by counting benzene synthesized from Makrana marble belonging to the Precambrian Railo formation in Rajasthan, India. Most of the marble blank count rates center around a value of 1.15 cpm. The mean count rate of marble blanks (excluding the four runs that had count rates in the range of 1.37–1.58 cpm, circled in Fig. 1) is $1.154 \pm .009$ cpm. This count rate is used as background in our calculation. Also given in Figure 1 are count rates for scintillation-grade benzene, anthracite and IAEA ^{14}C quality assurance material C-1. All these samples also yield count rates that are indistinguishable from the marble blank within errors.

The mean count rate of NBS oxalic acid standard batch SRM-4990C (OX-II) during 1991–1993 is $27.911 \pm .070$ cpm for 3 ml benzene. This yields a counting efficiency of 63% in the 11–98 keV region. We calculated $\Delta^{14}\text{C}$ values following Stuiver and Polach (1977). The $\delta^{13}\text{C}$ of some of the CO_2 samples was measured in our laboratory. For corals and tree rings the $\Delta^{14}\text{C}$ values are corrected for decay to the year of growth. Age calculations are based on ^{14}C half-life of 5730 ± 40 yr.

As an intercalibration exercise, we measured ^{14}C in IAEA quality assurance materials C-1, C-2, C-3, C-4 and C-5 (Table 1) and in NBS oxalic acid standard SRM-4990 (OX I). The mean $\delta^{13}\text{C}$ normalized count rate of OX II/OX I, based on three repeat measurements, is $1.268 \pm .004$, consistent with count rates published in the literature (Mann 1983). The $\delta^{13}\text{C}$ of OX II and OX I were taken as -17.3‰ and -19‰ , respectively. The OX II was normalized to a $\delta^{13}\text{C}$ value of -25‰ and OX I to -19‰ (Stuiver and Polach 1977). In addition, we carried out repeat measurements of several samples, the results of which agree well.

ACKNOWLEDGMENTS

The Task benzene synthesizer and the Packard liquid scintillation counter were procured through financial support from the Department of Ocean Development. We thank Davendra Lal, Scripps Institute of Oceanography, La Jolla, California, Michael Kashgarian, Lawrence Livermore National Laboratory, Livermore, California and Ingrid Olson, University of Uppsala, Sweden, for providing us with the NBS oxalic acid standard, and J. E. Noakes, Center for Applied Osotope Studies, Athens, Georgia, for helpful discussions and suggestions during the initial stages of establishing the benzene synthesizer system. We thank R. Ramesh and J. P. Bhavsar for assistance in various stages of sample collection and measurements. We acknowledge the help of R. Jani of the PRL Stable Isotope Laboratory for $\delta^{13}\text{C}$ measurements. We thank B. L. K. Somayajulu, Sheela Kusumgar and M. G. Yadav of PRL for help and discussions.

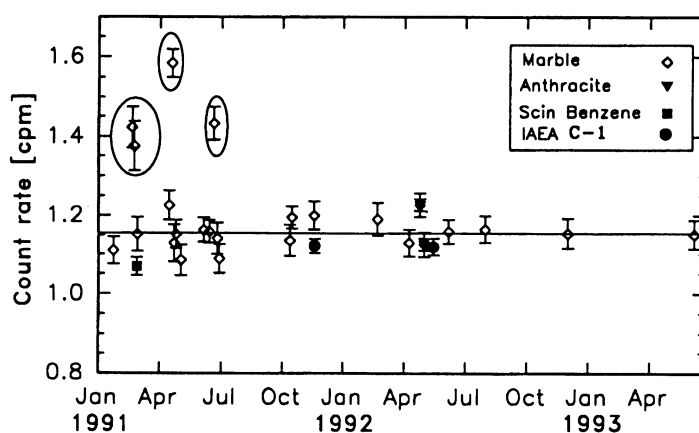


Fig. 1. Marble and other blank sample count rate (in 11–98 keV region). The mean blank count rate (excluding the four circled ones) is 1.154 ± 0.0088 cpm (horizontal line).

TABLE 1. IAEA Intercalibration Samples

Code	Source	$\delta^{13}\text{C}$ (‰)		^{14}C pMC (%)	
		IAEA	CH	IAEA	CH
CH-129	IAEA C-1	2.42 ± 0.38	2.76 ± 0.1	0.00 ± 0.02	-0.32 ± 0.20
CH-150	IAEA C-4	-23.96 ± 0.62	-25.77 ± 0.1	$0.20-0.44$	-0.17 ± 0.11
CH-151	IAEA C-5	-25.49 ± 0.72	-26.50 ± 0.1	23.05 ± 0.02	22.22 ± 0.20
CH-154	IAEA C-5	-25.49 ± 0.72	-25.40 ± 0.1	123.05 ± 0.02	23.06 ± 0.18
CH-122	IAEA C-2	-8.25 ± 0.31	-7.00 ± 0.1	41.14 ± 0.03	39.05 ± 0.33
CH-152	IAEA C-3	-24.91 ± 0.49	-26.10 ± 0.1	129.41 ± 0.06	128.56 ± 0.50
CH-153	IAEA C-3	-24.91 ± 0.49	-24.60 ± 0.1	129.41 ± 0.06	128.18 ± 0.50

RESULTS OF REPEAT MEASUREMENTS

Seawater from Pirotan Island, Gulf of Kutch. Surface seawater from Pirotan Island ($22^{\circ}36'\text{N}$, 70°E) collected in 1993, located within a few kilometers of coral (Gulf of Kutch) site, for study of surface seawater ^{14}C activity.

CH-174. Surface Seawater # 1

$$\Delta = 49 \pm 8\text{‰}$$

CH-175. Surface Seawater # 2

$$\Delta = 43 \pm 6\text{‰}$$

$$\delta^{13}\text{C} = -0.18\text{‰}$$

Charcoal (PRL # 1382). Collected from Mahidpur, Ujjain District in Madhya Pradesh (23°17'N, 75°28'E) from Trench MDP.TR.I at a depth of 221 cm by Rahmat Ali of Vikram University, Ujjain. Provided by S. Kusumgar. Est. $\delta^{13}\text{C} = -25\text{‰}$.

CH-145. Charcoal PRL # 1382 $\Delta = -341 \pm 7\text{‰}$

CH-148. Charcoal PRL # 1382 $\Delta = -364 \pm 4\text{‰}$

Groundwater Sample. Collected from the laboratory campus, Ahmedabad (23°N, 72°40'E). Well depth = 200 m. Est. $\delta^{13}\text{C} = 0\text{‰}$.

CH-188. Groundwater from PRL Campus $\Delta = -631 \pm 3\text{‰}$

CH-189. Groundwater from PRL Campus $\Delta = -630 \pm 3\text{‰}$

Amini Coral. Coral sample collected in 1988 from Amini Island, Lakshadweep Archipelago (10°N, 73°E) by R. Ramesh and S. Chakraborty for stable isotopic measurement to calibrate coral $\delta^{18}\text{O}$ against sea-surface temperature. Est. $\delta^{13}\text{C} = 0\text{‰}$.

CH-75. Amini Coral $\Delta = 56 \pm 7\text{‰}$

CH-89. Amini Coral $\Delta = 62 \pm 7\text{‰}$

CH-140. Amini Coral $\Delta = 36 \pm 7\text{‰}$

CH-141. Amini Coral $\Delta = 47 \pm 5\text{‰}$

Tree Ring. Sample collected by R. Ramesh from Gulmarg Forest compartment 63 near Tangmarh (34°04'N, 74°25'E) from a silver fir tree (*Abies pindrow*).

CH-158. Silver Fir Tree $\Delta = -38 \pm 5\text{‰}$
 $\delta^{13}\text{C} = -24.6\text{‰}$

CH-159. Silver Fir Tree $\Delta = -31 \pm 5\text{‰}$
 $\delta^{13}\text{C} = -25.2\text{‰}$

OCEANOGRAPHIC AND GEOCHEMICAL SAMPLES

Coral

We report ^{14}C time series data on a coral, *Favia speciosa* (GK), collected in June 1990 from Pirotan Island, Gulf of Kutch (22°36'N, 70°E), by S. Chakraborty and R. Ramesh. The coral was subsampled for ^{14}C assay based on X-radiography banding. We measured $\delta^{13}\text{C}$ on the coral CaCO_3 and used the values averaged over each set of sampled bands for $\Delta^{14}\text{C}$ calculation. $\Delta^{14}\text{C}$ values reported are decay-corrected to the average year of growth. The ^{14}C measurements were made to determine the air-sea CO_2 exchange rate in this area (Chakraborty 1993; Chakraborty *et al.* 1994). These measurements are part of our study on isotopic and trace element records in corals from the Indian coast (Chakraborty 1993).

CH-66. Pirotan Island Coral GK-B16 $\Delta = 55 \pm 7\text{‰}$
Coral bands 40–42; growth years 1988–1990. $\delta^{13}\text{C} = 0.66\text{‰}$

CH-67. Pirotan Island Coral GK-B15 $\Delta = 71 \pm 6\text{‰}$
Coral bands 36–39; growth years 1984–1987. $\delta^{13}\text{C} = 0.56\text{‰}$

CH-68. Pirotan Island Coral GK-B14 $\Delta = 96 \pm 7\text{‰}$
Coral bands 35; growth year 1983. $\delta^{13}\text{C} = -0.12\text{‰}$

CH-69. Pirotan Island Coral GK-B13 Coral bands 33–34; growth years 1981–1982.	$\Delta = 99 \pm 7\text{‰}$ $\delta^{13}\text{C} = -0.26\text{‰}$
CH-76. Pirotan Island Coral GK-B12 Coral bands 30–32; growth years 1978–1980.	$\Delta = 102 \pm 7\text{‰}$ $\delta^{13}\text{C} = -0.15\text{‰}$
CH-77. Pirotan Island Coral GK-B11 Coral bands 28–29; growth years 1976–1977.	$\Delta = 122 \pm 6\text{‰}$ $\delta^{13}\text{C} = 0.26\text{‰}$
CH-78. Pirotan Island Coral GK-B10 Coral bands 25–27; growth years 1973–1975.	$\Delta = 146 \pm 7\text{‰}$ $\delta^{13}\text{C} = 0.11\text{‰}$
CH-80. Pirotan Island Coral GK-B9 Coral bands 23–24; growth years 1971–1972.	$\Delta = 131 \pm 7\text{‰}$ $\delta^{13}\text{C} = -0.35\text{‰}$
CH-81. Pirotan Island Coral GK-B8 Coral bands 21–22; growth years 1969–1970.	$\Delta = 156 \pm 7\text{‰}$ $\delta^{13}\text{C} = 0.19\text{‰}$
CH-82. Pirotan Island Coral GK-B7 Coral bands 20; growth year 1968.	$\Delta = 170 \pm 6\text{‰}$ $\delta^{13}\text{C} = -0.06\text{‰}$
CH-83. Pirotan Island Coral GK-B6 Coral bands 18–19; growth years 1966–1967.	$\Delta = 147 \pm 8\text{‰}$ $\delta^{13}\text{C} = -0.39\text{‰}$
CH-84. Pirotan Island Coral GK-BS Coral bands 16–17; growth years 1964–1965.	$\Delta = 120 \pm 7\text{‰}$ $\delta^{13}\text{C} = -0.06\text{‰}$
CH-85. Pirotan Island Coral GK-B4 Coral bands 13–15; growth years 1961–1963.	$\Delta = 57 \pm 7\text{‰}$ $\delta^{13}\text{C} = -0.34\text{‰}$
CH-86. Pirotan Island Coral GK-B3 Coral bands 7–12; growth years 1955–1960.	$\Delta = 1 \pm 6\text{‰}$ $\delta^{13}\text{C} = -0.25\text{‰}$
CH-87. Pirotan Island Coral GK-B2 Coral bands 4–6; growth years 1952–1954.	$\Delta = -53 \pm 6\text{‰}$ $\delta^{13}\text{C} = -0.65\text{‰}$
CH-88. Pirotan Island Coral GK-B1 Coral bands 1–3; growth years 1949–1951.	$\Delta = -60 \pm 5\text{‰}$ $\delta^{13}\text{C} = -0.79\text{‰}$

TREE-RING SAMPLES

We list below ^{14}C measurements from the annual rings of a teak tree (*Tectona grandis*) from Thane ($19^{\circ}14'\text{N}$, $73^{\circ}24'\text{E}$) near Bombay, India. G. B. Pant (Pant and Borgaonkar 1983) provided the samples and their chronology. The individual rings were pulverized using a Wiley mill and pretreated following the method of Cain and Suess (1976). Briefly, the wood powder was soaked first in acetone for ~3 h (with intermittent ultrasonic agitation), then in 5% NaOH for 6–8 h, and finally in 1% HCl for ~6 h to remove resinous and oily substances. The sample was thoroughly washed with distilled water, dried and used for ^{14}C measurements. The $\delta^{13}\text{C}$ of the samples was not measured; however, it was measured in the cellulose of an adjacent teak tree (Ramesh, Bhattacharya and Pant 1989). The values ranged between -25 and -26‰ . We used a value of -25‰ in all samples for calculating $\Delta^{14}\text{C}$. As with coral, ^{14}C data on tree rings are used to determine the air-sea exchange rate of CO_2 in the Gulf of Kutch (Chakraborty 1993; Chakraborty *et al.* 1994).

CH-171. Tree Ring Th-1 Growth years 1979–1980.	$\Delta = 260 \pm 7\%$
CH-172. Tree Ring Th-2 Growth year 1978.	$\Delta = 299 \pm 6\%$
CH-173. Tree Ring Th-3 Growth year 1977.	$\Delta = 311 \pm 6\%$
CH-176. Tree Ring Th-4 Growth year 1976.	$\Delta = 341 \pm 7\%$
CH-177. Tree Ring Th-5 Growth year 1975.	$\Delta = 354 \pm 6\%$
CH-178. Tree Ring Th-6 Growth year 1974.	$\Delta = 420 \pm 7\%$
CH-179. Tree Ring Th-7 Growth year 1973.	$\Delta = 400 \pm 7\%$
CH-180. Tree Ring Th-8 Growth years 1971–1972.	$\Delta = 434 \pm 7\%$
CH-181. Tree Ring Th-9 Growth years 1969–1970.	$\Delta = 476 \pm 7\%$
CH-182. Tree Ring Th-10 Growth year 1968.	$\Delta = 534 \pm 7\%$
CH-183. Tree Ring Th-11 Growth year 1967.	$\Delta = 560 \pm 7\%$
CH-184. Tree Ring Th-12 Growth year 1966.	$\Delta = 587 \pm 8\%$
CH-185. Tree Ring Th-13 Growth years 1964–1965.	$\Delta = 630 \pm 8\%$
CH-186. Tree Ring Th-14 Growth year 1963.	$\Delta = 565 \pm 8\%$
CH-187. Tree Ring Th-15 Growth year 1962.	$\Delta = 338 \pm 6\%$
CH-190. Tree Ring Th-16 Growth year 1961.	$\Delta = 260 \pm 6\%$
CH-191. Tree Ring Th-17 Growth year 1960.	$\Delta = 238 \pm 6\%$

GEOLOGICAL SAMPLES

R. K. Pant and Navin Juyal collected oyster samples from the Saurashtra coastline to study sea-level changes (Juyal *et al.* 1994). The samples were cleaned mechanically to remove adhering impurities

and soaked in 30% H₂O₂ for 2 days to remove organic matter. We report ¹⁴C ages of the samples below.

CH-96. Chikasa Gosa Reef Oyster	>30,000
Collected from Chikasa, Saurashtra (21°45'N, 70°30'E) at 1 m asl.	
CH-97. Chikasa Gosa Reef Oyster	>30,000
Collected from Chikasa at 1 m asl.	
CH-98. Chikhli Oyster	>30,000
Collected from Chikhli (20°48'N, 70°52'E) at 4 m asl.	
CH-99. Patan Bridge Oyster	>30,000
Collected from Patan Bridge over the Hiren River (20°55'N, 70°30'E) at 12 m asl.	
CH-101. Babarkot Oyster	710 ± 40
Collected from Babarkot (20°52'N, 71°25'E) at 8 m asl.	
CH-102. Diu Oyster	3450 ± 45
Collected from Diu (20°44'N, 70°55'E) at 2 m asl.	
CH-103. Jafarabad Oyster	5460 ± 50
Collected from Jafarabad (20°52'N, 71°25'E) at 3 m asl.	
CH-108. Rohisa Oyster	4170 ± 50
Collected from Rohisa (20°50'N, 71°15'E) at 2 m asl.	

REFERENCES

- Cain, W. F. and Suess, H. E. 1976 Carbon-14 in tree rings. *Journal of Geophysical Research* 81: 3688–3694.
- Chakraborty, S. (ms.) 1993 Environmental significance of isotopic and trace elemental variations in banded corals. Ph.D. dissertation, University of Baroda: 141 p.
- Chakraborty, S., Ramesh, R. and Krishnaswami, S. (ms.) 1994 Air-sea exchange of CO₂ in the Gulf of Kutch based on bomb-carbon in corals and tree rings. *Proceedings, Indian Academy of Sciences (Earth and Planetary Sciences)* Special Volume, in press.
- Juyal, N., Pant, R. K., Bhushan, R. and Somayajulu, B. L. K. 1994 Radiometric dating of late Quaternary sea levels of the Saurashtra coast, western India, an experiment with oyster and clam shells. *Journal of the Geological Society of India*, in press.
- Mann, W. B. 1983 An international reference material for radiocarbon dating. In Stuiver, M. and Kra, R. S., eds., *Proceedings of the 11th International ¹⁴C Conference. Radiocarbon* 25(2): 519–527.
- Noakes, J. E., Kim, S. and Stipp, J. J. 1965 Chemical and counting advances in liquid scintillation age dating. In Chatters, R. M. and Olson, E. A., eds., *Proceedings of the 6th International Conference on Radiocarbon and Tritium Dating*. Washington, DC, Clearinghouse for Federal Scientific and Technical Information: 68–92.
- Noakes, J. E. and Valenta, R. J. 1989 Low background liquid scintillation counting using an active sample holder and pulse discrimination electronics. In Long, A., Kra, R. S. and Srdoč, D., eds., *Proceedings of the 13th International ¹⁴C Conference. Radiocarbon* 31(3): 332–334.
- Pant, G. B. and Borgaonkar, H. P. 1983 Growth rings of teak tree and regional climatology (an ecological study of Thane region). In Singh, L. R., Tiwari, R. C. and Srivastava, R. E., eds., *Environmental Management*. Allahabad, Allahabad Geographical Society: 153–158.
- Ramesh, R., Bhattacharya, S. K. and Pant, G. B. 1989 Climatic significance of δD variations in a tropical tree species from India. *Nature* 337: 149–150.
- Stuiver, M. and Polach, H. A. 1977 Discussion: Reporting of ¹⁴C data. *Radiocarbon* 19(3): 355–363.

GLIWICE RADIOCARBON DATES XI

*MIECZYSLAW F. PAZDUR, ROMUALD AWSIUK, TOMASZ GOSLAR, ANNA PAZDUR
ADAM WALANUS and ANDRZEJ ZASTAWNY*

Radiocarbon Laboratory, Institute of Physics, Silesian Technical University, Krzywoustego 2
PL-44-100 Gliwice, Poland

INTRODUCTION

The following list presents results of dating archaeological samples from Poland processed between 1979 and 1985. Three carbon dioxide-filled proportional counters (L1, L2 and L3) of different sizes were used for dating (Pazdur *et al.* 1982). Procedures for sample pretreatment, counting, statistical analysis and age calculations were essentially the same as previously described (Pazdur *et al.* 1982, 1985). All results are reported as conventional ^{14}C dates in years before AD 1950. Unless explicitly stated, the results are not corrected for isotopic fractionation.

ACKNOWLEDGMENTS

Most dates included in this list were made for the Research Project MR.III.5 coordinated by the Institute of History of Material Culture, Polish Academy of Science. This contribution was made possible by grant PB 740/6/91 from the State Committee for Scientific Research.

THE PALEOLITHIC AND MESOLITHIC

Rydno Series

Charcoal from various units of a hematite mine in Rydno (51°5'N, 21°10'E), Nowy Mlyn Village, Kielce district, foothills of Holy Cross Mts. Dated to establish main phases of hematite exploitation, lasting from the Late Paleolithic until the Roman period (Schild and Krolik 1981). Submitted 1982 by R. Schild, Institute of Archaeology and Ethnology, Polish Academy of Sciences, Warsaw.

Gd-710. Rydno Trench I/1977 **10,630 ± 320**

Small pieces scattered at base of Shaft 1 at depth 88–95 cm; collected 1977 by J. Moscibrodzka.

Comment (R.S.): Associated with the Masovian cycle dated to the Younger Dryas; expected age, 8800–7800 BC. Charcoal from hearth in uppermost part of same shaft dated to 1510 ± 55 BP: Bln-2036.

Gd-713. Rydno Trench III/1979 #1 **10,910 ± 220**

Scattered chips from the oldest phase of fill from the Great Opening consisting of conglomerates, depth 50–80 cm. All samples from Trench III/1979 collected 1979 by M. Marczak.

Comment (R.S.): No associated cultural material.

Gd-719. Rydno Trench III/1979 #2 **9840 ± 370**

Small pieces from fill of the Little Opening; depth 44 cm.

Gd-724. Rydno Trench III/1979 #3 **11,940 ± 300**

Small pieces from the 2nd phase of fill from the Great Opening consisting of sandy conglomerates; depth 70–80 cm.

Gd-714. Rydno Trench III/1979 #4 **10,710 ± 250**

From a concentration of charcoal at the base of sandy fill from the Great Opening, depth 145 cm.

Gd-725. Rydno Trench III/1979 #5 **12,290 ± 210**

From a concentration of charcoal at the base of sandy conglomerate fill from the Great Opening; depth 90–110 cm.

Gd-2003. Rydno I/1976 **3560 ± 80**

From a dwelling pit containing alluvial sediment with an admixture of hematite dust; depth 55–70 cm. Collected 1976.

Gd-1519. Rydno I/1981 **2660 ± 60**

From the fill of spaces between sandstone blocks marking the contour of a hearth; depth 70–110 cm. Collected July 1981 by H. Królik.

Gd-2002. Rydno I/1980 #12 **19,280 ± 280**

From a concentration of charcoal in an exploitation pit consisting of many units; depth 105–120 cm. Collected July 1980 by M. Marczak.

Comment (R.S.): Expected age: Late Paleolithic, *ca.* 12,500 BP.

Gd-3207. Rydno-Grzybowa Góra IV/1947 **8180 ± 60**

Charcoal from a small pit in the B horizon of Podzol in subsurface site Rydno-Grzybowa Góra (Schild 1975). Collected July 1947 by S. Krukowski, submitted 1985 by R. Schild.

Całowanie Series

Single fragments of partly burned wood from Late Paleolithic cultural layers at the edge of a dune at contact with a peat bog in Całowanie (52°6'N, 21°14'E), south of Otwock, Warsaw district. Całowanie is a key site for interdisciplinary studies of the Final Paleolithic in Poland. It is located in the center of an abandoned channel of the Vistula River filled with thick beds of peat and some sandy islands with traces of human occupation. Results of the first interdisciplinary studies in Całowanie, conducted by R. Schild over several seasons (1963–1969) were summarized by Schild (1982) and Dąbrowski (1981). Samples from Trench VII/1966 collected 1966 and from Trench X/1983 collected July 1983 and submitted 1983 by R. Schild.

Gd-1648. Całowanie #1A **10,140 ± 80****Gd-2147. Całowanie #1B** **10,030 ± 120**

Two parts of the same sample from Trench X/1983, Level 9b; depth 165 cm.

Gd-1662. Całowanie #2 **9750 ± 80**

From Trench X/1983, top of Level 9b at contact with base of Level 11a; depth 150 cm.

Gd-1667. Całowanie #3A **8780 ± 80****Gd-1668. Całowanie #3A** **8640 ± 80****Gd-2146. Całowanie #3C** **8270 ± 120**

Individual pieces of charcoal or charred wood from Trench X/1983, the topmost part of Level 11b, cultural layer VII; depth 75 cm.

Gd-2149. Całowanie #4A **9080 ± 100****Gd-1670. Całowanie #4B** **8300 ± 70**

From Trench X/1983, the base of Level 11a, overlying cultural layer VII; depth 70 cm.

Gd-1669. Całowanie #5	2610 ± 40
A small pale with traces of artificial treatment, Trench X/1983, top of Level 11a, cultural layer VIII; depth 50 cm.	
Gd-1717. Całowanie #6	9700 ± 80
Trench VII/1966, Level 11b, cultural layer VII; depth 127 cm.	
Gd-1719. Całowanie #7	9370 ± 60
Same location; depth 120 cm.	
Gd-2198. Całowanie #8	9350 ± 100
Same location; depth 120 cm.	
Gd-3041. Całowanie #9	9030 ± 50
Same location; depth 147 cm.	
Gd-1721. Całowanie #10	9380 ± 80
Same location; depth 140 cm.	

Comment (R.S.): This series supplements earlier ¹⁴C dates of charcoal or charred wood obtained in Groningen. The dates, in stratigraphic order, are as follows: base of Level 9b: 10,455 ± 90, GrN-5049; near top of Level 9b: 9935 ± 110, GrN-5254; base of Level 11b: 9250 ± 55, GrN-5251 and 9200 ± 75, GrN-5442; topmost part of Level 11a: 8360 ± 75, GrN-5966.

Chwalim Series

Wood and charcoal from a peat bog situated close to a Mesolithic settlement, Site 1 on a terrace of the Gniła Obra River in Chwalim (52°7'N, 15°55'E) near Kargowa, Zielona Góra district, Great Poland Lowland. Collected July 1979 and submitted 1979 by M. Kobusiewicz, Institute of the History of Material Culture, Polish Academy of Sciences, Poznań.

Gd-1164. Chwalim 1 WKT III/79 #1	9560 ± 90
Charcoal from a layer of brown undecomposed peat at the base of a peat bog adjacent to an older terrace with a Mesolithic settlement, Trench III/79; depth 190–200 cm.	
Gd-1165. Chwalim 1 WKT III/79 #2	9450 ± 80
Wood from a large tree trunk found at the base of a peat bog, same locality; depth 165 cm.	
Gd-1176. Chwalim 1 WKT II/79 #1	4630 ± 70
Fragments of a partly burned shingle found in a layer of black peat mixed with charcoal dust at the base of a peat bog adjacent to a younger terrace with a Neolithic settlement, Trench II/79; depth 210–220 cm.	

Comment (M.K.): Charcoals from layer associated with Mesolithic settlement were dated to 9500 ± 75: Bln-1766; charcoal from layer associated with a Neolithic settlement was dated to 3900 ± 50: Bln-1767; 4280 ± 45; Bln-2019; and 4375 ± 50: Bln-2018 (Kobusiewicz 1980).

Gd-389. Krzekótówek K-8-I/72	6880 ± 190
Charcoal from a hearth in a Mesolithic dwelling in Krzekótówek (51°42'N, 16°18'E), near Głogów, on a dune covering a terrace of the Krzycki Rów River. Collected 1972 and submitted 1976 by Z. Bagniewski.	

Comment (Z.B.): Date agrees well with archaeological dating to the beginning of the Atlantic phase.

Gd-2432. Janisławice J1**6580 ± 80**

Bone collagen from a Mesolithic grave in Janisławice (51°40'N, 20°5'E), near Gruchów, Skierniewice district. Collected 1937 by K. Jażdżewski; submitted 1985 by Z. Sulgostowska, State Archaeological Museum, Warsaw.

Comment (Z.S.): Expected age: 7th/6th millennium BC (Chmielewska 1954).

Ełk Series

Charcoal from Site I in Ełk (53°49'N, 22°20'E), Mazury Lakeland, northeast Poland. Collected 1970 and submitted 1982 by J. Trzeciakowski, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd-1527. Ełk I/1**6310 ± 70**

From a hearth in a cultural layer at depth 30–50 cm, associated with Late Paleolithic/Mesolithic artifacts.

Gd-1546. Ełk I/2**3050 ± 50**

Dispersed in cultural layer, Trench 2; depth 20–40 cm.

Gojście Series

Charcoal from an open Paleolithic site on terrace of Warta River in Gojście (51°4'N, 19°10'E), Kraków-Wieluń Upland, Częstochowa district. Collected and submitted 1983 by Bolesław Ginter, Institute of Archaeology, Jagellonian University, Kraków.

Gd-1642. GI/81/30–35 cm**2260 ± 40**

Hearth in Trench I; depth 30–35 cm.

Gd-1643. GII/81/30 cm**990 ± 50**

Hearth in Trench II; depth 30 cm.

Gd-2122. GIII/81/30–50 cm**1290 ± 80**

Hearth in Trench III; depth 30–50 cm.

Gd-2123. GIII/81/100 cm**4020 ± 90**

Hearth in Trench III; depth 100 cm.

Gd-2124. G-S/5/100–130 cm**4030 ± 90**

Hearth in Trench S/5; depth 100–130 cm.

Comment (B.G.): The site is associated with the exploitation of a flint mine of the Swiderian culture; expected age: 8–9 kyr BP. Dates are much younger than expected.

NEOLITHIC**Woźna Wieś Series**

Bone and charcoal from Site I of a hunting and harvesting group (Kempisty and Sulgostowska 1976), situated on a lake terrace in Woźna Wieś (53°45'N, 22°45'E), Łomża district, Mazury Lakeland, northeast Poland. Collected 1974 and 1978 and submitted 1984 by Z. Sulgostowska.

Gd-2431. W I/3/74**5900 ± 100**

Collagen from a human bone from a single skeleton found at depth 30–90 cm, Trench 3, Square 11.

Gd-3134. WW I/1/78**2990 ± 50**

Charcoal from a hearth (?), Trench 1; depth 60–90 cm.

Gd-2429. Firlus 8/10/4**6020 ± 100**

Charcoal from cultural layer 4 at the base of Pit 4, Trench 10, depth 70–80 cm, Site 8 in Firlus (53° 16'N, 18°38'E) on E shore of Młyńskie Lake, near Popowo Biskupie, Toruń district, Chełmińskie Lakeland. Collected 1983 and submitted 1984 by R. Kirkowski, Regional Museum, Grudziądz.

Comment (R.K.): Dated to establish a chronology for the Bandkeramik culture in the region of Chełmińskie Lakeland; expected age: 3600–3800 BC (Czerniak 1980).

Dęby Series

Charcoal from a Neolithic settlement in Dęby, Site 29 (52°40'N, 18°35'E), near Dobrze, district Włocławek, Kujawy Plateau.

Gd-2148. D29/32-186**4600 ± 90**

From the basal part of Object 32 of worship type; depth 30–50 cm. Collected 1983 by J. Czebreszczuk and submitted by A. Koško.

Comment (A.K.): Sample dates cultural disintegration in the Late Neolithic and the first occurrence of typical features of Bronze Age cultures in the Kujawy region (Koško 1981a).

Gd-2278. D29/84 #1**7250 ± 100**

Single fragments of charcoal from a pit made by a pole of a Neolithic cottage, Trench VII; depth 60 cm. Collected July 1984 by L. Domańska; submitted August 1984 by A. Koško.

Comment (A.K.): Dates influences of Janisławice culture; expected age: 4th millennium BC.

Gd-1928. D29/85 #3**6090 ± 70**

Charcoal dispersed in the vestibule of a Neolithic cottage; depth 60–70 cm. Collected July 1985 by L. Domańska; submitted October 1985 by A. Koško.

Comment (A.K.): Sample from the same cultural level as Gd-2278.

Gd-2482. D29/85 #4**7940 ± 80**

From a hearth belonging to a Late Mesolithic habitation, Trench XV/XX; depth 80–90 cm. Collected July 1985 and submitted 1986 by L. Domańska.

Białcz Stary Series

Charcoal from a Neolithic settlement in Białcz Stary (52°20'N, 16°40'E), Site 4, near Smigiel, Leszno district, Great Poland Lowland. Collected by L. Czerniak; submitted by T. Wiślański, Institute of the History of Material Culture, Polish Academy of Sciences, Poznań.

Gd-2054. BS 4/46**5820 ± 80**

Charcoal (*Pinus* sp., identified by K. Surmiński) from layer in upper part of Pit 46 belonging to Stroked Pottery culture, depth 90–100 cm. Collected June 1980.

Gd-1608. BS 4/109Be**5340 ± 70**

From the base of Pit 109Be of the late phase of the Bandkeramik culture (Czerniak 1980), depth 60–80 cm. Collected July 1982.

Gd-1753. BS 4/154**5860 ± 50**

From the base of Pit 154.

Dąbrowa Biskupia Series

Charcoal from large Neolithic settlement in Dąbrowa Biskupia, Site 21 (52°46'N, 18°32'E), district Bydgoszcz, Kujawy Plateau. Collected 1984 by M. Szmyt and submitted by A. Koško.

Gd-2277. DB 21-81/90A **8500 ± 110**

From depth 60 cm, the base of Object 81/90.

Gd-2289. DB 21-92a **4400 ± 140**

From the central part of Object 92; depth *ca.* 70 cm.

Gd-1929. DB 21-81/90BB **7920 ± 70**

From a collection of charcoal (hearth?) at the edge of a large half-dugout; depth 92–114 cm. Collected 1983 by P. Chachlikowski.

Gd-2509. Węgierce 12/1 **5860 ± 100**

Scattered fragments of bone from depth 1.1–1.5 m, Pit 1 of an early Neolithic settlement, Site 12 in Węgierce (52°45'N, 18°9'E) near Janikowo, district Bydgoszcz, Kujawy Plateau. Collected July 1985 by M. Szmyt; submitted December 1985 by A. Koško.

Comment (A.K.): Associated archaeological material indicates Phase 1b of the Late Bandkeramic culture; the date fits with expected age: 3800–3700 BC.

Opatowice Series

Charcoal from a Neolithic settlement in Opatowice, Site 33 (52°43'N, 18°33'E) near Radziejów, district Włocławek, Kujawy Plateau.

Gd-2287. Opatowice 33-3A **6190 ± 120**

From a half-dugout, Object 3, depth *ca.* 80 cm. Collected June 1983 and submitted 1984 by A. Koško.

Comment (A.K.): Dates the beginning of traces of southeastern European influences on Polish Lowland cultures (Koško 1981a).

Gd-2472. Opatowice 3/21 **4570 ± 80**

From the fill of Pit 21; depth 70–150 cm. Collected 1985 by P. Makarowicz; submitted October 1985 by A. Koško.

Comment (A.K.): Dates the classical phase of the Radziejów group of the Funnel Beaker culture.

Gd-1799. Jezuitska Struga 17-V/4 **7530 ± 70**

Charcoal from remnants of a pillar in the center of Object 4, Trench V, Site 17 in Jezuitska Struga (52°56'N, 18°18'E) near Rojewo, Bydgoszcz district, Toruń Basin. Collected July 1984 by D. Prinke; submitted September 1984 by A. Koško.

Gd-2151. Korzecznik 6/7 #17/18 **4890 ± 100**

Charred wood from a half-dugout of a Late Neolithic settlement in Korzecznik (52°19'N, 18°47'E) near Kłodawa, Konin district, Kujawy Lakeland. The sample is from two collections of charcoal in the fill of Object 12, Trench VII, Site 6/7; depth 40–60 cm. Collected July 1981 by J. Czebreszczuk; submitted October 1983 by A. Koško.

Comment (A.K.): Dated to establish the decline of Neolithic cultures in the Kujawy region (Koško 1979).

Gd-2152. Stara Wieś 9A:212/9B/2680**5820 ± 90**

Single pieces of charcoal from the center of dwelling pit at depth 30–60 cm, Site 9A of a Neolithic settlement in Stara Wieś (52°55'N, 18°15'E) near Rojewo, district Bydgoszcz, Toruń-Eberswald Pradolina. Collected 1983 by M. Szmyt; submitted 1983 by A. Cofta-Broniewska.

Comment (A.C.B.): Dated to establish a chronology of influences of the Single Grave culture in the Kujawy region (Kośko 1979).

Gd-1985. Inowrocław 95/1830**4930 ± 70**

Collagen from human bones from the grave of the Funnel Beaker culture, Site 95 in Inowrocław (52°46' N, 18°15' E), district Bydgoszcz, Kujawy Plateau. Collected July 1979 by J. Bednarczyk; submitted 1985 by A. Kośko.

Gd-1983. Krusza Podlotowa 2/31**4250 ± 70**

Collagen from an animal bone from Site 2 in Krusza Podlotowa (52°46'N, 18°14'E) near Inowrocław, district Bydgoszcz, Kujawy Plateau. The site is located in black soil cover of the lower terrace of the Noteć River Pradolina. Object 31 with animal bones and stones has the shape of a shallow pit *ca.* 20 m long with several collections of bones at depth 40–60 cm. Collected September 1985 by P. Chachlikowski; submitted by A. Kośko.

Comment (A.K.): Dates final phase of the Radziejów group of Funnel Beaker culture; the date is consistent with Gd-2472, 4570 ± 80 BP, corresponding to the classical phase of this group (Kośko 1981b).

Łagiewniki Series

Charcoal from pits in late phase settlement of the Funnel Beaker culture in Łagiewniki (52°39'N, 18°18'E), near Kruszwica, Bydgoszcz district, Kujawy Upland. Collected July 1977 by L. Czerniak; submitted June 1980 by T. Wiślański.

Gd-814. Łagiewniki 5A ob. 45**4630 ± 60**

From a storage pit, Object 45, Site 5A.

Comment (T.W.): Dates the latest phase of the Funnel Beaker culture, the Radziejów group (Kośko 1981b).

Gd-1276. Łagiewniki 3 ob. 29**4620 ± 50**

From the base of a grave pit, Object 29, Site 3; depth 100–120 cm.

Gd-813. Łagiewniki 3 ob. 40**4500 ± 110**

From the base of a refuse pit, Object 40, Site 3; depth 90 cm.

Comment (T.W.): Site 3 contains artifacts of the Funnel Beaker culture with influences from the “southeastern European factor” (Kośko 1981a).

Gd-2222. Lisewo L-31/439**5750 ± 510**

Charcoal from a storage pit, Object 4, depth 30–40 cm, Site 31 of the Funnel Beaker culture in Lisewo (53°18'N, 18°41'E), Toruń district, Chełmińskie Lakeland. Collected 1983 and submitted 1984 by S. Kukawka, Institute of Archaeology and Ethnography, Mikołaj Kopernik University, Toruń.

Comment (M.F.P.): Very small sample, diluted with inactive CO₂ for counting.

Gd-886. Zawada 1/80**5710 ± 120**

Charcoal, part of a burned log from a palisade of a fortified settlement, Site 1, Trench 52, Object 32, depth 55 cm. This site, with several cultural levels, is located in Zawada (50°28'N, 21°20'E) near Połaniec, Tarnobrzeg district. It was intensively occupied by the Tarnobrzeg group of the Lusatian culture. Collected 1980 and submitted March 1981 by J. Michalski, Institute of Archaeology, Warsaw University, Warsaw.

Comment (J.M.): The date is older than expected; Kanwiszer and Trzeciak (1984) published a series of dates confirming the Lusatian occupation.

Gródek Nadbużny Series

Charcoal from a Neolithic settlement situated on loess inselberg on a terrace of the Bug River in Gródek Nadbużny (50°48'N, 23°27'E) near Hrubieszów, Zamość district, Wolhynia Upland. Excavations at Site 1C resulted in the discovery of several phases of Neolithic occupation, associated with the Funnel Beaker (FB) and Wolhynia-Lublin Painted Pottery (WLPP) cultures and the Lengyel-Polgar Cycle (LPC). Collected 1983, 1984 and 1985 and submitted 1985 by S. Jastrzębski, Department of Archaeology, Maria Curie Skłodowska University, Lublin.

Gd-2160. G1C ob.2/83 s#1**5010 ± 110**

From the center of Pit 2/83, Trench I/83, depth 80 cm, FB culture.

Gd-2163. G1C ob.2/83 s#2**5030 ± 90**

From the lower layer of the same pit, depth 100 cm.

Gd-1918. G1C ob.7/83**4750 ± 50**

From the base of Pit 7/83, associated with a fragment of baked red clay, depth 120 cm, FB culture.

Gd-2441. G1C ob. 13D/84**4830 ± 90**

From Layer II containing numerous shells of bivalves with animal bones and dispersed charcoal, Pit 13D/84, Trench II/84, depth 100 cm, associated with artifacts characteristic of the FB culture and the late phase of LPC.

Gd-2454. G1C ob. 13E/84**4840 ± 120**

From Layer IV, Pit 13E/84, depth 70–90 cm, associated with pottery of the FB culture.

Gd-2455. G1C ob.13F/84**4330 ± 80**

From Layer IV, base of Pit 13F/84, depth 160 cm, FB culture.

Gd-2442. G1C ob.18C/84**4530 ± 70**

From Layer V at the base of Pit 18C/84, depth 140 cm, associated with baked clay and numerous fragments of pottery of the FB culture.

Gd-2440. G1C ob.10/85**4580 ± 90**

From Layer V at the base of Pit 10/85, depth 100 cm, FB culture.

Gd-2427. G1C ob.22/85**4690 ± 70**

From the fill of Pit 22/85, Trench I/85, depth 150 cm, FB culture.

Gd-2468. G1C s#25/85**4750 ± 120**

From the fill of a ditch, the upper part of Layer II, depth 110 cm.

Gd-2439. G1C s#27/85**5110 ± 60**

From the fills of the same ditch, Layer V, depth 200 cm.

Comments (S.J. and M.F.P.): The ditch is associated with the WLPP culture and is intersected by some pits associated with the FB culture. For a general outline of the chronology of the southeastern group of the FB culture, see Wiślański (1979); details of earlier excavations are described by Kowalczyk (1968). A general outline of the WLPP culture is given by Gurba (1974); elements of other cultures in this site are discussed by Kempisty (1962) and Poklewski (1958).

Sandomierz Series

Charcoal from Neolithic sites on a loess hill in Sandomierz (50°40'N, 21°45'E), Tarnobrzeg district, Sandomierz Upland. Collected 1980 and 1982 and submitted 1982 and 1983 by H. Kowalewska-Marszałek, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd 984. Żmigród 5110 ± 140
From the fill of Pit 3, depth 15–35 cm.

Gd-2040. Wzgórze Zawichojskie ob.4 5090 ± 100
From the fill of a ditch, Trench I/82, depth 130 cm.

Gd-2041. Wzgórze Zawichojskie p6 3770 ± 70
From the fill of Pit 6, Trench I/82, depth 40–75 cm.

Comment (H.K.M.): The first two samples are associated with the LPC of the Early/Middle Neolithic; the third is associated with the Mierzanowice culture dated to the end of the Neolithic/beginning of the Early Bronze Age. For a general reference, see Kruk (1973) and Kulczycka-Leciejewiczowa (1979).

Las Stocki Series

Charcoal from the settlement of Wolhynia-Lublin Painted Pottery culture (Gurba 1974), Site 7 in Las Stocki (51°20'N, 22°3'E) near Końskowola, Lublin district, on the loess cover of the Nałęczów Plateau, ca. 175 m asl. Collected 1982 and 1983 and submitted May 1984 by A. Zakościelna, Department of Archaeology, Maria Curie Skłodowska University, Lublin.

Gd-2204. LS 7/5-XI 4990 ± 100
Burning layer XI at the base of Pit 5, depth 120–130 cm.

Gd-2205. LS 7/19-IX 5020 ± 110
From cultural layer IX at the base of a pit below dwelling object 19, depth 130–140 cm.

Gd-1723. LS 7/36-V 5030 ± 50
From cultural layer V at the base of Pit 36, depth 65–70 cm.

Gd-1724. LS 7/28-X 5350 ± 60
From cultural layer X at the base of Pit 28, depth 120 cm.

Comment (A.Z.): The expected age was 3200–3000 BC for this series, which fits well with a previous ^{14}C date of the WLPP settlement in Wąwolnica, Nałęczów Plateau 5070 ± 210 BP, Lod 178 (Kanwiszer and Trzeciak 1986). Wiślański (1979) compared pottery assemblages with other sites in the area.

Pałecznica Series

Charcoal from a Late Neolithic site in Pałecznica (50°14'N, 20°18'E), Kielce district, Miechów Upland, at the top of a loess hill. Collected August 1983 and submitted November 1983 by Z. Liguzińska Kruk, Institute of the History of Material Culture, Polish Academy of Sciences, Kraków.

Gd-1673. Pałecznica #6**3590 ± 40**

From a channel with traces of wooden beams surrounding a mound, depth 60–70 cm.

Gd-2156. Pałecznica #7**320 ± 60**

From a layer at the top of a grave.

Comment (Z.L.K.): Gd-1673 dates the oldest phase of the Corded Ware culture in southern Poland (Machnik 1966, 1978); Gd-2156 is obviously erroneous.

Gd-2428. Wichorze 24/1/2**4340 ± 90**

Charcoal from the basal layer at depth 1 m in a midden pit associated with the Globular Amphora culture (KAK), Site 24, Trench 1, Object 2, atop a hill in the valley floor of the Struga Żacka River in Wichorze (53°18'N, 18°32'E), near Stolno Village, Toruń district, Chełmińskie Lakeland. Collected and submitted 1984 by R. Kirkowski.

Comment (R.K.): Dated to establish a chronology of habitation of KAK groups in Chełmińskie Lakeland; expected age: 2400–2600 BC (Bednarczyk *et al.* 1975).

BRONZE AGE**Gd-2297. Topólka R14/263****3470 ± 80**

Charcoal from the center of a furnace pit at depth 60–80 cm, Object 9 of Bronze Age settlement in Topólka (52°30'N, 18°14'E), district Włocławek, Kujawy Lakeland. Collected July 1984 by J. Czebreszczuk; submitted August 1984 by A. Koško.

Comment (A.K.): The date fits fairly well with the Early Bronze Age chronology established for the Kujawy region (Koško 1979).

Gd-2289. Narkowo N9/236**3290 ± 90**

Charcoal from the center of a hearth at depth 40–60 cm in Object 1 (furnace pit?) of a Bronze Age settlement, Site 9 in Narkowo (52°40'N, 18°35'E) near Dobrze, district Włocławek, Kujawy Plateau. Collected August 1984 by J. Czebreszczuk; submitted August 1984 by A. Koško.

Comment (A.K.): Associated material shows first traces of features typical for the Lusatian culture (Koško 1979).

Gd-1684. Podgaj 6A/3374**3840 ± 70**

Collagen from human bones from the base of a grave pit, Object 62, Site 6A of the Bronze Age in Podgaj (52°50'N, 18°37'E) near Aleksandrów Kujawski, district Włocławek, Kujawy Plateau. Collected August 1982 by P. Chachlikowski; submitted June 1983 by A. Cofta-Broniewska, Institute of Prehistory, Adam Mickiewicz University, Poznań.

Comment (A.C.-B.): Dated to establish a chronology of EB Epi-Corded Ware groups of the Polish Lowlands.

Bożejewice Series

Charcoal and collagen from human bones from a Bronze Age settlement in Bożejewice, Site 8 (52°36'N, 18°10'E) near Strzelno, district Bydgoszcz, Kujawy Plateau. Collected July and August 1980 and submitted May 1981 and June 1983 by A. Koško.

Gd-888. B8/2251**4140 ± 120**

Charcoal from a burned bow at the base of a burial pit, Object 32, depth 2 m.

Gd-1349. B8/2257 4040 ± 50

Charred wood from a coffin made of a single tree trunk ("log grave"), Object 2, depth 80 cm.

Gd-2171. B8/10822 2850 ± 80

Human bone from a grave pit, Object 5, depth 40 cm.

Comment (A.K.): Boundary of the 2nd and 3rd periods of the Bronze Age; sample dates the beginning of the Lusatian culture in the Kujawy region.

Gd-3025. B8/10852 3770 ± 50

Human bones from a grave pit, Object 24, depth *ca.* 60 cm.

Gd-2499. B8/10852bis 3760 ± 120

Repeat run of Gd-3025.

Comment (M.F.P.): Collagen extracted in 1981 was stored in glass jar for four years.

Gd-2462. Krusza Zamkowa 16/2350 2860 ± 80

Charcoal found at depth 50 cm between stones surrounding a grave in Krusza Zamkowa, Site 16 (52°45'N, 18°12'E) near Inowrocław, district Bydgoszcz, Kujawy Plateau. Collected 1981 by M. Klundner; submitted 1985 by A. Koško.

Comment (A.K.): Gd-2462 dates regressive forms of non-chamber graves discovered in an area of black soils on the Kujawy Plateau (Koško 1976).

Siciny Series

Charcoal and human bones from Bronze Age graves, Site 5, in Siciny (51°45'N, 16°32'E), near Niechlów, Leszno district, Great Poland Lowland. Collected and submitted by T. Wiślański, Institute of the History of Material Culture, Polish Academy of Sciences, Poznań.

Gd-1166. Siciny 5 gr.17#49 3620 ± 60

Charcoal from cremation burial 17, depth 60–80 cm. Collected and submitted 1979.

Comment (T.W.): Grave belongs to a well-developed phase of the Unietyce culture, I/II period of the Bronze Age.

Gd-2111. Siciny 5 gr.1#1 3610 ± 80

Gd-2164. Siciny 5 gr.1#2 3460 ± 70

Collagen from human bones of two skeletons from Grave 1 associated with a late phase of the FB culture, in a deep pit with a stony pavement, depth 120–130 cm. Collected 1978 and submitted 1982.

Gd-2165. Siciny 5 gr.13#A 3340 ± 90

Collagen from a poorly preserved human skeleton found at the base of Grave 13, depth 120–130 cm, underlying a pit of the Lusatian culture. Collected 1979 and submitted 1982.

Comment (T.W.): Gd-2165 is a unique set of copper artifacts and dates the final phase of the Bandkeramic culture.

Gd-388. Siedlnica S-6/2-II/75 3590 ± 110

Charcoal from a hearth in a dwelling of fishing and hunting population in Siedlnica (51°45'N, 16°21'E), near Wschowa, a terrace of the Kopanica River, Great Poland Lowland. Collected and submitted 1975 by Z. Bagniewski, Institute of Archaeology, Wrocław University, Wrocław.

Comment (Z.B.): Gd-388 is much younger than expected; the site is archaeologically dated to the end of the Boreal.

Gołdap Series

Charcoal from cultural layers of Site Ic in Gołdap (54°20'N, 22°20'E), Mazury Lakeland, northeast Poland. Collected 1972 and 1973 and submitted 1982 by J. Trzeciakowski.

Gd-2031. Goldap Ic, layer 1/1	2460 ± 100
Gd-2032. Goldap Ic, layer 1/2	1570 ± 60

Nieborowa Series

Charcoal from single hearths associated with mixed cultural material in Nieborowa (51°20'N, 23°29'E), near Bukowa Wielka Village, Chełm Lubelski district. The site is located in a denudational valley on a slope of fluvioglacial hill Pagór Uhruski. Samples from Site I collected 1967 and 1968 and submitted 1979; from Site II, collected 1977 and submitted 1982 by H. Mackiewicz, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd-1163. NbI/5B	1390 ± 60
From remains of a hut in an alluvial layer of sandy soil, Site I, Trench 5, depth 80–100 cm.	
Gd-1161. NbI/6A	7120 ± 70
Hearth at depth 45–60 cm, Site I, Trench 6.	
Gd-1160. NbI/7A	870 ± 40
Hearth at depth 60–70 cm, Site I, Trench 7.	
Gd-1162. NbI/9A	6750 ± 70
Hearth at depth 30–40 cm, Site I, Trench 9.	
Gd-1528. NbII/1H	930 ± 60
From a burned log at depth 80–90 cm, Site II, Trench 1.	
Gd-1529. NbII/1G	520 ± 60
Hearth at depth 35–70 cm, same location.	

Comment (M.F.P. & H.M.): Other dates from Site I: Le-335, 8250 ± 160; TF-754, 2680 ± 100; for earlier dates from Gliwice, see Mościcki and Zastawny (1976), Mościcki *et al.* (1978).

Szarbia Series

Charcoal from a pit dwelling, Site 9 on the south slope of a loess hill in Szarbia (50°19'N, 20°24'E) near Skalmierz, Kielce district, Miechów Upland. Collected 1981, 1982 and 1983 by B. Baczyńska; submitted 1982 and 1983 by J. Machnik, Institute of the History of Material Culture, Polish Academy of Sciences, Kraków.

Gd-2011. Szarbia #72/81	3670 ± 60
Trench V, Object 1, depth 95–115 cm.	
Gd-2012. Szarbia #30/82	3460 ± 60
Trench VII, Object 6, depth 120–140 cm.	
Gd-2103. Szarbia #162/82	3680 ± 100
Trench VII, Object 15, depth 180–200 cm.	
Gd-2104. Szarbia #122/81	3380 ± 100
Trench V, Object 14, depth 125–145 cm.	

Gd-2154. Szarbia #70/83 3830 ± 110
Trench IX, Object 29, depth 110–130 cm.

Gd-2153. Szarbia #69/83 3560 ± 110
Trench IX, Object 9, depth 130–150 cm.

Comment (J.M.): The series dates the youngest phase of the Mierzanowice culture. Another date from the same site is 3530 ± 60 BP: Bln-2575.

Ożarów Series

Fine charcoal lumps scattered in layers of clay, sand and debris in shafts of a flint mine in Ożarów (50°44'N, 21°40'E), Tarnobrzeg district, Kielce-Sandomierz Upland. Collected 1981, 1982 and 1984; submitted 1983 and 1984 by J. Budziszewski, Institute of Archaeology, Warsaw University, Warsaw.

Gd-2108. Shaft 3 Level 9/114-154 cm 3370 ± 80
Gd-2114. Shaft 3 Level 8/74-114 cm 3520 ± 80
Gd-2115. Shaft 4 Level 9/120 cm 3430 ± 80
Gd-2449. Shaft 1 s#1 3710 ± 120
From the top of sandy scree, Trench I, Shaft 1, Levels 8 and 9, depth 25–144 cm.

Gd-2450. Shaft E s#41 3440 ± 120
From the top of anthropogenic fill of Shaft E, Trench IV, Level 2, depth 70–125 cm.

Gd-2448. Shaft D s#40 3720 ± 120
From the top of anthropogenic fill of Shaft D, Trench IV, Levels 1 and 2, depth 50–90 cm.

Gd-2443. Shaft B s#39 3970 ± 70
From the top of sandy scree overlain by an anthropogenic layer, Trench IV, Shaft B, Levels 2 and 3, depth 105–160 cm.

Gd-2451. Shaft L s#60 3580 ± 220
From the top of sandy scree, Trench VII, Shaft L, Level 3, depth 80–95 cm.

Comment (J.B.): Ożarów site belongs to the Mierzanowice culture from the end of the Neolithic and the beginning of the Bronze Age; expected age: 1400–1800 BC (Machnik 1978). Other ¹⁴C dates of this culture in Poland are from Polany Kolonie II (Schild, Królik and Mościbrodzka 1977) and Iwanowice (Machnik 1978).

Ośłonino Series

Charcoal from a settlement of Rzućewska culture, Site 2 in Ośłonino (54°40'N, 18°28'E) near Puck, Gdańsk district, Kaszuby Coastal Area. The site is located on Kępa Pucka hill near the cliff shore of Puck Bay, 14 m asl. Collected by D. Król; submitted 1983 and 1984 by T. Wiślański.

Gd-1606. s#2/80 3930 ± 60
Part of a burned pile associated with pile cottage 2, Trench II/80, depth 2.68 m; collected July 1980.

Gd-1607. s#3/81 3940 ± 60
From the south part of fill of burned pile cottage 3, Trench IIA/81, depth 2.08 m; collected July 1981.

Gd-1752. s#4/83 3910 ± 70
From a burned pile from pile cottage 4/83, Trench X, depth 1.8 m; collected July 1983.

Gd-3067. s#4/83bis**3680 ± 70**

Duplicate run of Gd-1752.

Comments (M.F.P. & D.K.): Gd-3067 was dated as a check of a new proportional counter assembly (L2). The dates agree fairly well with the accepted chronology of the Rzućewska culture (Żurek 1953; Wiślański 1979; Machnik 1979).

Gd-2016. Słonowice 1**2810 ± 80**

Charcoal from depth 70–95 cm, Pit 8, Trench VIII, Site G in Słonowice (50°10'N, 20°29'E), near Kazimierza Wielka, Kielce district, Proszowice Plateau. Collected 1982 by K. Tunia and submitted by J. Machnik. The site is located in loessy cover on the south slope of the Małoszówka River valley. Associated artifacts belong to the Trzciniecka culture of the II/III period of the Bronze Age.

Comment (K.T.): Expected age: 1500–1000 BC.

Gd-1760. Ulucz 1/82**2960 ± 50**

Charcoal from the basal layer of a pit dwelling in Ulucz (49°40'N, 22°16'E), near Dydnia, Krosno district, west Carpathians. Site 3 is located on an alluvial cone of the Borownica River at its mouth to the valley of the San River. Gd-1760 is from the south of Object 13B, depth 70–110 cm, associated with pottery of the Late Bronze/Early Iron Age (Parczewski 1983). Collected 1982 and submitted 1984 by M. Parczewski, Institute of Archaeology, Jagellonian University, Kraków.

IRON AGE**Psary Series**

Charcoal from basal parts of iron smelting furnaces and other features of a settlement of the Roman period associated with iron metallurgy in Psary, Site 1 (51°40'N, 16°17'E), near Jemielno, Leszno district, Lower Silesia. The settlement covers ca. 20 ha with 8 smelting sites; the largest Site 1 consists of 89 iron smelting furnaces arranged in uneven rows (Mamzer 1983; Mamzer and Pazdur 1984). Collected 1982 and submitted 1983 by H. Mamzer, Institute of the History of Material Culture, Polish Academy of Sciences, Poznań.

Gd-1426. Pit #193**2080 ± 50****Gd-1427. Furnace #55****1950 ± 50****Gd-1428. Furnace #63****2030 ± 60****Gd-1429. Furnace #71****2110 ± 60****Gd-1430. Furnace #43****1890 ± 50****Gd-1431. Furnace #76****2030 ± 50****Gd-1432. Furnace #60****1930 ± 60****Gd-1633. Furnace #185****1910 ± 40**

Comment (H.M. & M.F.P.): This site is representative of a metallurgic region of Lower Silesia, consisting of > 50 sites situated mainly between the Barycz and Odra Rivers. These results indicated that the main activity of this metallurgic center is synchronous with the Holy Cross Mts. and Masovian centers of prehistoric iron metallurgy in Poland (Pazdur, Pazdur and Zastawny 1981; Pazdur 1990).

Opole-Grotowice Series

Wood of oak trunks from a terrace of the Odra River in Opole-Grotowice (50°35'N, 17°55'E), at depth ca. 5 m in series of fine gravels. Collected June 1975 by W. Piszczatowski and submitted 1975 by J. Kaźmierczak, Institute of Archaeology, Wrocław University, Wrocław.

Gd-392. OG #1	2020 ± 140
Gd-394. OG #2	2410 ± 140
Gd-393. OG #3	1630 ± 140

Izdebno Series

Wood and charcoal from a fortified settlement of the Lusatian culture at a peninsula in Wolskie Lake near Izdebno (52°45'N, 17°39'E), 13 km southwest of Żnin, Gniezno Upland, Great Polish Lowland. Collected 1979 and submitted 1985 by B. Nowaczyk, Institute of Quaternary Research, Adam Mickiewicz University, Poznań.

Gd-1184. Izdebno 79/1 **2580 ± 50**

Wood from an oak log from a road surrounding the settlement, presently 1.4 m below water level (Nowaczyk *et al.* 1982).

Gd-717. Izdebno 79/2 **2950 ± 140**

Charcoal from a layer of clayey sands overlying the courtyard of the settlement, depth 1.2 m.

Comment (B.N.): Older than expected.

Smuszewo Series

Wood and charcoal from the remains of an individual house, 80 cm deep, in a fortified settlement of the Lusatian culture, Early Iron Age in Smuszewo (52°54'N, 17°24'E), Piła district (Durczewski 1970). Collected 1984 by D. Durczewski and submitted 1985 by L. Krzyżaniak, Archaeological Museum, Poznań.

Gd-3171. Smuszewo 1/84 **2670 ± 40**

Wood from a wall.

Gd-3173. Smuszewo 2/84 **2650 ± 40**

Charcoal from the floor of a house, probably a hearth.

Gd-3172. Smuszewo 3/84 **2600 ± 40**

Wood from the floor.

Gd-3050. Michelin M-1/262 **1810 ± 40**

Wooden pile from an enclosure (?) on a terrace of the Wisła River in Michelin (52°35'N, 19°1'E), Site 1, near Włocławek. Collected and submitted by S. Kukawka.

Comment (S.K.): Expected age *ca.* 2000 BC, which is much younger than expected.

Poprad River Valley Series

Charcoal from selected sites in the valley of the Poprad River, Beskid Sądecki Mts., West Carpathians, associated with the decline of the Przeworska culture. Collected by K. Tunia and submitted 1983 by J. Machnik.

Gd-1626. Moszczenica Wyżnia A/6 **1960 ± 60**

Single fragments found in Pit 6, depth 30–50 cm, Site A, situated on a watershed between the Moszczenica and Potok Przysietnicki Rivers, altitude 440 m asl, in Moszczenica Wyżnia (49°30'N, 20°39'E) near Stary Sącz, Nowy Sącz district. Collected 1975.

Comment (K.T.): Expected age: 4th–5th centuries BC (Madyda-Legutko and Tunia 1978).

- Gd-1620. Moszczenica Wyżnia A/5** 1400 ± 60
From deep Pit 5, Site A, depth 50–105 cm. Collected 1975.
- Gd-1609. Moszczenica Wyżnia C/11** 650 ± 40
From Pit 11, depth 30–70 cm, Site C. Collected 1976.
- Gd-1619. Piwniczna A/2** 1770 ± 50
From Pit 2, depth 20–40 cm, Site A, located at the drainage of a watershed between the Poprad and Łomniczanka Rivers, altitude *ca.* 600 m asl, in Piwniczna (49°26'N, 20°43'E). Collected 1977.
- Gd-1618. Rytro A/13a** 820 ± 50
From Pit 13a, depth 30–40 cm, Site A, located at the drainage of a watershed on the west bank of the Poprad River, altitude 490 m asl, in Rytro (49°29'N, 20°40'E). Collected 1981.

MIDDLE AGES

Pułtusk Series

Organic remains from Level V in a medieval castle (Gołembnik 1985) in Pułtusk (52°43'N, 21°5'E). Collected and submitted 1979 by A. Gołembnik, Warsaw.

- Gd-699. PI, organic remains, 422 cm** 850 ± 60
Gd-1174. PII, straw, 429 cm 780 ± 60
Gd-1175. PIII, wood from hut, 416 cm 1000 ± 80
Gd-1173. PIV, chopped straw, 420 cm 830 ± 60
Gd-1172. PV, moss, 421 cm 960 ± 60

Orle Series

Wood from two piles found in a vertical position in Site I in Orle (54°39'N, 18°9'E), near Wejherowo, Gdansk district, in Reda-Łeba Pradolina, south of Stare Orle Lake, at depth 125 cm in a layer with mollusk shells. Collected 1984 and submitted 1985 by D. Król, Archeological Museum, Gdansk.

- Gd-2331. Orle pile #1** 990 ± 100
Gd-2328. Orle pile #2 1000 ± 80

Comment (D.K. and M.F.P.): Part of Pile 1 was dated independently at Groningen, GrN-12896: 1070 ± 30 BP. Results agree within ± 1σ confidence limits (Pazdur *et al.* 1986).

Stradów Series

Charcoal and burned wooden beams from a rampart of an Early Medieval castle in Stradów (50°23'N, 20°30'E), near Czarnocin, Kielce district (Dąbrowska 1973). Samples Gd-2013 and -2015 collected 1981 by U. Maj; the rest collected 1983 by H. Zoll-Adamikowa; submitted by J. Machnik.

- Gd-2013. Stradów #1** 900 ± 60
From a fire layer, depth 60 cm.
- Gd-2015. Stradów #2** 930 ± 60
From the center of a rampart, depth 90 cm.
- Gd-1671. Stradów #3** 890 ± 40
From Rampart IV, depth 15–25 cm.

Gd-1672. Stradów #4C 815 ± 40

Gd-2155. Stradów #4W 820 ± 80

Charcoal and wood from a large beam of Rampart II, depth 10 cm.

Gd-1674. Umianowice #12-14/78 880 ± 40

Large pieces of charcoal (*Pinus silvestris* L. and *Quercus* L. spp. (identified by M. Lityńska)) from the base of dwelling Pit 3, depth 1.2 m, below a layer of stones, on the lower terrace of the Nida River in Umianowice (50°36'N, 20°31'E) near Kije, Kielce district. Collected 1978 by W. Morawski; submitted 1983 by J. Machnik.

Comment (W.M.): Associated pottery is dated to an early phase of the Middle Ages (7th–10th century AD).

Gd-698. Gaik 4/79 1160 ± 60

Charcoal from the base of Pit 5/79, depth 1.6 m, Layer IV with stone construction, Early Medieval pottery and animal bones, Trench 26, on cultural hill Gaik, altitude 100 m asl, in Radzikowo Stare (52°28'N, 20°21'E), Płock district. Collected and submitted 1979 by I. Dąbrowska, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Comment (I.D.): Expected age: end of 7th century AD (Gorska 1979).

Gd-3181. Gródek Leśny #1 1360 ± 40

Charcoal from a layer at depth 28–30 cm at the abutment of three ramparts in the Early Medieval sanctuary “Gródek Leśny” near Przysuchy Village (51°20'N, 20°36'E), Radom district, Holy Cross Mts. Collected and submitted 1985 by E. Gąssowska, Heritage Protection Center, Kielce.

Gd-1902. Zamczysko #2 1070 ± 50

Charcoal, scattered at depth 30 cm in cult center “Góra Zamczysko” in Widełki near Daleszyce (50°47'N, 20°36'E), Kielce district, Holy Cross Mts. Collected and submitted 1985 by E. Gassowska.

Wyszogród Drwały Series

Charcoal from a settlement associated with an Early Medieval castle, Site 2a in Wyszogród Drwały near Wyszogród Village (52°23'N, 20°9'E), Płock district. Submitted 1984 and 1985 by W. A. Moszczyński, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd-2283. WD 1/5B/84 1280 ± 130

From the base of Object 5B/84, Layer XVI, depth 137–140 cm, associated with a furnace and characteristic pottery dated to the beginning of the 7th century AD. Collected 1984 by M. Dulinicz.

Gd-1932. WD 18/5B/84 1280 ± 40

From the same cultural layer, depth 136 cm. Collected July 1985 by M. Dulinicz.

Gd-2280. WD 2/19/84 1370 ± 60

From Object 19/84 of unknown function, Layer III, at the base of a pit, depth 55–60 cm, associated with pottery dated to Phase I of Early Middle Ages in Mazovian Lowland, 6th century AD. Collected 1984 by W. A. Moszczyński.

Gd-1931. WD 19/25/85 1290 ± 35

From a stone furnace in square dugout 25, depth 136–140 cm. Collected 1985 by Z. Kobylński.

Gd-3211. WD 20/24 1370 ± 40

From a niche in Object 24, depth 40–55 cm, associated with a unique pot with an engraving representing a rider. Collected 1985 by W. A. Moszczyński.

Białka Series

Charcoal from two mounds in Białka Village (51°N, 23°E) near Krasnystaw, Chełm district, Lublin Upland. Collected 1983 and submitted 1984 by E. Mitrus, Laboratory for Conservation of Monuments, Lublin.

Gd-1831. Białka I/1a 1320 ± 35

From small collection at the north part of Mound I, depth 60 cm.

Gd-3152. Białka I/3 1170 ± 40

From the center of Mound I, depth 65 cm.

Gd-3151. Białka I/4 1340 ± 35

From tomb pit in center of Mound I, depth 2.6 m.

Gd-2367. Białka I/5 1410 ± 90

Small lumps found at the northern boundary of Mound I, depth 30 cm.

Gd-3124. Białka V/24 1240 ± 50

Remains of a burned wooden structure in the center of Mound V, depth 70 cm. Collected July 1984 by B. Okupny; submitted 1985.

Kraków Kanonicza Series

Wood (*Abies alba* Mill., identified by Irena Gluza) from the walls of a trench containing a collection of iron axes. In sterile sand, the trench was at a depth 120 cm below a recent floor of a subbasement room in House 13 at Kanonicza Street, Old City, Kraków (50°4'N, 19°56'E), ca. 200 m north of Wawel Castle. Collected July 1979 and submitted 1981 by E. Zaitz, Archaeological Museum, Kraków.

Gd-794. P-1A 1075 ± 120

Gd-795. P-1B 1065 ± 55

Comment (M.F.P. and E.Z.): The collection is dated to the end of the 8th and the first half of the 9th century AD. The samples were greatly decomposed and, during standard treatment, sample P-2 from the base of a wall was completely dissolved in alkali solution and rejected. Sample P-1A from the middle of the wall was better preserved but, because of high loss of matter, was counted after dilution with inactive gas. Sample P-1B, collected from same level as P-1A, was treated only with acid.

Kraków Senacka Series

Wooden logs from a structure of unknown function, from Early Medieval layers, Trench III, south part of the garden of the Archaeological Museum, Senacka Street, Old City, Kraków (50°4'N, 19°56'E), ca. 250 m north of Wawel Castle. Samples P-3 and P-4 are *Quercus* sp.; P-5 is *Fraxinus excelsior* L. (identified by Irena Gluza). Collected 1978 and submitted 1981 by E. Zaitz.

Gd-1262. P-3 1450 ± 50

Log 4 from Layer IIIId, depth 260–270 cm.

Gd-1272. P-4 1380 ± 45

Log 8 from Layer IIIIf, depth 283–297 cm.

Gd-1273. P-5 1445 ± 40

Log 8 from Layer IIIh, depth 328–334 cm.

Kraków Rynek Series

Charcoal from pits found below St. Wojciech Church in Rynek Główny, Old City, Kraków (50°4'N, 19°56'E), ca. 700 m north of Wawel Castle. Collected 1962 and submitted 1981 by T. Radwańska, Archaeological Museum, Kraków.

Gd-797. P-6**1680 ± 55**

Charcoal (*Pinus silvestris* L., identified by Irena Gluza) from pit associated with oldest occupation layer 1, depth 280 cm below actual floor of the church.

Gd-796. P-7**1360 ± 50**

Charcoal (*Alnus* sp.) from a pit associated with occupation layer 2, depth 325 cm below the actual floor of the church.

Comment (T.R.): Both samples are archaeologically dated to the 10th century AD (Radwański 1975).

Czersk Series

Human bones and wood from a cemetery, Site 1, associated with an early medieval castle in Czersk (51°51'N, 21°14'E) near Piaseczno, Warsaw district. The cemetery is located on top of a hill, ca. 20 m above the valley floor of the Wisła River. Graves were dug in medium-grained sands, underlying an anthropogenic layer 2.5–3 m thick. Collected during several seasons of systematic excavations (1960–1980) and submitted 1980 and 1981 by J. Rauhutowa, Institute of the History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd-793. Grave 79/62-A**1090 ± 70****Gd-836. Grave 79/62-L****1025 ± 90****Gd-845. Grave 79/62-E****1210 ± 50**

Bones of the same skeleton as from Grave 79/62, Square 25B, depth 237 cm; collected 1962.

Gd-831. Grave 113/62-L**1040 ± 110****Gd-835. Grave 113/62-E****1080 ± 90**

Bones of the same skeleton as from Grave 113/62, Square 25BC, depth 293 cm; collected 1962.

Gd-833. Grave 130/62-L**1085 ± 100****Gd-834. Grave 130/62-E****1150 ± 110**

Bones of same skeleton as from Grave 130/62, Square 27C, depth 282 cm; collected 1962.

Gd-815. Grave 678/76-W**1235 ± 55****Gd-816. Grave 693/76-W****980 ± 65**

Highly decomposed wood, depth ca. 3 m; collected 1976.

Gd-1810. Grave 775/80-L**890 ± 40**

Bone collagen, Grave 775/76, Trench 3D, depth 3 m; collected 1980.

Gd-3098. Grave 786/80-L**830 ± 30**

Bone collagen, Grave 786/80, Trench 3D, depth 3 m; collected 1980.

Gd-3102. Grave 789/80-L**840 ± 30**

Bone collagen, Grave 789/80, Trench 3D, depth 3.3 m; collected 1980.

Comment (M.F.P. & J.R.): The cemetery is archaeologically dated to the 12th–13th centuries AD (Rauhutowa 1976). Bones from excavations in 1962 were used to test different procedures of collagen extraction (A–acid, L–Longin, E–EDTA, cf. Olsson 1979). These dates are internally consis-

tent, but older than expected, which may be explained by incomplete removal of humic contaminants. Dates Gd-1810, -3098 and -3102 are on bones from excavations in 1980, from collagen extracted according to a slightly modified Longin (1971) procedure, and are in fairly good agreement with the expected age of the cemetery.

HISTORICAL SAMPLES

Gd-1665. Cedynia 11/1

1070 ± 50

Charcoal from Hearth 5 at depth 30 cm, Site 11, in Osinów Dolny near Cedynia (52°55'N, 14°23'E). Collected June 1972 by C. Krocak; submitted 1983 by W. Filipowiak, National Museum, Szczecin.

Comment (W.L.): The site associated with a historical battle in AD 972 (Filipowiak 1973).

Św. Krzyż Series

Fragments of a corpse and wood from the putative coffin of Duke Jarema Wiśniowiecki in a crypt of Saint Krzyż Church at the top of St. Krzyż Mountain in Góry Świętokrzyskie (Holy Cross Mts.), 20 km east of Kielce. Collected and submitted 1981 by J. Widacki, Department of Criminology, Silesian University, Katowice.

Gd-856. JW3-coffin wood

530 ± 80

Gd-865. JW4-bone

280 ± 200

Comment: Very small sample, undersized, diluted.

Gd-857. JW1-interstines

280 ± 90

Gd-852. JW2-interstines

310 ± 80

Comment (M.F.P.): Samples were dated as part of an interdisciplinary study to check the authenticity of the corpse. ¹⁴C dates do not contradict this hypothesis (Goslar, Pazdur and Pazdur 1983). Duke Jarema Wiśniowiecki died suddenly in AD 1651 at the age of 39.

Gd-1689. Tupadły 2/2

80 ± 40

Collagen from a human bone from a burial of three individuals at the edge of a mound in Tupadły (52°42'N, 18°15'E) near Inowrocław, Bydgoszcz district, Kujawy Plateau. Collected 1983 and submitted by A. Kośko.

Comment (A.K.): Because of a lack of associated artifacts, this burial was expected to be either from the beginning of the second millennium BC or of historical age. Date confirms historical age of the burial, which is most probably connected with a battle near Tupadły in AD 1665.

UNKNOWN OR UNCERTAIN CHRONOLOGY

Gdańsk Boats Series

Oak wood from a stave boat and two dugouts from a collection of the Central Maritime Museum in Gdańsk (Smolarek 1991). Submitted March 1984 by M. Dyrkova, Central Maritime Museum.

Gd-1896. Curve boat

1200 ± 50

Outermost treerings from a "curve boat" found in 1951 on the bottom of the Baltic Sea in the Gotland Deep area, ca. 40 km west of Libawa (56°27'N, 19°25'E).

Gd-1895. Long dugout

1490 ± 50

Outermost part of a "long dugout" probably found near Gdańsk before 1914. The boat has been exhibited since 1945 in the Archaeological Museum, Gdańsk.

Gd-3176. Greatest dugout**1070 ± 40**

Outermost rings from the “greatest dugout” from a collection of the Central Maritime Museum, Gdańsk; proveniences uncertain.

Borkowo Series

Pine wood from two dugouts found at the bottom of Głębokie Lake in Borkowo Village (54°20'N, 18°20'E), Gdańsk district. Collected 1981 by W. Urbański; submitted by M. Dyrkova.

Gd-922. Dugout I**60 ± 60****Gd-1424. Dugout II****270 ± 40**

Comment (M.F.P. and M.D.): Dugouts were treated with preservatives (polyethylene glycol 1500); samples were stored in water at ambient temperature for ten weeks before being submitted for dating; then they were subjected to standard acid-alkali-acid treatment.

Tolkmicko Series

Oak wood from fragments of two stave boats found in a meadow in Tolkmicko (54°20'N, 19°31'E). Collected 1981 by J. Kucharski; submitted by M. Dyrkova.

Gd-920. Rib, W-15/7/80**380 ± 80****Gd-921. Rib, Boat Ia****400 ± 80****Gd-1212. Wreck W-18****740 ± 50**

Oak wood from the rib of the wreck of stave boat W-18 found in basal sediments at the mouth of the Wisła River (54°22'N, 18°56'E), *ca.* 7 m below water level. Collected 1980 by M. Iżewski; submitted by M. Dyrkova.

Comment (M.D.): The boat is typologically dated to the Middle Ages.

Gd-1213. Czarnowsko II boat**1000 ± 90**

Oak wood from the keel of a stave boat found in a meadow near Czarnowsko Village (54°45'N, 17°20'E), at depth 30 cm, *ca.* 250 m south of Łeba Lake shore. Collected 1980 by M. Iżewski; submitted by M. Dyrkova.

Comment (M.D.): Typologically dated to the 12th century AD.

Gd-2064. Ulanów-Sudoły dugout**1300 ± 50**

Oak wood from a dugout found in San River deposits at depth 70 cm in Ulanów-Sudoły (50°34'N, 22°4'E), Sandomierz Basin, southeast of Stalowa Wola. Collected 1983 by Z. Kocur; submitted by M. Dyrkova.

Gd-2230. Łąd boat**1120 ± 70**

Oak wood from rib 13 of a stave boat found in the Warta River floodplain at depth 2 m at the foot of a rampart of a medieval castle in Łąd (52°10'N, 17°50'E), Konin district, Great Poland Lowland. Collected 1984 by M. Brucki and submitted by M. Dyrkova.

Comment (M.D.): This is the first stave boat found inland in Poland.

REFERENCES

- Bednarczyk, J., Koško, A., Krawe, E. and Makiewicz, T. 1975 Studies on the final phase of the Globular Amphora Culture in Cuiavia. Settlements of the Globular Amphora culture in the trough of Pakoskie Lake. *Wiadomości Archeologiczne* 40(3): 275–289 (in Polish).
- Chmielewska, H. 1954 A Tardenoise culture grave in Janisławice, Skierniewice District. *Wiadomości Archeologiczne* 20(1): 23–48 (in Polish).
- Czerniak, L. 1980 *Societal Development of the Late Bandkeramic Cultures in Cuiavia*. Poznań, Adam Mickiewicz University Press (in Polish).
- Dąbrowska, E. 1973 *Great Fortified Settlements in the Upper Vistula Basin*. Wrocław-Warsaw-Kraków-Gdańsk, Ossolineum (in Polish).
- Dąbrowski, M. 1981 Pollen analysis of the Całowanie peat bog. *Archeologia Polski* 26(2) (in Polish).
- Durczewski, D. 1970 *An Early Slavonic Fortified Settlement in Smuszewo*. Poznań, Muzeum Archeologiczne (in Polish).
- Filipowiak, W. 1973 *Economic and Political Significance of Cedynia at the Beginning of the Polish State*. Szczecin, Muzeum Narodowe (in Polish).
- Gołembnik, A. 1985 The excavations in the castle hill in Pułtusk: New directions in archaeological research. In Edgren, T. and Jungner, H., eds., *Application of Scientific Methods in Archaeology*. Helsinki, National Board of Antiquities: 15–22.
- Górska, I. 1979 *Fortified Settlements of Mazowsze and Podlasie*. Wrocław-Warszawa-Kraków-Gdańsk, Ossolineum (in Polish).
- Goslar, E., Pazdur, A. and Pazdur, M. F. 1983 An attempt at radiocarbon dating the suspected corpse of Duke Jarema Wisniowiecki. *Archiwum Medycyny Sądowej* 32: 77–80 (in Polish).
- Guřba, J. 1974 The Wolhynia-Lublin Painted Pottery culture. *Annales UMCS* 28: 83–94 (in Polish).
- Kanwiszer, A. and Trzeciak, P. 1984 Łódź radiocarbon dates I. *Radiocarbon* 26(1): 111–126.
- _____. 1986 Łódź radiocarbon dates II. *Radiocarbon* 28(3): 1102–1209.
- Kempisty, A. and Sulgostowska, Z. 1976 The first Neolithic settlement with pottery of the Dubiczaj type in northeastern Poland. *Wiadomości Archeologiczne* 41: 305–324.
- Kempisty, E. 1962 Discovery of a Bandkeramic culture grave near Lublin, in Gródek Nadbużny, Hrubieszów District. *Wiadomości Archeologiczne* 28: 284–285 (in Polish).
- Kobusiewicz, M. 1980 Ausgrabungen auf einer mesolithischen und neolithischen Fundstelle bei Chwalim, Westpolen. *Veroff des Museums für Ur- und Fruhgeschichte Potsdam* 14/15: 337–342.
- Koško, A. 1976 A contribution to studies of the genesis and development of the Cuiavian enclave of so-called chamberless graves. *Archeologia Polski* 21(2): 402–408 (in Polish).
- _____. 1979 *Cultural Development of Kujawy Communities During the Late Neolithic and Early Bronze Age*. Poznań, Adam Mickiewicz University Press (in Polish).
- _____. 1981a *Contribution of Southeast European Cultural Patterns to the Development of the Lowland Funnel Beaker Culture Communities*. Poznań, Adam Mickiewicz University Press (in Polish).
- _____. 1981b A contribution to studies of the Radziejów Group of the Funnel Beaker Culture. In Cofta-Broniewska, A., ed., *Studies of the Funnel Beaker Culture in Poland*. Poznań, Adam Mickiewicz University Press: 191–212 (in Polish).
- Kowalczyk, J. 1968 Two assemblages dated with radiocarbon. *Wiadomości Archeologiczne* 33: 368–376 (in Polish).
- Kruk, J. 1973 *Settlement Studies in the Neolithic of the Loessy Uplands*. Wrocław-Warszawa-Kraków, Ossolineum (in Polish).
- Kulczycka-Leciejewiczowa, A. 1979 Early farming communities in the territory of Poland. Cultures of the Danube Circle. In Godłowska, M., Kulczycka-Leciejewiczowa, A., Machnik, J. and Wiślański, T., eds., *Prehistory of Poland*, Vol. II, *Neolithic*. Wrocław-Warszawa-Kraków-Gdańsk, Ossolineum: 19–164 (in Polish).
- Longin, R. 1971 New method of collagen extraction for radiocarbon dating. *Nature* 230: 241–242.
- Machnik, J. 1966 *Studies in Bandkeramic Cultures in the Malopolska Region*. Wrocław-Warszawa-Kraków, Ossolineum (in Polish).
- _____. 1978 *Frühbronzezeit Polens. Übersicht über die Kulturen und Kulturgruppen*. Wrocław-Warszawa-Kraków-Gdańsk, Ossolineum.
- _____. 1979 The Bandkeramic cultural circle. In Godłowska, M., Kulczycka-Leciejewiczowa, A., Machnik, J. and Wiślański, T., eds., *Prehistory of Poland*, Vol. II, *Neolithic*. Wrocław-Warszawa-Kraków-Gdańsk, Ossolineum: 337–412 (in Polish).
- Mamzer, H. 1983 Excavations of the iron smelting settlement of the Roman period in Psary, Leszno voivodship. *Sprawozdania Archeologiczne* 34: 141–152 (in Polish).
- Mamzer, H. and Pazdur, M. F. 1984 A chronology of the metallurgic site in Psary, Leszno voivodship, in the light of C-14 dating. *Archeologia Polona* 23: 67–85.
- Moscicki, W., Pazdur A., Pazdur, M. F. and Zastawny, A. 1978 Gliwice radiocarbon dates IV. *Radiocarbon* 20(3): 405–415.
- Moscicki, W. and Zastawny, A. 1976 Gliwice (Gdańsk) radiocarbon dates III. *Radiocarbon* 18(1): 50–59.
- Parczewski, M. 1983 Ulucz, province of Krosno, community of Dydnia, site 3. *Recherches Archéologiques de 1981*. Kraków.
- Pazdur, A., Awiśuk, R., Bluszcz, A., Pazdur, M. F., Walanus, A. and Zastawny, A. 1982 Gliwice radiocarbon dates VII. *Radiocarbon* 24(2): 171–181.

- Pazdur, A., Pazdur, M. F. and Zastawny, A. 1981 Ancient iron metallurgy in Poland in light of radiocarbon dating. *Materiały Archeologiczne* 21: 87–94 (in Polish).
- Pazdur, M. F. 1990 Absolute chronology of ancient iron metallurgy in Poland in light of the calibration of the radiocarbon time scale. *Materiały Archeologiczne* 25: 95–104 (in Polish).
- Pazdur, M. F., Awiśuk, R., Bluszcz, A., Goslar, T., Pazdur, A., Walanus, A. and Zastawny, A. 1985 Gliwice radiocarbon dates X. *Radiocarbon* 27(1): 52–73.
- Polkowski, T. 1958 Settlement of the Funnel Beaker culture in Gródek Nadbużny, Hrubieszów District (Site 1C). *Archeologia Polski* 2: 235–278 (in Polish).
- Radwański, K. 1975 *Kraków Before Location—Spatial Development*. Kraków, Muzeum Archeologiczne (in Polish).
- Rauhutowa, J. 1976 *Czersk in the Early Middle Ages from the 7th to 12th Centuries*. Wrocław-Warsaw-Kraków-Gdańsk, Ossolineum (in Polish).
- Schild, R. 1975 The Late Paleolithic. In Chmielewski, W. and Hensel, W., eds., *Prehistory of Poland*, Vol. II, *Paleolithic and Mesolithic*. Wrocław-Warsaw-Kraków-Gdańsk, Ossolineum: 159–338 (in Polish).
- _____. 1982 Archaeological stratigraphy of inland dunes as seen from the Mazowsze region. *Roczniki Gleboznawcze* 33(3–4) (in Polish).
- Schild, R. and Królik, H. 1981 Rydno—a final Paleolithic ochre mining complex. *Przegląd Archeologiczny* 29: 53–100.
- Schild, R., Królik, H. and Mościbrodzka, J. 1977 *A Chocolate Flint Mine from the Turn of the Neolithic and the Bronze Age in Polany Kolonie*. Wrocław-Warsaw-Kraków-Gdańsk, Ossolineum (in Polish).
- Smolarek, P. 1991 The underwater investigations of the Polish Maritime Museum in Gdańsk from 1982 to 1985. *Acta Universitatis Nicolai Copernici, Archeologia* 15: 3–13.
- Wiślański, T. 1979 The formation of local farming and breeding cultures: Tribes of the Funnel Beaker culture. In Godłowska, M., Kulczycka-Leciejewiczowa, A., Machnik, J. and Wiślański, T., eds., *Prehistory of Poland*, Vol. II, *Neolithic*. Wrocław-Warsaw-Kraków-Gdańsk, Ossolineum: 165–260 (in Polish).
- Zurek, T. 1953 A Paleolithic settlement in Rzućewo. *Fon-tes Archaeologici Posnaniensis* 4: 1–40 (in Polish).

GLIWICE RADIOCARBON DATES XII

ANNA PAZDUR, MIECZYSLAW F. PAZDUR and ANDRZEJ ZASTAWNY

Radiocarbon Laboratory, Institute of Physics, Silesian Technical University, Krzywoustego 2
PL-44-100 Gliwice, Poland

INTRODUCTION

The following list presents results of dating archaeological samples from excavations in Africa. Most results reported in this list were obtained from 1982 to 1993 for international research projects studying the origin and early development of food-producing cultures in northeastern Africa, including the Nile basin and the Sahara. Detailed information on these projects may be found in the series of conference proceedings edited by Krzyżaniak and Kobusiewicz (1984, 1989, 1993).

Three proportional counters (L1, L2 and L3), of 2.5, 5 and 1.5 liter volume, were used for dating (Pazdur *et al.* 1982). Procedures for sample pretreatment, counting, statistical analysis and age calculations were essentially as described in Pazdur *et al.* (1982, 1985). All results are reported as conventional ^{14}C dates in years before AD 1950. Dates listed with $\delta^{13}\text{C}$ values have been adjusted for isotopic fractionation by normalization to $\delta^{13}\text{C} = -25\text{‰}$. Sample descriptions are essentially based on information provided by submitters.

ACKNOWLEDGMENTS

This contribution is part of research supported by grant PB 740/6/91 from the State Committee for Scientific Research.

PALEOLITHIC

Wadi Kubbaniya Series

Charcoal from excavations of Upper Paleolithic sites of Kubbaniyan culture in Wadi Kubbaniya (33°N, 24°E), Western Desert, Upper Egypt, consisting of cultural layers in dune sands (Wendorf, Schild and Close 1980, 1987). Site E-78-3 is located *ca.* 25 km N of Assuan, sites E-78-4 and E-78-5 *ca.* 15 km N of Assuan, at elevations of *ca.* 100 m asl. Samples from E-78-3 collected 1982 and 1983 by Angela Close, from E-78-4 collected February 1983 by Hanna Wieckowska, from E-78-5 collected 1983 by Michał Kobusiewicz. Submitted 1982 and 1983 by Romuald Schild, Institute of History of Material Culture, Polish Academy of Sciences, Warsaw.

Gd-1522. Wadi Kubbaniya E-78-3/20	18,500 ± 220
From Level 20, Cut I/82, depth 150–200 cm.	
Gd-1520. Wadi Kubbaniya E-78-3/20/21	18,110 ± 160
From Level 20/21, Cut I/82, depth 150–200 cm.	
Gd-2091. Wadi Kubbaniya E-78-3/23	18,140 ± 400
From Level 23, Grid G-21–24, depth 150–200 cm.	
Gd-1610. Wadi Kubbaniya E-78-3/24	18,470 ± 180
From Level 24, Grid G-21–24, depth 50–150 cm.	
Gd-2092. Wadi Kubbaniya E-78-3/over 24	18,080 ± 350
Dispersed in white sand overlying cultural level 24, Grid G-21–24, depth 20–50 cm.	

Gd-1611. Wadi Kubbaniya E-78-4/c From Level c, depth 100–150 cm.	17,800 ± 170
Gd-1612. Wadi Kubbaniya E-78-4/e From Level e, depth 130–180 cm.	17,640 ± 140
Gd-2093. Wadi Kubbaniya E-78-4/f From Level f, depth 150–200 cm.	17,620 ± 340
Gd-2094. Wadi Kubbaniya E-78-5/f From Level f, depth 150–200 cm.	15,830 ± 220

Comment (M.F.P.): Bluszcz and Pazdur (1986, 1987) discuss in detail ^{14}C and TL dates obtained on materials from this site. Other conventional ^{14}C dates are presented by Haas (1987), and AMS ^{14}C dates by Donahue *et al.* (1987); Hietala (1987) analyzes and interprets all available ^{14}C dates.

NEOLITHIC

Nabta Series

Charcoal from excavations of Early Neolithic settlement on the shore of a seasonal lake, Nabta Playa (22°32'N, 30°42'E), Western Desert, Egypt, elevation 200 m asl. Collected 1990, 1991 and 1992 and submitted by R. Schild. Results of early excavations undertaken in 1975–1977 are discussed by Wendorf and Schild (1980) and Schild and Wendorf (1984); results of archaeobotanical studies are reported by Wendorf *et al.* (1992); Hedges *et al.* (1993) list dates recently obtained at the Oxford AMS facility.

Gd-6260. Nabta E-75-6#1/90 Pit I/90, X/12, the lowest part of the pit.	8260 ± 100
--	-------------------

Comment (M.F.P.): The date obtained by the Oxford AMS facility on single plant macrofossils (seeds, identified by K. Wasylikowa) from Pit I/90, X-Y/12, OxA-3220, 8025 ± 120 BP (Hedges *et al.* 1993), agrees fairly well.

Gd-6257. Nabta E-75-6#2/90 Feature 1/90, W/13.	7770 ± 110
--	-------------------

Gd-6498. Nabta E-75-6#1/91 Feature 1/90, NEQ, X/15, base of hearth.	7830 ± 110
---	-------------------

Gd-6254. Nabta E-75-6#3/90 Feature 1/90, Y/16.	8550 ± 130
--	-------------------

Comment (M.F.P.): Dates obtained by the Oxford AMS facility (Hedges *et al.* 1993) on single plant macrofossils (seeds, identified by K. Wasylikowa) from Feature 1/90 are: W/14, OxA-3214, 8080 ± 110 BP; W/14, OxA-3215, 8095 ± 120 BP; Y/17-17, OxA-3217, 8020 ± 160 BP; W/13, OxA-3218, 8050 ± 130 BP. Our date obtained on large pieces of charred wood is too old, probably because of the “old wood effect”.

Gd-4586. Nabta E-75-6#5/90 Pit, BB/10.	7450 ± 120
--	-------------------

Gd-6258. Nabta E-75-6#6/90 Feature 2/90, BB/12.	7920 ± 100
---	-------------------

Gd-6500. Nabta E-75-6#2/91 7910 ± 110

Feature 2/90, single pieces of charcoal scattered at the margin of the pit.

Comment (M.F.P.): Dates agree fairly well with results obtained at the Oxford AMS facility (Hedges *et al.* 1993): BB/12, OxA-3222, 8060 ± 120 BP.

Gd-4587. Nabta E-75-6#4/90 8600 ± 140

Feature 3/90, BB/17.

Comment (M.F.P.): Date obtained by the Oxford AMS facility (Hedges *et al.* 1993) on single plant macrofossils (*Sorghum* seeds, identified by K. Wasylikowa) from Feature 3/90: BB/17, OxA-3219, 7950 ± 160 BP.

Gd-6503. Nabta E-75-6#3/91 7590 ± 110

Feature 3/90, SEQ, Square DD/19, hearth in dark brownish sand.

Gd-6506. Nabta E-75-6#4/91 7850 ± 90

Feature 1/91, Square GG-HH/22, hearth.

Gd-6507. Nabta E-75-6#5/91 7610 ± 120

Feature 1/91, NWQ, layer with charcoal *ca.* 3–5 cm above the floor.

Gd-5971. Nabta E-75-6#6/91 7960 ± 70

Feature 1/91, Square HH/20–21, single pieces of charcoal from the filling of a pit.

Gd-6508. Nabta E-75-6#7/91 7540 ± 110

Pit, Square GG/10, charcoal dispersed at a depth of 95 cm in yellow sand.

Gd-6509. Nabta E-75-6#8/91 7480 ± 110

Base of Pit 2/90, depth 100 cm.

Gd-6510. Nabta E-75-6#9/91 7330 ± 100

Base of Pit 1/91.

Gd-6734. Nabta E-75-6#1/92 6710 ± 110

Pit 1/90, fireplace 1 in brown sand, Y/16.

Gd-6733. Nabta E-75-6#2/92 6620 ± 90

From cultural layer, Trench IV/91.

Gd-6742. Nabta E-75-6#4/92 6750 ± 100

Trench 1/90, from pothole in fireplace in brown sand, GG/14.

Gd-6746. Nabta E-92-8#6/92 3130 ± 110

Fireplace in cultural layer with remains of stone huts.

Dakhleh Oasis Series

Charcoal and ostrich eggshells were collected during several seasons of activities of the Dakhleh Oasis Project (DOP) expedition of the Royal Ontario Museum, directed by A. J. Mills. The Dakhleh Oasis is located in the Egyptian Sahara, with its center at 25°48'N and 29°05'E. The oasis is *ca.* 80 km long and up to 25 km wide, overlooked by a 400-m-high south-facing limestone escarpment. Its floor is flat clay plain, originally lacustrine, and rises slightly northward from 100–135 m asl. The DOP objective is to gain a detailed understanding of the cultural and environmental history of the Dakhleh Oasis since the beginning of the Holocene. Mills (1984) presented a general outline of the

DOP; Brookes (1983, 1989) presented results of geoarchaeological reconnaissance and sedimentological studies; Edwards and Hope (1989) briefly summarized results obtained in the study of Neolithic ceramics, giving a complete list of references to interim reports published by members of the DOP team; and McDonald (1990) discussed some aspects of cattle pastoralism at the site.

Samples of DOP surface subseries were collected 1990 during a surface survey for sites of the Bashendi culture at the base of a hill bearing rock art, a sandstone ridge south of the SE basin, SE corner of Dakhleh Oasis (23°41'N, 29°14'E), *ca.* 20 km S of Teneida, elevation 500 m asl. Samples from Site 228 with artifacts of the Bashendi culture and Site 264 of the Masara culture (25°25'N, 29°25'E) were collected 1989 and 1990 and submitted 1990; samples from other sites of the Bashendi culture in the SE corner of Dakhleh Oasis (25°25'N, 29°22'E) were collected and submitted 1991 by Mary M. A. McDonald, Department of Archaeology, University of Calgary, Canada. Samples from a calcareous Early Holocene lake (23°41'N, 29°14'E) were collected 1990 and submitted by Ian Brookes.

DOP 88 Subseries

Gd-5792. DOP 88#1

7200 ± 70

$\delta^{13}C = -5.5\text{‰}$

Ostrich eggshell from Cluster 1 on surface, Site 228, Square J6-J7, associated with potsherds of Bashendi culture, demonstrated archaeologically to be a living site with hearths and artifacts on, or slightly under, the surface, resting partly on silt or sand.

Gd-4622. DOP 88#2

6380 ± 100

Charcoal, scattered fragments (hearth?), just under surface, Cluster 1, Site 228, Square I11, associated with Bashendi potsherds.

Gd-6323. DOP 88#3

6940 ± 140

Charcoal, scattered fragments from buried Feature, Level 2, Site 228, Square A6, depth 12–14 cm, associated with the Bashendi culture.

Gd-4624. DOP 88#4

5770 ± 150

Charcoal, scattered fragments within an area 30 cm in diameter, probably a hearth, from the surface of Cluster 2, Site 228, Square 4–5, depth 1–3 cm.

Gd-6321. DOP 88#5

7600 ± 100

Charcoal from Stake Hollow, sandy layer below silt, depth 20 cm, Site 228, Square R20, Bashendi culture, early phase.

DOP 89 Subseries

Gd-4492. DOP 89#1

4310 ± 80

Charcoal from a rockshelter of the “Sheikh Muftah” cultural unit, Site 244 (McDonald 1990).

Gd-5646. DOP 89#2

5830 ± 70

Ostrich eggshell from surface scatter, same locality as DOP 89#3.

$\delta^{13}C = 0.2\text{‰}$

Gd-6168. DOP 89#3

6300 ± 110

Charcoal from Cluster f, hearth mound, Site 254.

Gd-6169. DOP 89#5

7320 ± 120

Charcoal from cultural layer 40 cm below surface, sealed by silts, Stake Hollow, K17b, Site 228.

Gd-6170. DOP 89#6

7360 ± 90

Charcoal from a hearth underlying the surface, Stake Hollow, J18a, Site 228.

Gd-5654. DOP 89#7 6990 $\pm$ 70

Charcoal from a hearth underlying the surface, Stake Hollow, M18b, Site 228.

Gd-4493. DOP 89#8 8340 $\pm$ 150

Charcoal from a hearth 35 cm below the surface, sealed by silts, Stake Hollow, K17, Site 228.

Comment: small sample, diluted with inactive CO_2 for counting.

Gd-5645. DOP 89#9 5930 $\pm$ 60

$\delta^{13}\text{C} = 0.89\text{‰}$

Ostrich eggshell from surface scatter around Cluster 1, hearth mound, Site 252, same locality as DOP 89#10.

Gd-4495. DOP 89#10 6120 $\pm$ 250

Charcoal from Cluster 1, hearth mound, underlying the surface. *Comment:* diluted with inactive CO_2 for counting.

DOP CVC Subseries

Gd-5722. DOP CVC 270 s#8 6470 $\pm$ 70

Ostrich eggshell from surface scatter over an area with many hut circles.

$\delta^{13}\text{C} = -4.4\text{‰}$

Gd-5720. DOP CVC 264 s#7

8730 $\pm$ 70

$\delta^{13}\text{C} = -1.1\text{‰}$

Ostrich eggshell from surface scatter over part of the surface of the hut-circle cluster, Masara culture.

Gd-5721. DOP CVC 266 s#6

7910 $\pm$ 80

Ostrich eggshell from surface scatter.

$\delta^{13}\text{C} = -2.6\text{‰}$

Gd-5718. DOP CVC 262 s#4

8650 $\pm$ 80

$\delta^{13}\text{C} = -2.8\text{‰}$

Ostrich eggshell from surface scatter, cluster within a scatter of chipped stone, Masara culture.

Gd-5717. DOP CVC 261 s#3

7380 $\pm$ 70

$\delta^{13}\text{C} = 0.0\text{‰}$

Ostrich eggshell from the surface, associated with both Masara and Bashendi artifacts, N part of SE basin.

Gd-5719. DOP CVC 257 s#1

6250 $\pm$ 50

$\delta^{13}\text{C} = -5.20\text{‰}$

Ostrich eggshell from the surface, associated with artifacts of Bashendi culture, N part of SE Basin.

DOP 90 Subseries

Gd-5799. DOP 90#2

7200 $\pm$ 70

$\delta^{13}\text{C} = -4.48\text{‰}$

Ostrich eggshell from the surface, Stake Hollow, Site 228, Square R20, Bashendi culture, early phase. Eggshell is just now being exposed through wind action; other eggshells still remain buried within a cultural layer up to 10 cm thick.

Gd-6322. DOP 90#5

7570 $\pm$ 110

Charcoal around hearth, depth 10 cm, under playa silts, Stake Hollow, Site 228, Square J16a, Level 2, Bashendi culture, sample associated with chipped stone, animal bones and ostrich eggshell.

Gd-4623. DOP 90#11**6480 ± 140**

Charcoal from the base of a cultural layer under silts, depth *ca.* 35 cm, Site 228, test trench in Square L17, sample associated with chipped stone, eggshell and bone, Bashendi culture.

Gd-6318. DOP 90#9**8660 ± 90**

Charcoal from a pocket of sand between sandstone slabs forming the wall of a hut circle, depth *ca.* 10 cm, Site 264, Square I30d, Hut I29, sample associated with chipped stone, Masara culture, Early Holocene wet phase.

Gd-6320. DOP 90#10**8950 ± 120**

Charcoal, layer of ash within a stone ring (hearth?) under a hut circle, depth *ca.* 35 cm, Site 264, Square I29, sample associated with chipped stone, Hut I29, Masara culture, Early Holocene wet phase.

DOP 91 Subseries

Charcoal and ostrich eggshell from surface excavations of several Neolithic sites of the Bashendi culture, SE basin, SE corner of Dakhleh Oasis (25°25'N, 29°22'E), *ca.* 20 km S of Teneida, Sahara Desert, SW Egypt. Collected and submitted 1991 by M. McDonald.

Gd-5993. DOP 91#7**5240 ± 110**

Charcoal, scattered fragments from a layer *ca.* 10 cm below the surface of a hearth mound, Cluster i, Bashendi culture Group B, Site 254.

Gd-5983. DOP 91#8**5940 ± 70** $\delta^{13}C = -1.2\text{‰}$

Ostrich eggshell, from thin surface scatter within a circle, radius *ca.* 50 cm around the hearth that yielded sample DOP 91#7, Bashendi culture Group B, Site 254.

Gd-6529. DOP 91#9**5180 ± 110**

Charcoal from hearth #126, depth 2–10 cm, Bashendi culture Group B, Site 254.

Gd-5985. DOP 91#10**5630 ± 50** $\delta^{13}C = 0.6\text{‰}$

Ostrich eggshell from thin surface scatter within a circle, radius *ca.* 5 m around mapping point #124, Bashendi culture Group B, Site 254.

Gd-5994. DOP 91#11**5810 ± 80**

Charcoal, in the form of a patch 40 cm × 25 cm and 4 cm deep, underlying the surface, Square I8d, Level 1, Site 271.

Gd-6534. DOP 91#13/#14/#15**6280 ± 100**

Very fine charcoal, underlying the surface; dated material was obtained by joining three subsamples collected from Squares E9a, F8a and G8b, Site 271.

Gd-6538. DOP 91#17–18**6360 ± 120**

Charcoal, underlying the surface; dated material was obtained by joining two subsamples collected from the same pit on the boundary of Squares I7b and I7d, excavated separately, Site 271.

Gd-5990. DOP 91#1**6850 ± 50**

Charcoal from a layer 5–10 cm below the surface of hearth mound #21, associated with potsherds belonging to Bashendi culture Group A, Site 275.

- 7100 ± 60**
 $\delta^{13}\text{C} = -4.3\text{‰}$
- Gd-5981. DOP 91#3**
Ostrich eggshell, collected from the surface, mapping point #17, Cluster 1, associated with potsherds of the Bashendi culture, Site 275.
- 6640 ± 70**
 $\delta^{13}\text{C} = -1.2\text{‰}$
- Gd-5984. DOP 91#12**
Ostrich eggshell, collected from the surface, mapping point #8, associated with potsherds belonging to the Bashendi culture Group A, Site 275.
- 6370 ± 70**
- Gd-5992. DOP 91#4**
Charcoal from scattered fragments in a layer at depth *ca.* 10 cm below the surface of hearth mound #44, Cluster 1, Bashendi culture Group B, Site 276.
- 5750 ± 50**
 $\delta^{13}\text{C} = -1.0\text{‰}$
- Gd-5982. DOP 91#6**
Ostrich eggshell from the surface around hearth #44, Bashendi culture Group B, Site 276.
- 7180 ± 60**
 $\delta^{13}\text{C} = -3.2\text{‰}$
- Gd-5985. DOP 91#19**
Ostrich eggshell from the surface excavation of an isolated stone circle (hut circle?), depth 0–20 cm, Site 277.
- 4380 ± 120**
- Gd-6535. DOP 91#20**
Very fine charcoal, underlying the surface, from an area of burning consisting of isolated patches under windblown sand filling a hut circle, Site 277.
- Comment* (M.M.A.McD.): There is no clear evidence for associating dated samples DOP 91#19 and DOP 91#20 with the Bashendi culture group; the date obtained on charcoal is younger than expected, probably rejuvenated by the admixture of much younger windblown organic matter. The date on ostrich eggshell fits well with the expected limits of the Bashendi culture.
- DOP 92 Subseries*
- 8420 ± 300**
- Gd-4844. DOP 92#1**
Charcoal from a hearth in red sand, depth 3–4 cm, Grid A, BIIa.
- Comment:* Small sample, diluted with inactive CO₂ for counting.
- 6860 ± 80**
- Gd-6636. DOP 92#2**
Charcoal from a hearth, depth 5–6 cm, middle part of Hut I, Grid A, B9c-d.
- 6840 ± 80**
- Gd-6637. DOP 92#3**
Charcoal from a hearth in Hut 4, depth 15 cm.
- 6640 ± 80**
- Gd-6645. DOP 92#4**
Charcoal from an ashy midden or hearth outside Hut 173, underlying the surface, depth 3–12 cm, associated with flecks and small chunks, Grid B, TIIId.
- 6920 ± 80**
- Gd-6638. DOP 92#5**
Charcoal from a hearth within Hut 173, depth 10 cm, Grid B, L12d.
- 6990 ± 70**
 $\delta^{13}\text{C} = -5.1\text{‰}$
- Gd-7088. DOP 92#6**
Ostrich eggshell collected on the surface around stone circles, west side of Grid B.

Gd-6632. DOP 92#7**6650 ± 80**

Ostrich eggshell from a surface cluster in an activity area within a hut circle, south side of Grid A.

*Dakhleh Oasis Lake Subseries***Gd-4618. Dakhleh Oasis DK 8/90****7030 ± 240**

Charcoal, Site 166-c, Square 06/04.

Gd-4563. Dakhleh Oasis DK 1/90**8680 ± 170**

Ostrich eggshell, Site 166-c, hearth, Square 05/03.

 $\delta^{13}C = -2.0\text{‰}$ **Gd-5712. Dakhleh Oasis DK 7/90****8180 ± 70**

Ostrich eggshell, Site 166-c, Square 06/04.

 $\delta^{13}C = -2.9\text{‰}$ **Qasr-el Sagha Series**

Charcoal from excavations of Neolithic settlements containing remains of the Fayum A culture (Ginter and Kozłowski 1984; Kozłowski and Ginter 1989) in Qasr el-Sagha (30°40'N, 29°20'E), Western Desert, north of Bisket Lake, southwest of Qasr el-Sagha Temple. Several sites occur within a layer of crossbedded sand from ancient deltaic deposits of Moeris Lake, elevation 100 m asl (Ginter *et al.* 1980; Kozłowski 1983; Pazdur 1983). Collected December 1980 and December 1981 and submitted 1981 and 1982 by Bolesław Ginter, Institute of Archeology, Jagellonian University, Kraków.

Gd-903. QS P7/80**5410 ± 110**

From hearth #1 in white silt layer, Site QS VID/80.

Gd-895. QS P10/80**5070 ± 110**

From a sandy layer below fossil soil, section 7, Site QS VIIA/80.

Gd-915. QS P10/80A**5160 ± 110**

From a sandy layer below fossil soil, section 6, Site QS VIIA/80.

Gd-916. QS P12/80**5080 ± 110**

From a sandy layer above fossil soil, section 6, Site QS VIIA/80.

Gd-904. QS P13/80**5010 ± 120**

From a layer of white sand, Trench 1, depth 250–255 cm, Site QS VIII/80.

Gd-874. QS P14/80**5120 ± 110**

From hearth #2, Site QS VIIG/80.

Gd-1372. QS P15/80**3890 ± 45**

From a furnace pit, Site QS VIIC/80.

Gd-919. QS P16/80**5960 ± 400**

From locus #2, Site QS VIIA/80.

Comment: Small sample, diluted with inactive CO₂ for counting.**Gd-980. QS P17/81****6380 ± 80**

From hearth #5, Site QS X/81.

Gd-1499. QS P18/81**6380 ± 60**

From hearth #1, Site QS IX/81.

Gd-2021. QS P19/81	6480 ± 170
From hearth #2, Site QS XI/81.	
Gd-1497. QS P20/81	6320 ± 60
From hearth #1, Site QS X/81.	
Gd-979. QS P21/81	6290 ± 100
From hearth #2, Site QS X/81.	
Gd-978. QS P22/81	4740 ± 100
From hearth #3, Site QS X/81.	
Gd-1495. QS P23/81	5650 ± 70
From a hearth in wadi silt, near Site QS VIE/81.	
Gd-977. QS P24/81	5450 ± 100
From layer of white sand below soil level, section 8, Site QS VIIA/81.	
Gd-1496. QS P25/81	5000 ± 60
From a layer of yellow sand above soil level, section 8, Site QS VIIA/81.	
Gd-973. QS P26A/81	4580 ± 180
From a sandy layer with washed hearth, depth 25–30 cm, section 8, Site QS VIIA/81.	
Gd-976. QS P26B/81	4820 ± 100
From a sandy layer with dispersed charcoal, depth 30 cm, section 8, Site QS VIIA/81.	
Gd-971. QS P27/81	3190 ± 130
From a hearth, Site QS VIIG/81.	
Gd-1486. QS P28/81-1/81-A	3460 ± 50
From Feature 1/81, Site QS VIA/81.	
Gd-969. QS P28/81-1/81-B	3430 ± 60
From Feature 1/81, duplicate run on the same sample.	
Gd-970. QS P28/81-2/81	3580 ± 60
From Feature 2/81, Site QS VIA/81.	

Comment (M.F.P.): For a list of previously obtained dates from Qasr el-Sagha, see Pazdur *et al.* (1982). Kozłowski and Ginter (1989) discussed the stratigraphy of the sites and evaluated the significance of the whole set of dates.

Malkata Armant Series

Charcoal and wood from excavations of several sites of Predynastic settlement at Malkata Armant (Ginter and Kozłowski 1994) with finds of the Nagadian culture, situated on a sand-and-gravel terrace over the Nile valley, eastern boundary of Western Desert, Egypt. Site MA-2/83 (25°40'N, 32°35'E), elevation 110 m asl; Site MA-6/83 (25°45'N, 32°35'E), elevation 110 m asl; Site MA-17/83 (25°40'N, 32°35'E), elevation 120 m asl; Site MA-18/83 (25°45'N, 32°35'E), elevation 130 m asl; Site MA-21/83 and Site MA-21A/83 (25°45'N, 32°35'E), elevation 130 m asl. Collected 1983–1988 and submitted 1984–1989 by B. Ginter and J. K. Kozłowski, Institute of Archaeology, Jagiellonian University, Kraków.

Gd-1756. MA-2/83 #1/83	6310 ± 80
Charcoal, from a pit with a hearth, depth 20–30 cm.	

Gd-1754. MA-6/83 #2/83	5560 ± 80
Charcoal, from hearth #1, depth 15–30 cm.	
Gd-3065. MA-17/83 #3/83	5140 ± 60
Charcoal, dispersed in a cultural layer, depth 10–15 cm.	
Gd-3072. MA-18/83 #4/83	5090 ± 50
Charcoal, from hearth #1, depth 10–25 cm.	
Gd-3068. MA-18/83 #5/83	5030 ± 60
Charcoal, from hearth #2, depth 15–25 cm.	
Gd-5438. MA-6/83S	12,270 ± 120
Freshwater mollusk shell, collected December 1987 by M. Pawlikowski.	
	$\delta^{13}C = -4.6\text{‰}$

Site Malkata Armant MA-21/83 Series

Gd-2235. MA-21/83 #6/83	5030 ± 100
Charcoal, from a pit with a hearth, depth 25–40 cm.	
Gd-2985. MA-21/83 Pit #5, >25 cm	5040 ± 80
Charcoal, from Pit #5, depth >25 cm.	
Gd-3141. MA-21/83 Feature #5, < 25 cm	5020 ± 50
Charcoal, from Feature #5, depth <25 cm.	
Gd-4386. MA-21/83 Pit #13, 5–15 cm	5160 ± 120
Charcoal, from Pit #13, depth 5–15 cm.	
Gd-1860. MA-21/83 Feature #26	4890 ± 50
Charcoal, from Feature #26.	
Gd-1979. MA-21/83 Feature #26, 20–25 cm	4920 ± 90
Charcoal, below Feature #26, depth 20–25 cm.	
Gd-5469. MA-21/83 Feature #27, 15 cm	5180 ± 50
Charcoal, from a hearth, Feature #27, depth 15 cm.	
Gd-5471. MA-21/83 Feature #33, 5–15 cm	4970 ± 50
Charcoal, from Feature #33, depth 5–15 cm.	
Gd-3203. MA-21/83 Feature #33, 5–10 cm	4970 ± 40
Charcoal, from Feature #33, depth 5–10 cm.	
Gd-1862. MA-21/83 Feature #34a, 32–36 cm	5100 ± 60
Charcoal, from Feature #34a, depth 32–36 cm.	
Gd-1856. MA-21/83 Feature #34c	5190 ± 50
Charcoal, from Feature #34c.	
Gd-3140. MA-21/83 Feature #34d, <17 cm	5140 ± 40
Charcoal, from Feature #34d, depth <17 cm.	
Gd-2346. MA-21/83 Feature #34e, <17 cm	4990 ± 80
Charcoal, from Feature #34e, depth <17 cm.	
Gd-2986. MA-21/83 Feature #35, 5–10 cm	5200 ± 90
Charcoal, from Feature #35, depth 5–10 cm.	

Gd-2984. MA-21/83 Feature #35a, 10–12 cm	4980 ± 90
Charcoal, from Feature #35a, depth 10–12 cm.	
Gd-1925. MA-21/83 Feature #37, 25–45 cm	5150 ± 60
Charcoal, from Feature #37, depth 25–45 cm.	
Gd-5475. MA-21/83 Feature #37, > 15 cm	4990 ± 50
Gd-3439. MA-21/83 Feature #37, > 15 cm	4990 ± 35
Charcoal, from Feature #37, depth > 15 cm.	

Comment: Independent age determinations on different parts of the same sample using two counting units, mean age 4990 ± 30 BP.

Gd-1980. MA-21/83 Feature #38, 25–30 cm	5070 ± 80
Charcoal, from Feature #38, depth 25–30 cm.	
Gd-1933. MA-21/83 Feature #38a, 50 cm	4950 ± 50
Charcoal, from Feature #38a, depth 20 cm.	
Gd-1999. MA-21/83 Feature #39, 5–15 cm	5040 ± 90
Charcoal, from Feature #39, depth 5–15 cm.	
Gd-2990. MA-21/83 Feature #40, 15–25 cm	5060 ± 100
Gd-5470. MA-21/83 Feature #40, 15–25 cm	4970 ± 50
Gd-3437. MA-21/83 Feature #40, 15–25 cm	5020 ± 30
Charcoal, from Feature #40, depth 15–25 cm.	

Comment: Repeated counting of same gas on different counting units; mean age: 5010 ± 30 BP.

Gd-1987. MA-21/83 Feature #40, >25 cm	4830 ± 70
Charcoal, from Feature #40, depth >25 cm.	
Gd-5409. MA-21/83 Feature #41, 15–25 cm	4930 ± 60
Charcoal, from Feature #41, depth 15–25 cm.	
Gd-3268. MA-21/83 Pit N of #41, 30–40 cm	4640 ± 100
Charcoal, small pit N of Feature #41, depth 30–40 cm.	
Gd-2530. MA-21/83 Feature #43, 25–35 cm	5010 ± 100
Charcoal, from Feature #43, depth 25–35 cm.	
Gd-2529. MA-21/83 Feature #48	4710 ± 100
Charcoal, from basal part of Feature #48.	
Gd-1981. MA-21/83 Feature #51, >30 cm	4930 ± 70
Charcoal, from Feature #51, depth >30 cm.	
Gd-5408. MA-21/83 Feature #51, 14–30 cm	4990 ± 50
Charcoal, from Feature #51, depth 14–30 cm.	
Gd-5462. MA-21/83 Feature #53, 10–15 cm	4950 ± 80
Charcoal, from Feature #53, depth 10–15 cm.	
Gd-1993. MA-21/83 Feature #53a, >15 cm	5080 ± 80
Charcoal, from Feature #53a, depth >15 cm.	

Gd-3255. MA-21/83 Feature #53b, >10 cm Charcoal, from Feature #53b, depth >10 cm.	4960 ± 60
Gd-3275. MA-21/83 Feature #53d, >15 cm Charcoal, from Feature #53d, depth >15 cm.	5080 ± 60
Gd-1857. MA-21/83 Feature #54, 10–20 cm Charcoal, from Feature #54, depth 10–20 cm.	4970 ± 50
Gd-3403. MA-21/83 Feature #54(?), 20–25 cm Charcoal, from Feature #54(?), depth 20–25 cm.	4940 ± 50
Gd-3144. MA-21/83 Feature #54a, 25–55 cm Charcoal, from Feature #54a, depth 25–55 cm.	4960 ± 50
Gd-3433. MA-21/83 Feature #54a, 30–40 cm Charcoal, from Feature #54a, depth 30–40 cm.	4980 ± 40
Gd-1998. MA-21/83 Feature #56, 35–40 cm Charcoal, from Feature #56, depth 35–40 cm.	4690 ± 80
Gd-3204. MA-21/83 Feature #57 Charcoal, from Feature #57.	4910 ± 50
Gd-3208. MA-21/83 Feature #58, 15–35 cm Charcoal, from Feature #58, depth 15–35 cm.	4820 ± 60
Gd-3209. MA-21/83 Feature #58, 40–45 cm Charcoal, from lower part of Feature #58, depth 40–45 cm.	4960 ± 50
Gd-3394. MA-21/83 Feature #59, 10–15 cm Charcoal, from Feature #59, depth 10–15 cm.	4980 ± 50
Gd-3434. MA-21/83 Feature #60, 0–5 cm Charcoal, from Feature #60, depth 0–5 cm.	5010 ± 25
Gd-3404. MA-21/83 Feature #75, 5–10 cm Charcoal, from Feature #75, depth 5–10 cm.	5020 ± 40
Gd-3435. MA-21/83 Feature #76, 5–10 cm Charcoal, from Feature #76, depth 5–10 cm.	5050 ± 25
Gd-3385. MA-21/83 Feature #77, 10–15 cm Charcoal, from Feature #77, depth 10–15 cm.	5310 ± 50
Gd-2528. MA-21/83 Layer Delta 25–27 Charcoal, from cultural layer delta, depth 25–27 cm.	4550 ± 110
Gd-3142. MA-21/83 M22, 10–15 cm Charcoal, from cultural layer at depth 10–15 cm, loc. M22.	5010 ± 40
Gd-3143. MA-21/83 M22, 2–5 cm Charcoal, from cultural layer at depth 2–5 cm, loc. M22.	4990 ± 40
Gd-2347. MA-21/83 M22, 5–10 cm Charcoal, from cultural layer at depth 5–10 cm, loc. M22.	5000 ± 60

Gd-5459. MA-21/83 A21, 5–20 cm	4950 ± 50
Charcoal, from cultural layer, depth 5–20 cm, loc. A21.	
Gd-1859. MA-21/83 B21, 15–20 cm	5060 ± 50
Charcoal, from cultural layer at depth 15–20 cm, loc. B21.	
Gd-3139. MA-21/83 B21, 2–5 cm	4960 ± 40
Charcoal, from cultural layer at depth 2–5 cm, loc. B21.	
Gd-1858. MA-21/83 B22, 5–15 cm	4950 ± 70
Charcoal, from cultural layer at depth 5–15 cm, loc. B22.	
Gd-1861. MA-21/83 Cult layer, 22–27 cm	4920 ± 60
Charcoal, from cultural layer, depth 22–27 cm.	

Site Malkata Armant MA-21/83 Palisade Series

Highly decomposed wooden piles from the remnants of a palisade.

Gd-2981. MA-21/83 P-303	5090 ± 90
Pile #303.	
Gd-5460. MA-21/83 P-313	5180 ± 60
Pile #313.	
Gd-2977. MA-21/83 P-315	5140 ± 90
Pile #315.	
Gd-2978. MA-21/83 P-316	5060 ± 90
Pile #316.	
Gd-2979. MA-21/83 P-317	5190 ± 90
Pile #317.	
Gd-5461. MA-21/83 P-321	5500 ± 50
Pile #321.	
Gd-2980. MA-21/83 P-323	5320 ± 110
Pile #323.	
Gd-4378. MA-21/83 P-325	5220 ± 90
Pile #325.	

Site Malkata Armant MA-21A/83 Series

Gd-3395. MA-21A/83 Feature #201	4820 ± 30
Charcoal, from Feature #201, PIV-1.	
Gd-3400. MA-21A/83 Feature #215a	4830 ± 40
Charcoal, from Feature #215a, PIV-2.	
Gd-3398. MA-21A/83 Feature #217	4790 ± 35
Charcoal, from Feature #217, PIV-3.	
Gd-3402. MA-21A/83 Feature #218a	4930 ± 30
Charcoal, from Feature #218a, PIV-4.	

Gd-5499. MA-21A/83 Feature #223a, 20–25 cm Charcoal, from Feature #223a, depth 20–25 cm.	4970 ± 60
Gd-6015. MA-21A/83 Feature #232x, 5–10 cm Charcoal, from Feature #232x, depth 5–10 cm.	5070 ± 110
Gd-5500. MA-21A/83 Feature #238, 15–20 cm Charcoal, from Feature #238, depth 15–20 cm.	4970 ± 60
Gd-5501. MA-21A/83 Feature #238a, 25–30 cm Charcoal, from Feature #238a, depth 25–30 cm.	4960 ± 50
Gd-3450. MA-21A/83 Feature #238b, 35–40 cm Charcoal, from Feature #238b, depth 35–40 cm.	5075 ± 25 $\delta^{13}\text{C} = -26.0\text{‰}$
Gd-5502. MA-21A/83 Feature #252, 15–30 cm Charcoal, from Feature #252, depth 15–30 cm.	4790 ± 60
Gd-5503. MA-21A/83 Feature #253, 25–40 cm Charcoal, from Feature #253, depth 25–40 cm.	4890 ± 60
Gd-3432. MA-21A/83 Feature #256a Charcoal, from Feature #256a.	5060 ± 35 $\delta^{13}\text{C} = -27.1\text{‰}$
Gd-3427. MA-21A/83 Feature #257 Charcoal, from Feature #257.	5090 ± 60 $\delta^{13}\text{C} = -28.1\text{‰}$
Gd-2925. MA-21A/83 Alfa03, 5–10 cm Charcoal, from cultural layer, depth 5–10 cm, loc. z/alfa 03.	4910 ± 80
Gd-5416. MA-21A/83 Alfa03, 50–70 cm Charcoal, from cultural layer, depth 50–70 cm, loc. z/alfa 03.	5160 ± 50
Gd-5410. MA-21A/83 Beta02, 20–25 cm Charcoal, from cultural layer, depth 20–25 cm, loc. beta 02.	4990 ± 50
Gd-3431. MA-21A/83 Beta02, 30–35 cm Charcoal, from cultural layer, depth 30–35 cm, loc. beta 02.	4990 ± 35 $\delta^{13}\text{C} = -27.1\text{‰}$
Gd-3428. MA-21A/83 Beta02, >60 cm Charcoal, from cultural layer, depth >60 cm, loc. beta 02.	5050 ± 70 $\delta^{13}\text{C} = -26.3\text{‰}$

Comment (M.F.P.): Correlation of ^{14}C dates with associated finds and site stratigraphy enables the assignment of precise time limits to phases of development of Predynastic settlements at Malkata Armant. The floruit of the oldest phase (A) at Site MA-21/83, defined by the interquartile range of the composite probability distribution of the appropriate set of five ^{14}C dates, is confined between 4040 and 3910 cal BC, with a midpoint at 3980 cal BC. The duration of the middle phase (B) at Site MA-21/83, based on the set of 21 dates, was ~3910–3760 cal BC, with a midpoint at 3840 cal BC. The duration of the youngest phase (C) at Site MA-21/83, based on the set of 21 dates, was ~3840–3720 cal BC, with a midpoint at 3760 cal BC. Corresponding analysis of results obtained for Site MA-21A/83 yielded the following estimates: phase A (1 date): floruit 4000–3940 cal BC, midpoint 3980 cal BC; phase B (5 dates): floruit 3900–3770 cal BC, midpoint 3840 cal BC; phase C (7 dates): floruit 3760–3650 cal BC, midpoint 3710 BC. Calculation of the composite probability distribution of the set of 7 dates obtained on wood samples from the palisade remains found at Site MA-21/83 yields a midpoint of 3990 cal BC, with uncertainty determined by the interquartile range 4100–3880 cal BC. ^{14}C dates

were calibrated according to the procedure described by Pazdur and Michczyńska (1989, 1993); Pazdur *et al.* (1994) discuss in detail the ^{14}C dates obtained for the settlements at Malkata Armant.

Uan Muhuggiag Series

Seeds, fruits and other macroscopic plant fragments from Uan Muhuggiag Rockshelter, located in the Central Acacus, Tadrart Acacus area, northern side of Wadi Teshuinat, North Sahara, Libya. Collected 1982 by B. E. Barich during the Libyan-Italian Joint Mission for Saharan Research; submitted April 1988 by K. Wasylikowa, Institute of Botany, Polish Academy of Sciences, Kraków. General characteristics of the site and its relevance to the late prehistory of the Libyan Sahara are described by Barich (1974, 1984, 1989); ^{14}C dates from the site previously obtained are discussed by Barich *et al.* (1984); present results are discussed by Pazdur (1993).

Gd-4290. UAM B1/Citr	2220 ± 220
Seeds of <i>Citrullus colocynthis</i> from Sector B, Level 1.	$\delta^{13}\text{C} = -25.0\text{‰}$
Gd-4288. UAM B1/Copr	2770 ± 80
Coprolites from Sector B, Level 1.	$\delta^{13}\text{C} = -21.0\text{‰}$
Gd-2854. UAM B1/Bal	3810 ± 80
Fruits of <i>Balanites aegyptiaca</i> from Sector B, Level 1.	$\delta^{13}\text{C} = -23.4\text{‰}$
Gd-5337. UAM B2b	5420 ± 50
Fruits of <i>Balanites aegyptiaca</i> from Sector B, Level 2b.	$\delta^{13}\text{C} = -24.4\text{‰}$
Gd-2853. UAM A2a	6030 ± 80
Coprolites from Sector A, Level 2a.	$\delta^{13}\text{C} = -21.7\text{‰}$
Gd-2962. UAM A1a	3720 ± 90
Kernels of <i>Balanites</i> sp. and other plant fragments from Sector A, Level 1a.	$\delta^{13}\text{C} = -25.5\text{‰}$
Gd-4363. UAM A1a-bis	3800 ± 140
Repeated run on the same sample.	$\delta^{13}\text{C} = -25.5\text{‰}$
Gd-4358. UAM A2c	5780 ± 80
Kernels of <i>Balanites aegyptiaca</i> from Sector A, Level 1a.	$\delta^{13}\text{C} = -24.1\text{‰}$
Gd-4362. UAM A2	5290 ± 110
Kernels of <i>Balanites aegyptiaca</i> from Sector A, Level 2.	$\delta^{13}\text{C} = -24.0\text{‰}$
Gd-2959. UAM B2	5340 ± 120
Kernels of <i>Balanites aegyptiaca</i> from Sector B, Level 2.	$\delta^{13}\text{C} = -24.4\text{‰}$
Gd-2960. UAM B2a	5420 ± 100
Kernels of <i>Balanites aegyptiaca</i> from Sector B, Level 2a.	$\delta^{13}\text{C} = -25.0\text{‰}$
Gd-4361. UAM B2a-bis	5480 ± 120
Repeated run on the same sample.	$\delta^{13}\text{C} = -25.0\text{‰}$
Gd-2855. TH2/I	5210 ± 90
Plant fragments from layer I, Site 2, in Ti-n-Torha (Barich 1974, 1984).	
Gd-926. BK-E-79-4	6330 ± 100
Charcoal from a hearth below stony plates in a layer of silts in Bir Kiseiba, ca. 150 km west of Assuan, Western Desert, Egypt (23°N, 30°E). The site is located at elevation 200 m asl on the border	

of a dry shallow water basin (playa). Collected 1980 and submitted 1981 by Michał Kobusiewicz, Institute of History of Material Culture, Polish Academy of Sciences, Poznań.

Kadero series

The Neolithic site at Kadero (15°45'N, 32°36'E), Khartoum Province, Sudan, is located on a low eroded mound of sand which rises *ca.* 1.8 m above the flat bottom of the main Nile valley floor. The site is 18 km north of the confluence of the White and Blue Niles, 6.5 km east of the channel of the main Nile. Excavations of the site were started in 1972 and resulted in discovery and detailed examination of two settlements and burial grounds (Krzyżaniak 1984). The studies undertaken involve subsistence economy based on food remains excavated from the southern settlement (Krzyżaniak 1978), lithic industry (Nowakowski 1984), pottery (Chłodnicki 1984), archaeozoology (Gautier, 1984) and archeobotany (Klichowska 1978, 1984). Separate studies were devoted to cemeteries discovered close to the Kadero settlement (Dzierżykray-Rogalski 1984; Prominska 1984). Shell and charred bones were collected from the northern settlement and a burial ground in 1987 and 1989 and submitted by Lech Krzyżaniak, Archaeological Museum, Poznań.

Gd-5653. Kadero 87/1	5450 ± 70
Single shell of Nile oyster <i>Etheria elliptica</i> , Unit C-65/66, depth 10 cm.	$\delta^{13}C = -4.9\text{‰}$
Gd-5651. Kadero 87/2A	5370 ± 60
Shells of <i>Etheria elliptica</i> , 3 fragments, Unit C-65/66, depth 10–20 cm.	$\delta^{13}C = -5.1\text{‰}$
Gd-6164. Kadero 87/2B	5510 ± 120
Shells of Nile bivalve <i>Aspatharia rubens</i> , 2 fragments, same locality.	$\delta^{13}C = -3.3\text{‰}$
Gd-5649. Kadero 87/3	5430 ± 600
Shells of <i>Aspatharia rubens</i> , Unit C-65/66/67, depth 20–40 cm.	$\delta^{13}C = -4.0\text{‰}$
Gd-6165. Kadero 87/4A	5770 ± 100
Shells of swamp snail <i>Pila ovata</i> , 5 fragments, Unit C-67/68, depth 0–40 cm.	$\delta^{13}C = -5.6\text{‰}$
Gd-5652. Kadero 87/4B	5420 ± 70
Shells of <i>Aspatharia rubens</i> , 10 fragments, same locality.	$\delta^{13}C = -3.2\text{‰}$
Gd-5648. Kadero 87/5A	5720 ± 50
Shells of <i>Pila ovata</i> , Unit C-67/68, depth 0–40 cm.	$\delta^{13}C = -4.8\text{‰}$
Gd-6161. Kadero 87/5B	5690 ± 80
Shells of <i>Aspatharia rubens</i> , same locality.	$\delta^{13}C = -1.7\text{‰}$
Gd-5650. Kadero 89/1	5480 ± 60
Shells of land snail <i>Limnicolaria flammata</i> , Unit C-75/76, depth 0–30 cm.	$\delta^{13}C = -7.5\text{‰}$
Gd-5647. Kadero 89/2	5960 ± 70
Shell of <i>Etheria elliptica</i> , single fragment, Unit C-75/76, depth 10–20 cm.	$\delta^{13}C = -11.4\text{‰}$
Gd-6198. Kadero 89/3	5390 ± 90
Burned animal bones, Unit C-75/76, depth 10–20 cm.	$\delta^{13}C = -21.1\text{‰}$
Gd-6167. Kadero 89/4	5510 ± 100
Shells of <i>Aspatharia rubens</i> , 6 fragments, base of Grave 114, depth 70 cm.	$\delta^{13}C = -4.4\text{‰}$

Comment (L.K.): Grave pit with well-defined boundaries, containing human remains with furniture.

Gd-6162. Kadero 89/5**5260 $\pm$ 120**Shells of Nile bivalve *Aspatharia rubens*, from Grave 101, depth 50 cm. $\delta^{13}\text{C} = -4.4\text{‰}$ *Comment* (L.K.): Grave pit boundaries not visible; grave contains human remains with furniture.**Minshat Abu Omar Series**

Charcoal and shell from excavations undertaken by Munich East-Delta Expedition (MOE) under the direction of Dietrich Wildung on a Late Predynastic–Early Dynastic cemetery situated in the Eastern Nile Delta, north of modern village Minshat Abu Omar (30°55'N, 32°02'E), ca. 30 km northeast of Faqus. According to Wildung (1984), the cemetery was used between Nagada II and the First Dynasty and then again in the Roman period. Kroeper (1984) summarized the results of the first stage of MOE activities in Minshat Abu Omar; Krzyżaniak (1989) presented comparative analysis of pottery and other finds from several sites in the study area. Collected and submitted 1990 by Lech Krzyżaniak, Archaeological Museum, Poznań.

Gd-6233. MAO 1990/1**3930 $\pm$ 70**

Charcoal and charred plant remains from wooden construction of the chamber of Grave 1590.

Gd-4566. MAO 1990/2**4120 $\pm$ 100**

Charred plant remains from the contents of funerary ceramic vessels 7–9 found in Grave 1930.

Gd-5713. MAO 1990/3**5240 $\pm$ 60** $\delta^{13}\text{C} = -6.1\text{‰}$ Shell of a river bivalve from depth 2.5 m below the surface of sandy hill (*gezira*), near Grave 1930, from pure sand.**Gd-6232. MAO 1990/4****9000 $\pm$ 110** $\delta^{13}\text{C} = -5.6\text{‰}$ Shell of land snail *Helicidae*, Square 13/21–20, pure sandy layer, depth 1–2 m.**IRON AGE****Dongola Series**

Charcoal from the excavation of a graveyard in Old Dongola, Northern Province, Egypt (18°13'N, 30°45'E). Collected February 1989 and submitted 1989 by Bogusław Zurawski, Department of Mediterranean Archaeology, Polish Academy of Sciences, Warsaw.

Gd-5666. Dongola I/89**1270 $\pm$ 30**

From a “lamp box” made of two bricks, above a grave pit, TEQ I-2, depth 15 cm.

Gd-3486. Dongola II/89**1120 $\pm$ 50**

From a kiln, depth 75 cm.

 $\delta^{13}\text{C} = -24.5\text{‰}$ **Gd-6180. Dongola IV/89****1020 $\pm$ 45**

From a “lamp box” at the west wall of a grave, TWH IV, depth 35 cm.

Gd-6179. Dongola XII/89**1090 $\pm$ 60**

From a burial chamber, TSJ-2, depth 175 cm.

Gd-5405. Dongola II/88**1360 $\pm$ 40**

Wood, fragment of a board from the altar of a Crusader Church found at depth 5 m in Dongola, Northern Province, Egypt (19°N, 30°E). Collected 1987 and submitted 1988 by Władysław Godlewski, National Museum, Warsaw.

Gd-5450. Dongola II/88bis**1400 ± 45**

Repeated run on the same sample.

Comment (M.F.P.) ^{14}C dates of two parts of the same sample predate the first Crusade by several centuries; the old wood effect seems a reasonable explanation.

Gd-3417. Tell Atrib IA**1770 ± 30**

Charcoal, scattered within a *ca.* 1-m-thick layer consisting of rubble (ash, mortar and marble, with numerous fragments of pottery, glass and bronze), depth 2–3 m, Sector T of mound Kon Sidi Youssef, Tell Atrib, in Benha (ancient Athribis), (30°25'N, 31°10'E), Lower Egypt, floor of Nile valley, elevation 2 m asl. Collected November 1981 and submitted 1988 by T. Gorecki, National Museum, Warsaw.

Asantemanso Series

Charcoal from excavations in Asantemanso, district Asante (6°30'N, 1°30'W), Adansemanso, district Adanse (6°17'N, 1°35'W), in Anyinam, district Amansie East (6°30'N, 1°32'W), and in Esiease, district Amansie East (6°28'N, 1°31'W), Ghana, Central Africa. Collected 1989, 1990 and 1991 and submitted 1990 and 1991 by P. L. Shinnie, Department of Archaeology, University of Calgary, Alberta, Canada.

Gd-6330. AS06-C55**410 ± 60**

Trench 6, cultural layer, depth 20–30 cm.

Gd-5807. AS07-C56**710 ± 50**

Trench 7, cultural layer, depth 80–90 cm.

Gd-6326. AS08-C65**410 ± 80**

Trench 8, cultural layer, depth 80–90 cm, associated with iron slag.

Gd-5798. AS08-C67**810 ± 40**

Trench 8, cultural layer, depth 50–60 cm, mixed with iron slag and ceramics.

Gd-5806. AS09-C69**440 ± 40**

Carbonized palm nuts from Trench 9, cultural layer, depth 30–40 cm.

Gd-5801. AS10-C71**2440 ± 60**

Trench 10, cultural layer, depth 40–60 cm.

Gd-5804. AS10-C70**2480 ± 60**

Trench 10, cultural layer, depth 40–60 cm.

Gd-6327. AS11-C74**420 ± 70**

Trench 11, cultural layer, depth 100–110 cm.

Gd-4644. AS12-C90**Modern**

Trench 12, pit feature, depth 155–177 cm.

Gd-5805. AS12-C91**300 ± 50**

Trench 12, cultural layer, depth 40–50 cm.

Gd-6329. AS13-C92**Modern**

Trench 13, cultural layer, depth 60–70 cm, associated with pipe fragments.

Gd-6328. AS13-C93**240 ± 70**

Trench 13, cultural layer, depth 60–70 cm, associated with pipe fragments.

Gd-5802. AS15-C101 480 ± 40
Trench 15, cultural layer, depth 30–40 cm.

Gd-5803. AS10-C118 590 ± 50
Trench 10, cultural layer, depth 60–80 cm.

Gd-5800. AS27-C140 470 ± 50
Trench 27, cultural layer, depth 20–40 cm.

Gd-6331. AS56-C173 640 ± 80
Trench 56, depth 50–60 cm.

Adansemanso Series

Gd-6540. AD-C201 310 ± 60
Base of cultural unit, depth 40–50 cm, associated with two glass beads, Trench A5.

Gd-5996. AD-C210 680 ± 50
Cultural layer below floor level, depth 130–140 cm, Trench B14.

Gd-6545. AD-C214 740 ± 80
Inside furnace structure in context with iron slag, Feature 2, Mound C, depth 130–140 cm.

Gd-6541. AD-C227 1050 ± 100
Mound C, cultural layer at depth 70–80 cm.

Gd-6537. AD-C234 1110 ± 100
Depth 50 cm, Trench St3.

Anyinam Series

Gd-6546. AN-C236 170 ± 80
Depth 50 cm.

Gd-5998. AN-C239 550 ± 50
Bottom of deep pit feature within house mound A, depth 310 cm, associated with European imports, Trench AyA.

Esiease Series

Gd-5997. ES-C262 230 ± 50
From cultural layer at depth 70–80 cm, associated with European imports, Trench EsC.

Gd-6543. ES-C265 190 ± 80
From cultural layer at depth 80–90 cm, associated with European imports, Trench EsD.

Gd-6542. ES-C271 450 ± 100
From cultural layer at depth 80–90 cm, associated with local pipes, Trench EsH.

Niani Series

Organic detritus, partly charred, from wooden-clayey building destroyed by fire, probably the palace of the King of Mali, Site #1, Palace (11°22'N, 8°23'E), in the royal quarter, Niani, near Sankarani, West Africa (Filipowiak 1977; 1981). Collected March 1973 and submitted 1984 by W. Filipowiak, National Museum, Szczecin.

Gd-2194. Niani #6/73**< 150**

From a fire layer in the northeast corner of the palace, below a layer of clay formed by decomposition of air-dried bricks (*banco*) of local origin, depth 15 cm, associated with baked and dried clay, stones and pottery.

Gd-2195. Niani #9/73**380 ± 60**

From a fire layer in *banco* clay, at the destroyed west wall of the palace, depth 32 cm.

Comment (W.F. and M.F.P.): Date of sample #6/73 is rejuvenated, probably by mechanical contamination with recent material. Date of sample #9/73 agrees well with other ^{14}C dates obtained for Site 1 in the royal quarter: KI-292: 380 ± 50 BP; Gif-915: 300 ± 90 BP.

Bir Safsaf Series

Partly decomposed wood from a large mound southwest of Bir Safsaf, Western Desert, Egypt. No association with definite cultural layer excavated at the site. Samples collected 1992 and submitted by R. Schild to check the rate of degradation of subfossil wood in specific conditions of desert sand cover.

Gd-7202. Bir Safsaf 7/92**890 ± 40****Gd-7208. Bir Safsaf 8/92****1350 ± 50****REFERENCES**

- Barich, B. E. 1974 La serie stratigrafica dell Uadi Ti-n-Torha. Per una interpretazione delle facies a ceramica sahara-sudanesi. *Origini* 8: 7–184.
- _____. 1984 The Epipalaeolithic-ceramic groups of Libyan Sahara: Notes for an economic model of the cultural development in the West-Central Sahara. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 399–410.
- _____. 1989 Uan Muhuggiag rock shelter (Tadrart Acacus) and the late prehistory of the Libyan Sahara. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Late Prehistory of the Nile Basin and the Sahara*. Poznań, Poznań Archaeological Museum: 499–505.
- Barich, B. E., Belluomini, G., Bonadonna, F., Alessio, M. and Manfra, L. 1984 Ecological and cultural relevance of the recent new radiocarbon dates from Libyan Sahara. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 411–417.
- Bluszcz, A. and Pazdur, M. F. 1986 TL and ^{14}C dating of the Upper Palaeolithic site at Wadi Kubbaniya, Egypt. *Acta Interdisciplinaria Archaeologica* 4: 97–105.
- _____. 1987 Thermoluminescence dating of the Middle Palaeolithic at Wadi Kubbaniya. In Wendorf, F., Schild, R. and Close, A., eds., *The Prehistory of Wadi Kubbaniya*, Vol. 2. *Stratigraphy, Paleoeconomy, and Environment*. Dallas, Texas, Southern Methodist University Press: 270–273.
- Brookes, I. 1983 Dakhleh Oasis—A geoarchaeological reconnaissance. *Journal of the Society for the Study of Egyptian Antiquities* 13: 167–177.
- _____. 1989 Early Holocene basinal sediments of the Dakhleh Oasis Region, South Central Egypt. *Quaternary Research* 32: 139–152.
- Chłodnicki, M. 1984 Pottery from the Neolithic settlement at Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 337–342.
- Donahue, D. J., Jull, A. J. T., Linick, T. W. and Zabel, T. 1987 AMS radiocarbon measurements on material from Wadi Kubbaniya. In Wendorf, F., Schild, R. and Close, A., eds., *The Prehistory of Wadi Kubbaniya*, Vol. 2. *Stratigraphy, Paleoeconomy, and Environment*. Dallas, Texas, Southern Methodist University Press: 280–283.
- Dzierżykray-Rogalski, T. 1984 Remarks on the position of human remains in the Neolithic graves at Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 333–335.
- Edwards, I. and Hope, C. A. 1989 A note on the Neolithic ceramics from the Dakhleh Oasis (Egypt). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Late prehistory of the Nile Basin and the Sahara*. Poznań, Poznań Archaeological Museum: 233–242.

- Filipowiak, W. 1977 Results of archaeological research of Niani. Nyame Akuma. *Newsletter of African Archaeology* 11: 32–33.
- 1981 Niani: *Capital of the Mali Kingdom in the 6th–17th Centuries*. Wrocław-Warsaw-Gdansk-Kraków, Ossolineum, 302 p.
- Gautier, A. 1984 The fauna of the Neolithic site of Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 317–319.
- Ginter, B., Heflik, W., Kozłowski, J. K. and Śliwa, J. 1980 Excavations in the region of Qasr el-Sagha, 1979. *Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo* 36: 105–169.
- Ginter, B. and Kozłowski, J. K. 1984 Tarifian and the problem of the origin of Nagadian. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 247–260.
- eds. 1994 *Predynastic Settlements near Armant - Sites 21 and 21A*. Heidelberg, Heidelberg Orientaler Verlag.
- Haas, H. 1987 The radiocarbon dates from Wadi Kubaniya. In Wendorf, F., Schild, R. and Close, A., eds., *The Prehistory of Wadi Kubaniya*, Vol. 2. *Stratigraphy, Paleoeconomy, and Environment*. Dallas, Texas, Southern Methodist University Press: 274–279.
- Hedges, R. E. M., Housley, R. A., Bronk Ramsey, C. R. and van Klinken, G. J. 1993 Radiocarbon dates from the Oxford AMS system: *Archaeometry* datelist 16. *Archaeometry* 35(1): 147–167.
- Hietala, H. J. 1987 Contemporaneity and occupational duration of the Kubbaniyan sites: An analysis and interpretation of the radiocarbon dates. In Wendorf, F., Schild, R. and Close, A., eds., *The Prehistory of Wadi Kubaniya*, Vol. 2. *Stratigraphy, Paleoeconomy, and Environment*. Dallas, Texas, Southern Methodist University Press: 284–291.
- Klichowska, M. 1978 Preliminary results of palaeoethnobotanical studies on plant impressions on potsherds from the Neolithic settlement at Kadero. *Nyame Akuma. Newsletter of African Archaeology* 12: 42–43.
- 1984 Plants of the Neolithic Kadero (Central Sudan): A palaeoethnobotanical study of the plant impressions on pottery. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 321–326.
- Kozłowski, J. K., ed. 1983 Qasr el-Sagha 1980. Contributions to the Holocene geology, the Predynastic and Dynastic settlements in the Northern Fayum Desert. *Zeszyty Naukowe Uniwersytetu Jagiellońskiego, Prace Archeologiczne* 35: 7–123.
- Kozłowski, J. K. and Ginter, B. 1989 The Fayum Neolithic in the light of new discoveries. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Late Prehistory of the Nile Basin and the Sahara*. Poznań, Poznań Archaeological Museum: 157–179.
- Kroeper, K. 1984 Minshat Abu Omar (Munich East Delta Expedition). *Bulletin de Liason du Groupe International d'étude de la Céramique Égyptienne* 9: 6–10.
- Krzyżaniak, L. 1978 New light on early food-production in the Central Sudan. *Journal of African History* 19: 159–172.
- 1984 The Neolithic habitation at Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 309–315.
- Krzyżaniak, L. 1989 Recent archaeological evidence on the earliest settlement in the eastern Nile Delta. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Late Prehistory of the Nile Basin and the Sahara*. Poznań, Poznań Archaeological Museum: 267–285.
- Krzyżaniak, L. and Kobusiewicz, M., eds., 1984 *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 504 p.
- 1989 *Late Prehistory of the Nile Basin and the Sahara*. Poznań, Poznań Archaeological Museum: 547 p.
- 1993 *Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the 2nd Millennium BC*. Poznań, Poznań Archeological Museum.
- McDonald, M. M. A. 1990 New evidence from the early to mid-Holocene in Dakhleh Oasis, South-Central Egypt, bearing on the evolution of cattle pastoralism. *Nyame Akuma. Newsletter of African Archaeology* 33: 3–9.
- Mills, A. J. 1984 Research in the Dakhleh Oasis. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 205–210.
- Nowakowski, J. 1984 The typology of lithic implements from the Neolithic settlement at Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 343–351.
- Pazdur, A., Awiuk, R., Bluszcz, A., Pazdur, M. F., Walanus, A. and Zastawny, A. 1982 Gliwice radiocarbon dates VII. *Radiocarbon* 24(2): 171–181.
- Pazdur, M. F. 1983 Radiocarbon dating of organic samples. In Kozłowski, J. K., ed., *Qasr el-Sagha 1980. Contributions to the Holocene geology, the Predynastic and Dynastic settlements in the Northern Fayum*

- Desert. *Zeszyty Naukowe Uniwersytetu Jagiellońskiego, Prace Archeologiczne* 35: 114–117.
- _____. 1993 Evaluation of radiocarbon dates of organic samples from Uan Muhuggiag and Ti-n-Torha. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the 2nd Millennium BC*. Poznań, Poznań Archaeological Museum: 43–47.
- Pazdur, M. F., Awiuk, R., Bluszcz, A., Goslar, T., Pazdur, A., Walanus, A. and Zastawny, A. 1985 Gliwice radiocarbon dates X. *Radiocarbon* 27(1): 52–73.
- Pazdur, M. F., Awiuk, R., Goslar, T., Michczyńska, D. J. and Pazdur, A. 1994 Radiocarbon chronology. In Ginter, B. and Kozłowski, J. K., eds., *Predynastic Settlements Near Armanet - Sites 21 and 21A*. Heidelberg, Heidelberg Orientaler Verlag: 109–123.
- Pazdur, M. F. and Michczyńska, D. J. 1989 Improvement of the procedure for probabilistic calibration of radiocarbon dates. In Long, A. and Kra, R. S., eds., *Proceedings of the 13th International ¹⁴C Conference*. *Radiocarbon* 31(3): 824–832.
- _____. 1993 Procedures for probabilistic calibration of radiocarbon dates with relevant specific examples. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Environmental Change and Human Culture in the Nile Basin and Northern Africa Until the 2nd Millennium BC*. Poznań Archaeological Museum, Poznań: 471–481.
- Prominska, E. 1984 The demography of the populations from Kadero (Central Sudan). In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 327–331.
- Schild, R. and Wendorf, F. 1984 The earliest Holocene production of cereals in the Egyptian Sahara. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 373–379.
- Wendorf, F., Close, A. E., Schild, R., Wasylkowska, K., Housley, R. A., Harlan, J. R. and Królik, H. 1992 Saharan exploitation of plants 8,000 years BP. *Nature* 359: 721–724.
- Wendorf, F. and Schild, R., eds., 1980 *Prehistory of the Eastern Sahara*. New York, Academic Press.
- Wendorf, F., Schild, R. and Close, A., eds., 1980 *Loaves and Fishes: The Prehistory of Wadi Kubbaniya*. Dallas, SMU Press.
- _____. 1987 *The Prehistory of Wadi Kubbaniya*, Vol. 2. *Stratigraphy, Paleoeconomy, and Environment*. Dallas, Texas, Southern Methodist University Press.
- Wildung, D. 1984 Terminal prehistory of the Nile Delta: theses. In Krzyżaniak, L. and Kobusiewicz, M., eds., *Origin and Early Development of Food-Producing Cultures in North-Eastern Africa*. Poznań, Polish Academy of Sciences and Poznań Archaeological Museum: 265–269.

RUDJER BOŠKOVIĆ INSTITUTE RADIOCARBON MEASUREMENTS XIII

BOGOMIL OBELIĆ,¹ NADA HORVATINČIĆ,¹ DUŠAN SRDOČ,^{1,2} INES KRAJCAR BRONIĆ,¹
ADELA SLIEPČEVIĆ³ and SANJA GRGIĆ⁴

INTRODUCTION

In this list, we present ¹⁴C ages of archaeological, geological, hydrogeological, botanical and atmospheric samples measured since our previous list (Srdoč *et al.* 1992). Chemical pretreatment and counting techniques using a methane-filled proportional counter are essentially the same as reported earlier. Sample descriptions are prepared in collaboration with collectors and submitters.

Age calculation follows the conventional protocol based on the Libby half-life of 5570 ± 30 yr and using AD 1950 as the reference year. Calibrated ages (for archaeological samples only) were calculated using the program by Stuiver and Reimer (1993), generally using method A (intercepts with calibration curve), and are given here as the period of maximal probability with 1 σ error. When method A gave two or more separate calibrated age ranges, method B was used instead. Ranges that do not contribute significantly to the overall probability were omitted.

Ages and standard deviations of samples were adjusted for stable isotope fractionation according to recommendations in Stuiver and Polach (1977), where $\delta^{13}\text{C}$ data were not available. The fractionation correction has not been applied for groundwater samples, calcareous deposits or aquatic plants. For geological and hydrogeological samples, only the pMC data are given.

ACKNOWLEDGMENTS

We thank E. Hernaus for sample preparation and J. Pezdič, Jožef Stefan Institute, Ljubljana, Slovenia, for stable isotope measurements.

ARCHAEOLOGICAL SAMPLES

CROATIA

Varaždin Series

Fragments of beams from Stari Grad (Old Town), Varaždin (46°18'N, 16°21'E), 173 m asl, north Croatia. Collected and submitted 1987 by Z. Matica, Croatian Institute for Restoration, Zagreb.

Comment (Z.M.): Expected age: 16th–17th century.

Z-1927. Varaždin 1 **400 ± 60**

Fragment of a beam from the wall above the first floor of the eastern tower; cal AD 1440–1627.

Z-1928. Varaždin 2 **330 ± 90**

Fragment of a beam from the western wall, first floor of a high Gothic tower; cal AD 1480–1650.

Z-1929. Varaždin 3 **520 ± 90**

Fragment of a longitudinal ceiling beam from the high Gothic tower; cal AD 1321–1449.

¹Rudjer Bošković Institute, P.O. Box 1016, 41001 Zagreb, Croatia

²Present address: Brookhaven National Laboratory, P.O. Box 5000, Upton, New York 11973 USA

³Faculty of Veterinary Medicine, University of Zagreb

⁴Institute of Geology, Sachsova 2, Zagreb

Z-1930. Rudine **510 ± 80**
Human bones from Grave 1, 1.5 m depth, at Rudine near Čečavac (45°24'N, 17°32'E), 467 m asl, central Croatia (Horvat 1962; Klaić 1986). Collected and submitted 1987 by D. Sokač-Štimac, Požega Valley Museum, Požega.

Comment (D.S.-Š.): Expected age: Roman period or Middle Ages; cal AD 1397–1449.

Z-2420. Trilj **650 ± 80**
Fragment of charred wood from a boat buried in the bed of the Ruda River, Cetinska Krajina near Trilj (45°16'N, 13°32'E), 60 m asl, south Croatia. Collected and submitted 1992 by Z. Brusić, Archaeological Museum, Zadar, south Croatia. Cal AD 1397–1449.

Z-1939. Škrinja Sv. Šimuna (St. Simeon's shrine) **970 ± 70**
Wood fragments (*Juniperus* sp.) from a coffin frame, Zadar (44°02'N, 15°15'E), south Croatia. The sarcophagus was richly decorated between 1377 and 1380 by goldsmith Francesco da Milano (Petricioli 1983). Collected and submitted Oct. 1987 by M. Domijan, Institute for Restoration, Zadar.

Comments (M.D.): Expected age: 14th to 17th century; cal AD 1010–1165. (A. Belamarić, Regional Institute for Restoration, Split): Wood from an old Byzantine coffin was probably used for construction of this coffin. (D.S.): Inner parts of a large log are typically 150–200 yr older than the outer parts; the use of inner parts of a tree felled at the time of the coffin construction can explain the deviation from the expected age.

Kopačina Cave Series

Animal bones, mostly red deer (*Cervus elaphus*) from the anterior of Kopačina Cave near Donji Humac (43°22'N, 16°32'E), 380 m asl, Brač Island, south Croatia. Samples are associated with Epipalaeolithic stone tools and wild faunal remains. Collected Aug. 1986 by B. Čečuk, Archaeological Institute of the Croatian Academy of Sciences and Arts, Zagreb, and submitted June 1992 by P. Miracle, Department of Anthropology, University of Michigan, Ann Arbor, Michigan.

Comment (B.Č.): Samples date the occupation of the cave and provide comparison with other Palaeolithic and Mesolithic sites in the eastern Adriatic basin, e.g., Šandalja II (Čečuk 1991). Expected age: 8000–15,000 BP.

Z-2404. Kopačina 1 **11,980 ± 270**
20–40 cm depth; 12,379–11,688 cal BC.

Z-2403. Kopačina 2 **13,160 ± 310**
140–160 cm depth; 14,183–13,225 cal BC.

Šandalja II Series

Animal bones from large ungulate mammals (*Bos*, *Bison* or *Equus*) from a cultural horizon in a cave, Šandalja limestone quarry near Pula (44°52'57"N, 13°53'48"E), 72 m asl, Istria, west Croatia (Malez 1979). Collected 1962 by M. Malez, Croatian Academy of Sciences and Arts, Zagreb, and submitted Sept. 1992 by P. Miracle.

Z-2421. Šandalja 1 **10,140 ± 160**
Bones from the bottom of Layer B, 270–340 cm depth; 10,222–9134 cal BC.

Z-2423. Šandalja 2 **13,050 ± 220**
Bones between Layers B and C, 340 cm depth; 13,911–13,189 cal BC.

Z-2424. Šandalja 3**13,120 ± 230**

Bones from the middle of Layer C, 390–440 cm depth; 14,023–13,285 cal BC.

Comment (P.M.): These three samples date the stratigraphy between the lower part of Layer C and the middle section of Layer B, and help determine whether the site was occupied during the last glacial maximum (*ca.* 18,000 BP). Previous measurements: GrN-4976 B (upper), 10,830 BP; GrN-4978 B (middle), 12,320 BP; Z-193 (Srdoč *et al.* 1973: 440) C (bottom), 21,740 BP. Expected age: 12,000–22,000 BP.

Z-2422. Šandalja 4**17,600 ± 370**

Bones from Layer H, 720–800 cm depth; 19,524–18,459 cal BC.

Comment (P.M.): Dates the lower part of the Šandalja sequence. The result completes previously published measurements Z-536 and -537 (Srdoč *et al.* 1979: 132–133). Expected age: >28,000 BP; cal BP 19,524–18,470.

Relja Series

Wood fragments from the Roman necropolis, Relja near Zadar (44°02'N, 15°15'E), south Croatia. Collected and submitted 1990 by Z. Brusić.

Z-2242. Relja 1**1910 ± 70**

Wood fragment from a well. Expected age: 2000 BP; cal AD 25–216.

Z-2243. Relja 2**2620 ± 80**

Wood fragment from a beam. Expected age 2500 BP; 827–770 cal BC.

Z-2244. Relja 3**2480 ± 80**

Wood fragment from a beam. Expected age: 2500 BP; 785–407 cal BC.

Dubrovnik – Mala Onofrijeva Česma Series

Wood fragments from a fountain, Dubrovnik (42°37'N, 18°06'E), south Croatia. Collected and submitted 1990 by J. Stošić and I. Žile, Institute for Preservation of Cultural and Natural Monuments, Dubrovnik (Žile 1993).

Z-2229. Dubrovnik 1**920 ± 80**

Fragment of a wooden post; cal AD 1022–1222.

Z-2230. Dubrovnik 2**920 ± 80**

Fragment of a wooden board; cal AD 1022–1222.

Z-2203. Kotluša**2930 ± 90**

Human bones on the ground inside Kotluša cave 200 m from the entrance, Civiljane (43°57'N, 16°24'E), Lika, central Croatia. Collected Nov. 1989 and submitted Feb. 1990 by S. Forenbaher, Department of Archaeology, University of Zagreb.

Comment (S.F.): Expected age: 3500 BP; 1262–993 cal BC.

Sisak Series

Fragments of wooden boats from the muddy bed of the Kupa River near Sisak (45°29'20"N, 16°22'30"E), Croatia. Collected by P. Pirs-Petrinjak, Sisak Town Museum, and submitted Oct. 1992 by M. Jurišić, Institute for Preservation of Cultural Monuments, Zagreb.

Z-2426. Sisak 1 **2000 ± 90**
 Fragment of Boat 1; cal AD 90–115 cal BC.

Z-2427. Sisak 2 **2140 ± 90**
 Fragment of Boat 2; 356–40 cal BC.

Z-2391. Stari Grad **1090 ± 80**
 Fragments of wood from a fireplace in Room G, 180 cm depth, Stari Grad (43°10'N, 16°36'E), Hvar Island, south Croatia. Collected by J. Jeličić and submitted 1992 by M. Katić, Institute for Preservation of Cultural Monuments, Split; cal AD 885–1020.

Nova Rača Series

Human bones from graves below the church sacristy, 30 cm depth, Nova Rača near Bjelovar (45°47'N, 16°57'E), 175 m asl, central Croatia. Collected Dec. 1985 and submitted March 1990 by G. Jakovljević, Bjelovar Museum.

Comment (G.J.): Samples were dated to determine the chronology of the strata containing human bones. Expected age: Middle Ages. Dates correspond to earlier measurements: Z-2184, -2187, -2255, -2256, -2258 and -2260 (Srdoč *et al.* 1992: 160–161).

Z-2303. Nova Rača 1 **530 ± 80**
 Bones from Grave 1, 30 cm depth; cal AD 1321–1444.

Z-2302. Nova Rača 2 **100.6 ± 1.5 pMC**
 Bones from Grave 14, 100 cm depth.

Čakovec Series

Wood fragments from a former coach depot in Old Town, Čakovec (46°24'N, 16°26'E), northwest Croatia, undergoing systematic archaeological excavation during restoration. Collected and submitted Dec. 1992 by M. Šmalcelj.

Comment (M.Š.): Expected age: Middle Ages.

Z-2436. Čakovec 48 **270 ± 110**
 Fragment of a log, Quadrant U-8, close to the wall base; cal AD 1482–1810 (92% probability; method B).

Z-2437. Čakovec 24 **320 ± 110**
 Fragment of a board under floor, Quadrant U-9; cal AD 1450–1670 (99% probability; method B).

Vindija Series

Animal bones (*Ursus spelaeus*) from a trench in sandy sediment, Vindija cave, Gornja Voća near Ivanec (46°18'12"N, 16°14'38"E), 275 m asl, northwest Croatia. Samples were used in dating and analysis of Mesolithic material culture (Malez *et al.* 1984). Collected July 1981 by M. Malez and submitted Nov. 1992 by M. Paunović, Croatian Academy of Sciences and Arts, Zagreb.

Z-2432. 2-Vi-G1 **18,280 ± 440**
 Layer G, 2.5 m depth. Expected age: 32,000–38,000 BP; [20,427]–19,303 cal BC.

Z-2433. 1-Vi-F d/d **26,600 ± 930**
 Layer F, 2.5 m depth. Expected age: *ca.* 30,000 BP.

Z-2447. Vi-E 18,500 ± 300
 Layer E. Expected age: >20,000 BP.

SLOVENIA

Z-2273. Valvazorjev Grad 110 ± 80
 Fragment of wood from a bell tower, Valvasorjev Grad near Medija (46°08'N, 14°46'E), central Slovenia. Collected Dec. 1990 by D. Kramberger, Institute for Protection of Cultural Monuments, Ljubljana, and submitted by J. Korošec, Slovenian Restoration Center, Ljubljana. Expected age: 17th century; cal AD 1690–1930 (99% probability; method B).

Z-2274. Predjamski Grad 480 ± 100
 Fragment of wooden lining of a niche, Predjamski Grad castle near Postojna (45°48'N, 14°07'E), southwest Slovenia. Collected and submitted 1990 by D. Kramberger.

Comment (D.K.): Expected age: 14th to 16th century; cal AD 1406–1471.

Z-2359. Hotiza, 3816/B 7030 ± 110
 Fragment of an oak dugout (monoxyle), length 9.3 m, found 6 m deep in sand at Hotiza village near Lendava (46°34'N, 16°30'E), northeast Slovenia. Collected by M. Erič and submitted May 1991 by I. Nemec, Institute for Protection of Cultural Monuments, Ljubljana (Nemec and Erič 1994); 5972–5732 cal BC.

Ljubljansko Barje Series

Samples of wood from the Ljubljansko Barje basin south and southwest of Ljubljana, where systematic archaeological excavation is in progress. Collected and submitted 1987 by T. Bregant, Department of Archaeology, Faculty of Arts and Sciences, Ljubljana.

Z-1931. Zornica – Blatna Brezovica 1 3140 ± 90
 Fragment of an oak dugout (*Quercus robur*) from Zornica near Blatna Brezovica (45°58'35"N, 14°20'20"E) (Dirjec 1990); 1511–1304 cal BC.

Z-1934. Zornica – Blatna Brezovica 2 3670 ± 100
 Wooden fragment of a pile-dwelling from a cultural layer, Sector B 4 (Dirjec 1991); 2190–1891 cal BC.

Z-1932. Preserje – Zakotek 2310 ± 90
 Fragment of a wooden boat from Preserje near Zakotek (45°57'50"N, 14°23'10"E); 407–207 cal BC.

Ajdovska Jama Cave Series

Charcoal from Ajdovska Jama cave at Nemška Vas near Krško (45°58'N, 15°30'E), east Slovenia. Collected by M. Horvat, Faculty of Science and Arts and submitted 1990 by A. Šercelj, Slovenian Academy of Sciences and Arts, Ljubljana. Samples from systematic excavation of a Neolithic site. Dates correspond to earlier measurements, Z-1042 to -1045 (Srdoč *et al.* 1984: 451), Z-1178, -1179, -1554, -1602, -1603 (Srdoč *et al.* 1987b: 138-139), Z-1822, -1860 (Srdoč *et al.* 1989: 86) and Z-2042 to -2044, -2123, -2179 (Srdoč *et al.* 1992: 156).

Z-2300. Ajdovska Jama 79/90 4440 ± 70
 Charcoal from the bottom of a funnel-shaped pit, Layer 106, 4.41 m depth. Expected age: Paleolithic; 3303–2923 cal BC.

Z-2301. Ajdovska Jama 20/90**4410 ± 70**

Charcoal from the lowest Holocene cultural layer 83, 2.64 m depth; 3260–2917 cal BC.

*SERBIA***Vladikina Ploča Series**

Wood fragment and bones from Vladikina Ploča cave, Rsovci near Pirot (43°11'26"N, 22°45'17"E), 720 m asl, southeast Serbia. Collected and submitted 1987 by D. Gavrilović, University of Belgrade.

Comment (D.G): Expected age: 500 BP. Dates period of cave occupation. Earlier measurements Z-1641 (Srdoč *et al.* 1989: 85) and -2096 (Srdoč *et al.* 1992: 157).

Z-1936. Vladikina Ploča 1**270 ± 70**

Wood from a wall inside the cave, 20 m from the entrance; cal AD 1510–1680 (79% probability; method B).

Z-1937. Vladikina Ploča 2**1740 ± 90**

Human bones from the dry part of the cave 15 m from the entrance; cal AD 221–416.

HYDROGEOLOGICAL AND GROUNDWATER SAMPLES*CROATIA***Hrvatsko Zagorje Series**

Samples of geothermal waters from two spas in Hrvatsko Zagorje, northwest Croatia, collected for investigation of water provenience. Collected March 1990 by A. Sliepčević and N. Horvatinčić.

Z-2306. Stubičke Toplice Spa 1**50.1 ± 1.0 pMC** $\delta^{13}C = -6.4\text{‰}$

Geothermal water from a borehole, 48–50 m depth ($t = 61.5^{\circ}C$, $pH = 6.6$, $HCO_3^- = 293 \text{ mg liter}^{-1}$, $\delta^2H = -83.0\text{‰}$, $\delta^{18}O = -11.0\text{‰}$, $k = 650 \mu S \text{ cm}^{-1}$), Stubičke Toplice Spa (45°56'N, 15°56'E). 3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-2309. Stubičke Toplice Spa 2**33.4 ± 0.6 pMC** $\delta^{13}C = -8.5\text{‰}$

Geothermal water from main catchment ($t = 47.1^{\circ}C$, $pH = 6.6$, $HCO_3^- = 301 \text{ mg liter}^{-1}$, $\delta^2H = -79.7\text{‰}$, $\delta^{18}O = -10.3\text{‰}$, $k = 603 \mu S \text{ cm}^{-1}$). 3H activity: $1.1 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-2308. Krapinske Toplice Spa**11.0 ± 0.8 pMC** $\delta^{13}C = -9.9\text{‰}$

Geothermal water from public spa ($t = 41.2^{\circ}C$, $pH = 7.3$, $HCO_3^- = 293 \text{ mg liter}^{-1}$, $\delta^2H = -74.9\text{‰}$, $\delta^{18}O = -10.4\text{‰}$, $k = 504 \mu S \text{ cm}^{-1}$), Krapinske Toplice (46°07'N, 15°49'E). 3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-2365. Podsused – PDS-2**26.5 ± 0.9 pMC**

Thermal water from exploitation borehole at Podsused (45°49'N, 15°50'E), west suburb of Zagreb. Collected and submitted 1991 by S. Tomić, INA-Naftaplin Co, Zagreb. Hydrogeological study of thermal water properties. The result completes previously published measurements Z-1558 and -1559 (Srdoč *et al.* 1987b: 144–145).

Eastern Slavonia Series

Groundwater samples from piezometers. Hydrogeologic investigation of water-bearing layers to determine the mean residence time and anthropogenic influence on groundwater quality near water

supply stations in eastern Slavonia, Croatia. Collected and submitted Oct. 1987 by S. Grgić (Grgić, Horvatinčić and Miletić 1991).

Z-1945. Kanovci – Vinkovci 1 **94.4 ± 1.5 pMC**

Groundwater from the overlying sediment above the first water-bearing Layer V-24/3, 5 m depth (pH = 7.0), Kanovci near Vinkovci (45°16'N, 18°49'E). ^3H activity: $4.9 \pm 0.4 \text{ Bq liter}^{-1}$.

Z-1944. Kanovci – Vinkovci 2 **31.9 ± 1.0 pMC**

Groundwater from the first water-bearing Layer P-1, 45 m depth ($t = 14.5^\circ\text{C}$, pH = 7.8, $\text{HCO}_3^- = 726 \text{ mg liter}^{-1}$). ^3H activity: $0.4 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1943. Kanovci – Vinkovci 3 **0.6 ± 0.5 pMC**

Groundwater from the second water-bearing Layer V-26, 82 m depth ($t = 14.5^\circ\text{C}$, pH = 7.82, $\text{HCO}_3^- = 799 \text{ mg liter}^{-1}$). ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1942. Trslana – Đakovo 1 **85.7 ± 1.2 pMC**

Groundwater from the first water-bearing Layer V-27, 45 m depth ($t = 13^\circ\text{C}$, pH = 7.0, $\text{HCO}_3^- = 606 \text{ mg liter}^{-1}$), Trslana near Đakovo (45°18'N, 18°25'E). ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1941. Trslana – Đakovo 2 **57.5 ± 1.0 pMC**

Groundwater from the second water-bearing Layer V-5/1, 88 m depth ($t = 13.4^\circ\text{C}$, pH = 7.6, $\text{HCO}_3^- = 726 \text{ mg liter}^{-1}$). ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Comment (S.G.): Although the investigated areas of Vinkovci and Đakovo belong to the same hydro-geologic zone, they represent two separate hydrodynamic systems with different infiltration rates and recharge areas.

Plitvice National Park Surface Waters

Tables 1 and 2 show the results of systematic measurements of ^{14}C activity of dissolved inorganic carbon (DIC) in surface water of the Bijela Rijeka and Crna Rijeka streams in the Plitvice Lakes area, central Croatia. These measurements were used to determine seasonal variations of ^{14}C activity and initial ^{14}C activity (Krajcar Bronić *et al.* 1992). The difference in ^{14}C activity of two springs was attributed to the geology of the recharge areas (Horvatinčić *et al.* 1989). We noticed an increase of ^{14}C activity in the downstream direction (Srdoč *et al.* 1986). Collected 1986 and 1987 by D. Srdoč and N. Horvatinčić.

TABLE 1. Bijela Rijeka Spring and Surface Water

Sample no.	Location	Date	pMC (± 1.1)	$\delta^{13}\text{C}$ (‰)	^3H (Bq liter $^{-1}$)
Z-1810	Spring	06/86	79.2		4.8
Z-1813	Mill*	06/86	77.5		
Z-1778	Spring	09/86	82.3		4.2
Z-1779	Mill	09/86	87.4		4.7
Z-1824	Mill	10/86	77.2		
Z-1844	Mill	11/86	83.7	-12.5	4.2
Z-1847	Mill	12/86	83.7	-13.9	4.0
Z-1850	Mill	02/87	83.0	-12.7	4.1
Z-1876	Mill	04/87	87.4		3.9

*Mill is located 1km downstream from the spring.

TABLE 2. Crna Rijeka Spring and Surface Water

Sample no.	Location	Date	pMC (± 1.1)	$\delta^{13}\text{C}$ (‰)	^3H (Bq liter $^{-1}$)
Z-1823	Bridge*	06/86	69.6		3.3
Z-1771	Spring	09/86	63.6		2.7
Z-1772	Bridge	09/86	61.5		2.9
Z-1834	Spring	10/86	60.6		3.4
Z-1825	Bridge	10/86	62.1		
Z-1848	Spring	12/86	70.7	-12.8	3.0
Z-1849	Bridge	02/87	66.7	-12.0	3.2
Z-1871	Bridge	04/87	85.3		2.2

*Bridge is located 3 km downstream from the spring.

Comment: Dates correspond to earlier measurements, Z-1024, -1159, -1281, -1434, -1337, -1379 and -1425 (Srdoč *et al.* 1987a: 131–132).

SLOVENIA

Z-2307. Čateške Toplice Spa V-15

20.9 ± 0.8 pMC

$\delta^{13}\text{C} = -10.2\text{‰}$

Geothermal water from exploitation Borehole V-15, depth 300–350 m ($t = 63.0^\circ\text{C}$, $\text{pH} = 6.3$, $\text{HCO}_3^- = 242$ mg liter $^{-1}$, $\delta^2\text{H} = -79.0\text{‰}$, $\delta^{18}\text{O} = -10.4\text{‰}$, $k = 460$ $\mu\text{S cm}^{-1}$), Čateške Toplice Spa near Brežice ($45^\circ 51'\text{N}$, $15^\circ 35'\text{E}$), east Slovenia. Collected by N. Horvatinčić and A. Sliepčević. Tritium activity: <0.2 Bq liter $^{-1}$.

SERBIA

Serbian Spas Series

Geothermal and groundwater water from central and south Serbia. This was a hydrogeological study of geothermal and cold water origin. Collected and submitted 1986 by M. Milivojević, Faculty of Mineralogy, Geology and Petrology Engineering, University of Belgrade and S. Grgić, Institute of Geology, Zagreb.

Z-1697. Banja Vrujci Spa

33.4 ± 0.6 pMC

$\delta^{13}\text{C} = -7.9\text{‰}$

Geothermal water from exploitation borehole ($t = 25.0$ – 26.4°C , $\text{pH} = 7.1$ – 7.4 , $\text{HCO}_3^- = 340$ mg liter $^{-1}$, $\delta^2\text{H} = -89\text{‰}$, $\delta^{18}\text{O} = -11.5\text{‰}$), Banja Vrujci near Ljig ($44^\circ 13'\text{N}$, $20^\circ 12'\text{E}$). Collected May 1986. Tritium activity: 0.8 ± 0.2 Bq liter $^{-1}$.

Z-1698. Ljig

8.1 ± 0.5 pMC

$\delta^{13}\text{C} = -4.5\text{‰}$

Geothermal water from a borehole ($t = 32.0^\circ\text{C}$, $\text{pH} = 7.6$, $\text{HCO}_3^- = 700$ mg liter $^{-1}$, $\delta^2\text{H} = -90\text{‰}$, $\delta^{18}\text{O} = -11.6\text{‰}$), Ljig ($44^\circ 13'\text{N}$, $20^\circ 15'\text{E}$). Collected Oct. 1986. Tritium activity: 1.0 ± 0.2 Bq liter $^{-1}$.

Z-1699. Čibutkovica

2.6 ± 0.4 pMC

$\delta^{13}\text{C} = -1.6\text{‰}$

Water from a spring ($t = 16.0$ – 18.0°C , $\text{pH} = 6.5$, $\text{HCO}_3^- = 3000$ mg liter $^{-1}$, $\delta^2\text{H} = -91\text{‰}$, $\delta^{18}\text{O} = -11.8\text{‰}$), Čibutkovica near Ljig ($44^\circ 18'\text{N}$, $20^\circ 15'\text{E}$). Collected May 1986. ^3H activity: 0.8 ± 0.2 Bq liter $^{-1}$.

Z-1700. Savinac

44.3 ± 1.1 pMC

$\delta^{13}\text{C} = -8.2\text{‰}$

Geothermal water from St. Sava spring ($t = 20.0^\circ\text{C}$, $\text{pH} = 7.3$, $\text{HCO}_3^- = 440$ mg liter $^{-1}$, $\delta^2\text{H} =$

–80‰, $\delta^{18}\text{O} = -10.8\text{‰}$), Savinac near Gornji Milanovac (44°02'N, 20°22'E). Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1701. Gornja Trepča Spa

Geothermal water from a spring ($t = 24.0^\circ\text{C}$, $\text{pH} = 6.9$, $\delta^2\text{H} = -88\text{‰}$, $\delta^{18}\text{O} = -12.0\text{‰}$), Gornja Trepča near Gornji Milanovac (43°56'N, 20°29'E). Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$31.9 \pm 0.6 \text{ pMC}$

$\delta^{13}\text{C} = -8.5\text{‰}$

Z-1702. Mataruška Banja Spa

Geothermal water from a spring ($t = 39.5\text{--}42.0^\circ\text{C}$, $\text{pH} = 6.9\text{--}7.7$, $\delta^2\text{H} = -83\text{‰}$, $\delta^{18}\text{O} = -10.6\text{‰}$), Mataruška Banja near Kraljevo (43°31'N, 20°37'E). Collected May 1986. ^3H activity: $0.8 \pm 0.2 \text{ Bq liter}^{-1}$.

$11.3 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -7.5\text{‰}$

Z-1705. Bogutovačka Banja Spa

Geothermal water from a spring ($t = 24.5^\circ\text{C}$, $\text{pH} = 7.4$, $\text{HCO}_3^- = 350 \text{ mg liter}^{-1}$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.6\text{‰}$), Bogutovačka Banja (43°40'N, 20°31'E). Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$27.3 \pm 0.6 \text{ pMC}$

$\delta^{13}\text{C} = -6.5\text{‰}$

Z-1710. Vrnjačka Banja Spa

Geothermal water from exploitation borehole ($t = 35.0^\circ\text{C}$, $\text{pH} = 6.7$, $\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -11.2\text{‰}$), Vrnjačka Banja (43°37'N, 20°55'E) near Kraljevo. Collected May 1986. ^3H activity: $1.1 \pm 0.2 \text{ Bq liter}^{-1}$.

$2.3 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -3.4\text{‰}$

Z-1706. Jošanička Banja Spa

Geothermal water from a spring ($t = 78.0^\circ\text{C}$, $\text{pH} = 7.8 - 8.3$, $\delta^2\text{H} = -86\text{‰}$, $\delta^{18}\text{O} = -11.6\text{‰}$), Jošanička Banja (43°23'N, 20°46'E), west slope of Mt. Kopaonik. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$32.9 \pm 1.0 \text{ pMC}$

$\delta^{13}\text{C} = -8.2\text{‰}$

Z-1716. Lukovska Banja Spa

Geothermal water from a spring ($t = 56.0\text{--}64.2^\circ\text{C}$, $\text{pH} = 6.8\text{--}7.2$, $\delta^2\text{H} = -73\text{‰}$, $\delta^{18}\text{O} = -10.7\text{‰}$), Lukovska Banja (43°10'N, 21°02'E), east slope of Mt. Kopaonik. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$4.4 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = 0.13\text{‰}$

Z-1712. Brus

Geothermal water from exploitation borehole ($t = 27.0^\circ\text{C}$, $\text{pH} = 7.5$, $\delta^2\text{H} = -96\text{‰}$, $\delta^{18}\text{O} = -11.3\text{‰}$), Brus (43°22'N, 21°03'E), east slope of Mt. Kopaonik. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$9.7 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -3.4\text{‰}$

Z-1715. Kuršumlijska Banja Spa

Geothermal water from exploitation borehole ($t = 63.0^\circ\text{C}$, $\text{pH} = 7.1\text{--}7.6$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.6\text{‰}$), Kuršumlijska Banja near Kuršumlija (43°04'N, 21°16'E). Collected May 1986. ^3H activity: $0.5 \pm 0.2 \text{ Bq liter}^{-1}$.

$4.5 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -0.2\text{‰}$

Z-1728. Prolom Banja Spa

Water from a spring ($t = 27.0^\circ\text{C}$, $\text{pH} = 7.3$, $\delta^2\text{H} = -89\text{‰}$, $\delta^{18}\text{O} = -11.6\text{‰}$), Prolom Banja near Kuršumlija (43°02'N, 21°26'E). Collected June 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

$71.9 \pm 0.8 \text{ pMC}$

$\delta^{13}\text{C} = -18.4\text{‰}$

Z-1711. Veluće

Geothermal water from an exploitation borehole ($t = 17.0\text{--}21.0^\circ\text{C}$, $\text{pH} = 6.4\text{--}7.0$, $\delta^2\text{H} = -91\text{‰}$,

$6.0 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -0.7\text{‰}$

$\delta^{18}\text{O} = -11.2\text{‰}$, Veluće near Kruševac (43°32'N, 21°05'E). Collected May 1986. ^3H activity: <0.2 Bq liter $^{-1}$.

50.7 ± 0.7 pMC

Z-1733. Rgošte

$\delta^{13}\text{C} = -9.5\text{‰}$

Geothermal water from a spring ($t = 29.0^\circ\text{C}$, $\text{pH} = 7.3$, $\delta^2\text{H} = -82\text{‰}$, $\delta^{18}\text{O} = -11.0\text{‰}$), Rgošte near Knjaževac (43°33'N, 22°13'E). Collected June 1986. ^3H activity: 2.5 ± 0.2 Bq liter $^{-1}$.

47.4 ± 1.0 pMC

Z-1724. Manastir Rača

$\delta^{13}\text{C} = -11.3\text{‰}$

Water from a spring ($t = 14.0^\circ\text{C}$, $\text{pH} = 7.5$, $\delta^2\text{H} = -81\text{‰}$, $\delta^{18}\text{O} = -11.0\text{‰}$), Manastir Rača near Bajina Bašta (43°56'N, 19°32'E). Collected June 1986. ^3H activity: 1.7 ± 0.2 Bq liter $^{-1}$.

0.9 ± 0.6 pMC

Z-1717. Bujanovačka Banja Spa

$\delta^{13}\text{C} = 1.8\text{‰}$

Geothermal water from exploitation borehole ($t = 45.2^\circ\text{C}$, $\text{pH} = 8.2$, $\delta^2\text{H} = -91\text{‰}$, $\delta^{18}\text{O} = -11.2\text{‰}$), Bujanovačka Banja near Bujanovac (42°25'N, 21°45'E). Collected May 1986. ^3H activity: 0.6 ± 0.2 Bq liter $^{-1}$.

4.6 ± 0.5 pMC

Z-1729. Sijarinska Banja Spa

$\delta^{13}\text{C} = 0.0\text{‰}$

Geothermal water from exploitation borehole ($t = 68.0^\circ\text{C}$, $\text{pH} = 6.8$, $\delta^2\text{H} = -91\text{‰}$, $\delta^{18}\text{O} = -11.3\text{‰}$), Sijarinska Banja near Lebane (42°47'N, 21°37'E). Collected June 1986. ^3H activity: <0.2 Bq liter $^{-1}$.

7.3 ± 0.5 pMC

Z-1737. Neresnica

$\delta^{13}\text{C} = -2.7\text{‰}$

Water from exploitation borehole ($t = 20.0^\circ\text{C}$, $\text{pH} = 6.8$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.3\text{‰}$), Neresnica near Majdanpek (44°26'N, 21°43'E). Collected June 1986. ^3H activity: 0.9 ± 0.2 Bq liter $^{-1}$.

8.2 ± 0.5 pMC

Z-1721. Selters

$\delta^{13}\text{C} = -2.9\text{‰}$

Geothermal water from exploitation borehole ($t = 43.7^\circ\text{C}$, $\text{pH} = 6.8$, $\delta^2\text{H} = -55\text{‰}$, $\delta^{18}\text{O} = -8.3\text{‰}$), Selters near Mladenovac (44°29'N, 20°42'E). Collected June 1986. ^3H activity: 0.9 ± 0.2 Bq liter $^{-1}$.

50.0 ± 0.6 pMC

Z-1732. Sokobanja Spa

$\delta^{13}\text{C} = -8.2\text{‰}$

Geothermal water from exploitation borehole ($t = 43.0^\circ\text{C}$, $\text{pH} = 7.4$, $\delta^2\text{H} = -83\text{‰}$, $\delta^{18}\text{O} = -11.3\text{‰}$), Sokobanja near Aleksinac (43°35'N, 21°52'E). Collected June 1986. ^3H activity: 2.0 ± 0.2 Bq liter $^{-1}$.

57.8 ± 0.7 pMC

Z-1730. Niška Banja Spa

$\delta^{13}\text{C} = -7.9\text{‰}$

Geothermal water from exploitation borehole ($t = 38.0^\circ\text{C}$, $\text{pH} = 7.4$, $\delta^2\text{H} = -86\text{‰}$, $\delta^{18}\text{O} = -11.3\text{‰}$), Niška Banja near Niš (43°17'N, 22°01'E). Collected June 1986. ^3H activity: 1.9 ± 0.2 Bq liter $^{-1}$.

Z-2100. Školska Česma

88.8 ± 1.8 pMC

Water from a spring in Niška Banja Spa. Collected July 1988. ^3H activity: 2.2 ± 0.2 Bq liter $^{-1}$.

60.0 ± 0.7 pMC

Z-1731. Krivi Vir

$\delta^{13}\text{C} = -10.3\text{‰}$

Geothermal water from a spring ($t = 20.6^\circ\text{C}$, $\text{pH} = 7.2$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.2\text{‰}$), Krivi Vir near Niš (43°49'N, 21°45'E). Collected June 1986. ^3H activity: 3.2 ± 0.2 Bq liter $^{-1}$.

- Z-1727. Pribojska Banja Spa** 2.9 ± 1.5 pMC
 $\delta^{13}\text{C} = -4.3\text{‰}$
 Geothermal water from a spring ($t = 36.2^\circ\text{C}$, $\text{pH} = 8.2$, $\text{HCO}_3^- = 200$ mg liter $^{-1}$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.7\text{‰}$), Pribojska Banja near Priboj na Limu ($43^\circ 34'\text{N}$, $19^\circ 32'\text{E}$). Collected June 1986. ^3H activity: 0.5 ± 0.2 Bq liter $^{-1}$.
- Z-1826. Čedovo** 14.1 ± 0.8 pMC
 $\delta^{13}\text{C} = -7.3\text{‰}$
 Water from a spring ($\delta^2\text{H} = -83\text{‰}$, $\delta^{18}\text{O} = -10.9\text{‰}$), Čedovo ($43^\circ 35'\text{N}$, $20^\circ 00'\text{E}$). Collected Oct. 1986. ^3H activity: <0.2 Bq liter $^{-1}$.
- Z-1770. Bogatić, BR-1** 12.8 ± 0.8 pMC
 $\delta^{13}\text{C} = -4.8\text{‰}$
 Water from a borehole ($\delta^2\text{H} = -89\text{‰}$, $\delta^{18}\text{O} = -11.3\text{‰}$), Bogatić near Sremska Mitrovica ($44^\circ 50'\text{N}$, $19^\circ 35'\text{E}$), Mačva. Collected Sept. 1986. ^3H activity: <0.2 Bq liter $^{-1}$.
- Z-1695. Dublje** 7.5 ± 0.5 pMC
 $\delta^{13}\text{C} = -2.9\text{‰}$
 Geothermal water from a borehole ($t = 50.0^\circ\text{C}$, $\text{pH} = 6.3$, $\text{HCO}_3^- = 500$ mg liter $^{-1}$, $\delta^2\text{H} = -96\text{‰}$, $\delta^{18}\text{O} = -12.5\text{‰}$), Dublje near Bogatić ($44^\circ 48'\text{N}$, $19^\circ 32'\text{E}$). Collected May 1986. ^3H activity: 1.6 ± 0.2 Bq liter $^{-1}$.
- Z-1827. Belotić** 3.1 ± 0.6 pMC
 $\delta^{13}\text{C} = -3.2\text{‰}$
 Water from exploitation borehole ($t = 24.0^\circ\text{C}$, $\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -11.5\text{‰}$), Belotić near Šabac ($44^\circ 49'\text{N}$, $19^\circ 33'\text{E}$). Collected Oct. 1986. ^3H activity: <0.2 Bq liter $^{-1}$.
- Z-1713. Suva Česma** 2.6 ± 0.4 pMC
 $\delta^{13}\text{C} = -2.4\text{‰}$
 Geothermal water from Suva Česma spring ($t = 24.0^\circ\text{C}$, $\text{pH} = 7.7$, $\delta^2\text{H} = -77\text{‰}$, $\delta^{18}\text{O} = -9.5\text{‰}$), Suva Česma near Prokuplje ($43^\circ 15'\text{N}$, $21^\circ 35'\text{E}$). Collected May 1986. ^3H activity: 0.4 ± 0.2 Bq liter $^{-1}$.
- Z-1714. Viča** 1.3 ± 0.4 pMC
 $\delta^{13}\text{C} = -3.7\text{‰}$
 Water from a spring ($t = 19.0^\circ\text{C}$, $\text{pH} = 8.0$, $\delta^2\text{H} = -88\text{‰}$, $\delta^{18}\text{O} = -11.0\text{‰}$), Viča near Prokuplje. Collected June 1986. ^3H activity: 1.9 ± 0.2 Bq liter $^{-1}$.
- Z-1722. Smederevska Palanka Spa** 8.4 ± 0.5 pMC
 $\delta^{13}\text{C} = 0.8\text{‰}$
 Geothermal water ($t = 47.2^\circ\text{C}$, $\text{pH} = 7.1$, $\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -11.1\text{‰}$), Smederevska Palanka near Smederevo ($44^\circ 23'\text{N}$, $20^\circ 57'\text{E}$). Collected June 1986. ^3H activity: <0.2 Bq liter $^{-1}$.
- Z-1725. Kosjerić** 40.9 ± 0.6 pMC
 $\delta^{13}\text{C} = -11.2\text{‰}$
 Geothermal water from a spring ($t = 23.2^\circ\text{C}$, $\text{pH} = 7.0$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.2\text{‰}$), Kosjerić near Užice ($44^\circ 00'\text{N}$, $19^\circ 57'\text{E}$). Collected June 1986. ^3H activity: 0.8 ± 0.2 Bq liter $^{-1}$.
- Z-1726. Rožanstvo Spa** 29.4 ± 0.6 pMC
 $\delta^{13}\text{C} = -11.5\text{‰}$
 Water from a spring ($t = 17.5\text{--}20.0^\circ\text{C}$, $\text{pH} = 7.3$, $\delta^2\text{H} = -81\text{‰}$, $\delta^{18}\text{O} = -10.9\text{‰}$), Rožanstvo near Užice ($43^\circ 43'\text{N}$, $19^\circ 55'\text{E}$). Collected June 1986. ^3H activity: 0.8 ± 0.2 Bq liter $^{-1}$.
- Z-1696. Petnica Spa, PT-2** 19.8 ± 0.5 pMC
 $\delta^{13}\text{C} = -10.2\text{‰}$
 Geothermal water from Borehole PT-2 ($t = 31.0^\circ\text{C}$, $\text{pH} = 7.5$, $\text{HCO}_3^- = 370$ mg liter $^{-1}$, $\delta^2\text{H} =$

–81‰, $\delta^{18}\text{O} = -10.1\text{‰}$), Petnica near Valjevo (45°15'N, 19°54'E). Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1734. Nikolićevo Spa

$3.9 \pm 0.4 \text{ pMC}$

$\delta^{13}\text{C} = -0.7\text{‰}$

Water from a borehole ($t = 36.4^\circ\text{C}$, $\text{pH} = 7.5$, $\delta^2\text{H} = -97\text{‰}$, $\delta^{18}\text{O} = -12.9\text{‰}$), Nikolićevo near Zaječar (43°57'N, 22°16'E). Collected June 1986. ^3H activity: $0.4 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1735. Gamzigradska Banja Spa

$15.1 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -5.3\text{‰}$

Geothermal water from a spring ($t = 42.0^\circ\text{C}$, $\text{pH} = 7.2$, $\delta^2\text{H} = -80\text{‰}$, $\delta^{18}\text{O} = -11.0\text{‰}$), Gamzigradska Banja near Zaječar (43°54'N, 22°11'E). Collected June 1986. ^3H activity: $0.8 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1723. Radaljska Banja Spa

$34.6 \pm 0.7 \text{ pMC}$

$\delta^{13}\text{C} = -14.8\text{‰}$

Geothermal water from a spring ($t = 28.2^\circ\text{C}$, $\text{pH} = 9.2$, $\text{HCO}_3^- = 70 \text{ mg liter}^{-1}$, $\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -11.8\text{‰}$), Radaljska Banja near Zvornik (44°24'N, 19°11'E). Collected June 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1703. Ovčar Banja Spa

$20.8 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -3.3\text{‰}$

Geothermal water from a spring ($t = 38.0^\circ\text{C}$, $\text{pH} = 7.6$, $\delta^2\text{H} = -77\text{‰}$, $\delta^{18}\text{O} = -10.7\text{‰}$), Ovčar Banja near Čačak (43°55'N, 20°12'E). Collected May 1986. ^3H activity: $0.8 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1845. Kupinovo

$29.2 \pm 0.8 \text{ pMC}$

$\delta^{13}\text{C} = -2.4\text{‰}$

Water from a borehole, Kupinovo (44°42'N, 20°03'E). Collected Dec. 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1736. Boleč Spa

$12.9 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -12.5\text{‰}$

Water ($t = 22^\circ\text{C}$, $\delta^2\text{H} = -95\text{‰}$, $\delta^{18}\text{O} = -12.1\text{‰}$), Boleč near Belgrade (44°42'N, 20°35'E). Collected June 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1841. Grocka

$31.8 \pm 0.8 \text{ pMC}$

$\delta^{13}\text{C} = -4.5\text{‰}$

Water from a borehole ($\delta^2\text{H} = -57\text{‰}$, $\delta^{18}\text{O} = -3.2\text{‰}$), Grocka near Belgrade (44°48'N, 20°49'E). Collected Dec. 1986. ^3H activity: $0.3 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1938. Belgrade, IEBP-3

$2.4 \pm 0.5 \text{ pMC}$

Water from exploitation Borehole IEBP-3 ($\delta^2\text{H} = -80\text{‰}$, $\delta^{18}\text{O} = -11.5\text{‰}$) near Belgrade (44°47'N, 20°28'E). Collected Sept. 1987. ^3H activity: $0.5 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1707. Novopazarska Banja Spa

$7.7 \pm 0.5 \text{ pMC}$

$\delta^{13}\text{C} = -3.5\text{‰}$

Geothermal water from a borehole ($t = 54.0^\circ\text{C}$, $\text{pH} = 7.4$, $\delta^2\text{H} = -89\text{‰}$, $\delta^{18}\text{O} = -11.7\text{‰}$), Novopazarska Banja near Novi Pazar (43°06'N, 20°31'E). Collected May 1986. ^3H activity: $0.2 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1708. Rajčinovića Banja Spa

$2.4 \pm 0.4 \text{ pMC}$

$\delta^{13}\text{C} = -10.0\text{‰}$

Geothermal water ($t = 38.6^\circ\text{C}$, $\text{pH} = 8.2$, $\delta^2\text{H} = -86\text{‰}$, $\delta^{18}\text{O} = -10.9\text{‰}$), Rajčinovića Banja near Novi Pazar. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1709. Gornji Gradac Spa

$62.6 \pm 1.0 \text{ pMC}$

$\delta^{13}\text{C} = -10.3\text{‰}$

Geothermal water ($t = 21.0^\circ\text{C}$, $\text{pH} = 7.2$, $\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -10.3\text{‰}$), Gornji Gradac near Novi Pazar. Collected May 1986. ^3H activity: $1.2 \pm 0.2 \text{ Bq liter}^{-1}$.

Surdulica Series

Water samples from springs and an old mine are part of a study of the mechanism of water formation in the Surdulica geothermal system, south Serbia (Milovanović *et al.* 1989; Hadžišehović *et al.* 1993). Collected and submitted 1986 by S. Stanković, Geozavod, Belgrade, S. Grgić and B. Obelić.

Comment: Dates complete previously published measurements (Srdoč *et al.* 1992: 163–164).

Z-1764. Mt. Besna Kobila **72.2 ± 1.2 pMC**

Water from a spring, Mt. Besna Kobila (42°28'N, 22°08'E). Collected July 1986.

Z-1761. Stari Glog 1 **71.1 ± 1.2 pMC**

Water from a spring ($\delta^2\text{H} = -76\text{‰}$, $\delta^{18}\text{O} = -10.0\text{‰}$), Stari Glog, Mt. Besna Kobila. Collected July 1986.

Z-1804. Stari Glog 2 **69.8 ± 1.1 pMC**

Water from a spring near Stari Glog, Mt. Besna Kobila. Collected Oct. 1986.

Z-1807. Golemi Izvor **76.0 ± 1.2 pMC**

Water from Golemi Izvor spring ($\delta^2\text{H} = -82\text{‰}$, $\delta^{18}\text{O} = -11.4\text{‰}$), Mt. Besna Kobila. Collected Oct. 1986. ^3H activity: $70.0 \pm 0.3 \text{ Bq liter}^{-1}$.

Z-1809. Topli Dol **90.0 ± 1.3 pMC**

Springwater feeding Topli Dol river (42°40'N, 22°08'E). Collected Oct. 1986.

Z-1765. Blagodat **55.2 ± 1.0 pMC**

Water from Blagodat mine ($\delta^2\text{H} = -75\text{‰}$, $\delta^{18}\text{O} = -10.9\text{‰}$) at Kriva Feja (42°33'N, 22°09'E). Collected July 1986. ^3H activity: $7.3 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1808. Crna Reka River **39.7 ± 1.0 pMC**

River water, Crna Reka ($\delta^2\text{H} = -78\text{‰}$, $\delta^{18}\text{O} = -10.9\text{‰}$) at Kriva Feja. Collected Oct. 1986. ^3H activity: $1.5 \pm 0.2 \text{ Bq liter}^{-1}$.

Vranjska Banja Series

Geothermal water from Vranjska Banja Spa (42°32'N, 22°02'E) and its surroundings. Collected and submitted 1986 by S. Tomić and B. Obelić.

Z-1718. Vranjska Banja 1 **6.0 ± 0.5 pMC**
 $\delta^{13}\text{C} = -6.6\text{‰}$

Geothermal water from exploitation Boreholes A-1 and A-2 ($t = 84.0^\circ\text{C}$, $\text{pH} = 7.8$), Vranjska Banja. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1719. Vranjska Banja 2 **4.5 ± 0.5 pMC**
 $\delta^{13}\text{C} = -3.7\text{‰}$

Geothermal water from exploitation Borehole A-1 ($t = 80.2^\circ\text{C}$, $\text{pH} = 7.7$, $\delta^2\text{H} = -86\text{‰}$, $\delta^{18}\text{O} = -11.1\text{‰}$), Vranjska Banja. Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1759. Vranjska Banja 3 **18.0 ± 0.6 pMC**

Geothermal water from an old catchment ($t = 80^\circ\text{C}$, $\delta^2\text{H} = -81\text{‰}$, $\delta^{18}\text{O} = -11.0\text{‰}$), Vranjska Banja. Collected July 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1760. Vranjska Banja 4 **4.4 ± 0.6 pMC**

Geothermal water from an old catchment. Collected July 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1762. Vranjska Banja 5**10.4 ± 0.6 pMC**

Geothermal water from exploitation Borehole B-1 ($\delta^2\text{H} = -85\text{‰}$, $\delta^{18}\text{O} = -11.2\text{‰}$) located in Vranjska Banja Spa park. Collected July 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1763. Vranjska Banja 6**77.5 ± 1.2 pMC**

Geothermal water from exploitation Borehole B-1. Collected Oct. 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1802. Vranjska Banja 7**1.3 ± 0.5 pMC**

Geothermal water from a spring ($\delta^2\text{H} = -87\text{‰}$, $\delta^{18}\text{O} = -11.2\text{‰}$) near the hotel in Vranjska Banja Spa. Collected July 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1803. Vranjska Banja 8**2.7 ± 0.6 pMC**

Geothermal water from a spring near the hotel. Collected Oct. 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Z-1805. Vranjska Banja 9**16.8 ± 0.7 pMC**

Water from infiltration (14°C , $\text{pH} = 7.0$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.1\text{‰}$) near the railway station. Collected July 1986. ^3H activity: $1.7 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1806. Vranjska Banja 10**73.6 ± 1.2 pMC**

Water from infiltration near the railway station. Collected Oct. 1986. ^3H activity: $1.5 \pm 0.2 \text{ Bq liter}^{-1}$.

Z-1720. Toplac**26.9 ± 0.6 pMC** $\delta^{13}\text{C} = -7.8\text{‰}$

Geothermal water from a borehole (23.0°C , $\text{pH} = 7.6$, $\delta^2\text{H} = -79\text{‰}$, $\delta^{18}\text{O} = -10.7\text{‰}$), Toplac near Vranje ($42^\circ33'\text{N}$, $21^\circ57'\text{E}$). Collected May 1986. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Bačka Series

Collected and submitted April 1986 by M. Hadžišehović, Boris Kidrič Institute, Vinča.

Z-1687. Bačko Novo Selo**24.5 ± 0.7 pMC**

Water from Well 27 at Bačko Novo Selo ($45^\circ55'\text{N}$, $19^\circ08'\text{E}$), north Serbia.

Z-1689. Mladenovo**16.8 ± 0.6 pMC**

Water from Well 4 at Mladenovo ($43^\circ17'\text{N}$, $22^\circ01'\text{E}$), north Serbia.

Lim Valley Series

Tap water from Lim Valley, southwest Serbia. Collected and submitted May 1990 by M. Hadžišehović.

Z-2231. Seljašnica**89.5 ± 1.1 pMC**

Tap water from Seljašnica ($43^\circ22'\text{N}$, $19^\circ35'\text{E}$).

Z-2232. Čadinje**94.1 ± 1.1 pMC**

Tap water from Čadinje ($43^\circ22'\text{N}$, $19^\circ37'\text{E}$).

BOSNIA AND HERZEGOVINA**Z-2331. Lješljani SB-1****116.6 ± 1.3 pMC**

Groundwater from Borehole SB-1, Lješljani near Bosanski Novi ($45^\circ02'\text{N}$, $16^\circ25'\text{E}$), Bosnia. Collected and submitted April 1991 by N. Miošić, Geoinženjering Co., Sarajevo. ^3H activity: $<0.2 \text{ Bq liter}^{-1}$.

Tuzla Series

Groundwater and mineral water from the environs of Tuzla salt mine. Samples were part of hydro-geological study. Collected and submitted March 1992 by N. Miošić.

Z-2381. Živinice **17.8 ± 0.4 pMC**

Groundwater from Kiseljak near Živinice (44°27'N, 18°39'E). ³H activity: 1.2 ± 0.2 Bq liter⁻¹.

Z-2384. Lukavac **14.8 ± 0.6 pMC**

Water from well Petrak near Lukavac (44°31'N, 18°32'E). ³H activity: <0.2 Bq liter⁻¹.

Z-2382. Bokanići **1.1 ± 0.8 pMC**

Mineral water from borehole at Kiseljak near Bokanići (44°30'N, 18°32'E). ³H activity: <0.2 Bq liter⁻¹.

Z-2383. Ljubače **1.6 ± 0.8 pMC**

Groundwater from Kiseljak near Ljubače (44°29'N, 18°36'E). ³H activity: 2.8 ± 0.2 Bq liter⁻¹.

GEOLOGICAL SAMPLES

CROATIA

Plitvice National Park Samples

Z-2213. Lake Prošće **67.5 ± 0.7 pMC**

Tufa from a submerged barrier, Lake Prošće, 5–7 m depth. Collected and submitted March 1990 by D. Srdoč and D. Petricioli, Center for Marine Research, Rudjer Bošković Institute, Zagreb.

Lake Kozjak Series

Samples of tufa and fragments of sunken trees from the surface of a submerged barrier dividing Lake Kozjak into Upper and Lower Basin. Dating the period of barrier growth before flooding by rising lake-water level. Collected and submitted March 1990 by D. Srdoč and D. Petricioli.

Z-2214. Lake Kozjak 1 **72.4 ± 0.7 pMC**

Tufa, 18 m water depth.

Z-2215. Lake Kozjak 2 **71.2 ± 0.8 pMC**

Tufa, 5 m water depth.

Z-2216. Lake Kozjak 3 **97.4 ± 0.9 pMC**

Fragment of a branch from the top of a submerged tree, growing on the crest of the tufa barrier, presently 5–6 m below the lake surface.

Z-2217. Lake Kozjak 4 **95.9 ± 0.9 pMC**

Fragment of a branch from the top of a submerged tree; the tree base is presently 12 m below the lake surface.

Lake Gavanovac Series

Tufa profiles above Lake Gavanovac. Collected Feb. 1990 by D. Srdoč. The results complete previously published measurements Z-656, -657, -659, -668, -672, -673, -677 (Srdoč, Obelić and Horvat-inčić 1980).

- Z-2204. Lake Gavanovac 1** **59.5 ± 0.5 pMC**
Surface layer, Profile I.
- Z-2205. Lake Gavanovac 2** **66.8 ± 0.7 pMC**
Surface layer, Profile II.
- Z-2206. Lake Gavanovac 3** **61.2 ± 0.6 pMC**
Compact tufa, Profile III.
- Z-2362. Pag** **99.5 ± 0.9 pMC**
Shells from a deposit along the shoreline, presently 5 m asl, saltworks southeast of Pag (44°26'N, 15°04'E), Pag Island, south Croatia. Collected July 1989 and submitted June 1991 by Lj. Marjanac.
- Z-2228. Bednja** **1130 ± 110**
Fossil oak (*Quercus niger*) from the bed of the Bednja River near Bednja (46°10'N, 16°15'E), north-west Croatia. Collected and submitted May 1990 by M. Milinović, Zagreb.
- Comment* (M.M.): Expected age: >1000 BP.
- Lake Prukljan Series**
- Sediment, tufa and shells from brackish Lake Prukljan near Skradin (43°49'N, 15°55'E), south Croatia. The sediment sample was collected and submitted 1984 by M. Juračić, Faculty of Natural Sciences and Mathematics, University of Zagreb, and the tufa and shell samples by D. Petricioli, May 1990.
- Z-1277. Prukljan 1** **70.5 ± 1.1 pMC**
Lake-bottom sediment, 16–25 cm depth, in 25-m-deep water near Cape Vukinac.
- Z-2366. Prukljan 2** **105.3 ± 0.8 pMC**
Tufa from a submerged barrier, 3.5 m depth.
- Z-2367. Prukljan 3** **103.9 ± 0.7 pMC**
Shells from a submerged tufa barrier, 3.5 m depth.
- Z-1856. Vindija** **1.7 ± 0.6 pMC**
Speleothem from Vindija cave, Gornja Voća near Ivanec (46°18'12"N, 16°14'38"E), north Croatia. Collected and submitted 1987 by M. Malez.
- Z-2090. St. Jakov 51-12-L** **3.6 ± 0.7 pMC**
Calcareous tufa, St. Jakov near Knin (44°04'N, 16°13'E), 140 m asl, south Croatia. Collected and submitted 1989 by Z. Velimirović, INA-Inženjering Co., Zagreb.
- Comment* (Z.V.): Expected age: Holocene.
- Z-2091. Raštevčić 71-9-L** **3.4 ± 0.6 pMC**
Soil carbonate, Raštevčić near Zadar (44°05'N, 15°32'E), 134 m asl, south Croatia. Collected and submitted 1989 by Z. Velimirović.
- Z-2092. Smilčić 72-9-L** **9.8 ± 0.7 pMC**
Soil carbonate, Smilčić near Zadar (44°05'N, 15°30'E), 150 m asl, south Croatia. Collected and submitted 1988 by Z. Velimirović.
- Comment* (Z.V.): Expected age: Holocene.

Z-2093. Ljubač 3-8-K**0.7 ± 0.7 pMC**

Soil carbonate, Ljubački Zaliv (44°13'N, 15°13'E), 0 m asl, south Croatia. Collected and submitted 1989 by Z. Velimirović.

Z-2094. Susak Island 4-VI-4-J**7.0 ± 0.7 pMC**

Soil carbonate, Susak Island (44°30'N, 14°20'E), south Croatia. Collected and submitted by Z. Velimirović.

General Comments (Z.V.): Samples Z-2090, -2091, -2092, -2093 and -2094 were dated for stratigraphic and sedimentologic study. (D.S.): High percentage of mineral carbonates impeded this study.

Kninsko Polje Series

Peat from boreholes, Kninsko Polje (44°02'40"N, 16°12'35"E) near Knin, south Croatia. Collected and submitted May 1988 by V. Jurak, Faculty of Mining, Geology and Petroleum Engineering, Zagreb.

Z-2052. NB-2**>37,000**

Peat, Borehole NB-2, 7.1 m depth, 225 m asl. Expected age: Würm 2/3.

Z-2054. NB-3-1**2210 ± 210**

Peat, Borehole NB-3, 7.1–10.0 m depth, 219.6 m asl. Expected age: Holocene, Atlantic phase.

Z-2053. NB-3-2**8140 ± 250**

Peat, Borehole NB-3, 16.4–27.0 m depth. Expected age: Holocene, before Boreal phase.

SLOVENIA**Malo Polje Series**

Lake chalk from a moor at Malo Polje (46°21'N, 13°51'E), 1600 m asl, Mt. Triglav, Julian Alps, northwest Slovenia. Collected and submitted 1987 by A. Šercelj, as part of systematic palynological investigation of Holocene vegetation in Slovenia.

Comment (A.Š.): Dates correspond to earlier measurements Z-1922 and -1923 (Srdoč *et al.* 1989: 94).

Z-1924. Malo Polje**19.5 ± 0.4 pMC**

Lake chalk, 100–120 cm depth.

Z-1925. Malo Polje**1.8 ± 0.2 pMC**

Lake chalk, 300–320 cm depth.

Z-1852. Divaška Jama cave**72.9 ± 1.1 pMC**

Recent speleothem, "macaroni"-shaped, from Divaška Jama cave near Škocjan (45°49'N, 14°01'E), west Slovenia. Collected and submitted March 1987 by J. Urbanc, Jožef Stefan Institute, Ljubljana.

Comment (D.S.): Used to determine the initial ¹⁴C activity of speleothems.

Lendava Series

Wood fragments from postglacial deposits near Lendava (46°33'N, 16°27'E), 170 m asl, northwest Slovenia. Collected and submitted 1991 by J. Pezdič, Jožef Stefan Institute, Ljubljana.

Z-2294. Lendava 1 **7390 ± 180**

Fragment of wood from sandstone, 5 m depth, at Puconci (46°41'N, 16°09'E), 200 m asl, on the edge of the Panonian basin.

Comment (J.P.): Expected age: Late Postglacial.

Z-2292. Lendava 3 **530 ± 130**

Fragment of wood from young clastic sediment, 1 m depth, near Lendava.

Z-2431. Ljubljansko Barje **540 ± 120**

Fragment of wood from clayey-peaty sediment, 2 m depth, Ljubljansko Barje near Ljubljana (45°56'N, 14°33'E), 320 m asl, Slovenia. Collected and submitted Oct. 1992 by J. Pezdič.

*BOSNIA AND HERZEGOVINA***Z-1837. Kravica Falls** **76.8 ± 1.2 pMC**

Recent tufa, Kravica Falls on Trebižat River near Ljubuški (43°12'N, 17°34'E), Herzegovina. Collected June 1986 by D. Srdoč.

Comment (D.S.): Used to determine the initial ¹⁴C activity of calcareous tufa.

Z-2364. Livno 71-14-M **38.2 ± 0.9 pMC**

Siltite from an outcrop at the northeast part of Livanjsko Polje near Livno (43°50'N, 17°02'E), central Bosnia and Herzegovina. Collected and submitted June 1991 by Lj. Marjanac.

Z-1835. Banja Ilidža Spa IB-2 **3.7 ± 0.6 pMC**

Calcareous deposit from Banja Ilidža Spa near Sarajevo (43°49'N, 18°18'E), Bosnia. Collected and submitted Dec. 1986 by B. Đerković, Geoinženjering, Sarajevo.

*SERBIA***Z-1935. Vladikina Ploča** **2.8 ± 0.6 pMC**

Speleothem from the top of a calcite barrier, Vladikina Ploča cave, Rsovci near Pirot (43°11'26"N, 22°45'17"E), 720 m asl, Serbia. Collected and submitted 1987 by D. Gavrilović.

Comment (D.G.): Expected age: 10,000 BP.

Z-1949. Orahovo ET-71142 **26,600 ± 1500**

Fossil soil from Borehole BT-51, 810 cm depth, Orahovo (45°52'N, 19°46'E), 150 m asl, Bačka, Vojvodina. Collected and submitted 1987 by M. Galečić, Geoinstitut, Belgrade. Dated to help draft the geologic map of Vojvodina. This result completes previously published series Z-1952 to -1956 (Srdoč *et al.* 1992: 167). Expected age: Würm.

Z-1993. Nišava River **3520 ± 140**

Fragment of wood from the bed of the Nišava River near Pirot (43°09'N, 22°35'E), southwest Serbia. Collected and submitted 1987 by N. Antić, Niš, Serbia.

Z-2111. Mol E-8426 **10.2 ± 0.7 pMC**

Clayey aleurite from Borehole K-59-A, 4.9–5.3 m depth, Mol near Ada (45°46'N, 20°08'E), 82 m asl, Bačka, Vojvodina. Collected and submitted Feb. 1989 by D. Koprivica, Geoinstitut, Belgrade. Dated to help draft the geologic map of Vojvodina.

Comment (D.K.): Expected age: Würm 2/3.

Lovćenac Series

Fossil soils from Lovćenac (45°41'N, 14°43'E) 100 m asl, Bačka, Vojvodina. Collected and submitted 1989 by M. Galečić, Geoinstitut, Belgrade.

Z-2109. E-71263 **11.6 ± 0.8 pMC**
Organic part of fossil soil from Krivaja River bank near Lovćenac.

Z-2110. E-71262 **12.8 ± 0.7 pMC**
Inorganic part of fossil soil from open profile, brickyard near Lovćenac.

Z-1851. Bački Breg **5.8 ± 0.6 pMC**
Fluvial sediment from Borehole MB-1 at Bački Breg (45°55'N, 18°56'E), 85 m asl, 4.8–5.0 m depth, Vojvodina. Collected and submitted 1987 by S. Trifunović, Geological Institute, Belgrade. Expected age: Würm 3.

MONTENEGRO

Z-1680. Gurdić Cave **0.5 ± 0.5 pMC**
Stalactite from submerged Gurdić Cave near Kotor (42°25'N, 18°47'E), Montenegro, used in studying sea-level oscillations. Collected and submitted April 1986 by P. Habič, Slovenian Academy of Sciences and Arts, Postojna, Slovenia.

UNITED STATES

Z-1889. Falls Creek **113.3 ± 1.2 pMC**
 $\delta^{13}C = -7.7\text{‰}$
Recent tufa deposited from freshwater at Falls Creek, Oklahoma. Collected and submitted 1987 by D. Srdoč and H. Chafetz.

Comment: (D.S.): This recent calcareous deposit contains a large proportion of *Oocardium stratum*.

Turner Falls Series

Travertine samples from Turner Falls on Honey Creek, Oklahoma. Collected and submitted May 1987 by H. Chafetz, Department of Geosciences, University of Houston (Srdoč, Chafetz and Utech 1989).

Z-2209. HC1-1 **109.5 ± 0.9 pMC**
Porous soft travertine. $\delta^{13}C = -7.1\text{‰}$

Z-2110. HC1-29 **112.0 ± 0.9 pMC**
Very porous soft travertine.

Z-2211 HC1-30 **109.5 ± 0.8 pMC**
Porous homogeneous soft travertine covered with moss.

Z-2122. 2-CBF **1.5 ± 0.5 pMC**
Porous layered hard travertine.

Bridal Veil Series

Travertine from Bridal Veil at Turner Falls. Collected and submitted 1988 by H. Chafetz.

Z-1903. 2 **109.0 ± 1.2 pMC**
Recent soft travertine.

Z-1902. 3 **2.0 ± 0.6 pMC**
 Porous hard travertine.

White Bluff Series

Tufa from an active crest at White Bluff, Texas. Collected and submitted Dec. 1989 by H. Chafetz.

Z-2207. 1 **106.3 ± 0.8 pMC**
 Porous, very soft travertine, partly covered with moss.

Z-2208. 2 **98.3 ± 0.8 pMC**
 Very porous, soft travertine.

Comment: Dates correspond to earlier measurement Z-2191 (Srdoč *et al.* 1992: 174).

CZECH REPUBLIC

St. Jan pod Skalou Series

Travertine from Central Bohemian Karst near St. Jan pod Skalou (49°53'N, 17°02'E). Travertine barriers intersecting Kačák Creek. Collected 1985 by D. Srdoč and J. Šilar, Faculty of Science, Charles University, Prague.

Z-1766. 1 **52.7 ± 1.0 pMC**
 Holocene travertine with embedded mollusk shells, upper barrier.

Z-1836. 2 **53.8 ± 1.0 pMC**
 Same as above, lower barrier.

BOTANICAL SAMPLES

We measured of ^{14}C activity and ^{13}C content of terrestrial, marsh and aquatic plants growing in and around Plitvice Lakes. We found that aquatic mosses used carbon from the DIC in lake and stream water, whereas the source of carbon in marsh plants was atmospheric CO_2 . Aquatic plants using DIC in freshwater for photosynthesis are not suitable for ^{14}C dating unless the initial activity of incorporated carbon is well known (Marčenko *et al.* 1989). In several cases, the carbon isotopic composition of various parts of aquatic plants was measured.

Aquatic and Marsh Plants Series

Aquatic and marsh plants growing in and around Plitvice Lakes. Collected 1987 by D. Srdoč, E. Marčenko, Rudjer Bošković Institute, Zagreb, and S. Golubić, Boston University, Biological Science Center.

Z-1958. *Fontinalis antipyretica* **80.4 ± 0.9 pMC**
 Confluence of Bijela Rijeka and Vukmirovića streams. Collected June 1987. $\delta^{13}\text{C} = -47.5\text{‰}$

Z-1963. *Chara* sp. **92.2 ± 0.6 pMC**
 Confluence of Bijela Rijeka and Vukmirovića streams. Collected June 1987.

Z-2046. *Ranunculus trichophyllus* **79.6 ± 0.8 pMC**
 Bijela Rijeka stream, Nenadića mill. Collected June 1987. $\delta^{13}\text{C} = -28.7\text{‰}$

Z-2050. *Veronica anagallis aquatica* **111.1 ± 1.1 pMC**
 Emergent part of plant, Bijela Rijeka spring. Collected May 1988. $\delta^{13}\text{C} = -31.0\text{‰}$

Z-2051. <i>Veronica anagallis aquatica</i>	77.1 ± 0.7 pMC
Submerged part of plant, Bijela Rijeka spring. Collected May 1988.	$\delta^{13}\text{C} = -36.0\text{‰}$
Z-1960. <i>Cratoneurum commutatum</i>	108.1 ± 1.6 pMC
Lake Kaluđerovac. Collected April 1987.	$\delta^{13}\text{C} = -34.6\text{‰}$
Z-2039. <i>Petasites albus</i>	118.9 ± 1.6 pMC
Flowers, Lake Burgetić. Collected May 1988.	$\delta^{13}\text{C} = -30.6\text{‰}$
Z-2040. <i>Petasites albus</i>	116.1 ± 1.1 pMC
Root, Lake Burgetić. Collected May 1988.	$\delta^{13}\text{C} = -28.6\text{‰}$
Z-2107. <i>Corylus avellana</i>	126.5 ± 2.0 pMC
Leaves, Lake Labudovac shore. Collected Sept. 1987.	$\delta^{13}\text{C} = -27.0\text{‰}$
Z-1767. <i>Fagus silvatica</i>	124.1 ± 1.7 pMC
Leaves, Plitvica stream shore. Collected Sept. 1986.	
Z-1964. <i>Neckera crispa</i>	126.7 ± 1.6 pMC
Plitvica spring. Collected June 1986.	$\delta^{13}\text{C} = -26.1\text{‰}$
Z-1959. <i>Cratoneurum commutatum</i>	104.3 ± 0.6 pMC
Moss sprinkled with stream water, Spiljski Vrt. Collected July 1987.	$\delta^{13}\text{C} = -40.6\text{‰}$

ATMOSPHERIC CO₂ SAMPLES

CROATIA

Table 3 shows ¹⁴C activity of samples of atmospheric CO₂ collected in Zagreb from 1983 to 1993. Ca. 125 ml of saturated carbonate-free sodium hydroxide solution was exposed to the open atmosphere.

TABLE 3. Atmospheric CO₂ Measured in Zagreb

Sample no.	Collection date		pMC (± 1.5)	δ ¹⁴ C (‰)
Z-1153	1983	06/23–08/31	134.0	346.0
Z-1579	1985	07/15–09/09	122.1	226.4
Z-1749		10/25–01/06	119.2	198.0
Z-1788	1986	01/06–03/13	114.9	154.7
Z-1796		03/17–04/30	117.1	176.4
Z-1739		04/30–06/03	123.2	237.7
Z-1768		06/03–07/25	121.1	216.6
Z-1885		09/01–11/27	114.8	153.9
Z-1887		11/27–02/13	112.0	125.7
Z-2440	1987	04/30–06/19	115.4	159.6
Z-2439		06/19–12/07	116.7	172.2
Z-2108		09/01–09/01	122.5	230.9
Z-2418	1992	06/30–07/31	110.6	111.5
Z-2419		07/31–09/01	114.1	146.9

REFERENCES

- Čečuk, B. 1991 Investigations in Kopačina cave on Brač Island. *Obavijesti Hrvatskog Arheološkog Društva* 23(3): 43–45 (in Croatian).
- Dirjec, B. 1990 Dugouts discovered during the last few years at Ljubljansko barje. In *Poročilo o Raziskovanju Paleolita, Neolita in Eneolita v Sloveniji—Predkovinske Kulture Slovenije*. Slovenian Academy of Arts and Sciences, Ljubljana, Slovenia, Occasional Publications: 135–139 (in Slovenian).
- Dirjec, B. 1991 Pile dwellings near Zornica at Blatna Brezovica. In *Poročilo o Raziskovanju Paleolita, Neolita in Eneolita v Sloveniji—Predkovinske Kulture Slovenije*. Slovenian Academy of Arts and Sciences, Ljubljana, Slovenia, Occasional Publications: 193–206 (in Slovenian).
- Grgić, S., Horvatinčić, N. and Miletić, P. 1991 Radiocarbon and tritium measurements of groundwater in eastern Slavonia. *Geološki Vjesnik* 44: 309–312.
- Hadžišehović, M., Miljević, N., Šipka, V., Golobočanin, D. and Popović, R. 1993 Isotopic analysis of groundwater and carbonate system in the Surdulica geothermal aquifer. *Radiocarbon* 35(2): 277–286.
- Horvat, A. 1962 Rudina in Požega Valley – a Roman architectural monument in Slavonia. *Peristil* 5: 11–28 (in Croatian).
- Horvatinčić, N., Srdoč, D., Šilar, J. and Tvrdíková, H. 1989 Comparison of the ^{14}C activity of groundwater and recent tufa from karst areas in Yugoslavia and Czechoslovakia. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 884–892.
- Klaić, N. 1986 St. Michael Church and Monastery at Rudina. *Vjesnik Muzeja Požeške Kotline* 4–5: 33–59 (in Croatian).
- Krajcar Bronić, I., Horvatinčić, N., Srdoč, D. and Obelić, B. 1992 Experimental determination of the ^{14}C initial activity of calcareous deposits. In Long, A. and Kra, R. S., eds., Proceedings of the 14th International ^{14}C Conference. *Radiocarbon* 34(3): 593–601.
- Malez, M. 1979 Investigations of the Paleolithic and Mesolithic in Croatia. In Benac, A., ed., *Ancient History of Yugoslavian Lands*, Vol 1, *The Paleolithic and Mesolithic*. Sarajevo, Academy of Sciences and Arts of Bosnia and Herzegovina: 195–296 (in Croatian).
- Malez, M., Šimunić, A. and Šimunić, A. 1984 Geological, sedimentological and palaeoclimatological relations of Vindija Cave and its environs. *Proceedings of the Yugoslav Academy of Arts and Sciences*, 411/20: 231–264 (in Croatian).
- Marčenko, E., Srdoč, D., Golubić, S., Pezdič, J. and Head, M. J. 1989 Carbon uptake in aquatic plants deduced from their natural ^{13}C and ^{14}C content. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 785–794.
- Milovanović, B., Stanković, S., Komatina, M., Hadžišehović, M., Župančić, M., Miljević, N., Stepić, R. and Obelić, B. 1989 Isotopic investigation of the Surdulica geothermal system. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 893–901.
- Nemec, I. and Erič, M. 1994 Preliminary report on a fossil tree trunk from Hotiza, Slovenia. *Soboški Zbornik* 3 (in Slovenian).
- Petricioli, I. 1983 St. Simeon's Shrine in Zadar. Zagreb, Spektar.
- Srdoč, D., Chafetz, H. and Utech, N. 1989 Radiocarbon dating of travertine deposits, Arbuckle Mountains, Oklahoma. In Long, A., Kra, R. S. and Srdoč, D., eds., Proceedings of the 13th International ^{14}C Conference. *Radiocarbon* 31(3): 619–626.
- Srdoč, D., Horvatinčić, N., Krajcar Bronić, I., Obelić, B. and Sliepčević, A. 1992 Rudjer Bošković Institute radiocarbon measurements XII. *Radiocarbon* 34(1): 155–175.
- Srdoč, D., Horvatinčić, N., Obelić, B., Krajcar Bronić, I. and Sliepčević, A. 1987a Rudjer Bošković Institute radiocarbon measurements IX. *Radiocarbon* 29(1): 115–134.
- Srdoč, D., Krajcar Bronić, I., Horvatinčić, N. and Obelić, B. 1986 Increase of ^{14}C activity of dissolved inorganic carbon along a river course. In Stuiver, M. and Kra, R. S., eds., Proceedings of the 12th International ^{14}C Conference. *Radiocarbon* 28(2A): 515–521.
- Srdoč, D., Obelić, B. and Horvatinčić, N. 1980 Radiocarbon dating of calcareous tufa: How reliable data can we expect? In Stuiver, M. and Kra, R., eds., Proceedings of the 10th International ^{14}C Conference. *Radiocarbon* 22(3): 858–862.
- Srdoč, D., Obelić, B., Horvatinčić, N., Krajcar Bronić, I. and Sliepčević, A. 1984 Rudjer Bošković Institute radiocarbon measurements VIII. *Radiocarbon* 26(3): 449–460.
- _____. 1989 Rudjer Bošković Institute radiocarbon measurements XI. *Radiocarbon* 31(1): 85–98.
- Srdoč, D., Obelić, B., Sliepčević, A., Krajcar Bronić, I. and Horvatinčić, N. 1987b Rudjer Bošković Institute radiocarbon measurements X. *Radiocarbon* 29(1): 135–147.
- Srdoč, D., Sliepčević, A., Obelić, B. and Horvatinčić, N. 1979 Rudjer Bošković Institute radiocarbon measurements V. *Radiocarbon* 21(1): 131–137.
- Srdoč, D., Sliepčević, A., Planinić, J., Obelić, B. and Breyer, B. 1973 Rudjer Bošković Institute radiocarbon measurements II. *Radiocarbon* 15(2): 435–431.
- Stuiver, M. and Polach, H. A. 1977 Discussion: Reporting of ^{14}C data. *Radiocarbon* 19(3): 355–363.
- Stuiver, M. and Reimer, P. J. 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program. In Calibration 1993. *Radiocarbon* 35(1): 215–230.
- Žile, I. 1993 Dubrovnik ramparts and fortifications, an analysis based on recent archaeological finds. *Dubrovnik* 3: 223–228 (in Croatian).

RADIOCARBON UPDATES

Retirement

Jürgen Freundlich operated the Köln Radiocarbon Laboratory continuously from 1963 until his retirement in 1992, producing *ca.* 4500 ^{14}C dates, almost entirely (99%) on archaeological and paleobotanical samples, mainly from Europe and Africa. His work includes 300 dates on wood samples, which were of much help in constructing the North German oak chronology. The dating systems he built include two 0.5-liter proportional counters filled to 3 atm with purified CO_2 . With counter backgrounds of 0.7 and 1.4 cpm (modern standards 10.5 and 10.2 cpm), the system has an accuracy *ca.* $\pm 3\%$ and is well calibrated (oxalic value unchanged since 1973, offset $\max \pm 10$ BP in comparison with Belfast and Seattle). The counters can measure finite ^{14}C ages up to 44,000 BP. Jürgen is still active in ^{14}C research, giving regular support to his successor in the laboratory, Bernhard Weninger.

Relocations and New Laboratories

Walter Kutschera has left the Argonne National Laboratory in Illinois for the University of Vienna, where he is helping to develop a new AMS facility based on a 3 MV pelletron tandem, scheduled to begin operation in 1995/1996; it will be called the Vienna Environmental Research Accelerator (VERA). His new address is:

Prof. Walter Kutschera
Institut für Radiumforschung und Kernphysik
der Universität Wien
Boltzmannngasse 3
A-1090 Vienna
Austria

Tel: 43-1-31367-3500
Fax: 43-1-31367-3502
E-mail: walterku@pap.univie.ac.at

Laboratory Services

A vanadium-alumina-silica catalyst ($\text{V}_2\text{O}_5 \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$) is available for benzene synthesis in liquid scintillation laboratories. 100 g of the catalyst can produce up to 65 g benzene with a yield of 98%. It has been widely used for over 20 years by many ^{14}C laboratories. For detailed information, contact: Dr. Kh. A. Arslanov, Institute of Geography, St. Petersburg State University, Sredniy Prospect 41, St. Petersburg 199004 Russia.

Meetings

The **7th International Conference on Accelerator Mass Spectrometry**, co-sponsored by The University of Arizona and the Lawrence Livermore National Laboratory, will be held in Tucson, Arizona, on 20–24 May 1996. This conference will focus especially on global change research, new AMS applications and new techniques; pre-conference workshops are planned on global change research and geological applications of AMS. For conference information, please contact:

AMS-7 Conference
NSF-Arizona AMS Facility
Physics Building
The University of Arizona
Tucson, Arizona 85721-0081 USA

Tel: 602-621-6810
Fax: 602-621-9619
Telex: 187167 AZU TUC
E-mail: AMS@ccit.arizona.edu

The next biennial conference of the **International Committee for Radionuclide Metrology (ICRM)** will be held in Paris, France, from 15 to 19 May 1995. The conference aims to facilitate international cooperation and exchange of information on techniques and applications of radionuclide metrology. Principal areas of interest will include: alpha-particle spectrometry, beta-particle and gamma-ray spectrometry, life sciences, low-level measurements, radionuclide metrology techniques and nuclear decay data. Among the specific topics considered will be source preparation techniques, reference materials and calibration standards, detector development, liquid scintillation counting, internal gas counting and surface contamination monitoring. Deadline for abstracts is 1 November 1994. The Proceedings will be published in *Nuclear Instruments and Methods in Physics Research*. Abstract submission and registration forms can be obtained from the organizing committee:

Secretariat ICRM '95
LPRI
BP 52
F-91193 Gif sur Yvette Cedex
France

Fax: (33) 1 69 08 95 29

The **13th Congress of the International Union of Prehistoric and Protohistoric Sciences** will be held in Forlì, Italy, on 8–14 September 1996. Major conference sections will include a wide range of topics in theory and methodology, archaeometry, paleoecology, the Paleolithic, Mesolithic and Neolithic in Europe and the Near East, and the prehistory of Africa, Asia, Oceania and the Americas. Archaeological excursions will be conducted to a variety of sites in Italy. Paper, colloquium and poster proposals with abstracts are due by 31 December 1994. For further information, contact:

Secretary of the 13th IUPPS Congress
Casa Saffi
Via S. Marchesi 12
I-47100 Forlì, Italy

Tel: 39-543-35725
Fax: 39-543-35805

Internet Resources

A new Listserv mailing list, C14-L, has been established as a vehicle for communication among researchers, students and anyone involved in work with radioisotopes and scientific dating issues. E-mail sent to the list address is forwarded to all list members, and messages from the list are archived and available for later searching and retrieval. To subscribe, send an e-mail message with any "Subject" heading to: `listserv@listserv.arizona.edu`. In the first line of the message (not the Subject), enter the following:

SUBSCRIBE C14-L My Name

replacing "My Name" with your full name, e.g., "Pierre DuPont". You will automatically be added to the list and receive an introductory message explaining how to send mail and set Listserv options.

RADIOCARBON's Gopher and World-Wide-Web servers are up and running. Both contain **RADIOCARBON** publication information on our journal, conference proceedings, special issues and books, along with links to other ¹⁴C-related resources on the Internet (software, searchable and full-text databases, etc.). Relevant addresses:

Gopher: `packrat.aml.arizona.edu [port 70]`
WWW: `http://packrat.aml.arizona.edu/`

If you have or know about other relevant Internet-based sources of information, we encourage you to let us know about them so that we can expand our links.

RADIOCARBON

*In Association with the American School of Prehistoric
Research, Peabody Museum, Harvard University
announces the publication of*

Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean

Edited by OFER BAR-YOSEF and RENEE S. KRA

This sourcebook results from a workshop convened by the editors at the 14th International Radiocarbon Conference, 24 May 1991, in Tucson, Arizona. *Late Quaternary Chronology and Paleoclimates of the Eastern Mediterranean* brings together the results of varied radiometric dating techniques into one convenient reference. The volume includes: 1) discussions of TL, ESR and U/Th dating relevant to the hotly debated issues of the origins of modern humans and the fate of the eastern Mediterranean Neanderthals; 2) comprehensive compilations of radiocarbon dates encompassing the past 40,000 years, with special reference to the shift from foraging to agriculture and animal domestication, as well as critical re-evaluations of the available dates; 3) summaries of the paleoclimates of the area during the last 20,000 years as viewed through marine, continental, palynological and paleohydrological sequences. This 377-page book contains 23 articles by international scholars well-known in their respective fields.

ISBN 0-9638314-1-0

✂ - - - - -

Please send me _____ copy(ies) @ \$55.00 (1995 price)
(*RADIOCARBON* subscribers pay \$50.00 – a 10% discount)

Subtotal _____

Postage and handling per book is \$2.50 (U.S.) and \$4.00 (Foreign)

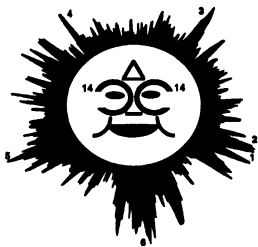
Postage _____

Sorry, we do not accept credit cards.

Total _____

I have enclosed a check or money order payable to *RADIOCARBON*. Send my order to this address:

Please photocopy this form and send it with payment to: *RADIOCARBON*, Department of Geosciences,
The University of Arizona, 4717 E. Ft. Lowell Rd., Tucson, AZ 85712 USA
All orders must be prepaid. Thank you.



RADIOCARBON

An International Journal of Cosmogenic Isotope Research

CALIBRATION 1993

A Special Hardcover Edition

Edited by Minze Stuiver, Austin Long and Renee S. Kra

CALIBRATION 1993 amends and extends the time series published in the 1986 Calibration Issue. This special hardcover edition contains tree-ring-derived calibration curves for the radiocarbon time scale, a marine calibration curve employing U/Th coral data, and discussions of atmospheric and marine reservoir influences on measured ^{14}C ages. Calibration procedures are also reviewed.

A 5¼" diskette of the new IBM-PC based program, CALIB 3.0.3C (M. Stuiver and P. Reimer, University of Washington), is included. The program integrates the new atmospheric and marine data presented in this issue, and allows for calibrations from "conventional radiocarbon years" to calendar dates for the past 18,360 ^{14}C years.

CALIBRATION 1993 represents the state-of-the art calibration, and provides an essential tool for ^{14}C research and dating.

RADIOCARBON

Department of Geosciences
The University of Arizona
4717 E. Ft. Lowell Rd.
Tucson, Arizona 85712 USA

Please send me _____ copy(ies) of **CALIBRATION 1993** @ \$50.00

Student rate: \$27.50 with student identification

Postage and handling per book is \$2.50 U.S. and \$4.00 foreign

Subtotal _____

Postage _____

Total _____

I have enclosed a check or money order payable to **RADIOCARBON**. Please send my order to this address:

LSC 92



VIENNA, AUSTRIA
14–18 September 1992

RADIOCARBON

An International Journal of Cosmogenic Isotope Research

LIQUID SCINTILLATION SPECTROMETRY 1992

*Edited by JOHN E. NOAKES,
FRANZ SCHÖNHOFER and HENRY A. POLACH*

Liquid Scintillation Spectrometry 1992 contains papers presented at an international conference, "Advances in Liquid Scintillation Spectrometry", held in Vienna, Austria, 14–18 September 1992. The volume reports state-of-the-art research and technology in the field of liquid scintillation counting. The Methods section contains sample preparation and measurement techniques, scintillators and solvents, alpha measurements and standardization. The Bioscience Applications section is an overview of liquid scintillation spectrometry in molecular biology and implications of epidemiological studies. Environmental Applications include the use of tritium, radon, radium, uranium and other radionuclides in studies of radiation protection, tracer techniques and waste management. The editors are leading scientists from the USA, Austria and Australia, and the authors are international academic scholars and industrial researchers. The 512-page hardcover volume contains extensive bibliographical references and a comprehensive index. It was published in October 1993 by *RADIOCARBON*.

ISBN 0-9638314-0-2

LSC 94 – PROCEEDINGS OF THE INTERNATIONAL CONFERENCE GLASGOW, SCOTLAND 8–12 AUGUST 1994

Liquid Scintillation Spectrometry 1994 continues the series of conference proceedings, most recently from Glasgow. Themes include: New Instrumentation, Advances in Liquid and Solid Scintillators, Bioscience Applications, Environmental Applications, Alpha Counting, Cerenkov Counting, Data Handling Algorithms/Computer Applications and Software, and Sample Handling and Disposal, among others. This volume contains peer-reviewed articles covering a wide range of liquid scintillation topics. It will be available in 1995.



Please send me _____ copy(ies) of **LSC 92** @ \$90.00

Please send me _____ copy(ies) of **LSC 94** @ \$90.00

(*RADIOCARBON* subscribers – \$75 each volume)

Special combined rate: LSC 92 and LSC 94 @ \$150.00 (save \$30)

Postage and handling per book: \$2.50 U.S. and \$4.00 foreign

Subtotal _____

Postage _____

Total _____

Please put me on a waiting list for **LSC 94** ☐

Payment enclosed ☐ Please send a pro-forma invoice ☐

I have enclosed a check or money order payable in US dollars to *RADIOCARBON*.

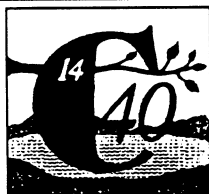
Please send my order to this address:

Name _____

Address _____

Telephone _____ Fax _____

RADIOCARBON, Department of Geosciences
The University of Arizona, 4717 E. Ft. Lowell Rd., Tucson, Arizona 85712 USA



From Springer-Verlag and *RADIOCARBON*

RADIOCARBON AFTER FOUR DECADES: AN INTERDISCIPLINARY PERSPECTIVE

Special Hardcover Edition

Edited by **R. E. Taylor**, *University of California, Riverside*,
A. Long and R. S. Kra, *both of The University of Arizona, Tucson*

Here, for the first time, are collected accounts of significant achievements and assessments of historical and scientific importance. **Radiocarbon After Four Decades: An Interdisciplinary Perspective** commemorates the 40th anniversary of radiocarbon dating and documents the major contributions of ^{14}C dating to archaeology, biomedical research, earth sciences, environmental studies, hydrology, studies of the natural carbon cycle, oceanography and palynology.

All of the 64 authors were instrumental in the establishment of, or major contributors to, ^{14}C dating as a revolutionary scientific tool. The 35 chapters provide a solid foundation in the essential topics of ^{14}C dating and include: The Natural Carbon Cycle; Instrumentation and Sample Preparation; Hydrology; Old World Archaeology; New World Archaeology; Earth Sciences; Environmental Sciences; Biomedical Applications; and Historical Perspectives.

Radiocarbon After Four Decades: An Interdisciplinary Perspective serves as a synthesis of past, present and future research in the vastly interdisciplinary field of radiocarbon dating.

RADIOCARBON subscribers are eligible to receive a 25% discount off the \$89.00 list price and pay only \$66.25. Please send completed order forms and pre-payment (checks must be made payable to Springer-Verlag) to:

RADIOCARBON, Department of Geosciences
The University of Arizona, 4717 E. Ft. Lowell Road
Tucson, AZ 85712 USA

☐ Please send me ____ copy(ies) of **Radiocarbon After Four Decades: An Interdisciplinary Perspective** (97714-7) @ \$89.00

☐ I am a current *RADIOCARBON* subscriber. Please send ____ copy(ies) @ \$66.25 each (a 25% discount).

____ Subtotal

____ Sales tax (CA, MA, NJ and NY residents; Canadian residents please add 7% GST)

____ Postage and handling**
(\$2.50 for 1st book + \$1.00 for each additional book)

____ **AMOUNT ENCLOSED**

****For orders outside North America, surface charge is \$10.00 for the first book and \$7.00 for each additional book. Air mail charges are \$45.00 per book.**

METHOD OF PAYMENT:

☐ Check or money order enclosed, **MADE PAYABLE TO SPRINGER-VERLAG, NY**

Charge my: ☐ AmEx ☐ MC ☐ Visa ☐ Discover

Card no. _____

Expiration date _____

Signature _____

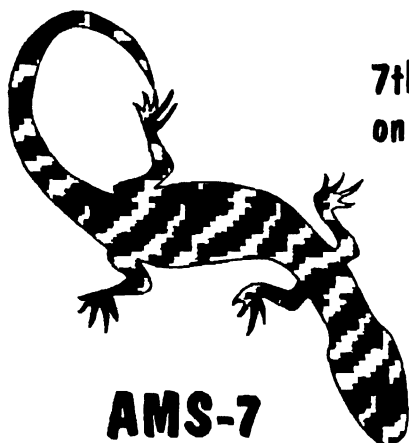
Name _____

Address _____

City/State/Zip _____

Country _____

Please send this form to *RADIOCARBON* at the address above. Thank you.



7th International Conference on Accelerator Mass Spectrometry

**Tucson, Arizona
May 20-24, 1996**

The 7th International Conference on Accelerator Mass Spectrometry, co-sponsored by The University of Arizona and the Lawrence Livermore National Laboratory, will be held in Tucson on 20-24 May 1996. The University of Arizona is a center for AMS, radiocarbon dating, global change and tree-ring research. We believe this combination is unique, and will give a more interdisciplinary atmosphere to AMS-7. We plan to highlight global change research, new AMS applications and new techniques.

Pre-Conference Workshops: *Applications of AMS to Global Change Research* (Tucson). This workshop will include discussions on the many applications of AMS to global change, and the global change record in many different reservoirs: tree rings, lake and marine sediments, coral and ice. *Geological Applications of AMS* (Tucson or Pasadena, California). This small topical workshop will focus on the applications of AMS dating to the geological record. It will focus in particular on paleoseismicity and the use of AMS measurements of *in-situ*-produced isotopes for geologic applications.

Field Trip: A post-conference field trip highlighting archaeological sites in northern Arizona and the Grand Canyon and Flagstaff areas will be arranged if numbers warrant.

Fees: We expect registration fees to be in the vicinity of \$250-300, with a small charge for associated workshops.

Organizing Committee:

Timothy Jull, Chair
George Burr
Warren Beck
Doug Donahue
Steven Leavitt, Tree Ring Lab
Marc Caffee, LLNL

For Conference information contact:

AMS-7 Conference
NSF-Arizona AMS Facility
Physics Building
The University of Arizona
Tucson, Arizona 85721-0081 USA
E-mail: AMS@ccit.arizona.edu
Tel.: (602) 621-6810
Fax: (602) 621-9619
Telex: 187167 AZU TUC



Liquid Scintillation Alpha Spectrometry



W. Jack McDowell and Betty L. McDowell

East Tennessee Radiometric/Analytical Chemicals Inc., Knoxville

Alpha liquid scintillation was developed to obtain accurate analytical determinations of alpha-emitting nuclides where no other methods were sufficiently accurate. With the present emphasis on clean-up of radiation contamination, alpha liquid scintillation has become an important tool in the determination of low concentrations of alpha-emitting nuclides. This book is the first to address the subject of alpha liquid scintillation in its entirety. It also examines how alpha spectrometry by liquid scintillation can be done without interference from beta/gamma radiation. Scientists interested in the analysis of alpha-emitting nuclides for environmental monitoring, remediation clean-up, accountability and research will find this to be a valuable book.

Features

- Describes recently developed methods that avoid interference from beta/gamma radiation, variable quenching, high background, poor energy resolution and a non-calibrated energy scale
- Provides a collection of analytical procedures that have been tested and are ready to use
- Discusses alpha liquid scintillation in its entirety

Contents

Introduction

The Evolution of Alpha-Liquid Scintillation Spectrometry

Factors Influencing the Effectiveness of Liquid Scintillation for Alpha Spectrometry

Available Instrumentation

Accuracy and Reproducibility

Principles of Solvent Extraction

Appendices:

Special Reagents and Equipment

Analytical Procedures

Half-Life and Liquid Scintillation Peak-Shape Properties of Some Alpha-Emitting Nuclides

October 1993

ISBN 0-8493-5288-6

c. 192 pp.

Appx. US \$69.95/Outside U.S. \$84.00

CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431 (407) 994-0555

NOTICE TO READERS AND CONTRIBUTORS

The purpose of *RADIOCARBON* is to publish technical and interpretive articles on all aspects of ^{14}C and other cosmogenic isotopes. In addition, we present regional compilations of published and unpublished dates along with interpretive text. Besides the triennial Proceedings of Radiocarbon Conferences, we publish Proceedings of conferences in related fields. Organizers interested in such arrangements should contact the Managing Editor for information.

Our regular issues include NOTES AND COMMENTS, LETTERS TO THE EDITOR, RADIOCARBON UPDATES and ANNOUNCEMENTS. Authors are invited to extend discussions or raise pertinent questions regarding the results of investigations that have appeared on our pages. These sections also include short technical notes to disseminate information concerning innovative sample preparation procedures. Laboratories may also seek assistance in technical aspects of radiocarbon dating. Book reviews are encouraged. We include a list of laboratories and a general index for each volume.

Manuscripts. When submitting a manuscript, include three printed copies, double-spaced, and a floppy diskette, single-spaced. We will accept, in order of preference, FrameMaker 4, WordPerfect 6.0 or 5.1, Microsoft Word, Wordstar or any IBM word-processing software program on $3\frac{1}{2}$ " or $5\frac{1}{4}$ " IBM disks, or high-density Macintosh diskettes. ASCII files are also acceptable. We also accept E-mail and ftp transmissions of manuscripts. Papers should follow the recommendations in INSTRUCTIONS TO AUTHORS (1994, vol. 36, no. 1). Offprints of these guidelines are available upon request. Our deadlines for submitting manuscripts are:

<i>For</i>	<i>Date</i>
Vol. 37, No. 2, 1995	January 1, 1995
Vol. 37, No. 3, 1995	May 1, 1995
Vol. 38, No. 1, 1996	September 1, 1995

Half-life of ^{14}C . In accordance with the decision of the Fifth Radiocarbon Dating Conference, Cambridge, England, 1962, all dates published in this volume (as in previous volumes) are based on the Libby value, 5568 yr, for the half-life. This decision was reaffirmed at the 11th International Radiocarbon Conference in Seattle, Washington, 1982. Because of various uncertainties, when ^{14}C 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*, 1962, vol. 195, no. 4845, p. 984), 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, California, 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 cal AD/BC, citing the specific calibration curve used to obtain the estimate. Calibrated dates should be reported as "cal BP" or "cal AD/BC" according to the consensus of the Twelfth International Radiocarbon Conference, Trondheim, Norway, 1985.

Measuring ^{14}C . In Volume 3, 1961, we endorsed the notation Δ , (Lamont VIII, 1961), for geochemical measurements of ^{14}C activity, corrected for isotopic fractionation in samples and in the NBS oxalic-acid standard. The value of $\delta^{14}\text{C}$ 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 $\delta^{14}\text{C}$ as the observed deviation from the standard. At the New Zealand Radiocarbon Dating Conference it was recommended to use $\delta^{14}\text{C}$ 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 of the 8th Conference on Radiocarbon Dating, Wellington, New Zealand, 1972). The Ninth International Radiocarbon Conference, Los Angeles and San Diego, California, 1976, recommended that the reference standard, 0.95 NBS oxalic acid activity, be normalized to $\delta^{13}\text{C} = -19\text{‰}$.

In several fields, however, age corrections are not possible. $\delta^{14}\text{C}$ and Δ , uncorrected for age, have been used extensively in oceanography, and are an integral part of models and theories. Thus, for the present, we continue the editorial policy of using Δ notations for samples not corrected for age.

CONTENTS

FROM THE EDITORS – To Our Friends

<i>Austin Long, Renee S. Kra and A. J. T. Jull</i>	iii
--	-----

ARTICLES

¹⁴ C Age Corrections in Antarctic Lake Sediments Inferred from Geochemistry <i>Rolf Zale</i>	173
Radiocarbon Chronology of Late Glacial and Holocene Sedimentation and Water-level Changes in the Area of the Gościąg Lake Basin <i>Anna Pazdur, M. F. Pazdur, Tomasz Goslar, Bogumił Wicik and Maurice Arnold</i>	187
Radiocarbon and Uranium-Series Dating of the Plitvice Lakes Trāvertines <i>Dušan Srdoč, J. K. Osmond, Nada Horvatinčić, Adel A. Dabous and Bogomil Obelić</i>	203
Radiocarbon Calibration Curve Variations and Their Implications for the Interpretation of New Zealand Prehistory <i>B. G. McFadgen, F. B. Knox and T. R. L. Cole</i>	221
The Rapid Preparation of Seawater ΣCO ₂ for Radiocarbon Analysis at the National Ocean Sciences AMS Facility <i>A. P. McNichol, G. A. Jones, D. L. Hutton and A. R. Gagnon</i>	237
AMS ¹⁴ C Age Determinations of Tissue, Bone and Grass Samples from the Ötztal Ice Man <i>Georges Bonani, Susan D. Ivy, Irena Hajdas, Thomas R. Niklaus and Martin Suter</i>	247

DATE LISTS

CH	Physical Research Laboratory (Chemistry) Radiocarbon Date List I <i>Ravi Bhushan, Supriya Chakraborty and Seth Krishnaswami</i>	251
Gd	Gliwice Radiocarbon Dates XI <i>Mieczysław F. Pazdur, Romuald Awiuk, Tomasz Goslar, Anna Pazdur, Adam Walanus and Andrzej Zastawny</i>	257
Gd	Gliwice Radiocarbon Dates XII <i>Anna Pazdur, Mieczysław F. Pazdur and Andrzej Zastawny</i>	281
Z	Rudjer Bošković Institute Radiocarbon Measurements XII <i>Bogomil Obelić, Nada Horvatinčić, Dušan Srdoč, Ines Krajcar-Bronić, Adela Šliepčević and Sanja Grgić</i>	303

RADIOCARBON UPDATES	325
---------------------	-----